Investigating the Difference of Digital Elevation Models between *Shuttle Radar Topographic Mission (SRTM) & Photogrammetry Techniques*

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ABSTRACT

This report focuses on the investigation for the differences in SRTM and the Photogrammetry technique applied in remote sensing. SRTM was a mission that launched a space shuttle, and captured data from space. Photogrammetry is a technique where data is captured from photographs taken from an airplane.

In order to compare the two methods, their data had to be standardized by using a programmed called IDL, where the data from the Photogrammetry map was altered and placed into Matrix. Thus the software used for comparison, ENVI could understand both data sets and compare their properties via its functions such as geo-referencing, layer stacking and re-sampling.

The main method used for comparison was to compare heights of areas obtained from SRTM DEM and Photogrammetry DEM with a reference trig beacon. Thus deviations could be obtained from those simulations, and the technique that had a height that deviated more from the trig beacon would prove to be the less efficient method.

Results of the simulation proved that SRTM had acquired more accurate heights, as its height deviated less to the trig beacon when compared with the Photogrammetry height values. In most cases the SRTM over-estimated the height of regions, while Photogrammetry techniques under-estimated the height values. However, there was no large deviation between the two methods, and both methods still have their own advantages that cannot be traded off.

For my family

ACKNOWLEDGEMENTS

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NOMENCLATURE

ASI   - Italian Space Agency

DEM   - Digital Elevation Model

DLR   - German Aerospace Centre

DTED - Digital Terrain Elevation Data

ENVI   - Environment for Visualizing Images (Analysis

    software programme)

NASA - National Aeronautics & Space Administration

NIMA - National Imager and Mapping Agency

SAR   - Synthesis Aperture Radar

ROI   - Region of Interest

RRSG - Remote Radar Sensing Group (UCT)

SRTM - Shuttle Radar Topographic Mission

UTM   - Universal Transverse Mercator

SOI   - Survey of India

Chapter One
Introduction

In the Shuttle Radar topographic mission (SRTM) of 2000, space shuttle image radar was used to create height maps of most of the landmass of the earth. This mission launched a shuttle into space, and acquire data to determine heights of the earth's terrain. This set of data that was obtained was of a very high accuracy. The main objective of this project is to compare the height maps produced by the SRTM with the more traditional method of height maps generation provided by the South African Survey & Mapping. The data of the maps provided by the South African Survey & Mapping are obtained via Aerial photographs. This method entails the acquisition of data from photographs taken from an aeroplane.

1.1 BACKGROUND & REVIEW TO THE STUDY

In order to compare the height maps by performing simulations on the computer, the height maps will be in a form of Digital Elevation Models (DEM). DEM can be generated in different ways. Before radar interferometry, most of the DEM were generated from optical stereo data. In 2000, the SRTM was able to provide a global high quality DEM covering the earth between latitudes 60°N and 57°S [2]. For this particular thesis project the domain interest area is the DEM of Cape Town which is approximately 34.2°S latitude and 18.7°E longitude. The South African Survey and Mapping has DEM generated from aerial photography.

The main approach for this project is to compare the two types of DEM's. The comparison of the two data-sets was enabled by using the analysis tool of the ENVI software. Data-sorting also had to be applied by using the programme IDL to convert data into a Matrix so that all data format would be in a standard form that can be recognized by ENVI. IDL is a programming language similar to Matlab whereas ENVI is a software program built on top of IDL and it consists of different analysing tools for DEM dataset. It has functions such as interpolation and co-registration of maps. After the analysis, it would be possible to work out and display the discrepancies between the two types of DEM's.

1.2 PURPOSE OF STUDY

The purpose of this study is to gain a better understanding about the two methods used to generate heights for maps. By doing a comparative study between the two methods, the pros and cons of each method can be clearly formulated. Thus each method could be further developed for future technologies, where their weaknesses may be developed to become a fully functional method where more accurate data can be obtained, and more accurate maps can be generated for a new and improved method with fewer limitations.

1.3 SCOPE

The scope of this thesis project regards the comparison in accuracy of the two types of DEM data. In order to run this task, essential data is required to be retrieved. This data is retrieved by using specific techniques and technology.

The techniques and technologies are listed below, and shall be discussed in detail throughout the thesis. Briefly, they entail the following:

➢ **Data sorting**

There were two sets of data that were handy, one was a DEM provided by the South Africa Surveys and Mapping, and the other was a SRTM DEM. The two data-sets had contained similar data, however they could not be compared directly by using the software ENVI since the format of the data from Survey's & Mappings could not be recognized by ENVI. The aim of the thesis was to compare the two data-sets, thus it was essential to convert the data from Surveys & Mapping into a matrix by using the IDL programme. This process is data sorting. Since ENVI was the primary programme used to compare the data-sets, this step was an essential start for the development for the rest of the thesis.

➢ **Co-ordination Transformation**

The co-ordinations of the data from Survey and Mapping must be transformed into sets of Latitude and Longitude coordination. This is done so that it can be compared with the SRTM data which is in latitude and longitude.

➢ **Data interpolation and co-registration**

In order to align the two sets of data for comparison, the maps will need to be interpolated and co-registered into the right dimensions. The alignment of these maps makes it more accurate for comparing the two maps. Initially, the two sets of data have different sizes in terms of their dimensions (grid sizes and the size of the map). Thus the process of "Interpolation and

co-registration" converts the dimension to a single dimension, thus making it possible for comparison.

> **Data comparison**

The height of the two data sets is then obtained through the process discussed above. After obtaining the heights, they can be compared and the deviations between the two heights can be calculated. A 'difference' height map can be constructed, showing the height difference between the two maps.

1.4 THE PLAN OF DEVELOPMENT OF THE THESIS

A general description of how the thesis is organized shall be shown is a diagram below. This will allow the reader to gain a better understanding on how the thesis shall develop, as the thesis was developed according to this structure.

INTRODUCTION
↓
LITERATURE REVIEW
↓
METHODOLOGY
↓
RESULTS
↓
CONCLUSION AND RECOMMENDATION
↓
BIBLIOGRAPHY; REFERENCES; APPENDICES
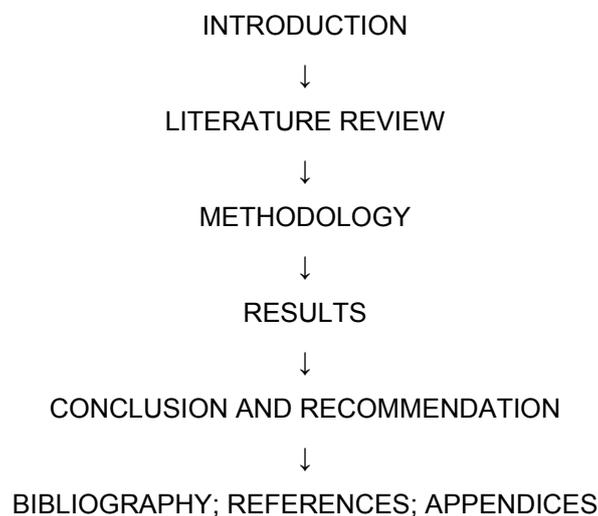
Note that a summary of each section shall be provided after its relevant components have been discussed.

Chapter Two
Literature Review

The focus of this thesis is to highlight on two types of DEM data. These two types of data are known as SRTM and aerial photograph data. This section concentrates on the theoretical aspects on the generation of the two types of DEM's. Another factor that shall also be broadly discussed is the different types of Map projection. Map projection is an important element of this thesis, since it relates to projecting the round earth into a flat map.

The topics shall be introduced accordingly:

> Shuttle Radar Topography Mission (STRM)

> Photogrammetry

> Map Projection

> Datum

> Case Study

2.1 Shuttle Radar Topography Mission (SRTM)5

The SRTM was jointly performed by NASA, the German Aerospace Centre (DLR) and the Italian Space Agency (ASI) [1]. The mission was to launch a space shuttle into space that could take data from the earth to generate DEM maps.
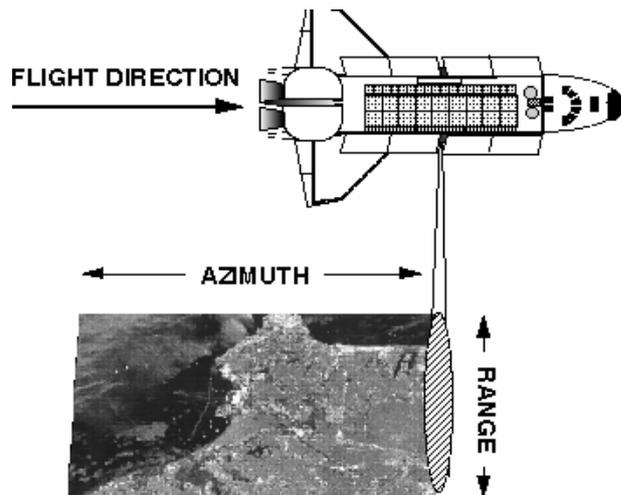
Fig 2.1 *Building up a radar image using the motion of the platform [3]*

The DEM of SRTM covers the earth between latitude 60°N and 57°S [2]. The SRTM-DEM is generated by the synthesis aperture radar (SAR) technique to acquire the data. Further details on SAR will be discussed later. The SRTM mission only took 11 days for data acquisition, as the radar could actively scan the earth's surface independent of darkness or cloud cover. During the data acquisition period, two antenna pairs operating in C- and X-bands was simultaneously illuminating and recording radar signals onboard [2].

"The DEM accuracy requirements are ±16 m absolute and ±6 m relative vertical accuracy. The relative accuracy describes the error in a local 200-km scale while the absolute value stands for the error budget throughout the entire mission. The precision shall be valid for 90% of the data." [2]

After gaining some background on the SAR technique used by SRTM, it is however important to touch on Radar imagery. This will give a better guidance as to how images are taken using the SAR technique.

2.1.1 Radar Imagery

Imaging radar is very similar to a flash camera where the flash camera provides its own light via its flash to illuminate the target area and records on film the light that is reflected back at it through the camera lens [3]. In the case of imaging radar, instead of a flash light, it transmits a pulse (radar signal) at radio wavelength to the target region. The readings taken on the target region are recorded to the computer by using an antenna. The pulse normally covers a small band of frequencies, centre on the frequency selected from the radar. The bandwidth for imaging radar is normally ranging from 10 to 200 MHz [3]. When the pulse reaches the earth surface, the energy in the radar pulse is scattered in all directions, only some of the pulse will be reflected back toward the antenna in a specific polarization (vertical or horizontal). The polarization will not necessarily be the same as that of the transmitted pulse. The reflected pulse will be weaker and are also known as backscatter or echo. The backscatter are converted to digital data and passed to a data recorder for processing. [3]
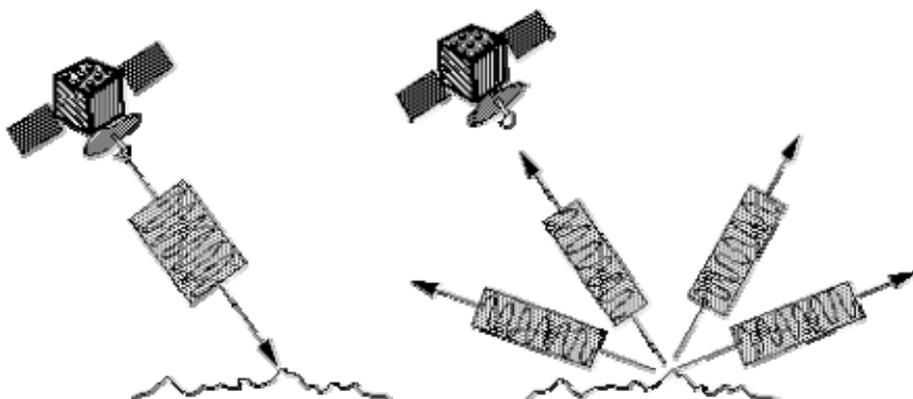
Fig2.2 *Radar transmits a pulse Measures reflected echo (backscatter) [3]*

In terms of the backscatter, when a large amount of backscatter is reflected back to the antenna, the features on the map will be very bright. In contrast, the dark areas on the map represent a low backscatter. The amount of backscatter depends on the texture of the surface area. A rough surface will result in large amount of backscatter. Whereas flatter surfaces result in smaller amounts of backscatter [3].
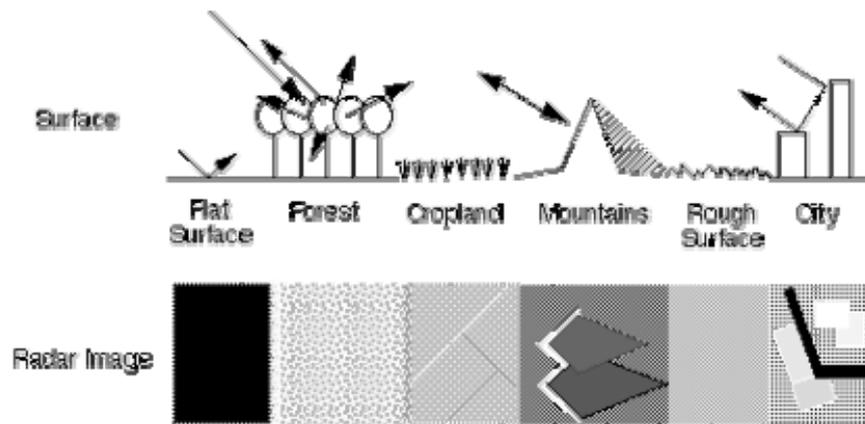
Fig2.3 *Demonstrates how the different surface areas differ in the brightness of their image.[3]*

