Locating potential landing zones with the help of Digital Surface Models

Master thesis

Auke Blokland

Delft University of Technology

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by

Auke Blokland

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Thesis committee:	Prof. dr. ir. R. F. Hanssen,	TU Delft
	Dr. ir. F. J. van Leijen,	TU Delft
	Ir. R. L. Voûte,	TU Delft, CGI Nederland

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Abstract

The current procedure of the 11 Air Manoeuvre Brigade (11 AMB) is based on a manual non integrated and slow method that uses only outdated and only topographical data. In the procedure are all 5 aspects of a potential landing zone taken into account, the so called 5S: Slope, Shoots, Surface, Size and Security. This research led to an automated and fast method that uses more actual 3D data (WorldDEM) and delivers better results (validated on the Edesche Heide) than using the current method. The automated procedure has been restricted to two of the five aspects (Slope and Shoots). The aspects Size and Security are discussed in the research but not integrated in the automated method. Using the new method the Pathfinders can be better prepared for a mission, can perform their tasks faster and can perform their tasks saver.

Contents

1 Introduction

1.1. Pathfinders of the 11 Air Manoeuvre Brigade

The ministry of Defence contributes to worldwide peace, freedom, security and protects all that the Dutch upholds. The Dutch Ministry of Defence is organized in seven different sections, such as the navy, the army and the air force. Two of the armed forces have a special cooperation in the form of the 11 Air Manoeuvre Brigade (11 AMB).

The 11 Air Manoeuvre Brigade should be worldwide deployable within 7 to 20 days to defend the territory of the Netherland and the territory of allied nations. Furthermore, the 11 AMB is deployed to protect the international rule of law, support law enforcement and brings help in case of natural disasters or humanitarian disasters.

This brigade consists of infantry units of the army and helicopter units of the air force. The infantry units come from the 11 Airmobile Brigade, a rapidly deployable light infantry combat unit travelling on foot or by light vehicles. The Defence Helicopter Command (DHC) forms the air force component of the 11 AMB. The DHC provides combat helicopters and transport helicopters to make the 11 AMB fast, flexible and decisive. In addition to the DHC there is an intensive cooperation with a squadron transport aircraft of the air force [1] [2]. To get to the actual deployment of the 11 Air Manoeuvre Brigade in a mission four steps are taken. The steps are visualized in figure 1.1.

1. Notice from Ministry of Defence
   First, the Ministry of Defence decides whether the 11 AMB is deployed and what kind of missions must be executed in which area. This order only holds a rough estimation of where the missions must be executed. The staff of the 11 AMB now takes over the planning of the mission [3].

2. Search for potential landing zones
   Second, the staff of the 11 AMB will look for potential landing zones. Depending on the mission certain locations are appointed as possible landing zones. The first steps of finding potential landing zones are done by looking at the available 2D maps of the area of interest. Based on these maps and the requirements of a landing zone it is possible to locate areas which have potential. The quality of the maps can differ per location. Some regions are well mapped. Others are not well mapped or not mapped at all.

3. Deployment of the Pathfinders
   Third, after the staff of the 11 AMB appointed potential landing zones, the potential landing zones must be confirmed. Pathfinders will make sure the potential landing zone is indeed a landing zone. The Pathfinders perform this task secretly and often in enemy territory. Therefore, they have to infiltrate the area without being spotted. This can be done by air by free fall or with helicopters

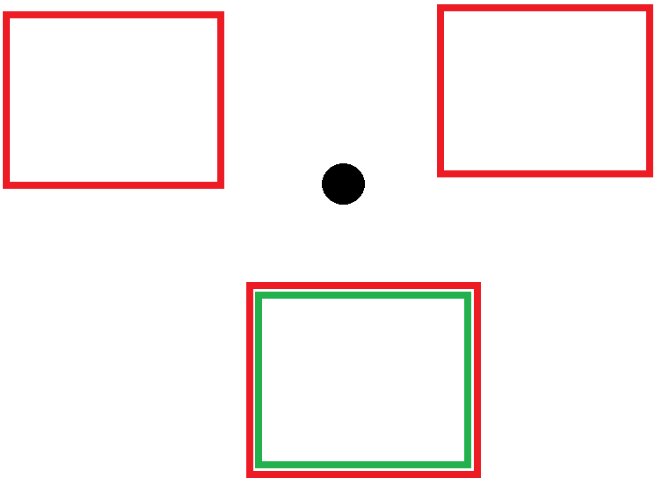


Figure 1.1: The ministry of Defense decides where and what type of mission must be executed (Step 1). This location is visualized as a black dot. The staff of 11 Air Manoeuvre Brigade then searches for potential landing zones (Step 2). The potential landing zones are visualized as red rectangle. The Pathfinders check the potential landing zones in the field (Step 3). The correct landing zones is visualized by the green rectangle inside the red rectangle.

or over the ground with the help of vehicles [2] [3] [4].

Pathfinders must explore possible landing zones to check whether paratroopers, helicopters or planes are able to land. For each type of deployment during a mission the requirements of the landing zone are different. These requirements are checked by performing several tasks. First of all they measure the dimensions of the landing zone to determine the number of paratroopers or the number of helicopters can land in a single wave. Secondly they perform slope measurements in the landing zone. The terrain must be relatively flat to make it possible for planes and helicopters to land and take off. Next the Pathfinders must mark obstacles. The presence and height of obstacles (e.g. trees) play an important role in calculating the approach and escape routes of helicopters. Also, the carrying capacity of the soil must be determined to make sure planes and helicopters can land. Furthermore the local weather conditions and weather history play an important role. Wind and visibility play a role in the approach routes. The tools available for checking the requirements are manual tools like clinometers, binoculars and different applications on mobile phones [3] [4]. Techniques to collect data with drones or with remote sensing in any other form are not used. Remotely sensed data is data which is acquired without physically interacting with the object of interest [5]. A wide range of remote sensing data types exists such as laser remote sensing, radar remote sensing and optical remote sensing.

4. Actual deployment of 11 AMB
Last, after the potential landing zone can be marked as a landing zone, the Pathfinders contact the staff of the 11 AMB and communicate the details of the landing zone. Once the staff of the 11 AMB gives green light for the mission, the Pathfinders must mark the landing zones and marshal the incoming planes and helicopters [4].

The 11 Air Manoeuvre Brigade is able to perform multiple types of deployment. The different types of deployment can roughly be distinguished as [2].:

- Air assault: Offensive operation to, for example, form a bridgehead in enemy territory. A combination of firepower, speed and surprise are used. Armed- and transport helicopters and infantry are continuously closely involved in the operation.
- Air drop: Units and material are being dropped by parachute in the area of interest.

- Air landing: Units and material are put down on the ground by airplanes.
- Air attack: Heavily armed Apache attack helicopters carry out an attack. Military from the Luchtmobiele brigade support the attack from the ground. This can be done by pointing targets.
- Ground attack: Parts of the Luchtmobiele Brigade perform a ground move to provide a link-up to attack targets or perform reconnaissance.
- Air raid: Infantry perform in co-operation with transport- or attack helicopters a fast and small scale fallout operation.

Because the 11 Luchtmobiele Brigade needs to be quickly deployable there is only a small time window to prepare the mission. The 11 Luchtmobiele Brigade operates worldwide, from arctic areas to the dessert areas to jungle area [4]. The tasks of the Pathfinders take place in physically and mentally challenging conditions with a restricted amount of supplies. A better preparation for the Pathfinders missions can be a key difference to complete them successfully. In this research a method will be developed to decrease the time of step 2, step 3 and step 4.

1.2. Problem statement

Nowadays the staff of the 11 AMB is using 2D maps of an area to locate potential landing zones. The 2D maps are topographic maps with height contour lines if available. If old maps or no maps at all must be used in the preparation of the Pathfinder mission, the Pathfinders don't know what they will encounter in the field. The process to find potential landing zones from these maps is relatively long process in the preparation window of a mission. This could result in not evaluating all potential landing zones. The best or safest potential landing zone can be missed. So, Pathfinders can be better prepared for their mission starts. Furthermore the lack of information makes it more likely the Pathfinders will not land closely to a potential landing zone. The Pathfinders then have to move by foot in enemy territory to find another potential landing zone. Leading to longer time in the field and potentially unsafe situations. In the field the Pathfinders don't have an integrated tool available to perform their task. Multiple separate third party tools must be used which makes their work slower.

1.3. Research questions

The resulting main research question is:

To which extent can potential landings be located with the help of a Digital Surface Model based on satellite data, supplemented by drone data acquired at the potential landing zone?

An area has to meet requirements concerning slope, size and surface to serve as a landing zone. This research will investigate which parameters can be estimated with the help of remote sensing and look at additional possibilities that can be applied.

Four sub-questions are formulated in order to answer the main research question:

- What are the aspects of a landing zone?
  The landing zone the Pathfinders are looking for has to meet multiple requirements. These requirements are divided into different categories. Each category will be discussed to see each aspect the Pathfinders are looking for.
- What data types can be used to locate potential landing zones?
  Each of the aspects stated above are investigated to see with the help of what type of remotely sensed data they can be determined.
- To what extent is the WorldDEM digital surface model suitable as input for the new developed method?
  The resulting potential landing area will be investigated. Are the resulting landing areas at the same locations as the Pathfinders have determined? Are the resulting landing areas comparable

to the landing areas generated with the help of Actueel Hoogtebestand Nederland (AHN) as input? Actueel Hoogtebestand Nederland is a digital height map of the Netherlands [6]. Where do differences occur and are those differences explainable?

- To what extent can the drone data enrich the results obtained with the WorldDEM data?
  Once the results and the uncertainty of the results are known a discussion can be held whether the use of the drone data will enrich the results. What is the added value of drone data? Is the WorldDEM result useful itself?

1.4. Methodology

The term remote sensing is very broad. This is exactly how this research will start. Many different types of remote sensing data and how the data can be useful will be discussed. From this wide range of data types a single data type will be chosen to analyze in more detail.

Also, several types of data sources will be discussed. From the systems which collect data from multiple satellite missions and deliver all the data integrated in one system to the data of single satellite missions. Furthermore, the Netherlands Army is in possession of different types of data both in the Netherlands and abroad. From all the sources the spatial resolution, the availability, the year of acquisition and the relative accuracy is noted. Last, a choice is made to use a source of data.

An ArcGIS model, a collection of data and geoprocessing tools connected to form one executable function [7], is developed. All the steps in the developed method will be explained in order of appearance in the ArcGIS model. For each function the different options will be discussed. The functions will begin with the preparation of the data. Next the functions used for calculating the aspects of the landing zone are discussed. Last the execution of the new method will be explained.

The new method will be tested using different case studies. A description is given of the area where the case study takes place and why. In a case study will be investigated how the input of the new method differs and what the effects are on the resulting landing areas.

1.5. Restrictions

The Pathfinders are trained to locate landing zones for helicopters, airplanes and paratroopers. This research will be limited to the helicopter landing zones. The requirements for the for helicopter, airplane and paratroopers are diverse. Therefore, it is not possible to locate potential landing zones for any combination of helicopter, airplane and paratrooper at the same time. The use of software is limited to the use of ArcGIS. ArcGIS is the software choice of the Dutch military and therefore a solution to the problem should be developed in this software package. The choice for the data is based on the data available to the military. A Digital Surface Model is being build by the military, but is not yet available worldwide. Therefore an already available comparable Digital Surface Model is used, WorldDEM. The case studies used in this research will all be located in the Netherlands. This choice is made, to make a assessment of the case studies by the Pathfinders possible. Furthermore some data sources are only available in the Netherlands. Due to the fact the case studies are all in the Netherlands, the results might not be reliable for types of areas not discussed in the case studies or comparable types of areas worldwide.

2
Background

2.1. Landing zones

In this section, the background of the helicopter landing zone is given. First of all, an overview of the requirements is given. In this overview, the different requirements are explained and the corresponding values to the requirements are given. Next, the current methods of finding landing zones. The last part of this section holds an investigation of how the five groups of requirements can be achieved with the help of different types of data. This last part also holds other opportunities which come with the use of the different types of data.

2.1.1. Requirements of landing zones

The helicopter landing zones must meet the requirements stated in the manual HB-4-42 Helicopter Handling for helicopter missions. In this manual five different groups of requirements are listed. These five groups are Slope, Shoots, Surface, Size and Security [4].

Slope

The slope is a measure indicating the rate of elevation change over a distance [8]. In the manual three different types of slopes are distinguished: forward slope, reverse slope and lateral slope. All the slopes are relative to the flying direction of the helicopter, see figure 2.4. A forward slope means the front of the aircraft is pointing in the downward direction of the slope. A backward slope is opposite to the forward slope and therefore the front of the aircraft is pointing in the upward direction of the slope. A lateral slope is present when the direction of the slope is perpendicular to the flight direction of the aircraft [4].

The maximum value of the slope is given in table 2.1. The maximum value of the slope depends on what time of day the mission is executed. A distinction has been made between missions executed during daytime and missions executed during night time. The maximum value of the slope also depends on the type of slope. Last, the maximum value of the slope depends on the type of helicopter used during the mission. A distinction has been made between the Cougar/NH90 type helicopter and the rest of the helicopter types [4].

Size

Five different sizes of landing points are distinguished, see table 2.2. The sizes are related to the maximum width of the landing point. The size of the landing point used during a mission depends on the type of helicopter, the weather conditions, the time of day and possible requests of the pilot. The landing point is divided into three parts, see figure 2.2. The blue part in the middle is called the 'Hard Surface' (HS). The striped red part surrounding the blue part is called the 'Cleared to Ground Level' (GCL). The outer part of the landing point, given in dotted green, is called the Free of Obstructions (FOO) area [4].

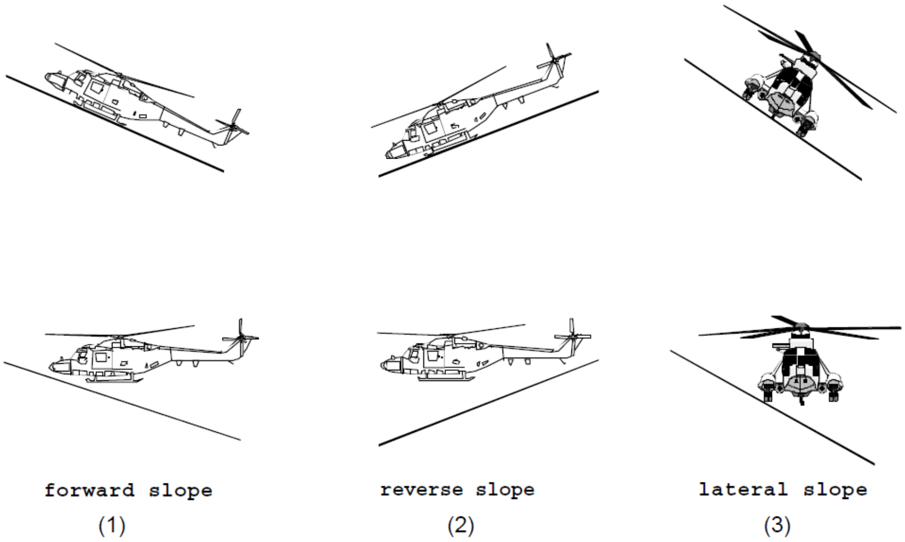


Figure 2.1: The different types of slope distinguished by the Dutch Military. The slopes are relative to the flying direction of the helicopter [4].

	Day	Night
Forward	7 degrees	3 degrees
Lateral	7 degrees	3 degrees
Reverse	7 degrees	0 degrees
Reverse Cougar/NH90	5 degrees	0 degrees

Table 2.1: The maximum value of the slope depends on what time of day the mission is executed. A distinction has been made between missions executed during day time and mission executed during night time. The maximum value of the slope also depends on the type of slope. Last, the maximum value of the slope depends on the type of helicopter used during the mission. A distinction has been made between the Cougar/NH90 type helicopter and the rest of the helicopter types [4].

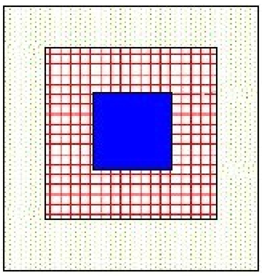


Figure 2.2: An example of a landing point. The area is divided in three parts. In blue the 'Hard Surface', in striped red the 'Cleared to Ground Level' and in dotted green the 'Free of Obstructions' [4].

	Hard Surface	Cleared to Ground Level	Free of Obstructions
Size 1	6 meter	14 meter	25 meter
Size 2	11 meter	20 meter	35 meter
Size 3	15 meter	35 meter	50 meter
Size 4	15 meter	35 meter	80 meter
Size 5	15 meter	60 meter	100 meter

Table 2.2: Five different sizes of landing points are distinguished. For each size different measures for the Hard Surface, the Clear to Ground Level and the Free of Obstruction are set. The size used during a mission depends on the type of helicopter, the weather conditions, the time of day and possible requests of the pilot [4].

	Minimum angle	Distance over which the angle is measured
Day	6 degrees	500 meter
Night - Black light ops	6 degrees	500 meter
Night - White light ops	4 degrees	3000 meter

Table 2.3: Overview of the rules set regarding the shoots. The angle and the length over which the angle is measured depend on the time of day when the mission is executed and whether night vision equipment is used. Black light ops means there is night vision equipment used and for white light ops there is no night vision equipment used [4].

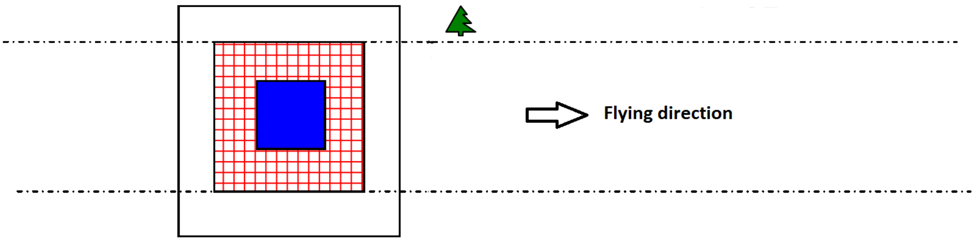


Figure 2.3: The search for obstacles is performed in the flying direction. This is done over the width of either the GCL or the FOO depending on the size of the landing point. In this figure landing point size 5 is displayed . Obstacles may be present outside of the strip, visualized by the dotted lines, like the tree in the image [4].

Surface

The requirements regarding the surface are related to three different parts of the landing point. The three different parts can be seen in figure 2.2. The Hard surface must have a minimal soil bearing capacity equal to the weight of the helicopter used during the mission. If this bearing capacity is not reached it is possible to exit the helicopter using a hover jump or fast roping. During a hove jump the helicopter will hover close above the ground while the soldiers jump out of the helicopter. Fast roping means the helicopter will deploy a rope along which the soldiers are going down [4].

In the GCL no obstacles, flammable materials or loose materials may be present. Grass up to a height of 0.25 meter is allowed if the grass is not flammable. In the FOO all obstacles with a height exceeding 0.60 meters must be removed [4].

For the whole landing point, no water and dense vegetation may be present. Also, the risk for white-out or brown-out conditions must be minimized [4]. A white-out is an in-flight visibility restriction due to snow [9]. A brown-out is an in-flight visibility restriction due to sand or dust [10].

Shoots

Shoots are the optimal incoming and outgoing flying angles for an aircraft in the flight direction. These angles are called Obstacle Angle (OA). The angles are measured between the touchdown point of the aircraft and the top of the obstacle. This is done for the width of the landing point and in the flight direction over a certain distance. In table 2.3 an overview is given for the shoot requirements. The maximum angle that is used and the distance over which this angle is measured depends on the time of the day the mission is executed and if night vision equipment is used during nighttime missions. If night vision equipment is used during a mission it is called Black Ops. White ops are missions where no night vision equipment is used during the mission [4].

The search for obstacles is only performed in the flying direction, see figure 2.3. In addition to the flying angle, the search for obstacles is only performed over the width of either the GCL or the FOO. The width of the FOO is used for landing point size 1 and size 2. The width of the GCL is used for landing point size 3, size 4 or size 5. Obstacles outside this strip are not a problem. Only if there are no obstacles present the landing point can be used [4].

	Ratio
Day	10 : 1
Night - Black light ops	10 : 1
Night - White light ops	14 : 1

Table 2.4: The ratio mentioned above is defined as the ratio between distance from the obstacle towards the touch down point and the height of the obstacle. The ratio depends on the time of day the mission is executed and the usage of night vision equipment [4].

Security

For security, it is important the landing zone is located where the enemy can exert influence as little as possible. Furthermore, the landing zone, the approach route and the departure route should be free from flat fire [4]. Flat fire means the trajectory of the round has almost no curvature [3].

2.1.2. Current method of finding landing zones

At the moment Pathfinders are working to a great extent manually. The start of the planning of a missions is done by a analog study of maps available of the area. Based on the requirements described above, potential landing zones are located. These landing zones will be evaluated by the Pathfinders, once deployed in the field.

In the field several tasks must be performed. First, the security of the area is assessed. Then the longitudinal direction of the field is determined together with the wind direction [4].

The next step is calculating the shoots. To calculate the shoots a clinometer is used or the ratio method is used. The clinometer is an optical device for measuring elevation angles above the horizontal plane [11]. The clinometer method holds a measurement of the angle from the touchdown point towards the top of an obstacle. The ratio method holds a fictional projection of the obstacle in the horizontal plane. The height of the obstacle is then measured by counting the steps it takes to walk the distance of the projected obstacle. With the help of a ratio, see table 2.4, the distance between the obstacle and the touchdown point can be calculated. The ratio depends on the time of day the mission is executed and the usage of night vision equipment. The ratio mentioned above is defined as the ratio between the distance from the obstacle towards the touchdown point and the height of the obstacle [4].

Thereafter, the surface requirements are met by the Pathfinders by performing different actions. The bearing capacity of the soil is tested using loaded vehicles. A vehicle must be able to drive to the touchdown point, stop at the touchdown point and drive away from the touchdown point without any problems. The vehicle must be loaded such that the weight per wheel is the same as the weight per wheel of the helicopter used during the mission. Loose materials, flammable materials and obstacles exceeding the height restriction must be removed [4].

Last, slopes are measured by two persons of roughly the same height. The first person holds the clinometer at the potential touch down point, the point where the helicopter touches down. The second person walks a distance equal to half the size of the landing zone. The first person now uses the clinometer to determine the angle between the persons by looking through the clinometer directly in the face of person two [4].

If all the steps above are successfully completed the landing points are marked with contrasting triangles, smoke or light sources [4].

2.1.3. Fulfilling the requirements with the help of different data types

In this part of the chapter, different data types will be discussed which make it possible to deduct information regarding the requirements discussed before. None of the following data types is used by the Dutch military yet. All the suggestions are possible solutions to locate potential landing zones with the requirements in mind.

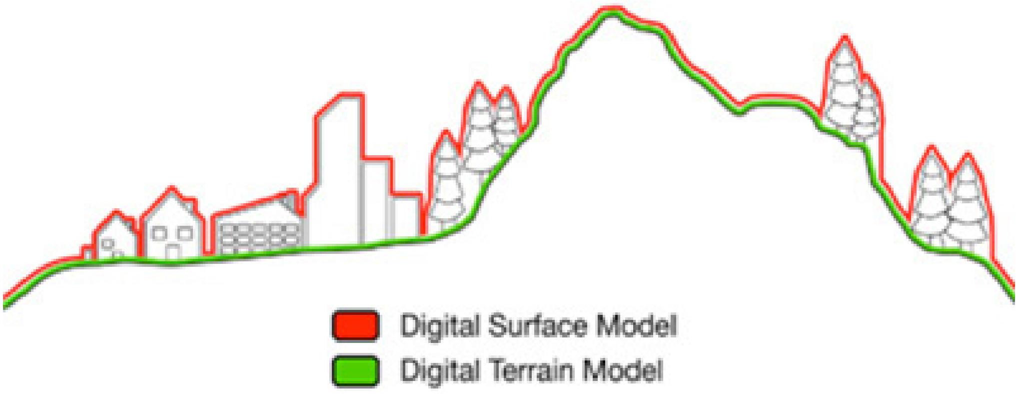


Figure 2.4: The term Digital Elevation Model (DEM) is both used for Digital Surface Model (DSM) and Digital Terrain Model (DTM). The difference between the two is whether objects on top of the ground level are taken into account [16].

Digital Elevation Model

To fulfill the requirements regarding the slope, the size of the slope and the direction of the slope relative to the flying angle must be known. The direction of the slope is also known as the aspect. It is an indication of which way the downward slope is facing and it can be defined as the compass direction of the slope [8].

With the help of a Digital Elevation Model the slope [12][13] and aspect [14] can be calculated. The term Digital Elevation Model (DEM) is used for both a Digital Terrain Model (DTM) as a Digital Surface Model (DSM), see figure **??**. A Digital Terrain Model is a bare-earth raster grid. Non-ground points like buildings and trees are filtered out and only the topography is left. In contrary to a Digital Terrain Model, a Digital Surface Model does include the reflections of tree canopy and man-made features [15].

The different slope types described in paragraph 2.1.1 are relative to the flying angle. Therefore an additional step is needed to get from the aspect to the corresponding slope type. Once the flying direction is known, the aspect can be transformed in a slope type by looking what the direction of the slope is relative to the flying direction.

A Digital Elevation Model can also help with the shoots calculations. The pixel size of a DEM is known and therefore the distance can be calculated based on the number of pixels times the size of the pixel. Also, height differences are known because the height of each pixel is known in a DEM. If these two parts are known, it is possible to calculate the angle between pixels.

The surface of a potential landing zone can not have obstacles exceeding a height of 0.60 meters. These obstacles should be detectable with the help of the Digital Elevation Model. Differences in values between pixels can be calculated to indicate height differences of 0.60 meter.

The security aspect of the potential landing zone might also be calculable with a Digital Elevation Model. It is possible to derive if a location is in direct line of sight of another location. A direct line of sight makes it possible to be vulnerable to flat fire. In search for a potential landing zone, the area from where enemy flat fire is possible should be as low as possible.

Multispectral data

The potential landing zone should be free of water and dense vegetation. This information can be deducted from multispectral data by combining different bands of the multispectral imagery. Each object has its own characteristics how different bands in the electromagnetic spectrum are reflected and absorbed. The most used indices are the normalized differential indeces. These indices are calculated by subtracting two different bands and divide the result by the sum of these bands. By selecting the right bands it is possible to locate green vegetation (Normalized Difference Vegetation Index (NDVI) [17]), buildings (Normalized Difference Building Index (NDBI) [18]) and water bodies (Normalized Difference Water Index (NDWI) [19]). Also, it is possible to detect snow and clouds. These indeces can be further exploited by combining the indeces with other information.

The NDVI is studied over the past years to seek for improvement. These improvements are found by taking into account the soil reflections. The result is a Soil Adjusted Vegetation Index (SAVI). By adding the canopy background adjustment factor L it no longer necessary to perform additional calibration for different soils due to soil brightness variations [20].

The SAVI index is developed further into the Modified Soil Adjusted Vegetation Index (MSAVI). Using the SAVI method it is necessary to have prior knowledge about the vegetation amounts to correctly estimate the canopy background adjustment. The MSAVI method replaces the constant soil adjustment factor, L, with a self-adjusting one. Besides improving the vegetation dynamic response this method also further reduces the soil background variations [21]. Rondeaux (1996, [22]) performed a comparison which resulted in the MSAVI as the best choice.

The ability to locate water bodies has also evolved from the NDWI. In 2006 Xu created the Modified Normalized Difference Water Index (MNDWI) by replacing the near infrared (NIR) band of the NDWI by a middle infrared band [23]. By inserting the middle infrared band, the MNDWI can enhance open water features while efficiently suppressing and even removing built-up land noise as well as vegetation and soil noise. This makes the MNDWI more suitable for built-up dominated land areas. Eight years later the method is improved even further. By introducing the Automated Water Extraction Index (AWEI) it is possible to differentiate between non-water pixels and shadow pixels more accurately. The downside is the fact that the AWEI may faultily classify water in areas with highly reflective surfaces such as ice and snow [24].

In the research published by Zha in 2003, a method was proposed to classify built-up areas. To do this he used bands 3, 4 and 5 of the Thematic Mapper. These bands correspond to the red, NIR and shortwave infrared (SWIR) areas of the electromagnetic spectrum. Zha built a new index, the Normalized Differential Built-up Index (NDBI), which uses the NIR and SWIR bands. For built-up and barren areas the reflectance from band 4 to band 5 increases drastically. This is not the case for woodland, farmland, rivers or lakes. Therefore this difference is so useful. By subtracting the NDVI from the NDBI the difference between built-up and barren areas with other land cover types increases even further [18].

The bearing capacity of the soil is one of the factors in the group of surface requirements. According to Bachmann et al [25] it is possible to determine soil bearing capacity with the help of multispectral imagery recorded in the 0.35 - 2.50 micrometer range. In the research, the imagery was compared with in-situ measurements of the bearing capacity of the soil. The results showed a correlation between these data sets, but only for a specific test case. There are no general correlations found for determining soil bearing capacity in different soil types.

Furthermore, the surface of the landing zone is not allowed to be flammable. Chuvieco et all [26] combined the NDVI and remotely sensed surface temperature to make an estimation of the danger rating for a forest fire. A comparable approach could potentially be used to detect flammable surface material.

Polarimetric radar data

The surface requirements also state the risks for brown-out and white-out conditions. Preliminary results show that helicopter brown-out regions can be predicted by means of a simple threshold using polarimetric radar data [27]. The chance for a brown-out is related to multiple characteristics which can be observed with the help of polarimetric radar data. These characteristics are soil moisture content, particle size distribution and surface texture. White-out conditions are difficult to predict yet.

Weather data

The weather data can provide the main wind direction in the area of interest. The wind direction is important for flying direction. The flying direction is in its turn important for the calculations of the

	Slope	Surface	Shoots	Size	Security
Digital Surface Model	■		■	□	■
Multispectral data		■		□	
Polarimetric radar data		■		□	
Wind data			■	□	
Precipitation data		■		□	
Temperature data		■		□	
Infrastructure data				□	■

Table 2.5: Overview of requirements, possibilities and data types. If a combination of data type and requirement or possibility can be fulfilled it is indicated by a filled black square. The open squares in the size column indicate that the requirement can't be solved with one particular type of data, but depends on the input of all the data types.

shoots and the slopes.

2.1.4. Other opportunities

The data types mentioned in the previous section can be used to cover the set requirements for a landing zone. The use of this data also brings more opportunities which can be exploited. Furthermore, opportunities are created by adding more data types. All the additional opportunities are discussed in this section.

Digital Elevation Model

In section 2.1.3 is described how a Digital Elevation Model can be used to uncover places from where flat fire is possible. The security section can be extended by adding more opportunities made possible by the use of a Digital Elevation Model. Assuming the locations from where flat fire is possible are know, it is possible to position the deployed troops in such way the risk of getting shot is minimized.

A same kind of analysis as the flat fire analysis can be done for the whole flying route of the helicopters. Assuming the location of the enemy is known, it is possible to make a direct line of sight analysis [28]. The result can be used to set a flying route with the minimum amount of direct line of sight time. Helicopters can now fly saver towards the landing zone.

In the previous examples, a defensive way of thinking is used. But, also there are also opportunities for offensive purposes. The direct line of sight analysis can be used to position troops optimized for the attack. Snipers can be advised to take certain positions to have a clear line of sight on the target. Thinking further, snipers or other troops can also be positioned in such a way teams can support each other in case the attack goes not according to the plan.

Weather data

Besides the wind direction, weather data provides more useful data. The precipitation data is useful because rain infiltrates the ground and changes the soil moisture content [29]. The soil moisture content is one of the factors related to the soil bearing capacity [25]. Weather data also holds temperature data. With the help of temperature data and precipitation data, the Pathfinders can be advised to bring or not to bring certain clothing during the mission.

Infrastructure data

Information about the infrastructure in the area of the landing zone can be used for security analysis. On one hand, the infrastructure information can be used to analyze how incoming troops can move over nearby roads or stay unseen by avoiding roads. On the other hand, a security analysis can be made to see how quickly enemy troops can access the landing zone using the infrastructure. This information can be incorporated in the new developed method to plan the missions.

2.1.5. Overview

An overview of the requirements, possibilities and data types is given in table 2.5. In the table can be seen that the Digital Elevation Model can be used for the most requirements and opportunities. In the slope calculations, it can be used for the size of the slope and the aspect of the slope. The Digital Elevation Model can also be used for the shoots requirement to find the area which meets the requested flying angles. For the security, the Digital Elevation Model can be used to find the areas vulnerable to flat fire and how to position troops for best view and cover.

The size column is filled with open squares. This means the size requirements can't be solved with one particular type of data but needs the input of all the data types. Distances can be measured with the help of a Digital Elevation Model, but it is only useful to measure distances in the area which fulfills all the five requirement groups. Once an area fulfilling all the requirements of all the groups is known, the dimensions of a landing zone can be searched. This search can be performed by a script. An example of such a script is the largest rectangle script of D3Plus [30]. The script of D3Plus is capable of finding the largest rectangle in a polygon in any orientation or ratio. It is possible to give a minimum length, width, orientation or ratio as a parameter.

The Digital Elevation Model will be used for the remaining part of the research. This decision is based on two factors. First, the Digital Elevation Model can be used for four of the five requirement groups. This makes the Digital Elevation Model the most useful data type. Last, the Dutch Military is working on a Digital Surface Model in the TREx project. Together with 29 other countries, the Netherlands Army is producing a worldwide DSM and DTM with a pixel size of 12 by 12 meters, the TREx project [31]. For this project, the raw data from the TanDEM-X satellite mission is used. This DEM is designed to have an absolute vertical accuracy of 4 meters and a relative vertical accuracy of 2 meters. The Dutch Military is looking for opportunities to use this Digital Surface Model. This research will help to show potential possibilities.

Until now, opportunities for both a Digital Surface Model and a Digital Terrain Model are discussed. From this point forward only the Digital Surface Model will be the focus. To find potential landing zones all the obstacles in the area are important. These obstacles are only represented in a Digital Surface Model, not in a Digital Terrain Model. Therefore the Digital Terrain Model will no longer be of interest.

2.2. Available data sources

The decision has been made to look into the possibilities given by the use of a Digital Surface Model. In this chapter, the available Digital Surface Models are reviewed and assessed. First, the Digital Surface Models currently available for the Netherlands Army will be collected. Next, other sources for Digital Surface Models will be investigated. Both domestic and worldwide sources are evaluated. The domestic sources are evaluated because the case studies are located in the Netherlands. The global sources are evaluated because the Pathfinders must be able to operate worldwide. Based on a list of characteristics for the Digital Surface Models, a Digital Surface Model will be chosen and used in the remaining part of this research. An overview of the global Digital Surface Models is given in table 2.6.

2.2.1. Data availability for the Netherlands Army

The data sources available to the Netherlands Army can be divided into two categories: domestic and global. First, all the data available in the Netherlands will be discussed followed by the data available worldwide.

Domestic data

The first source of domestic data are topographic maps. In the Netherlands topographic maps are made twice a year. One run results in a map with a resolution of 10 centimeters. The second has a resolution of 25 centimeters. The topographic maps are scaled to many different scales ranging from 1:10000 to 1:100000.

With the help of these topographic images and the 2D information stored in TOP10NL, the Top10NL 3D map is created. This Digital Surface Model uses photogrammetry to build a Digital Surface Model of the Netherlands. The TOP10NL 3D Digital Surface Model has the advantage to be able to look under objects like bridges. This is not possible using ordinary Digital Surface Models or topographic maps [31]. By using this technology the actuality of the Digital Surface Model can be increased. The dataset is freely available to use, provided the appropriate credits [32].

Beside the TOP10NL 3D maps the Netherlands Army has also access to another digital elevation model of the Netherlands. AHN is the digital height map of the Netherlands measured using laser altimetry on an airplane or helicopter platform. The data can be used freely by everyone without any limitations [6]. Between 2007 and 2012 the AHN2 data is acquired. In 2014, the start was made on obtaining the AHN3 data. The measuring process will not be finished before 2019. The AHN is distributed to the public in different formats. The first option is to download AHN as a point cloud. The AHN2 point cloud is divided in a ground level version and a non-ground level version. The AHN3 point cloud is offered as one point cloud and can be filtered for ground level and non-ground level by classification. The second option is to download AHN as a raster file. The raster files can be downloaded for both AHN2 and AHN3 as a DTM or DSM. Both the DTM and the DSM are available in a 0.5 meter and 5 meter resolution GeoTIFF file [33]. The AHN data holds a systematic error with a maximum of 5 centimeters and on top of that a stochastic error with a maximum of 5 centimeter [34].

Global data

To cover the need for data from all over the world the Netherlands Army is cooperating with other countries in different projects. For Topographic maps, the Netherlands Army joined the Multination Geospatial Co-production Program (MGCP). Members of this program share their topographic maps with each other to have a better coverage of the world. Topographic maps are available on scale 1:50000 or DTED level 2. The term DTED is explained in the next paragraph.

DTED stands for Digital Terrain Elevation Data. These are standards for digital datasets developed by the National Geospatial Agency (GIA) of the USA. Currently, 3 DTED levels are used and three more levels are proposed. DTED level 0 uses a spacing of 30 arc second (around 1000 meters) and can be used for general modeling and assessment activities. DTED level 1 uses a spacing of 3 arc seconds (around 100 meters) which is equivalent to the contour information on a 1:250000 scale map. A spacing of one arc second is used for DTED level 2. This matches to approximately 30 meters and is equivalent to contour information represented on a 1:50000 scale map [35].

For height data of the world, the Netherlands Army joined the TREx program. Together with 29 other countries the Netherlands Army is producing a worldwide DSM and DTM with a pixel size of 12 by 12 meters [31]. For this project, the raw data from the TanDEM-X satellite mission is used. This DSM is designed to have an absolute vertical accuracy of 4 meters and a relative vertical accuracy of 2 meters. According to the planning, the project will be completed in 2025. If height data of a certain area is needed before project TREx can deliver, it is possible to buy the data from Airbus [36].

2.2.2. Alternative data sources

Services are established around acquiring data in small time windows. The International Charter Space and Major Disasters [37] and the Copernicus Emergency Management Service [38] are examples of these services. Satellites of all connected parties will be used to collect data as quickly as possible from a particular area. These examples are services used for Disaster Management and may not be used for the planning of military operations [39] [40].

Without being able to collect new data in a short time frame, already existing data collecting services should be used. For example, the Copernicus Open Access Hub makes it easy to download raw data from the different Sentinel missions. This service is free from legal or paywall restrictions [41]. Once the raw data is downloaded it must be processed into a product like a Digital Surface Model. This end product is not provided by these services.

Other services collect all the raw data from multiple satellite missions in one database. From this database, it is possible to process the data using your own code. This way you can create your own insights and end products. An example of such service is the Google Earth Engine. Google collected and organized data in an easy to use interface. This way the user does not have to worry about downloading, storing and georeferencing data. Depending on the organization type the services are freely available or available by paid licenses. "Under the terms of service, using Earth Engine for evaluation purposes is generally OK, but if/when those uses are productionized / operationalized by a commercial or governmental agency, then alternative arrangements need to be discussed", according to Joel Conckling of Google. This statement makes the use of this service only possible for research. For the planning of military missions, it might be usable after making arrangements with Google. However, it is not usable because of the data policy of the Google Earth Engine. In the data policy is written Google can use the customer data, customer code and costumers application [42]. Sharing information about military missions is not possible [3].

The last group of services makes it possible to download end products. Like the USGS EarthExplorer website, it is possible to select an area of interest and the desired data set. The data will automatically be filtered and the usable end products are ready to download.

From all these different services and sources, the Digital Surface Models can be compared to see which Digital Surface Models show potential to be used in this research. Because the Netherlands Army is working on the TREx project only the sources which have comparable or better specifications with the TREx project are investigated. The spatial resolution, the accuracy, the availability and the age of the different sources will be compared.

An overview of all the sources is given in table 2.6. All sources displayed in the table are single Digital Elevation Models except the ESRI Topographic Map. The ESRI Topographic Map consists of many Digital Elevation Models combined in one service. The service with the highest resolution for the area of interest is displayed.

2.2.3. The selected data sources

In table 2.6 can be seen that the WorldDEM and the TREx Digital Elevation Models have the best spatial resolution and are built with the latest data. This makes the WorldDEM and the TREx DEM the best choice. Because the Dutch Army is working on the TREx DEM, the DEM source used in this investigation should ideally be the TREx DEM. Because the TREx project is not ready to use yet there is only one eligible source: WorldDEM. WorldDEM is just like TREx made from the acquisitions of TanDEM-X mission. Both DEMs will have the same spatial resolution and the same relative vertical accuracy. WorldDEM is a paid source but is freely available for the TU Delft for research purposes. In the restrictions is stated that paid sources should not be used in this research. In this case, the paid source is only a temporary source because eventually WorldDEM can be replaced by the TREx project.

The WorldDEM digital surface model is created with the help of the reflection of pulses send in a known direction. The pulses sent are radar pulses in the X-band by the TanDEM-X satellite and the TerraSAR-X satellite. Both satellites measure the time it takes between sending the pulse and receiving the reflection of the pulse. The radar pulse is traveling at the speed of light. Now the speed of the pulse and the time it takes for the pulse to travel to the reflective surface and back are known, the distance to the reflective surface can be calculated. Furthermore, the location of both the satellites must be known. If both locations are known the distance between the satellites can be calculated. The last step is applying the triangulation method to the collected information. This results in a 3D position of the reflective surface [43].

The WorldDEM Digital Surface Model is available in Geographic Coordinates. The horizontal reference datum is the World Geodetic System 1984 (WGS84-G1150) and the vertical reference datum is the Earth Gravitational Model 2008 (EGM2008) [44].

The 12 meter spatial resolution of the WorldDEM Digital Surface Model makes it possible to miss some important objects on the ground. To check if the model with the WorldDEM data as input is capable of correct locating potential landing zones control runs are performed. Because the case studies are all located in the Netherlands the AHN can be used for this check. As described in section 2.2.1 the AHN was built with the help of laser altimetry.

Laser altimetry works by emitting a pulse of laser light towards the object of interest. The object of interest will partly reflect the laser pulse back towards the source. The time it takes between the emitting of the pulse and receiving the reflection of the pulse is recorded. This time difference together with the speed of the laser pulse can be used to calculate the distance between the source of the pulse and the object of interest. To be able to locate the object in a 3D environment the location of the source must be known. Also, the direction in which the pulse is emitted is necessary to locate the object of interest in a 3D environment [45].

The AHN products are available in compound coordinate system EPSG 7415 [46]. This compound coordinate system consists of a horizontal reference datum RD New and the vertical reference datum NAP height [47].

Only in the Netherlands, the AHN products are available and therefore only in the Netherlands, a control run can be performed. The Pathfinders can be deployed worldwide, so a worldwide Digital Surface Model like AHN is needed to be able to do a control run. Because no worldwide Digital Surface Model with the resolution of AHN is available, a solution is applied where a Digital Surface Model can be created anywhere. With the help of drones and photogrammetry, a Digital Surface Model can be made at any location. The errors in the created drone based Digital Surface Model are comparable with AHN or smaller [48] [49] [50].

Photogrammetry is the art, science, and technology of obtaining reliable information about physical objects and the environment through processes of recording, measuring, and interpreting photographic images and patterns of recorded radiant electromagnetic energy and other phenomena [51]. This technique can be used in the same way as the radar altimetry. If the location and orientation of two different images are known, the camera parameters are known and an object is visible in at least two images a 3D position can be calculated. This is done with the help of the triangulation method.

For two case studies, Exloo and Valkenburg, Digital Surface Model are made with the help of a drone. This is done by two different companies. Both the Digital Surface Models are given in the compound coordinate system EPSG 7415. ATMOS UAV made the first Digital Surface Model of the old military airfield near Katwijk in the Netherlands. ATMOS UAV used their self-designed drone, Marlyn. Marlyn was equipped with a multispectral camera recording the bands red, green, blue, red-edge and near-infrared. With the help of photogrammetry software of Pix4D, a Digital Surface Model is built with a spatial resolution of 8 centimeters. The second Digital Surface Model is made by EyeFly. With the help of the M600 drone platform, a heathland near Exloo in the Netherlands is mapped. The drone of EyeFly was equipped with a 100MP camera. After using the photogrammetry software Pix4D the resulting Digital Surface Model has a spatial resolution of 5 centimeters.

	Spatial Resolution	Availability	Year of data acquisition	relative vertical accuracy (90% confidence)
WorldDEM [44]	0.4 arcsec - 12m	pay wall	2014	<2m if slope <=20%
TREx [36]	0.4 arcsec - 12m	military	2014	<2m if slope <=20%
Jaxa Alos [52]	1 arcsec - 30m	free available	2007	<=5m
SRTM [53]	1 arcsec - 30m	free available	2000	<=10m
ESRI topographic map [54]	ranging from 0.5-928m	pay wall	constantly updating	varying by location and source
ASTER [55]	1 arcsec - 30m	free available	2011	10-25m
GMTED 2010 [56]	7.5 arcsec - 225m	free available	2010	30m

Table 2.6: Overview of the Digital Surface Model sources compared in this research. For each of the sources the spatial resolution, the avaibility, the year of acquisition and the relative vertical accuracy is given.

3 Methodology

In the previous chapter, the data is selected for the remaining of the research. In this chapter, the software package ArcGIS Pro will be introduced together with the functions used in ArcGIS Pro. A method will be developed in ArcGIS Pro with which the aspects linked to the Digital Surface Model in table 2.5 are integrated. The security requirements are not discussed, because the security is a very specific part which requires military knowledge. Possibilities for the security part are given in chapter 2.

3.1. ArcGIS Pro

ArcGIS Pro is a software package to create and manage data, make maps and perform analysis. It can be used to work with imagery, automate workflows and manage workflows. Important for this research is the fact that ArcGIS Pro can create 3D scenes to make it possible to display and interact with the data in 3D [57].

To automate workflows ModelBuilder is integrated into ArcGIS Pro. ModelBuilder is a visual programming language for building geoprocessing workflows, see figure 3.1. Geoprocessing models automate and document spatial analysis and data management processes. It is possible to create and modify geoprocessing models in ModelBuilder, where a model is represented as a diagram that chains together sequences of processes and geoprocessing tools, using the output of one process as the input to another process [58].

The ModelBuilder is integrated into the interface of ArcGIS Pro, see figure 3.2. In the middle of the interface, a map is given. All the data added to the project is visualized on this map. On the left,

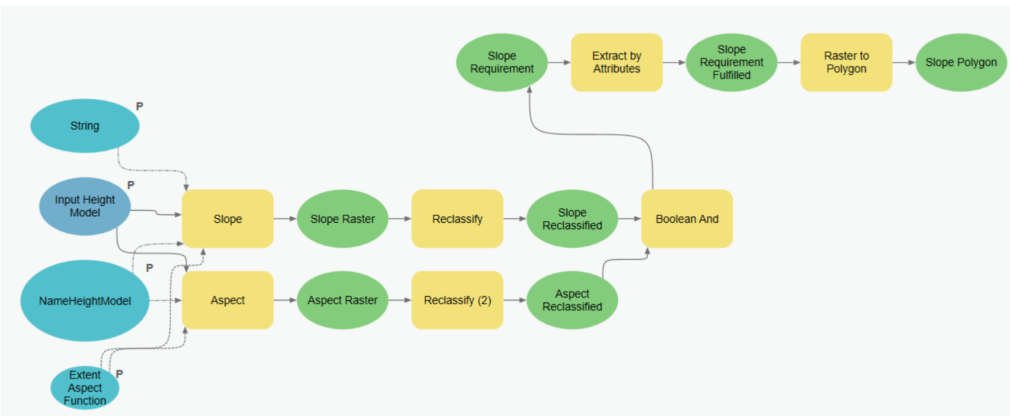


Figure 3.1: The ModelBuilder interface in ArcGIS Pro. A model is represented as a diagram that chains together sequences of processes and geoprocessing tools, using the output of one process as the input to another process [58].

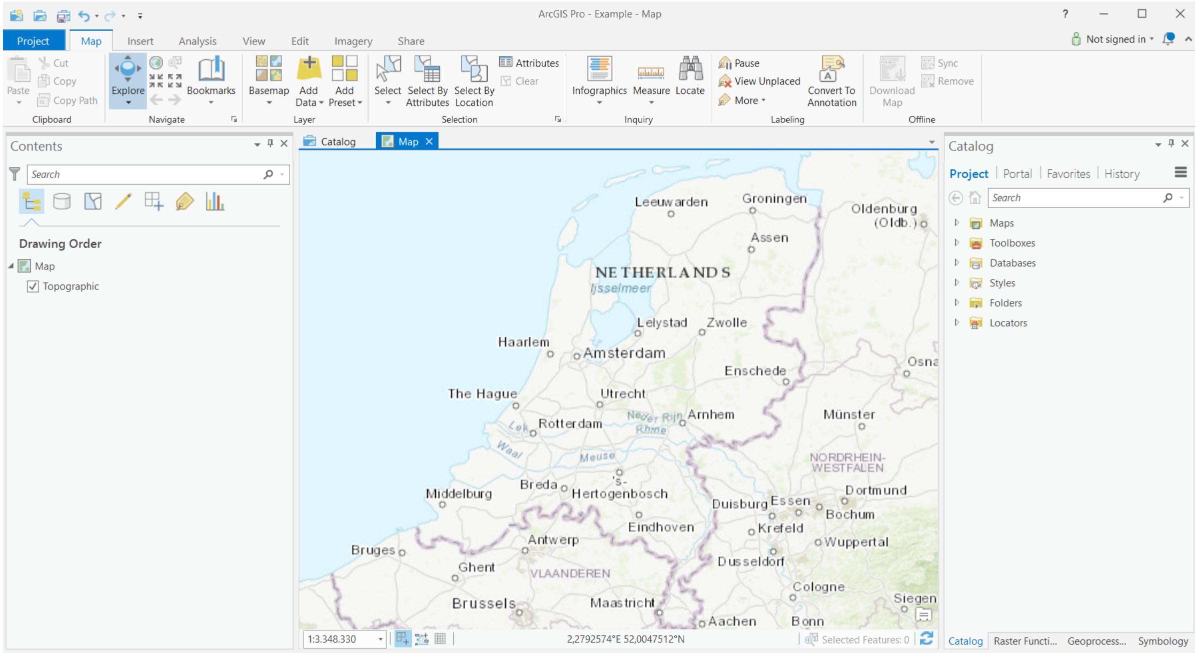


Figure 3.2: The ArcGIS Pro interface. In the middle of the interface, a map is given. All the data added to the project will be visualized on this map. On the left, an overview of all the layers of data added to the project. On the right the catalog with, among other things, the maps, toolboxes and databases. The ModelBuilder models are saved in a toolbox.

an overview of all the layers of data added to the project. On the right the catalog of the maps, the toolboxes and the databases is visualized. The ModelBuilder results are saved in a toolbox.

Inside the ModelBuilder a model is created to locate potential landing zones with a Digital Surface Model as input. Several steps are taken to get to a potential landing zone, see figure 3.4. These steps are discussed in the following sections. In the model, variables are present which can be adjusted by the user before running the model. After the model is selected, a side panel will show the variables which have to be filled before the model can be started, see figure 3.3. This panel is connected to the map of ArcGIS Pro. This means the available layers in the map can be selected using a drop-down menu in the side panel. The variables (e.g. maximum size of the slope, flight direction and maximum angle for the incoming and outgoing route) can be adjusted for any type of mission. This way a model is created which is highly modular.

To make the model usable for different projects, the workspace can be adjusted in one of the variables. This way, the results are written in the geodatabase of the active project. The storing process of the results is one of the most time-consuming executions. The total processing time can be lowered by not writing all the results to the geodatabase. Only the final results will be written to the geodatabase and not the intermediate steps. This is done using the 'in_memory' option in the output location of the intermediate step.

3.2. Preparing the data

Project

Different data sources are used. Not all of the data sources are given in the same coordinate system. To make sure all the data is in the same coordinate system the 'project' function is used. By projecting every layer in the same coordinate system it is possible to prevent inaccuracies in any execution of ArcGIS functions on the different data layers [59]. The different Digital Surface Models are all set to the compound coordinate system EPSG 7415 [46]. This compound coordinate system consists of the horizontal reference datum RD New and the vertical reference datum NAP height [47].

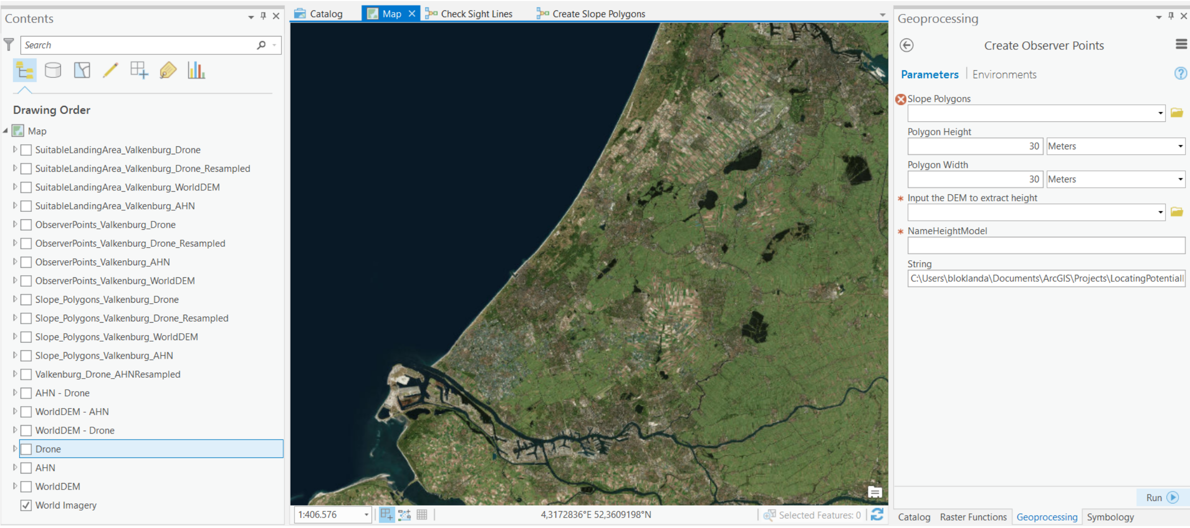


Figure 3.3: The geoprocessing panel is visible on the right side of the ArcGIS interface. Before running the model, the variables can be set in the panel.

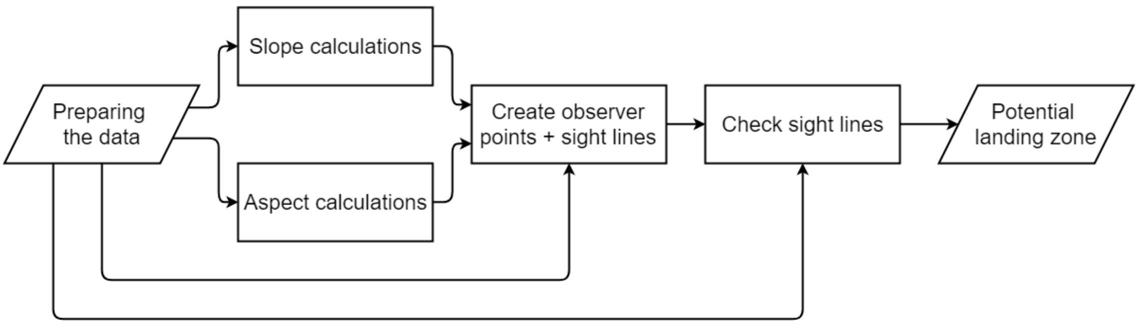


Figure 3.4: A flowchart of the steps taken to get from a DSM to a potential landing zone. First, the data is prepared. Then, the slope calculations and aspect calculations are performed. Next, the observer points and sight lines are created. Last, the sight lines are checked.

Snap raster
The 'snap raster' environment is used to snap or align an extent during execution. The lower left corner of the extent is snapped to a cell corner of the snap raster and the upper right corner is adjusted using the output cell size. As a result, when the output cell size is the same as the snap raster cell size, the cells in the output raster are aligned with the cells of the snap raster.

If the lower-left corner of the extent does not match with any cell corner of the input raster, it will create a shift in the cell alignment between the input and the output raster. This difference in cell alignment will trigger a resampling of the input raster to perform the analysis. Most Spatial Analyst tools use the nearest neighbor resampling technique, except for the Surface tools, which use bilinear interpolation.

By using the snap raster function the data sources will be interpolated. This interpolation will cause an error to some extent. To prevent this error the 'snap raster' function is not performed. The consequence is the fact that the rasters are potentially misaligned [60]. This potential misalignment does not have consequences for the execution of other functions.

Resample
The 'resample' function resizes the pixels without changing the extent of the dataset. Inside the resampling function, there are 11 different resampling methods: Nearest Neighbour, Bilinear Interpolation, Cubic Convolution, Majority, Bilinear Interpolation Plus, Gaus Blur, Gaus Blur, Plus, Average, Minimum, Maximum and Vector Average [61].

In this research the resample function will be used to increase the pixel size of the AHN and drone Digital Surface Models. The method selected is the average method. This increase in pixel size is only needed for the slope calculations and aspect calculations. If the pixel size is not increased, the slope will exceed the set maximum slope for the smallest obstacles. The Pathfinders are not looking for the smallest obstacles This is because the Pathfinders are not looking for the smallest changes in slope [3]. More about the slope calculations in section 3.3.

3.3. Slope
The first task of the Pathfinders which will be discussed is the slope of the terrain. The slope functions are executed very fast in ArcGIS Pro. The total processing time of the new developed method will take advantage of the speed of this step by processing this step first. This way a relatively large part of the area no longer needs to be taken into consideration in a relatively small amount of time. Reducing the area before going to the next step will increase the performance of the coming steps. In the coming sections the ArcGIS functions are discussed to make clear what the functions do and what options are present in the ArcGIS functions. Then, the choice for a certain option is explained and a description is given how the functions are incorporated in the new developed method.

3.3.1. Explanation of the functions
The slope is a measure indicating the rate of elevation change between DEM cells. The aspect is an indication of which way the slope is facing; it can be defined as the compass direction of the downhill slope [8]. In ArcGIS Pro functions are available to calculate the slope and aspect from a DEM. There are two different methods implemented in these functions. The first method is the planar method, the second the geodesic method.

Using the planar method, the calculation will be performed on a projected flat plane using a 2D Cartesian coordinate system. Different from the planar method, the geodesic method considers the shape of the earth as an ellipsoid [62].

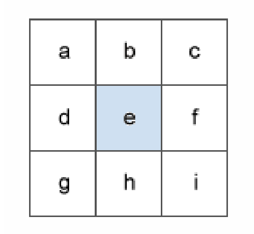


Figure 3.5: Cell of interest including the eight neighboring cells [62].

Slope Planar Method

The planar method is based on a basic algorithm. The equation to calculate the slope is

$$s = \arctan\sqrt{[dz/dx]^2 + [dz/dy]^2} \tag{3.1}$$

where s is the slope in degrees, dz/dx is the height difference in the x-direction and dy/dz the height difference in y-direction. The height differences are calculated using the eight surrounding cells of the cell to be calculated, see figure 3.5. The surrounding cells are identified with the letters a to i, with e the cell for which the slope is calculated [62].

The individual weight of the corner cells (a, c, g and i) is 1. The other cells (b, d, f and h) have weight 2. If one of the cells has the value 'NoData' in the DSM, the weight of this cell will be zero. The difference in height for the x direction can be calculated by

$$\frac{dz}{dx} = ((c + 2f + i) * \frac{4}{w_1} - (a + 2d + g) * \frac{4}{w_2})/(8 * \Delta x) \tag{3.2}$$

where c, f, i, a, d and g correspond to the values of the DSM. The weight w_1 can be calculated by adding the individually weights of c, f and i and the weight w_2 can be calculated by adding the individually weights of a, d and g.

The difference in height in the y direction can be calculated by

$$\frac{dz}{dy} = ((g + 2h + i) * \frac{4}{w_3} - (a + 2b + c) * \frac{4}{w_4})/(8 * \Delta y) \tag{3.3}$$

where g, h, i, a, b and c correspond to the values of the DSM. The weight w_3 can be calculated by adding the individually weights of respectively g, h and i and the weight w_4 can be calculated by adding the individual weights of a, b and c. The height change in x-direction and y-direction can be inserted in equation 3.1 [62].

Slope Geodesic Method

Contradicting the planar method the geodesic method calculates the slope in a geocentric 3D coordinate system, also known as ECEF. In this system, the shape of the earth is set as an ellipsoid. The origin of the coordinate system is in the center of the earth. Before the start of the calculations, the coordinate system is set to the ECEF coordinate system [62].

For each location a 3x3 cell neighborhood plane is fitted using the Least Squares Method, see figure 3.6. For each of the cell centers, the distance between the real z-value and the fitted z-value is calculated. From this plane the normal is computed at the location of the plane's center. Also, the normal of the ellipsoid is calculated at the same location. The geodesic slope is the angle between the normal of the topographic surface and the normal of the ellipsoid surface. Any surface parallel to the ellipsoid surface has slope zero [62].

Aspect Planar Method

Just like the slope function the aspect function uses a 3x3 neighborhood window, see figure 3.5, to calculate the aspect of a cell. Also, the usage of weights is the same as the slope function. The aspect

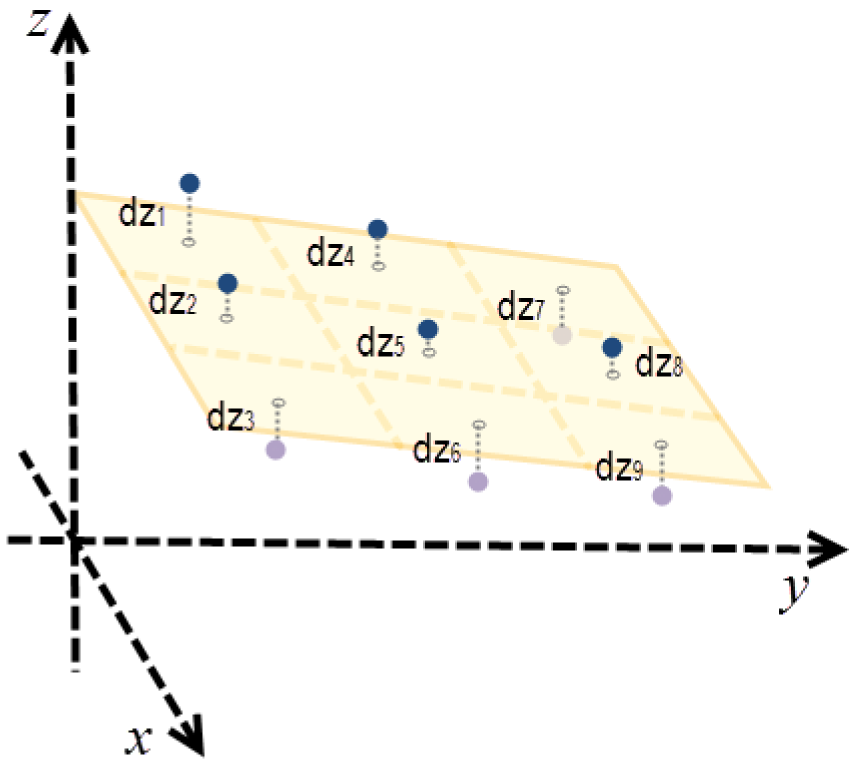


Figure 3.6: The 3x3 cell plane's best fit will be calculated using the least squares method [62]

is calculated with the help of the change of height in the y-direction and x-direction. The two rates of height change are then implemented in equation 3.6. Flat surfaces will get value -1 because atan2(0,0) is undefined. The atan2 function is the multi-valued inverse tangent function [63]. The difference in height for the x-direction can be calculated by

$$\frac{dz}{dx} = ((c + 2f + i) * \frac{4}{w_1} - (a + 2d + g) * \frac{4}{w_2})/8 \tag{3.4}$$

where c, f, i, a, d and g correspond to the values of the DSM. The weight w_1 can be calculated by adding the individually weights of c, f and i and the weight w_2 can be calculated by adding the individually weights of a, d and g.

The difference in height in the y direction can be calculated by

$$\frac{dz}{dy} = ((g + 2h + i) * \frac{4}{w_3} - (a + 2b + c) * \frac{4}{w_4})/8 \tag{3.5}$$

where g, h, i, a, b and c correspond to the values of the DSM. The weight w_3 can be calculated by adding the individually weights of respectively g, h and i and the weight w_4 can be calculated by adding the individual weights of a, b and c.

The equation to calculate the aspect is

$$a = \arctan(\frac{dz}{dy}, -\frac{dz}{dx}) \tag{3.6}$$

where a is the aspect, dz/dx is the height difference in the x-direction and dy/dz the height difference in y-direction.

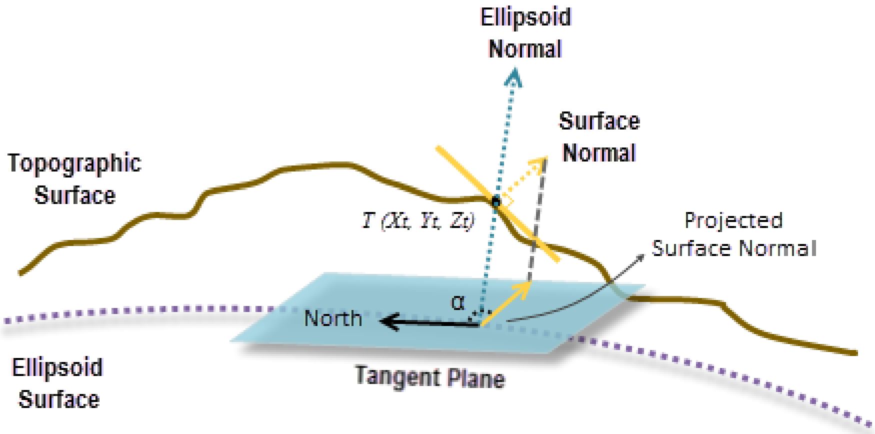


Figure 3.7: The computation of the aspect using the geodesic method visualized [63].

The resulting value of the aspect calculation is not related to a direction relative to the geographic cardinal directions (north, east, south and west [64]). The value can be converted to the geographical cardinal directions by the following formula [63]:

$$\text{cell value} = \begin{cases} 90 - \text{aspect}, & \text{if aspect} < 0 \\ 360 - \text{aspect} + 90, & \text{if aspect} > 90 \\ 90 - \text{aspect}, & \text{otherwise} \end{cases}$$

Aspect Geodesic Method

To calculate the aspect with the geodesic method a 3x3 neighborhood plane is fitted around the cell to be processed using the Least Squares Method. The steps are visualized in figure 3.7. After the plane is fitted the normal of the plane is calculated. Next, the geodesic aspect is calculated by measuring the angle, in the clockwise direction, between the north and the perpendicular projection of the surface normal on the reference plane on the ellipsoid [63].

3.3.2. Implementation in the new method

The first step is to calculate the slope and aspect of the whole area of interest. For the execution of the slope and aspect function, the method is set to geodesic. The geodesic buffers are not influenced by the distortion from a projected coordinate system [65].

Second, for each of the slope types, the cells with a suitable combination of slope value and aspect value are selected. Figure 3.8 shows an example of the forward slope type. In orange, the input raster with slope and aspect values are visualized. In blue, the variables flight direction and maximum slope value are visualized. These variables can be adjusted before running the new method. The green part shows the resulting raster. The suitable cells are given value 1 using the remap function. The remap function makes it possible to change or reclassify the pixel values of the raster data [66]. The unsuitable cells are given value 0. This workflow is also executed for the reverse slope type and lateral slope type. The variables can be adjusted for the different slope types.

The suitable cells of each of the slope types are combined with the 'boolean and' function. The 'boolean and' function gives the cell of interest value 1 if all the corresponding input raster cells have value 1. If one or more of the corresponding input raster cells have value 0, the 'boolean and' function will output value zero [67]. The pixels with value 1 after applying the 'boolean and' function are the pixels where both the slope and the corresponding aspect are suitable.

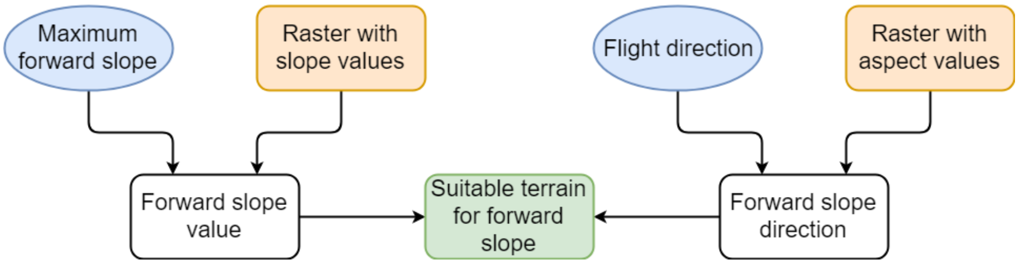


Figure 3.8: A visualization of how a suitable terrain is found for a forward slope. The raster with slope values and the raster with aspect values are combined with requirements for each of the rasters. The combination of the slope and the aspect will result in a suitable terrain. The suitable cells are given value 1. The other cells will get value 0.

3.4. Shoots

The end point of the section about the slope and aspect is the starting point for the section about the shoots. From this point, multiple steps are taken which will result in a suitable area for both the slope and the shoots. First, the used functions are explained. Then, the process of calculating the shoots is discussed.

3.4.1. Explanation of the functions

Raster to Polygon

The 'Raster to Polygon' function converts a raster dataset to polygon features. The different values in the raster dataset will result in different polygon features. In the function, the option is available to simplify the output of the function. If this function is turned on, the edges of the polygons are smoothed. This function is not used in the ModelBuilder because the result must represent the original area of the raster dataset [68].

Grid Index Features

The 'Grid index features' function overlays a data layer with a grid of rectangular polygons. The size of the rectangular polygons can be set in the x-direction and y-direction or the total number of columns in x-direction and y-direction can be set. Inside the function, there is the option to 'Generate Polygon Grid that intersects input feature layers or datasets'. In practice, this means the grid is only generated where the polygon intersects with the data layer which is overlayed [69].

Features to Point

The 'Features to Point' function creates a point at the centroid of the input feature. This can be done for point features, line features and polygon features. The function has an option called 'Inside'. When this option is turned on the output point will be placed on top of a point or line feature or inside a polygon feature [70]

Extract Values to Points

The function 'Extract Values to Points' extracts the cell values of a raster layer at the location of a set of point features and records the values in the attribute table of the output feature class [71].

Create Sight Lines

The function 'Construct Sight Lines' function creates line features that represent sight lines from one or more observer points to features in a target feature class. If the target features class consists of lines or polygons the 'Sampling Distance' parameter must be used. With the 'Sampling Distance' sight lines can be created with an interval at the line or border of the polygon [72]. The 'construct sight lines' function has to option to output the azimuth and vertical angle in the attribute table.

Line of Sight

The 'line of sight' tool calculates intervisibility between the first and last vertex of each line feature given its position in 3D space relative to the obstructions provided by a surface or multipatch feature class. The first vertex defines the observation point, whereas the last is the observation target. The result of this function is a feature class containing the column 'TarIsVis' in the attribute table. The

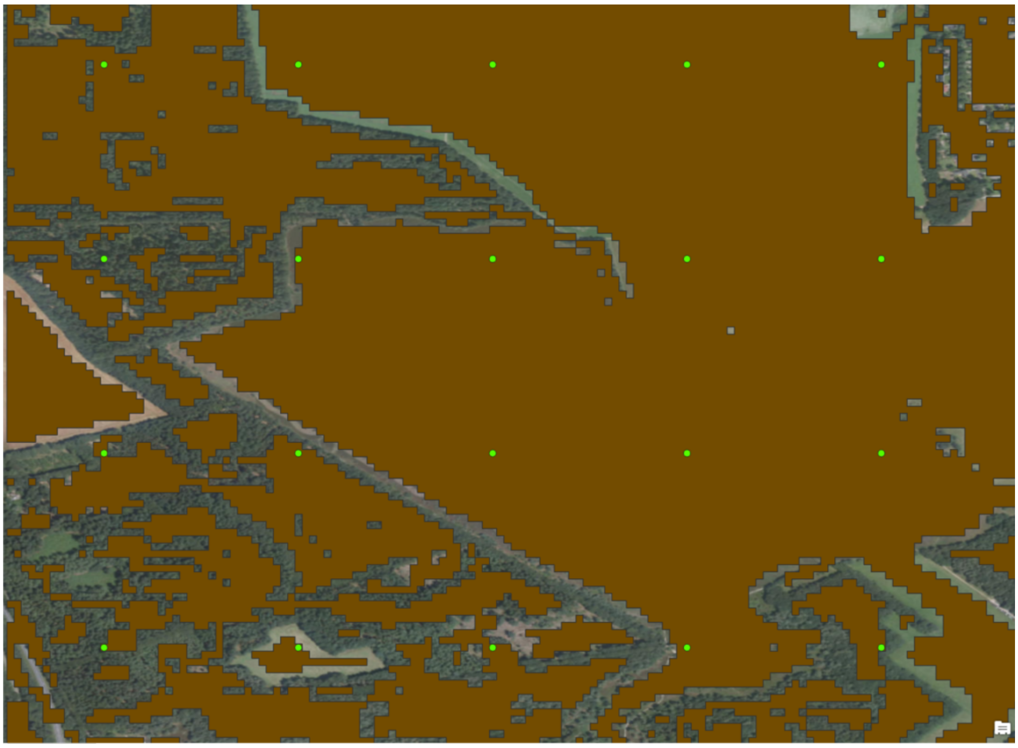


Figure 3.9: The area suitable regarding the slope and aspect requirements is given in brown. The green points are the observer points. The interval between the observer points can be adjusted.

'TarIsVis' field describes whether the target point is visible from the observer by using a value of 1 to denote visibility and 0 for non-visibility. Inside the tool, there is an option to generate a feature class with obstruction points. The obstruction point is the first location along the sight line that impedes the observer's visibility of the target [28].

3.4.2. Implementation in the new method

To calculate the shoots using the ModelBuilder, multiple functions have to be executed consecutively. First, the resulting raster from the slope calculation is turned into a polygon using the 'Raster to Slope' function, see figure 3.9. In brown, the resulting polygon can be seen.

Inside the polygon, a raster of 'observer' points is created. From these points, a check is performed to see if the required shoots are possible. The observer points are created by executing the 'Grid index features' function, 'Feature to Point' function and 'Extract Values to Points' function after each other. The result is a grid of observer points, see figure 3.9. The height of the observer points is the height of the corresponding location in the Digital Surface Model.

From the observer points, sight lines are created using the 'Create Sight Lines' function, see figure 3.10. The starting points of the sight lines are the observer points. The starting point can be raised if necessary by filling in the 'Raise Observer Point' variable before running. This can be done to make sure the sight lines will not get blocked by small obstacles nearby which aren't in the interest of the Pathfinders [3]. The end points are created using a buffer and the 'Sampling Distance'. First, a buffer is built around each observer point. This buffer is then raised above the observer point. How large the buffer is and how much the buffer is raised depends on the variables in table 2.3. These variables are required as input for the new method. The edge of the buffer forms the end of the sight lines. The space between the end points can be set using the 'Sampling Distance'. Both for the start point and the end point the height can be given an option. This way the sight lines are created in 3D.

The sight lines are created 360 degrees around the observer point. Because the shoots only have to be calculated in the flight direction, it is possible to select only the sight lines in a certain direction.

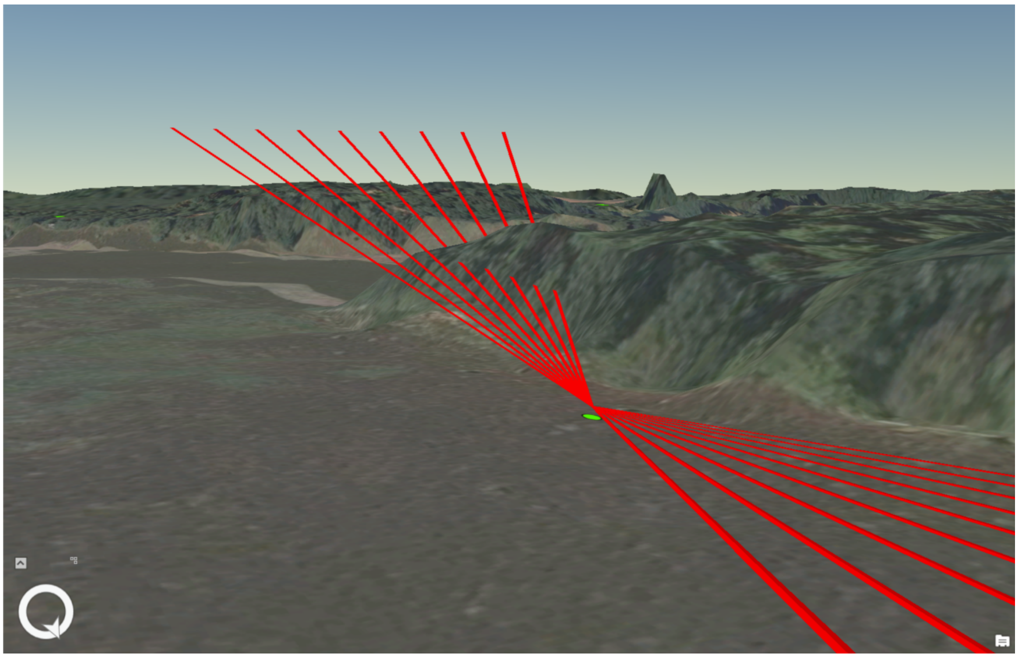


Figure 3.10: The sight lines are created 360 degrees around the observer point. The observer point is given in green. It is possible to select the sight lines according to the wind direction. A selection of the sight lines can be seen in red. Some sight lines are interrupted by the surroundings of the observer point. Only observer points with no interrupted sight lines are suitable regarding the shoot requirements.

If the main wind direction is not known at the time the new method is started, the selection step can be skipped. This way all the sight lines are selected for the next step. The resulting area of the new method is then suitable for any wind direction during the mission.

The sight lines are now created under the angle which must be clear for the incoming and outgoing aircraft. To check if the sight lines are clear the 'line of sight' function is executed. In the attribute table of the resulting feature class is noted if the start point and the end point have a clear line of sight with a 1. If there is no clear line of sight, a 0 is noted.

Combining shoots and slopes

Once all the sight lines are analyzed, the last steps of the new method can take place. For each of the observer points, a check is performed if one of the starting sight lines from this point is blocked. If any of the sightlines are blocked to observer point will be deleted.

The remaining observer points within the aggregation distance are connected and a polygon is formed. The aggregation distance is the maximum distance between observation points to be connected. The aggregation distance must be equal to the polygon length used in the 'grid index feature' function [73]. This way gaps occur at places where observer points are deleted.

Because the generated grid with observer points is not as detailed as the raster generated in section 3.3.2 an error may occur. This error is prevented by executing the 'boolean and' function with the polygon created by the aggregation of the observer points and the result of the section 3.3.2 regarding the slopes.

3.4.3. Introducing a safety margin

The shoots are calculated by assuming the height given by the Digital Surface Model is correct. In chapter 2 the different Digital Surface Model are discussed together with their vertical accuracies. Due to this vertical accuracy, the actual height might be higher than given in the Digital Surface Model. A higher actual height results in an unsafe situation for helicopters. To prevent this unsafe situation a safety margin should be built in. This safety margin is constructed by calculating what the horizontal impact would be for a vertical height change. The calculation can only be performed if the obstacle angles and the distance over which no obstacles may be present are known. The size of the safety buffer can be calculated by

$$b = \frac{d * \tan(a) + v}{\tan(a)} \tag{3.7}$$

where b is the size of the safety buffer in meters, d the distance to look for obstacles in meters, a is the obstacle angle used for the mission in degrees and v the vertical uncertainty in meters. The size of the safety buffer should be subtracted from the original landing zone given by the new method.

3.5. Summary

With the help of the ModelBuilder in ArcGIS Pro, a new method is made to calculate potential landing zones. The new method is built by a sequence of functions where the output of a function is the input for the following function. Parameters inside the functions are converted to variables outside of the function. The variables van be filled in the side panel before running the new method. By filling in variables such the DSM, the flight direction, the maximum slope and the obstacle angle, the new method becomes highly modular. The modularity makes it possible to adjust the new method specifically to a mission. The result is a polygon which is suitable for both the slope and the shoots. To incorporate the uncertainty in height in a Digital Surface Model it is possible to apply a safety buffer. In the next chapter, the results of the new method are verified in different case studies.

4
Results

In the previous chapter, the ModelBuilder is introduced and the new method is explained. The way the new method can be executed using the side panel is highlighted and the settings in the functions are discussed. In this section, the new method is being tested in different areas. The areas are chosen to be as similar as real mission areas as possible. The military will avoid areas in cities, forests and highly populated areas. Therefore grassland, dunes, heathland and semi-urban area are the preferred areas. These areas will be highlighted and the other areas are ignored in this research. Three of these areas are used in the case studies. Grassland is the subject of the Valkenburg case study and heathland is the subject of the Exloo case study. For both Valkenburg and Exloo three different Digital Surface Models are available, the WorldDEM DSM, the AHN DSM and the drone DSM. The third case study, about the Edesche Heide, is a heathland area for which the WorldDEM DSM and the AHN DSM are available. The drone DSM is not available because no permissions have been given to fly a drone over the area.

The goal of the case studies is to test whether the WorldDEM Digital Surface Model is a useful product to locate potential landing zones. This is done by comparing the results of the new method for the WorldDEM, AHN and drone Digital Surface Models. It should be noted that all the case study areas are located in the Netherlands. Therefore, results can't be extrapolated to comparable regions worldwide or to new types of area without additional research.

All the case studies are structured in the same way. First, a description of the area is given. In this subsection, the features in the area are described, such as vegetation and height differences. Also, the ground cover present in the area will be discussed. Next, a comparison between the Digital Surface Models is made. First, in general, the biggest differences will be discussed. Later on, a more detailed comparison will be done in the area where the helicopter most likely can land.

The last comparison that will be made, are differences between the resulting landing zones. For the different areas, the outputs of the new method for the different Digital Surface Models will be given. For the case studies, a wind direction is assumed from south-west to northeast. The figures are all oriented with the top of the figure pointing in the north direction. Included are the sight lines ranging from 10 to 40 degrees azimuth and from 190 to 220 degrees azimuth.

4.1. Airbase Valkenburg

4.1.1. Description of the area

The first location is at the location where the former airbase Valkenburg used to be, see figure 4.1. The eastern and northern parts of the area are relatively flat. This area is covered with grass and old concrete runways. A tree line is situated at the western border of the area. In the south-west part of the area, there was a helicopter landing point fenced with a small dike. In the southern part of the area excavation works were going on. The total area measured is 0,2 square kilometers.

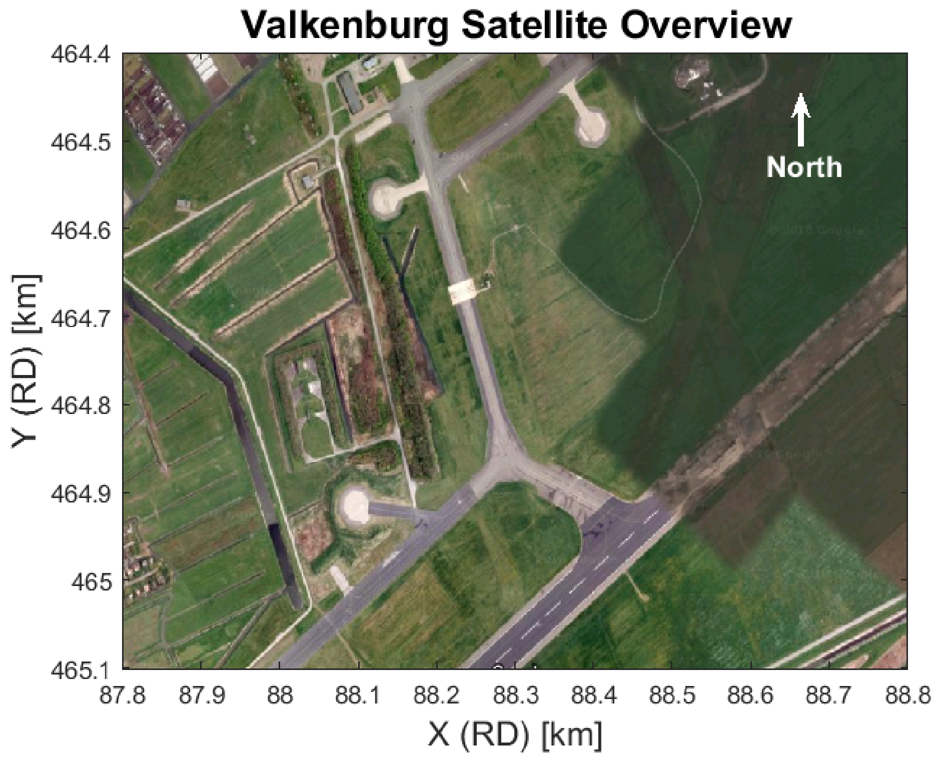


Figure 4.1: An overview of the area of the Valkenburg case study.

As mentioned in section 2.2.3 ATMOS UAV equipped the drone with a multispectral camera recording the bands red, green, blue, red edge and near infrared. In total 1645 images are used, but even more were taken during the flight. Using the photogrammetry software of Pix4D a Digital Surface Model is created with a pixel size of 8 centimeters.

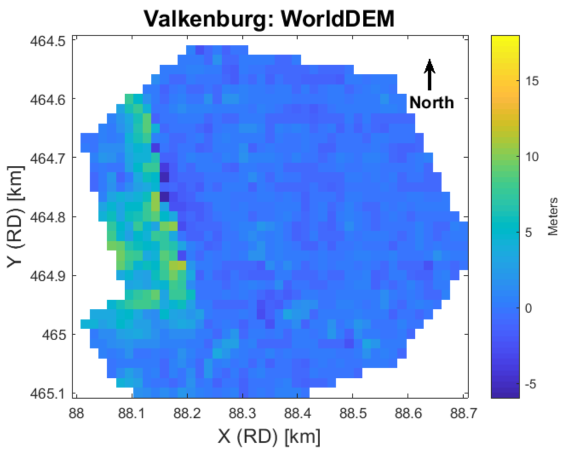
4.1.2. Comparing the Digital Surface Models

The features described above are all visible in the different Digital Surface Models. The trees on the east side of the figure are in all Digital Surface Models clearly visible. The excavation works in the southern part are only visible in the most recent Digital Surface Model: the Drone Digital Surface Model. The grassland on the right side of the image is in the WorldDEM figure not a flat surface. The height of the grass differs throughout the field. However, the drone and the AHN Digital Surface Models show relative constant heights in the grass field. This is remarkable because you should expect that the satellite would show the least local height differences due to the fact the local height differences are averaged out in pixels of 12 by 12 meters. The Digital Surface Models of WorldDEM, AHN3 and the drone can be seen respectively in figures 4.2a, 4.2b and 4.2c.

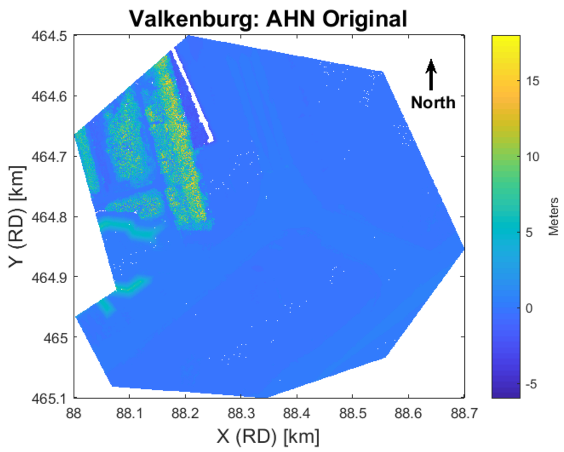
To see what the differences are between the Digital Surface Models, the Digital Surface Models are subtracted from each other, see figures 4.3a, 4.3b and 4.3c. Before subtracting the pixels size of the AHN3 and drone Digital Surface Model is resized to the pixel size of the WorldDEM. There are three figures with differences: WorldDEM - AHN3, WorldDEM - Drone and AHN3 - Drone.

The largest errors occur in the areas where trees are present. For every difference calculated between the three Digital Surface Models, the differences, both positive and negative, are relatively high at the tree sections compared to other areas. Also, the excavation works are visible in difference figures where the Drone Digital Surface Model is used.

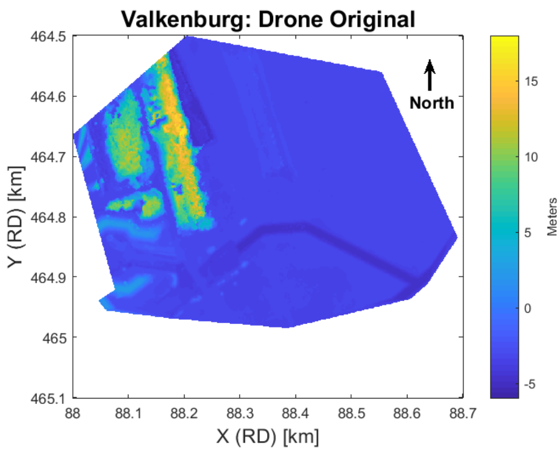
The grass field gives a non-constant picture in the differences where the WorldDEM is used. The differences between the AHN3 and the drone Digital Surface Model show a constant difference despite



(a) A top view of the WorldDEM Digital Surface Model for the Valkenburg Area.

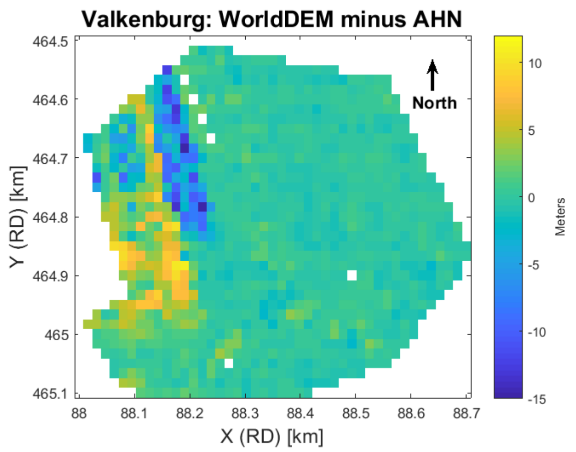


(b) A top view of the AHN3 Digital Surface Model for the Valkenburg Area.

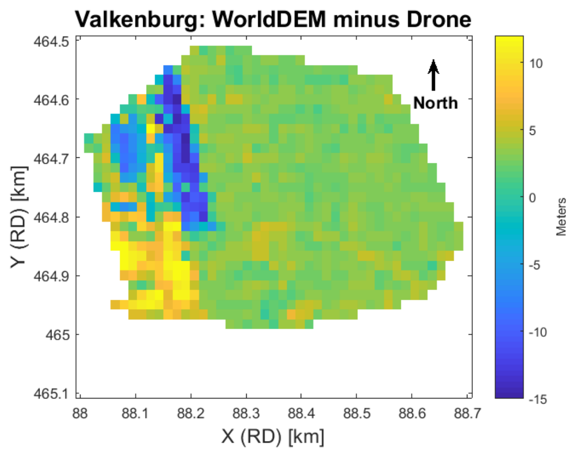


(c) A top view of the Drone Digital Surface Model for the Valkenburg Area.

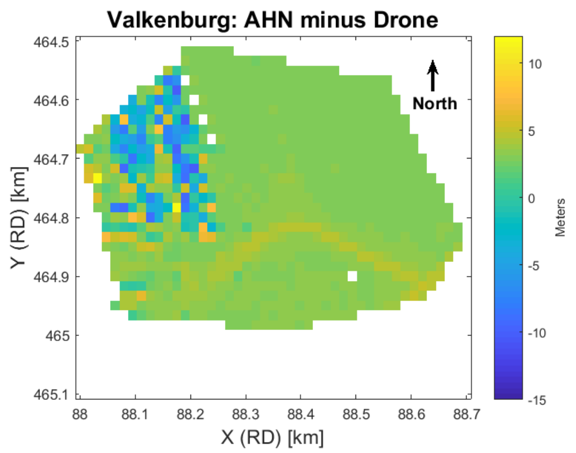
Figure 4.2: For the Valkenburg case study three different Digital Surface Models are available, the WorldDEM DSM, the AHN DSM and the drone DSM. The heights are given in meters above NAP. In all the three DSMs the tree line, on the left side, is clearly visible. The drone DSM is the only DSM showing the recent excavation works in the south, seen by the darker blue line.



(a) The differences in height between the WorldDEM and AHN3 Digital Surface Model.



(b) The differences in height between the WorldDEM and Drone Digital Surface Model



(c) The differences in height between the AHN3 and Drone Digital Surface Model.

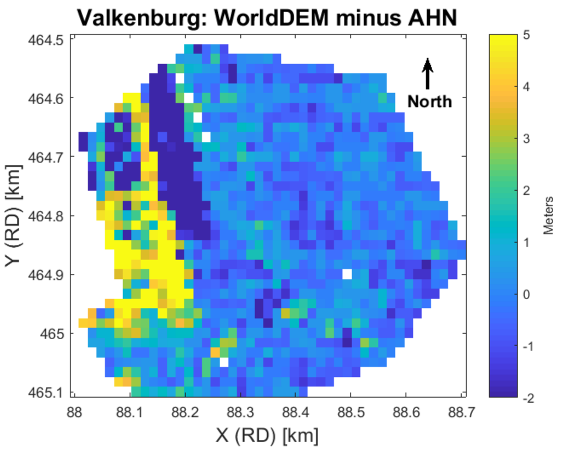
Figure 4.3: The differences between the three Digital Surface Models. The differences are given in meters. The largest differences, both positive and negative, occur at the location of the trees. The grass field and the concrete runways show relative low differences.

the different techniques used.

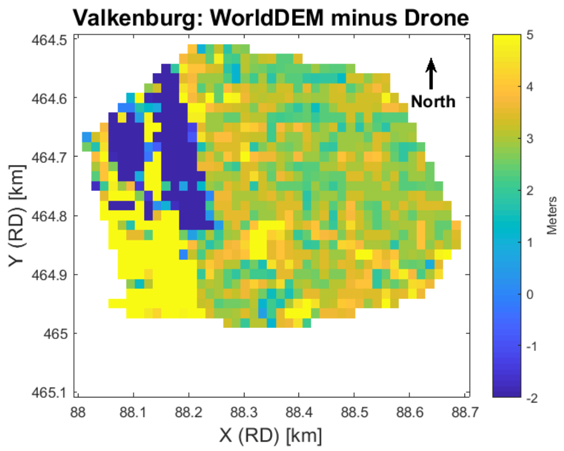
To have a better look at the differences in the grass field a second set of figures is made. In this second set, the color bar is limited to the differences seen at the grass field. This way, more high-contrast figures for the grass field are created. These high-contrast figures can be seen in figures 4.4a, 4.4b and 4.4c. In the high-contrast images too, the differences in the grass field are not constant when the WorldDEM is used. Smaller and more constant differences can be seen in the figure with differences between AHN and the drone DSM. In the figure with differences between AHN and the drone DSM, the excavation works in the bottom of the image are clearer than in the other high-contrast figures. In figures 4.5a, 4.5b and 4.5c the another set of detail figures is given. The set in the appendix does not have an equal colorbar for the three figures. This way is the height differences are more contrast rich.

4.1.3. The resulting landing areas

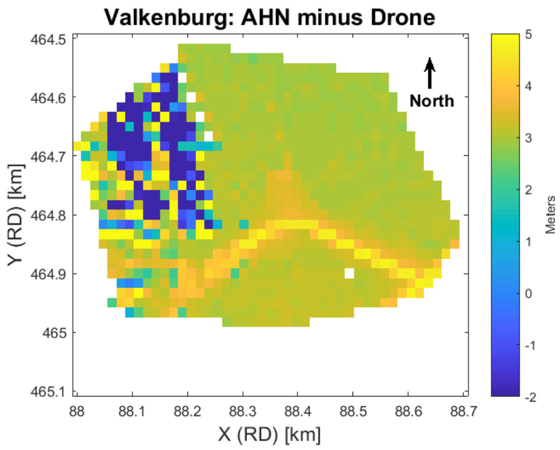
The resulting potential landing areas produced by the new method differ for each of the input Digital Surface Models. The WorldDEM Digital Surface Models as input results in a large potential landing area, see figure 4.6a. Most of the landing area is situated on the grassland to the east of the treeline. Large gaps are present in this part of potential landing zone despite the fact there are no obstacles in the



(a) The differences in height between the WorldDEM and AHN3 Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.

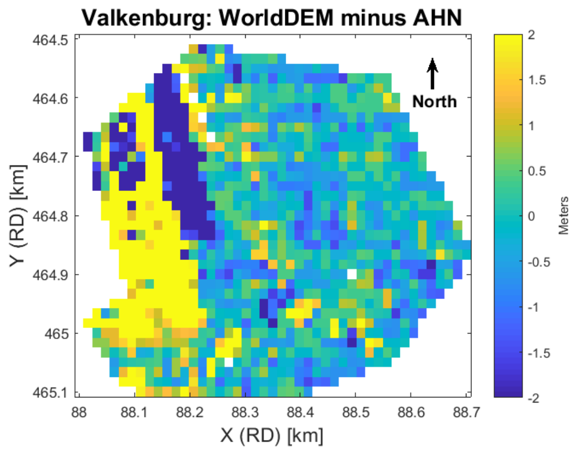


(b) The differences in height between the WorldDEM and Drone Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.

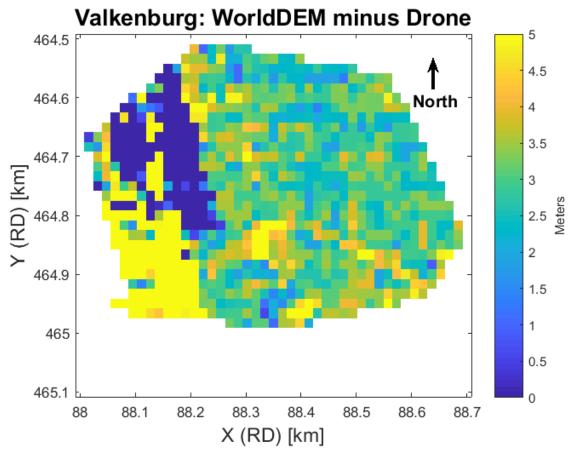


(c) The differences in height between the AHN3 and Drone Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.

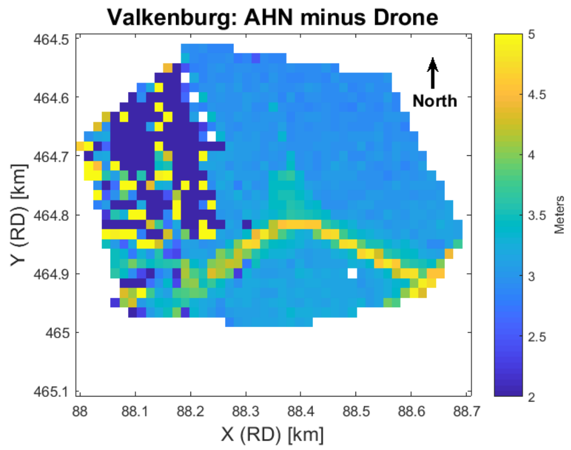
Figure 4.4: To have a better look at the differences at the grass field, the color bar is limited to the occurring differences at the grass field. This way more high-contrast figures for the grass field are created.



(a) The differences in height between the WorldDEM and AHN3 Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.

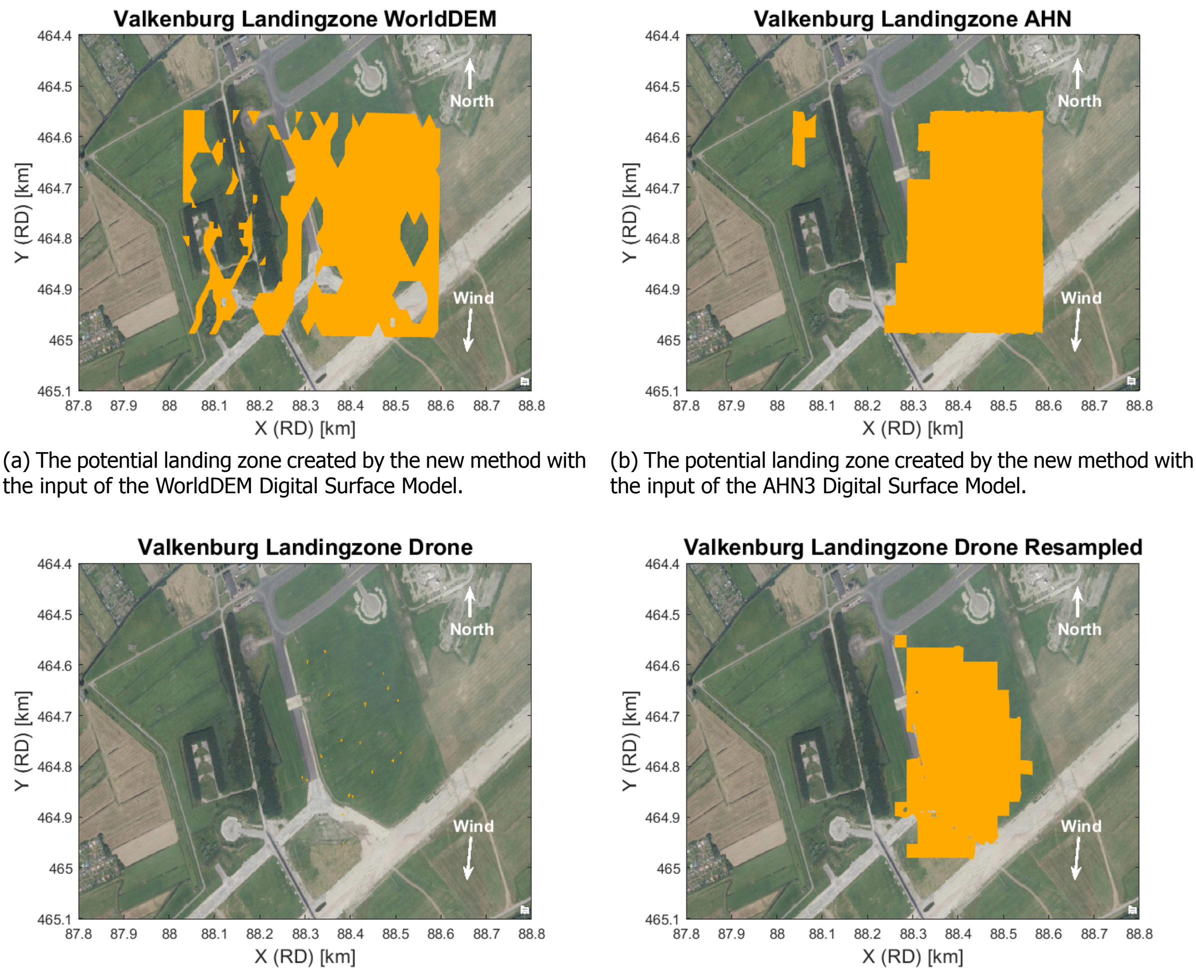


(b) The differences in height between the WorldDEM and Drone Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.



(c) The differences in height between the AHN3 and Drone Digital Surface Model. The color bar is limited to the differences seen in the grass field. This way a more contrast rich figure is created.

Figure 4.5: To have a better look at the differences at the grass field, the color bar is limited to the occurring differences at the grass field. This way higher contrast figures for the grass field are created.



(a) The potential landing zone created by the new method with the input of the WorldDEM Digital Surface Model.

(b) The potential landing zone created by the new method with the input of the AHN3 Digital Surface Model.

(c) The potential landing zone created by the new method with the input of the Drone Digital Surface Model.

(d) The potential landing zone created by the new method with the input of the Drone Digital Surface Model resampled to pixels of 50 centimeters.

Figure 4.6: The new method is executed for the different Digital Surface Models available for the Valkenburg case study. The resulting landing zones from the new method are

flight direction.

If the AHN3 Digital Surface Model is used as input for the new method the results are more as expected, see figure 4.6b. Almost the whole grass field to the east of the treeline is appointed as a potential landing zone. The whole area is filled with no gaps. Also, a small landing area in the north-west corner of the case study area is appointed as a potential landing zone.

The input of the drone Digital Surface Model for the new method does not result in useful landing zones. The potential landing zones are splintered in tiny fragments, see figure 4.6c. These fragments are located in the same area where the WorldDEM and AHN Digital Surface Model results are located. So the found location is in accordance with the other Digital Surface Models, but the size of the potential landing zone is not in accordance. The splintered result is due to the very small pixel size of the drone Digital Surface Model. With a pixel size of only 8 centimeters, the drone Digital Surface Model is smaller than the 50 centimeters of the AHN Digital Surface Model and the 12 meter of the WorldDEM Digital Surface Model. Due to this small pixel size, the slope is calculated over small distances. This will result in the fact that relatively small local height difference can cause a too high slope size regarding the requirement. These local exceedances lead to a splintered area.

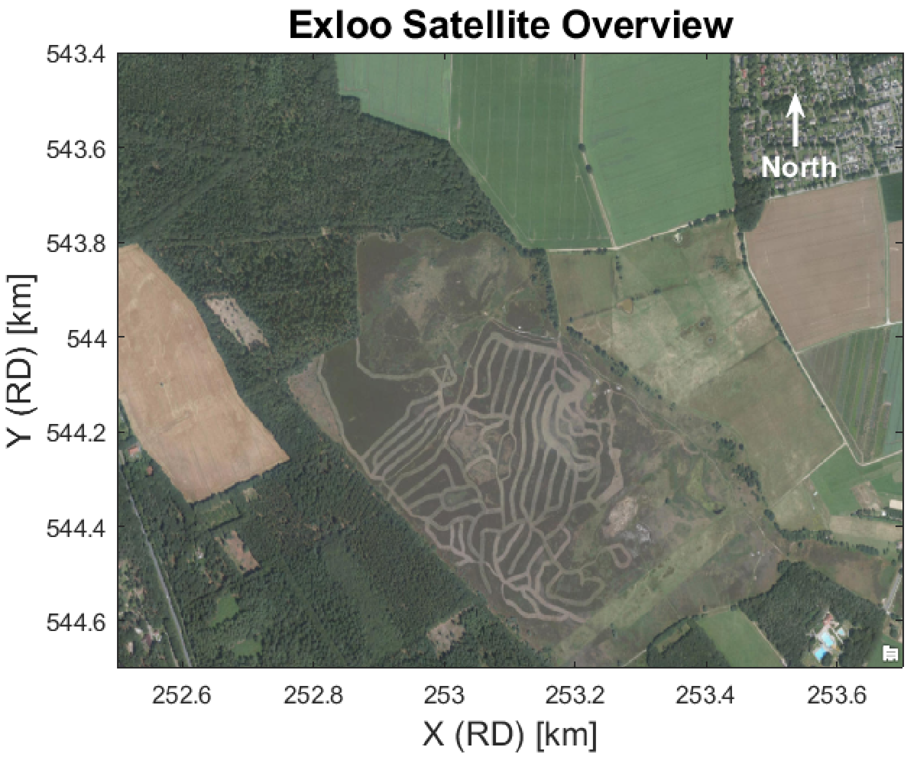


Figure 4.7: Satellite overview of the heathland near Exloo.

The drone Digital Surface Model with its original pixel size is not useful. To prevent the splintered result, the pixel size of the drone Digital Surface Model is increased to a pixel size of 50 cm. A pixel size of 50 centimeters is chosen because the AHN DSM also has pixels of 50 centimeters. A good comparison can be made now the pixel sizes in both Digital Surface Models are equal. All the pixels overlapping the new pixel size are averaged to create one new value for the new pixel size. The averaging of data will probably introduce an error because the original height is replaced. This resampled drone Digital Surface Model is then used as input for the new method. The results can be seen in figure 4.6d. The potential landing zone resulting from the new method is now a contiguous area to the east of the treeline. This location matches the location of the potential landing zone resulting from the input of the AHN3 Digital Surface Model. Differences occur at the southern part. The recent excavation works are only present in the drone Digital Surface Model. The resampled drone Digital Surface Model shows no potential landing zone at the place of the excavations.

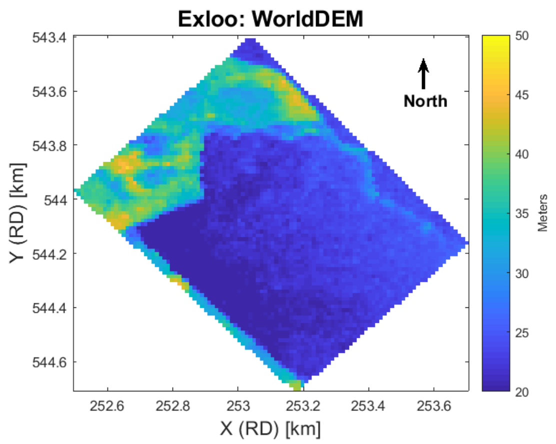
4.2. Exloo

Description of the area

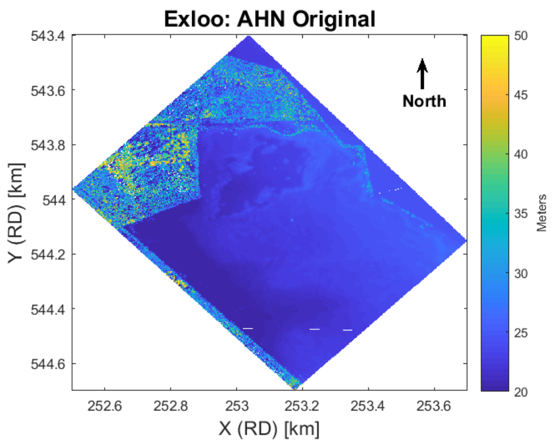
The location in Exloo is situated at a heathland near the village. The height in the heathland is much more varying in height than the area at the airbase. The terrain is surrounded with forest in the northern and western part and by a tree line in the eastern part. The southern border the heathland continues without a natural border. The ground is covered by heathland, low grass, high grass and small bushes. Throughout the terrain, there are freestanding trees and in the south, there is a small swampy area. In total, the area measured is 0,8 square kilometers and can be seen in figure 4.7.

4.2.1. Comparing the Digital Surface Models

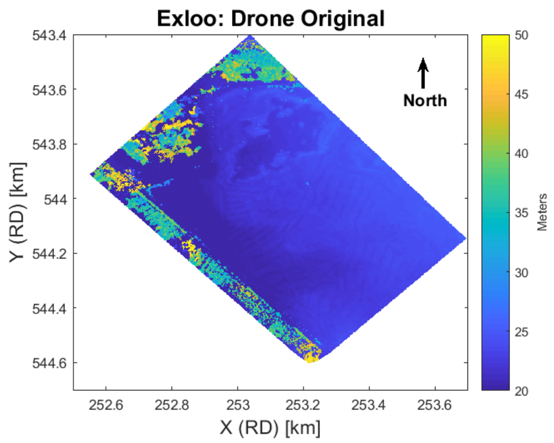
The first set of images, figures 4.8a, 4.8b and 4.8c, represent the original Digital Surface Models how they are exported from ArcGIS Pro. In all the figures the full range of values is plotted, which can be seen in the color bar at the side of the figure. In all of the images, the trees at the edges of the



(a) Representation of the WorldDEM Digital Surface Model of the heathland near Exloo.



(b) Representation of the AHN2 Digital Surface Model of the heathland near Exloo



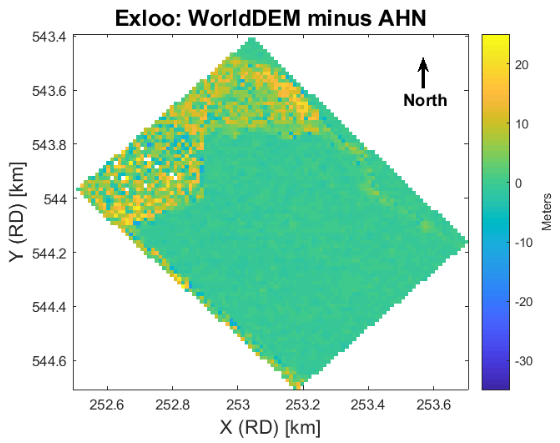
(c) Representation of the Drone Digital Surface Model of the heathland near Exloo

Figure 4.8: The heathland near Exloo is available in three different Digital Surface Models, the WorldDEM DSM, the AHN DSM and the drone DSM.

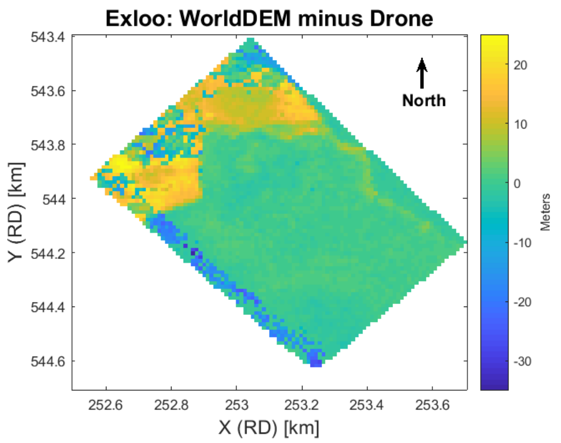
heathfield are visible. The heathfield itself is in all the figures relatively flat, which at first view makes it a suitable landing area.

To visualize the differences between the Digital Surface Models the different Digital Surface Models are subtracted from each other. The pixel sizes of the Digital Surface Models differ and therefore all the pixel sizes are made equal to the pixel size of the WorldDEM. This means the multiple pixels of the AHN and Drone Digital Surface Models are averaged to the pixel size of the WorldDEM. The differences between the Digital Surface Models are given in figures 4.9a, 4.9b, 4.9c. The differences at the locations of trees are, both positive and negative, larger than the errors of the heathland itself.

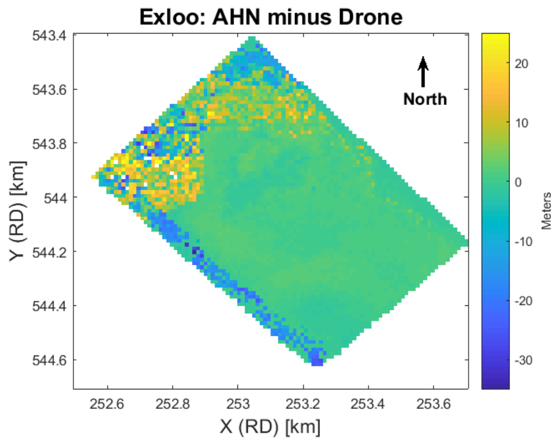
To have a better look at the differences at the possible touch down area of the helicopters the minimum and maximum differences are set to what is visible at the heathland itself. This can be seen in figures 4.10a, 4.10b, 4.10c. The detailed figures show differences between -2 and 2 meters. If the drone Digital Surface Model is part of the difference then there is some gradients are visible in the heathland. The difference between AHN and WorldDEM shows an almost uniform difference throughout the heathland.



(a) Difference between the WorldDEM Digital Surface Model and the AHN2 Digital Surface Model.

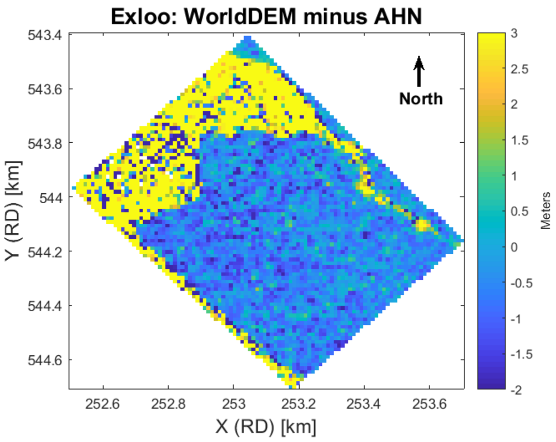


(b) Difference between the WorldDEM Digital Surface Model and the Drone Digital Surface Model.

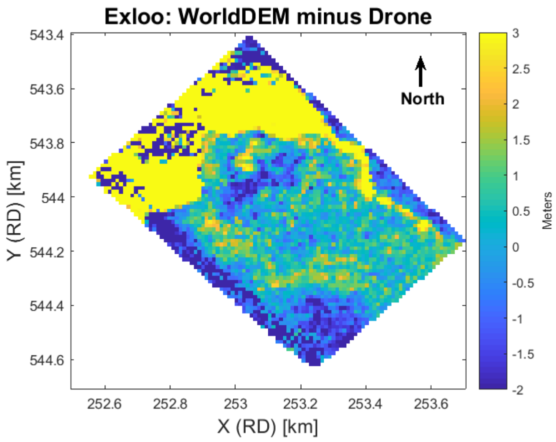


(c) Difference between the AHN2 Digital Surface Model and the Drone Digital Surface Model.

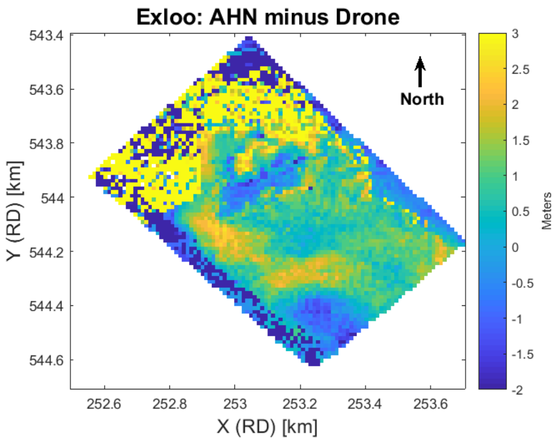
Figure 4.9: The differences between the three available Digital Surface Models.



(a) Difference between the WorldDEM Digital Surface Model and the AHN2 Digital Surface Model. The color bar is limited so a more detailed overview is created of the potential touch down area.

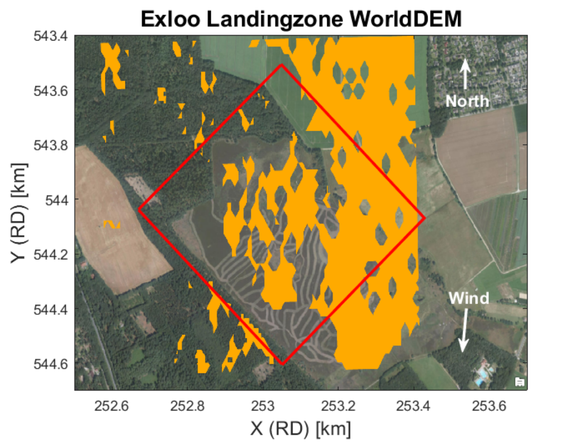


(b) Difference between the WorldDEM Digital Surface Model and the Drone Digital Surface Model.The color bar is limited so a more detailed overview is created of the potential touch down area.

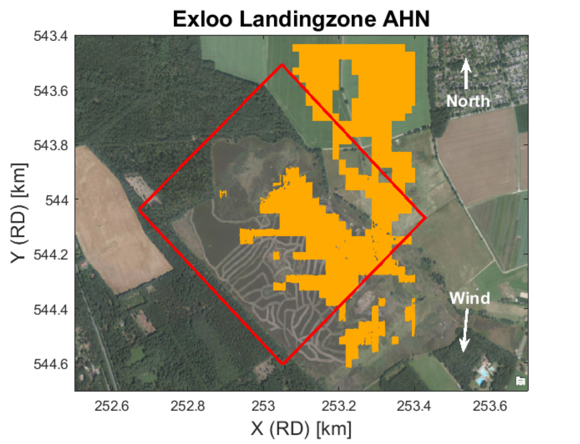


(c) Difference between the AHN2 Digital Surface Model and the Drone Digital Surface Model.The color bar is limited so a more detailed overview is created of the potential touch down area.

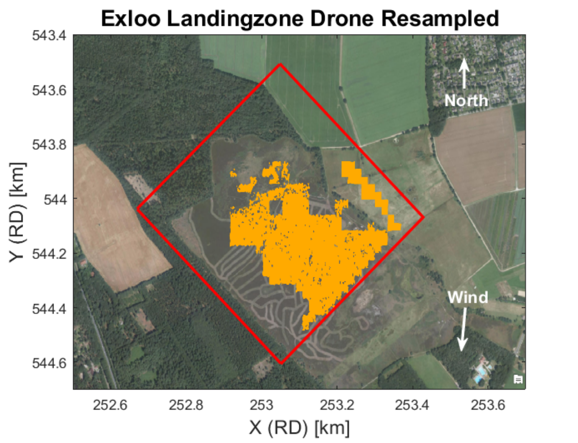
Figure 4.10: The differences between the three available Digital Surface Models. The color bars are limited to be able to see more details in height differences at the heathland.



(a) The resulting potential landing area from the new method with the WorldDEM Digital Surface Model as input.



(b) The resulting potential landing area from the new method with the AHN2 Digital Surface Model as input.



(c) The resulting potential landing area from the new method with the Drone Digital Surface Model. The pixel size of the DSM is resampled to 50 centimeters.

Figure 4.11: The resulting potential landing zones in orange for the Exloo case study. The area marked by the red square is the area available for all the Digital Surface Models. The wind direction is indicated by the arrow in the lower right corner.

4.2.2. The resulting landing area

The results for the Exloo case study are not unambiguous. The result acquired with the WorldDEM as input shows a potential landing zone in the eastern corner and northern part of the heathland. This can be seen in figure 4.11a. Not only the eastern and northern part of the heathland shows up as a potential landing zone, but also the grassland to the north of the heathland is marked as a potential landing zone. Important to notice is the fact the WorldDEM results also show potential landing zones on top of a forest.

Once the AHN Digital Surface Model is given as input for the new method the results are comparable with the WorldDEM results. From the northern part towards the northeastern part of the heathland, a potential landing zone is marked, see figure 4.11b. Also, the grassland to the north of the heathland is marked as a potential landing zone, like the WorldDEM results. Although the locations of the potential landing zones are in general in the same area there are differences in the exact locations. For both the AHN and the WorldDEM Digital Surface Model the field to the west is not appointed as a potential landing zone.

The input of the drone Digital Surface Model resulted in no potential landing zone at all. The pixel size of 5 centimeters is apparently too small. Just like in the Valkenburg case study the pixel size of

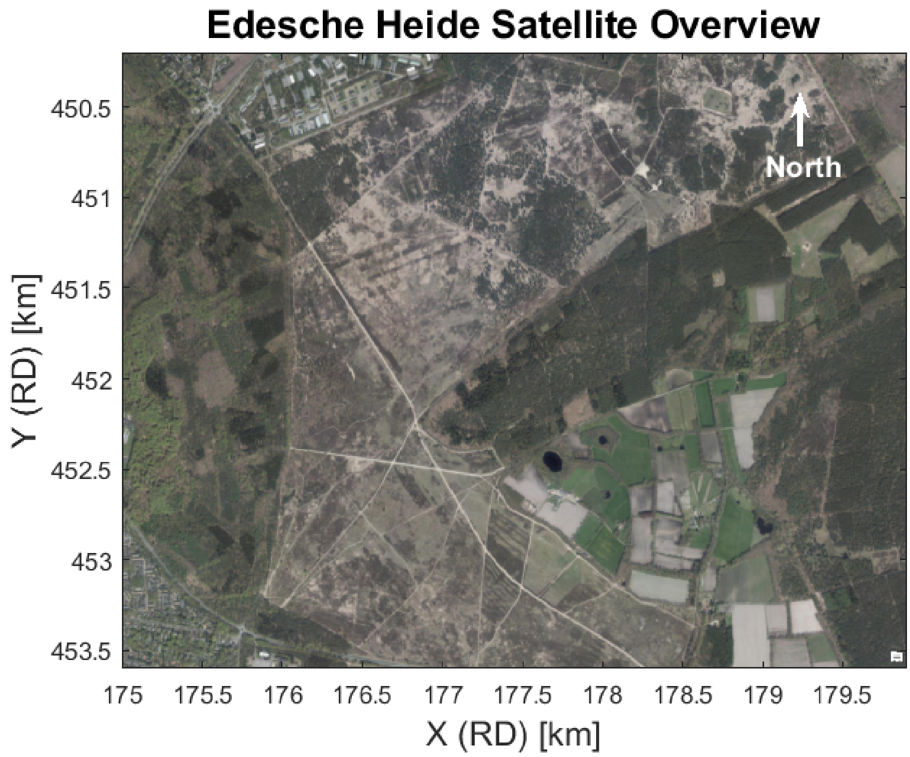


Figure 4.12: The area of the Edesche Heide case study

the drone Digital Surface Model is increased to 50 centimeters. This is also done by averaging multiple pixels to one new pixel value. Once this resampled Digital Surface Model is given as input to the new method the result looks better, see figure 4.11c. The result is comparable with the result of the AHN2 results. The northeastern part of the heathland is appointed as a potential landing zone. Also, the part of the grassland to the north of the heathland is appointed as a potential landing zone, just like in the WorldDEM and AHN2 results are visible. The part is limited in size because of the extent of the drone Digital Surface Model. The square hole in the potential landing zone in the western part is due to a freestanding tree.

4.3. Edesche Heide

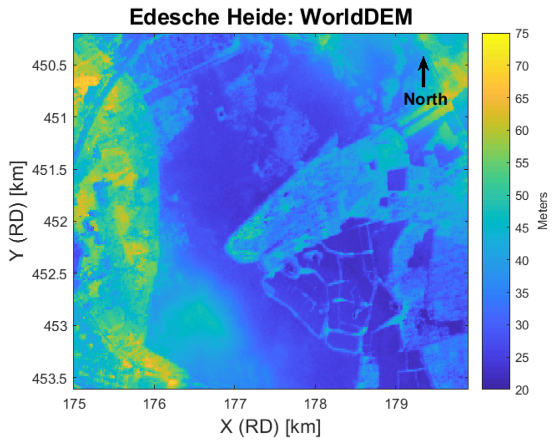
4.3.1. Description of the area

The heathland near Ede is often used for a military practice of helicopter landings. The heathland consists of small bushes, short grass, tall grass and varies sand paths. Except for the western part the heathland is surrounded by trees. The trees in the west and east form a thick forest, while the trees to the north form a thin forest. To the south of the heathland, a hill is located. The heathland flows into grassland, bushes and freestanding trees going up the hill.

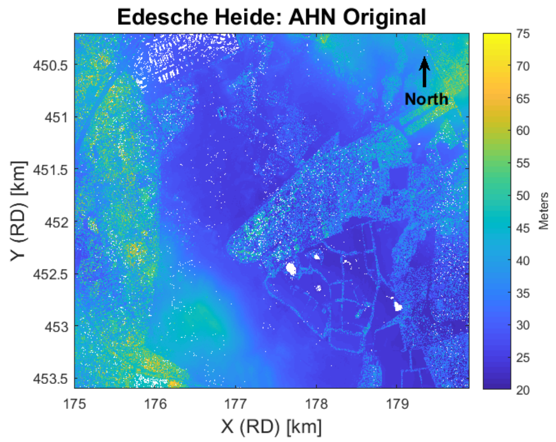
For this area, it is not allowed to fly with drones unless a clearance is given by the fight controller of the Ministry of Defence. Because of these regulations, it was not possible to fly over the Edesche Heide with a drone. Therefore there is no drone Digital Surface Model available in this area and only the WorldDEM Digital Surface Model and the AHN3 Digital Surface Model will be used.

4.3.2. Comparing the Digital Surface Models

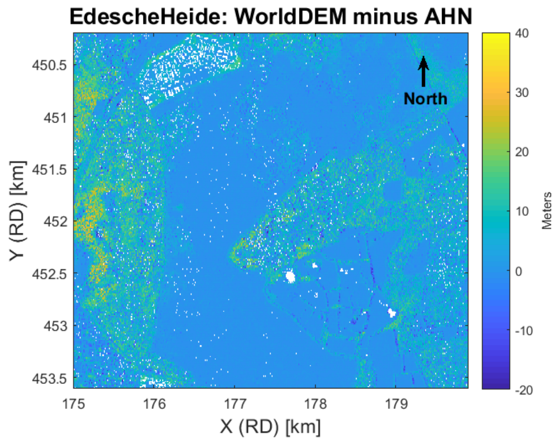
For both the Digital Surface Models the height of the described features in the previous section are visible, see figures 4.13a and 4.13b. The forest is visible, the hill is visible and also the patches of farmland in the east are visible. The heathland and the vegetation on the hill are in both Digital Surface



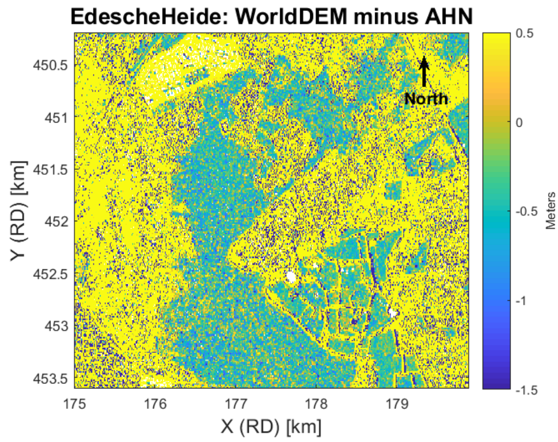
(a) The WorldDEM Digital Surface Model of the Edesche Heide.



(b) The AHN3 Digital Surface Model of the Edesche Heide.



(c) The difference between the WorldDEM and the AHN3 Digital Surface Models. A correction is applied to set both Digital Surface Models in the same vertical reference system.



(d) The difference between the WorldDEM and the AHN3 Digital Surface Models. The color bar is fixed between -1 and +1 meters to create an high contrast figure of the differences on the heathfield and on the hill.

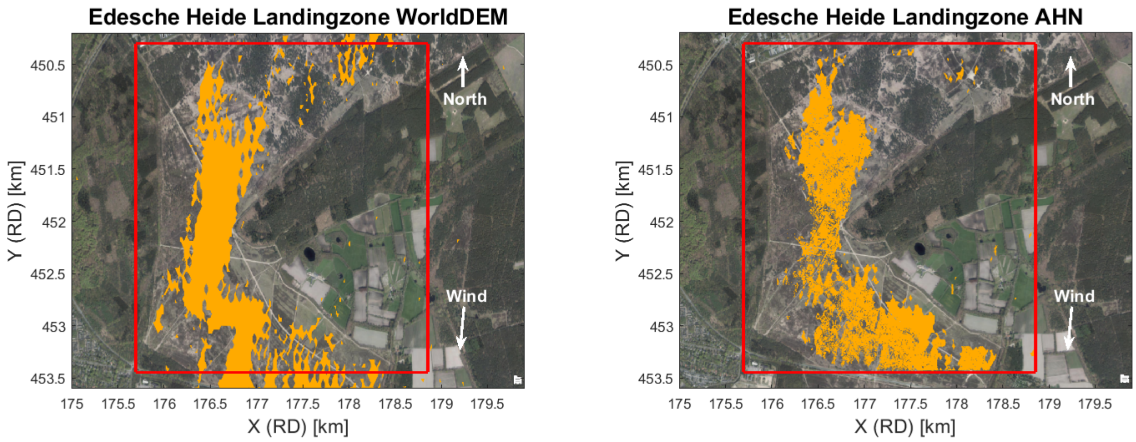
Figure 4.13: The original Digital Surface Models together with the difference between the Digital Surface Models. Two figures with the differences are included. One with the full range of differences and one with a limited range to be able to see the differences at the heathland in detail.

Models represented as flat areas.

To calculate the differences the pixel size of the AHN3 Digital Surface Model, which is originally 0,5 meter, is resampled to 12 meters. This is the pixel size of the WorldDEM Digital Surface Model. The resampling is done by averaging all the AHN3 pixel inside a WorldDEM pixel. The result of the average is given to the new pixel of the AHN Digital Surface Model.

Differences occur in the fact that the AHN Digital Surface Model can represent the height of free-standing trees more accurate. Due to the smaller pixel size, the height of the tree is not averaged with the surrounding ground. This averaging with the ground surrounding the tree is also visible in the thin forest to the north of the heathland and the trees surrounding the farmland in the eastern part.

The height differences between the Digital Surface Models are calculated by taking the height in the WorldDEM and subtract the height of the AHN Digital Surface Model. The resulting differences at the heathfield, the farmland and the hill area are all between -1 and +1 meter. In the areas where a thick forest is present the results are not as uniform as the mentioned difference above. The differences are larger both positive and negative. The sections with thin forest or lines of trees show a more constant



(a) The potential landing zones resulting from the new method with the input of the WorldDEM Digital Surface Model.

(b) The potential landing zones resulting from the new method with the input of the AHN4 Digital Surface Model.

Figure 4.14: The potential landing zones, in orange, generated by the new method in the Edesche Heide case study. The area marked by the red square is the area available for all the Digital Surface Models. The wind direction is indicated by the arrow in the lower right corner.

negative difference.

To check if the relatively flat areas are really flat a second set of images in added. In this second set of images the color bar is limited to differences between -1 and +1 meters, see figure 4.13d. This way the local height differences are more clearly visible.

4.3.3. The resulting landing area

The potential landing area marked by the new method using the WorldDEM Digital Surface Model is given in the heathland area. The results show long strips of potential landing area in the direction of the set flight direction. Just like in the Exloo case study, some of the potential landing areas is given on top of the trees surrounding the heathland.

Given the AHN digital surface as input for the new method, the results are much more centered at the center of the heathland. No areas are marked as potential landing zones where freestanding trees are present and no potential landing zones are located on top of the forest.

For an extra analysis with the knowledge of the Pathfinders the area to look for potential landing zones is increased for the WorldDEM and the AHN run, see figures 4.14a and 4.14b. For the World-DEM Digital Surface Model, the potential landing zone is extended. Beside the heathland also the hill to the south, the farmland to the east and another heathland to the north are looked in to. The hill to the south is for the largest part considered as a potential landing zone by the new method. There are some gaps present, but in general, it is considered to have potential as a landing zone. The farmland is only considered to be not suitable except for a few small spots. The heathland to the north is marked as potential area although in the flight direction some strips are marked as not suitable.

The extended area with the AHN3 Digital Surface Model as input show roughly the same potential landing zones. The hill to the south of the heathland is largely covered as a potential landing zone. The gabs in the polygon are smaller due to the smaller pixel size of the AHN3 which make it a more contiguous area. The farmland is just like the WorldDEM showed not suitable as landing zone except for a few small spots. The heathland to the north is marked as a potential landing zone although only for a few small spots.

4.4. Summary

For all the case studies, a potential landing zone can be generated using the new method. For the WorldDEM and the AHN Digital Surface Models, this went without any problems. For the Drone Digital Surface Model, a resampling must be applied because of the the small pixel sizes. The landings zones generated are roughly located in the same area. Although they are in the same area they are often not exactly in the same place. Especially the WorldDEM potential landing zones compared to the Drone and AHN potential landing zones are not aligned.

Furthermore, the WorldDEM potential landing zones are sometimes located on top of forest sections. Potential landing zones are also located on top of freestanding trees and dense vegetation of medium height. For the AHN and Drone Digital Surface Models also some potential landing zones are situated on top of medium-high dense vegetation.

The differences between the Digital Surface Models showed a relatively low difference in the areas which are covered with heath, grass or roads. Hills in the landscape do not cause larger errors. Larger differences are seen in the section where trees are present. The WorldDEM is consistently showing higher values than the AHN and Drone Digital Surface Models show at places with trees standing tightly together. At places with thin forest or where only one line of trees is present the AHN and Drone Digital Surface Models show higher values than the WorldDEM.

5 Discussion

The case studies in the previous chapter delivered two results. First, the potential landing zones calculated for each of the available Digital Surface Models per case study. Second a comparison between the Digital Surface Models available per case study. In this chapter, the differences between the interesting type of areas will be discussed in more depth using variograms. Furthermore, the assessment of the Edesche Heide by the Pathfinders is compared to the results of the new method. The differences in the Digital Surface Models will be analyzed and last, the processing time is discussed.

5.1. Detecting suitable landing areas based on variograms of height

The Pathfinders are mainly interested in areas like dunes, grassland, heathland and semi-urban areas. Cities, forests or other areas with dense vegetation or urban characteristics will be avoided. Each of these areas has different characteristics like different types of vegetation, different gradients in the landscape and different types of soil coverage.

To have a better look at the height differences in each type of area variograms can be used. The empirical variogram can provide this correlation between height and distance in an area. A variogram can be described using three different parameters. First, there is the sill. The sill is the limit at which the variance remains constant over infinite step size. The higher the sill the more height differences are present in the area. The range is the distance before the sill is reached. If the range is small it means height differences are present in shorter distances. A larger range gives an indication of the height differences are present over larger distances. Last, the nugget is the jump invariance at the origin. This jump can be the effect of measurement errors and/or the effect of variations in height smaller than the sampling distance [74]. The sampling distance used is 10 meters. Height differences smaller than 10 meters are present in the area. This means the jump effect can be caused by height differences smaller than the sampling distance.

The variogram can be used to give a first indication of the potential of an area. The Pathfinders are looking for an area with no obstacles or big differences in height. In the variogram can this search be visualized as a line which won't reach the higher variances and stay as low as possible. Despite the fact that single freestanding obstacles won't be visible in the variogram, it could be used as a first indicator before further analyzing the area.

For each of the areas with interest, a variogram is made. This is done for all the available Digital Surface Models in the area. So differences between the data sets become visible. In figure 5.1 are all the variograms of the different types of areas shown. On the vertical axis, the variance in meters squared is visible and on the horizontal axis the distance in meters. For each type of area, the World-DEM Digital Surface Model is used. Not all variograms are the same length due to the fact, not every selected area is equal in size.

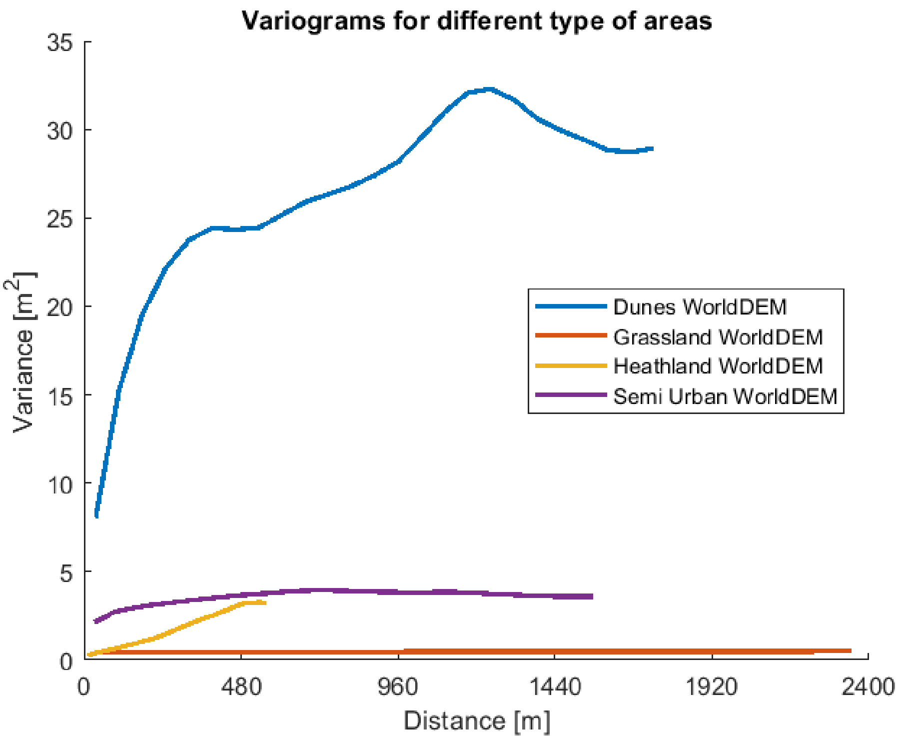


Figure 5.1: Variograms of the different types of areas in which the Pathfinders are interested. For all the variograms the WorldDEM Digital Surface Model is used. Not all variograms have to same length due to different size of the area type.

In the variogram can be seen that the sill of the grassland area is not higher than 1 meter squared. The sill of the heathland area and the semi-urban area are close to each other around 4 meters squared. The variogram of the heathland is much shorter than the other variograms so it is hard to say if the sill is actually reached. The sill of the dune area is the highest of the four area types with a sill of 30 meters squared.

To have a more detailed look at the variograms for the different area types the areas are separated. For each area also the variograms of the original AHN Digital Surface Model and the resampled AHN Digital Surface Model are added. The resampled AHN Digital Surface Model has the same pixel size as the WorldDEM Digital Surface Model of 12 meters. The variograms of the different areas are given in figures 5.2, 5.3, 5.4 and 5.5.

The difference between the empirical variograms in a certain type of area is relatively small. In the grassland area, the difference of the sill is 0,04 meters squared. For the heathland and the semi-urban area, the difference in sill between the empirical variograms is 0,4 meters. In the dune area, the difference in sill can be up to 15 meters squared. The variograms made out of the AHN Digital Surface Models are not reaching the sill seen by the shape of the variogram.

The sill is reached after about 500 meters, but the most interesting part of the variogram is the distances smaller than 500 meters. In the manual of the Pathfinders is stated that the first 500 meters of the incoming flight path and outgoing flight paths are important to determine a landing zone. So to indicate the potential of an area the increase in variance over the first 500 meters is interesting. Favorable the variance stays as low as possible in these first 500 meters.

5.2. Checking the potential landing zone with the Pathfinders

In chapter 4 the potential landing zones for three different cases are calculated. For each of the case studies, multiple potential landing zones are available because multiple Digital Surface Models are given

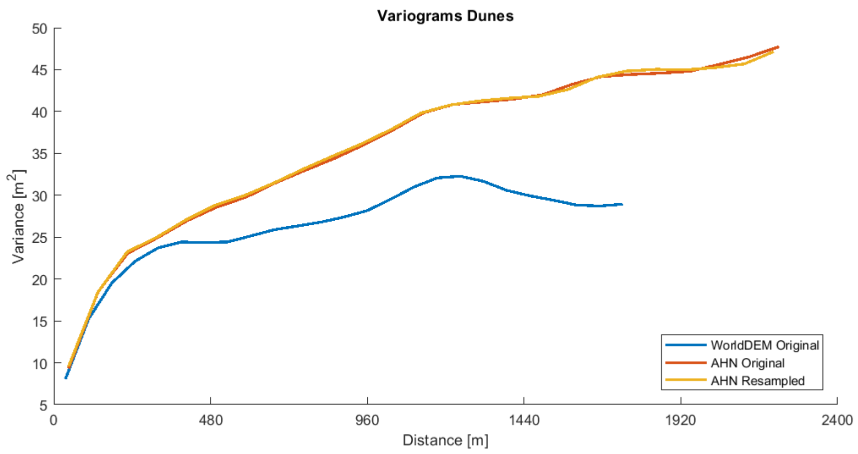


Figure 5.2: Variograms of the dune area in which the Pathfinders are interested. The empirical variograms of the WorldDEM, the original AHN3 and the resampled AHN3 Digital Surface Models are shown.

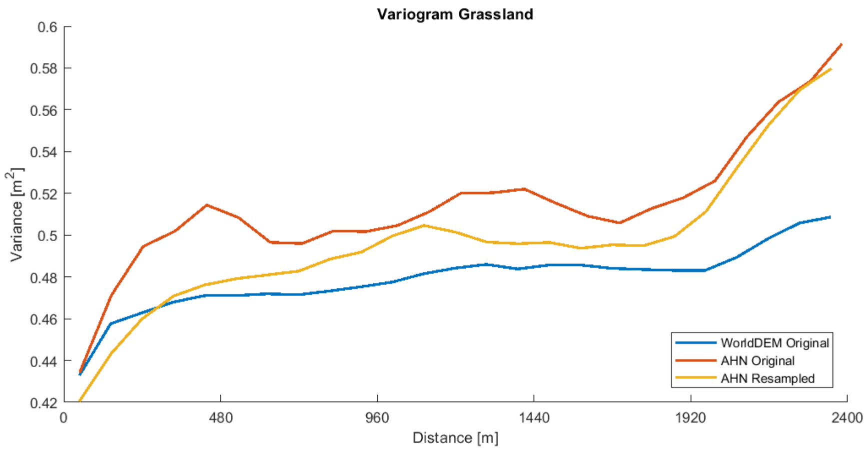


Figure 5.3: Variograms of the grassland area in which the Pathfinders are interested. The empirical variograms of the WorldDEM, the original AHN3 and the resampled AHN3 Digital Surface Models are shown.

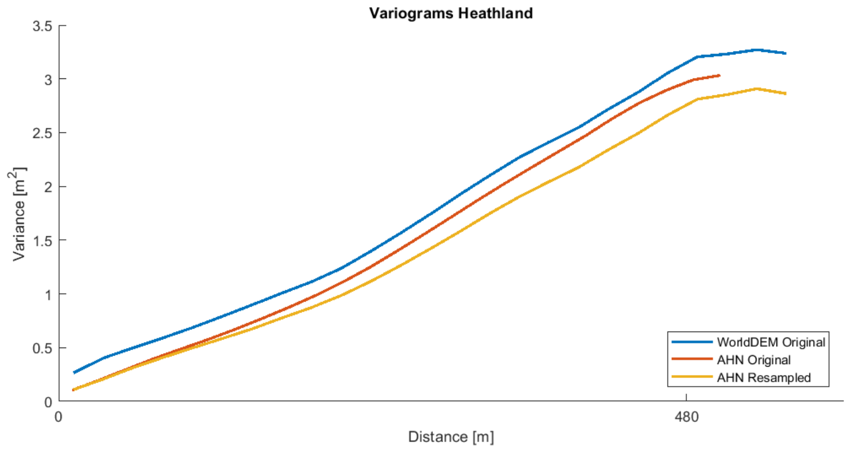


Figure 5.4: Variograms of the heathland area in which the Pathfinders are interested. The empirical variograms of the WorldDEM, the original AHN2 and the resampled AHN2 Digital Surface Models are shown.

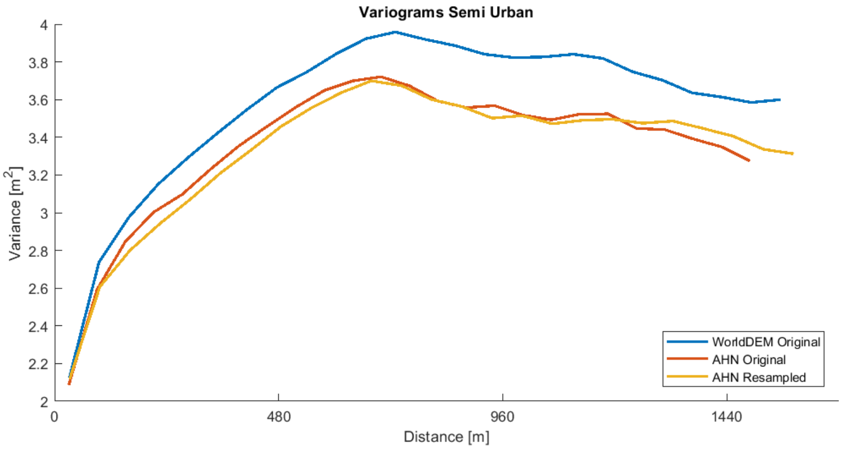


Figure 5.5: Variograms of the semi-urban area in which the Pathfinders are interested. The empirical variograms of the World-DEM, the original AHN3 and the resampled AHN3 Digital Surface Models are shown.

as input for each area. In the case study chapter the results are briefly described. The potential landing zones are per case study compared with each other to see the differences. However, never is checked if the potential landing zones given by the new method are correct. To perform this check the Pathfinders did an assessment of the area of the Edesche Heide case study and the Valkenburg case study. Four different sections of the Edesche Heide area are inspected by the Pathfinders and a conclusion is drawn for each location whether it is a suitable landing zone and why. The different locations are visible in figure 5.6. The following subsections in the report are numbered according to the numbers of the sections in the overview. The four sections are in order: the top of the hill, the heathland near the access road, the main heathland and the heathland in the north. The last subsection is about the Valkenburg case study

5.2.1. Detail: Top of the hill

First, the top of the hill in the south of the case study area was visited. Both the WorldDEM as the AHN3 Digital Surface Model showed this area as a potential landing zone. For various reasons, the top of the hill is not a suitable landing area. The area is covered with high vegetation in the form of bushes and small trees. Furthermore, the required hard surface size is not present. Also, there are burial mounds present in the area which make the area unsuitable to land. All the reasons stated above are not clearly distinguishable by looking in detail at the Digital Surface Models.

On top of these reasons, the WorldDEM Digital Surface Model showed the potential landing zone on top of freestanding trees. The freestanding trees were noticed in the AHN3 Digital Surface Model and the related potential landing zone was, therefore, avoiding the trees. If the difference between the Digital Surface Models has been viewed in detail and a freestanding tree is actually visible. In figure 5.8 the freestanding trees are visible in darker green than the surroundings. The darker the color green becomes the more negative difference is. A negative difference means the AHN3 value is larger than the WorldDEM value. The fact that trees are given lower values in the WorldDEM Digital Surface Model compared to the AHN Digital Surface Model is supported by the research of Bloo [75].

To make sure this is not a one-off miss of the WorldDEM, other locations are checked where free-standing trees are present. In all of the locations where freestanding trees are present the AHN3 values are higher than the WorldDEM values. This observation is also visible in the case study of the heathland near Exloo 4.2.

The Pathfinders also noticed the fact the potential landing zones are to close to freestanding trees which are observed. This is due to the fact no safety margin is taken into account.

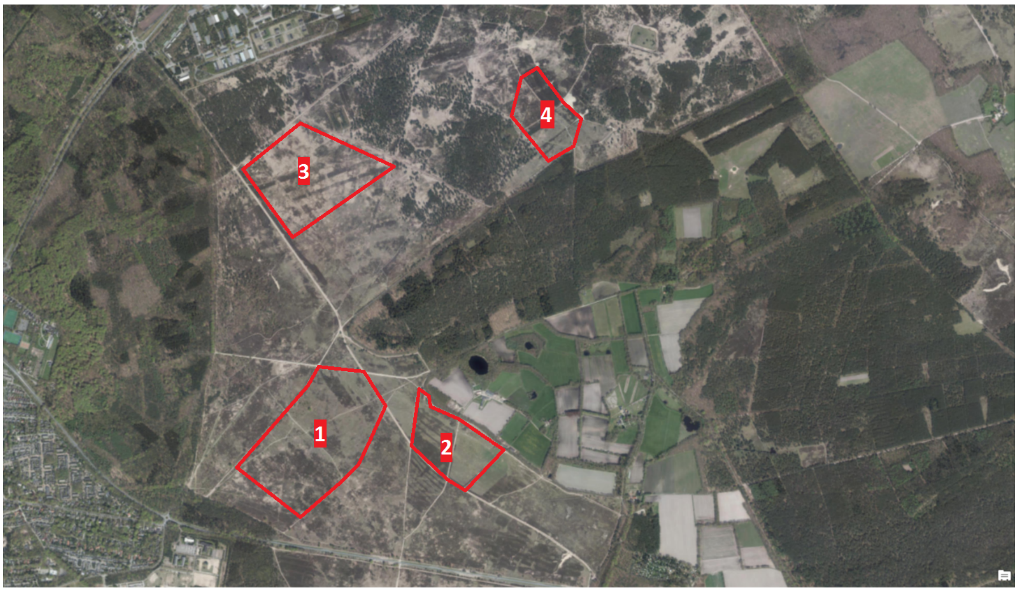


Figure 5.6: The Pathfinders did an assessment of the Edesche Heide. Four sections of the Edesche Heide were inspected and per section, the conclusions are drawn whether is a suitable landing zone and why. The four sections are in order: the top of the hill, the heathland near the access road, the main heathland and the heathland in the north.

5.2.2. Detail: Heathfield to the north of access road

From the top of the hill, the Pathfinders also made an assessment of the area to the north of the access road. This strip of heathland is known by the Pathfinders and should be marked as a potential landing zone. The results from the new method correctly show this strip heathland as a potential landing zone. However not the whole strip is marked as a landing zone. This is because of the shoots requirements in combination with the set flight direction.

5.2.3. Detail: The main heathfield

For the main heathfield, a large potential landing zone is marked both for the AHN3 as the WorldDEM input. This marking as a potential area is correct. The gaps in the potential landing zones are due to local height differences on the ground. However, the Pathfinders stated this variability is not a 'no-go' for the mission. The fact the eastern part of the heathfield was suitable as landing area was already known because the 11 Air Manoeuvre Brigade uses this part as a training ground. Together with the Pathfinders also the western part of the heathland is checked on the spot to make sure this part is also suitable as a landing zone.

5.2.4. Detail: Heathfield in the north

To the north of the main heathfield, another smaller heathfield is present. According to the Pathfinders observations, almost the whole area can be marked as a landing zone. Provided that the shoots are taken into account and the ditches in the heathfield are excluded. The results from the new method show potential landing zones in the area, but not in the way the Pathfinders assessed the area. Both the WorldDEM and AHN3 results show small spots of potential landing zones. Not the whole area. The gaps are the result of the shoots calculations.

Another problem encountered in this area is the fact the trees in the WorldDEM Digital Surface Model are almost not recognized. Therefore the potential landing zone of the WorldDEM input is placed over trees, which should not be happening. This is due to the fact the slope between the pixels is not exceeding the limits.

Before is already stated the ditches in the area should be avoided as a potential landing zone. The WorldDEM Digital Surface Model was not successful in recognizing the ditches in this part of the heathland. The AHN3 Digital Surface Model was. In the figures below the WorldDEM and the AHN3 Digital

Surface Models are displayed next to each other. In the AHN3 figure, the ditch is clearly visible. In the WorldDEM figure, it is not.

5.2.5. Valkenburg case study

The whole area to the east of the treeline is supposed to be a potential landing area according to the Pathfinders. In the resulting potential landing zones from the AHN and drone Digital Surface Model, this area is marked perfectly. The WorldDEM results show also potential landing zones on top of the tree lines. This should not happen. Furthermore, there are gaps in the potential landing zone of the WorldDEM located on the grass field in the east. These gaps are created because of the shoots calculations. By the assessment of the Pathfinders, it should be one closed area because the shoots do not affect the landing zone in the set flight direction.

5.2.6. Summary of the assessment of the Pathfinders

Due to the assessment of the pathfinders, it became clear the new method can not flawlessly predict potential landing zones. The flaws uncovered by the Pathfinders are mainly due to the vegetation present in the terrain and due to freestanding objects. This objects can either be above ground like a tree or below the ground level like a ditch. Most of the times the AHN3 Digital Surface Model did notice the freestanding obstacles in contrary to the WorldDEM Digital Surface Model. Both Digital Surface Models had problems rejecting areas with bushes and other lower vegetation types. The WorldDEM Digital Surface Model had one other problem which was not encountered with the AHN3 Digital Surface Model. The WorldDEM results show potential landing zones on top of patches of trees. Due to the larger pixel size, the variability in the crown of the trees is smoothed and therefore not rejected in the slope calculations.

5.3. Look into the differences between the Digital Surface Models

In the previous chapter, the differences between the Digital Surface Models are calculated and given in figures. From this figures stands out that the largest differences occur at the locations where trees are present. These differences can be split into two groups. First, the differences above zero which occur at locations with trees that are close together. This means the WorldDEM value given at these locations is higher than the value given by the AHN or Drone Digital Surface Model. Second, the locations where trees are widely spaced and the differences are below zero. At this locations, the values of the AHN or Drone Digital Surface Models are higher than the values given by the WorldDEM Digital Surface Model. The differences potentially occur due to the differences in the techniques by which the Digital Surface Models are created, the differences in pixel size or the moment in time at which the data is acquired.

5.3.1. Differences due to different technique

Modern lasers are capable of delivering multiple returns per emitted laser pulse. For vegetation, this could mean a reflection is created on the outer leaves, the branches and the ground. For the Digital Surface Models used in this research, all objects are included. The height given is, therefore, the first reflection received acquired [33].

For the WorldDEM DSM, X-band radar is used. The X-band has a relatively high frequency and reflects in the crown layer of the branches and the foliage of the canopy [76]. Where the laser altimetry receives a reflection from the outer leaves the X-band radar pulses can penetrate as deep as 6 meters into the canopy. This penetration depth is correlated with many parameters like the type of tree, the density of the leaves and the moisture content of the leaves [77] [78]. The amount of penetration changes the scattering center of the signal. The higher the penetration depth the closer the scattering center is located to the ground.

Due to the different techniques applied, height differences can be present in the same area once the WorldDEM and the AHN Digital Surface Model are compared.

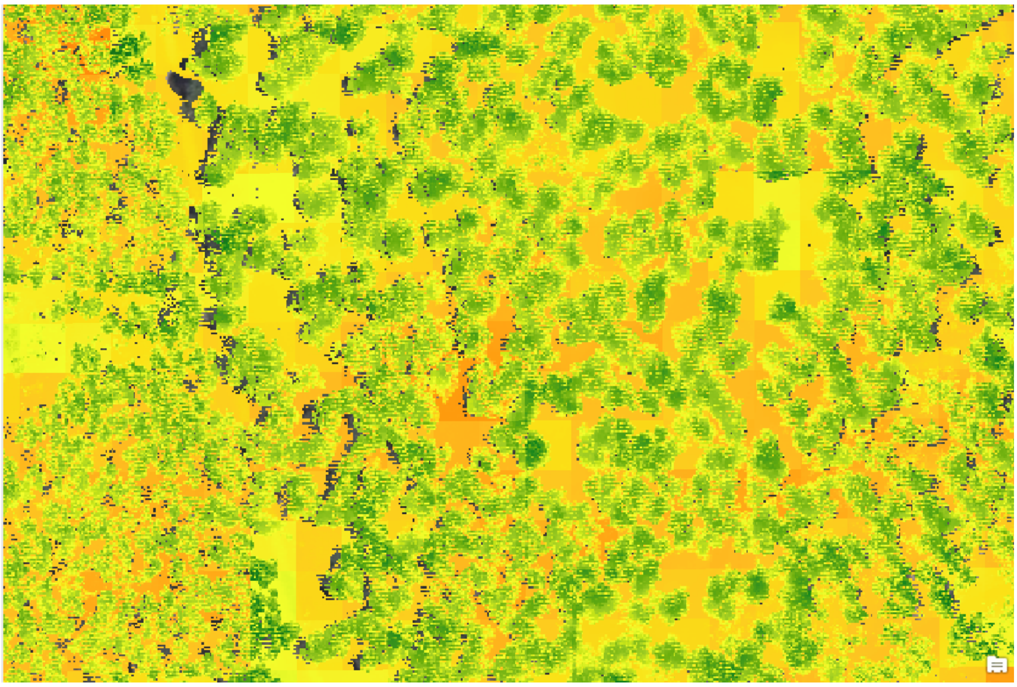


Figure 5.7: In this figure, the WorldDEM Digital Surface Model minus the AHN3 Digital Surface Model is given. The value of the crown of the trees in the AHN Digital Surface Model is higher than the value given by the WorldDEM. This is represented in the green colors. The areas between the trees are showing yellow and red colors. This is where the WorldDEM gives higher values than the AHN because of the averaging that happens due to the larger pixel size of the WorldDEM.

5.3.2. Difference due to a different time of acquisition

A hypothesis is that the differences do occur due to the fact the data of the Digital Surface Models is not acquired at the same time. The AHN3 laser altimetry missions are flown in the first quarter of the year when there are none to little leaves present on the trees [79]. The result is that the laser only reflects on the trunk and the branches of the tree. Laser beams missing the trunk and branches can reflect on the ground under the tree. Because the pixel size is relatively small the laser beams reflecting on the ground can lower the pixel size significantly. This way a tree profile is formed which is jumping back and forth in height [75].

The radar signals where the WorldDEM is based on could, in contrast to AHN, be acquired during a period when there are leaves on the trees. Depending among other things on moisture content in the leaves and the density of the leaves a different height can be determined. When the trees are standing closer to each other the leaf density will be higher and the penetration will be less. The WorldDEM Digital Surface Model will now give a value closer to the actual top of the canopy. Especially the area between trees is now displayed higher in the WorldDEM than in the AHN. These areas are covered by the canopy giving high values in the WorldDEM, but the AHN will register the ground level when flying over when there are no leaves on the trees. This can be seen in figure 5.7 where the trees itself are green (AHN gives higher value) and the spaces between the trees are red (WorldDEM gives higher values).

The difference in the example before is related to the seasons in one year. But the difference in acquisition can also be a matter of multiple years. The data on which the WorldDEM is based is acquired in 2014. AHN3 data of the Edesche Heide is acquired in the first quarter of 2018. A difference of at least 3 years. In this period trees could have grown and therefore the same area could show different height between the Digital Surface Models.

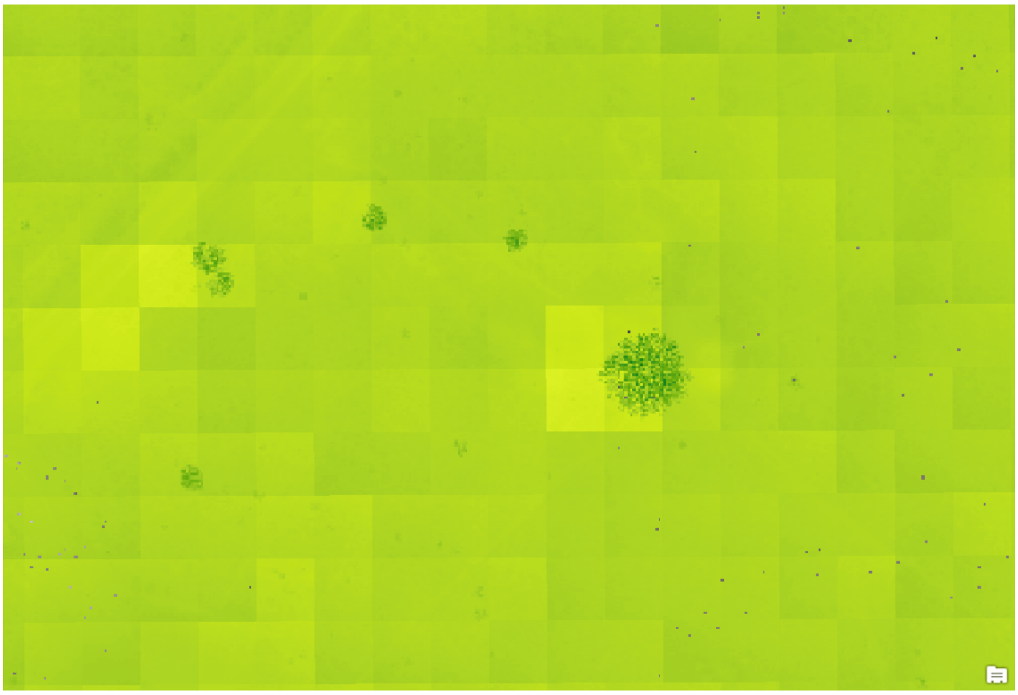


Figure 5.8: In this figure, the WorldDEM Digital Surface Model minus the AHN3 Digital Surface Model is visualized. The five darker green spots are freestanding trees. The darker the color green becomes the more negative the difference is. A negative difference means the AHN3 value is larger than the WorldDEM value.

5.3.3. Difference due to the difference in pixel size

Assuming the height of trees is correctly measured in both Digital Surface Models then still a difference could be present due to the difference in pixel size. Considering a transition from trees to ground. The 12-meter pixel size of the WorldDEM is not always completely filled uniformly. Therefore the pixel value is an average of all the objects in the pixel. Suppose the pixel of the WorldDEM is half filled with trees of the same height and the other half is filled with ground level. The pixel will get the value of the average of the two.

The pixel of AHN is only 50 centimeters. The change of a 50/50 cell distribution with trees and ground level is still possible, but seen over multiple pixels the transition between trees and ground level will be more abrupt. This difference is visible in figure 5.8 where the difference between WorldDEM and AHN is displayed for free-standing trees on a hill. Especially for freestanding trees, a line of trees or thin forest this can be observed.

5.3.4. The consequences of the differences

The difference in technique, time of acquisition and pixel size between the WorldDEM and AHN Digital Surface Models lead to a difference in height at a specific location. These differences have an effect on the results of the slope calculations and the shoots calculations.

The pixel size will give the average over a certain area. For the WorldDEM pixel of 12 meters, this means averaging over a larger area than the AHN. Local differences will be invisible. In the slope calculations areas which are over a larger area even will be appointed as a potential landing zone. Areas like to top of a forest is now seen as an even area and will be approved by the slope calculations. The difference in technique and the difference in moment of the acquisition will affect the height of the pixel but will not change the smoothed effect of the large pixel of the WorldDEM.

The shoots calculation are affected by the pixel size. Due to the pixel size, the local peak can be averaged with lower heights in the WorldDEM pixel. Due to this averaging the shoots calculations can

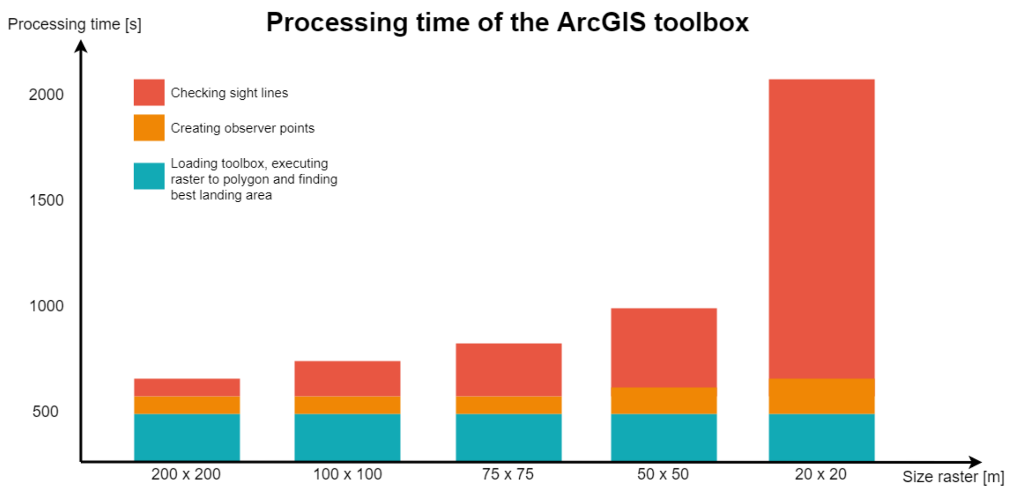


Figure 5.9: The processing time of the ArcGIS toolbox for different observer point raster sizes. The trend seen in raster size 200x200 meter to 50x50 meter is not representative for the processing time of the 20x20 meter.

potentially approve a potential landing area while the extreme value should cause a rejection. The time of acquisition in combination with the technique used is important for the WorldDEM Digital Surface Model too. Once there are leaves on the trees the radar penetration depth is limited. However, when there are no leaves, the radar penetration depth is larger and therefore there is an underestimation of the height of trees. The underestimation can cause a falsely appointed potential landing zone.

Most of the potential problems described above are not applicable to the AHN Digital Surface Model. The pixel size is such that a problem with averaging is not happening. The laser altimetry registers the top of the branches without penetration. The moment of acquisition is always in the first quarter of the year.

5.4. Examination of the processing time

The Pathfinders have in the worst case scenario a week to prepare a mission. The new method can be run easily in this period. For the different parts of the new method, the processing time is noted. By changing the parameters insight is given in the way the processing time changes. If the area of interest in increased linear the processing time increases exponentially. This could be expected due to the fact the both in the height and the width increases linearly. The linear increase in the number of sight lines which will be calculated causes a linear growth of the processing time. The only remarkable observation is done when the distance between the observer points is linearly decreased beyond a certain threshold. The processing time first increased linearly while the observer points come closer to each other. But beyond the threshold, the processing time increases more than could be expected by the trend extrapolation. This can be seen in figure 5.9 The exact value of the threshold is not found. The threshold could have a relationship with the used hardware to perform the calculations. Because no other machines were available to perform the calculations this hypothesis can't be verified.

When a Digital Surface Model is used with smaller pixels the processing time increases by the ratio between the WorldDEM pixel size and the new Digital Surface Model pixel size. This is valid unless the threshold discussed above is reached.

6
Conclusions

This thesis showed that potential landing zones can be located with the help of a Digital Surface Model based on satellite data in a better way than the current approach of the Dutch Army.

The current procedure of the 11 Air Manoeuvre Brigade (11 AMB) is based on a manual non integrated and slow method that uses only outdated and topographical data. In the procedure all 5 aspects of a potential landing zone are taken into account, the so called 5S: Slope, Shoots, