Vegetation in clutter data | Thesis report

HOGESCHOOL UTRECHT
UNIVERSITY OF APPLIED SCIENCES

The extraction of vegetation attributes from remote sensing imagery, and its incorporation into clutter data.

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Author: Michel Leonard Wolters
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FACULTY OF BUILT ENVIRONMENT (IGO)

VEGETATION IN CLUTTER DATA

FINAL REPORT OF THE RESEARCH CONDUCTED FOR THE OBTAINMENT OF THE DEGREE

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PREFACE

Before you lays my thesis report, entitled “Vegetation in Clutter Data”. This report has been written for the obtainment of my Bachelor of Built Environment degree in Geodetics/Geo-Informatics at the University of Applied Sciences Hogeschool Utrecht. This research has been commissioned and conducted at GeoTerraImage in Pretoria, South Africa, between January 25th 2010 and May 30th 2010.

GeoTerraImage gave me the possibility to develop an unprecedented workflow concerning more detailed feature extraction in imagery, as an addition to the feature extractions GeoTerraImage has already established thus far. Although I have learned about remote sensing during my studies, the internship at GeoTerraImage has widened my view of remote sensing and imagery analysis. There are a lot of possibilities and areas of applications still to be researched and developed with remote sensing.

Before this research was started, acquaintance with the current workflows at GeoTerraImage was a prerequisite. Also, it was necessary to become familiar with the dynamics of vegetation in South Africa, the background of clutter data and the possibilities of the software available to GeoTerraImage. The various areas of expertise of GeoTerraImage’s employees and directors has been used as feedback and guidelines to develop the methodology, since combination and manipulation of existing functions and workflows can create new and different ways to generate more detailed metadata.

With this report I want to accomplish the awareness of the possibility to generate more detailed metadata with existing methods and available data, since these means have not yet reached their full potential. Even though this report is limited to the extraction of more accurate vegetation metadata, the workflows can also be used to generate metadata of different features, landscapes and vegetation types, not limited to urban areas.

I would like to thank my supervisors Fanie Ferreira and Pieter Sevenhuysen for all their help and support concerning my thesis and stay in South Africa. Their helpfulness, good advices and feedback have significantly contributed to a pleasant and productive stay in South Africa and at GeoTerraImage. Besides my supervisors, I would also like to thank my colleagues Zibusiso Ncube, Lungile Moyo, Fritz Schoeman and Cobus Stals, the employees at Datadesign Erdas Support and the South African Department of Rural Development and Land Reform. Without them, my research would not have been possible.

Finally I would like to thank Pieter Benjamin Bresler for taking care of my accommodation in South Africa and my parents for their support and endless confidence in my abilities. Special thanks to Jane Arrak.

Michel Leonard Wolters
Pretoria, South Africa
May 30th, 2010

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COMPENDIUM

Telecommunication services have become essential to modern society. The dependence on wireless communication services increases daily. More sophisticated wireless devices are able to exchange more data as the technology becomes more sophisticated. Higher frequencies with a wider bandwidth have to be used in order to accommodate this exchange of information as well as the continually growing consumer base. However, the higher the frequency the more interference it experiences from smaller objects in the terrain. To take these obstructions into account, the telecommunication companies use clutter data to extrapolate the best location to place transmitter towers.

Clutter data is a thematic raster layer; it describes the location of different types of land cover in a terrain with different pixel values. GeoTerraImage produces this data in different spatial resolutions, depending on the frequency the telecommunication company use. The highest resolution that is being produced at the moment is 2.5 meters. Due to the demand of increasingly accurate clutter data sets, the resolution of these datasets has to be increased and expanded. More data needs to be appended to the different vegetation classes, namely type and height.

This report discusses the types of interference that radio signals can encounter. Also, a study of the different vegetation types in South Africa and the Area of Interest is discussed. These topics have been researched in order to understand clutter data and the necessity of higher resolutions, as well as to research which classes the vegetation have to be segmented in. Anticipation of problems during vegetation classification, as well as the rendition to what type of imagery should be used for the vegetation classification has also been researched.

Using the different software available to GeoTerraImage, a methodology has been devised to extract the additional vegetation information in remote sensing imagery. The software used for this process is Erdas Imagine, Leica Photogrammetric Suite with two different terrain extraction algorithms, as well as ArcGIS and eCognition. Finally, the practical and economic feasibility, as well as the conclusions, recommendations and examinations for future developments are being discussed.

By extracting a Digital Surface Model from the imagery available and subtracting it from a Digital Terrain Model, a Difference Elevation Model can be created. This model describes the elevation of objects independently from the terrain. There are two different ways to extract these object and vegetation heights; with the enhanced Automatic Terrain Extraction (eATE) and the adaptive Automatic Terrain Extraction (aATE) algorithms. The multispectral imagery has been used in order to classify the different objects and vegetation certain areas. These areas have been used to determine the median heights in the Difference Elevation Model. This separate vegetation classification is necessary to ensure the temporal accuracy of the results. Vegetation is dynamic; using different data sources to extract the vegetation classes and vegetation heights can result in the end result being inaccurate. The height attributes in the Difference Elevation Model has then been segmented into different classes and intersected with the existing clutter data set.

Using the results of an on-site measurement of the trees in a testing area, the results of the extracted vegetation heights have been checked for accuracy. Even though this measurement is not very accurate, it was sufficient enough to conclude that the vegetation heights extracted in this research do not accurately represent the actual heights. The cause of this is the lack of accurate reference material. The software available is unable to accurately generate data which can be used as reference data for the generation of object heights.

The vegetation classification with the means available has been successful. It has also been checked for accuracy with data generated by GeoTerraImage as well as an on-site field study. The classification methods have been thoroughly analyzed in order to come up with an accurate supervised classification of the image. Comparison of the data concluded that the vegetation classification as performed for this research was accurate enough; however, by using the software to its fullest, the results can be even better.

This research concludes that extraction of detailed vegetation information is not possible with the means available to GeoTerraImage today. More detailed reference data is essential for the successful extraction of vegetation heights. This accurate data is not available in sub-Saharan Africa at this time. GeoTerraImage would be forced to extract this data itself, or to hire contractors to acquire this accurate data in a multitude of countries. This is not considered feasible for GeoTerraImage. In the future, with the increasing need of accurate data and decreasing cost of means that are able to acquire this data, the costs of acquiring this accurate data may decrease as well. This would make enhancing clutter data feasible for GeoTerraImage. Meanwhile, it is recommended that GeoTerraImage conducts research on additional software, datasets and imagery with which it is possible to extract accurate bare earth models.

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Chapter 1 Introduction

One of GeoTerraImage's products is Radio Frequency (RF) planning datasets, which is used by telecommunication companies in order to optimize their wireless communication networks. These datasets include clutter data, elevation models and vector datasets. The clients of GeoTerraImage use these datasets in order to extrapolate the range of radio waves in any given area, taking into account the different obstructions (natural or artificial) as well as the land use and land cover in that area, since these elements have different effects on radio waves.

GeoTerraImage has delivered clutter data and Radio Frequency datasets since 1999. It is active in 90% of all countries and 400 cities on the African continent. Among its clients are the major telecom companies in Africa, such as MTN and Vodacom.

This assignment has been completed as part of the fourth and final year of the Geodesy & Geo-Informatics study at the University of Applied Sciences Hogeschool Utrecht, Utrecht, The Netherlands. The objective of this research is to answer the question:

Can the current clutter data as produced by GeoTerraImage be expanded with urban vegetation height information, in order to produce a more precise and useful product?

This research has been conducted at the headquarters of GeoTerraImage in Pretoria, South Africa. It has started on the 25th of January 2010 and it has ended on the 30th of May, 2010.

§ 1.1 Motivation

In the past decades, wireless signals have become the backbone of communication as we know it today. Ever since the first wireless voice transmission, research into the interference created by different elements on earth has been essential for the placement of different transmitters in any given area. Now, as more and more data is being exchanged and the user base grows at an astounding rate, wider bandwidths are necessary in order to develop a network with complete coverage and sufficient capacity. Meanwhile, the shape of our landscape is changing drastically. New suburban areas, higher buildings and the morphology of our natural landscape in conjunction with agricultural developments, mandate continuously updated radio frequency planning datasets.

That is what clutter data is for. Clutter data enables the wireless communication companies to extrapolate the ideal position for their transmitters, taking the local situation into account. With the introduction of more wireless computers, it is feasible to expand to wider bandwidths such as HSPA+ and WiMAX. However, wider bandwidths have a carrier wave with a higher frequency, which suffer more interference from smaller natural or artificial objects. Although GeoTerraImage is able to classify big objects such as buildings, roads, water bodies and forests, it is not yet able to extract detailed vegetation information, heights in particular.

This thesis report will research the possibility to extract more detailed vegetation information with the means available to GeoTerraImage, and to incorporate this metadata in existing clutter data sets.

§ 1.2 Objective

The main objective is to develop a new methodology or workflow in order to extract detailed vegetation information based on stereo satellite imagery. The main research question is:

Can the current clutter data as produced by GeoTerraImage be expanded with urban vegetation height information, in order to produce a more precise and useful product?

To answer this question, certain research questions need to be answered beforehand, namely:

1. What requirements or specifications do GeoTerraImage and the customer have of the end result? [Chapter 4]
2. What methodology must be followed to create a vegetation Digital Surface Model, so that it may be incorporated in the clutter data? [Chapter 6 thru Chapter 12]
3. Can a vegetation classification system be created according to height intervals and incorporated into the clutter data? [Chapter 5, Chapter 9 and Chapter 10]
4. Develop a methodology for vegetation height classification based on stereo images. [Chapter 10]
5. Evaluate the results with data gathered on-site. [Chapter 11]
6. Which available data is best suited for the end product in terms of time, resources and accuracy? [Chapter 11]
7. Will the end result increase the radio frequency planning datasets oriented product value? [Chapter 12]

These questions will be answered in this report.

§ 1.3 Proceedings

The thesis is an independent research within GeoTerraImage. GeoTerraImage does not have an independent research & development department or team since it is mostly a value adding company. Instead, individual activities and sometimes grouped activities will facilitate small research projects in order to accommodate feature specific results. The topic of this thesis report is one of the few topics that GeoTerraImage has to solve at this point.

Literary study
Prior to the development of the methodology, certain aspects have to be researched. These aspects are the vegetation in South Africa, radio wave propagation and interference properties and the software available. Different books, existing guides and workflows have been used to research these topics. Also, magazine articles and research reports have been used to study this topic. For research in the potential and functions of different software, interactions with software developers, software experts as well as books and internet sources have been used.

Methodology development
To develop the different methodologies, the literature studies, expertise from in-house staff, knowledge obtained at previous internships and the university has been used. Regrettably, certain aspects of clutter data are classified by GeoTerraImage and its competitors. This means that this research has been limited in certain ways, especially when analyzing the clutter data.

Execution
With the literature studies and methodology development, the vegetation information in the "Area of Interest" will be extracted. The result will be checked for accuracy with the results of a field study.

§ 1.4 Report structure

This report starts with the delineation of the company GeoTerraImage in Chapter 2. In Chapter 3, the different means available for this report are being discussed. Chapter 4 discusses the background information of clutter data, as well as the interactions radio frequency signals encounter and the necessity of incorporating additional vegetation information in clutter data sets. The different vegetation in South Africa and Pretoria, as well as a anticipation of classification issues and ideal test locations for supervised classification are being discussed in Chapter 5, whereas Chapter 6 talks about the conceived approach to enhance clutter data sets. Chapter 7 through Chapter 12 examines the individual processes described in Chapter 6 at a greater detail, including the setting used, choices made, results generated as well as a reflection of the workflow used. Chapter 11 discusses the final results of the research; how these quality controls have been conducted, the theoretical explanation of errors in the results and what the final conclusion is to these results. Chapter 13 discusses the economical and practical feasibility of incorporating the workflow in the day to day operations of GeoTerraImage. Finally, Chapter 14 conclusions and recommendations will be made concerning the project, as well as an outlook to future developments in software or the need for clutter data, and how these developments will impact both GeoTerraImage as well as the workflow devised in this report.

Chapter 2 COMPANY PROFILE

GeoTerraImage is an independent consultancy company, stationed in Pretoria, South Africa. It is composed of a dynamic group of dedicated and skilled professionals with a combined 80 years' experience in remote sensing, image processing, image interpretation and other related geo-spatial technologies. Established in 1999, it has since grown to become a leading geospatial information provider in Sub-Saharan Africa.

GeoTerraImage provides specialist geospatial mapping and remote sensing services, focused on earth observation, satellite imagery and aerial photography. That is used in combination with a mixture of data sources to provide custom solutions. Image interpretation experience gained through a variety of projects around the world has provided the employees of GeoTerraImage with unique skills and experience which is unique in Southern Africa and on par with European companies.

GeoTerraImage's business model is based on a combination of providing specialist consultancy and partnering with other consultants to facilitate more complex and higher quality projects. Products of GeoTerraImage include, but are not limited to, Telecommunication Data packages, Growth Indicator, Urban Landscape Characterization and Land Cover Mapping. These products can be used for a wide range of applications, such as telecommunication network planning, natural resource management, agricultural, forestry and urban planning.

Currently, GeoTerraImage employs 13 full time members of staff, all of which are at least graduate level technical specialists, apart from the company secretary. This group of people is supported by a team of external freelancers, consultants and strategic business partners. The company is led by 4 highly skilled directors.

The company does not have clearly defined departments; employees work cooperatively on projects depending on complexity and volume, taking advantage of each employee's skills and expertise. It does not have a Research and Development department; instead, solutions to specific issues are solved on a problem to problem basis.

Chapter 3 MEANS AVAILABLE AND AREA DEFINITION

There are different ways to extract vegetation heights with different data and software. However, it is the objective of this research to extract vegetation metadata with the means available to GeoTerraImage. Research in the capabilities of other means is possible, but these means should be available in South Africa and its usage economically feasible to the company. In this chapter, the means available by GeoTerraImage will be discussed. Recommendations of other means will be discussed in § 14.2.

§ 3.1 IMAGERY

As stated in § 1.2, the objective is to extract vegetation information with the help of remote sensing imagery. Although LIDAR (Light Detection and Ranging) might produce a more accurate result, it will be omitted in this report. This is because LIDAR data and equipment is not as ubiquitous as in Europe or Northern America, which makes it expensive and not feasible for GeoTerraImage to use.

The imagery available for this project is:

1. **Stereo Formosat-2 imagery**
   Formosat-2 is a Taiwanese National Space Program Office imaging satellite, launched in 2004. Its objective is to collect high resolution panchromatic and multispectral imagery in a 2 m and 8 m pixel resolution, respectively, for various applications. These applications can be vegetation analysis, land cover research and events monitoring (European Space Agency). Even though the name and origin implies differently, Formosat-2 is also used to collect data elsewhere than the island of Formosa (Taiwan). The satellite orbits the earth in a sun-synchronous orbit at an altitude of approximately 880 km. The imagery of Formosat-2 has 5 bands, Panchromatic, Red, Blue, Green, Near-Infrared. The imagery available to GeoTerraImage describes an area of 671 km^2 around the center of the City of Tshwane municipality, encompassing the 'Area of Interests'. See Figure 1 for an example picture of the imagery and a picture of the Formosat-2 satellite.

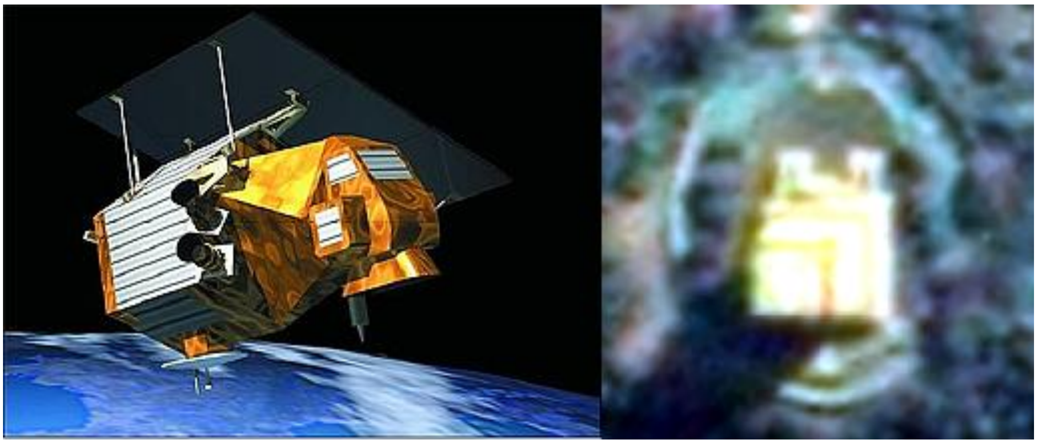


FIGURE 1: THE FORMOSAT-2 SATELLITE (LEFT) AND THE VOORTREKKERSMONUMENT IN PRETORIA (RIGHT).

2. **Stereo Ikonos imagery**
   The Ikonos satellite is a Spanish high resolution imagery satellite operated by GeoEye. It collects high resolution imagery at 0.82 m pixel resolution for panchromatic images and 3.2 m pixel

resolution for multispectral images, including near infrared. It orbits the earth at an altitude of 681 km in a sun synchronous orbit (Sandau & Roser, 2008). However, it lacks the near infrared band. Therefore, this imagery is used for experimenting with higher resolution images and the elevation model and feature extraction, in particular in conjunction with the eATE algorithm. See Figure 2 for an example picture of the imagery and a picture of the Ikonos satellite. The imagery available to GeoTerraImage describes an area of 126 km^2 around Centurion, just south of Pretoria.

FIGURE 2: THE IKONOS SATELLITE (LEFT) AND THE VOORTREKKERSMONUMENT IN PRETORIA (RIGHT).

§ 3.2 Reference data

Besides imagery, there are different resource datasets available to GeoTerraImage. These are listed below.

Aerial orthophotos

Definition:	Aerial orthophotos of South Africa, pan-sharpened.
Usage:	Used as X and Y reference for stereo models (Chapter 7).
Source:	CDSM South Africa.
Created using:	A Zeiss Intergraph DMC camera (106 Megapixel).
Format:	Spectral raster dataset.
Accuracy:	Spatial resolution of 50 cm.

See also attachment 3 for more background information.

Cadastral data

Definition:	Building and/or cadastral parcel outlines of Gauteng Province.
Usage:	Used as a reference to generate breaklines (Chapter 12).
Source:	South Africa Cadastral Services.
Created using:	Surveyor measurements.
Format:	2D vector shapefile.

South African NDEM

Definition:	Digital Terrain Models (bare earth models) of South Africa.
Usage:	Used as a reference to generate Difference Elevation Models (Chapter 10).
Source:	CDNGI, Rural Development South Africa.
Created using:	Analogue aerial photography converted to 5 meter contours used in 1:10.000 topographical maps. The individual map separators (layers) has

	been extracted and digitized to contours. These contours have then been converted to a gridded dataset with a surfacing process. See also Attachment 3: Background of .
Format:	Gridded raster dataset.
Accuracy:	2.5 meters
Spatial resolution:	5 meters

See also attachment 3 for more background information.

Digital Surface Model

Definition:	Digital Surface Models (terrain models including object heights) of Gauteng Province.
Usage:	Used as a reference Z coordinates source to append stereo model (Chapter 7).
Source:	Teleatlas
Created using:	Remote Sensing Imagery, generated from a non-gridded dataset (point cloud).
Format:	Gridded raster dataset.
Accuracy:	Spatial resolution of 10 meters.

§ 3.3 SOFTWARE

Although GeoTerraImage uses a lot of different software, only some will be used to generate an end result for this thesis. These are:

1. **ArcGIS 9.3:** It is used to display and analyze the different results created during this thesis. Also, it is used to access ERDAS extensions and for various 2D or 3D shapefile manipulations.
2. **Erdas Imagine 10.1 Advantage, Essentials and Professional:** This software suite is used for various applications such as supervised classification, image comparison etc.
3. **Leica Photogrammetric Suite (LPS) with the eATE extension:** This software suite is used to create stereo models, extract Digital Elevation Models and to generate and resample orthos from the stereo imagery.
4. **Stereo Analyst for Imagine (SAfI):** This is used for feature extraction from stereo imagery for the creation of 3D models and shapefiles, which can be used to create breaklines for Terrain Editor for Imagine.
5. **Terrain Editor for Imagine (TEI):** Terrain Editor for Imagine works as a plugin to Leica Photogrammetric Suite. It can be used to create, modify and export Digital Elevation Models from stereo models.
6. **Global Mapper 10:** Used for conversion and display of results.
7. **eCognition:** An image analysis software package. Used to intersect different datasets.

Besides these software packages, another experimental piece of software has entered testing phases during this thesis, namely Shadow2Height from Erdas. This software is able to extrapolate heights from various objects using the time and date of the collection of the imagery. Since the final release version is not available at the time this research was conducted, it is therefore not incorporated in the final methodology. The possibilities and prospects of using this software is discussed in § 14.3.

All of the software and their functions that have been used in this report will be discussed further in the applicable steps between Chapter 7 and Chapter 12.

§ 3.4 AREAS OF INTEREST

Since the imagery available covers 2 different parts of Pretoria, 2 different 'Areas of Interest' have been selected for this project. These 'Areas of Interest' have been chosen due to the diverse situations in the areas they cover, in terms of land use and terrain elevations. The ease of accessibility as well as the relevance also plays a role; the headquarters of GeoTerraImage are located in Pretoria and the clutter data for Pretoria is produced by GeoTerraImage.

1. **Union Buildings Area of Interest (Formosat-2 imagery):** The area chosen is the area in the area of the Union Buildings in Pretoria, South Africa. It is a rectangular shape, with the lower left corner having coordinates 25 44'48"S 28 12'21"E and the upper right corner 25 43'29"S 28 14'31"E. See also Figure 3. This area was more suitable than other areas due to the amount of vegetation on the hillside and the suburban area next to it. The area is 8.2 km^2 in size.
2. **Voortrekker Monument Area of Interest (Ikonos imagery):** The chosen for the Ikonos imagery is the area around the Voortrekker Monument, south of Pretoria. Other areas in the Ikonos imagery were unsuitable due to marginal elevation differences. The area is 9 km^2 in size.

Because the Ikonos imagery lacks a Near Infrared Band, the procedures conducted in the Voortrekker Monument Area of Interest will be limited to Digital Surface Model, Digital Terrain Model and Difference Elevation Model studies. All procedures will be applied in the Union Building Area of Interest. This has been done in order to investigate all possibilities of the aforementioned software and available data.

FIGURE 3: THE UNION BUILDINGS AREA OF INTEREST (WITHIN YELLOW RECTANGLE). PRETORIA CITY CENTER IS IN THE LOWER RIGHT CORNER. THE UNION BUILDINGS ARE LOCATED JUST ABOVE THE LOWER RIGHT CORNER.

FIGURE 4: THE VOORTREKKER MONUMENT AREA OF INTEREST (WITHIN THE YELLOW RECTANGLE). THE VOORTREKKERSMONUMENT IS IN THE UPPER RIGHT CORNER, THE CENTER OF PRETORIA IS DIRECTLY ABOVE THE AREA OF INTEREST.

Chapter 4 CLUTTER DATA

Please note: The extraction methodology for clutter data is classified company information. Therefore, it is not incorporated in this report. Instead, only background information is provided.

§ 4.1 WHAT IS CLUTTER DATA?

Clutter refers to radio frequency reverberation and scattering from objects which inhibit the propagation of radio frequency signals. Examples can be manmade and natural structures, but also weather conditions and other atmospheric or natural phenomena. Depending on the size, density and shape of these objects, radio signals can behave in different ways when they encounter such objects. Clutter data, as created by GeoTerraImage, is part of the Telecommunication data package. Included in that package besides clutter data is infrastructure data (in the form of vector files) and a low resolution Digital Terrain Model (for rural areas) or a low resolution Digital Surface Model (for urban areas). Clutter data are thematic raster images, which incorporates the position, height and shape and classes of different types of land cover. Thematic raster are raster images that are qualitative and categorical. The client can use this data to calculate or predict signal propagation when the signals encounter these types of land cover. See Figure 5 for an example of clutter data. Depending on the contractor and the usage of this data, different spatial resolutions and different classes can be incorporated into the data. This depends on the wavelength of the frequency used by the client. For example, low frequency AM signals experience less interference than high frequency WiMAX signals, and a lessor or higher spatial resolution and class density can be used accordingly. Since the range of these telecommunication signals is limited, transmitters have to be placed in strategic locations. With clutter data, the telecommunication companies can predict the interference of the signals. The companies are then able to deduct a suitable location to achieve a sufficient coverage for any given area. The client assigns to each different class in the thematic raster layer a different electromagnetic interference factor (also referred to as a decibel factor) which indicates how much the signal degrades when it passes through it.

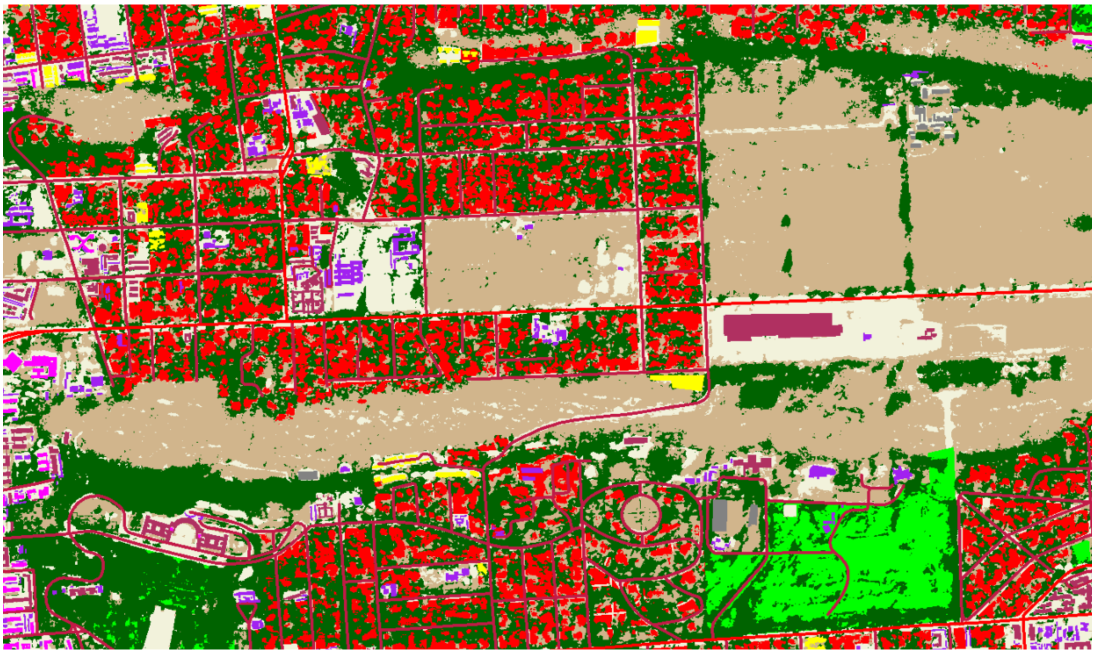


FIGURE 5: CLUTTER DATA OF THE UNION BUILDINGS AREA OF INTEREST. EACH COLOR SIGNIFIES A CERTAIN OBJECT CLASS, SUCH AS ROADS, BUILDINGS AND VEGETATION.

Since most interactions to radio frequency, as well as the occurrence of higher frequency telecommunication data occurs in urban areas, most clutter data projects that GeoTerraImage delivers is of urban areas. GeoTerraImage produces this clutter data in different spatial resolutions, since these radio frequency signals are mostly used in conjunction to facilitate an optimal support for multiple devices. GeoTerraImage also generates clutter data sets for rural areas, where different (agricultural) land usage determines the propagation of these radio frequency signals. A lower resolution of clutter data set can suffice due to the lack of higher frequency signals and big obstructions.

§ 4.2 Interactions of radio frequency signals

Radio frequency signals for telecommunication services propagate from the transmitter to receivers in a coverage area. These shortwave radio frequency signals are broadcasted in every direction and travel in a straight line. However, due to man-made and natural objects the radiofrequency waves can experience interference. Radio frequency interference caused by these objects comes in different forms. There are 4 clearly distinguishable interactions (Norton, 2000) (see Figure 6):

1. **Absorption:** This means that the radio frequency signals are transformed into another form of energy (mostly warmth) and thus cease to exist. This interaction occurs mostly when the signals encounter water bodies.
2. **Deflection:** Deflection occurs when the radio frequency signals encounter objects whose dimensions are larger than the wavelength of the carrier wave. These waves are being rebounded in a uniform trajectory; much like a mirror deflects light.
3. **Diffusion:** Diffusion (or scattering) occurs when the radio frequency waves encounters objects whose dimensions are similar to the carrier wave's wavelength. The signal then disperses in various trajectories. With high frequency radio frequency signals such as WiMAX, this occurs mostly when the signals encounter vegetation.
4. **Diffraction:** Diffraction occurs when the radio frequency waves encounter the corners or edges of obstacles. It acts as a relay or secondary source, because it changes the trajectory of the signals encountering it, radiating it beyond the 'Line of Sight'. This interaction enables reception of radio frequency signals even if the receiver and transmitter are not in sight of one another.

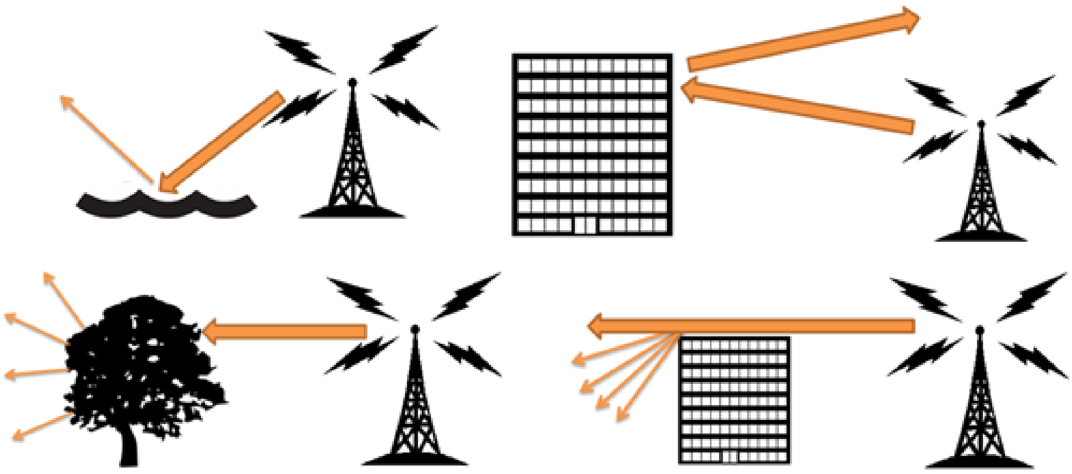


FIGURE 6: FROM LEFT TO RIGHT: GRAPHICAL REPRESENTATIONS OF ABSORPTION, DEFLECTION, DIFFUSION AND DIFFRACTION.

Besides interference with natural and artificial objects, other factors are also relevant to the propagation of radio signals, such as the curvature of the earth, atmospheric conditions and solar radiation. These interferences usually occur when great distances are involved. However, because the urban clutter data sets as well as this research only cover a small part of the earth's surface, these interferences have been omitted from this report.

§ 4.3 Necessity of detailed vegetation information in clutter data

Currently, the most prominent radio frequency signals for telecommunication in South Africa are the GSM, GPRS, EDGE and HSPA protocols. With the clutter data that GeoTerraImage currently produces (with spatial resolutions ranging from 2.5 to 100 meters), this is sufficient for analytical purposes. However, in recent years, portable computers and highly advanced mobile phones have become ubiquitous, making expansion to wider bandwidths such as WiMAX feasible (Cisco, 2010). These higher frequency signals create the necessity of higher resolution vegetation clutter data. For example, due to the high frequency of WiMAX signals, a clutter data set with a resolution of 1 meter is necessary to properly analyze the signals' propagation (GeoConnexion UK, 2007). Originally, clutter data that GeoTerraImage produces limits the classification to high, medium or low vegetation. GeoTerraImage extracts these vegetation classes in two different ways, either with spectral analysis or texture and brightness based analysis, depending on the expertise of the employee conducting the classification and the datasets available. GeoTerraImage also uses external reference sources to analyze vegetation, for example a database of golf courses boundaries. This classification is made over a wide area and may be inconsistent with the actual situation. This is one of the reasons why vegetation classification is also conducted during this research.

Also, because vegetation is more dynamic than artificial structures (it grows, it gets cut down etc.), it is important that the vegetation data originate from the same imagery in order to ensure the consistency of the data. Before a recommendation can be made on which classes should be used in vegetation classification, a closer look at the different vegetation in South Africa has to be made. This is discussed in Chapter 5. Proposed classes for vegetation classification can also be found in Chapter 5.

Only recently has the 2.5 m clutter data been expanded with the land cover product, which has a more detailed vegetation classification. GeoTerraImage uses a zonal analysis technique to intersect this land cover data with the existing clutter data, enhancing the data. With the introduction of higher frequency signals such as WiMAX, this vegetation classification may not be sufficient. Each vegetation class, depending on the type of vegetation, can have a different height. If the height of a forest increases, so does the density and therefore the interference of radio frequency signals. Knowing the heights of the vegetation is thus essential for higher resolution clutter data.

The vegetation classes GeoTerraImage extracts for land cover products are:

- Natural forest and woodland
- Thicket bushland
- Exotic trees
- Grassland
- Open bare soil, short vegetation, concrete slabs and sand.

A research of vegetation types found in the 'Area of Interest' has to be conducted in order to ascertain whether this classification is sufficient. See Chapter 5.