The length of the imaging radar antenna determines the resolution in the azimuth (along-track) direction of the image [3], therefore the longer the antenna the better the solution will be. It is very common in practice to use SAR (Synthesis Aperture Radar) to create a long antenna by combining signals received by the antenna as it moves along its flight track. Consequently synthetic aperture is constructed by, moving a real aperture or antenna through a series of positions along the flight track.
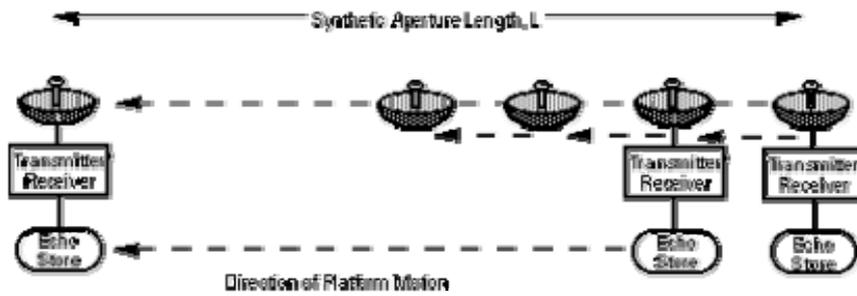
Fig2.4 *Constructing a Synthetic Aperture [3]*

As the radar moves along its track, a pulse is transmitted at each position. The return echoes pass through the receiver and are recorded in an 'echo store', since the radar is moving relative to the ground, the returned echoes are Doppler-shifted [3]. Targets ahead of the aircraft produce a positive doppler offset; targets behind the aircraft produce a negative offset. By comparing the Doppler-shifted frequencies to a reference frequency, the returned signals can be focused to be on a single point. This focusing operation is commonly known as SAR processing. The trick in SAR processing is to correctly match the variation in Doppler frequency for each point in the image: this requires very precise knowledge of the relative motion between the platform and the imaged objects (which is the cause of the Doppler variation in the first place). [3]

2.1.2 Radar Interferometry

Interferometry is the field of physics that deals with the interaction between superimposed wave trains [8]. Radar Interferometry is the term used when two measurements from two radars are combined to give a measurement of the height of the surface.
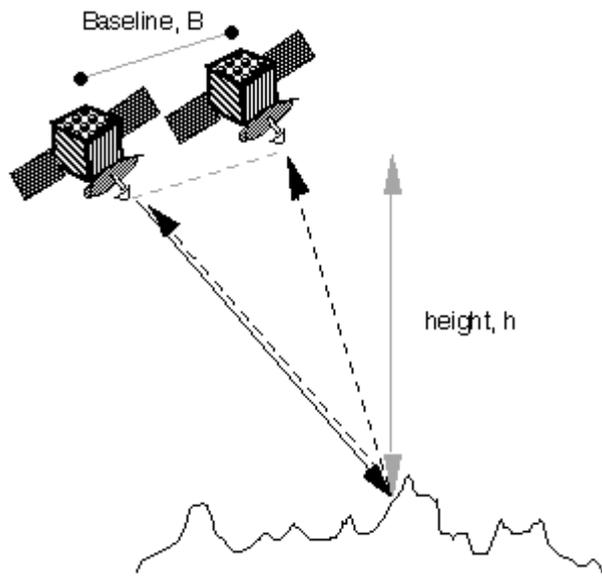
Fig.2.5 *Height measurement with 2 imaging radar [4]*

The two imaging radars are located in different positions, but the separation between them is normally quite small, ranging from a few meters to at most a kilometre [4]. The two imaging radars measure the same target surface at the same time, due to the slight difference in the position of the radar the measurement are differed by a phase shift [4]. The height of the target region is a function of this phase shift. Although the data is being captured from the same plane and at the same time, the data recorded is different due to its positioning on different angles.

The alternate technique is to use one imaging radar at a time. This technique takes two measurements on different orbit tracks in different times (e.g. a day apart). This technique is known as the repeat pass interferometry. The short coming of this technique is that the condition of the target surface can change between passes [4]. For instance, between passes certain conditions such as heavy rain could alter the measurements due to higher water content in the

terrain. In the section below, the method of how the height of a target region is obtained from the phase shift shall be elaborated.

Based on the radar imaging section, the Synthetic Aperture Radar (SAR) emits electromagnetic radiation and then records the strength and time delay of the returning signal to produce images of the ground [5]. The emitted electromagnetic radiation as sine wave can be illustrated as a Sine wave (Fig2.5). SAR images are determined by the amplitude of the reflected sine wave from the target surface - shown in images as grey level intensity values, [5] as shown on the illustrated figure below.
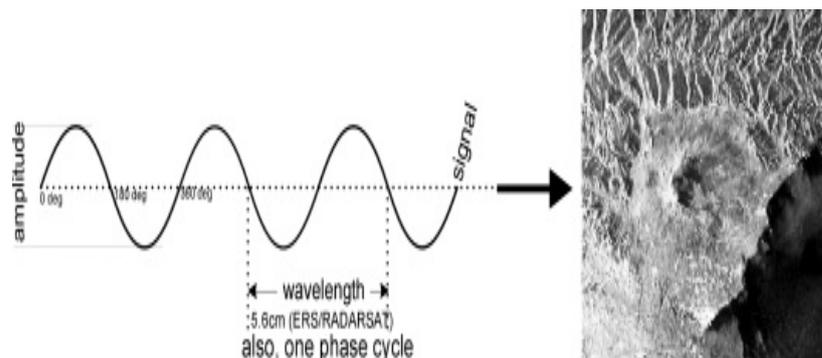
Fig2.6 *Sine wave representing the electromagnetic radiation [5]*

Ideally, it can be considered that when the two imaging radars are located at the exact same position and measures the target surface at the exactly the same time, the reflected sine waves would have the same magnitude and be in phase with each other [5]. It is illustrated on the graph below on how the sine wave starts to repeat itself every 360 degrees. Therefore the phase shift must be less than or equal to 360 degrees.
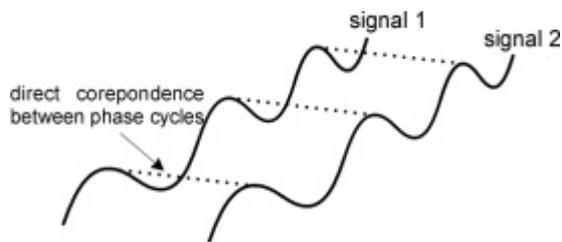
Fig.2.7 Shows the phenomenon when the two signals are perfectly in phase.[5]

In practice, the position of the two imaging radars are never identical, therefore the corresponding difference in the path between the radars and the target surface means there is a difference in phase between the two signals. This is known as phase shift.

The physical path difference can be expressed as a difference in phase angle between the two signals. [5]
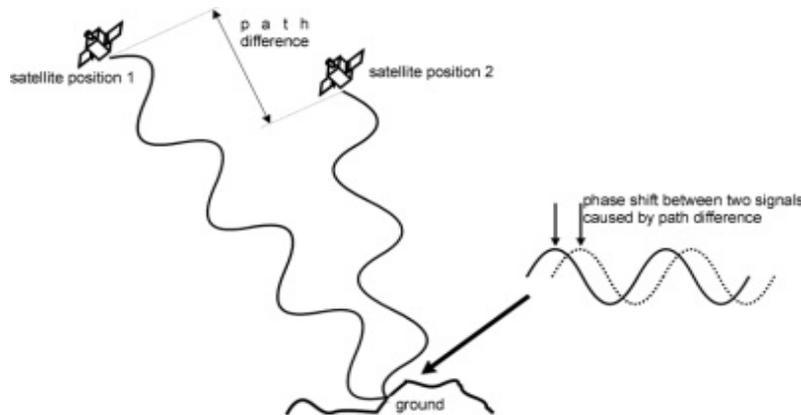
Fig 2.8 Shows the phenomenon when there is a phase shift between two signals

SAR interferometry can generate the phase difference between the two phase signals by subtracting the phase value in one image from that of the other, for the same targeted point on the ground [5]. The phase difference for any point on the ground will take a value ranging from zero to 360 degrees. Neighboring ground points will yield other values of phase difference owing to changes in

the path difference. For a collection of points in a given area of ground, the 360 possible degrees of phase difference can be quantized into 256 grey levels and visualized as a fringe of differing grey level intensities [5].

A fringe is similar to that of contours, where each level refers to a constant different phase. The constant phase difference within a fringe is directly related to constant path difference, which is a function of ground elevation as this affects the distance to the satellite [5]. Therefore, constant path difference can be related to constant elevation. i.e. the phase difference contours within the fringe are indeed height contours. The spacing and shape of fringes depend of many parameters (e.g. wavelength, geometry & topography). The flatter an area is, the more regular spaced the fringes would be (similar to contour lines), and vice versa for steeper terrain.

As mentioned above the phase value is wrapped onto a fixed range from 0 -360 degrees, thus in order to compute the terrain heights and generate a DEM, the fringes must be unwrapped. We can unwrap the fringes by adding the correct multiples of 360 degrees to the phase difference at each pixel.

After reading the above section, it is quite clear on how SRTM captures data. In principle, this method utilizes radar imagery to capture the heights of the target terrain. Through this method the height values are derived from the phase shift of the two imaging radars. The phase shift is consequently quantized into different grey levels on a map. The next section deals with photogrammetry, after understanding the SRTM section, it would be easy to see how they differ.

2.2 PHOTOGRAMMETRY

This method of obtaining data involves pictures taken from an aircraft, and heights are derived from the photos using the concept of image parallex. This allows one to obtain heights of terrain from these aerial photographs. The DEM from the Surveys and Mapping are all photogrammetric measurements. The DEM has height accuracy of approximately 2,5m and a grid spacing of 25m by 25m [6]. In this section the complete operational process of aerial photography shall be discussed in great detail.

The photogrammetric DEM generation method was the first method of remote sensing. Although there are a number of different methods such as satellite and electronic scanners, it is still the most widely used method today. The main reason for this trend is due to a more cost-effective operational cost compared to the SRTM. The most common type of aerial camera is a mapping camera. This type of camera consists of a low distortion lens, a shockproof lens cone and a large magazine used to hold and store the film during and after exposure [6].

In order to accurately perform measurement using aerial photographs, there are two important geometric properties to be considered, namely the angle and the scale. Below, the variables that concerning the measurements are defined, the variables are as follows:

➢ Angle of photographs

➢ Scale of aerial photographs

➢ derivations of heights from aerial photographs

2.2.1. Angle of photographs

The photographs can be classified into different types based on the angle at which an aerial photograph was taken. There are 3 types: vertical, high oblique and low oblique [6]. Vertical photograph was taken with the camera axis pointing vertically downward, Oblique photographs are taken with the axis pointing obliquely downward, and high oblique includes the horizon.
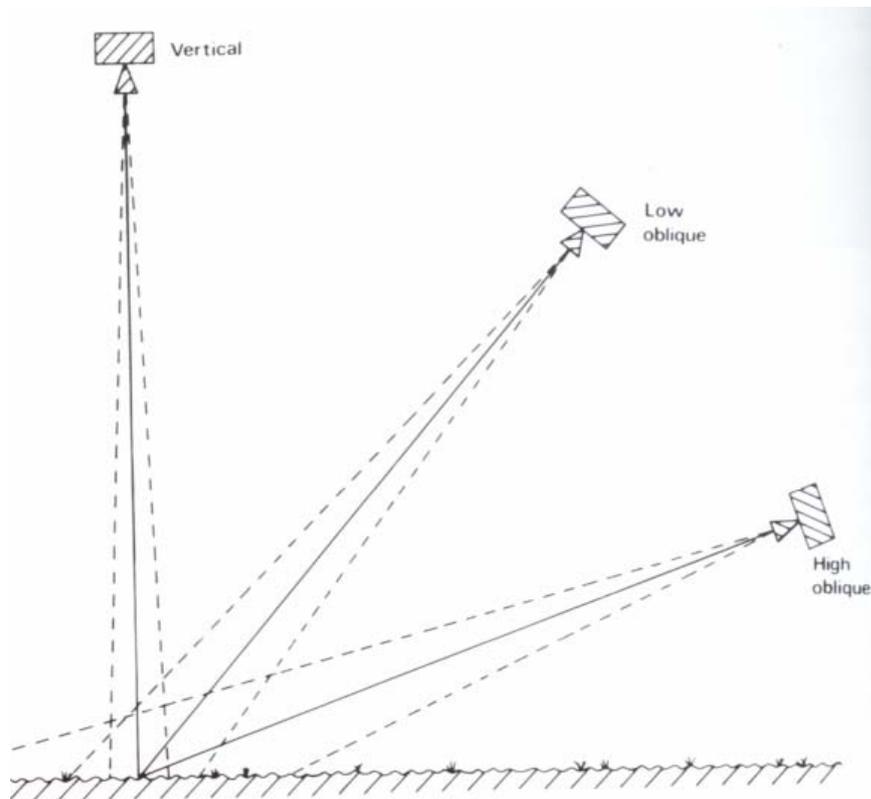
Fig 2.9 Illustration of the different angles at which an aerial photograph can be taken [6]

Vertical aerial photographs are the most common type as its properties is similar to those of a map with approximately constant scale over the whole

photograph. Thus most maps are derived from data obtained from aerial photographs. . Oblique photographs also have their advantages as its coverage areas are many times bigger than that of a vertical aerial photograph, measuring from the same height with the same focal length lens [6].

Vertical aerial photographs are normally taken in sequences along the aircraft's line of flight. In order to enable adjacent points on a run to be viewed three dimensionally the photographed areas are overlapped front ways (forward lap) in the order of 60% to ensure that all the areas are covered, the aerial photographs also overlap sideways (sidelap) by 30% [6]. The overlaps ensure each point on the ground appears at least two times in a block of aerial photographs.
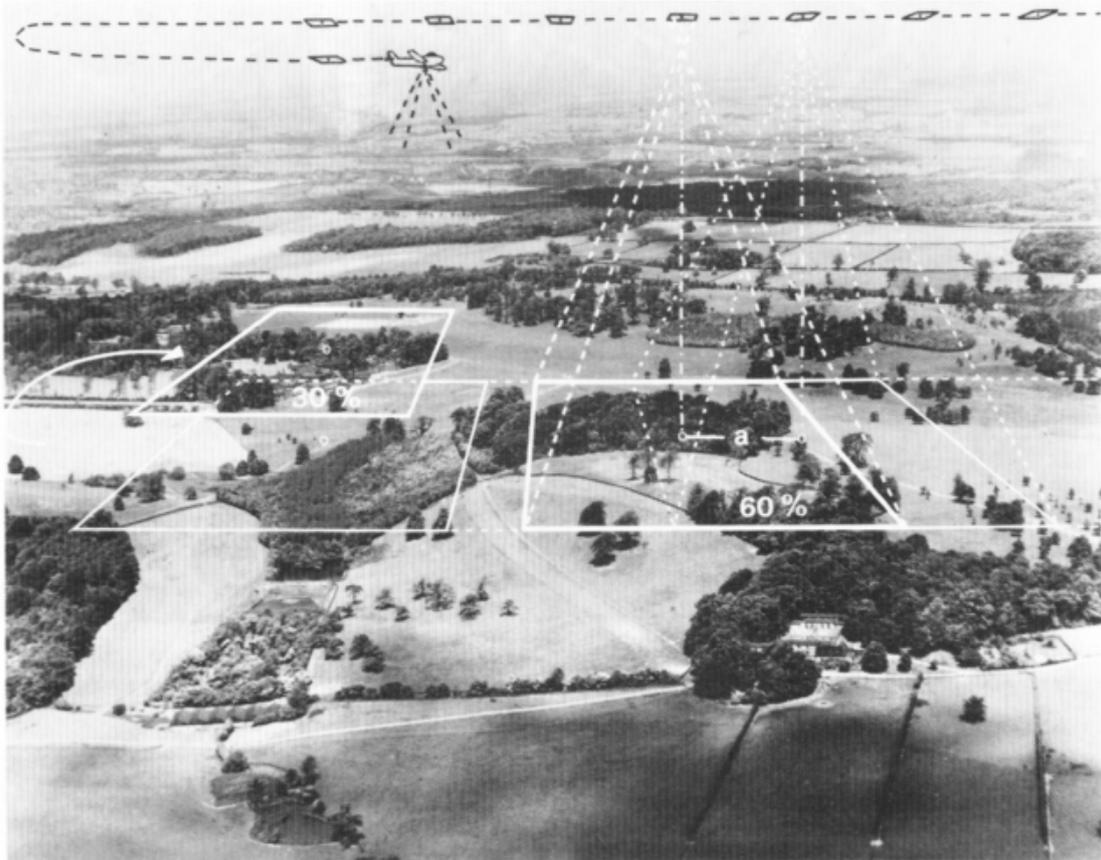
Fig 2.10 Illustration of the over-lapping technique applied in aerial photographs [6]

2.2.2 Scale of aerial photos

Aerial photographs can be produced in different scales depending on the particular application. A large scale aerial photograph (e.g. 1:2000) consists of a detailed and high spatial resolution view of a small area. A small aerial photograph (e.g. 1:50000) will provide a overview with low resolution overview of a large area.

"The scale (S) of an aerial photograph is determined by the focal length (f) of the camera and the vertical height of the lens above the ground. The focal length (f) is the distance between the centre of the camera lens and the film. The vertical height can be calculated by taking the height of the lens above sea level (H) and minus the height of the ground above sea level (h)" [6].

The above mentioned parameters can be related by the formula:

$$S = \frac{f}{H - h}$$
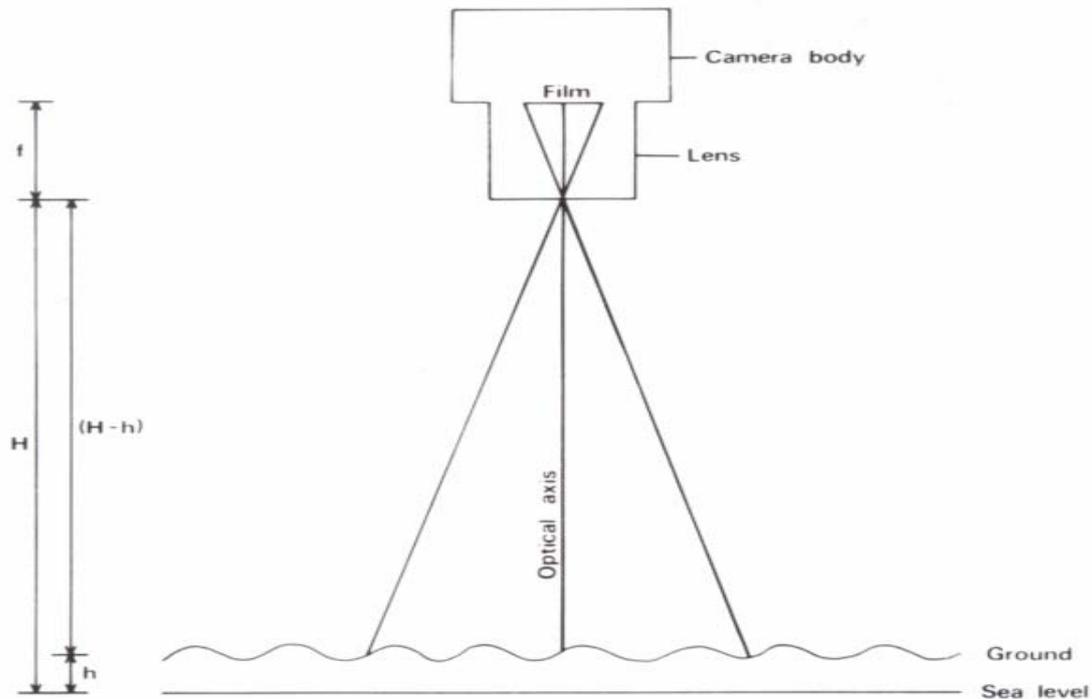
Fig 2.11 *Shows the measurement required for the calculation of scale [6]*

2.2.3 Derivation of height from aerial Photographs

The height from an aerial photograph can be measured using an interpreter.

When two successive aerial photographs are being observed, a tall object (e.g.

tree top) moves more than does a small object (e.g. tree base) [6]. The

interpreter can estimate the height by measuring the amount of movement

between the tree base and tree top on successive aerial photographs. This is

known as the parallax phenomena. The parallax bar is an adjustable metal bar,

on each end of the bar there are two glass plates [6]. On each glass plates

there is a small spot called a 'half mark'. During measurement, the two half

marks must be placed on the top of the same object (tree top) on each

successive photograph, the distance between the two half marks are

measured using a micrometer [6]. This measurement process is repeated by

placing the two half marks on the bottom of the same object (tree base). The difference between the two measurements (tree top and tree base) is the parallax displacement (Δp). The distance between the centers of the two photographs (pa) must also be measured in order to calculate the height [6]. The equation for height calculation is as follows:

$$\Delta h := \frac{\Delta p \cdot (H - h)}{Pa + \Delta p}$$

Δh = height of object in m

Δp = difference in distance between the top and bottom of the feature on the two photographs in mm

Pa = distance between the central points of the photographs

(H-h) = aircraft flying height above the surface of ground
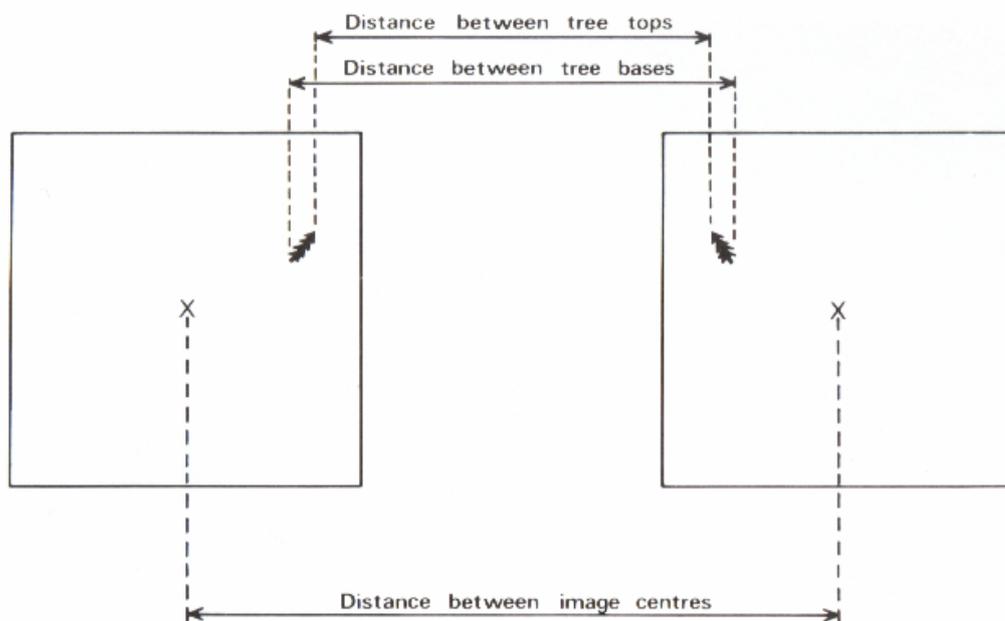
Fig 2.12 Illustration of the measurements required for calculation of height [6]

The process of acquiring height values from aerial photographs have been well described in this section. The variables concerning the accuracy and methodology of this remote sensing technique have been elaborated carefully and in great detail. Thus one already has an idea on how this technique differs from the SRTM technique by the way data has been captured and the difference between their technicalities.

2.3 MAP PROJECTION

Map projection involves projecting the real world on a flat sheet of paper. This is relatively complicated, since the earth is round and has different forms of terrain and water content, however a map is usually a flat rectangular shape. Another factor to consider is that the world is very large, and projecting the earth on a life-size map is ridiculous, thus this is also a task for map projectors. There are different techniques of projection, and each projection has its own coordination system and properties that projects the real shape and distance of the earth onto a flat map. For this thesis three kinds of projection were applied, namely: *Gauss Conform projection, Universal Transverse Mercator (UTM) projection and the ordinary Geographical projection by using latitudes and longitudes.*

2.3.1 Gauss Conform Projection

This is the common type of projection used within South African maps. This projection has one origin for the latitude coordinates by using the equator as

reference and all the odd number of Longitude lines is used as reference of the longitude coordinates (*e.g. Lo19°, Lo21°*) [7]. As all the longitude references are odd numbers, the width of each segment will be 2 degrees. The length of each segment is known as the belt. Each of the 2 degrees belt is flattened with reference to its respective odd Lo. For instance, Lo21° has a flat surface representing the areas between 20° and 22° [7]. The Lo's are also known as the central meridian of its respective zone.

The coordinates are referred to two axes. The Y axis run from west to east and X axis runs from north to south. Hence the coordinates are in the form of southings (X-Axis) and westings (Y-Axis). Southings are measured southwards from the equator and increasing in meters towards the South Pole. Westings are measured from the central meridian of each respective zone and Y is positive west of the meridian and negative east of the meridian [7]. Below is an illustration on how the Southings and Westings are applied in map projection with the Gauss Conform Projection system in Fig 2.11
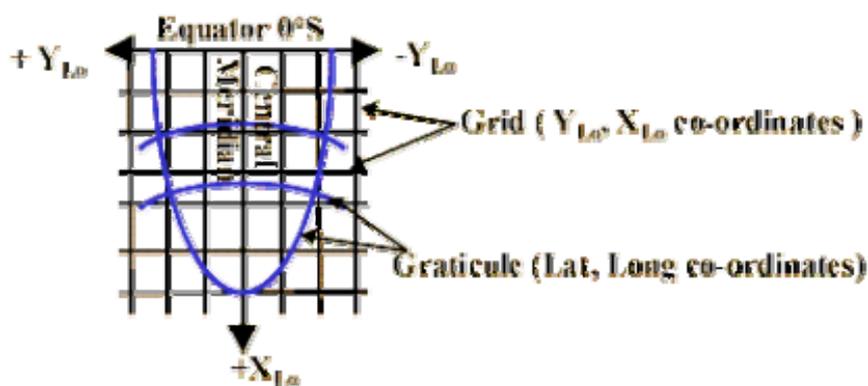
Fig2.13 X & Y Axis of a Gauss Conform Projection system [7]

2.3.2 Universal Transverse Mercator (UTM) Projection

This type of projection was used as a basis for the creation of the Gauss Conform projection. The longitude from -180°west to +180°east is divided into 60 longitudinal zones. Each zone is denoted by number 1 to 60 that are 6 degrees wide apart from a few areas around Norway and Svalbard. The latitude from 80°S to 84°N is divided into 20 latitudinal zones [9]. Each zone is denoted by the letters C to X and letter O has been omitted. Each of the zones is 8 degrees from south to north, except for Zone X where it's 12 degrees south to north. Therefore the combination of a longitudinal zone number and a latitudinal zone letter will comprise a reference area. (E.g. Cape Town is 34H)

In addition to the reference area, the coordination system is in a form of Eastings and Northings.   In terms of Eastings, the origin is given as 500 000m west of the central meridian of each longitudinal zone, therefore at the central meridian the Eastings will be 500000m. For Northings, The origin for the southern hemisphere is defined as 10 000 000m south of the equator and for the northern hemisphere is defined as equator [9].
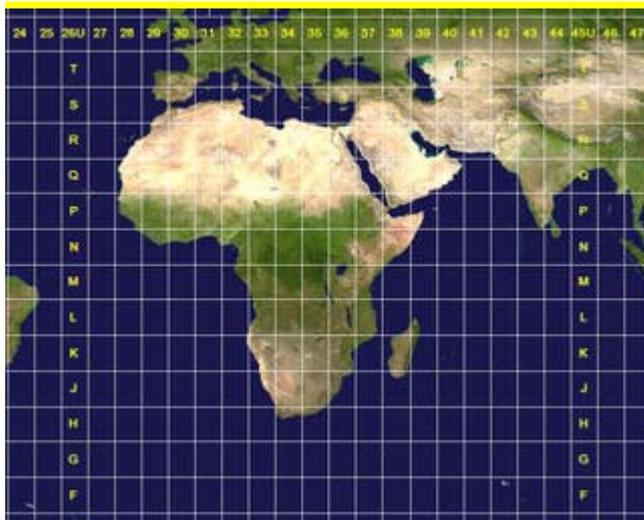
Fig2.14 *Illustration of UTM grid in the African region [13]*

2.3.4 Latitude and Longitude projection

This is the most common type of projection. Greenwich is used as a reference for the longitude and it's known as the central meridian. Longitudes are vertical lines expressed in terms of angular distance in degrees, minutes and seconds from a point west or east of the central meridian [10]. Similarly, the equator is used as a reference for the latitudes. Latitudes are horizontal lines expressed in terms of angular distance in degrees, minutes and seconds from a point north and south of the equator. The longitude and latitudes are divided in minutes and seconds for precision purpose, there are 60 minutes in 1 degree and 60 seconds in 1 minute [10].
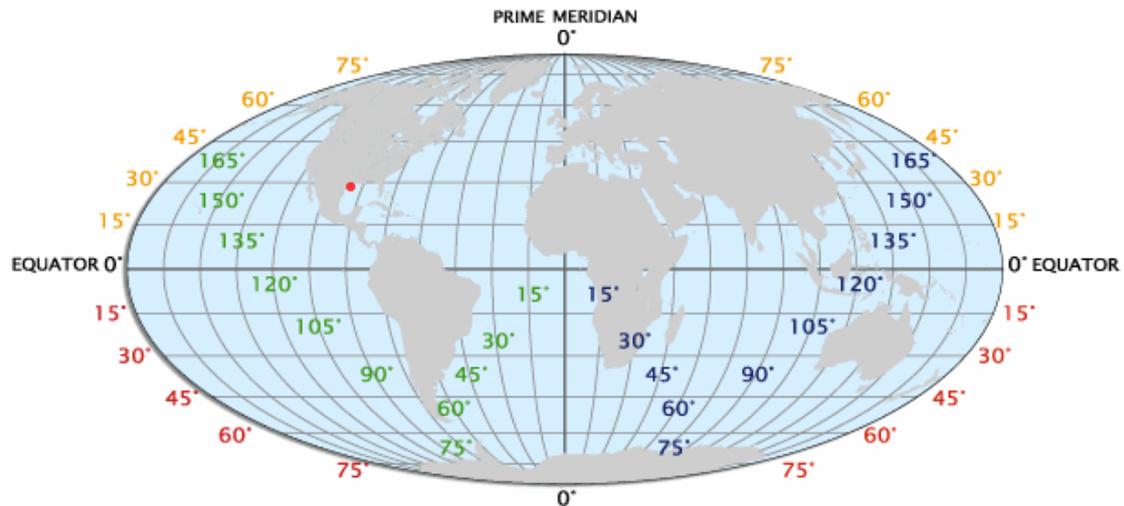
Fig 2.15 *Illustration of latitude and longitude projection [10]*

2.4 DATUM

A datum is a reference point on the earth's surface against which position measurements are made [11]. There are 2 terms which need to be defined before explaining the different types of datum, namely a Geoid and Ellipsoid.

Geoid:

As the surface of the world is of a irregular nature and never perfectly smooth. The geoid is a physical model that approximately coincides with the mean ocean surface. Basically it's a smoother representation of the earth [12].

Ellipsoid:

The ellipsoid is a mathematical surface which often used to approximate the shape of the earth. It is less irregular then the geoid [12].
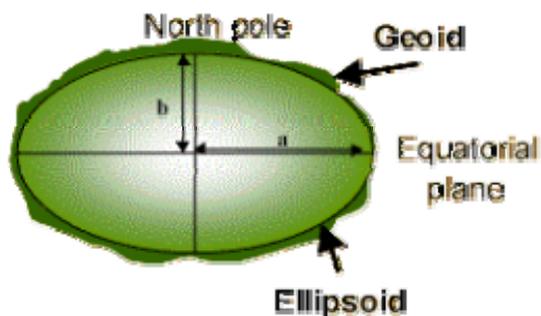
Fig2.16 *Illustration of a Geoid & Ellipsoid [12]*

Different ellipsoids are used as reference for different geodetic datums. However in this Thesis project, it is only important to know about the Cape Datum and the Hartebessthoek94datum.

2.4.1 Cape Datum

The Modified Clarke 1880 is the reference ellipsoid. Before 1999, the Cape datum is the co-ordinate reference system used by South Africa. The initial point of the Cape datum is the Bufflesfontein trigonometrical beacon near Poet Elizabeth where the scale and orientation characteristics were defined by periodic astronomic azimuth and base line measurements [12].

2.4.2 Hartebeesthoek94 datum

The WGS84 is the reference ellipsoid. The initial point of the Hartebeesthoek94 datum is the radio astronomy telescope near Pretoria where the scale and orientation characteristics were defined within the GPS operating environment [12].
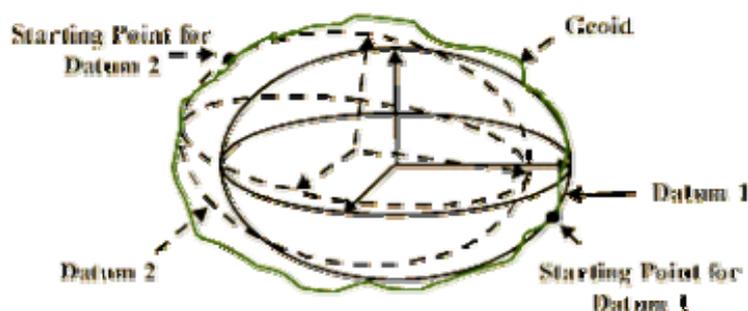
Datum 1 = Cape datum

Datum 2 = Hartebeesthoek94 datum

Fig 2.17 Illustration of the ellipsoids of the two different datums [12]

After reading the above section, the basic ideas about the different types of map projections and datums have been well explained. It should provide a theoretical framework for a better understanding regarding the different types of projections that will be applied in the methodology and results of this thesis project.

2.5 CASE STUDY

In a similar study conducted by Y.S Rao *et al* [14], involving the comparison of DEM's derived from Interferometric Synthetic Aperture Radar (InSAR) and optical stereo (photogrammetry) techniques, the test sites used for the comparison in this project were Koyna and Mumbai in India [14]. At some part of the Koyna area, the very high slopes of hills were present which lead to distortions in both data. The Mumbai area consists of urban settlements, lakes, coastal areas, reserved forrest and hills, thus the comprehensiveness of this area makes it a good test site for the DEM's comparison. The height vales from the Survey of India topomaps (SOI) and GPS were used to compare with the two DEM's.

In terms of the result of the comparison, the optical stereo DEM is more accurate than that of InSAR for the Koyna test site. The InSAR DEM is more accurate than that of the optical stereo for the Mumbai test site [14].

Based on the study's conclusion, it states that the main reason for their difference is due to the different viewing geometry of the two sensor systems [14]. At hilly terrains with slopes facing away from the sensor is good for InSAR techinique, but it's a disadvantage for optical stereo.

According to the study's conclusion above suggests that there is no definite answer on which type of DEM generation technique is better, as the quality of the two DEM's vary depending on the geographic characteristics of the test sites. As the test sites from the case study above are different to the test site for this project, therefore this it is an interesting guideline for this thesis topic.

2.6 SUMMARY

This chapter is based on gaining a greater theoretical understanding on the topic of how the height maps are generated from satellite sensor imagery and aerial photography. This chapter consists if three sections: Shuttle Radar Topographic Mission; Photogrammetry; and Map projection.

The SRTM uses the Synthesis Aperture Radar (SAR) technique to acquire its data. In order to understand such a technique, the concept of radar imagery will be discussed first. The imaging radar transmits a pulse to the target region, the pulse will be scattered in all directions. When the pulse reaches the surface of the earth some of the scattered pulse will be reflected back to the antenna of the shuttle [3]. This is formally known as the backscatter. The backscatter will be converted into digital data and passed into a data recorder on board. SAR is a technique used to synthesis a long antenna by combining the signals received by the antenna as it moves along its flight track. When measuring the height of a point, two imaging radars in different locations on the plane are used. The distance between them is fairly small. The actually height of a point is determined by the phase shift difference between the received pulse from

the two antennas. The amount of phase shift difference (0° to 360°) will be quantized into 256 grey levels, therefore the different intensities of grey level on the maps represents the respective heights of each point [5].

Photogrammety is the most common method of DEM generation due to its cheap cost. This method involves a mapping camera that captures the aerial photos for the target region. The angle from which the photographs are taken and the scale of the photographs are important factors for the accuracy of the measurement. After the photograph is taken, the height of a point can be determined from the photograph by using an interpreter [6].

Map projection involves giving co-ordinations to all locations on the earth. The Data from Survey and Mapping is in Gauss conform projection. This type of projection is only used in South Africa. The Gauss conform projection was derived from Universal Transverse Mercator (UTM). The SRTM data are based on latitude and longitude coordination.

Chapter Three
Methodology

In this thesis project, two different sets of DEM data were used for analysis. Firstly, there is the SRTM data in DTED (Digital Terrain Elevation Data) format, which can be read by using the ENVI programme. The other DEM data consists of aerial photograph data from the South Africa survey & mapping. The DEM from Surveys & Mapping has a grid spacing of 25m x 25m and it is referenced to the WGS84. The 25m DEM also has a height accuracy of approximately 2.5m. The file is in ASCII format (available in the attached CD), thus data manipulation is required, as this format is unrecognizable by ENVI. ENVI is the standard programme used to compare the two data sets, thus it is inevitable that the first step to progress with the research was to apply data manipulation to the data from Surveys and Mapping.

3.1 DATA MANIPULATION

The ASCII file consists of 3 columns:

  i. 1st column = Westings

  ii. 2nd column = Southings

  iii. 3rd column = Height in meters at a particular point.

This data covers the area of Cape Town; therefore Lo19 is the central meridian. The initial data was much unorganized. For instance, the westings values were in descending order for the first 50000 lines then the values starts to ascend and then it starts descending again. Due to this varying characteristic of the data, ultra-edit has been used to edit software for text files, and sorts the file in descending order.
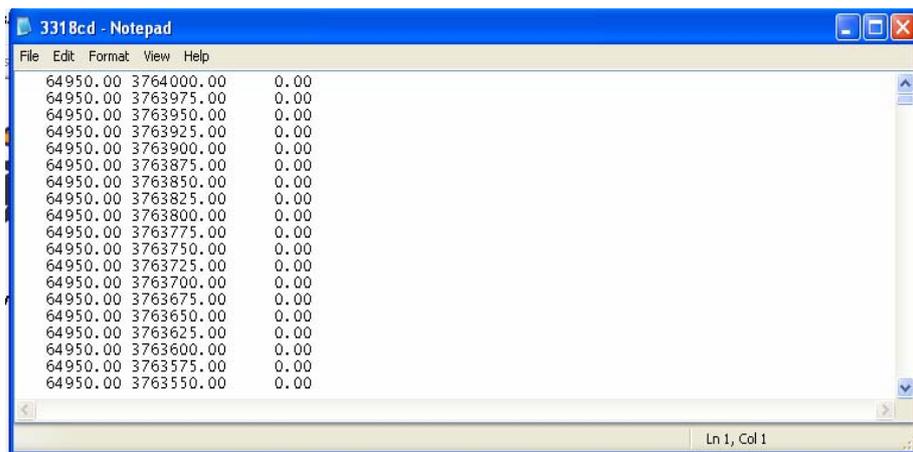
Fig 3.1 shows an illustration of the edited ASCII file

In support for the explanation follows, a simplified version of the actual ASCII file (Fig 3.2) has been created. The numbers stated in the following explanation is referred to Fig 3.2. The westings coordinates are in descending order; therefore the first line for westings coordinates start with the largest westings number (64950). It will stay constant while the southings decrease by 25m per line (from 376400). After the southings have decreased for several hundred of lines, it will return to a larger value (376400). The westings will decrease by 25m (64925) and stay constant while the southings will start decreasing again. This process repeats until the end of the file is reached.
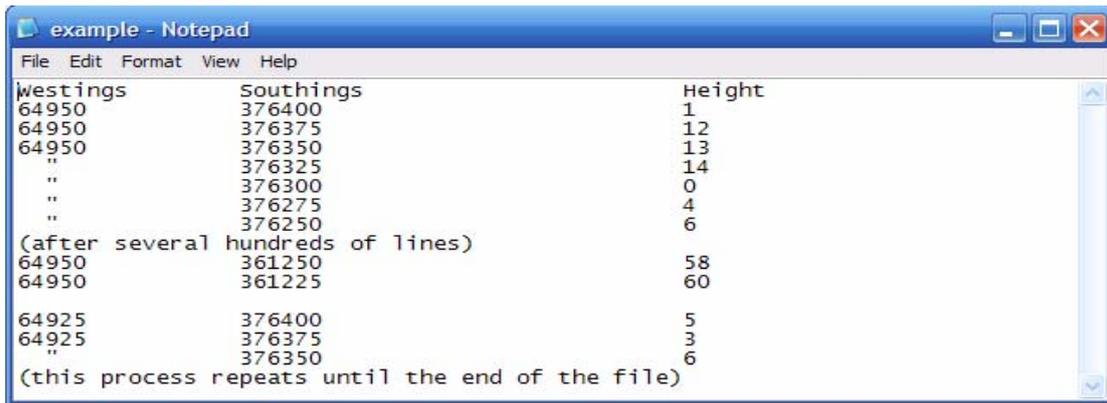
Fig 3.2 Illustration of simplified version of the ASCII file

Hypothetically, imagine the DEM map as a matrix, and the heights of each point are placed into the elements of the matrix. This descending data trend implies that the heights of the map is filled up from the lower left corner (last row of first column of the matrix) up till the upper left corner (first row of first column of the matrix), consequently the data will fill up from the last row of the second column to the first row of the second column of the matrix. This process will repeat until all the height values have been put into the matrix. Below is an illustrated example of the height values being placed into the matrix of the map (Fig. 3.3).

Staring point:
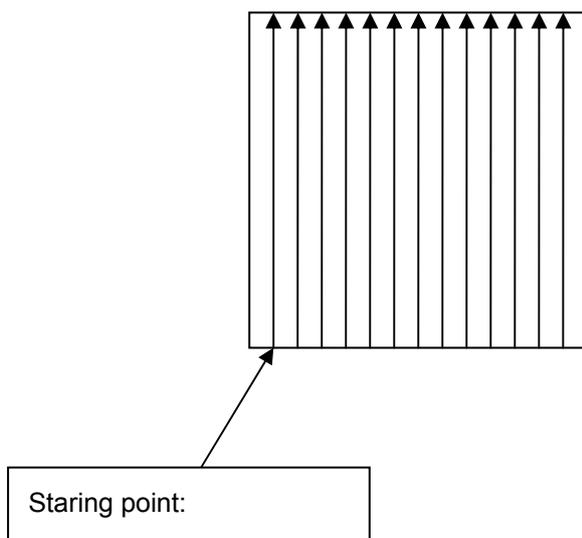
Fig 3.3 Height values are placed into the matrix of the map

After understanding the data structure of the ASCII file, the data needs to be placed in a matrix in IDL. The westings and southings of the map will be used to form the dimension of the matrix. The height can then be inserted into the matrix in IDL. It is more practical in IDL to insert the height into a matrix from the first column to the last column of the same row. The result matrix in IDL is rotated 90 degrees; therefore its orientation will not be the same as that of the map. This orientation problem can be easily corrected using the rotation function in ENVI.
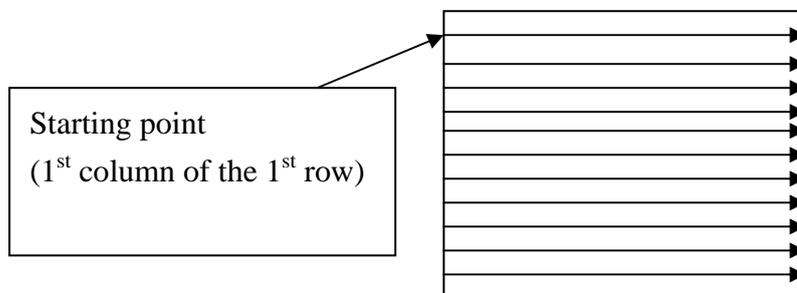
Fig 3.4 Illustration of how height values are placed into matrix in IDL

The previous ASCII file example was a simplified version of the actually ASCII file from the Survey and Mapping. The data structure of the actual ASCII file is not as perfect as that of the example. For different westings values, the range of the southings are also different, therefore some columns of the matrix of the map will contain more rows than others.
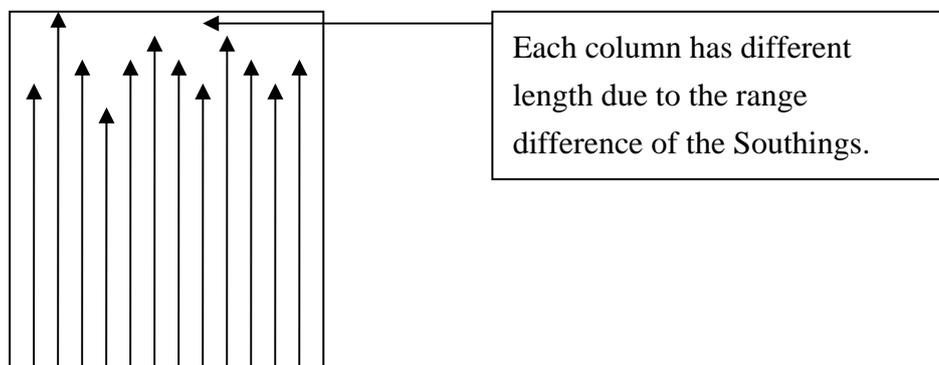
Fig 3.5 Matrix of map generated from ASCII file

The number of columns for the IDL matrix can be found by taking the largest value of southings and subtract it by the smallest value of southings, and divided the answer by 25(the grid size). In this case the number of columns is 1134.

The number of rows for the IDL matrix can be calculated similarly by finding the difference between the largest and smallest values of westings and divide the answer by 25. In this case the number of rows is 763. Therefore it can create an 1134(column) by 763(row) matrix in IDL and place the height into the matrix from the first row of the first column.

For an unidentified basis, there are duplicated points in the ASCII file data where each duplicated point has its own height values. However, the height values vary to a small extent (max 1m), for simplicity it has been programmed to use the first height value that appeared and ignore all the rest.
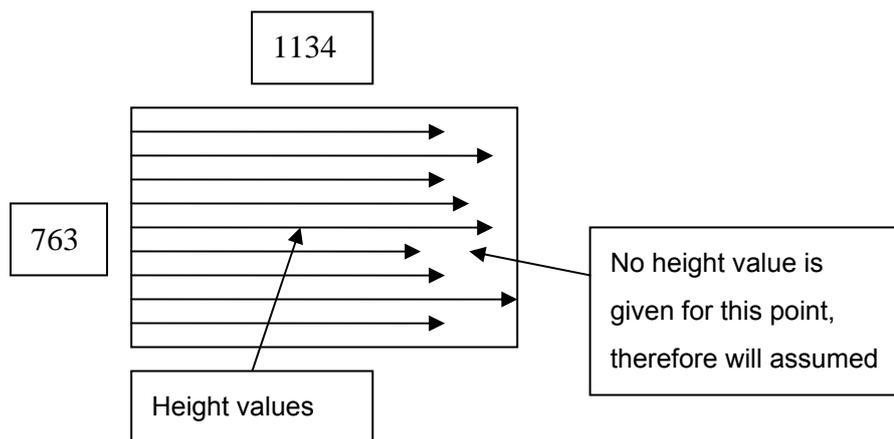
Fig 3.6 *shows the resultant IDL matrix*

The IDL function has been used to write the resultant IDL matrix in TIFF format, therefore the data can now be read by ENVI. The programming code that has been completed for this project in IDL is attached in Appendix A.

3.2 ORIENTATION CORRECTION
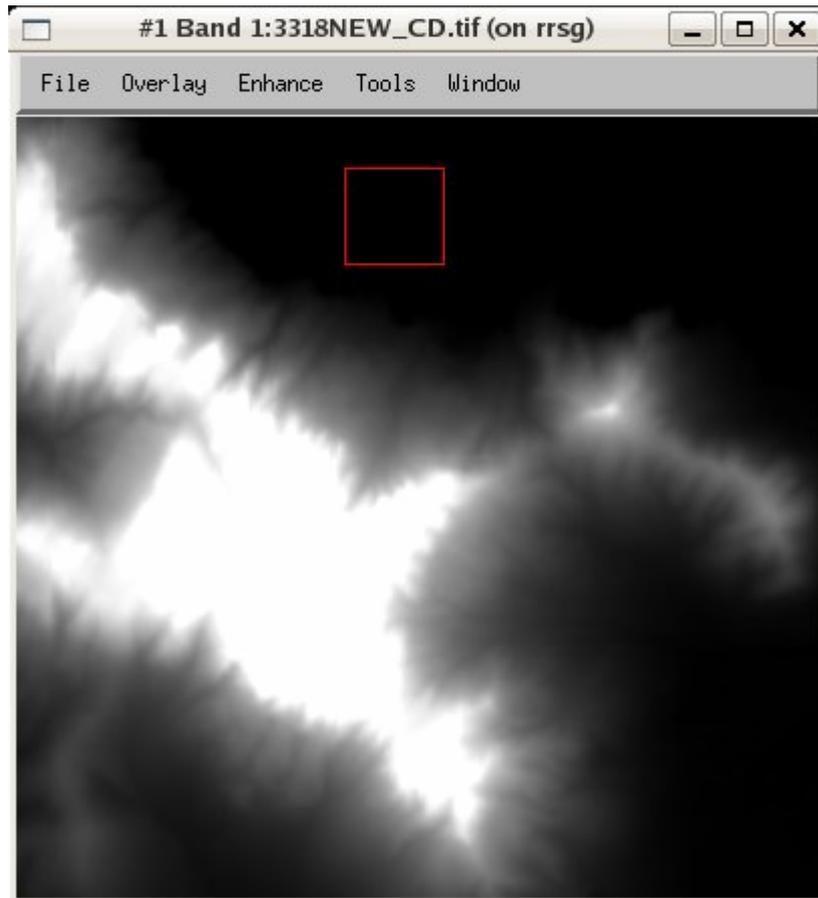
Fig 3.7

Illustration of tiff image

read by ENVI

The above image is data from the Surveys and Mappings. This data is read by ENVI as a tiff image. Thus the above illustration is a tiff image of Table Mountain.

As mentioned earlier in data manipulation, the IDL matrix is rotated by 90 degrees, therefore the tiff image has also been affected and is also rotated by 90 degrees. The rotation functions in ENVI was applied to rotate the tiff image

back to its original position thus shifting the image by 270 degrees in order to correct the orientation of the image. The correct orientation of the image is depicted in Fig 3.8.
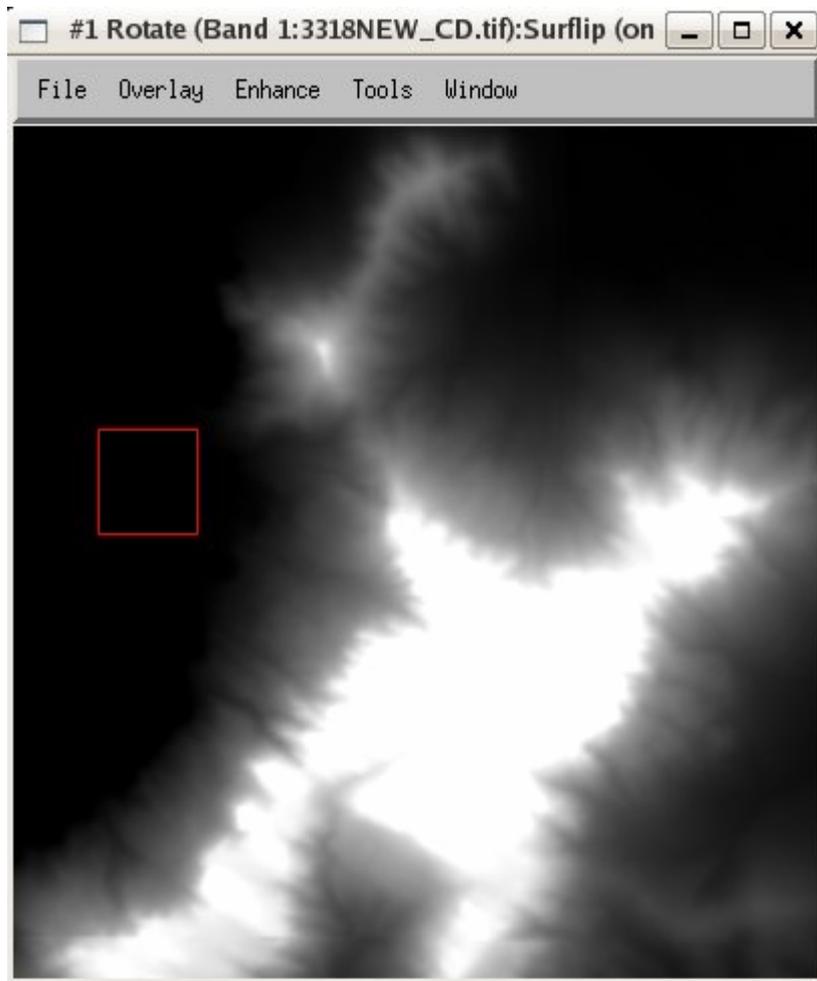
Fig 3.8 *shows the rotated tiff image*

3.3 DATA GEO-REFERENCING

The Aerial Photographic image in ENVI is actually in a form of 1134 by 763 matrix, a specific point in the map will have a coordinate of the form (column, row). This coordination does not represent any point in the real world, therefore it is necessary to reference the points in the map to the real world.

In ENVI, geo-referencing can be done by specifying the latitude and longitude of the 4 corners of the image. Each point in the image is now referenced to the real world in Latitude and Longitude. The 4 corners of the image can be determined by using the largest and smallest values of westings and southings in the ASCII text file. Bear in mind that the values are in Gauss Conform projection, therefore transformation software called Xtran was used to translate the Gauss Conform projection into Latitude and Longitude.

> ➢ The largest and smallest values for westings are: 64950 and 45950.
> ➢ The largest and smallest values for southings are: 3764050 and 3735725.

Using the above values, the 4 corners of the image can be computed.

| (64950, 3735725)		(45900, 3735725)
(64950, 3764050)		(45900, 3764050)
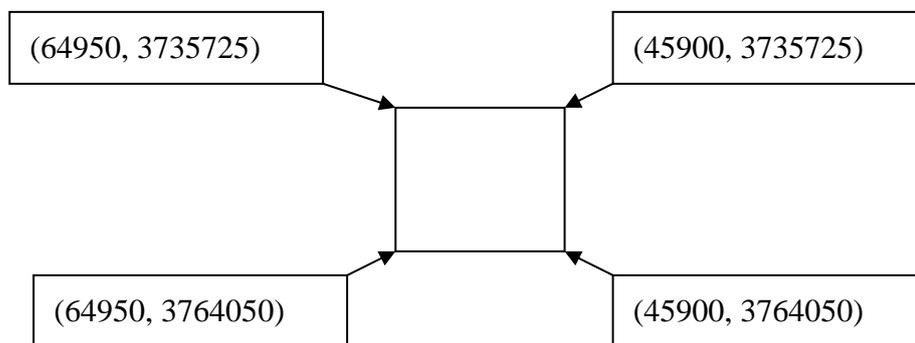
Fig 3.10 *Four corners of the image being computed*

Once the four corners have been computed, the Gauss Conform coordinates can be converted. This is applied by using Xtran, where the coordinate values are converted into Latitude and Longitude. Fig 3.11 illustrates the converted four corners along with their longitudes and latitudes.

| Lat: 33 44' 49.56"
Long: 18 17' 48.03" | | Lat: 33 44' 49.56"
Long: 18 30' 15.67" |
| Lat: 34 00' 5.38"
Long: 18 17' 48.03" | | Lat: 34 00' 5.38"
Long: 18 30' 15.67" |
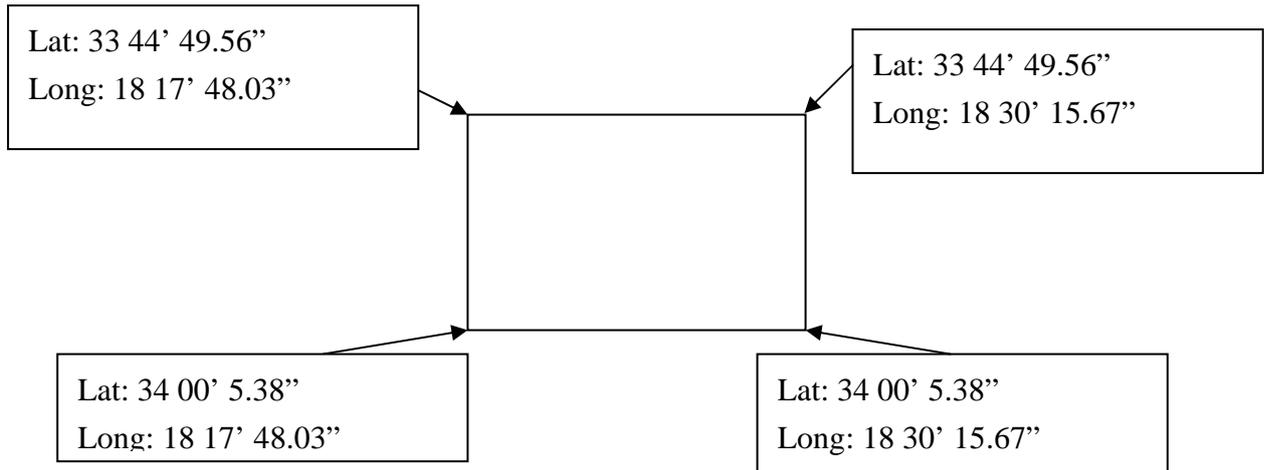
Fig 3.11 *Latitudes and Longitudes of the 4 corners of the image*

3.4 DTED DATA

The SRTM DEM data were obtained from the UCT Remote Radar Sensing Group (RRSG) server. The data is in Digital Terrain Elevation Data (DTED) format. DTED is a standard of digital dataset which is a uniform matrix containing terrain elevation values. DTED were developed by the National Imagery and Mapping Agency (NIMA), it was mainly created for the support of military applications. DTED are classified into different levels depending on their resolutions. Te following table (fig 3.12) gives the basic characteristics of each level [15].

DTED level	Post spacing	Ground Distance	Row x column	Tile size
1	3 sec	~100 m	1200 x 1200	1 x 1 degree
2	1 sec	~ 30m	3600 x 3600	1 x 1 degree
3	0.3333 sec	~ 10m	900 x 900	5 x 5 degree
4	0.1111 sec	~ 3m	540 x 540	1 x 1 minute
5	0.0370 sec	~ 1m	810 x 810	30 x 30 second

Table a: *Table of DTED levels*

The DTED data obtained form RRSG can be directly read in by ENVI. According to the header file created by ENVI, the DTED data is a 900 x 900 matrix, therefore this is a level 3 DTED data which has a grid size of 10m x 10m.

3.5 RESAMPLING OF DATA

As mentioned earlier, DTED data's grid size is 10m and the survey and mapping data grid size is 25m. In order to stack the two data on top of each other, the grid sizes should have a common size, thus it is required that either DTED is down-sampled to 25m or survey and mapping is up-sampled to 10m. The process   Generally up-sampling is a more accurate method. This method is more accurate due to a better resolution since the Surveys and Mapping data is up-sampled from 25m to DTED's 10m. Meaning that data is captured every 10m instead of 25m, thus meaning that all height values within every 10m is shown more accurately.

However, all data from survey and mapping are in a 25m grid format it would require the process of interpolation. Interpolation is a method of constructing new data points from a discrete set of known data points. There are mainly 3 types of interpolation that can be used, they are namely: nearest neighbour interpolation, bilinear interpolation and cubic convolution interpolation. In the research for this particular thesis is cubic convolution interpolation, as it will give the most accurate result.

Once the maps are stacked together, it is possible to start the process of comparison by using ENVI. The process of comparison shall be discussed in the next chapter, Chapter 5 Results, as it will be easier to understand the process

3.6 SUMMARY

The DEM obtained from the Survey and Mappings are in ASCII files, each file consists of 3 columns, they each represent the Westings, Southings and height of a specific point. The DEM from the SRTM are in DTED (Digital Terrain Elevation Data) format, in order to compare the height of the two sets of data, the maps are placed on top of each other by using ENVI. This technique requires perfect alignment of the two maps.

Before 1999, all the data from the Survey and Mapping were in Cape datum and the Modified Clarke 1880 is the reference ellipsoid, the data from the SRTM is in Hartebeesthoek94 datum and the WGS84 is the reference ellipsoid [12]. The data from the Surveys and Mapping are referenced to the WGS84 ellipsoid, thus no transformation is needed as the two dataset are in Hartebeesthoek94 datum. In order for ENVI to read in the ASCII data, the IDL is required to place the height of the map into a matrix and then write the matrix into a tiff format file so that it can be recognized by ENVI.

The next step is a function called layer stacking in ENVI, this process adjusts the two maps so that they are aligned. Before stacking the two images, there

are two problems which need to be solved. Firstly, once ENVI is able to read in the Survey and Mapping data, the four corners of the map need to be geo-referenced, this can be done by specifying the latitude and longitude of the four corners. Secondly, the DTED image has a grid size of 10m and the Survey and Mapping data has a grid size of 25m. In order to compare the height of the two maps at the exact same point, the two maps must have the same grid size. The best solution is to up-sample the Survey and Mapping data to 10m grid by using cubic convolution interpolation. After solving the above two problem, the data will be able to be perfectly align with one another.

Chapter Four
Results

The DEM maps can be perfectly aligned after applying the steps stated in the methodological section. Once these maps have been aligned it is possible to observe that the different maps of the same location more or less resemble each other in terms of the size and shape of the particular terrain.   However it is essential to magnify the map so that areas may be observed from a closer range. This allows a better opportunity for one to learn the difference between the two maps during the process of comparison.

For the comparison to be possible for this thesis, a software was essential to be able to read data and images of maps. This programme is known as ENVI (Environment for visualizing images). The programme was used to open the two maps on the screen directly next to each other (note in mind that these maps have been stacked and aligned so that their properties, such their sizes and different formats of data have been formatted to a standard one).

 ENVI is used to open the two maps on the screen. The link display function is a function in ENVI that links the information of map A with map B. This may sound slightly confusing, however, when a cursor is pointed at a specific point in Map A the latitude and longitude of that point is automatically shown. That certain latitude and longitude of the point in Map A can automatically be

detected and displayed in Map B by using the cursor window. Thus this links the maps congruently making it easy to compare.

4.1 COMPARION WITH TRIG BEACONS

In order to obtain results for the comparison process, four trig beacons were chosen for the initial study:

1. Lion's Head

2. Lion's Rump (Signal Hill)

3. Devil's Peak

4. MacClear's beacon on the highest point of Table Mountain.

These trig beacon data were obtained from Surveys and Mapping in the form of an excel spreadsheet (Excel spreadsheet can be viewed in CD), and they depict accurate indications on the heights of its location. The height deviation between the heights identified in trig beacons and the location's actual height is only by a few centimeters.

The heights of those four trig beacons were used as a reference, when the comparison between the two methods of measuring was being applied. Therefore the height deviations between the two methods and the reference heights could be obtained from this study.

4.1.1 Comparison using Lion's Head as Reference Height

Trig Beacon 1: Lion's Head

Latitude: 33 56' 6.4263"

Longitude: 18 23' 20.7558"

Height: 650m
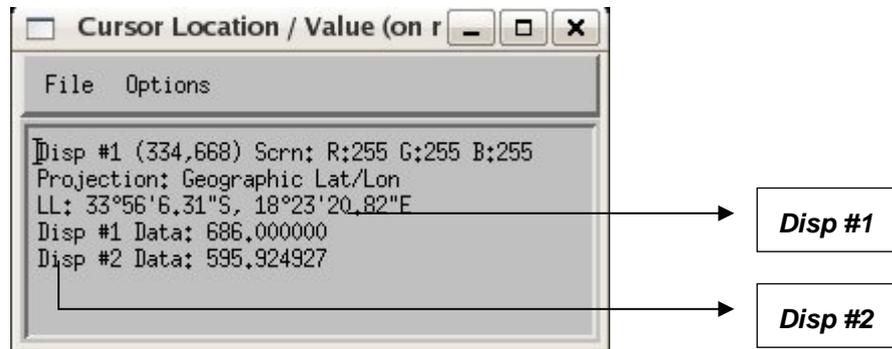
Fig 4.1 is an illustration of a Cursor window pointing at the Lion's Head

The Disp #1 in Fig 4.1 represents the height of the SRTM data and Disp #2 represents the height of the Survey and Mapping data. The latitude and longitude values are not exactly the same as that of the trig beacons, however they are relatively close. This is because the maps only have a grid size of 10m; therefore it is not possible to have a height value at every latitude and longitude point. The properties of the cursor window are the same for all of the other trig beacons used for comparison.

From the display of Fig 4.1, it shows that the SRTM data has a height of 686m and the Survey and Mapping data has a height of 595.924m. As stated above, the reference trig beacon of Lion's Head has a height of 650m. This example showed that SRTM is more accurate relative to the photogrammetry method applied by Surveys and Method.

Below are two illustrations of an X-plot. The X-plot shows the horizontal view of the landscape of the Lion's Peak. The red line in Fig 4.2 represents the direct

location of the reference trig beacon in Lion's Head. The Y-Axis of the diagram in represents the height of the landscape in meters.
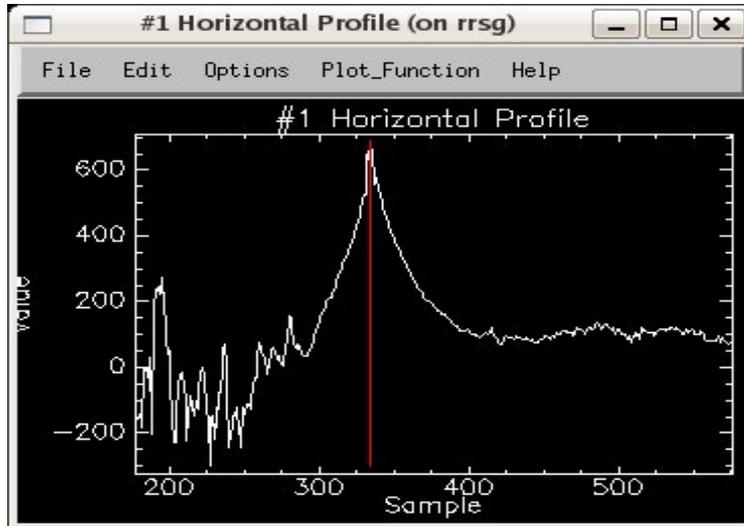

Fig 4.2 x-plot of the SRTM Data at Lion's Head
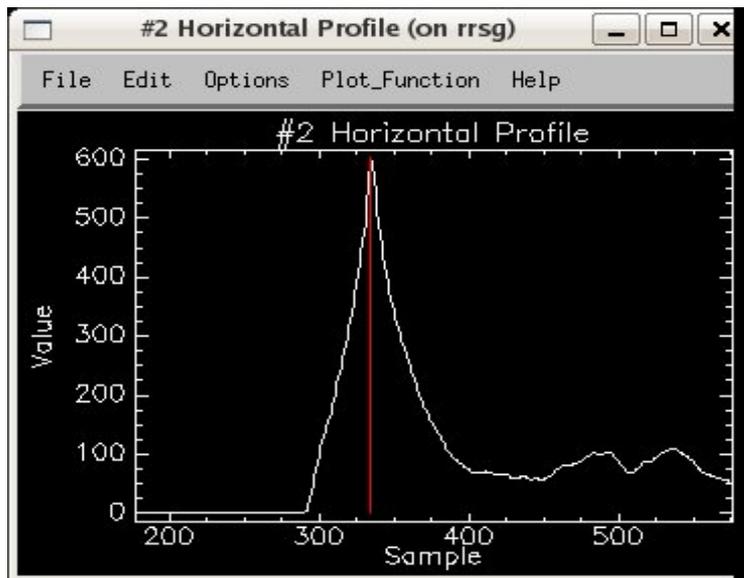
Fig 4.3 x-plot of the Surveys & Mapping data at Lion's Head

From the above illustrations, it shows that the height of the peak of Lion's Head is relatively similar. The deviation between the height differences is barely noticeable, however statistically, the figures show that STRM is closer to the value provided by the reference trig beacon.

4.1.2 Comparison using Lion's Rump as Reference Height

Trig Beacon 2: Lion's Rump

Latitude: 33 55' 1.23"

Longitude: 18 24' 14.08"

Height: 352.3m
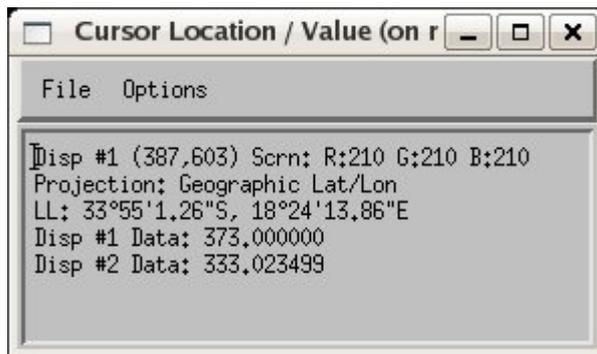
Fig 4.4 Cursor window pointing at the Lion's Rump

The SRTM data has a height of 373m and the Survey and Mapping has a height of 333.02m. In comparison to the height value (352.3m) given by the trig beacon, both data are out by approximately 20m, but Survey and Mapping data is slightly closer.
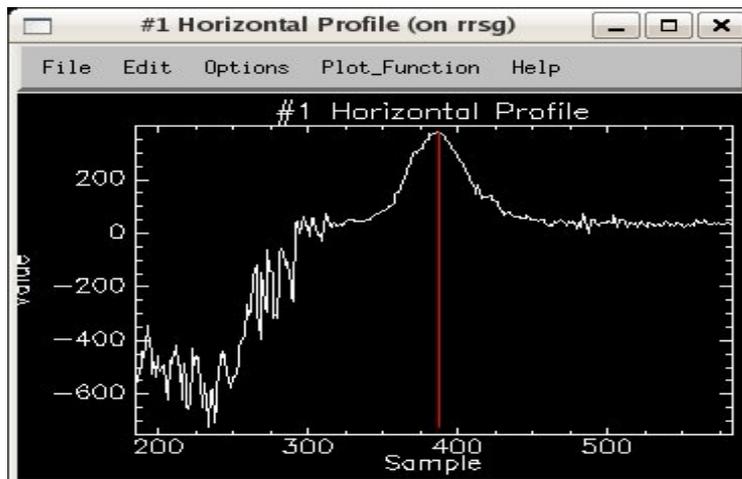

Fig 4.5 is an x-plot of the SRTM data at the Lion's Rump
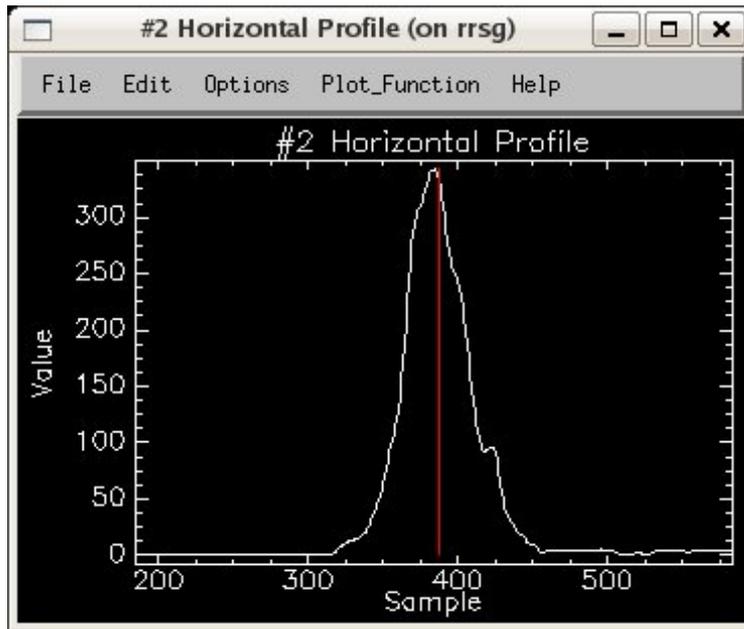
Fig 4.6 is an x-plot of the Surveys & Mapping data at the Lion's Rump

4.1.3 Comparison using Devil's Peak as Reference Height

Trig Beacon 3: Devil's Peak

Latitude: 33 57' 15.35"

Longitude: 18 26' 20.66"

Height: 958.9m
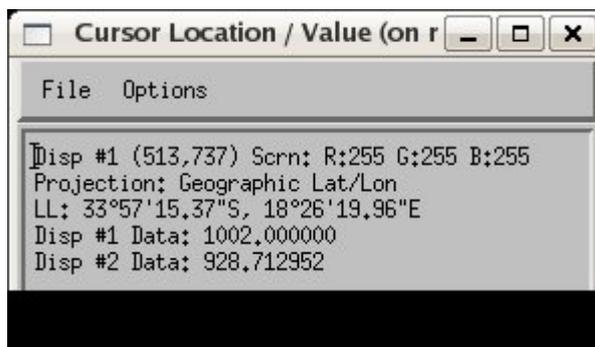
Fig 4.7 is an illustration of a cursor window pointing at the Devil's Peak

From the cursor display, the SRTM data has a height of 1002m and the Survey and Mapping has a height of 928.71m. In comparison to the height value (958.9m) given by the trig beacon, the Survey and Mapping data is slightly closer.
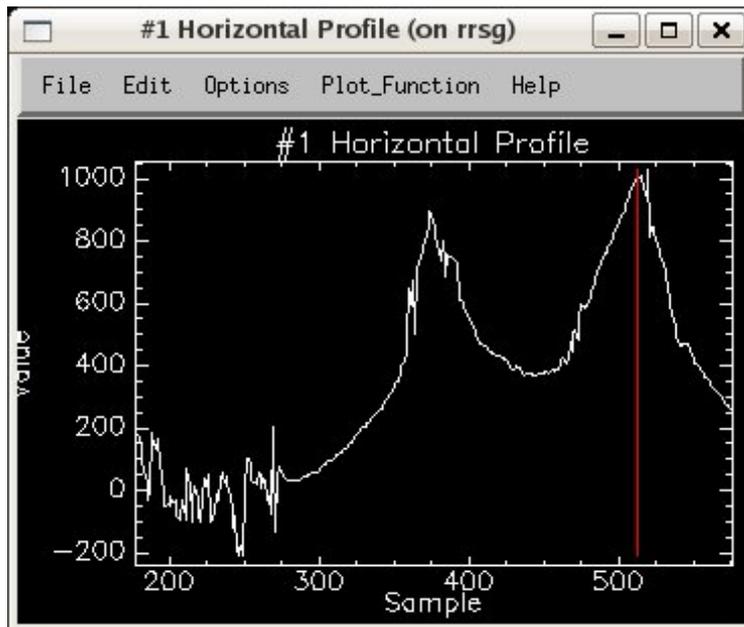


Fig 4.8 is an x-plot of the SRTM data at the Devil's Peak
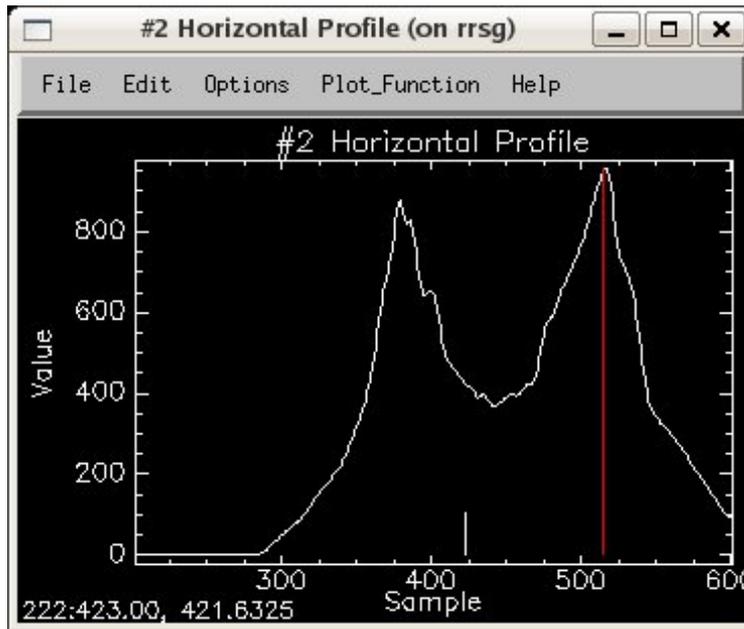
Fig 4.9 is an x-plot of the Surveys & Mapping data at the Devil's Peak

4.1.4 Comparison using MacClear beacon as Reference

Trig beacon 4: MacClear beacon on highest point of Table Mountain

Latitude: 33 58' 0.59"

Longitude: 18 25' 31.99"

Height: 1088m
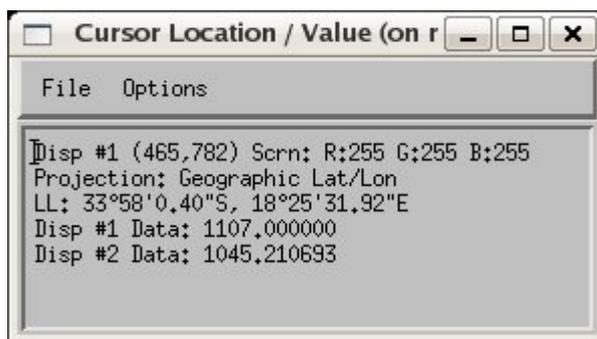
Fig 4.10 is an illustration of a cursor pointing at the MacClear beacon

From the cursor display, the SRTM data has a height of 1107m and the Survey

and Mapping has a height of 1045.21m. In comparison to the height value

(1088m) given by the trig beacon, the SRTM data is closer with a height deviation of 19m.
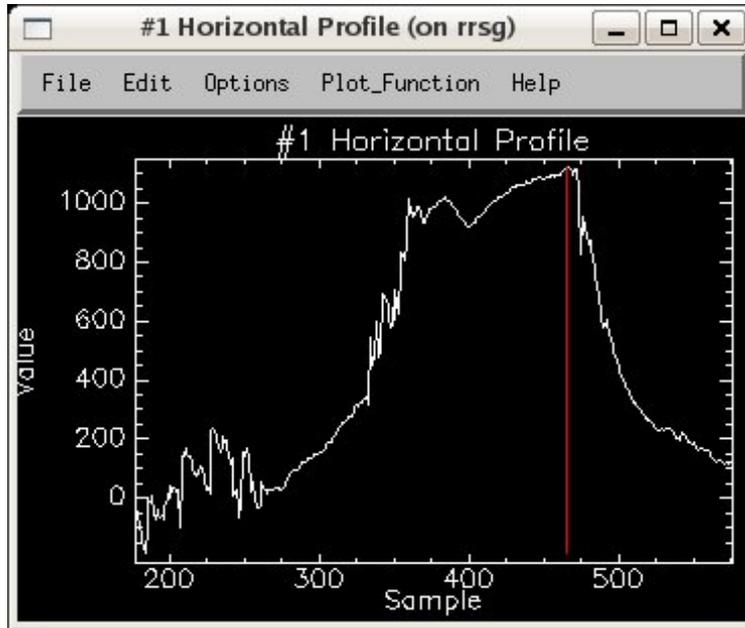
Fig 4.11 *is an x-plot of the SRTM data at the MacClear beacon*
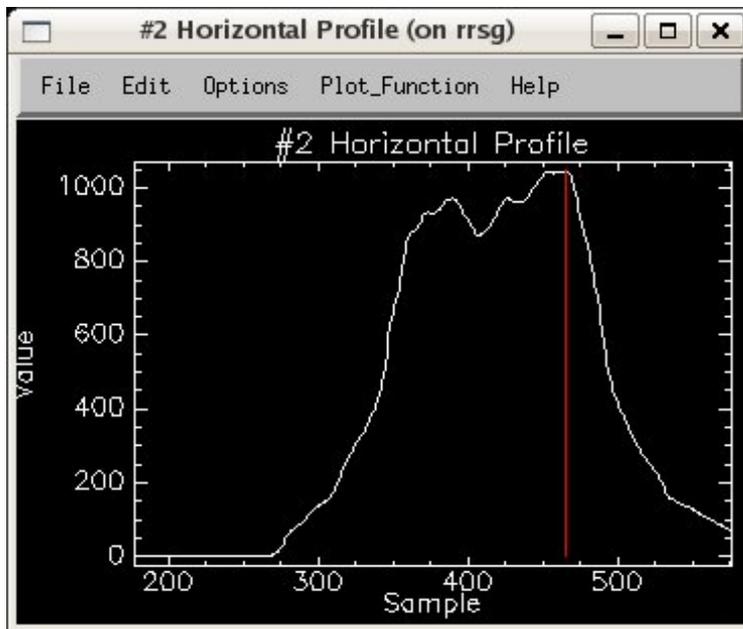
Fig 4.12 *is an x-plot of the Surveys & Mapping data at the MacClear beacon*

4.2 ANALYSIS OF HEIGHT DIFFERENCE

After gaining figures from ENVI on the comparison between the deviations between the DEM data-sets and their reference trig beacons, a table can be constructed to show the findings of this simulation.

TRIG Beacon	Height of reference Beacon	STRM's Height	Surveys & Mapping Height
Lion's Head beacon	650m	686m	595.92m
Lion's Rump beacon	352.3m	373m	333.02m
Devil's Peak beacon	958.9m	1002m	928.71m
McClears beacon	1088m	1107m	1045.21m

Table b: *Heights of two methods compared to reference beacon.*

In order to get an idea of which method is more accurate, it can be determined by calculation of the average difference of the two methods. The height difference between each tirg beacons and that of the specific method is first calculated. Adding the difference at each trig beacon and then divided by 4 will give the average difference.

SRTM *average difference:*

$$\frac{(686-650)+(373-352.3)+(1002-958.9)+(1107-1088)}{4}$$

= 29.7m

Surveys & Mapping *average difference:*

$$\frac{(650-595.92)+(352.3-333.2)+(958.9-928.71)+(1088-1045.21)}{4}$$

= 36.54m

The above results show that the SRTM data is more accurate as its average

difference is less than that of the Surveys and Mapping.

4.3 SEA LEVEL

In some of the x-plots from the SRTM data in the above section, the height

vales become negative(less than 0) at certain points. Therefore a coastal area

in Cape Town has been chosen in order to have an investigation on the

difference in height in the sea.
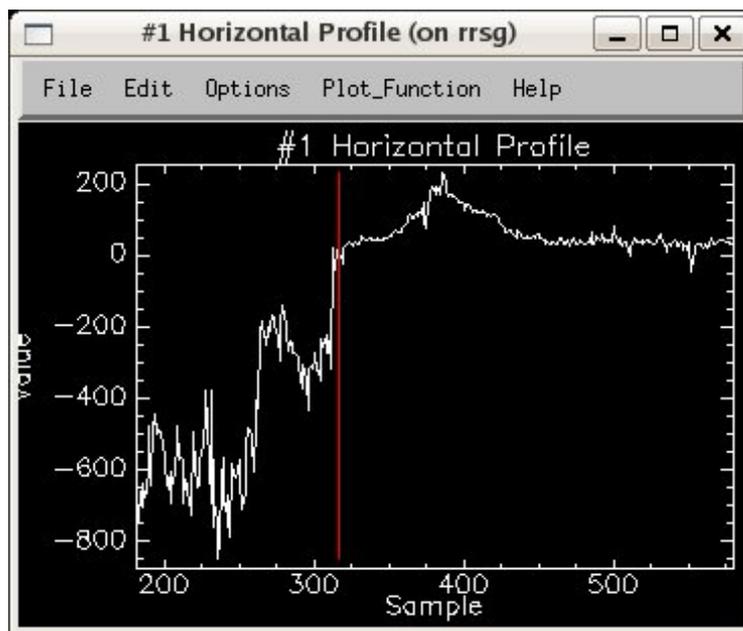
Fig 4.13 is an x-plot of the coastal area in the SRTM data
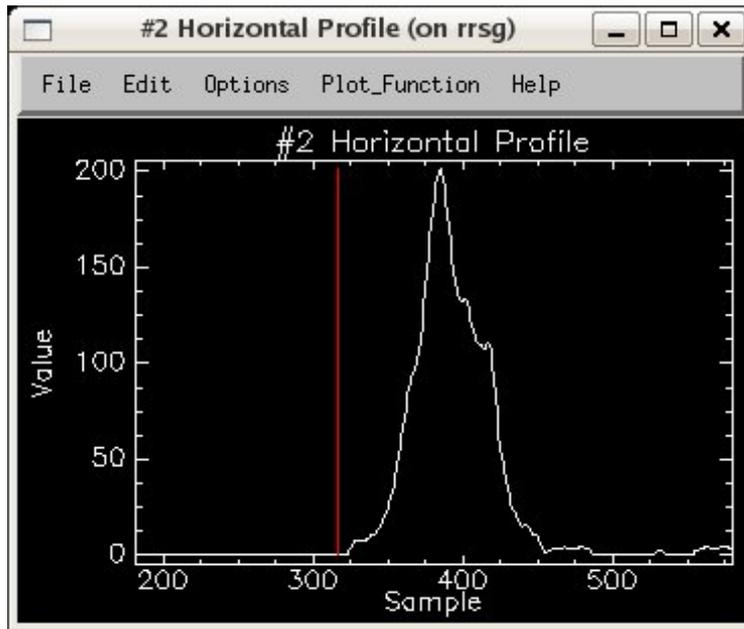
Fig 4.14 is an x-plot of the coastal area in the Surveys & Mapping data

From the above two plots, it shows that the end of shore is at around 320 samples, the shape the land beyond 320 samples are significantly different. This is because the SRTM data has negative height values in the sea area and height values in the sea areas of the Surveys & Mappings data are all zeros,

4.4 STATICTICS ON TABLE MOUNTAIN PLATEAU

The front part of the Table Mountain is relatively flat hence it's where its name came from. This front section of the Table Mountain is known as the plateau. It will be interesting to see how flat the plateaus of the two maps are. Because only the front part of the Table Mountain (plateau) is needed to compute the statistic calculation, therefore it is required to highlight this interested area to form a region of interest (ROI). The two maps will be linked when highlighting the ROI, therefore the ROI of the two maps will be exactly the same.
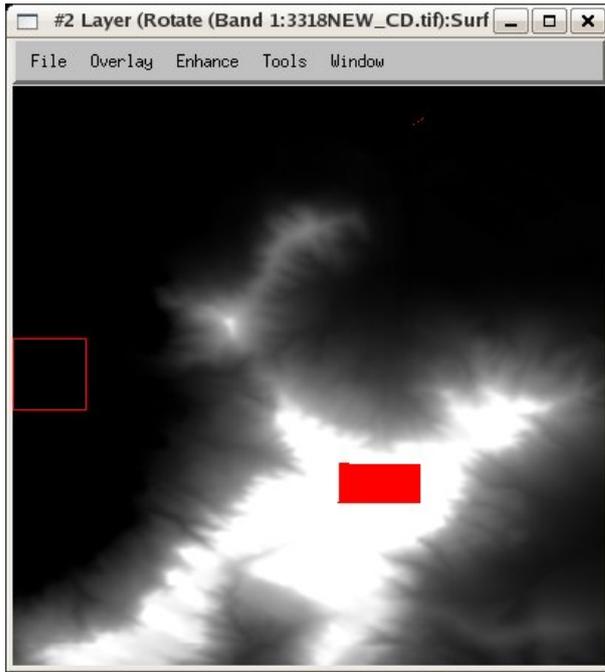
Fig 4.15 *ROI of the map from the Surveys and Mapping*
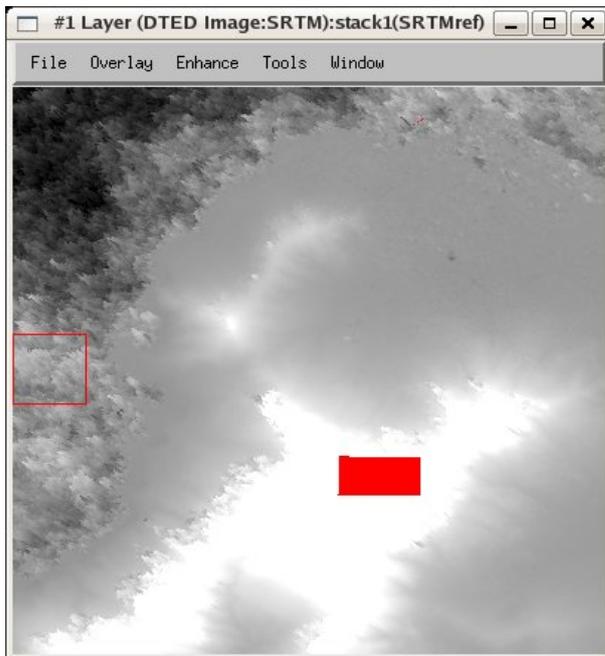
Fig 4.16 *ROI of the map from the SRTM*

After the ROI has been specified, the statistic report function in ENVI can be used.
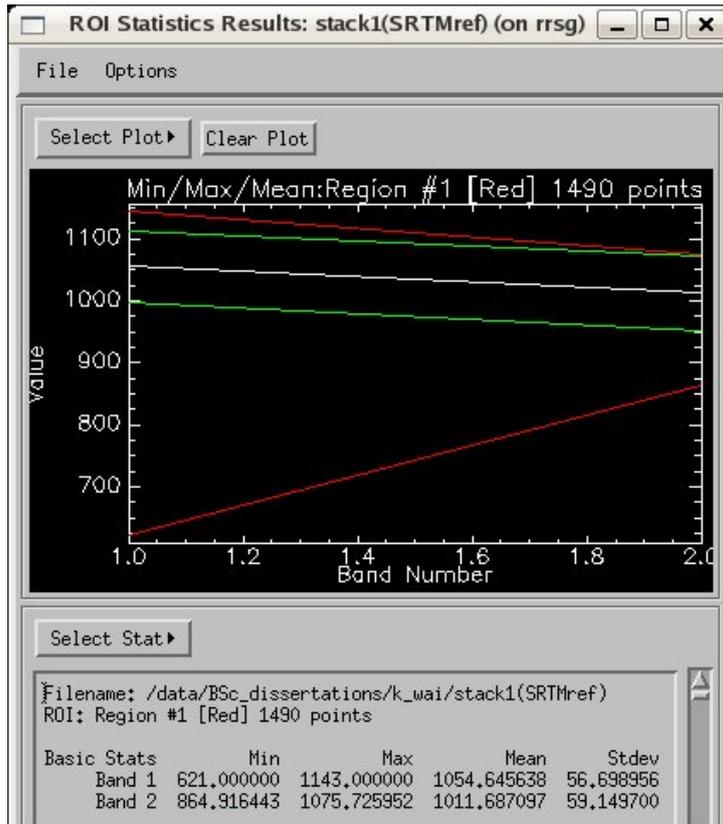
Fig. 4.17 *is a statistic table generated in ENVI*

From the statistic display, band 1 represents the statistic calculations for the map from SRTM and band 2 represents the statistic calculations for the map from Survey and Mapping.

From the statistic plot of band 1, the red line on top represents the maximum height, the red line at the bottom represents the minimum height, the white line represents the mean height and the two green lines represent the mean height +- the standard deviation.

The standard deviation for both of the maps are approximately 58m, this is relatively flat.

The above sections sum up the results obtained from the analysis using ENVI, conclusions based on the findings will be drawn in the following chapter.

4.5 SUMMARY

Once the two dataset are stacked together, the height at a specific latitude and longitude on each map can be obtained. Thus the result section comprises of comparisons between the two maps. The first comparison done in this chapter, a trig beacon excel file was obtained from the Surveys and mapping. The excel file contained information about the height, longitude and latitude of a many trig beacons in the areas surrounding Cape Town. The height of a trig beacon is the most accurate, therefore it is used as a reference for the height comparison between the dataset.

Four trig beacons have been used for the comparison, namely: Lion's Head, Lion's Hump (Signal hill), Devil's Peak and the MacClear beacon on top of Table Mountain. The x-plot function of ENVI is capable of generating the horizontal view of a slope. This function can be used to provide a closer look at certain areas and the shape of a mountain will be available for comparison.

The statistical report of the Plateau at the front of the Table Mountain can be generated using ENVI. Firstly, the Plateau area on the Table Mountain on both maps must first be highlighted; this can be done by the ROI (Region Of Interest) ENVI function. The Statistical report of the ROI can then be computed. The statistical report includes the maximum, minimum and the mean height as well as the standard deviation of the two maps.

From some of the x-plots of the SRTM data in the first part of this chapter, it shows that height in the sea is a negative number. Therefore a coastal area has been chosen to the compare the height in the sea between the SRTM and Surveys & mapping dataset. The different x-plots of the coastal area will be generated for comparison.

This chapter will discuss the conclusions from the findings obtained from the previous chapter. There are also limitation and possible errors with the study that will be elaborated on. This chapter serves as a concluding chapter to the thesis, and the research question is finally answered in this chapter as to what the differences between the two DEMs are.

5.1 CONCLUSION

Based on the findings of this project, the following conclusions can be drawn:

- After comparing the DEM's heights to the four reference trig beacons, the average difference was calculated for each method. SRTM shows to be more accurate, since there is a smaller average difference of 29.7m, whereas the other method deviated by 36.54m. The sample and scale of research is small, this cannot hold reliability.

- The height values of the SRTM data is always larger than the actual height values provided by the trig beacon. This is because some of areas are covered with trees or plantations, the backscatters received by the antenna are actually reflected from the trees and plantations, if

this is the case, the actual height values will always be smaller than that of the SRTM data.

- The height values of the Surveys & Mapping data is always smaller than the actual height values provided by the trig beacon. According to Prof Merry from the Geomatics department at U.C.T (2006), the original height of the aerial photographs taken by the Surveys and Mappings are also the height at the top of the trees or plantation. However, the Survey and Mappings will take the trees or plantation into account by estimating the average heights of the trees or plantation and find out the actual height by taking the original and minus the estimated heights of the trees. A very good example will be the MacClear beacon as its height is 1088m, but the heights from Surveys and Mappings and SRTM are respectively 1045.2m (smaller) and 1107m (bigger).

- The overall shapes of the mountain displayed by the x-plot function are relatively similar for the SRTM and Surveys and Mappings dataset.

- From the Fig.5.13, the SRTM is able to obtain the relative height (negative) of the seabed to the sea level.

- From the statistical report on the Plateau of Table Mountain, both of the SRTM and Survey & Mapping dataset resembles the flat characteristic of the table mountain.

5.2 POSSIBLE ERRORS

The height difference between the SRTM and the Surveys and Mappings data sets are relatively large ranging approximately from a few meters to 80 meters. Possible errors could occur in the data manipulation process. They are as follows:

- In order for ENVI to read in the Surveys & Mapping data, the height values from the Surveys & mapping data had to be put into a matrix using IDL programming. As the data were in un-organized manner, some programming error is possible and result the wrong height values being put into a wrong co-ordinate. Therefore the height values at a specific latitude and longitude can be wrong.

- If the 4 corners of the map were not specified correctly, the two maps may not be perfectly aligned. As a result the height difference between the maps can be rather significant.

- As mentioned before, when comparing the heights from SRTM and Surveys and Mapping with the height from the trig beacon, the latitudes and longitudes are not exactly the same. Therefore these can cause of the difference in height.

6.1 RECOMMENDATION

Based on the conclusions and the experience gained from the project, the following recommendations can be made for future work within this topic:

- The height of the trig beacon lies inbetween the heights of the SRTM and Surveys & Mapping. More accurate height values can be obtained by taking the average height between the SRTM and Surveys & Mapping data.

- If the relative height of the sea bed to the see level is the interested part in an analysis, it will be recommended to use SRTM data. Since the SRTM method can detect negative heights.

- The ASCII file obtained from the Surveys & Mapping must be sorted by using software (e.g Ultraedit), before writing it in to a matrix or data analysis. As it contains a number of unusual errors. For instance, there were different height values for a specific co-ordinate.

- It is recommended to convert the co-ordinates into latitude and longitude, this makes it easier while doing analysis in ENVI.

- If one were to use Surveys & Mapping data for analysis, it is recommended to use the Hartebeesthoek94 datum as its has the WGS84 since the ellipsoid reference which is an universal format.

After analysing the result, the pros and cons of radar interferometry and photogrammetry can be drawn from the result of the study. Radar interferometry uses more advanced technology than photogrammertry, and this could be the reason why its measurement is more accurate, however this methodology proves to be less cost effective thus photogrammertry still proves to be the more popular method.

There is no definite recommendation that either one is better than the other, since both have their strengths and effectiveness in different scenarios. For example, the photogrammertry method does not prove to be effective when recording heights of sea beds or negative height values, however in this scenario radar interferometry would be a more accurate method. Thus it is difficult to conclude on the better method. However, it can be recommended that in the future it can be researched on how the two methods can be integrated so that the best of both may be used to compute a perfect map.

Appendix A

```
; to find the number of row for the matirx
last1 = min(CD_ASCII.field2,i); extract the last element of the array(field2)
first1 = max(CD_ASCII.field2,i); extract the first element of the array(field2)
ans1 = (first1-last1)/25
row = ans1 + 1

; to find the number of column for the matrix
last2 = min(CD_ASCII.field1,i);
first2 = max(CD_ASCII.field1,i)
ans2 = (first2-last2)/25
column = ans2 + 1

a = fltarr(row, column)
temp = CD_ASCII.field1(0)
line = long64(0)
i = long64(0)
count = long64(0)
for j = 0, row do begin
        if CD_ASCII.field1(line) eq temp then begin
            if CD_ASCII.field2(line) eq CD_ASCII.field2(line+1) then begin
                temp = CD_ASCII.field1(line)
                line = line+1

                ;count = count + 1
                j = j-1
                ;break
            endif else begin

                a (j,i) = CD_ASCII.field3(line)
                temp = CD_ASCII.field1(line)
                line = line+1; compare the next line

            endelse

        endif else begin
            i = i + 1
```

Appendix A – IDL *Code*

```
            if (i eq column) then break
            j = -1
            temp = CD_ASCII.field1(line)
        endelse


        ;if (line eq 303188) then print, line
        if (line eq 589661) then break
endfor
;print,count
;write_tiff,'/home/wxxkax003/3318_CD2.tif', a,orientation=3,/float
end
```

Appendix A – IDL *Code*

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Appendix A – IDL *Code*

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