Chapter 5 VEGETATION IN SOUTH AFRICA

This chapter talks about the different vegetation biomes and bioregions in South Africa. Since the 'Area of Interest' defined in this report is located in South Africa and one of GeoTerraImage's highest priorities is South Africa, a better understanding and knowledge of the vegetation types in South Africa is relevant. This helps to predict and anticipate problems encountered when performing a vegetation classification. Also, it will enable the analyst to make an appropriate class distinction between the vegetation types, taking the eventual clutter data specifications in mind. Furthermore, eventual anomalies in the vegetation classification can be explained when being familiar with the vegetation in the area. Because both "Area of Interest" (§ 3.4) are located in Pretoria, a closer examination will be taken to different vegetation types in that area. Note that only the 'Area of Interest' near the Union Buildings will be analyzed, since supervised classification of the 'Voortrekker Monument Area of Interest' is not possible due to lack of near infrared bands in the Ikonos imagery. Most data sources covering the vegetation in South Africa incorporate Swaziland and Lesotho in their studies. The same has been done in this report.

§ 5.1 OVERVIEW

South Africa is one of the world's most diverse countries in terms of flora. There are roughly 20.000 different plant species, which represent about 10% of all plant species on earth (Southern Domain, 2002). All of these are spread out through a various number of biomes, all over the country. Rutherford & Westfall (1994) emphasized that:

1. A biome is the largest land community unit recognized at a continental or sub continental scale and does not recognize any subsets of a biome as a minor biome. Instead, those subsets are classified as bioregions.
2. Biome patches should have a minimum size of 20 km in shortest distance.
3. Biomes are defined primarily on combinations of dominant life growth forms and not on the basis of floral taxonomic characteristics.
4. Biomes are defined secondarily on the basis of major climate features that most affect the vegetation. Minor features that may happen to correlate with the biome but are insignificant or irrelevant are omitted.
5. Biomes do not include alien species or unnatural situations, unless irreversibly changed by man but self-sustaining in their present state.

Each biome in South Africa has a very different climate; from the subtropical regions near the Indian ocean coast, the higher cooler grassland in the Free State, the dry areas of the desert regions to the west. Each of these characteristics determines what kind of vegetation naturally occurs there. Therefore, analyzing the different biomes in South Africa is a good start to make up a suitable height classification for the area, since not only the height of the vegetation but also the type and distribution of this vegetation are relevant for clutter data.

The most prominent biomes in South Africa are (Mucina L., 2006):

1. *Albany Thicket:* Semi-arid biome with inconstant precipitation. Mostly thicket cover.
2. *Desert:* Areas with a Mean Annual Precipitation less than 70 mm and a vegetation cover of less than 10%

3. *Forests:* Biome containing green, multilayered vegetation dominated by trees (mostly evergreen or semi-deciduous), with a crown cover of 75% or more.
4. *Fynbos:* Consisting heavily of Fynbos vegetation, evergreen shrubs.
5. *Grassland:* Predominant herbaceous layer, occurring mostly in highlands in South Africa.
6. *Indian Ocean Coastal Belt:* Biome with even rainfall. Has a hot and damp tropical character in summer and mild winters.
7. *Nama-Karoo:* Arid continental biome with little effect of ameliorating influences of the oceans. Non perennial rivers depending on rainfall in higher regions.
8. *Savanna:* Seasonality of precipitation, subtropical region with virtually no frost.
9. *Succulent Karoo:* Semi-desert region with strong maritime influence with a mild climate.

See Figure 7 for a geographical distribution of the biomes in South Africa and Figure 8 for a percentage distribution.

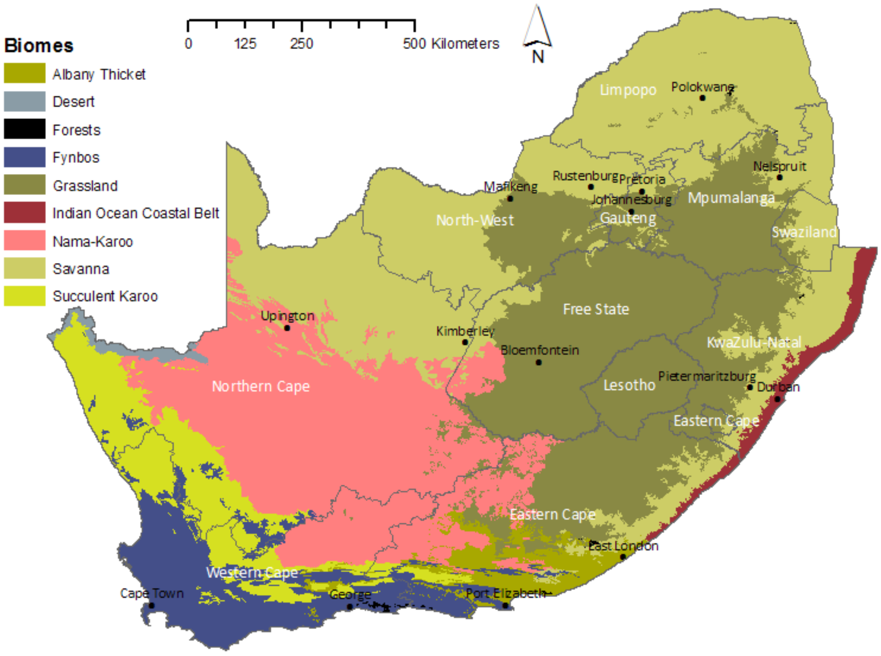


FIGURE 7: GEOGRAPHICAL LOCATION OF BIOMES IN SOUTH AFRICA, LESOTHO AND SWAZILAND.

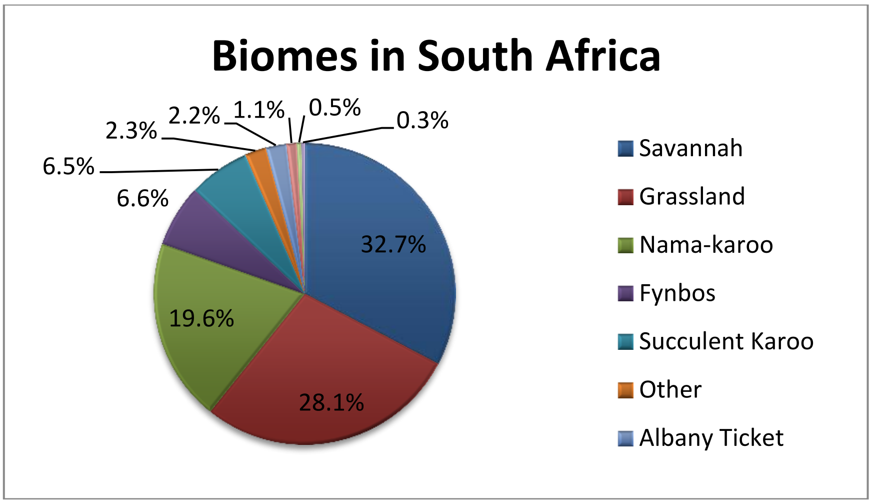


FIGURE 8: DISTRIBUTION OF VEGETATION IN PERCENTAGES IN SOUTH AFRICA, LESOTHO AND SWAZILAND.

§ 5.2 Vegetation in Pretoria and the Union Building Area of Interest

§ 5.2.1Indigenous vegetation in Pretoria and the Union Building Area of Interest

As is visible in Figure 7, Pretoria lies on the border of two biomes; the Savannah biome and the Grassland biome. The border of this biome lies around the southern edge of the city, which has a higher elevation than the rest of the city. There are 3 bioregions intersecting Pretoria, of both the Grassland and Savannah biome. The Savannah bioregion is quite diverse; the valley has a different vegetation types than surrounding hills, and even the hills have distinguishable vegetation types on different sides of the hill. The 'Area of Interest' is entirely encompassed in the Savannah biome, and it borders 3 vegetation units. Despite urbanization and experimental farms (so called Proefplaas), the following 3 bioregions are distinguishable:

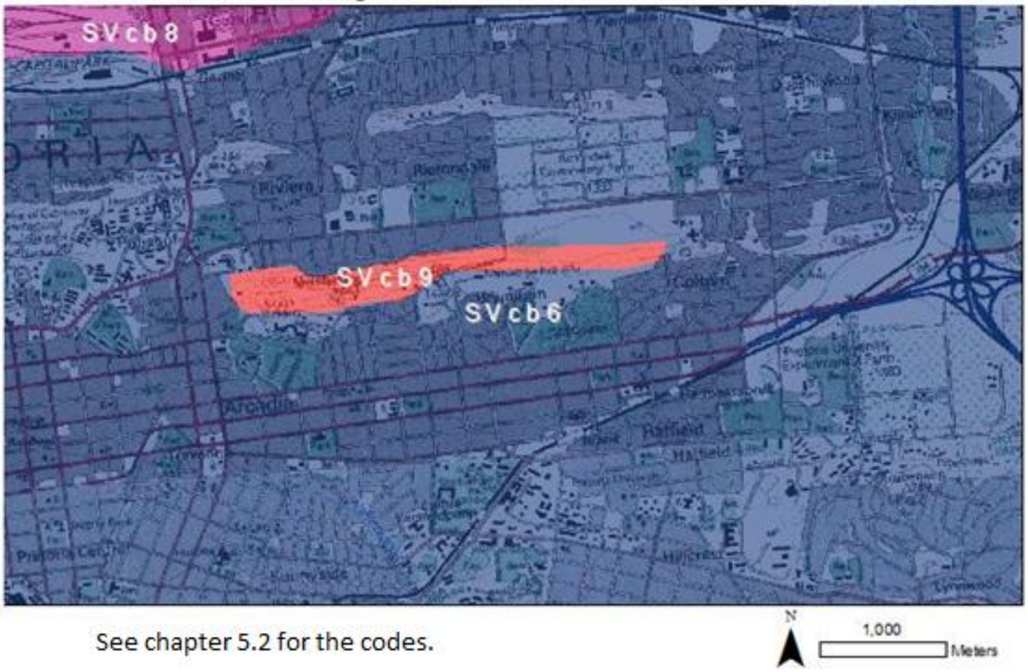
Name:	**Marikana Thornfeld**
Description:	Open woodland with predominantly Acacia Karoo trees and shrubs along drainage lines.
Altitude:	Between 1050 and 1450 m.
Dominant tree:	Acacia Karoo trees, up to 12 m high.
Herbaceous layer:	Open to closed, dominated by grasses.
Occurrence:	Mostly in the middle and southern valleys in Pretoria City and the Area of Interest.
Code:	SVcb6

Name:	**Moot Plains Bushveld**
Description:	Open to closed, low, thorny savannah dominated by Acacia species in valleys and plains.
Altitude:	Between 1050 and 1450 m.
Dominant tree:	Acacia Karoo trees, up to 12 m high.
Herbaceous layer:	Dense, dominated by grasses.
Occurrence:	In valleys in Pretoria City, north of the Area of Interest.
Code:	SVcb8

Name:	**Gold Reef Mountain Bushveld**
Description:	Tree and shrub layers are almost continuous. Predominantly Acacia Kaffra trees on northern slopes.
Altitude:	Between 1200 and 1750 m.
Dominant tree:	Acacia Kaffra trees, up to 12 m high.
Herbaceous layer:	Dense, dominated by grasses.
Occurrence:	On the large mountain rims in Pretoria and the Area of Interest (near the Union Buildings).
Code:	SVcb9

These classes are specified by the South African National Biodiversity Institute (SANBI). See Figure 9 for a geographical location of these vegetation units.

Vegetation Units in Area of Interest



See chapter 5.2 for the codes.

FIGURE 9: MAP OF THE AREA OF INTEREST AND THE VEGETATION UNITS LOCATED THEREIN.

§ 5.2.2 Exotic vegetation in Pretoria and the Union Building Area of Interest

Besides the aforementioned indigenous vegetation, there is also a lot of exotic vegetation in Pretoria. There are a lot of different alien trees in Pretoria, especially in parks and gardens of houses. The most prominent exotic trees are the Cypress, Palm, Eucalyptus and Jacaranda tree (Urban Forest Protection Group). Because of their deep roots and size, they consume more water than indigenous trees, resulting in a different infrared footprint for exotic trees.

§ 5.3 ANTICIPATION OF CLASSIFICATION ISSUES

There are different ways to classify vegetation, such as texture based (used by GeoTerraImage in some instances when only panchromatic imagery is available), using NDVI values or greenness values (used by eATE, see § 7.2.2). The manual vegetation classification that will be performed during this research is a classification based on the near infrared band of the multispectral imagery. As such, the classification issues discussed below are issues that may be encountered by such method. These issues may be interchangeable with other vegetation classification methods. However, since these methods have not been performed during this research, they will not be necessarily taken into account in this section.

§ 5.3.1 General health of vegetation

Climate change has a radical influence on the vegetation inside biomes, since it can transform vegetation relatively rapidly. This calls for a constant interval of surveying and re-classification with new imagery to track these changes and to incorporate mutations into the datasets. This will keep the dataset as accurate and up to date. Since the health of vegetation also determines the leaf density of trees and the density of the herbaceous layer, radio frequency signals from telecommunication towers may interact radically different over time. However, this depends on what the wavelength is of the radio frequency signals that are transmitted.

§ 5.3.2 Exotic vegetation

With the colonization of South Africa by the Europeans, they have introduced a wide variety of exotic vegetation to South Africa (Urban Forest Protection Group). These exotic species have been planted in rural areas (mostly in tree plantations, as windbreaks or demarcation of property) and in urban areas, where they are used as shade for the inhabitants or decoration purposes. There is a downside to this exotic vegetation; these species use more natural resources than indigenous vegetation while procreating at a higher rate than indigenous species. As a result, these exotic species “contaminate existing biomes and cause the demise of different indigenous species” (WWF South Africa, 2008). Since exotic trees use more natural resources, they tend to grow to a great size and height compared to their indigenous counterparts. Because of the density in which they are planted (in parks and plantations), their leaf density and the amount of moisture in those trees, these trees have a bigger impact on radio frequency signals than indigenous vegetation. In rural areas, exotic vegetation in plantations have a regular pattern of being planted and harvested, which could also significantly influence the signal strength in certain areas as the vegetation heights and density changes. These features should be taken into account when classifying vegetation; exotic trees should be appointed a class of their own.

§ 5.3.3 Annual distribution of rainfall

The annual distribution of rainfall differs in each biome. Some biomes, such as the Karoo biome, have long periods of drought while others are generally moist. Other biomes have wet winters or wet summers. These situations drastically change the vegetation in those areas. If there is a long period of drought, it may be hard to for the supervised classification methods to make a distinction between the differences of vegetation as well as other objects in a specific area. The worst time to analyze infrared images is during and just before the end of the dry season. This has to do with the amounts of water contained in the vegetation, which will cause different classes of vegetation to have similar infrared signatures. This may result in problems when appointing test areas for classification. If it is not possible to conduct a field survey of the area to be classified it is essential to have imagery of different seasons in order to compare results of classification, and not only relying on visual inspection of this imagery. This minimizes the occurrence of strange anomalies (a vegetation class that ‘disappears or segregates and integrates with other vegetation types, for example) (Jensen, 2005).

§ 5.3.4 Deciduous trees and impact of seasonal changes

Leaves from deciduous trees contain a lot of water, generating a lot of interference for radio signals. In winter and autumn, deciduous trees lose their vigor and enter a hibernation stage. In that stage, the deciduous trees lose their leaves (see Figure 10). In these months, radio signals can experience less interference from trees, resulting in a stronger signal in certain areas. However, if imagery is acquired during those months, it may not be as useful as imagery acquired in summer or spring. If a deciduous tree loses its vigor, it has a different infrared footprint on imagery than when it has its leaves. This makes it hard for classification to separate these trees from other tree species. Imagery acquired in winter or autumn is not as useful as imagery acquired in summer or spring. This has to do with the deciduous trees that lose their leaves in those months. If a vegetation classification is conducted during those months, it can change the outcome of the classification compared to when it is conducted in other months. In panchromatic imagery, the difference between deciduous trees and evergreens over different seasons can be hard to distinguish due to the changing texture of this vegetation and density of the deciduous tree canopies (Eastman, 2005).

In this research, a vegetation classification of moderate accuracy is discussed. In urban areas, as the demand for more accurate vegetation information grows, it is recommended to make a separation between deciduous trees and other trees. Such a separation is possible and recommended for rural clutter data sets, since different plantations have deciduous trees or pine trees, making the process of specifying testing locations easier. Separation between these different tree species requires imagery taken in different seasons. This enables evergreens (with a relative constant infrared footprint) to be separated from deciduous trees (whose infrared footprint changes when it loses its vigor). Also, additional research into deciduous tree species in South Africa is recommended in order to predict those changes before the imagery is acquired (i.e. when they lose their vigor etc.).

FIGURE 10: DECIDIOUS TREES WITH AND WITHOUT LEAVES (LEFT AND RIGHT RESPECTIVELY).

§ 5.3.5 Canopy density and leaf size

Vegetation classification also depends on the canopy density and leaf size, besides the overall health of the vegetation. If a certain species of trees has a low canopy density and small leaves (like the Acacia Kaffra trees), more light will pass through these trees and less near-infrared light is reflected. The bigger the leaves and the denser the canopy, less visible light is reflected but more infrared light is reflected, making it easier to classify. The eATE algorithm uses a classification using the Normalized Difference Vegetation Index value (NDVI value) in which these factors become relevant. See § 7.2.2 for more explanation of the NDVI values and how eATE uses this to classify vegetation (Jensen, 2005).

§ 5.3.6 Other influences

Not only do the different vegetation, seasons and health of vegetation play a role in producing a useful vegetation classification; other factors may also interfere:

- *Spatial resolution:* When a multispectral image with a low spatial resolution is being classified, the boundaries between objects, such as water bodies, buildings and parks, may become diluted inaccurate. Also, the identification of a formation class of a specific bioregion or vegetation unit can be influenced by the resolution. A higher spatial resolution makes a better distinction of these different objects.
- *Artificial structures:* Artificial structures (such as buildings or termite hills) can hide important elements or spectral wavelengths, or dilute results in terms of height.
- *Overhanging vegetation:* Some vegetation can hang over buildings or other structure, which creates a problem when filtering buildings from vegetation.
- *Shadows:* Shadows of mountains, vegetation, buildings etc. can obscure areas and dilute spectral signatures assigned to specific objects, such as vegetation (see Figure 11). Sensors of remote sensing satellites are not in the same position. Although this difference is small,

the speed of the sensor and the distance between the sensor and the area being observed causes the panchromatic and multispectral images to not conform 100%.

Due to all these factors, a classification method will never reach 100% accuracy. Some trade-offs may have to be taken to generate a usable result, such as grouping of similar vegetation or building types.

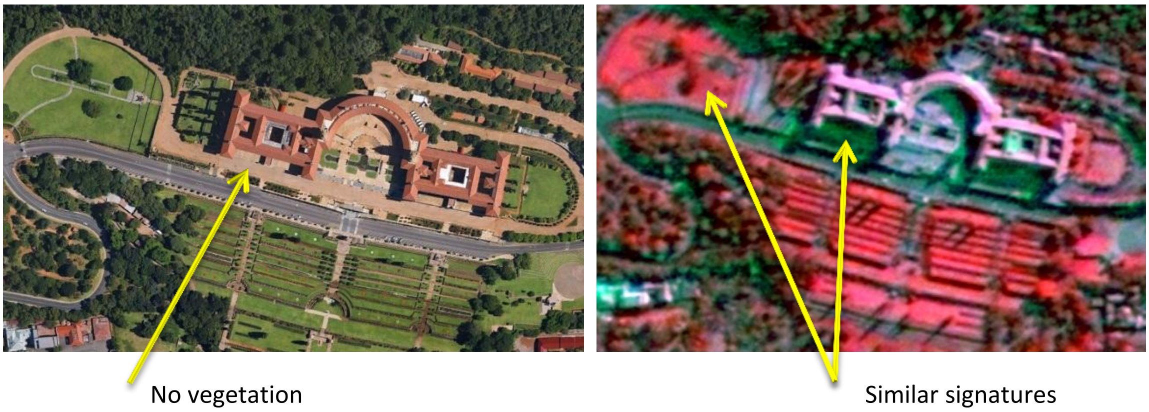


FIGURE 11: SIMILAR SIGNATURES CAUSED BY SHADOWS AND INTERPOLATION OF MULTISPECTRAL IMAGERY. THIS IS CAUSED BY THE DIFFERENT POSITION OF THE CAMERAS WHEN THE IMAGERY WAS TAKEN.

§ 5.4 Suitable classification situations in the Union Building Area of Interest

Within the 'Union Building Area of Interest', there are several areas which are suitable as testing areas for classification methods, based on near infrared bands. These areas contain similar vegetation type, while the near infrared signature is homogenous. Also, these areas are of suitable size. A suitable size is an area where the range of near infrared bands for a specific class is homogenous enough and, preferably, as grouped as possible, while still quickly recognizable for the common analyst. These sites have been picked using the multispectral imagery as a reference, and using an on-site field study to verify conclusions derived from interpreting the imagery. Below, each test site has been described. A map of these locations is found in Figure 13. On site pictures of these areas are found in Figure 12. These testing areas have been incorporated in the classification method, as described in § 9.3.

Location 1
Place: The northern side of the mountain range of the Union Buildings.
Type: Indigenous
Vegetation: Bushveld (class SVcb9), condense trees up to approx. 10 m high, herbaceous layer up to approx. 1 m.

Location 2
Place: Mountain ridge in the northern part of the Area of Interest.
Type: Indigenous
Vegetation: Bushveld (class SVcb9), condense trees up to approx. 10 m high, herbaceous layer up to approx. 1 m.

Location 3
Place: Experimental farm (proefplaats), north eastern corner of the Area of Interest.
Type: Indigenous

Vegetation: Bushveld (class SVcb6), very sparse trees (exotic and alien) up to approx. 7 m high, prominent herbaceous layer up to approx. 1 meter.

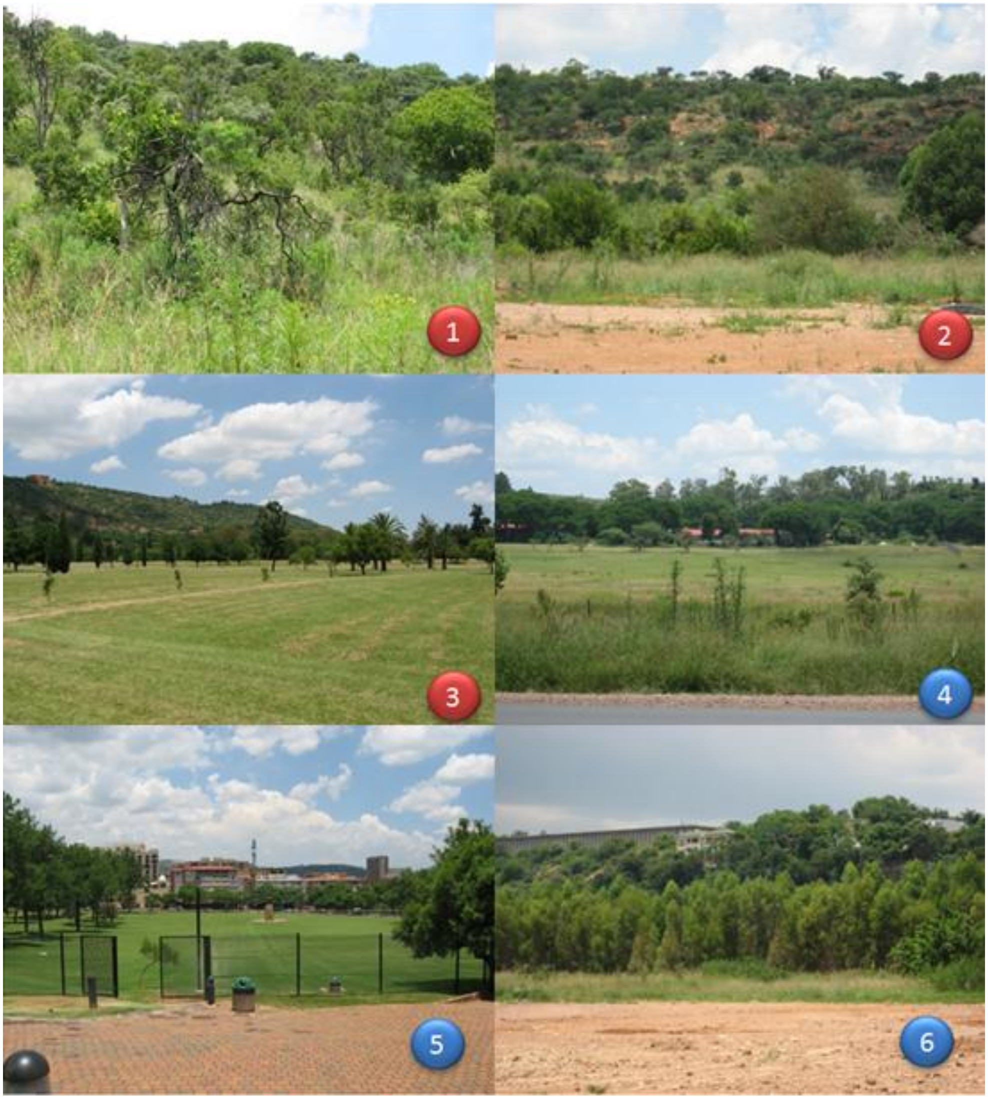


FIGURE 12: PICTURES OF THE TEST LOCATIONS DESCRIBED IN THIS SECTION.

Location 4
Place: Just south of the Union Buildings.
Type: Exotic
Vegetation: Herbaceous layer up to approx. 20 cm high, surrounded by alien trees up to approx. 20 m high.

Location 5
Place: Park just north of the Union Buildings.
Type: Exotic
Vegetation: Sparse exotic trees up to approx. 7 m high, herbaceous layer up to approx. 20 cm high.

Location 6
Place: Tree plantations next to the Department of Foreign Affairs.

Type: Exotic
Vegetation: Sparse trees up to approx. 7 m high, herbaceous layer up to approx. 20 cm.

Location 7
Place: Presidential golf course south of the Department of Foreign Affairs
Type: Exotic
Vegetation: Herbaceous layer up to approx. 20 cm high, surrounded by alien trees up to approx. 20 m high.
Note: Restricted area and therefore not included in Figure 13.

Using these testing areas, the resulting classes which can be separated are:

1. Bushveld Trees (areas 1, 2)
2. Bushveld Grass (area 3)
3. Exotic Trees (areas 4, 6, 7)
4. Exotic Grass (areas 4, 5, 6, 7)

As is visible, the evergreen and deciduous exotic trees are hard to distinguish. Therefore, these will be grouped together.

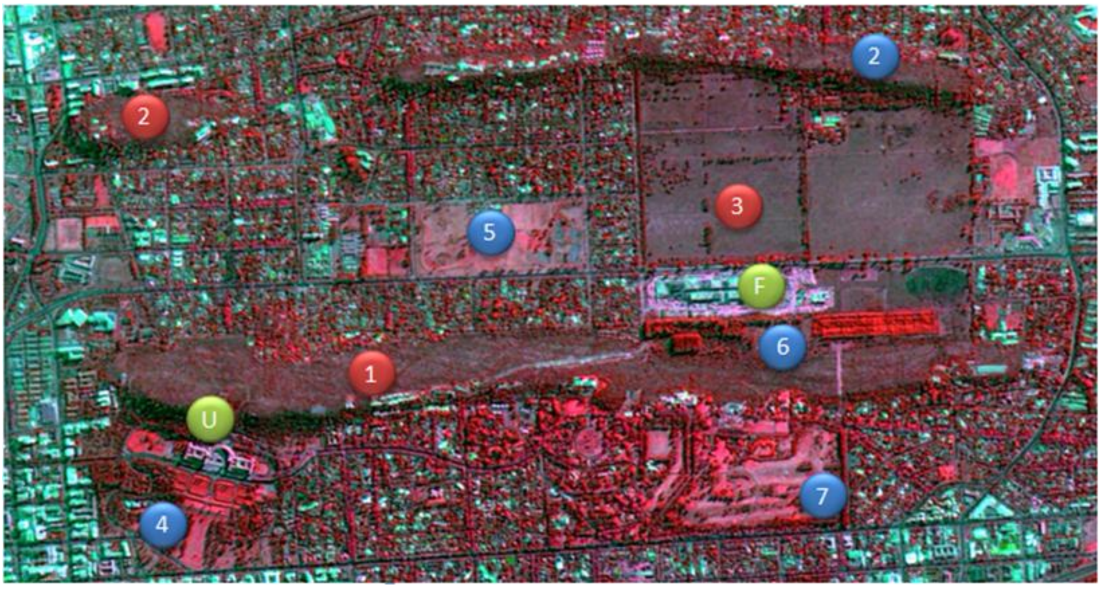


FIGURE 13: THE TEST LOCATIONS FOR VEGETATION CLASSIFICATION (A NEAR INFRARED IMAGE OF THE AREA OF INTEREST).

§ 5.5 LIMITATIONS OF AVAILABLE SATELLITE IMAGERY

The available satellite imagery, specified in § 3.1, each has its own limitations which are discussed below.

Formosat-2
The Formosat-2 imagery is very useful as it is stereo imagery with near infrared bands. The spatial resolution (8m) is sufficient for the extraction of vegetation data for the current clutter data. However, if, in the future, higher resolution clutter data is necessary, it is essential to acquire higher resolution imagery (for example for WiMAX suitable clutter data, see § 4.3). A higher spatial resolution multispectral imagery will result in clearer definitions of vegetation

Ikonos

The Ikonos available at GeoTerraImage is acquired in September, the blooming season of the Jacaranda tree (Kasrils, 2001). When the Jacaranda tree blooms, the tree turns into a pink/purple color. Because the Ikonos imagery available does not have an infrared band, it makes the classification of these trees difficult. When analyzed, the spectral signatures of the Jacaranda trees overlap with certain other objects in the image (Figure 14). The other vegetation types in the area covered by the Ikonos imagery are also hard to distinguish because of the similar color different vegetation types have with each other.

FIGURE 14: BLOSSOMING JACARANDA TREES ON IKONOS IMAGERY (FALSE COLOR).

Chapter 6 CONCEIVED APPROACH

The objective of this research is to extract the vegetation heights from stereo remote sensing imagery (see § 3.1). A lot of steps have to be taken to achieve that objective. Those steps are described in this chapter. First, the workflow itself is discussed, which is displayed in Figure 15. In this workflow, the purple boxes indicate data available to GeoTerraImage (see Chapter 3). The green boxes indicate data created during this process. The light blue boxes indicate the processes performed on this data. Outputs of the data available to GeoTerraImage as the data created during this process can be found in the attachments. The overall workflow is discussed in § 6.1, whereas the individual processes are discussed in the following chapters as indicated in § 6.1.

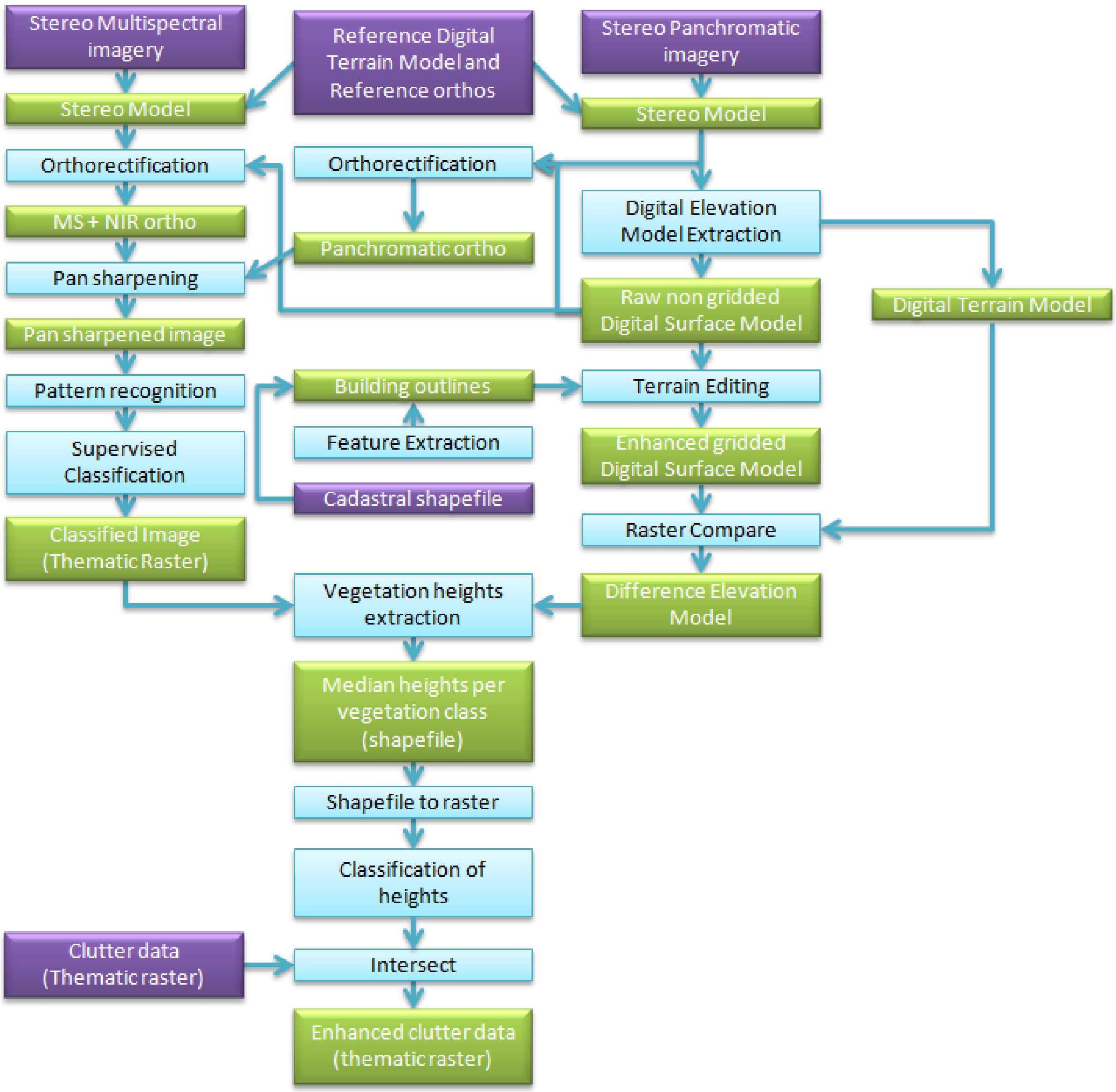


FIGURE 15: A FLOWCHART DETAILING THE APPROACH DEVISED TO ENHANCE CLUTTER DATA.

§ 6.1 REQUIRED STEPS

In order to acquire the vegetation heights (or indeed any object's height), it is necessary to generate Digital Elevation Models or (DEM's). A DEM is a dataset that contains elevation values based on horizontal geographic coordinates. There are two different types of Digital Elevation Models, both of which have to be generated. These types are:

1. A **Digital Terrain Model (DTM)**. This DEM is a digital representation of the theoretical surface on the ground (a bare earth model).
2. A **Digital Surface Model (DSM).** This DEM is a digital representation of the theoretical surface of high points, including artificial and natural structures.

See also Figure 16 and Figure 17 for a graphical representation of the difference between a Digital Surface Model and a Digital Terrain Model.

FIGURE 16: A DIGITAL TERRAIN MODEL (COLORED LINE), WHERE ONLY THE GROUND LEVEL IS INCORPORATED. ALL BUILDINGS (GRAY) ARE NOT INCORPORATED IN THIS ELEVATION MODEL.

FIGURE 17: A DIGITAL SURFACE MODEL (COLORED LINE), WHERE THE HEIGHTS OF THE OBJECTS ARE INCORPORATED, OR THE GROUND LEVEL IN CASE THERE ARE NO OBJECTS ON THE TERRAIN.

Before it is possible to extract these Digital Elevation Models, one has to first reference the stereo imagery available for this project (§ 3.1) using the reference Digital Terrain Model and aerial orthophotos (§ 3.2). These steps are discussed in Chapter 7.

The Digital Surface Model created in the previous step can be inaccurate in some areas due to search window, correlation and interpolation variables. To compensate for this problem, the errors have to be adjusted and the Digital Surface Model has to be enhanced. The model can be enhanced by adjusting it manually. Additional reference sources, such as the cadastral data shapefile, can be used to enhance this semi-automatically. The vector shapefile is originally in 2D, it has to first be converted to 3D before it can be used. After filtering out the building outlines from the cadastral shapefile, the shapefile is ready to be incorporated in the Digital Surface Model, creating an enhanced Digital Surface Model. Building outlines not incorporated in the cadastral dataset can be added manually. These steps are discussed in Chapter 8.

The classification of multispectral imagery (with a near infrared band) for this project is not possible when the images are still in stereo; they have to be orthorectified. This means that the stereo image, with a perspective view, is transformed to an orthophoto, with an orthogonal view. The reason why it is not possible to classify stereo images for this research is the inability to convert these images to ortho when this data has to be compiled into the clutter data. The images also has to be pan-sharpened, this is done to enhance the spectral resolution as well as the geographic resolution of the images, producing a more accurate result. At this stage, the test areas from § 5.4, can be specified for a classification process. These steps are discussed in Chapter 9. The end result is a thematic raster image with the different (vegetation) classes.

By subtracting the Digital Terrain Model (generated previously) from the Digital Surface Model, all that remains is the height of the structures on top of the ground level; a Difference Elevation Model (DIEM). This DIEM is then intersected with the thematic raster generated in the previous step. Intersecting the thematic raster with the DIEM, segments the DIEM. The elevation is now separated by the classes specified in the thematic raster in a vector polygon shapefile. Because these classes separate vegetation by type, the mean value of the elevation each segment can be taken. A radical height difference between vegetation is usually described by a change in infrared signature and thus separate classes, which authorize the usage of mean values. These steps are discussed in Chapter 10. See Figure 18 for a graphical representation of a DIEM. The mean heights extrapolated will then be classified by intervals of 5 meters.

The raster file generated in the previous process can now be intersected with the original clutter data. The end result is an enhanced clutter data set signifying, apart from existing classes, both the type and the median height of vegetation. See Chapter 12.

FIGURE 18: A DIFFERENCE ELEVATION MODEL. THE GROUND LEVEL HAS BEEN DEDUCTED FROM THE DIGITAL SURFACE MODEL, LEAVING THE HEIGHTS OF THE OBJECTS. THE MINIMUM VALUE IN A DIFFERENCE ELEVATION MODEL IS 0 ELEVATIONS.

§ 6.2 ALTERNATIVE ROUTES AND SHORTCUTS IN THE WORKFLOW

The workflow as specified in the previous chapter can be adjusted. New experimental software from Erdas, namely the Shadow2Height software can extrapolate the heights of objects on the surface, making the breakline generation process easier. The Shadow2Height software is able to extrapolate the height of objects in an image using the shadow that this object creates as a reference. Each picture is taken at a specific time on a specific date at a specific angle. Taking the angle with which the image was collected, the angle of the sun at that time, the location of the sensor and the elevation of the sun on the horizon, it is possible to extract the height of the objects. This experimental software is not incorporated in this research. Additional research is needed into this software to analyze the potential and its abilities prior to its usage in this process.

Chapter 7 RAW DIGITAL ELEVATION MODEL EXTRACTION

This chapter discusses the process from using the remote sensing imagery available to GeoTerraImage to generate Digital Elevation Models (DEM). The first paragraph discusses the processes to be executed prior to Digital Elevation Model extraction; the first 4 blocks in Figure 19. The second and third paragraph discusses the process of the Digital Elevation Model extraction, with the use of different algorithms (and their dynamics). Finally, the fourth paragraph discusses the final result; a raw Digital Elevation Model. Leica Photogrammetric Suite has been during this entire process.

The projection used by GeoTerraImage for all its telecommunication products in South Africa is the UTM projection type with a WGS84 Spheroid. Depending on the location in South Africa, different UTM zones have to be used. Pretoria is in UTM zone 35 south. GeoTerraImage uses the WGS84 projection as vertical reference system. GeoTerraImage uses these projections because the planning software used by clients is limited to UTM projections. South Africa does possess a native projection, the Hartebeeshoek 94 (Wonnacot, 2000).

FIGURE 19: PROCESS OF EXTRACTING DTM'S AND DSM'S.

§ 7.1 PREPARATIONS

With two stereo photos of the same scene, it is possible to create a stereo model. With this stereo model, it is possible to generate Digital Elevation Models. These Digital Elevation Models are based on the differences in parallax between the two stereo images, and the correlation of each pixel in the two images. Since both stereo images have been taken in a different position, it is possible to determine the height difference between all the different objects in the image. First of all, the stereo photos need to have a geo reference (external orientation). See Figure 20 for a graphical representation. With the help of the reference aerial orthophotos and the reference Digital Terrain Model, it is possible to assign X, Y and Z reference points (called Ground Control Points, GCPs), to these images. These control points will assign the X, Y and Z coordinates from the reference data to the points created in the stereo imagery. Normally, these control points will be measured by a surveyor in the field, but these means are not available to GeoTerraImage at the time of this research. Because of this, the reference ortho photos and reference Digital Surface Model have been used.

When placing ground control points manually (as is the case in this research), the points have to be placed on areas which are distinguishable on all images used in the process. These ground control points need to be placed in places on the imagery which are easily distinguishable on all pictures. The ground control points have to be placed on ground level. Placing points on objects in the imagery is not allowed, this is because the imagery is collected in different angles. An object will lean in different directions, depending on which side the sensor was located during the collection process. In other words, points can only be attributed to places on the imagery which are located on the terrain.

The imagery available to this project is of relative low resolution. As such, ground control points are easiest specified on clear borders visible in the terrain. A good example is street intersections, field boundaries (without walls), road markings (such as on airfields). See also Figure 21.

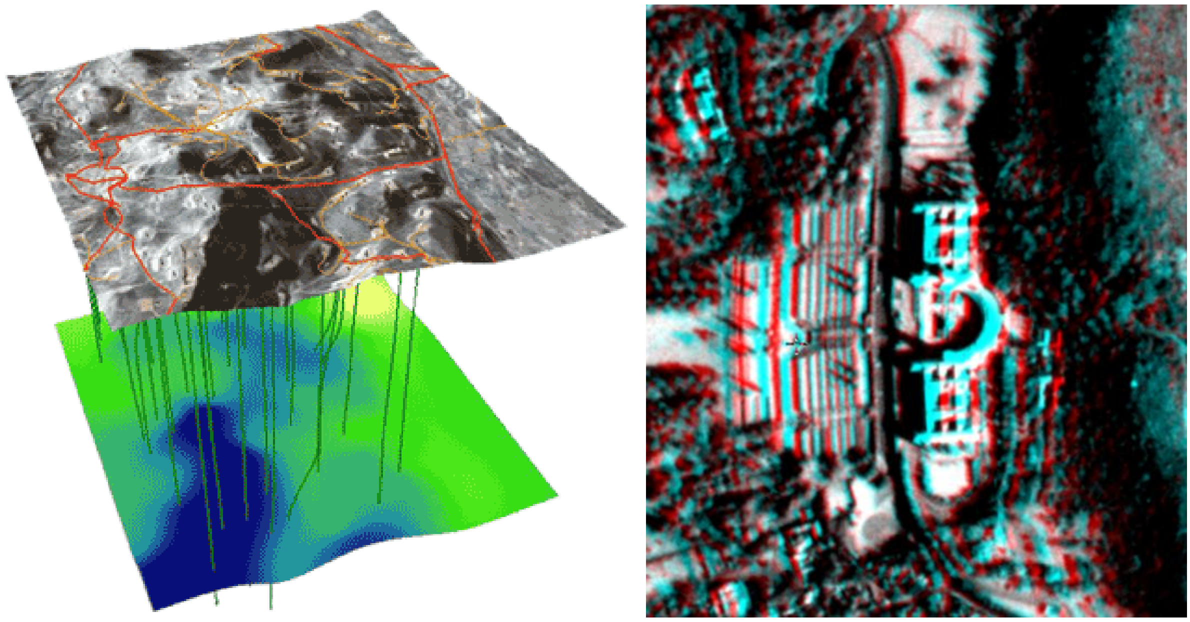


FIGURE 20: LEFT: A GRAPHICAL REPRESENTATION OF LINKING A STEREO MODEL (ABOVE) WITH A DIGITAL ELEVATION MODEL (BELOW). RIGHT: A STEREO MODEL OF THE UNION BUILDINGS.

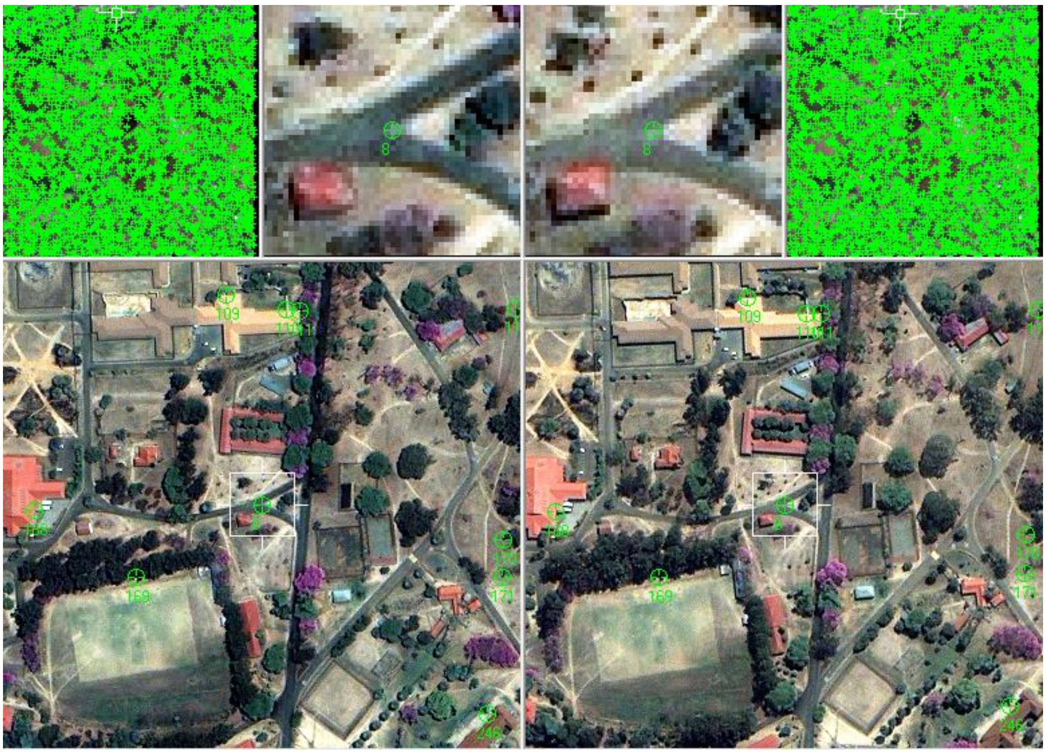


FIGURE 21: AN EXAMPLE OF A GROUND CONTROL POINT, PLACED ON IKONOS IMAGERY. ROAD INTERSECTIONS ARE OFTEN EASY PLACES TO PLACE GROUND CONTROL POINTS. THE HIGHLY DENSED AREAS IN THE TOP LEFT AND RIGHT CORNERS IS AN OVERVIEW OF ALL GROUND CONTROL AND TIEPOINTS CREATED.

At least 3 distributed ground control points are needed to reference a stereo model (ESRI, 2009). However, to avoid errors due to false points, specifying more ground control points will reduce the Root Mean Square (RMS) error. This error quantifies the difference between estimators and the value being estimated; in this case the difference where the 'from' point ended up as opposed to the actual location that was specified, the 'to' point position. The value describes the consistency of the location of the control points in the model; a large value indicates an inconsistent control point. If the scene is large, there are many differences in altitude and land cover which can dilute the vertical reference. Using more ground control points will improve the results, as the error of the points is mediated using the Root Mean Square error. Ground Control Points with a major error can then be recognized and filtered out. In the research, a total of 20-30 ground control points, evenly distributed throughout the scene in both vertical and horizontal direction have been placed. This seemed to produce a usable result, as in: the ortho reference images and the orthorectified images (explained in § 9.1) were conforming. Lack of control points in either the horizontal or vertical plane will result in a distortion in these planes, causing the reference orthos and orthos to be non-conforming.

Row #	Point ID	Type	Usage	Active	X	Y	Z	RX	RY	RZ	Total RMSE
1	1	Full	Control	✔	616857.306	7145849.345	1462.332	0.959291	0.628503	-1.096008	1.661541
2	3	Full	Control	✔	613493.758	7142791.650	1414.448	-1.187397	1.647230	-1.685820	2.056632
3	4	Full	Control	✔	612476.093	7147152.932	1496.345	-1.795074	2.835307	-1.596315	3.109160
4	5	Full	Control	✔	612512.414	7149938.392	1369.677	-2.472283	-3.007123	-0.609043	4.282120
5	6	Full	Control	✔	617338.992	7148246.156	1445.062	-0.348718	0.644772	1.772503	0.603997
6	7	Full	Control	✔	615408.405	7149731.845	1364.224	-0.738072	-1.841348	1.486723	1.278378
7	8	Full	Control	✔	616606.875	7150090.322	1343.287	1.000847	-2.428820	3.609361	1.733517
8	10	Full	Control	✔	619179.790	7147801.362	1387.611	1.081334	0.492429	2.084857	1.872926
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

FIGURE 22: A RMS ERROR TABLE OF GROUND CONTROL POINTS. X, Y AND Z INDICATE THE COORDINATES FOR THAT POINT. RX, RY, RZ INDICATE THE ERROR VALUES FOR EACH POINT. THE TOTAL RMSE INDICATES THE TOTAL ROOT MEAN SQUARE ERROR. ACCORDING TO GEOTERRAIMAGE GUIDELINES, THIS ERROR MAY NOT EXCEED 5.

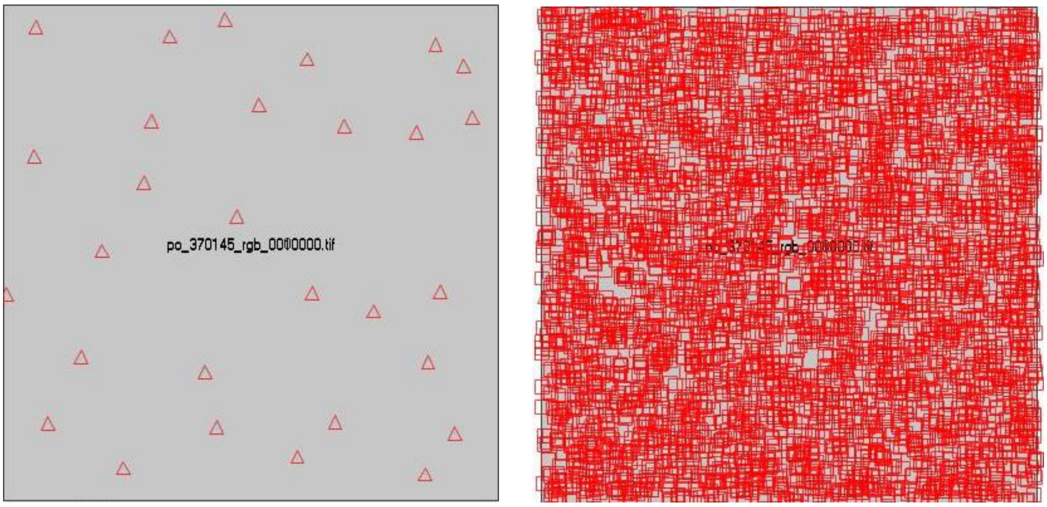


FIGURE 23: LEFT: CONTROL POINTS, GIVING THE STEREOMODEL AN EXTERNAL REFERENCE. RIGHT: TIEPOINTS, DEFINING THE INTERNAL REFERENCE OF THE TWO IMAGES.

Before the stereo model can be used to extract information, the model has to successfully pass the triangulation iterations, where the RMS error value should be lower than 5 for optimal extraction results (the total RMS error value is a dimensionless number). If the RMSE value is more than 5, the images will be too course. See Figure 22 for a table of RMSE values of ground control points. If the model passes the triangulation iterations, additional tiepoints may be calculated automatically with LPS. These additional tiepoints will ensure the relative orientation of the stereo model (since the external orientation of the stereo model is being defined by the manually placed 20-30 ground control points, see Figure 23 for a graphical representation of the tiepoints and control points). If a triangulation iteration of the ground control points is not performed and tiepoints are generated, it might be necessary to regenerate these points in case the RMS error of the control points is too high, in which case the tiepoints may be generated in a wrong location in which the pixel of both images seems to have a similar value. With the control points placed and tiepoints created, it is possible to generate Digital Elevation Models.

Two different algorithms can be used to extract Digital Elevation Models; the aATE and its successor, the eATE algorithm (adaptive Automatic Terrain Extraction, enhanced Automatic Terrain Extraction, respectively). These algorithms require separate licenses, thus both of these algorithms have to be tested thoroughly in order to investigate which algorithm generates the best, most useful in the most efficient way. The variables used by eATE are discussed in the next paragraph. The limits and differences of aATE are discussed in the third paragraph.

§ 7.2 VARIABLES IN THE EATE ALGORITHM

In the imagery, it is possible to draw certain area-of-interest (aoi) polygons in which it is possible to define different patterns and situations. eATE can then be configured to apply a certain strategy on this area of interest. These processes performed in eATE strategies are discussed in § 7.2.1. After these processes some additional processes are applied before the Digital Elevation Model is generated. These are discussed in § 7.2.2.

§ 7.2.1 Strategies

The strategies are defined by series of settings, which the user is able to manipulate to produce a specific result most suitable for the situation. The strategies as discussed below are used by eATE in performed in consecutive order, per pyramid level (top to bottom). A pyramid level consists of the base image and a series of successively smaller sub-images at half the resolution of the previous image (Adelson, 1984) (Microsoft Seadragon). See also Figure 24.

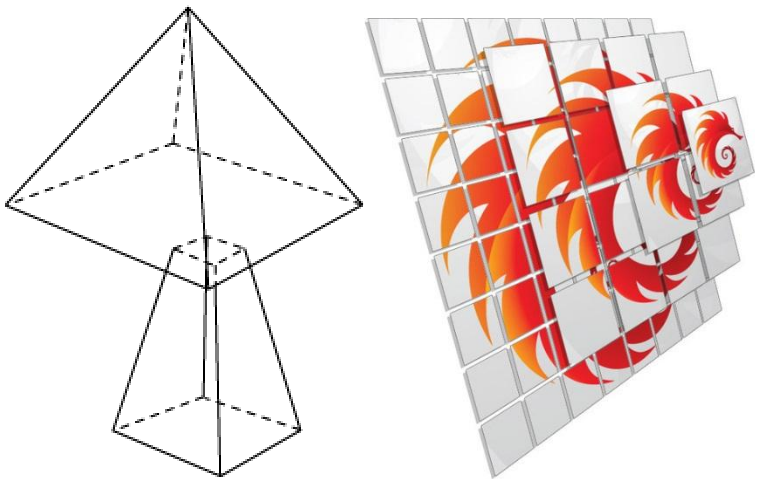


FIGURE 24: PYRAMID LEVELS.

Correlation

eATE works with two different correlation methods of points, namely the Sum of Squared Differences (SSD) and the Normalized Cross Correlation (NCC). The SDD method measures the similarity of pixels by subtracting the pixels of the reference and target image within a square neighborhood. These absolute differences are then squared and aggregated in each search window. Finally, it is optimized with a winner takes all strategy, which means that the pixel with the lowest difference is collected and attributed to the search window. If both images were an exact match, this difference would be 0 (Hantahuja, 2010).

The NCC method is more complex than the SSD method. It first normalizes the brightness in each image, by subtracting mean spectral pixel values of the image (or area of interest) and dividing it with the standard deviation of the pixel values. The standard deviation is the square root of the variance; the mean of the deviation squared of that variable from the overall mean. The larger the variance, the more each variable differs from each other and the greater the difference between variables and the overall means. It then applies a cross correlation of the pixels on both images, in which the pixels between the reference image and the target image are being compared. The NCC uses a template of both images to identify patterns that match on both images, enabling the eATE algorithm to identify objects such as building outlines. The NCC method generates a better result than the SDD but increases processing time.

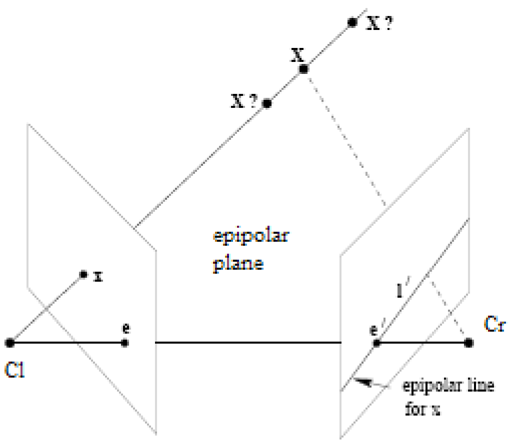


FIGURE 25: CL AND CR ARE THE CAMERA CENTERS. THESE, ALONG WITH THE POINT X, ARE LOCATED IN THE EPIPOLAR PLANE. THE INTERSECTION OF THIS EPIPOLAR PLANE WITH THE IMAGES IS CALLED THE EPIPOLAR LINE.

Using both algorithms, the two images are matched with a pair-wise matching, which identifies a point in the master image and then searches for the corresponding point in the second image. The camera centers and the points in the images lie in a common plane. The intersection of this plane with the image is described as the epipolar line. As such, the corresponding values for X in both images are found along this epipolar line (see Figure 25 for a graphical representation). A good match of corresponding values is prominent in homogenous areas or repeated patterns, as objects such as trees might obstruct similar features. It can be expanded with the reverse matching process, which swaps the reference and search image to recheck generated points.

Interpolation

If points are not correlated, they have to be interpolated. These interpolated points are used to seed the next correlation. There are three types of interpolation, namely Mean, Region and Spike.

- The **Mean** interpolation algorithm searches from the missing point to known values and weighs the contribution based on the distance of the point to be interpolated. The further the distance between the known point and the missing point, the less weight this point will have on the value of the missing point.

- **Region** is similar to the Mean interpolation method. The difference is that the method is constrained within a region segmented from the master image (see edge constraint below).
- **Spike** is the same as region, except that it removes points that eATE identifies as spikes based on the surrounding points.

The parameters in which eATE should search for similar points considered for interpolation is specified in the Point Threshold (the number of points considered for interpolation, a spiral search determines the closest points), whereas the Search Window specifies the maximum (square) search size surrounding the point to be interpolated.

Least Square Refinement

The objective of the Least Square Refinement method is to find a good estimation of parameters that fit a function of a set of data. It requires that the estimated parameters deviate as little as possible from the original function. In eATE, the Least Square Refinement is an algorithm that uses least squares to refine the correlation to provide improved sub pixel results, which increases accuracy of the Digital Elevation Model (Erdas, 2009).

External reference files

While the strategy procedures correlate and interpolate points, different external reference sources can be used to match the generated Z values. This means that points generated will be compared to the external reference files. A specific search range can be applied to these external reference files, which can be used to indicate how accurate the external reference file is. These search ranges can be applied above and below the points in the reference sources. If elevation values drop below or above the search ranges, these points will be classified as blunders and omitted. Since the reference files available to this research do not incorporate the object heights above terrain at the accuracy that the algorithm is able to generate, the search range for points above the reference files has to be high. However, because bare earth reference files do describe the elevation of the terrain, the search window for points below the terrain can be kept to the accuracy of the reference files used. It is not possible for the elevation model extracted to have less elevation than the reference file, if the terrain did not undergo drastic changes in the time between collection dates. Otherwise, a larger search range has to be specified (Fengliang, 2008) (Aktaruzzaman, 2008).

These external reference files can have a specific weight on the end result. It can be used for different pyramid levels. The higher the pyramid levels, the less weight these reference files will have on the final result.

Blunder elimination

The search window specified for the external reference file may not be sufficient to filter out all the blunders and mismatches. To eliminate these blunders, a blunder elimination technique is used by eATE. The technique is the Principal Component Analysis (PCA) based blunder elimination. The use of PCA allows the number of variables in a multidimensional data set to be reduced. This technique is based on piecewise smoothness constraint on the object space. The point cloud generated is fitted to a principal plane, points within the range specified by the analyst will be kept and points that fall outside the range are omitted. See Figure 26. The range is described as a distance (meters, feet) depending on the type of projection has been attributed to the stereo model. This blunder elimination is very useful to filter out points, but it can be unsuitable when a Digital Surface Model in some situations (depending on the range specified). If a model is generated from an urban area with highly irregular buildings or areas where there are lots of trees, some points could be filtered even though they were not supposed to be (Fengliang, 2008) (Gordon, 2009) (Aktaruzzaman, 2008).

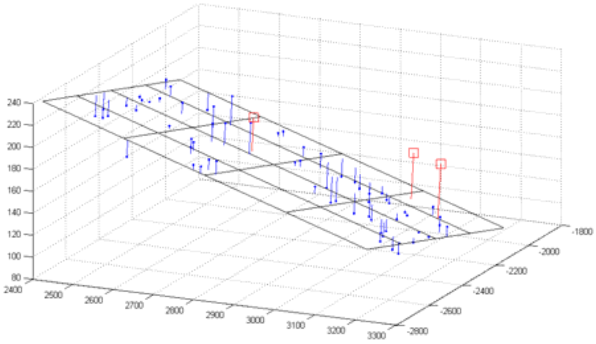


FIGURE 26: THE PRINCIPAL PLANE IN AN XYZ SPACE WITH BLUNDER POINTS (RED) AND IN-RANGE POINTS (BLUE).

Edge constraint

When the eATE algorithm interpolates pixels, it encounters sudden differences in heights (an edge), mostly from buildings. Normally, eATE would use the search window as defined by the user and ignore these differences, generalizing the edge. By applying an edge constraint, the eATE algorithm will take these edges into account and does not let the search windows overlap the edges. This means that extra triangles will be generated on both sides of the edge, which causes triangles to no longer overlay the edge. As a result, the edges are more visible in the final output. See also Figure 27.

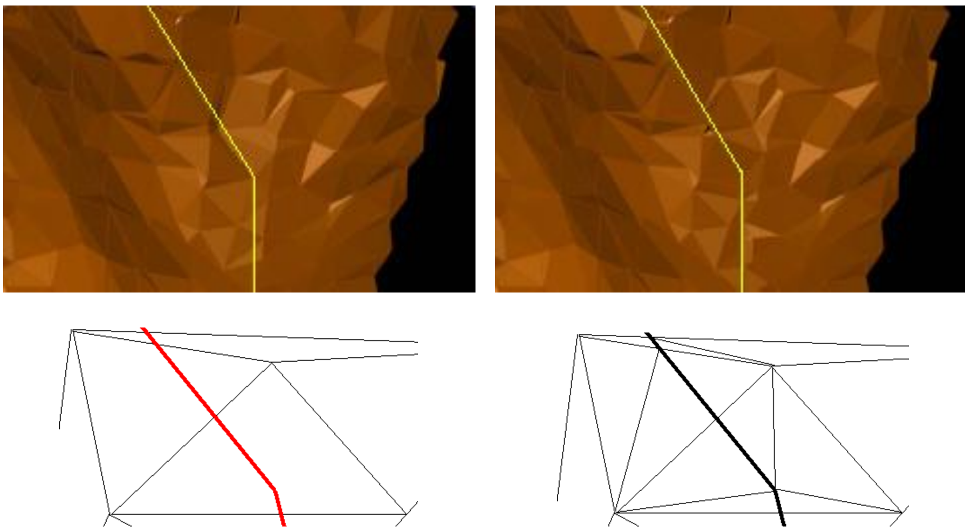


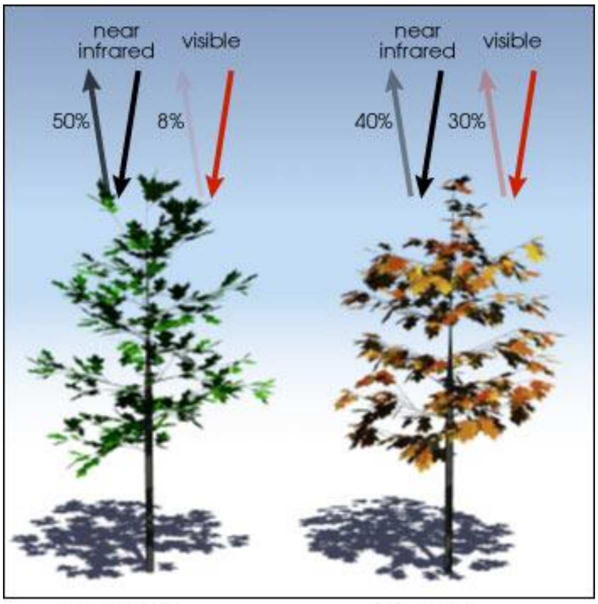
FIGURE 27: LEFT: NO EDGE CONSTRAINT APPLIED. EDGE IS OVERLAPPED BY TRIANGLES (EDGE IS IGNORED).
RIGHT: EDGE CONSTRAINT APPLIED. TRIANGLES NO LONGER 'IGNORE' THE EDGE. THE YELLOW AND RED LINES ARE THE EDGE.

Smoothing

The generated Digital Elevation Model can also be smoothed. It looks for spikes in elevation and removes the points that define a too extreme height difference compared to surrounding points. eATE has different settings for none to rigorous smoothing. Using this smoothing could filter out objects on terrain; however, depending on the density of these objects it can also use the heights of these objects as a reference commence a smoothing procedure. eATE is able to use its classification algorithm (see § 7.2.2) to counteract this problem.

§ 7.2.2 Output proceedings

After the strategies have generated a point cloud, some final procedures are conducted before the point cloud is exported to a non-gridded dataset. These so-called output proceedings are discussed below.



$$\frac{(0.50 - 0.08)}{(0.50 + 0.08)} = 0.72 \qquad \frac{(0.4 - 0.30)}{(0.4 + 0.30)} = 0.14$$

FIGURE 28: HEALTHY VEGETATION (LEFT) REFLECTS MORE NEAR-INFRARED LIGHT THAN VISIBLE LIGHT, WHEREAS UNHEALTHY VEGETATION OR VEGETATION WITH A LOW DENSITY (RIGHT) REFLECTS MORE VISIBLE LIGHT. THE NDVI, NIR AND VIS VALUES ARE EXAMPLES, IN REALITY THESE VALUES ARE MUCH MORE VARIED.

Classification

eATE uses a rudimentary classification method to recognize buildings and vegetation in the imagery, which can then be filtered out of a Digital Surface Model.

- *Buildings* are classified by the slope in which a height difference occurs. This helps to identify sharp discontinuities produced by structures. In order to filter buildings from cliffs or other sharp terrain differences, an object area can be defined. If the object encountered by eATE has an area between the minimum and maximum parameters, it is classified as a building. In conjunction to the area, a minimum object height can be defined; all sharp edges which describe a height difference higher than that minimum object height are classified as buildings.
- *Vegetation* is classified in a different way than supervised classification (§ 9.3.1). In case the imagery is multispectral, it uses the greenness of pixels to classify it as vegetation or non-vegetation. If the imagery contains near-infrared layers and visible light layers, it will calculate the NDVI (Normalized Difference Vegetation Index) value for the points and use it to distinguish vegetation from non-vegetation. NDVI values are calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation (left) absorbs most of the visible light but reflects a large portion of the near-infrared light. Unhealthy vegetation or vegetation with a low density reflects more visible light and less near infrared light (Resonancepub, 2001). See Figure 28 for an example. NDVI = (NIR-VIS)*(NIR+VIS) is the formula used to calculate the NDVI. Calculations of the NDVI value of any given pixel always

results in a number between -1 and 1. Values close to -1 indicate unhealthy trees or small leaves or non-dense canopy, values close to 1 indicate the highest possibility of canopy density, health and size of leaves. Values close to 0 are non-green leaves and can be classified as other objects than vegetation. In case of panchromatic imagery, it is not possible to classify vegetation; eATE is not able to classify vegetation on their texture and brightness. For the imagery available, the classification method is not sophisticated enough to analyse vegetation in areas where different types of vegetation are found, such as in the "Area of Interests" studied in this research. This has to do with the wide variety of vegetation and the distribution of nutrients in the soil in the Areas of Interest.

Thinning of points
eATE is capable to thin points. This means that the number of terrain points is reduced in an area where there is a high density of points.

- **Regular Spacing:** It is possible to thin points by a regular spacing, removing points which are in a specific area of each other. All points in a specific grid cell size will either be mediated to one point, or the point within the grid cell of the highest quality of correlation will be preserved.
- **Planar Surface:** A thin by planar surface can be applied to remove redundant points in the entire image. This removes all points within a certain range of the planar surface (a smooth, edgeless or flat test surface).

Although this thinning of points may improve Digital Terrain Models, it can also cause sharp edges (such as cliffs) to become less prominent in the end result. It can be used in situations where the terrain is relatively constant, smooth or flat, in which it can aid to filter out objects on this terrain (Erdas, 2009).

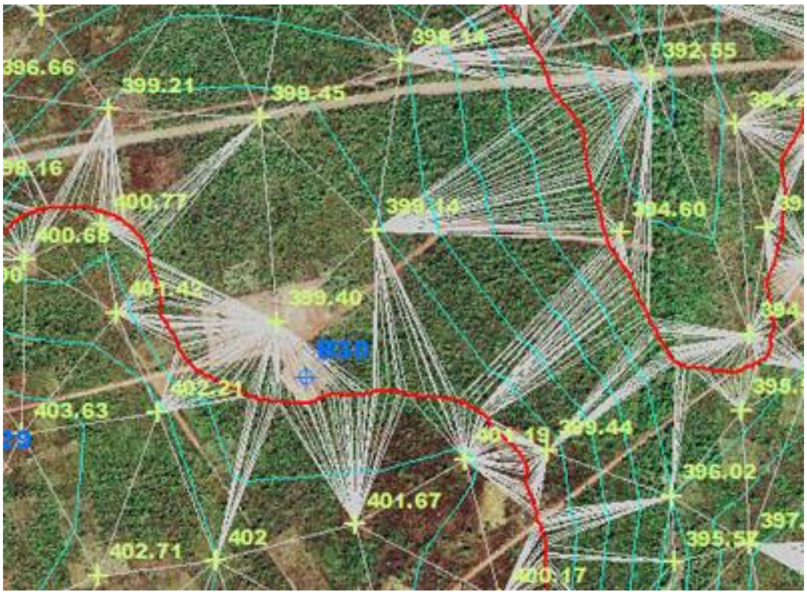


FIGURE 29: A NON-GRIDDED DATASET. YELLOW POINTS ARE MASS POINTS, LIGHT BLUE LINES IS THE TIN NETWORK, THE RED LINE IS A BREAKLINE.

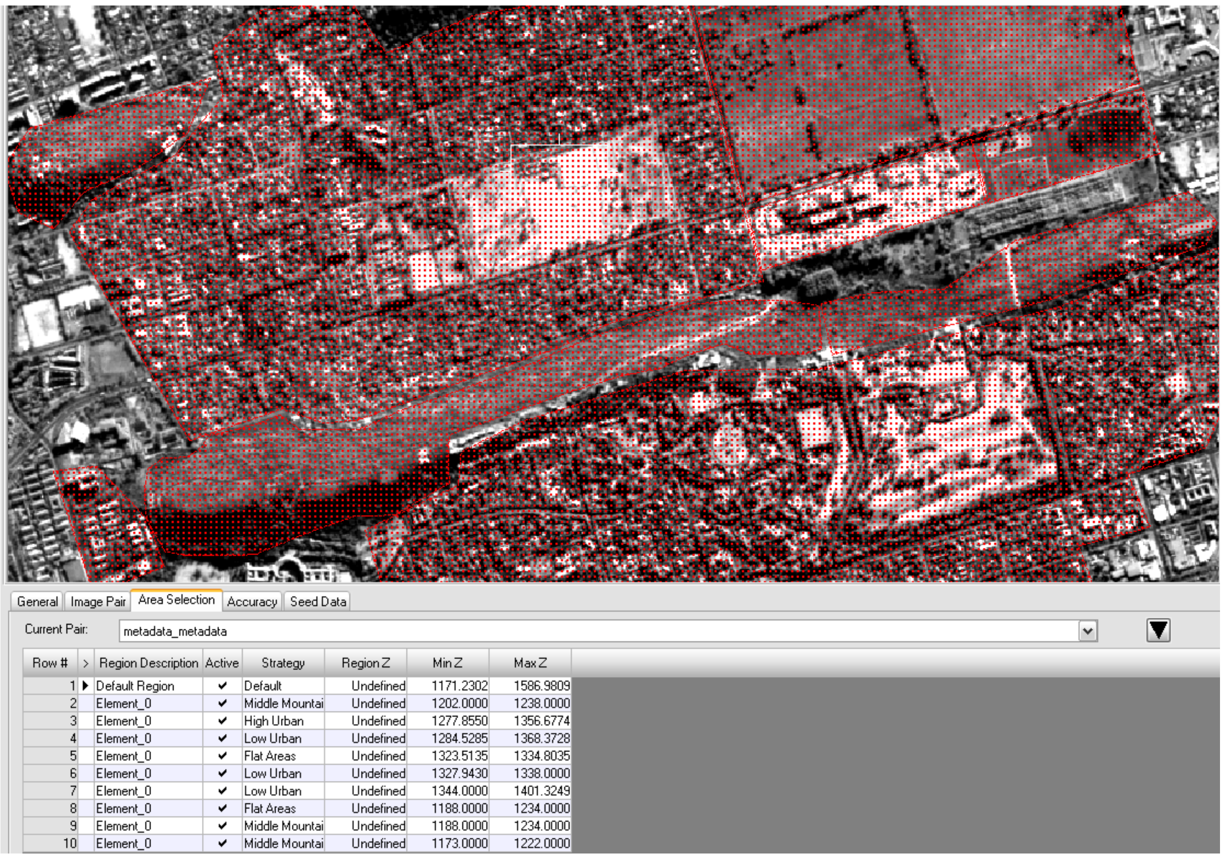
Export of Digital Elevation Model
The points collected and processed by the process described in this paragraph are called mass points. These mass points are used as the basic elements to build a Triangulated Irregular Network

(TIN). Each mass point has an important, yet equal, significance in terms of defining the TIN surface. Ideally, mass points are placed in locations that describe the more important variations in the shape of the surface described by the stereo imagery. The mass points and TIN network are exported to a TIN file. This type of file (composed of points) is also called a non-gridded dataset. See also Figure 29 (Satellite Imaging Corporation, 2005).

§ 7.3 DIFFERENCES AND LIMITATIONS OF AATE

The aATE algorithm is considered a simple and lessor algorithm compared to the eATE algorithm. It lacks detailed settings manipulation for applying correlation, interpolation and generalization on the model. Also, it does not incorporate any blunder filtering like the eATE algorithm. These differences are discussed in this paragraph.

Pattern specification
The aATE algorithm is more of an automated processor than its counterpart. In eATE, the analyst is able to manipulate the variables deemed necessary to create a useful result. aATE uses predefined variables and algorithms to recognize patterns automatically. aATE has different algorithms built in for these situations: urban areas, high urban areas, mountains, forests and hills. The analyst does not always have to rely on the pattern recognition algorithm of aATE; it is also possible to manually draw area-of-interest polygons (aois) and appoint a specific interpretation algorithm to that area. See Figure 30. It is not possible to specify specific interpolation, correlation, blunder elimination and other strategies like the eATE. This results in inaccurate results when creating a Digital Surface Model in urban areas.



Row #	>	Region Description	Active	Strategy	Region Z	Min Z	Max Z
1	▶	Default Region	✔	Default	Undefined	1171.2302	1586.9809
2		Element_0	✔	Middle Mountai	Undefined	1202.0000	1238.0000
3		Element_0	✔	High Urban	Undefined	1277.8550	1356.6774
4		Element_0	✔	Low Urban	Undefined	1284.5285	1368.3728
5		Element_0	✔	Flat Areas	Undefined	1323.5135	1334.8035
6		Element_0	✔	Low Urban	Undefined	1327.9430	1338.0000
7		Element_0	✔	Low Urban	Undefined	1344.0000	1401.3249
8		Element_0	✔	Flat Areas	Undefined	1188.0000	1234.0000
9		Element_0	✔	Middle Mountai	Undefined	1188.0000	1234.0000
10		Element_0	✔	Middle Mountai	Undefined	1173.0000	1222.0000

FIGURE 30: AREA-OF-INTEREST POLYGONS (RED DOT HATCH) FOR PATTERN SPECIFICATION FOR AATE.

Adding external breaklines (3D shapefiles)
Contrary to the eATE algorithm, it is possible to incorporate a 3D vector shapefile into the Digital Surface model. The algorithm then converts the shapefile to breaklines. Breaklines are lines that indicate an abrupt change in elevations in a Digital Elevation Model.

It is possible to select a 3D shapefile to be incorporated into the Digital Surface Model, converting it into breaklines which generates a result that would not need additional modifying. However, since the process is automated, it is not guaranteed that all the breaklines have been incorporated successfully. Also, the aATE algorithm does not convert the breaklines in the external reference file as solid breaklines (the actual limits of a Triangulated Irregular Network). It uses them as an indication. Because of that, the end result still needs to be modified later, making the incorporation of breaklines at this stage superfluous. In short, it is more accurate to incorporate the breaklines later when the terrain is being edited, rather than in the Digital Surface Model extraction process.

Lack of variables to be specified for the aATE algorithm
Furthermore, the aATE algorithm cannot be configured with the following variables:

- Correlation methods
- Interpolation methods
- Least Square Refinement
- Edge constraint
- Thinning points methods
- Smoothing methods.

Limitations in processing power
The Digital Elevation Model extraction, as performed by the aATE algorithm, is a single process. The reference imagery and all the pattern analysis are stored in the cache memory of the hardware. This severely limits of the data that can be used by the aATE algorithm at any time. Using the reference data, and appoint pattern recognition, the hardware was able to incorporate a maximum area of 8 km^2. eATE segments the overall process into multiple processes, while all the data generated intermediary is combined in a final process. This enables the maximum area and attached reference data to be almost unlimited, though it will severely increase overall processing time. This is another reason why eATE might be suitable to be used in the extraction methodology, since clutter data sets generally cover a larger area than 8 km^2.

Digital Terrain Models
In short, it is not possible to generate an accurate enough Digital Surface Model with the aATE algorithm. Most of the different elevation points cannot be generated by the aATE algorithm because of its limitations. It might be possible to generate a Digital Terrain Model. A Digital Terrain Model incorporates far less points, making it possible to generate a model with aATE. However, it cannot classify objects like eATE is able to, only when it is specified by the analyst with the pattern specification. By using the pattern specification to classify the objects and using a large search window, while constraining the exported Digital Surface Model with the reference Digital Terrain Model, it might be possible for the aATE algorithm to export points only for the terrain, ignoring the objects on the terrain. The end result can then be checked by comparing reference model with the generated model. This is discussed in the next paragraph.

§ 7.4 Results Formosat-2 imagery

§ 7.4.1Digital Surface Model

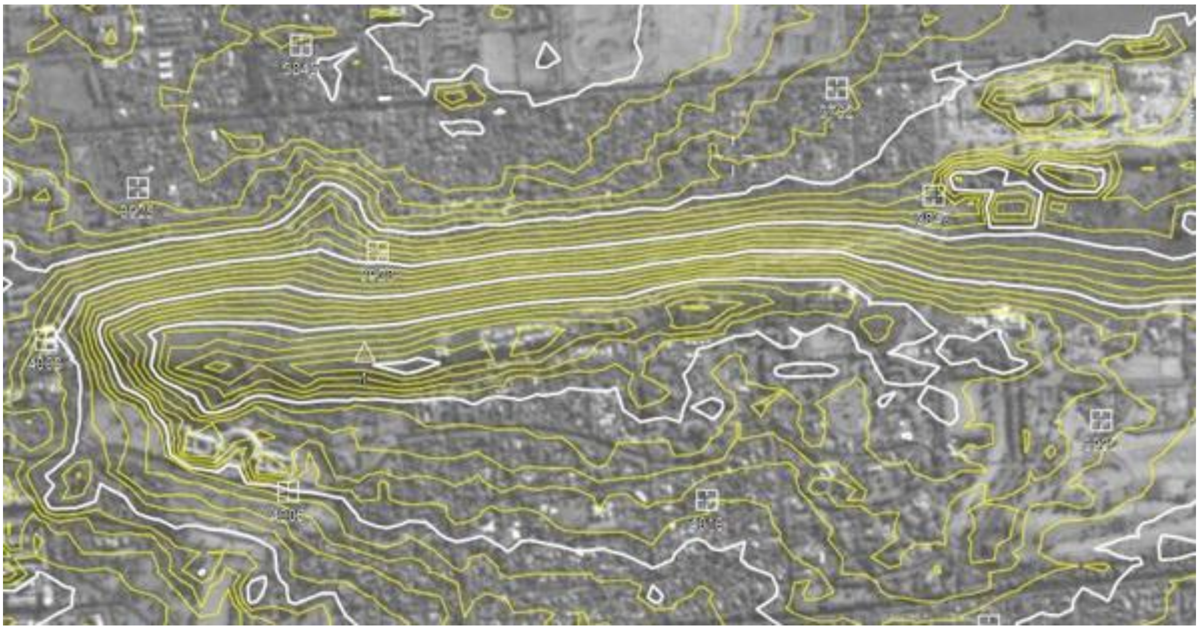


FIGURE 31: THE DIGITAL SURFACE MODEL EXTRACTED.

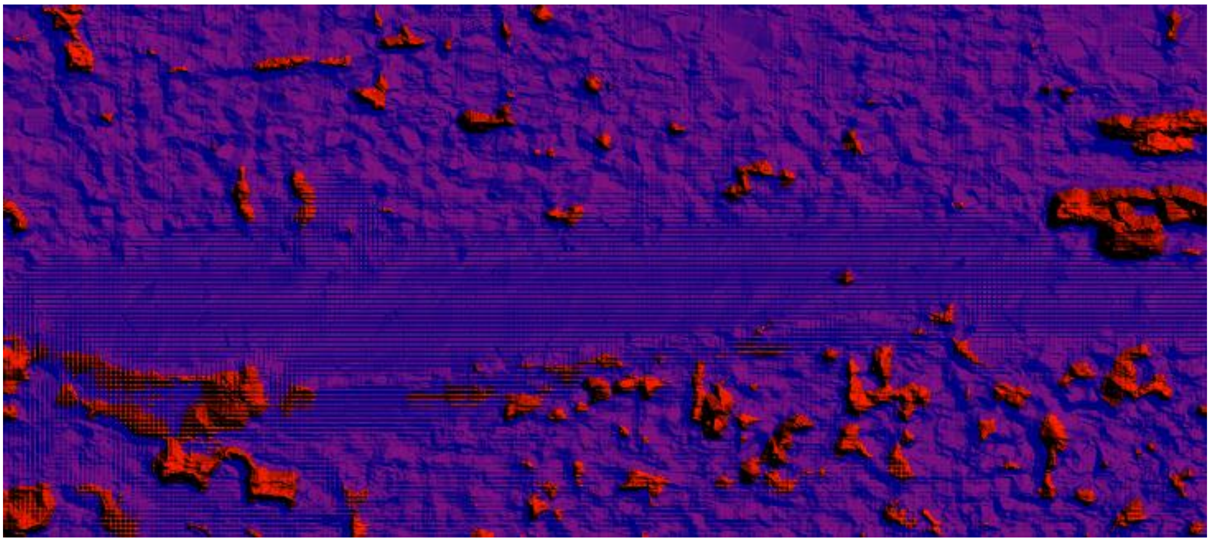


FIGURE 32: THE DIFFERENCE ELEVATION MODEL DERIVED.

See also Figure 31. The Digital Surface Model is able to distinguish the Union Buildings as well as some other buildings, but it was not able to distinguish the vegetation heights next to the union buildings, on the hill and in the suburban area next to the Union Buildings. However, to verify this assumption, the Digital Surface Model has been compared with the terrain models, both used as a reference and the one generated with the aATE algorithm. For the Difference Elevation Model, see Figure 32 (similar for each comparison). In this figure, blue indicates negative values and red indicate positive values. This result means that the Digital Surface Model is largely below the Digital Terrain Models, something which is impossible (as objects cannot have negative elevations). Note: the extraction of Difference Elevation Models is discussed in Chapter 10.

§ 7.4.1 Digital Terrain Model

The generated Digital Terrain Model, with the aATE algorithm, is very peculiar. The same settings have been used as the eATE algorithm (discussed below). For strange reasons however, it defines the hill where the union buildings is located, as an irregular shape, which is not possible.

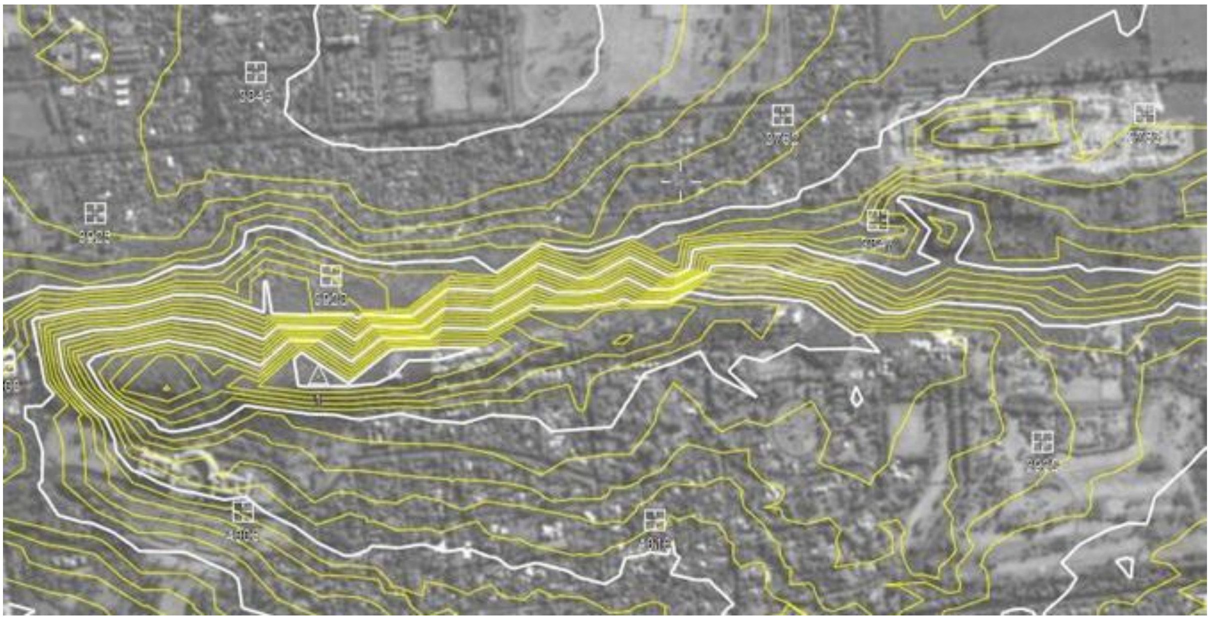


FIGURE 33: THE DIGITAL TERRAIN MODEL EXTRACTED FOR THE FORMOSAT-2 IMAGERY, WITH THE AATE ALGORITHM.

§ 7.5 RESULTS IKONOS IMAGERY

The key of generating a useful Digital Surface Model for both ‘Areas of Interest’ was to find a balance between the two extremes; too specific or too general. Many experiments have been conducted using different settings for both algorithms. The results are visible its gridded format in Attachment 1: Data Generated. Below, the differences between aATE and eATE results are discussed independently and comparatively with the help of 3D representations of the generated data. Non-gridded data is difficult to present in a 2D space, hence it has been omitted from this report.

§ 7.5.1 Digital Surface Model

eATE algorithm

The Digital Surface Model extracted using the eATE algorithm, was of sufficient quality. Mass points have been placed in the general right position with a proper z elevation. That means that the mass points placed by the eATE algorithm are placed in such a way that the vegetation bodies are visible. See also Figure 34. What the eventual accuracy is of the generated data remains to be seen until after the generation of a Difference Elevation Model (Chapter 10), as it also depends on the accuracy of the Digital Terrain Model and Ground Control Points used as the reference data when the stereo model was geo referenced.

Proof of the inaccuracy of the classification method used by the eATE is visible when looking at buildings. The Voortrekker Monument is a good example. The Voortrekker Monument, located on top of a hill, is known to be 41 meters high. In the generated Digital Surface Model, the Monument seems to be ignored by the algorithm, being nearly indistinguishable from the surrounding areas.

However, the algorithm has been able to distinguish the trees and the grass areas around the Monument. See Figure 35 for comparison photos of the generated imagery and the actual situation.

The inability of eATE to accurately classify the imagery could also be blamed on the imagery itself. eATE uses, as mentioned in the previous paragraph, the NDVI values to classify vegetation. The spectral information in the Ikonos imagery might not be sufficient for the algorithm to calculate this value. The eATE algorithm cannot cope with the Formosat-2 imagery. On the panchromatic imagery, eATE is not able to classify the vegetation, and both the panchromatic and multispectral imagery lack the spatial resolution for the eATE algorithm to clearly distinguish building outlines for its edge constraint algorithm.

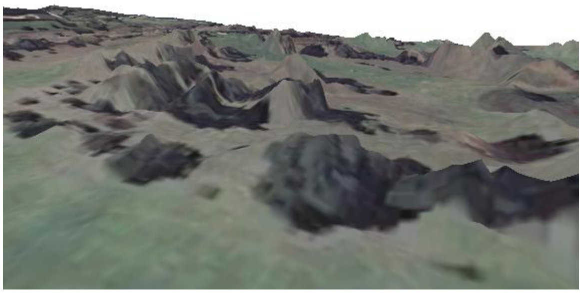


FIGURE 34: A SNIPPET OF THE EATE RESULTS, IN GRIDDED FORM WITH THE AERIAL PHOTOS DRAPED OVER IT.

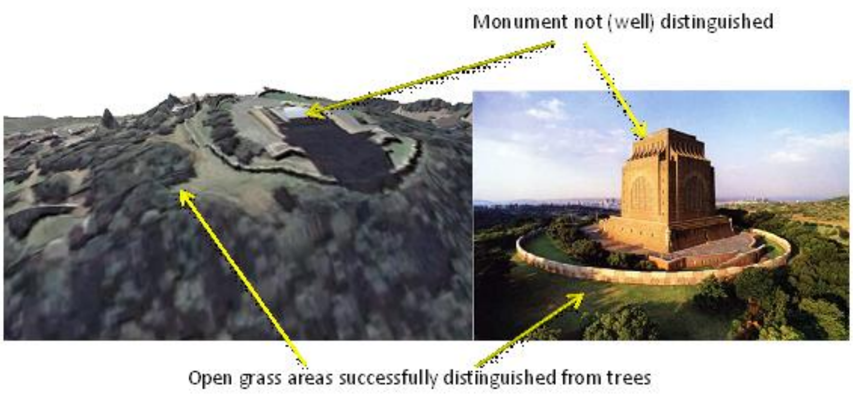


FIGURE 35: EATE DIGITAL SURFACE MODEL OF THE VOORTREKKER MONUMENT.

Either way, it is clear that the Digital Surface Models generated have to be enhanced. This will make the building outlines more prominent, avoiding dilution of nearby vegetation and result in a more accurate vegetation height. See Chapter 8.

aATE algorithm

Despite its limitations, the aATE algorithm is able to generate a Digital Surface Model, although it placed mass points at a lower density than the eATE algorithm. This caused the heights of objects not to be prominent enough. This could hamper a successful vegetation heights extraction, since smaller areas of vegetation (such as on the golf course) may have too generalized results. See Figure 36. For the same reason, the aATE algorithm was not able to distinguish buildings from the terrain.

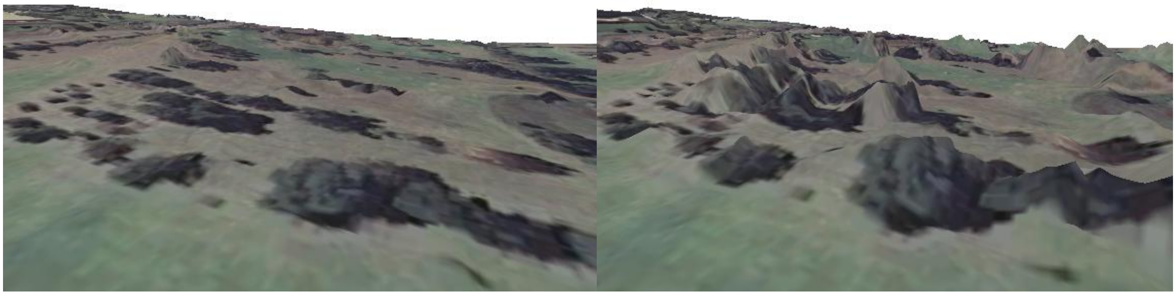


FIGURE 36: THE GOLF COURSE NEAR THE VOORTREKKER MONUMENT. LEFT THE AATE GENERATED MODEL, RIGHT THE EATE GENERATED MODEL.

§ 7.5.2 Digital Terrain Model

eATE algorithm

The extraction of a Digital Terrain Model is theoretically possible with the eATE algorithm. However, there was not enough time in this research to configure the eATE algorithm in such a way that a Digital Terrain Model is extracted successfully. Especially the search window size and interpolation method has to be configured correctly in order for the search window size not to be too big to overgeneralize the result, but not be too small that all irregular heights from buildings and other objects will be incorporated. It is recommended that some additional research is conducted in order to find out the right variables for the search window size, correlation method and blunder elimination. Also, additional research into the classification method of eATE has to be conducted. In theory, this classification method should be able to filter the other objects from the Digital Surface Model.

aATE algorithm

The aATE algorithm has successfully generated a Digital Terrain Model. When comparing the Digital Terrain Model extracted with the reference Terrain Model, the model was within the accuracy of the Terrain Model. Also, the features on the terrain have been successfully omitted from the result. This Digital Terrain Model can be used as a reference for the Difference Elevation Model generated later in the research. It remains to be seen, however, how larger area aATE is able to generate at one time, since it only works with a single process per extraction rather than several. This topic has not been researched in this project.

§ 7.6 CONCLUDING: THE FORMOSAT-2 IMAGERY VS. IKONOS IMAGERY

The results for the Formosat-2 imagery do not have a high enough accuracy. Both algorithms had trouble analyzing the images, which lead to a grave overgeneralization of points or a failed correlation and interpolation of the points. This renders the results unusable. To narrow down the possibility of a misconfiguration of the algorithms, the same variables have been used to generate the elevation models. The Ikonos imagery produced good results, while the Formosat imagery generated bad and inconsistent results. Hereby it is concluded that the spatial resolution of the imagery, or the stereo model in the Erdas software and the lack of accurate ground control points have attributed to the unsuccessful extraction of the vegetation heights. The ultimate recommendation is that for vegetation height extraction the Ikonos imagery is used, rather than the Formosat-2 imagery.

Additional steps discussed in this report concerning vegetation heights extraction will feature Ikonos imagery for elevation values.

Chapter 8 ENHANCING DIGITAL SURFACE MODELS

The previous chapter discusses the Digital Surface Model extraction procedure using the eATE and aATE algorithms. As shown in § 7.4, the end result may be inaccurate in some areas, especially in areas where there are abrupt differences in height. See also Figure 37. On the left, the mass points in each search window have been interpolated. Between these mass points the elevation might change radically. To compensate for this, additional breaklines and mass points have been placed in the non-enhanced Digital Surface Models, one is able to make features more prominent. On the right, a comparison is made of the raw vs. the enhanced Digital Surface Model (green dashed and red constant line, respectively).

When the non-gridded datasets have been enhanced, they can be exported to gridded datasets. This procedure is discussed in § 8.3.

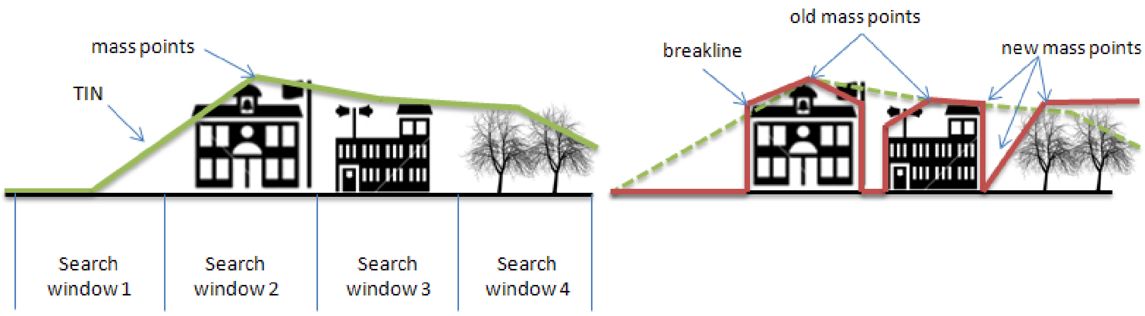


FIGURE 37: GRAPHICAL REPRESENTATIONS OF A RAW DIGITAL SURFACE MODEL (LEFT) AND AN ENHANCED DIGITAL SURFACE MODEL (RIGHT).

§ 8.1 ADDITIONAL REFERENCE SOURCES

There are several software packages that can manipulate elevation models. For this research, the Terrain Editor for Imagine is used. It is possible to enhance the generated Digital Surface Models by incorporating or removing mass point and breaklines in these elevation models. Besides using this software, a partially automated way can be used in order to avoid long manual labor processing times; with the means of additional reference sources.

An additional reference source available for this research is the cadastral data. The cadastral data is comprised of parcel boundaries and building outlines, although not all building outlines are available. It is only available for important landmarks or buildings of sufficient size. This means, buildings that are not higher than 5 stories and have a smaller footprint than 300m^2 are generally omitted. Most general stand-alone suburban housing in the “Area of Interests” is therefore not incorporated in this dataset. Despite this, the building outlines available will be used for the partial automation of the process; it might be possible that the cadastral data will be expanded with more building outlines in the future in the areas in which GeoTerraImage operates. This makes the discussion of using the available building outlines as seeds for the Digital Surface model relevant for this report.

See Figure 38 for a snippet of the cadastral data. The cadastral data is available for the entire Gauteng region in a 2D vector shapefile. Importing this data directly into Terrain Editor is not possible; the features first need a 3D attribute. Generating a 3D attribute is difficult if this data is not available from the cadastral services. However, because it is important to distinguish the boundaries of the building rather than the actual height of the buildings, accurate reference sources are not mandatory. A general 3D reference is necessary to avoid sharp discrepancies in the data, i.e.: assigning an attribute of 0 elevations to a building, whereas the rest of the area is at an altitude of 1300 meters, will generate strange results and could lead in misinterpretations of the elevation data. For this reason, the extracted raw Digital Surface Model has been used to extrapolate the mean height of the buildings.

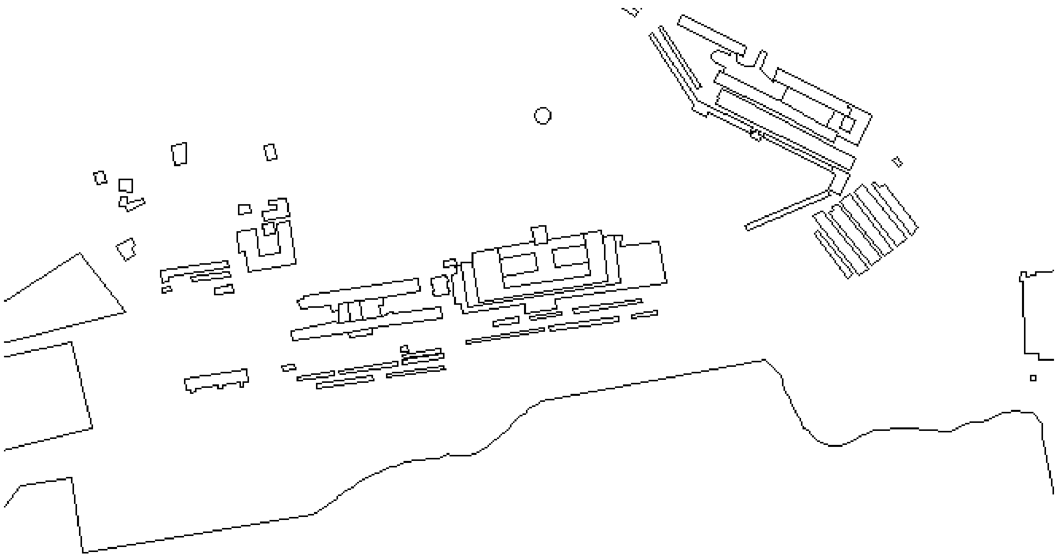


FIGURE 38: THE CADASTRAL DATA AVAILABLE.

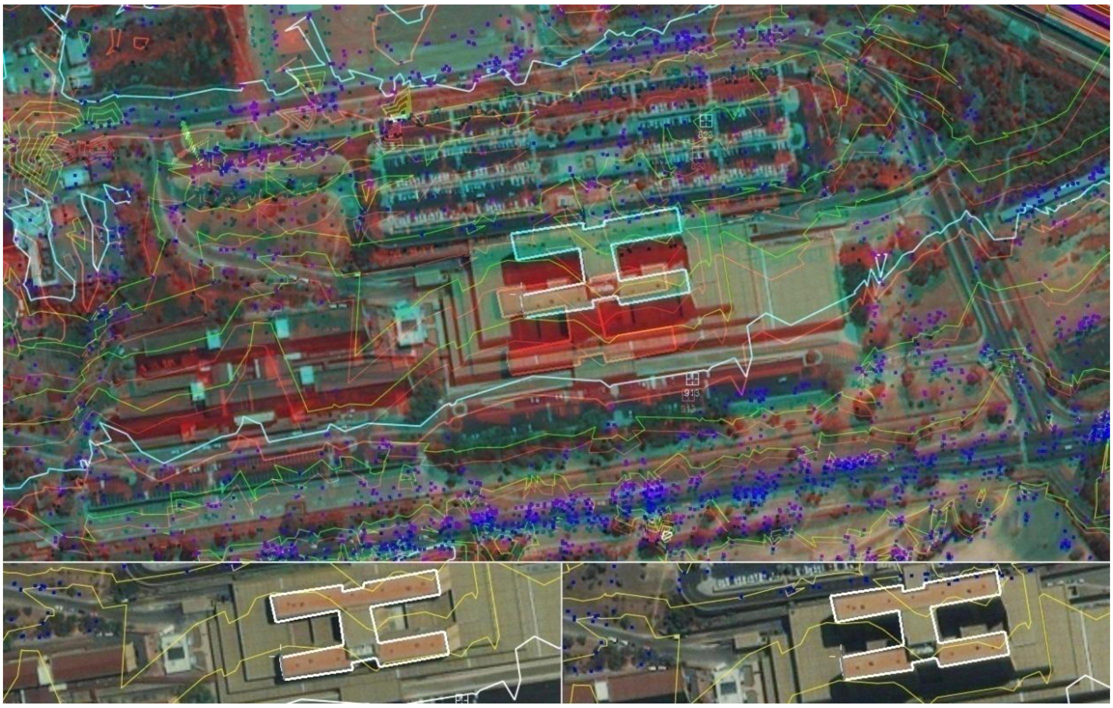


FIGURE 39: INCORPORATING THE CADASTRAL DATA IN THE TERRAIN WITH TERRAIN EDITOR. (STEREO VIEW ABOVE, LEFT AND RIGHT ORIGINAL IMAGE IN THE BOTTOM).

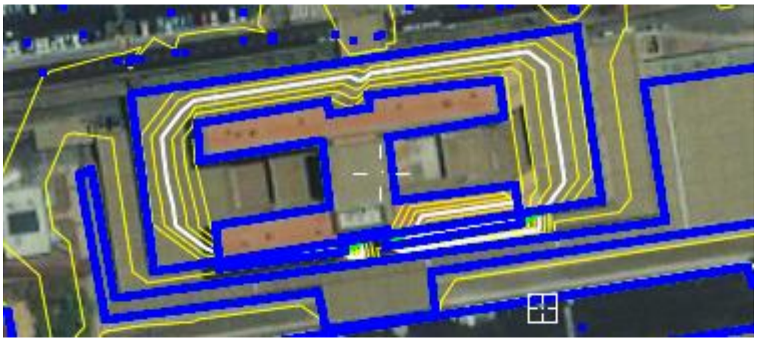


FIGURE 40: ADDING AND MODIFYING FEATURES IN TERRAIN EDITOR.

Extracting the mean heights of vector polygon shapes is conducted by cutting out the elevation at the specific area the polygon covers. The mean value of that elevation model in that area is then assigned to the polygon, giving it a uniform 3D attribute. This 3D shapefile can then be imported into Terrain Editor for Imagine (see Figure 39). In Terrain Editor, it is also possible to reposition the breaklines to a new height, in case the difference in height of the building and terrain is too great. It can also be positioned to the exact height (using the stereo view and parallax) of the building, if necessary. Also, some additional breaklines can be drawn in Terrain Editor in case the building is large and individual features are necessary to be extracted. Finally, when the breaklines is at its correct position, it can be added to the elevation model (see Figure 40).

§ 8.2 FEATURE EXTRACTION

As mentioned before, not all buildings have been incorporated in the cadastral data available to GeoTerraImage. These additional features can be added in Terrain Editor, but this could be a delicate task. This has to do that the addition of breaklines and mass points in the terrain automatically renders the terrain, which the hardware has to compute causing wait times. By using Stereo Analyst for Imagine, it is possible to acquire these building outlines which can be imported later as breaklines. This saves processing and thus waiting times. The features extracted can be exported to a 3D shapefile, and can be imported into the Terrain Editor extension in the same way as the breaklines are imported.

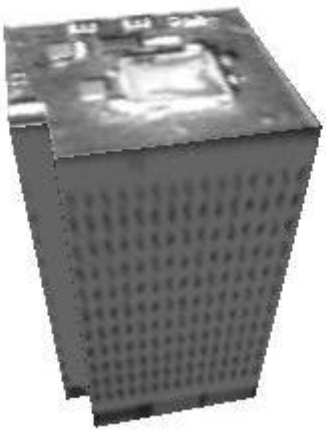


FIGURE 41: A STRUCTURE EXTRACTED WITH STEREO ANALYST FOR IMAGINE. ITS TEXTURES ARE BASED ON THE IMAGERY.

Overall, extracting buildings can be a tedious process. It can be useful in case a certain building is not incorporated in the cadastral data or if the data needs modification or reinterpretation (for example: if the building boundaries in the imagery and cadastral data do not match). It is not efficient to extract features in an entire area of interest. With Stereo Analyst for Imagine, it is not possible to automate the process.

This process can be used to generate 3D models of areas. Stereo Analyst is able to generate 3D models in an ERDAS format, and is able to texture the features with the imagery used for extrapolation or other images. This is not discussed in this report, since it is not required to extract vegetation heights from buildings (Kennedy, 2009) (Strynatka, 2008).

§ 8.3 EXPORTING A NON-GRIDDED DATASET TO A GRIDDED DATASET.

With the Digital Surface Model extracted, the non-gridded dataset can be exported to a gridded dataset. A Gridded dataset is a raster image in which each cell (pixel) has an elevation value attached to it. The cell size has to be specified by the analyst; a large cell size generalizes the output, while a small cell size describes the elevation model more precisely. The values attributed to each cell are based on the quality with which the points in a cell have been extracted in Chapter 7. If the quality of the mass points located in the cell size is the same, the mean elevation within the cell size will be attributed to the cell. As such, a gridded dataset can have a very high accuracy with a small spatial resolution, or a high spatial resolution but a low accuracy, depending on how the non-gridded data was extracted from the process in the previous paragraph.

As is visible in Figure 42, the enhanced model displays the buildings better than the original model.

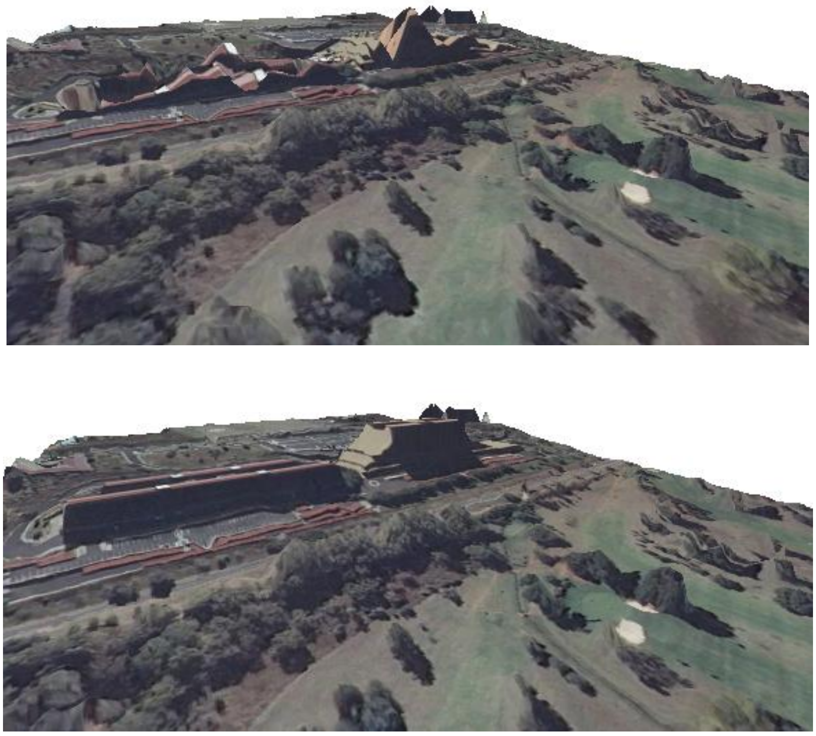


FIGURE 42: TOP PICTURE: THE UNMODIFIED DIGITAL SURFACE MODEL. BUILDINGS DO NOT HAVE SOLID BOUNDARIES. LOWER PICTURE: MODIFIED DIGITAL SURCFACE MODEL. BUILDINGS NOW HAVE SOLID BOUNDARIES.

Chapter 9 CLASSIFICATION OF THE IMAGERY

Before one can commence with supervised classification (pattern recognition), the Multispectral imagery has to be orthorectified and pan-sharpened. It is possible to classify stereo imagery, but it is not possible to orthorectify this thematic raster. Therefore, the images have to be orthorectified prior to classification. The original Formosat-2 Multispectral imagery does not have a sufficient high enough resolution, which is necessary to accurately distinguish the different features from each other. That may result in important data becoming inaccurate or too generalized. In the first paragraph, the process of orthorectification is discussed. In paragraph 2, different pan-sharpening methods are discussed. Pattern recognition is discussed in paragraph 3. The results are discussed in paragraph 4. Naturally, there are some problem areas and limitations of the supervised classification performed. That is discussed in paragraph 5.

§ 9.1 ORTHORECTIFICATION

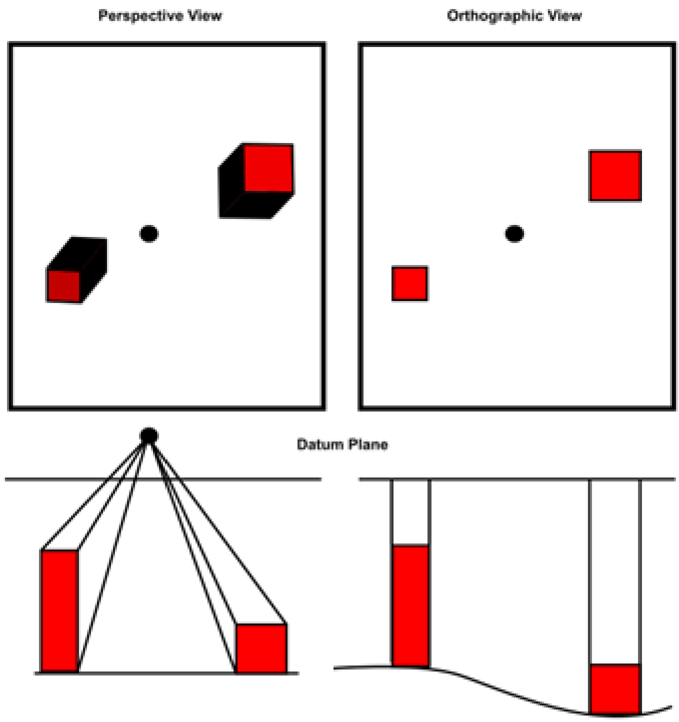


FIGURE 43: ORTHOGRAPHIC VIEWS PROJECT OBJECTS FROM THE SURFACE AT A RIGHT ANGLE TO THE DATUM PLANE. PERSPECTIVE VIEWS PROJECT OBJECTS FROM THE SURFACE ONTO THE DATUM PLANE FROM A FIXED LOCATION. THE BLACK DOT INDICATES OBSERVER POSITION.

Orthorectification is a process in which the stereo photos are being converted to ortho photos (see Figure 43) (Jensen, 2005). It is important that all imagery is viewed from a right angle to the datum plane, so that all the data in the imagery is on conform location. Otherwise, contradiction of the position of objects on the image can occur. First, the panchromatic imagery has to be orthorectified. After the 2 stereo images have received an external reference (referenced with points in a referenced image) and an internal reference (referenced in relation to each other), the images are ready to be orthorectified.

Orthorectification is a point-by-point correction of the scale and height displacements caused by variations in distance between the sensor and the topography described by the image. The image is analyzed by dividing the area in the photograph into small, equal sized pixels. The geometric correction of the images requires the calculation of the distortion at each point, after which the image is shifted to a proper location. The stereo model is systematically analyzed following a raster pattern, to ensure that all details in the stereo model are recorded orthogonally in relation to the datum plane (see Figure 43). The orthophoto is created when each pixel is placed in its precise geographic position, taking into consideration the camera location, the orientation of the camera platform and the heights of all the points in the area photographed. An external elevation model Is used to describe these heights. This elevation model (discussed in Chapter 7 and Chapter 8) is used to correct the different scales which occur due to these differences in elevation in the area (Satellite Imaging Corporation, 2005).

§ 9.2 Pan-sharpening

Having orthorectified the panchromatic and multispectral + near-infrared imagery, the images can be pan-sharpened. Pan-sharpening combines the panchromatic imagery with the multispectral imagery, creating an image with both a high spatial and spectral resolution. There are many different ways to perform pan-sharpening in different software. Popular software besides Erdas Imagine is ArcGIS, which has a crude pan-sharpening method which is not compatible to Erdas Imagine formats.

Erdas Imagine boasts several different pan-sharpening methods, namely:

- **HPF Resolution merge Procedure:** This algorithm reads the pixels from the image files and calculates the ratio between the multispectral cell size to panchromatic cell size, value R. It then filters the high spatial resolution image and resamples the low spatial resolution image to the pixel size of the filtered high resolution image. This filtered image is added to each multi-spectral band. The result is then weighted to the global standard deviation of the multispectral band it has been combined with. Finally, the multi-spectral image is stretched to match the mean and standard deviation of the original low spatial resolution image.
- **Subtractive Resolution Merge:** A subtractive resolution merge calculates a transparency mask of the image, with which it will determine the opacity level of each pixel. This so called synpan is calculated of both images to a similar level and then placed on top of each other. It then combines the pixel values and removes the synpan layer by upscaling the image with a sharpening filter (Kari, 2009).
- **Wavelet Resolution Merge:** The high spatial resolution panchromatic image is decomposed to a lower spatial resolution, the same resolution as the low spatial resolution multispectral image. The data of the low spatial resolution panchromatic image is replaced with the spectral data from the low spatial resolution multispectral image. This image is then reverse decomposed to the original high spatial resolution of the panchromatic image.
- **Ehlers Fusion:** This fusion technique is characterized by an object oriented segmentation of the multispectral imagery. The geographic location of the pixel in the multispectral dataset is determined by a segmentation of the panchromatic image. Pixels that are contained within these segments are candidates for the definition of the pan-sharpened data. This method is also called the Spectral Angle Mapper (SAM) (Ehlers, 2005).
- **Modified IHS resolution merge:** This function uses band 4 (near infrared) as an additional input to filter out the effect of near-infrared influences on the pan band, which results in a more natural result. The modified IHS method can also be configured in such a way that it emphasizes the Near Infrared band so that in the result, the infrared band will be

emphasized rather than omitted. IHS stands for Intensity, Hue and Saturation (Siddiqui, 2003).

The Modified IHS resolution merge function has been used to pan sharpen the imagery available for this research, since it is the only algorithm that keeps the near infrared data. See also Figure 44 for a comparison of the end result to the original imagery.

FIGURE 44: THE PANCHROMATIC IMAGE (LEFT), THE MULTISPECTRAL + NEAR-INFRARED IMAGE (MIDDLE) AND THE PAN-SHARPENED RESULT (RIGHT).

§ 9.3 PATTERN RECOGNITION

Pattern recognition is the science of finding meaningful patterns in data, which can be extracted through classification. Spectral pattern recognition is derived through statistics of the spectral characteristics of all pixels in an image. These pixels are sorted based on mathematical criteria. There are two ways of pattern recognition, namely supervised and unsupervised. Supervised classification is a classification based on information classes specified by the user, whereas unsupervised classification is a classification based on the spectral classes. Therefore, unsupervised classification can be performed in case no reference data or on-site verification is available of the area to be classified, whereas this data is a prerequisite of supervised classification (Jensen, 2005) (Banman) (Lillesand, Kiefer, & Chipman, 2004) (Short, 2001).

§ 9.3.1 Supervised classification

Supervised classification is closely controlled by the analyst. In this process, signatures of information classes are specified which represent patterns or land cover features that are recognized or identified using external reference data or on-site verification. By identifying patterns with training areas (area-of-interest polygons, aois), the software can then identify pixels with similar characteristics and classify the pixels accordingly. A supervised classification is best executed in a small area. The smaller the area, the fewer variations in pixels and classes occur, making classification easier and more accurate. However, a supervised classification is never 100% accurate (Erdas, 2009).

An image can be divided in two ways, a continuous raster image and its accompanying feature space. The continuous raster layer is a layer wherein pixels can have an indefinite value, depending on the bit size of the raster image. Raster images are all 8-bit images with a 8-8-4 distribution, resulting in a maximum amount of pixel values of 256 (pixel value 0 to 255). A feature space is an abstract space where each pixel value is represented as a point in an n-dimensional space (n = natural number). The dimension of the feature space is determined by the variety of pixel values used to describe the bands in a continuous raster image. The maximum pixel value in a feature space of an unsigned 8-bit raster image is thus 255*255. A feature space in Erdas is always displayed as a 2D image, wherein the X and Y axes signify the Band A value and Band B value. So, if feature space layers are generated from an RGB (red green blue) image, there will be 6 feature spaces; Band R-G / G-R, G-B / B-G, B-R / R-B. An example of an n-dimensional space is a Euclidian system.

Training areas (signature specification)
The training areas are area-of-interest polygons (aois) specified by the user. These aois cover an area with certain pixel values. With these values, a spectral signature can be devised. A spectral signature is a set of data that defines the training area. There are two kinds of spectral signatures, namely a parametric and a non-parametric signature. A parametric signature is based on statistical parameters of the pixels inside the training area in the image space, such as mean value, minimum and maximum value and the number of pixels in the training area. A nonparametric signature is based on an aoi defined in the feature space. The signature is based on the location in relation to the aoi within the feature space. A nonparametric signature does not take statistics (like its parametric counterpart) into account. With these signatures, a supervised classification can be conducted using nonparametric rules and parametric rules.

Nonparametric rules
The nonparametric rule is a type of classifier that is not statistically based and thus makes no assumptions of the properties of the data. This classifier assigns pixels to classes based on the pixel position in the feature space. There are two different nonparametric rules, the feature space rule and the parallelepiped rule. The feature space rule determines if the candidate pixels lie within nonparametric training areas in the feature space. If the candidate pixel lies within a feature space, it is classified as the signature appointed to that feature space. If the candidate pixel lies outside the aoi, it receives no classification. See also Figure 45.

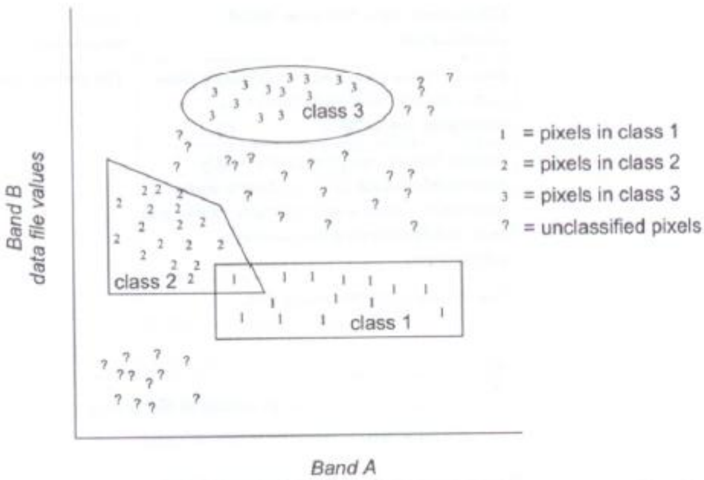


FIGURE 45: A FEATURE SPACE CLASSIFICATION (2D).

In the parallelepiped decision rule, the training areas in the feature space are used. It uses the high and low limits of pixel values in every band (a parallelepiped). When the pixel values are located between the limits for each band in the signature, then the pixel is classified to that signature. If the pixel values fall outside this parallelepiped they receive no classification. See also Figure 46. A disadvantage of this rule is that parallelepipeds have corners, meaning that pixel located far away from the mean of the signature can still be classified.

In short, when a nonparametric rule is used, pixels in the image will be classified according to the presence of similar pixels in aois in the feature space layer (Erdas, 2009).

Both nonparametric classification rules have shared limitations. Overlap is a common occurrence when the nonparametric classification rules are executed. It is possible that a pixel lies inside multiple feature space objects. Because no probabilities of which class the pixel is most likely to be placed in are computed, the only way to solve this problem is to consider the order in which the different classes are processed. Another disadvantage for nonparametric classifier rules is that frequently many of the pixels in an image will not be assigned to any class, resulting in a large amount of non-classified pixels. It is therefore used as a rough classification which can define broad class categories, only to be refined later by parametric classification rules (Kloer, 1994) (Erdas, 2009).

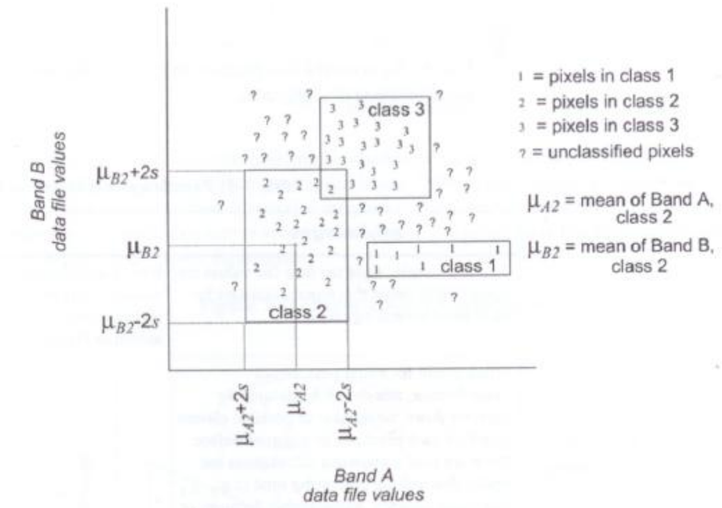


FIGURE 46: A PARALLELEPIPED CLASSIFICATION (2D).

Parametric rules

Parametric rules classify the pixels based on the aois specified in the image space. The aois are polygons either drawn manually, or specified by adjacent spectrally similar pixels. Parametric rules classify the pixels based on the signatures mean and covariance of the pixel values within the aoi. Every pixel with that value is placed in the corresponding class. To classify pixel values located in multiple signatures, there are three parametric classification rules. The maximum likelihood decision rule is based on the probability that a pixel belongs to a particular class. Normally, these probabilities are equal, unless specified otherwise. The minimum distance rule calculates the spectral distance between the candidate pixel value and the mean vector for each signature, classifying the pixel to the signature the pixel value is closest to. The Mahalanobis distance rule is similar to the minimum distance rule, except that a covariance matrix is used in the equation to calculate the probability in which class the candidate pixel shall be placed. This is useful in areas where certain classes cover a wide variety of pixel values. Correctly classified pixels may be farther from the mean than those of a uniform class (Kloer, 1994).

Hybrid classification

A so called hybrid classification uses both the parametric and nonparametric rules. Usage of the different class definitions, as described above, will lead to a more complete and accurate overall classification of the image. See also Figure 47. The nonparametric rules always have a decision priority over the parametric rules. If the nonparametric does not classify a pixel, it is classified by parametric rules. If a nonparametric rule classifies a pixel, the pixel receives either none, one or multiple classifications. If the pixel does not adhere to any classification parameter, the unclassified rule is applied and the pixel is either submitted to the parametric rule or remains unclassified. If a pixel adheres to a single classification parameter, it will be appointed to a unique class. If the pixel adheres to multiple classification parameters, either the pixel is classified by order (in which the nonparametric rule classifies pixels according to signature priority), remains unclassified or is classified using the parametric rule.

This hybrid classification method enables usage of only the parametric or only the nonparametric rule, aside from using both in conjunction. This results in a better overall classification, since nonparametric rules and parametric rules independently rarely classify an image entirely (Kloer, 1994).

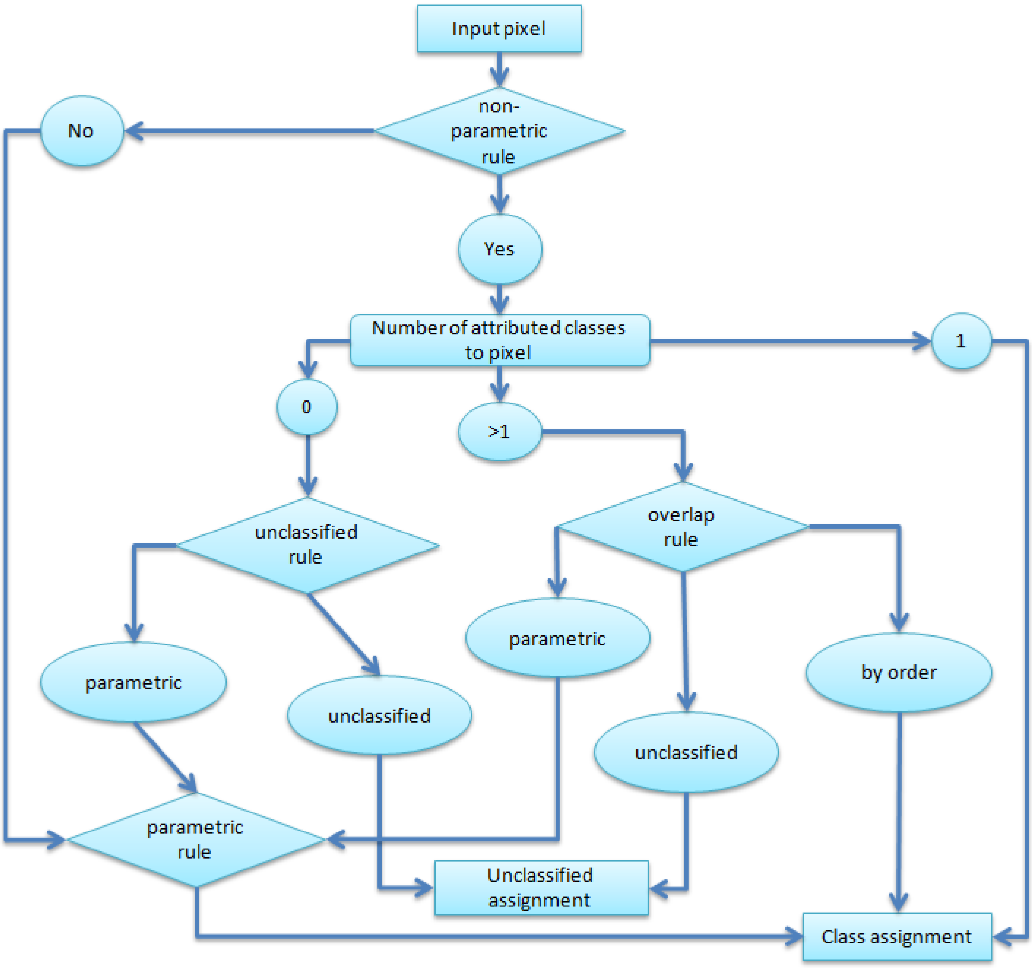


FIGURE 47: A WORKFLOW OF A HYBRID CLASSIFICATION. SQUARES: INPUT AND OUTPUT. DIAMONDS: DECISIONS. OVALS AND CIRCLES: ANSWERS.

Evaluating signatures

A parametric signature can be evaluated in different ways:

- **Feature Space:** The parametric signatures can be displayed in the feature space. A parametric signature is always an ellipsoid in the feature space, since it describes the concentration of the pixel values around the mean of the signature. Overlap always occurs, but the matter of overlap determines the separability of the signatures. See Figure 49.
- **Contingency matrix:** An aoi is not always homogenously defined. Some pixels may be classified twice in any aoi. A contingency matrix defines how much percent of the pixels in

each aoi occur in overlapping signatures. See Figure 48 for an example of a contingency matrix. In this classification, signatures have a large overlap with other signatures.

A nonparametric signature can only be evaluated by applying a nonparametric classification rule and analyzing the original image with the output image (Kloer, 1994) (Erdas, 2009).

ERROR MATRIX

Classified Data	Reference Data: Bushveld	Grass	Exotic Tre	Bush Grass
Bushveld	100.00	25.52	12.46	89.73
Grass	0.00	74.48	17.82	0.00
Exotic Tre	0.00	0.00	69.72	8.09
Bush Grass	0.00	0.00	0.00	2.18
Buildings	0.00	0.00	0.00	0.00
Class 1	0.00	0.00	0.00	0.00
Column Total	4796	525	578	3350

Classified Data	Reference Data: Buildings	Row Total
Bushveld	30.65	8149
Grass	13.48	556
Exotic Tre	1.30	680
Bush Grass	6.30	102
Buildings	48.26	222
Class 1	0.00	0
Column Total	460	9709

----- End of Error Matrix -----

FIGURE 48: A CONTINGENCY MATRIX OF A CLASSIFICATION WITH LARGE OVERLAPS.

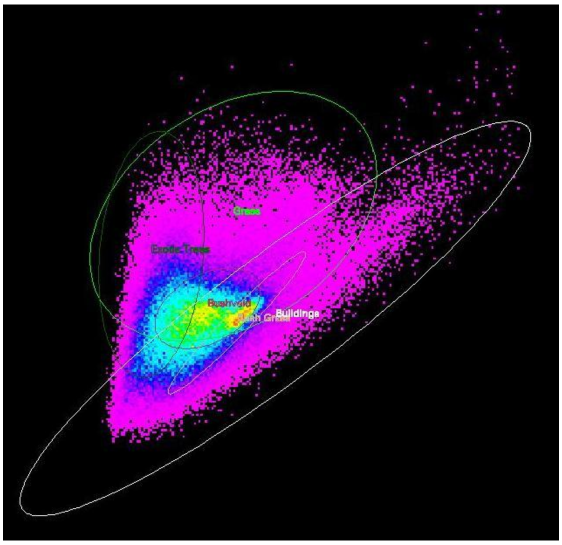


FIGURE 49: A FEATURE SPACE OF AN IMAGE, WITH ELLIPSOIDS OF PARAMETRIC SIGNATURES. SOME ELLIPSOIDS ALMOST CLOMPLETELY OVERLAP EACH OTHER, INDICATING A LARGE SIGNATURE OVERLAP.

§ 9.3.2 Unsupervised classification

If no reference or on site data is available for the area, but a classification has to be performed, an unsupervised classification can be executed. Unsupervised classification (also called clustering) is based on the natural groupings of pixels in the image data when they are plotted in a feature space. These patterns do not necessarily correspond to meaningful characteristics in the scene, such as easily recognized areas of a land cover type. These patterns are simply clusters of pixels with similar spectral characteristics. In some situations, it is important to identify groups of pixels with similar spectral characteristics rather than to sort different pixel values to recognizable categories. Unsupervised classification can also enable the analyst to attribute different definitions to the classes as generated by the unsupervised classification method. Since reference data and on site verification of the land cover is verified for this research, an unsupervised classification is not used (Lillesand, Kiefer, & Chipman, 2004) (Jensen, 2005) (Banman) (Short, 2001).

§ 9.4 RESULT

The final classes for the supervised classification are: Bushveld trees, Bushveld Grass, Exotic Trees, Exotic Grass and man-made structures (as per specifications from § 5.4). The aoi polygons have been specified using an on-site research as to the location of these different vegetation classes. See § 5.4. It is not necessary to classify separate man-made structure classes, since the classification of vegetation is the goal of this research. It is possible to extract more classes from the imagery, but this was not performed in this research. It is the primary objective to classify different vegetation types. See § 11.1 for a quality control of the extracted thematic raster.

See Figure 50 for final result. This is a thematic raster where each pixel received a value according to the classification discussed above. This image is also found at a higher resolution in 'Attachment 1: Data Generated'.

In the methodology, the vegetation classification thematic raster will be used to generate vegetation heights. In this research however, because the Ikonos imagery does not have a near infrared band available while the Formosat-2 imagery Digital Elevation Model extraction failed, these two processes will be evaluated separately from each other. To extrapolate vegetation heights for the final result, a testing area is chosen and a separate small scale vegetation classification is performed. Definition of this test area and the steps are discussed in Chapter 10.

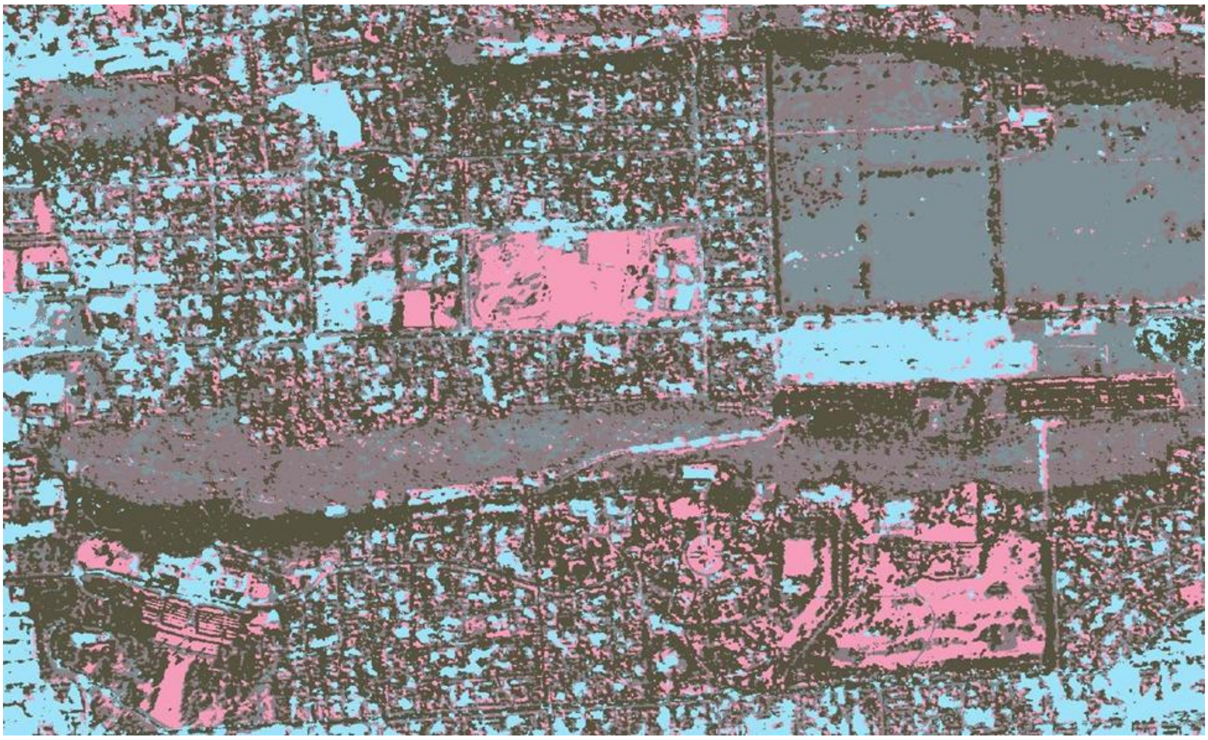


FIGURE 50: THE THEMATIC RASTER EXTRACTED.

Chapter 10 VEGETATION HEIGHTS

At this point, a thematic raster describing the different vegetation types has been created. Also, a gridded enhanced Digital Surface Model and Digital Terrain Model has been generated. With this information, it is possible to extrapolate the vegetation heights.

The thematic raster generated in the previous chapter not only describes vegetation, it also describes the type of vegetation. This is important, because the boundaries of the vegetation can have an influence on the height extrapolated in this chapter. A location of a class of exotic trees may receive a specific height, while the location of a class of exotic grass may receive another. This avoids dilution of heights in a similar way that it was important to make buildings more prominent in Chapter 8.

Before the vegetation heights can be extracted, a method of vegetation elevation classification has to be specified. After that, the vegetation heights can be extracted. These steps are discussed in the following paragraphs.

§ 10.1 DIFFERENCE ELEVATION MODEL

Extracting vegetation heights is possible with the generation of a Digital Surface Model and a Digital Terrain Model.

At this stage, an enhanced Digital Surface Model has been generated, as well as a supervised classification of the vegetation in the 'Area of Interest'. These datasets, along with a Digital Terrain Model of the area, are necessary to generate vegetation heights.

By subtracting the Digital Surface Model from the Digital Terrain Model, the ground elevation level will be deducted from the ground and object elevation level, leaving only the object elevation level. See Figure 51. This model is called a Difference Elevation Model. This operation can be done with the image difference function in Erdas. The image difference function calculates the difference between pixel values in two raster images. This function is generally used to detect image mutations in raster images, such as mutations in terrain caused by erosion.

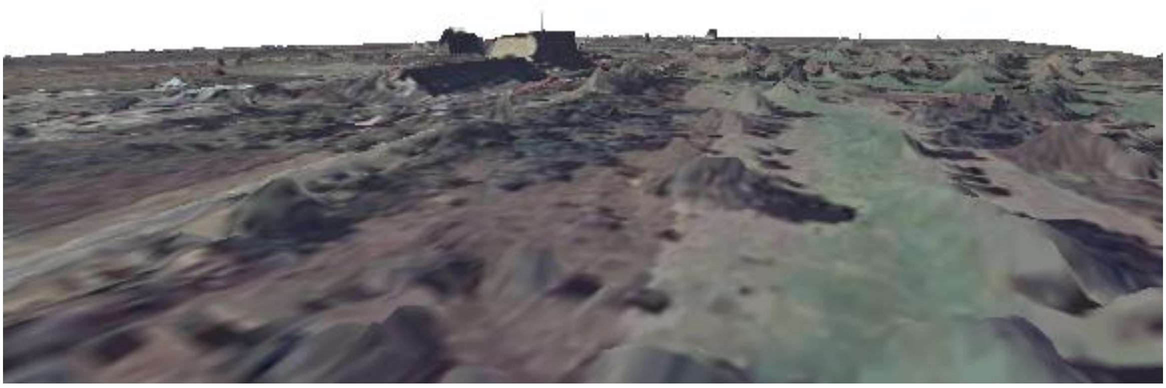


FIGURE 51: THE DIFFERENCE ELEVATION MODEL IN 3D WITH THE REFERENCE PHOTOS DRAPED OVER IT. ALL THE HILLS AND MOUNTAINS HAVE BEEN FILTERED.

In a Difference Elevation Model, in theory, the elevation cannot drop below 0. However, this is the case in the generated Difference Elevation Model. This is because the Digital Terrain Model has been generated with a larger search window than the Digital Surface Model. This means that small discrepancies that have been generated by cliffs, holes or burrows, are either ignored or filtered. The Digital Surface Model, with a smaller search window, recognizes these small burrows or sudden edges, and incorporates them in the final result. See Figure 52.

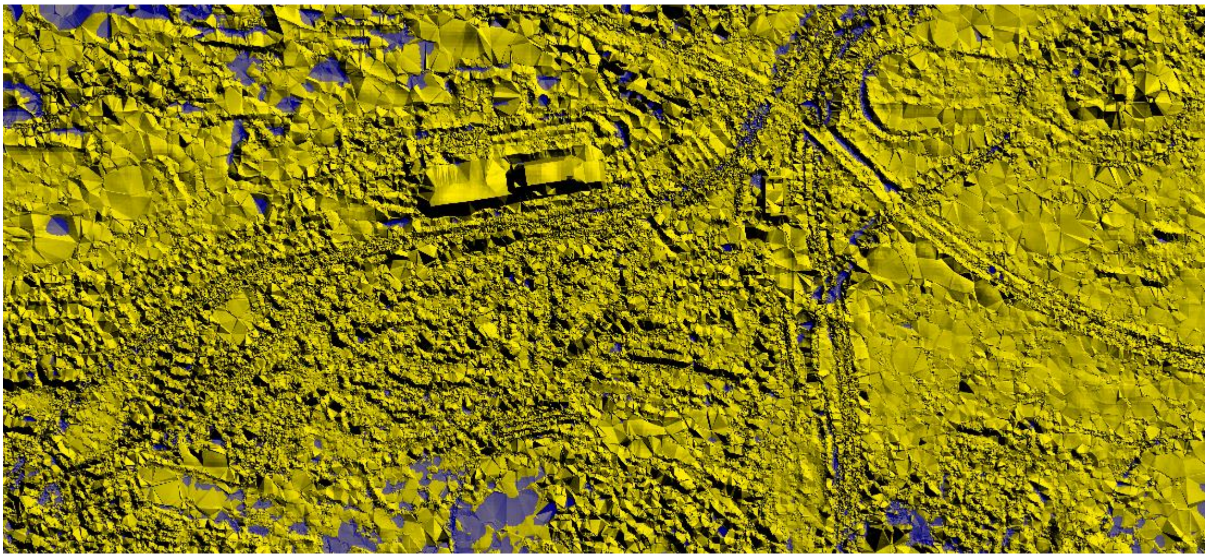


FIGURE 52: THE DIFFERENCE ELEVATION MODEL. BLUE COLORS SIGNIFY NEGATIVE VALUES.

With the Difference Elevation Model extracted, it can now be combined with the thematic raster from Chapter 9. Software used for this procedure is eCognition. In eCognition, both the gridded dataset and the thematic layer are placed on top of each other. eCognition will then search for borders in the thematic layer and searches for the appropriate elevation values within the boundary in the gridded layer.

These elevation values will not be a constant, since it describes vegetation heights which never are constant. For that reason, the median elevation value will be calculated and attributed to each region as per description of the thematic layer.

§ 10.2 HEIGHT CLASSIFICATION

Pixels in a thematic raster layer have a special attribute. These values signify the properties of the areas as per described in the raster layer. For example, pixel value 1 has the attribute of 'vegetation', indicating that everything with pixel value 1 is vegetation in the raster image. Each class has its own value.

However, if the heights are extracted (and intersected) with the vegetation classes, the new dataset cannot simply be incorporated with the existing clutter dataset. If for each elevation (in meters) a new class has to be created in the thematic data, this will increase the amount of classes drastically. For example, if the vegetation is narrowed down to an elevation of 1 meter, and there are 4 vegetation classes, assuming that the highest vegetation (in general) can reach up to 25 meters in height, this will mean an additional 100 classes.

To avoid this situation, the heights have to be classified as well. An interval of 5 meters could be used for example. The accuracy will be low, but the vegetation is still distinguishable from low, medium, high and very high classes. If appointing a 5 meter interval to the classes, this will mean an increase of 5*4=20 classes, assuming that the highest vegetation can grow up to 25 meters. Considering that some classes may never reach a specific height class (such as the grass layers, which are unable to grow taller than 5 meters), this can be narrowed down to (1*2)+(5*2)= 12 additional attributes. Also, since these new classes will replace the some of the current vegetation classes in clutter datasets, this will mean an addition of 10 classes to the original clutter data.

The eventual classes will be intervals of 5 meters and lower, 5m-10m, 10m-15m, 15m-20m and 20m and higher for each vegetation class.

If the vegetation heights are rounded to meters, rather than classified in intervals of 5 meters, it is recommended that a vector shapefile is used rather than a thematic raster. A vector shapefile is far more versatile than a thematic raster.

§ 10.3 END RESULT

The end result is polygon vector shapefile with different attributes, namely mean height, vegetation class, height class (integer), vegetation class (integer), combination of vegetation class and height class (integer). These attributes are necessary to later incorporate this raster dataset in the existing clutter data set.

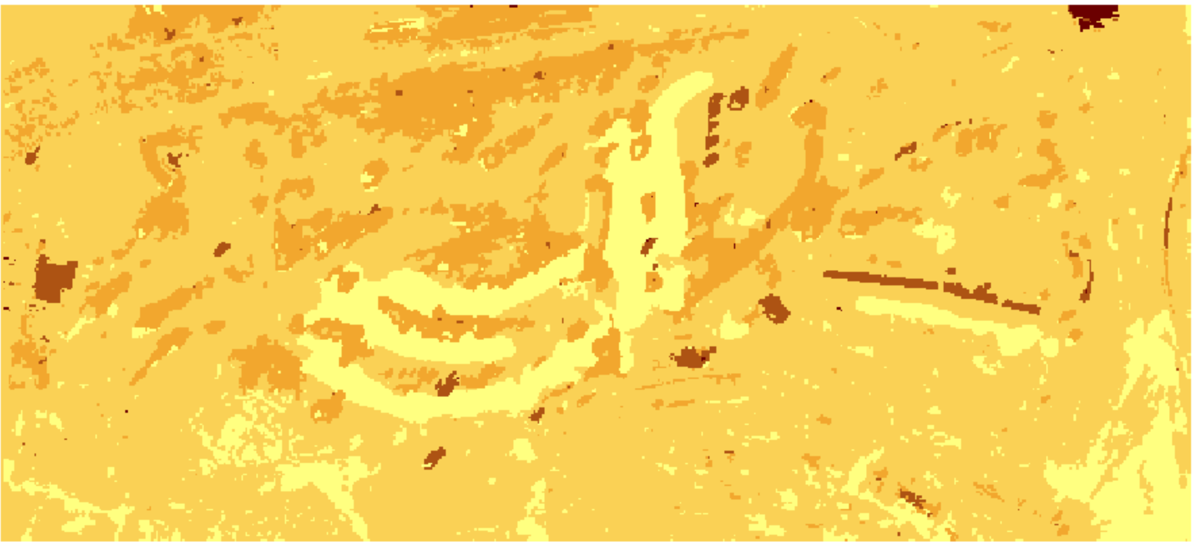


FIGURE 53: THE SHAPEFILE OF THE DIEM. THE THEMATIC RASTER AND HEIGHTS CLASSES HAVE BEEN INCORPORATED IN THIS DATA. DARKER COLORS SIGNIFY HIGHER ELEVATIONS.

Chapter 11 QUALITY CONTROL

As mentioned in previous chapters, a successful vegetation classification was only performed in the 'Union Buildings Area of Interest'. This is because no infrared bands are available of the Ikonos imagery. Successful vegetation heights extraction and classification was performed in the 'Voortrekker Monument Area of Interest', this is because the height extraction for Formosat-2 imagery was deemed inaccurate prior to the quality control.

§ 11.1 VEGETATION CLASSIFICATION

To check the quality of the vegetation classification, it has to be compared to existing data available at GeoTerraImage and the on-site data acquired for this research. This is done by picking out several control areas; two control areas where the supervised classification received its training areas (as defined in § 5.4) and two areas where there were no training areas. The control areas are discussed below.

§ 11.1.1 Control Areas

Control area 1: Union Buildings

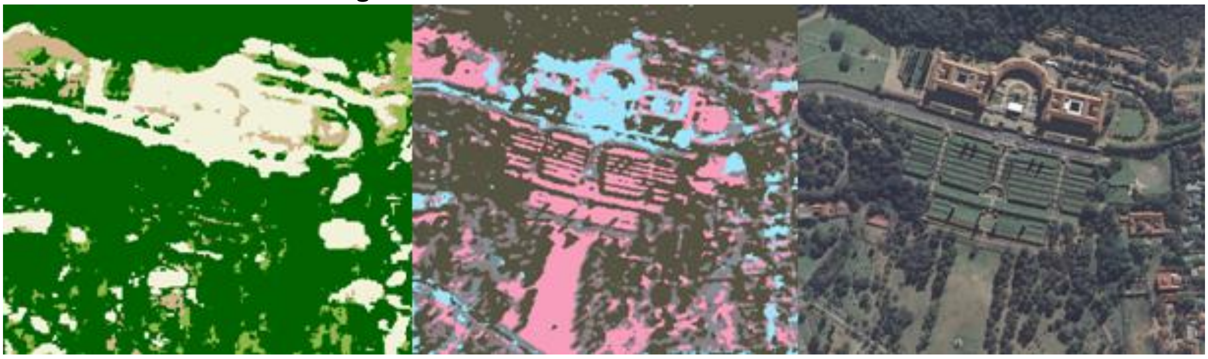


FIGURE 54: CONTROL AREA 1. LEFT: NEW LANDCOVER FROM GEOTERRAIMAGE. MIDDLE: SUPERVISED CLASSIFICATION FROM FORMOSAT-2 IMAGERY. RIGHT: AERIAL ORTHOPHOTO, TRUE COLOR.

In reality, the Union Buildings have a grass terrace in front of it and a grass lawn. In the new land cover classification produced by GeoTerraImage, these features are not visible. However, in the supervised classification conducted during this research, these features are visible. Both thematic raster layers have problems analyzing the shadows. The 'contours' in the left image are caused by shadows and have the attribute of exotic grass, even though there is no grass on those locations. The classified image classifies it as exotic trees.

Control area 2: Park north of Union Buildings

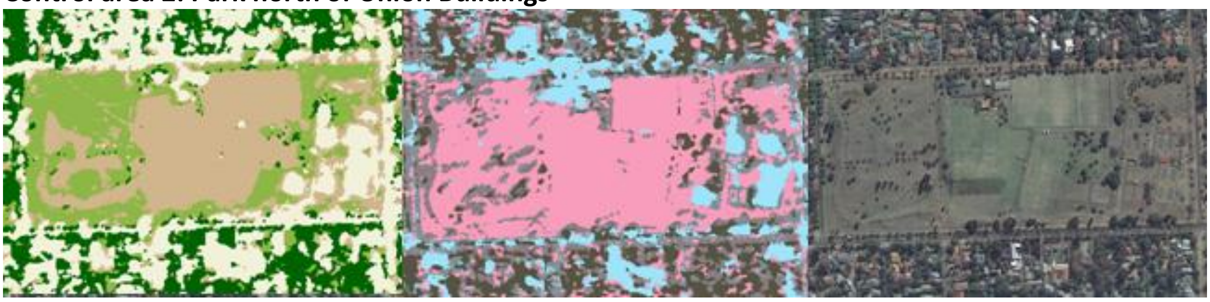


FIGURE 55: CONTROL AREA 2. LEFT: NEW LANDCOVER FROM GEOTERRAIMAGE. MIDDLE: SUPERVISED CLASSIFICATION FROM FORMOSAT-2 IMAGER. RIGHT: AERIAL ORTHOPHOTO, TRUE COLOR.

This predominantly exotic park is composed of tennis courts in the right corner, a few natural sports fields in the middle and a grass mall with a few trees on the left corner. Both the new land cover and the classification from this research are reasonably conforming to each other; they look different because of different classes they describe (see § 4.3 and § 5.4). However, the new land cover does generalize some exotic trees near the tennis court and the lawn, something which the supervised classification does recognize. In the suburban area, the supervised classification sees more trees than the new land cover. This is difficult to check for accuracy.

Control area 3: Circle park near presidential residence

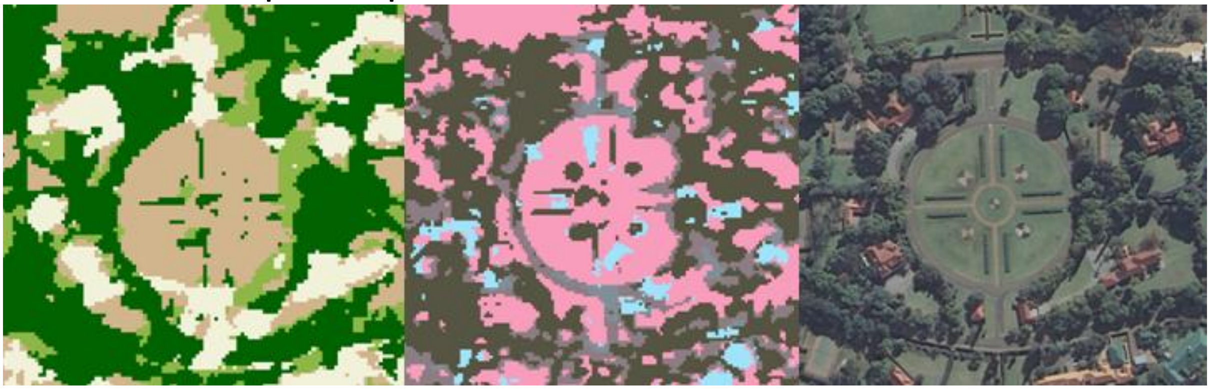


FIGURE 56: CONTROL AREA 3: LEFT: NEW LANDCOVER FROM GEOTERRAIMAGE. MIDDLE: SUPERVISED CLASSIFICATION FROM FORMOSAT-2 IMAGERY. RIGHT: AERIAL ORTHOPHOTO, TRUE COLOR.

This control area is not featured in as one of the classification areas from Chapter 5. This makes it more interesting to compare results, as this area has not been used as a training area in the Supervised Classification. The classified image features more of the detail from the circle, especially the road around it, which the new land cover data does not cover. However, the supervised classification has some trouble analysing the vegetation in the circle; it classifies it as light blue, which is urban. The road is classified as tarmac and as bush.

Control area 4: Urban area just north of the Union Buildings

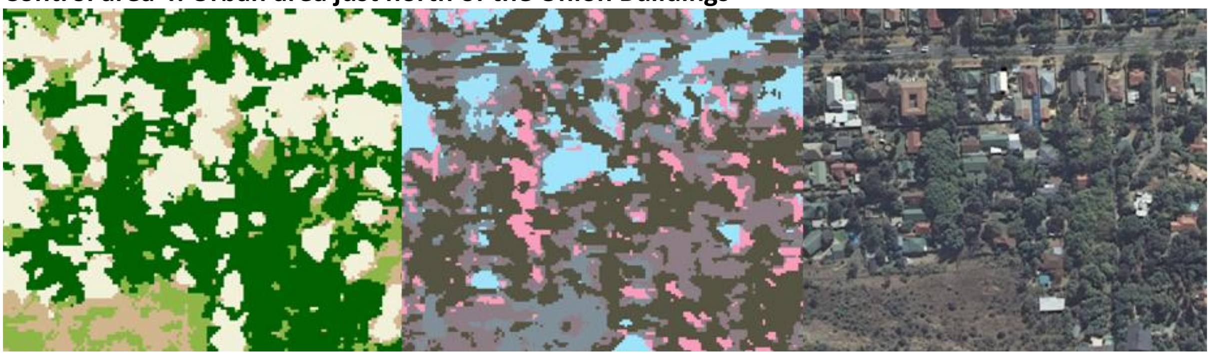


FIGURE 57: CONTROL AREA 4: LEFT: NEW LANDCOVER FROM GEOTERRAIMAGE. MIDDLE: SUPERVISED CLASSIFICATION FROM FORMOSAT-2 IMAGERY. RIGHT: AERIAL ORTHOPHOTO, TRUE COLOR.

Like control area 3, this area is not featured as one of the classification areas. This is also a particularly difficult area to classify, because of the non-homogenous situation. One of the biggest issues in the supervised classification is that the big trees in the center of the image are partially classified as grass. However, it was able to distinguish the trees to the side of the road near the top of the image. The Bushveld area to the south is classified in a similar way between the land cover and the supervised classification.

§ 11.1.2 Conclusion

As is visible, the classified image as extracted during this research incorporates more detail than the land cover data previously generated, but mostly in the areas that have been specified in Chapter 5 as suitable testing areas. Both datasets struggle with objects that cast a shadow; it classifies it as vegetation even though it isn't. In other areas, the land cover seems to be more accurate than the supervised classification, but only by a small margin. The accuracy of the results cannot be calculated or derived in different ways than comparing it to the original data and the available data. It is therefore concluded from visual inspection, personal judgement, evaluation of the datasets and the control areas above that the supervised classification as performed in this research is of reasonable accuracy. This means that the datasets is generally conform to the actual land cover classes but that there is room for improvement to classify objects that are spectrally similar to each other for the interpreter.

Some problems may arise from situations where trees are classified as grass, like in control area 3. Even though this classification does not occur on a regular base sometimes is classified as that brings with it a number of problems. The vegetation heights are based on the outline of each pixel value in the thematic raster. If a thematic raster classifies a certain land cover type in a wrong way, this could dilute the vegetation heights. This is a problem which is hard to overcome, since supervised classification is never 100% correct. A more accurate supervised classification and a smaller testing area is not always the solutions for the problems, as it increases processing time. However, since the vegetation types in the clutter data are (possibly) already wrongly classified, adding the heights to that kind of classification might not have that big of an impact. The only solution is to check the vegetation in the actual situation, or to incorporate vegetation heights in a different kind of set than the clutter data. For example, if the vegetation types are attributed a certain height as described in Chapter 10, the vegetation types can then be grouped together, creating an alternate dataset (such as a difference elevation model with median heights as an addition to the clutter data set). More research is necessary for this solution.

§ 11.2 VEGETATION HEIGHTS

§ 11.2.1 Control method

Vegetation heights can be measured with a theodolite. But, because this is not GeoTerraImage's area of expertise, none was available. A protractor with pendulum was used instead. The pendulum would be tied to the protractor. Since a pendulum always points to the gravitational center of the earth, the angle between the pendulum and the view line towards the canopy and bottom of the tree is measured. See for more information Attachment 2: Formulas for quality checks. The accuracy of this measuring method is not up to surveying standards. However, it is important that it is determined in which height class the vegetation is located in, and to finally compare those results with the vegetation height classification as generated in Chapter 10.

Measuring all vegetation in an area of 8 km^2 is a massive undertaking. Because there are no measurement data available for vegetation heights (such as governmental records or LIDAR data) for the areas where the vegetation height has been extracted, a testing location has been appointed. This testing area should incorporate high and low vegetation, preferably in a sharp contrast to each other, as well as some terrain elevation differences.

One site suited these requirements in particular, namely the golf course located in the 'Voortrekker Monument Area of Interest'. A golf course is composed of short exotic vegetation (each tee is planted exotic grass). The golf course in question also incorporates a lot of high exotic trees within the golf course and in the perimeter of the golf course. Also, the golf course has terrain elevation differences as indicated by the Digital Terrain Model.

The measured tree heights have been grouped together and displayed in Figure 58.

FIGURE 58: THE MEASURED HEIGHTS IN THE GOLF COURSE. RED IS VEGETATION BETWEEN 10-15 METERS HIGH. BLUE IS BETWEEN 15-20 HIGH. ORANGE IS 20 METERS OR HIGHER.

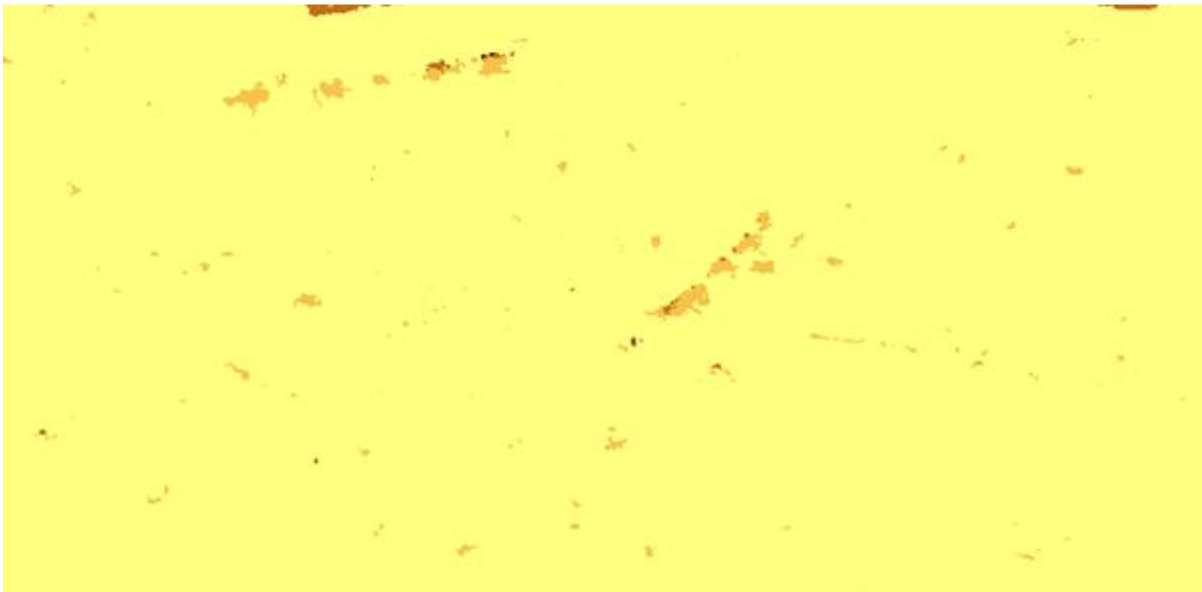


FIGURE 59: HEIGHT CLASSIFICATION ON THE RASTER IMAGE EXTRACTED FROM CHAPTER 10. YELLOW IS 0-5 METERS. ORANGE IS 5-10 METERS. DARK ORANGE IS 10-15 METERS.

As is visible in Figure 59, the vegetation heights do not correspond at all to the measured tree heights. There are a couple of reasons for this result, which are discussed in the next paragraph.

§ 11.2.2 Rationalization

There are a few speculations why the vegetation heights extracted are so inaccurate. 'Keeling over' vegetation (high vegetation that appears to 'fall over' in the photos due to parallax) may dilute the vegetation signatures. The shadows casted by the trees dilute the signatures and thus the supervised classification of the imagery. However, because the Digital Surface Model describes the vegetation heights due to a small search window, the mass points signifying the points of the tree and the points of the terrain are close together. Those points are located in the same signature from the supervised classification, diluting the calculation of the median heights of those areas.

In other words, the supervised classification has to be performed to a very high accuracy in order to segregate the vegetation from the shadows. This is very difficult to achieve, because the shadows and exotic trees are very close to each other, spectrally. See Figure 60.

FIGURE 60: LEFT: THE VEGETATION AND ITS SHADOW. IF HIGH VEGETATION DOES DISPLAY NEAR INFRARED BANDS, IT USUALLY IS QUITE DARK, MAKING THE SHADOWS AND VEGETATION VERY SIMILAR. THIS IS HARD TO DISTINGUISH IN THE SUPERVISED CLASSIFICATION (RIGHT)

Besides adjusting the signatures in the supervised classification, it is also possible to manually recode certain areas in the supervised classification. By doing this, it enables the values for certain areas to become more accurate in terms of 'tree' mass points to fall within classification areas and 'grass' mass points to fall in the grass vegetation areas. See Figure 61.

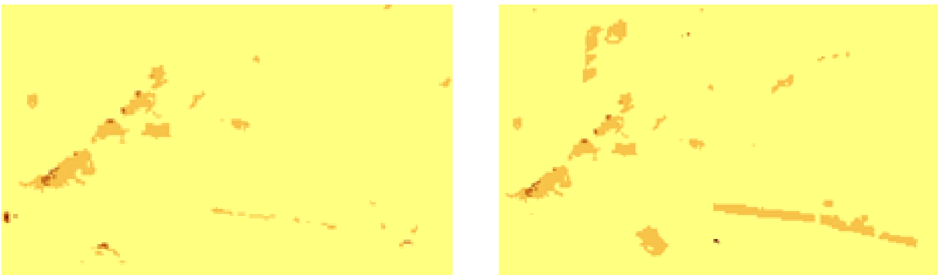


FIGURE 61: LEFT: BEFORE ENHANCING THE SUPERVISED CLASSIFICATION. RIGHT: AFTER ENHANCING THE SUPERVISED CLASSIFICATION.

As is visible in Figure 61, the heights are now clearly visible, and some groups of trees have also appeared, as they have been better distinguished in the supervised classification thematic raster. However, the vegetation heights are still off.

A manual examination has been made of the Digital Surface Model, in which the vegetation heights are extrapolated. There it was concluded that the heights from the vegetation have indeed been given a more accurate height, at an accuracy of 2 meters compared to the measured values. This meant that trees would be roughly placed in the correct class they were placed in with measured results. As a comparison, the height of the Voortrekker Monument was examined. The height of the Voortrekker Monument in the Difference Elevation Model was 37 meters, a 4 meter difference with the actual height; a 90% accuracy.

Chapter 12 ENHANCING CLUTTER DATA

Despite inaccurate vegetation heights extrapolated with the help of the vegetation classification, it is still researched how to enhance clutter data with this data. At this moment, the vegetation heights and types have been intersected and exported to a vector polygon shapefile. Each polygon in this shapefile has been attributed an integer, according to the vegetation type classes and vegetation height classes. This data now has to be incorporated into the clutter data. Due to the limited time available for this research, an outline is given for this procedure. This procedure has not been executed during this research, and thus needs additional research in a follow up research.

§ 12.1.1Procedure

Incorporating this data in the clutter data is not easy. The clutter data already incorporates vegetation classes. These vegetation classes have to be overwritten with the new vegetation classes. This has to do with the fact that pixels in a thematic raster can only be attributed one specific value, rather than several. In other words, only one attribute of the shapefile can be incorporated in the thematic raster layer.

There are 2 different ways to incorporate both the vegetation type and vegetation height in he clutter data.

The first way is to create a specific classification for each vegetation class and each vegetation height class. For example, exotic trees with a height of <5 meters, is appointed class 11. Exotic trees with a height between 5 and 10 meters are appointed class 12. Bushveld with a height of 5-10 meters is appointed class 22, etc. After this is completed, this shapefile can be converted to a thematic raster layer, where pixel value 22 displays the bushveld vegetation with a height of 5-10 meters, etc.

In the clutter data, where originally each vegetation class is appointed one specific pixel value, all vegetation classes have to be appointed to a single pixel value. This is done to replace the vegetation classes originally in the clutter data, with the new classes generated. After this, it is important that no pixels in the clutter data have the same pixel values as specified in the data to be incorporated. No pixel value should be 22, because this will be added to the bushveld vegetation from the other dataset.

When all vegetation classes in the clutter data have been grouped together as one pixel value, and when no pixel has the same value as the pixel values in the data to be added, the thematic raster images can be combined.

A specific rule has to be applied with the help of the modeler in Erdas, which indicates that the grouped vegetation classes in the clutter data is replaced with the vegetation classes from the data to be added. A conditional EITHER IF rule can be used for this purpose. An example is:

EITHER (new_vegetation_classes_dataset) + (clutter data) IF (clutter data) E (pixel value with vegetation classes in clutter data) AND (new_vegetation_classes_dataset) NE 0 OR (clutter data) OTHERWISE

If the pixel values in the new vegetation classification are 0 (a pixel value in all thematic rasters), 11, 12, 21 and 22, and the clutter data vegetation classes have been grouped to class 10, the rule would be:

EITHER (new_vegetation_classes_dataset) + (clutter data) IF (clutter data) E 10 AND (new_vegetation_classes_dataset) NE 0 OR (clutter data) OTHERWISE

This rule will replace all clutter data pixels with value 10 with the pixel values from the new vegetation classes dataset, except when that value is 0, in which case the clutter data is kept in place.

§ 12.1.2 Limitations

A downside to his methodology is that the vegetation classification in the clutter dataset and the dataset added has to match exactly. This is not possible if the vegetation has been classified with different imagery. Because of this, the new vegetation class dataset might not overlay the vegetation classes from the clutter data completely, leaving spots with unedited clutter data information from the original file. It is also possible that the new dataset might cover a larger area than the vegetation being replaced from the clutter dataset. This would mean that information is being thrown away, because it overlaps pixels with values other than 10 (pixels that are not classified as vegetation in the original clutter data). There are four different solutions to this problem:

1. Sharpening filters. This sharpens the empty areas with pixel values surrounding the area. An sharpening area of different dimensions (3x3 pixels, 7x7 pixels etc) can be defined, which sharpen the empty areas with the pixels surrounding the empty area. Areas that are larger than the sharpening filter are not sharpened. The accuracy of the eventual clutter data set may suffer, because the sharpening filter corrects these areas depending on the pixel values that surround this area. This does not always represent the actual situation.
2. Manually attributing a pixel value to the open spaces. This can be used in conjunction to method 1. Areas with pixel value 0 can be manually edited. This is a time consuming operation.
3. A uniform classification and heights extraction for clutter data. Instead of replacing existing clutter data pixel values, an entirely new clutter dataset can be deduced from the imagery. This is a very expensive (but effective) solution to avoid ‘gaps’ and inaccurate data.

Solution number 3 is probably the best solution. Surely it will increase processing time and costs, however, having gaps in clutter data with a high resolution is something which GeoTerraImage should avoid.

Chapter 13 FEASIBILITY

§ 13.1 PRACTICAL

The methodology as developed during this research will enable GeoTerraImage to extract vegetation heights and to incorporate this data into existing clutter data sets. The theory behind it is sound and proven with this research. Extracting vegetation heights from the imagery is a process that largely depends on the area which has to be analyzed as well as the diversity of situations in that area. A homogenous area will generate more accurate and quicker results, whereas an irregular area will mandate, especially in the vegetation classification, more detailed study areas. In general, vegetation type and height extraction is deemed practically feasible by GeoTerraImage. There are two equally important factors which inhibit GeoTerraImage to apply this methodology in the near future. These factors are reference and control data, as well as hardware. By measuring ground control points in the reference data, the digital elevation models as well as the stereo model can be appended to true coordinates, which could lead to a more accurate result. The results generated have to be checked in certain test locations as well. Hardware is important due to the sheer processing time of the overall project. On average, extracting a Digital Surface Model with the eATE algorithm took 11 hours for an area of 8 km^2, with the algorithm not even set at its maximum settings. During this time, the hardware was intensively used, rendering it useless for parallel processes. Acquiring dedicated powerful hardware for the process will enable parallel processing of multiple projects.

§ 13.2 ECONOMICAL

Classified information considering hourly wages of employees as well as pricing for clutter data makes it impossible to produce a substantiated reasoning to the economic feasibility. This economic feasibility has been derived from feedback of company directors as well as logical deduction.

The economic feasibility is hard to extrapolate, due to the classified pricing of clutter data sets. However, considering that GeoTerraImage is a value added company, some assumptions can be made for the economic feasibility of this project. Hardware is more expensive in South Africa than in Europe or Northern America. This is a relative small price to pay, averaged out by the multitude of projects at GeoTerraImage; other projects may benefit from a dedicated machine. The big issue is reference data.

Accurate reference and control data is hard to come by in South Africa. Datasets that are widely available in European and North American countries, such as LIDAR, are significantly more expensive in South Africa. This makes it not feasible at this moment for GeoTerraImage to acquire these datasets in the scale it produces data. Other reference datasets, such as the Digital Elevation Model, can be replaced with ground control points (as mentioned in previous occasions). Since GeoTerraImage does not have a dedicated surveyor branch or equipment, this equipment and man power has to be hired externally. Considering that GeoTerraImage produces clutter data for a large number of cities all around Africa, hiring a surveying team and equipment in all those cities does not weigh up to the value added to clutter data. GeoTerraImage can appoint a testing area nearby its head office, such as Pretoria. Even though GeoTerraImage has competitors, these competitors are probably experiencing similar predicaments as GeoTerraImage in terms of acquiring accurate reference and control data. A testing location, to show clients what GeoTerraImage is capable of, may generate leverage for the production of enhanced clutter data sets at a higher price. This is possible, since a high protocol for telecommunication (WiMAX) has not been deployed yet in South Africa. GeoTerraImage could only generate and provide enhanced clutter data sets for testing areas for that protocol, which demand accurate clutter datasets as described in this report. When the protocol is deployed in more areas by more carriers, GeoTerraImage can follow suit, which could make the production of enhanced clutter datasets with additional reference and control data feasible in the long term.

Chapter 14 DISCUSSION

This chapter discusses the conclusions, recommendations and outlook that have been derived from this research.

§ 14.1 CONCLUSIONS

With the new methodologies as discussed in this research it is possible to generate vegetation heights. The Difference Elevation Model, generated with the Digital Terrain and Digital Surface model, describes the objects independently from the terrain, while objects on the imagery are classified using a supervised classification method. It is possible to generate a feature specific dataset where the height and types of the objects can be described. This dataset can then be incorporated in the clutter dataset.

However, there are severe limitations in terms of generating accurate data to be used for vegetation extraction.

- The object types as specified in the supervised classification are too general; this leads to an inaccurate object height.
- The different elevations extracted of vegetation leads to long processing times for larger areas.
- Dynamics of vegetation mandate that the imagery to be analyzed is collected in the dry and wet season, depending on the vegetation types that occur in that area.
- Diversity of vegetation types and alternation between artificial structures and vegetation can dilute the end result when extracting the elevation models.
- No accurate dataset describing heights is available (such as LIDAR), generalizing elevations.
- The different datasets have to be referenced and checked for quality, which can be performed by a team of surveyors. This is outside of GeoTerraImage's area of operation and expertise.

In short, most of the limitations are based on the lack of additional means and resources, which GeoTerraImage does not have available.

§ 14.1.1 Quality improvement

Even within GeoTerraImage's area of expertise, there are certain steps that GeoTerraImage may undertake in order to enhance the results generated with the developed methodology. These steps entitle the adjustment of the variables in the terrain extraction algorithm, such as search window size, correlation and blunder techniques. By adjusting those variables, vegetation and other objects can become more prominent in the Digital Surface model, and thus in the Difference Elevation Model. However, more accurate Difference Elevation Models will also create the necessity of accurate supervised classification. The supervised classification can be made more accurate by adjusting the spectral signatures in the feature space of each image, which results in the pixels being associated into signatures more appropriate to the type of object classified. The quality of the end results can also be adjusted by using different or additional reference data. This is further discussed in the recommendations segment of this chapter (paragraph 2).

§ 14.1.2 Limitations of the research

Some aspects of this research have not been completed due to time restraints. It is recommended that these subjects are investigated in a follow up research. Those aspects are:

- Incorporation into clutter data. The theory has been devised and it is deemed possible, but it has not been executed.
- Economic feasibility. Classified information of hourly wages of employees and price of clutter data make it impossible to define a substantiated economic feasibility.
- Supervised classification. The supervised classification of the Ikonos imagery was not accurate enough due to the lack of an infrared image. Since the Formosat-2 imagery has been successfully and accurately performed, some additional research is necessary to investigate supervised classification results of Ikonos imagery.

§ 14.2 RECOMMENDATIONS

During this research, the following recommendations have been devised which may help to increase the speed and accuracy of the devised methodology, in the event that it will be adopted into the standard workflows of GeoTerraImage. All of the recommendations have been grouped to a specific subject and may include pointers to further research to benefit the final result.

§ 14.2.1 Imagery

It is recommended that the imagery will be acquired in pan-sharpened Multispectral + Near Infrared bands. This will help with the classification methods as used by the eATE (enhanced Automatic Terrain Extraction) algorithm processes. Also, it is recommended to acquire imagery taken in the right season, in which all vegetation emits a distinguishable Near-Infrared signature. A preliminary vegetation study is essential to extrapolate the most suitable date. If, in the future, GeoTerraImage wants to expand its vegetation classification to distinguishing evergreens with deciduous trees, imagery from both the dry and wet season are necessary (preferably within a certain time span) to distinguish the different classes. Considering that extracting vegetation metadata usually points to generating clutter data sets with a high spatial resolution, it is necessary for this imagery to be of an adequate resolution for the end result, keeping in mind the limitations of the available hardware. See also the point “Processing” below. Due to the necessity of higher clutter datasets, it is concluded that the use of Formosat-2 imagery is too inefficient due to compatibility issues with Erdas, while not adding value (due to its lacking spatial resolution) to the classification of vegetation and the extrapolation of Digital Elevation Models. The Ikonos imagery is deemed sufficient for further use.

§ 14.2.2 Ground Control Points

One of the major limitations encountered in this research is the lack of proper reference points. This in turn diluted the results. It is therefore recommended that ground control points are measured throughout the area of interest in order to achieve more accurate results. Using ortho photos as a horizontal reference are sufficient when the desired end result will have a low spatial resolution (such as 2.5 meters). If GeoTerraImage wants to expand to higher resolution clutter data, using accurately measured ground control points are essential to achieve a good accuracy. Using Digital Elevation Models as a Z reference is not recommended for the actual product.

§ 14.2.3 Cadastral Datasets

Acquiring an accurate Cadastral Dataset with building outlines will benefit the accuracy of the Digital Surface Model, when using the aATE algorithm as it helps to avoid dilution of buildings with other objects. Currently, only building outlines of major buildings are available, smaller buildings are usually omitted in their cadastral boundaries. Additionally, if GeoTerraImage wishes to extrapolate building heights, an accurate building outline set can replace the building recognition algorithms in eATE.

§ 14.2.4 Object Filter research

One of the major limits in this research was the lack of availability of a Digital Terrain Model. It is possible to generate a Digital Terrain Model from the Digital Surface Model, eliminating the need for a Digital Terrain Model altogether (in case Ground Control Points are available to reference the stereo model). In this case, the Digital Surface Model has to be filtered, excluding the objects on the terrain. However, this cannot be done with the current software. A special filter has to be developed and programmed which is able to filter out these objects. Additional research in the development of this kind of filter is recommended, as this filter can hold the key for a successful vegetation height extraction performed by GeoTerraImage.

§ 14.2.5 LIDAR dataset comparison

If feasible, it is recommended that a separate research will discuss the extraction of vegetation heights using LIDAR (Light Detection And Ranging) point datasets, and compare it to this research. Considering that GeoTerraImage's coverage expands beyond Southern Africa, it might be feasible to experiment and implement a workflow for areas where LIDAR is more ubiquitous. It could be a region suitable for expansion in the future in other countries outside Africa, or when LIDAR data becomes more common in South Africa. LIDAR datasets can be used for both height extrapolation and classification of objects, producing similar results as the remote sensing imagery (Lillesand, Kiefer, & Chipman, 2004).

§ 14.2.6 Processing

One of the mayor obstructions during the development of this methodology is the hardware constraints at GeoTerraImage. Even though newer hardware is more expensive in South Africa compared to Europe or the United States, the process will greatly benefit a dedicated processing machine. The intensive processes of extracting Digital Elevation Models are all optimized for 64 bit processing. It is therefore recommended that GeoTerraImage will acquire a dedicated processing machine with the latest standards in terms of processors and operating systems. This will ensure a significant gain of time and resources for GeoTerraImage, in comparison with the time and resources spent on this research with the hardware available. Furthermore, the Digital Elevation Model extraction process of eATE is optimized for multiple processes on multiple systems, in case GeoTerraImage decides to acquire more dedicated processor machines. A general benefit to acquiring a dedicated processing computer is that employees of GeoTerraImage are not limited in their capabilities due to a slow computer because of intensive processes running in the background. It will enable them to fully focus their priorities on other duties while the processes are underway, which in turn increases efficiency of the workplace.

§ 14.2.7 Incorporation in clutter data workflow

The best results are achieved when the clutter data and the vegetation classification are updated and generated in conjunction. This has to do with the dynamics of vegetation in relation to other objects. Also, the difference between objects and vegetation will be in unison if one supervised classification is conducted instead of several (which could lead to conflicting results). Note that the size of the area which has to be classified is not too large in order to accommodate big differences between suburban, urban and rural vegetation types.

§ 14.2.8 Switching from thematic raster layers to vector layers

With the increase of attribute information required for different objects, it might be If the different heights have to be accurately incorporated into clutter data, this may lead to a sharp increase in thematic raster classes. To avoid this, it is recommended that clutter data will be converted to vector shapefiles, in which heights of objects such as vegetation as well as other metadata is simply added into the attributes of each polygon.

§ 14.3 FUTURE OUTLOOK

With this report, GeoTerraImage will have gained knowledge of the process of extracting vegetation metadata from remote sensing imagery and how this information may enhance clutter data. It is therefore recommended that this knowledge is distributed within the organization and to continue to expand the resolution and accuracy of the datasets if the accurate reference data becomes available. Because the industry requires increasingly accurate datasets, GeoTerraImage may consider extracting building heights. With some minor modifications, the methodology as described in this report can be used to extrapolate building heights. Future software from Erdas which is now in the final stages of development can be used to automate the building heights extraction. This software is called Shadow2Height. It uses the metadata of the imagery concerning the position of the sun at the time of the collection of the data. It then calculates the height of objects with the shadow that is casted by that object. This height can then be assigned to a building outlines dataset. It might be a problem extracting everything to a thematic raster; switching to vector layers may hold the key to incorporating more data into clutter data set, as well as accommodating a higher spatial resolution.

FIGURE 62: LEFT: THE WHITE HOUSE GENERATED IN SOCET SET WITH IKONOS IMAGERY. RIGHT: PRETORIA IN (LOW RESOLUTION) 3D FOR THE FIFA WORLD CUP 2010.

Using stereo photography and the data extracted using this research, GeoTerraImage is also able to expand their portfolio of products in the 3D modeling sector. This is possible with the means used in this report, with the addition of a few programs which are more capable of performing these tasks than Erdas alternatives. 3D visualization of certain areas can be used for touristic purposes (Oosterom, 2007). This has already been conducted in South Africa on a limited scale by Google, with the World Cup taking place in South Africa in the year that this report is written. A candidate for software that can be experimented with is SOCET SET (see Figure 62), which is compatible with LPS and ArcGIS (Strynatka, 2008).

Besides the tourism industry, these models can also be used for analytical purposes in GIS systems. Some examples can be:

- Risk analysis: Predicting the impact of (natural) disasters, such as flooding, fires and explosions, in an urban or rural area. This can be used by the government on all levels, as well as urban planners and emergency services.
- Sound wave propagation analysis: This data is similar to clutter data as it describes obstructions which interfere with the propagation of waves. It can be used to analyze the propagation of sound waves emitted by nearby industry or infrastructure, in order to reduce noise pollution in existing situations or to extrapolate a suitable location of new urban development. Client base could be government on all levels as well as urban planners and architectural bureaus.

The demand of this kind of data in the coverage area of GeoTerraImage should be analyzed, prior to development of these products.

GLOSSARY

aATE	adaptive Automatic Terrain Extraction, an algorithm to extrapolate elevation models.
AoI	Area of interest (in this report to specify the overall testing area)
aoi	area-of-interest polygons (to recognize patterns etc.)
Bioregions	A place, locale or area that constitutes a natural ecological community. It is a subset of a biome.
Breakline	A line in a TIN that represents a distinct interruption in the slope of a surface, such as building outlines and bridges. Breaklines are enforced as triangle edges.
Cell Size	In raster data, data is represented spatially on a matrix of grid cells (pixels) which are assigned a specific value for image characteristics or attributes. Cell size also refers to the actual size of the grid cells or pixels (pixel resolution).
Correlation	Mutual relation of two or more things. (in the report it refers to the relation of pixels on 2 different images.
Continuous raster image	A raster image which is continuous rather than gridded or thematic. Panchromatic and multispectral images are continuous raster images, for example.
Difference Elevation Model	A Difference Elevation Model is a Digital Elevation Model, containing the elevation values of objects on the terrain, independently from the terrain. As such, a Difference Elevation Model contains no values lower than 0 elevations. Acronym used in this report: DIEM.
Digital Elevation Model	A Digital Elevation Model is a dataset containing elevation values. This data can be compiled in a gridded or non-gridded fashion. Acronym used in this report: DEM.
Digital Surface Model	A Digital Surface Model is a Digital Elevation Model, incorporates the elevation values of the terrain and the objects on the terrain. Acronym used in this report: DSM.
Digital Terrain Model	A Digital Terrain Model is a Digital Elevation Model, which contains the elevation values of the terrain excluding the objects on the terrain. Acronym used in this report: DTM.
eATE	enhanced Automatic Terrain Extraction, similar to aATE.
EDGE	Enhanced Data Rates for GSM Evolution, a telecommunication protocol that is an extension to the GSM protocol
Feature Space	A feature space is an abstract space where each pixel value is represented as a point in an n-dimensional space. The dimension of the feature space is determined by the variety of pixel values used to describe the bands in a continuous raster image.
GCP	Ground Control Points
Georeferenced Stereo Model	A stereo model with internal and external reference points.
GPRS	A telecommunication protocol for mobile internet access
Gridded data	In this report, a Digital Elevation Model with the elevation values of the non-gridded data, extracted with cell sizes.
GSM	Global System for Mobile communication, a standard for mobile telephony.
GTI	GeoTerraImage.

Herbaceous layer	A vegetation layer containing only soft vegetation, i.e. no stems.
HIS	Hue Intensity Saturation
HSDPA	High Speed Downlink Packet Access, a telecommunications protocol which allows current data systems to have a higher data transfer rate.
HSPA	a term for a high frequency used for telecommunication
IMG	Image (referring to the default Erdas export file format)
Interpolation	A method of constructing new data points within the range of a discrete set of known data points.
LIDAR	Light Detection and Ranging (also LADAR, Laser Detection and Ranging).
LPS	Leica Photogrammetric Suite.
LTF	The name of an enhanced version of TIN files (smaller file size, more efficient).
Mass Points	Irregularly distributed sample points, with an x-, y-, and z-value, which are used as the basic elements to build a Triangulated Irregular Network (TIN). Each mass point has an important, yet equal, significance in terms of defining the TIN surface. Ideally, mass points are placed in locations that describe the more important variations in the shape of the surface being modeled.
MS	Multispectral.
Multispectral imagery	Imagery composed of Red, Green, Blue and Near-Infrared bands.
NCC	Normalized Cross Correlation.
NDVI	Normalized Difference Vegetation Index.
NIR	Near Infrared.
Nongridded data	In this research, a Digital Elevation Models with elevation values in a point cloud or triangulated irregular network format.
Orthometric height	The orthometric height is the distance between the physical surface and the geoid along a line of force.
Orthorectification	Orthorectification is a process in which photos with a perspective view (stereophotos) are converted to photos with an orthogonal view (orthophotos).
Pansharpening	A process in which the geographical resolution of an image with a low spectral resolution is combined with an image with a high spectral resolution and a low geographical resolution.
Planar surface	A smooth test surface. In this report, planar surface refers to the testing surface as used in eATE.
Root Mean Square (RMS) error	The Root Mean Square Error (RMSE) represents the difference between original control points and new control point locations.
SDD	Sum of Squared Differences
Spectral raster image	A continuous raster image, such as a photograph.
Stereo Model	A model composed of 2 stereo images.
TEI	Terrain Editor for Imagine.
Thematic raster image	A raster image where each pixel value signifies a theme, such as land cover.
TIN	Triangulated Irregular Network. A dataset with triangles defined by mass points that describe the elevation differences an area.
TrigNet	A GNSS reference station network used in South Africa, consisting of continuously operating GPS base stations.

WiMAX	Worldwide Interoperability for Microwave Access, a term for a high frequency used for telecommunication, especially for data transfer.

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ATTACHMENT 1: DATA GENERATED

In this attachment, an overview of the reference imagery and data generated is given, along with annotations. This reference data is either the data as available to GeoTerraImage, or the data as generated for the purposes of this report. The images are in consecutive order; please see the report for a description on how these images are generated. These annotations are cited below the images. Unless otherwise specified, the north is at the top (stereo images not included).

UNION BUILDINGS AREA OF INTEREST

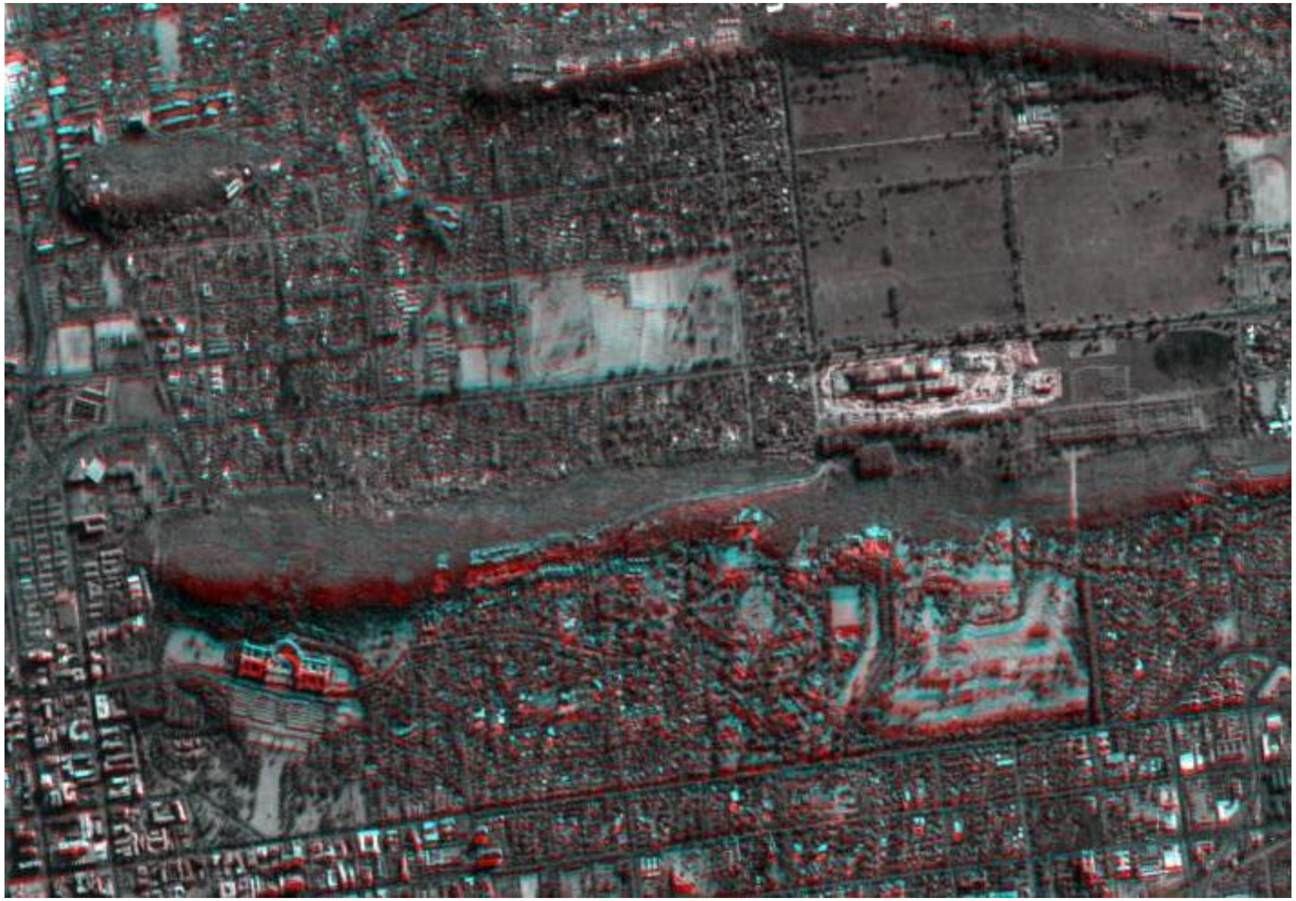

IMAGE 1: STEREO MODEL OF THE AREA OF INTEREST. (CHAPTER 7)

IMAGE 2: THE AERIAL ORTHO PHOTO FROM THE DEPARTMENT OF RURAL DEVELOPMENT AND LAND REFORM. USED AS REFERENCE MATERIAL FOR THE STEREO MODEL. (CHAPTER 3, CHAPTER 7)

IMAGE 3: THE PANCHROMATIC FORMOSAT-2 IMAGE OF THE AREA OF INTEREST. (CHAPTER 3, CHAPTER 7, CHAPTER 9)

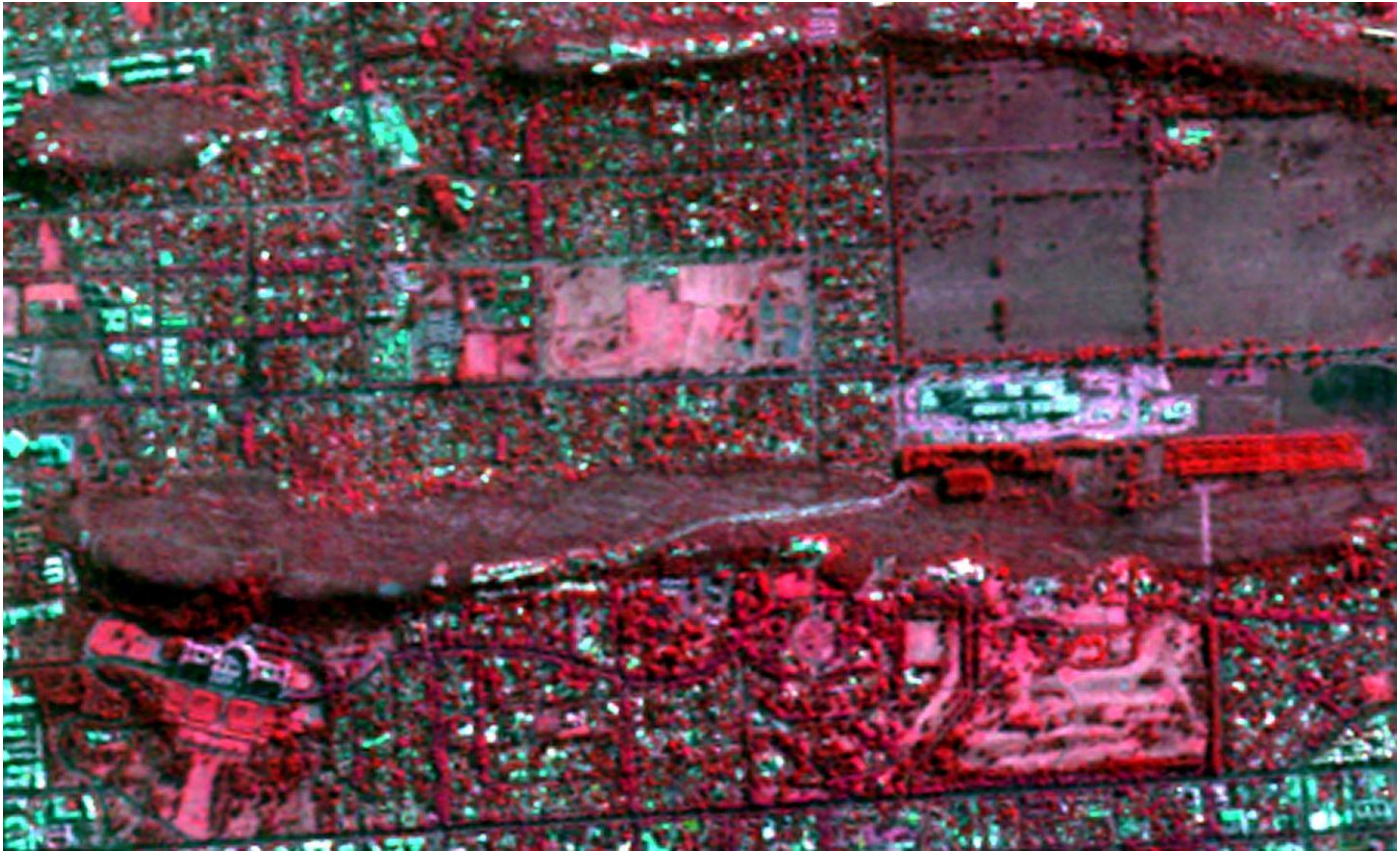

IMAGE 4: THE MULTISPECTRAL FORMOSAT-2 IMAGE OF THE AREA OF INTEREST. (CHAPTER 3, CHAPTER 7, CHAPTER 9)

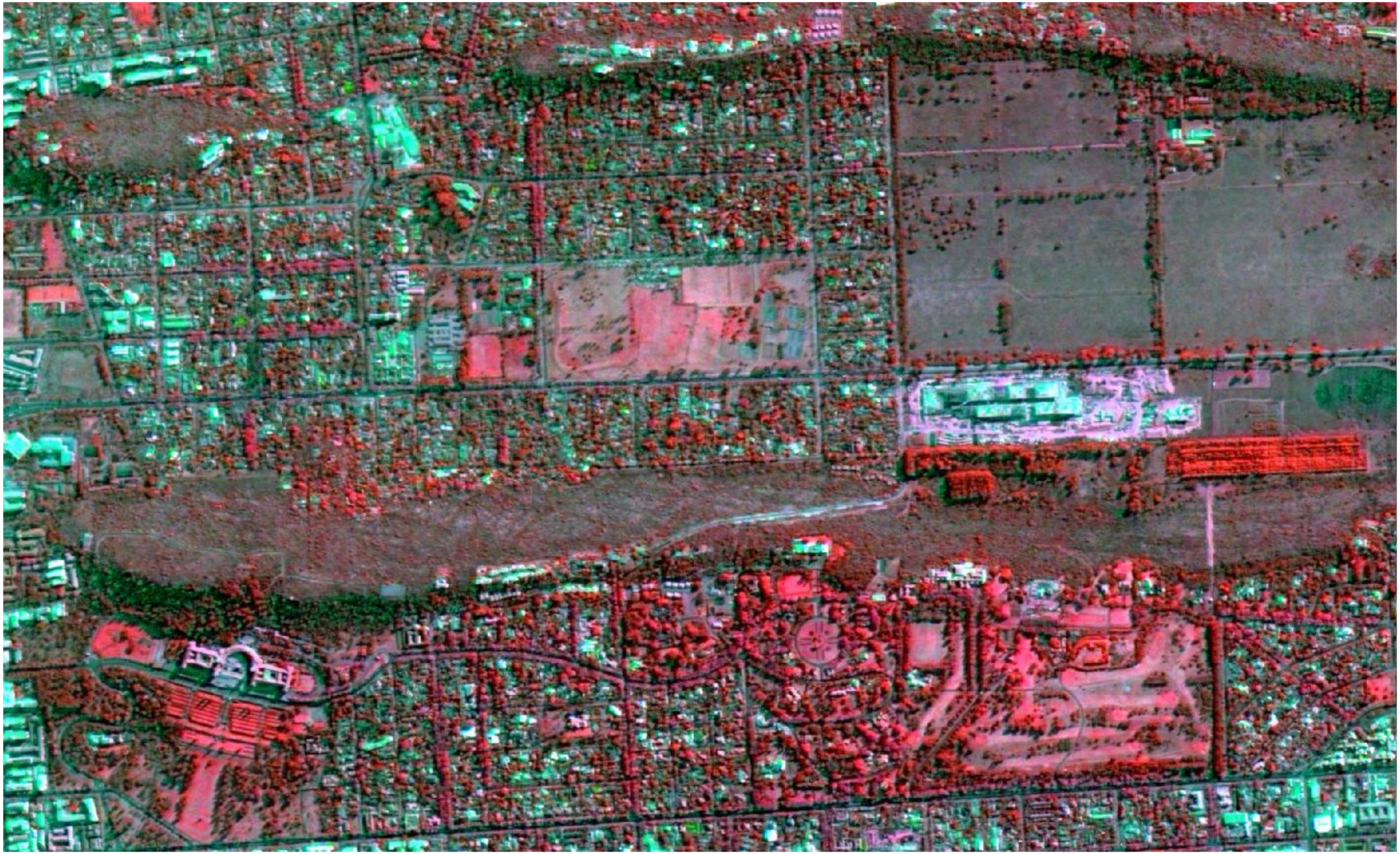

IMAGE 5: THE PAN-SHARPENED IMAGE OF THE TWO PREVIOUS IMAGES OF THE AREA OF INTEREST. USED FOR SUPERVISED CLASSIFICATION. (CHAPTER 9, CHAPTER 11)

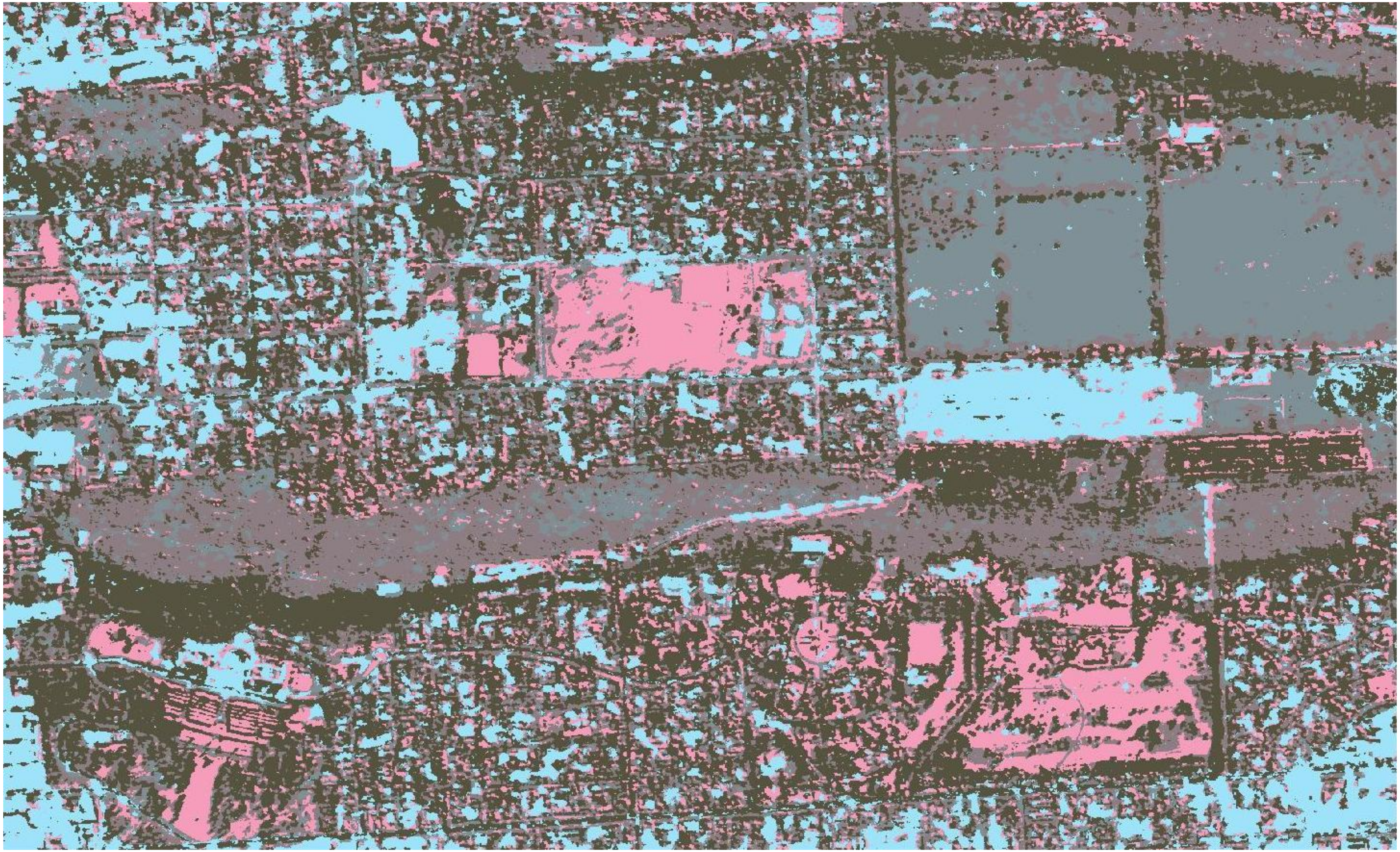

IMAGE 6: THE SUPERVISED CLASSIFICATION OF THE PAN-SHARPENED IMAGE. PINK IS EXOTIC GRASS, DARK GREEN IS EXOTIC TREES. THE LIGHTER COLOURS OF GREEN IS BUSHVELD TREES AND BUSHVELD GRASS. LIGHT BLUE ARE OBJECTS CONSIDERED TO BE NON-VEGETATION. (CHAPTER 9, CHAPTER 11)

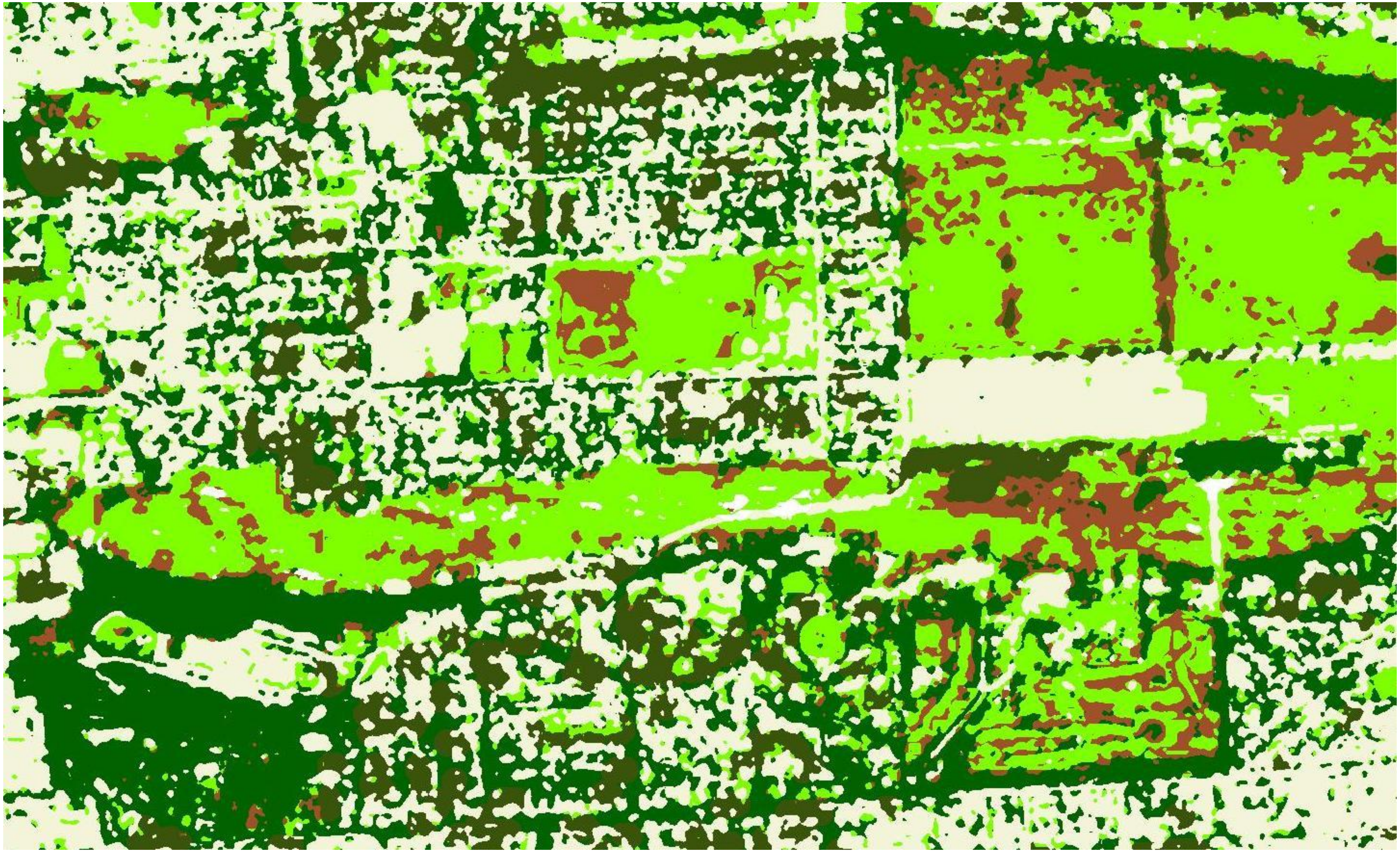

IMAGE 7: THE LAND COVER DATA PRODUCED BY GEOTERRAIMAGE, AND AS USED IN THE CLUTTER DATA. (CHAPTER 9, CHAPTER 11)

IMAGE 8: THE NEW VEGETATION LAND COVER DATA, STILL TO BE INCORPORATED IN THE FINAL CLUTTER DATA. IT HAS BEEN PRODUCED BY GEOTERRAIMAGE. THIS DATA HAS BEEN USED TO CHECK THE SUPERVISED CLASSIFICATION AS PRODUCED IN THIS REPORT FOR ACCURACY. (CHAPTER 9, CHAPTER 11)

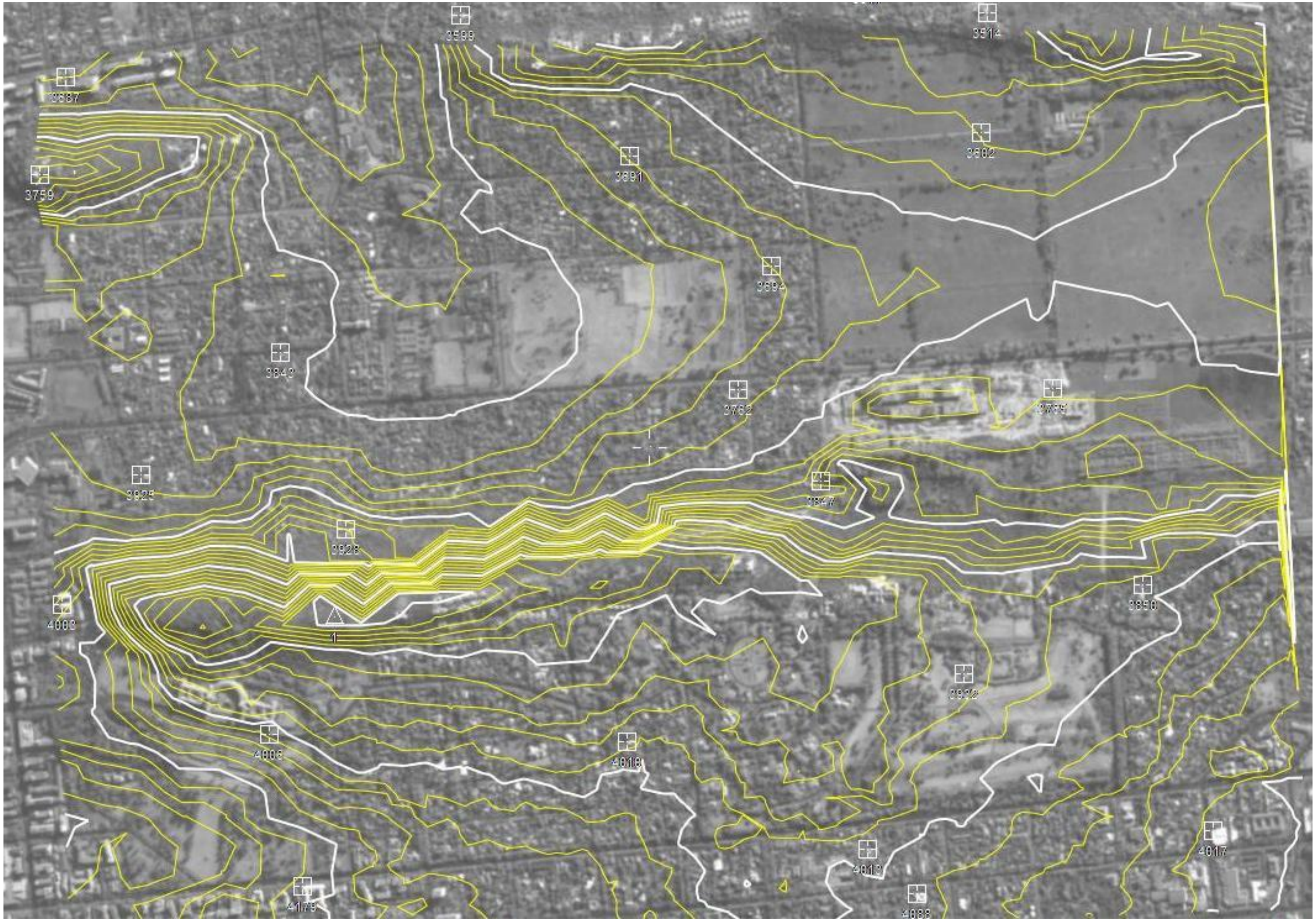

IMAGE 9: THE AATE DIGITAL SURFACE MODEL OF THE UNIONBUILDINGS. EACH CONTOUR INDICATES AN INTERVAL OF 5 METERS. AS IS VISIBLE, AATE DOES NOT GENERATE ENOUGH POINTS FOR ALL THE OBJECTS IN THE IMAGE. THIS IS ALSO THE MAXIMUM ACCURACY ACHIEVED BY AATE FOR AN AREA THIS SIZE. ALSO, SOME STRANGE MISCORRELATION APPEARS IN THE HILL, JUST NORTH OF THE UNIONBUILDINGS. (CHAPTER 7)

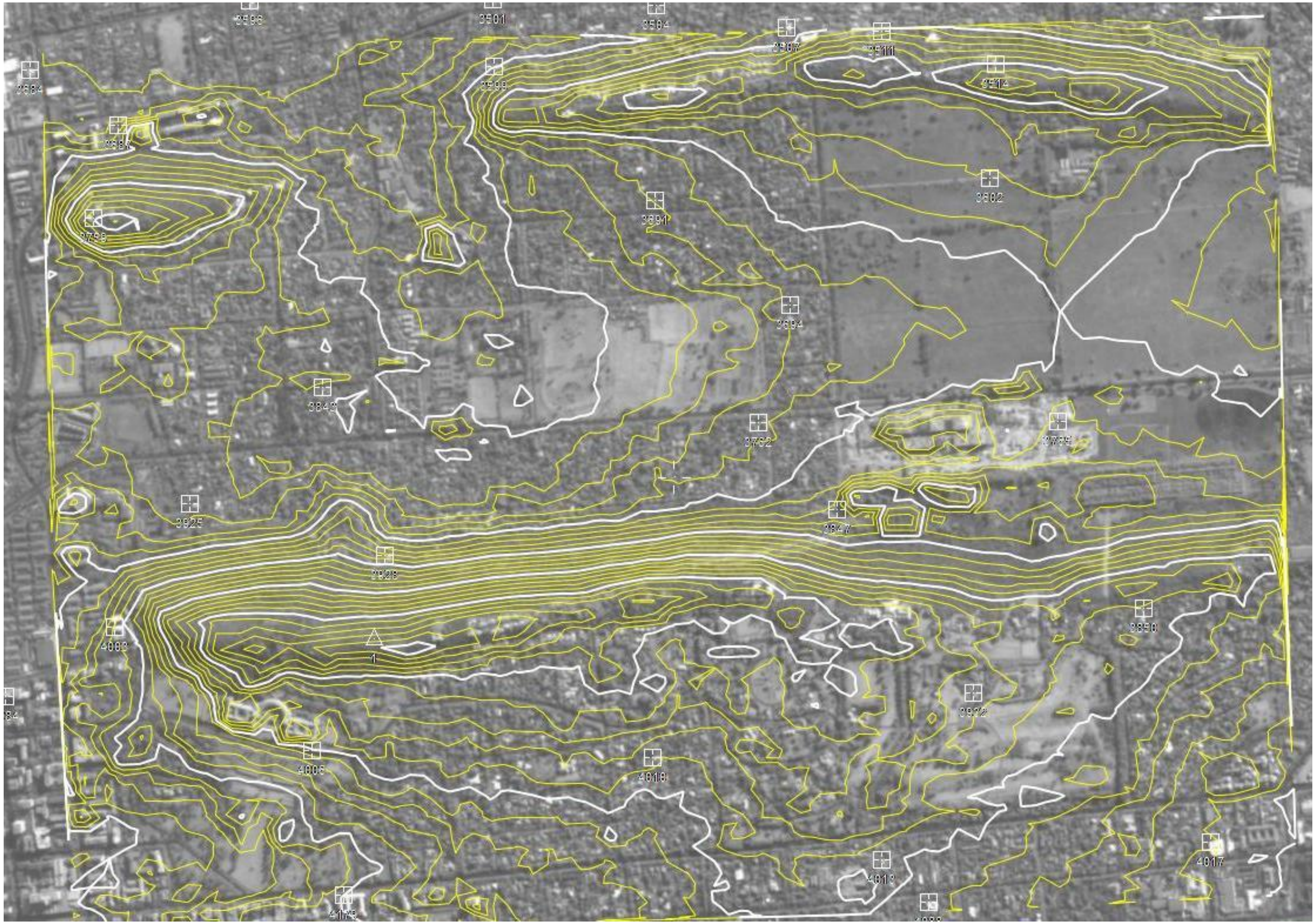

IMAGE 10: THE DIGITAL SURFACE MODEL OF THE UNIONBUILDINGS AREA OF INTEREST, AS GENERATED BY THE EATE ALGORITHM. THE EATE ALGORITHM WAS CAPABLE OF DISTINGUISHING DIFFERENT OBJECTS, SUCH AS THE UNIONBUILDINGS AND THE MINISTRY OF FOREIGN AFFAIRS. HOWEVER, THE VEGETATION IN THE PROEFPLAAS, THE UNION BUILDINGS PARK AND THE HILL NORTH OF THE UNION BUILDINGS IS HARD TO DISTINGUISH. THIS COULD HAVE TO BE ATTRIBUTED TO THE LOWER SPATIAL RESOLUTION OF THE FORMOSAT-2 IMAGERY, SINCE THE PROCESS WAS OPTIMALIZED FOR THE EXTRACTION OF ALL OBJECTS. THE SAME CONFIGURATION WAS USED FOR THE VOORTREKKER MONUMENT COUNTERPART, IN WHICH THE ALGORITHM WAS ABLE TO DISTINGUISH DIFFERENT OBJECTS A WHOLE LOT BETTER. (CHAPTER 7)

VOORTREKKER MONUMENT AREA OF INTEREST

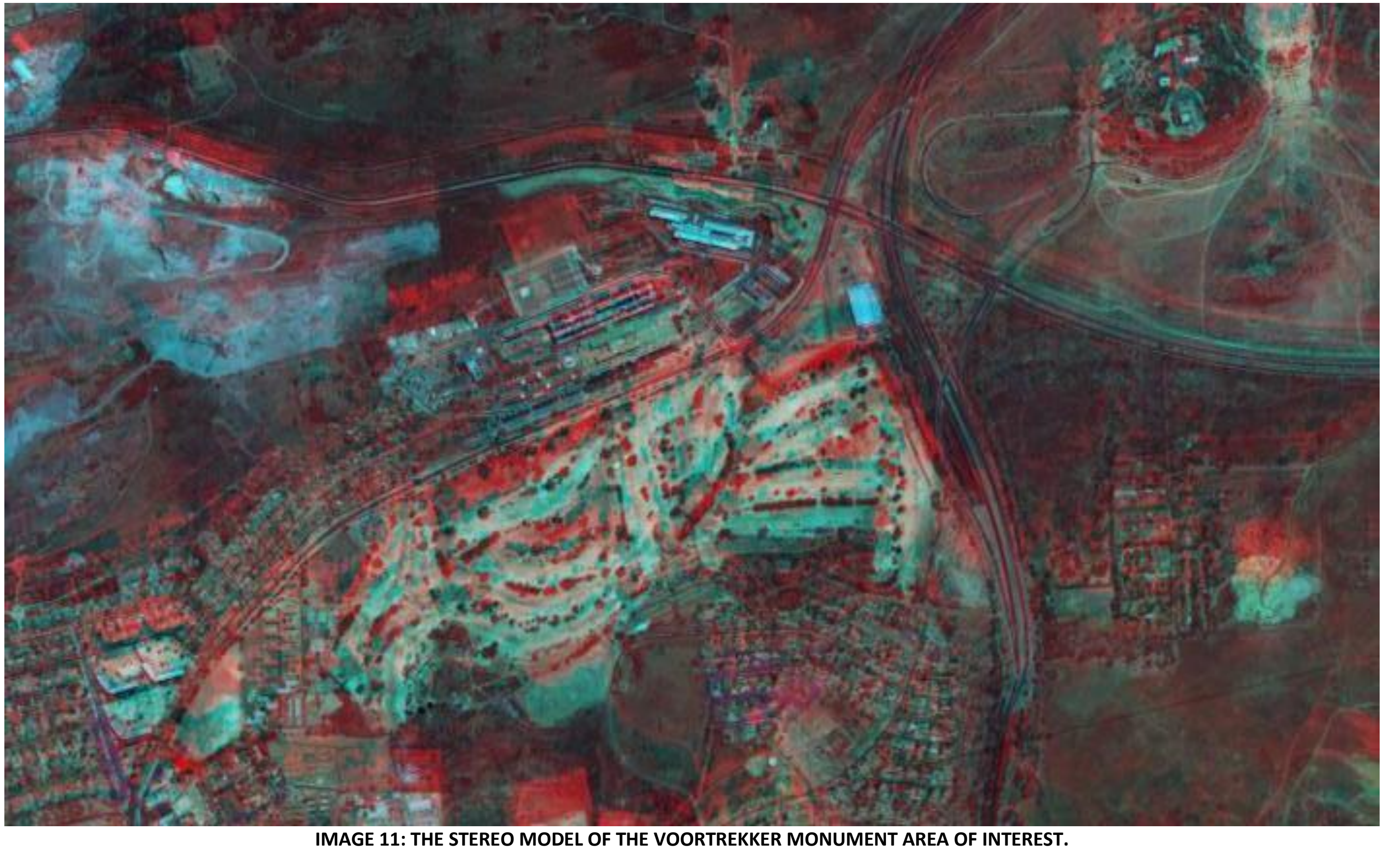

IMAGE 11: THE STEREO MODEL OF THE VOORTREKKER MONUMENT AREA OF INTEREST.

IMAGE 12: AERIAL PHOTO OF THE VOORTREKKER MONUMENT AREA OF INTEREST.

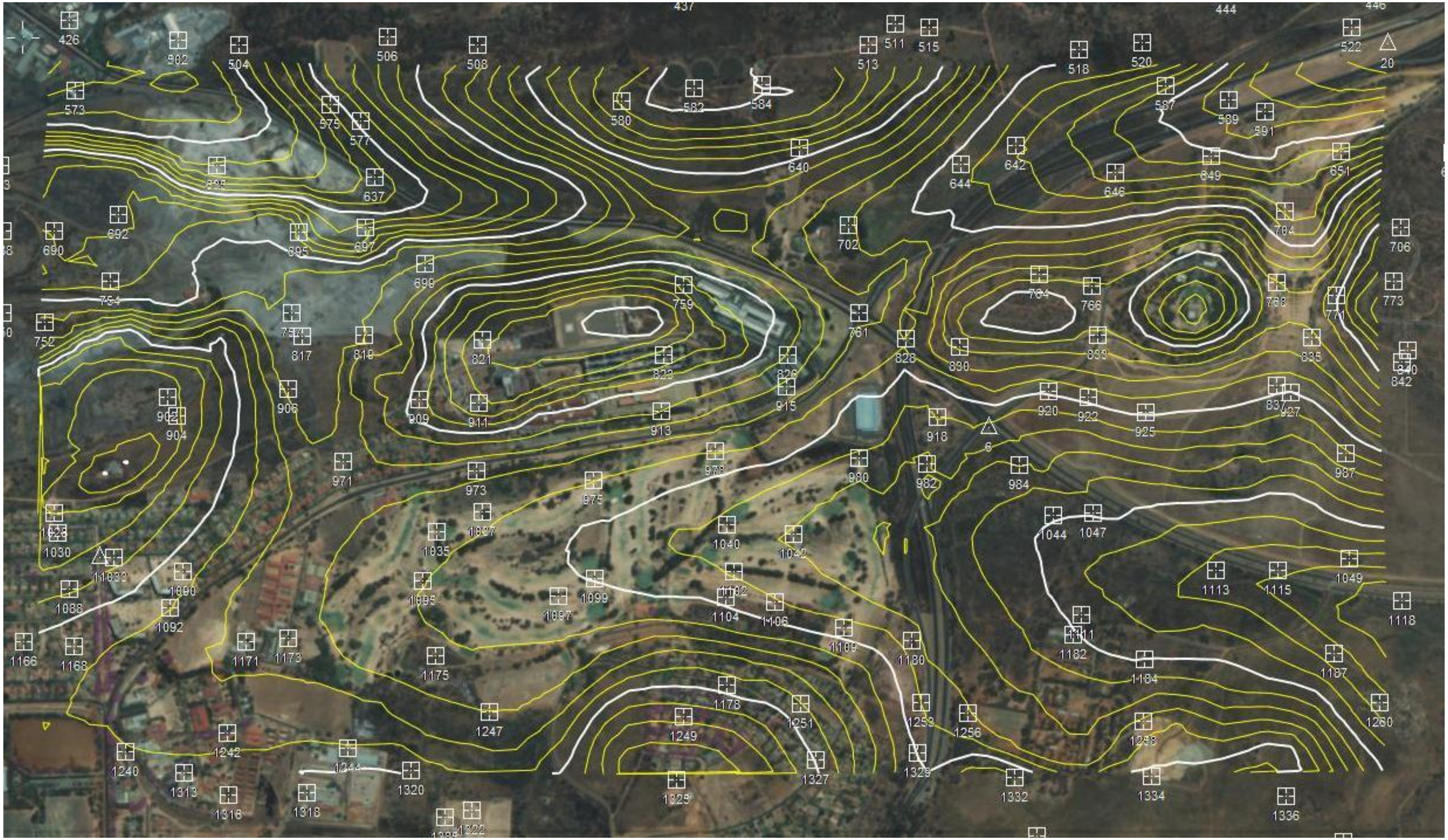

IMAGE 13: THE DIGITAL TERRAIN MODEL AS EXTRACTED WITH THE AATE ALGORITHM. EACH LINE IS A CONTOUR WITH AN INTERVAL OF 5 METERS. CLEARLY VISIBLE IS THE LACK OF OBJECTS INCORPORATED BY THE TERRAIN, SUCH AS TREES AND BUILDINGS. (CHAPTER 7)

IMAGE 14: THE DIGITAL SURFACE MODEL AS EXTRACTED WITH THE EATE ALGORITHM. EACH LINE IS A CONTOUR WITH AN INTERVAL OF 5 METERS. CLEARLY VISIBLE IS THE INCORPORATION OF OBJECTS, SUCH AS TREES AND BUILDINGS, WHEN COMPARED WITH THE DIGITAL TERRAIN MODEL IN THE PREVIOUS FIGURE. HOWEVER, NOT ALL BUILDINGS HAVE BEEN INCORPORATED IN THE SAME LEVEL OF DETAIL, ESPECIALLY BUILDINGS IN SUBURBAN AREAS. THE ACCURACY OF THIS DIGITAL SURFACE MODEL IS TO BE EXAMINED WITH A GENERATION AND QUALITY CONTROL OF THE DIFFERENCE ELEVATION MODEL. (CHAPTER 7)

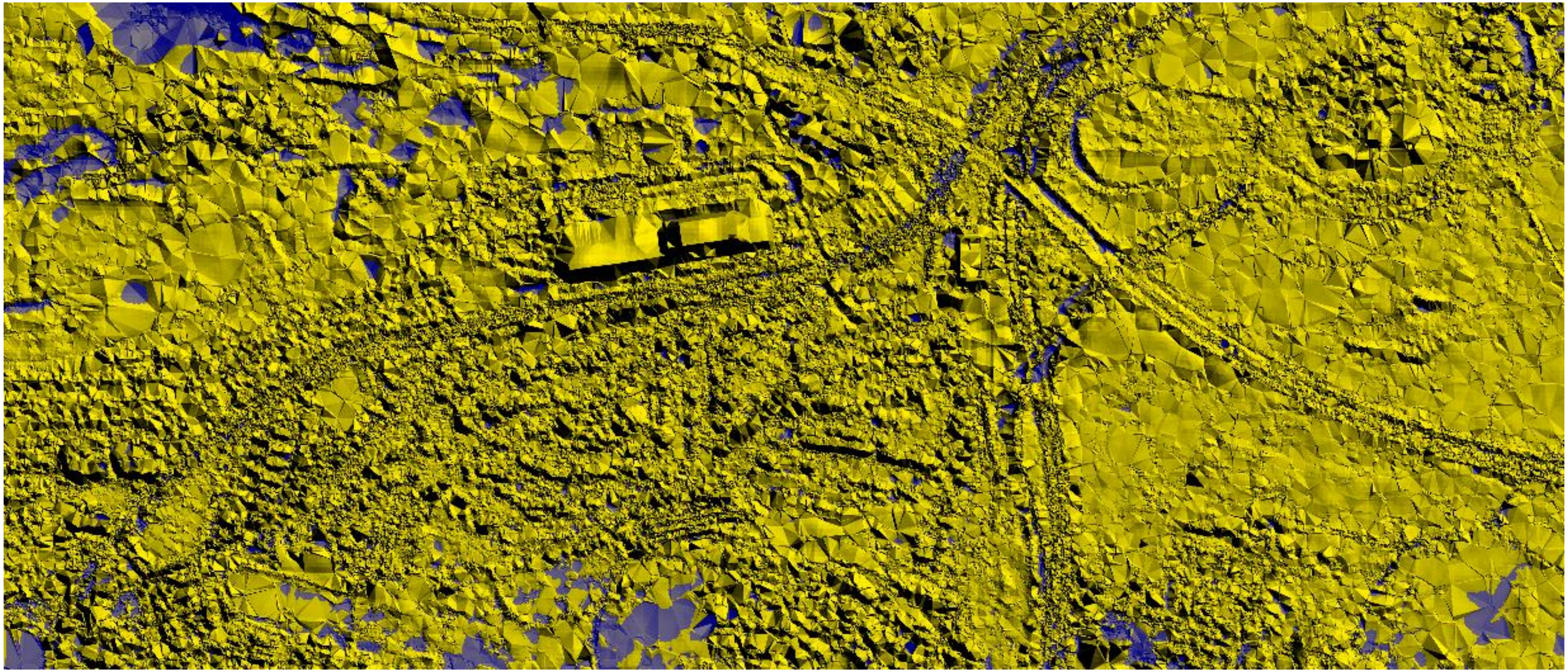

IMAGE 15: THE DIFFERENCE ELEVATION MODEL. BLUE AREAS INDICATE NEGATIVE ELEVATIONS; THIS HAS TO DO WITH THE SEARCH WINDOW DIFFERENCE OF THE DIGITAL TERRAIN MODEL AND DIGITAL SURFACE MODEL EXTRACTION.

ATTACHMENT 2: FORMULAS FOR QUALITY CHECKS

In this attachment, the formula is discussed which is used to calculate the heights of trees. This formula has been devised due to the lack of accurate reference data with which to check the results generated in Chapter 10.

The formula is based on simple trigonometry and the sinus rule.

The measurements have been conducted using an angle measurement device. Measurements were taken using a pendulum attached to it. Measurements have been conducted 3 times per tree. Accuracy of these measurements are not precise, a factor of 1 meter is taken into account. Accurate measurements are not that mandatory, since the vegetation heights are classified in different groups, with levels of 5 meters. This median, the vegetation is either grouped in the 0-5 meter class, 5-10 meter class, 10-15 meter class, 15-20 meter class and 20 meters or higher class. This is due to the limitations of a thematic raster; only a few raster attributes can be used to describe the vegetation heights. If vegetation heights are (for example) grouped into classes of 1 meter, this causes a sharp increase in existing attribute classes for each pixel value. An additional 25 classes have to be added already occupied raster attribute table. Using height classifications was the only reasonable option to avoid this. Also, due to the lack of accurate reference data and measurement systems, a more accurate description of vegetation heights will be irresponsible due to the occurrence of grave errors in either the reference data or measurement method described in this attachment.

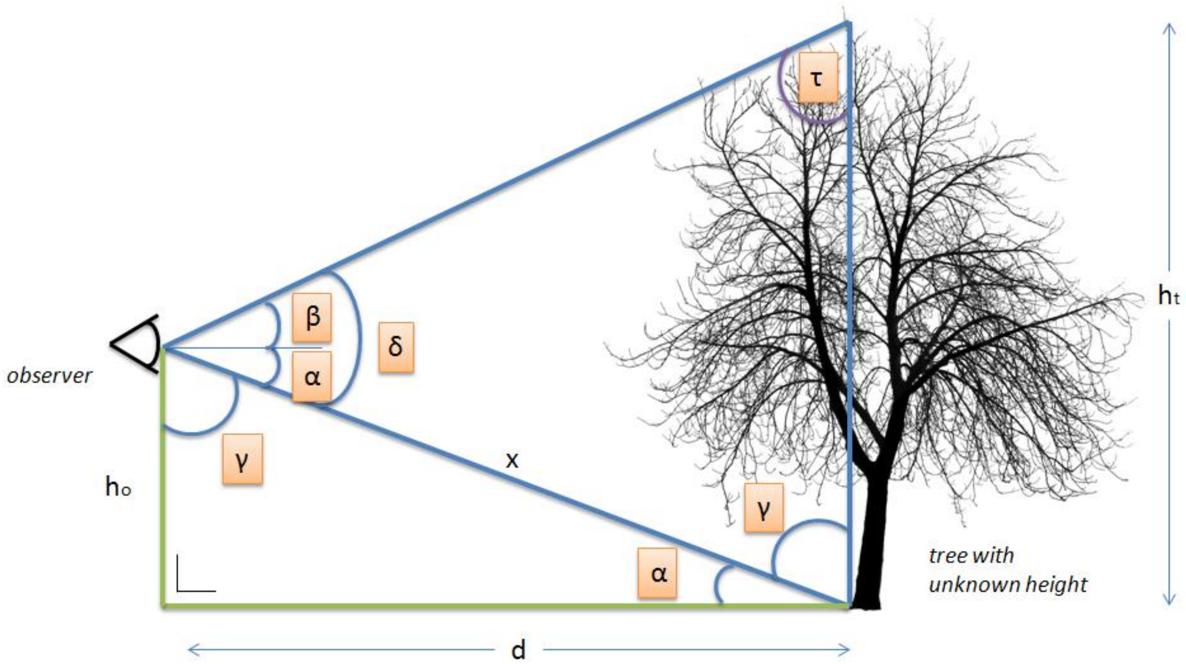

DIAGRAM 1: DIAGRAM OF THE PROPOSED CALCULATION METHOD FOR TREE HEIGHTS.

Values to be measured:

- h_o: Height of observer
- α: Angle between horizontal plane and view to bottom of tree
- β: Angle between horizontal plane and top of tree
- d: horizontal distance between observer and tree

Values to be calculated:

- δ: Total angle between view to bottom and top of tree.
- h_t: Height of tree

Separate formulas:

$$\alpha + \beta = \delta$$

$$\frac{h_o}{\sin(\alpha)} = \frac{d}{\cos(\alpha)} = \mathrm{x}$$

$$90 - \alpha = \gamma$$

$$180 - \delta - \gamma = \tau$$

$$\frac{\sin(\delta * x)}{\sin \tau} = h_t$$

Final formulas:

$$\frac{\sin(\alpha + \beta) * \frac{h_o}{\sin(\alpha)}}{\sin(180 - (\alpha + \beta) - (90 - \alpha))} = h_t$$

or

$$\frac{\sin(\alpha + \beta) * \frac{d}{\cos(\alpha)}}{\sin(180 - (\alpha + \beta) - (90 - \alpha))} = h_t$$

Simplified:

$$h_o \csc(\alpha) \csc(90 - \beta) \sin(\alpha + \beta) = h_t$$

or

$$d \sec(\alpha) \csc(90 - \beta) \sin(\alpha + \beta) = h_t$$

Necessary values to be measured:

- h_o *or* d
- α
- β

ATTACHMENT 3: BACKGROUND OF NDEM AND AERIAL ORTHOPHOTOS

This attachment discusses background information of the National Digital Elevation Model and the digital orthophotos. These reference datasets have been used during this research (as specified in § 3.2).

The National Digital Elevation Model (NDEM) used as reference data for this report, has been generated by the South African Department of Rural Development and Land Reform. Prior to implementing digital photogrammetric methods, profile lines spaced at intervals of 60-80 meters on the orthophoto maps, were run across the model. Breaklines, ridge lines and profiles were captured and mass points from these breaklines were used to determine the DEM. The NDEM consists of heights computed at 200 meter intervals (taken from 1:160.000 photography in stereo models) and 50 meter intervals, where the elevation data is sourced from 1:32.000 analogue photography in stereo models.

The new NDEM will be generated at 25 meter intervals across the entire country. This DEM has been generated by digitizing the 20 meter contours and spotheights from the 1:50.000 topography map separates (analogue layers from topography maps). The mass elevation data (breaklines, ridge lines and profiles) from the NDEM discussed previously will then be added to this new NDEM.

A newer NDEM that is being generated at this time will use the new digital imagery (this imagery is also used for this research). The Department of Rural Development and Land Reform use Post Marked Ground Control Points (PGC) to reference the imagery. This means that, after the Department has received the imagery, points of detail are identified on the imagery and measured in the field. The accuracy of these points is at least 30 centimeters in both horizontal and orthometric directions. The Department uses GPS measurement equipment, using the TrigNet Reference Station Network as base station. The ellipsoidal heights are used to determine orthometric height with a 7-10 centimeter geoid.

For each digital photography job there are two PGC points (for redundancy in case one point has a weak solution) surveyed in each corner and GPS air stations are used in the aerial triangulation. For cross strips, border strips etc. additional PGC's are surveyed to properly reference these additional photographs. The NDEM is used for orthorectification. If no NDEM is available for the area, it will be captured using the photos collected.

rural development
& land reform

Department:
Rural Development and Land Reform
REPUBLIC OF SOUTH AFRICA

This information about the NDEM and aerial photos has been provided by Patrick Vorster, Deputy Director of Survey Services for the National Geospatial Information department of the South African Department of Rural Development and Land Reform.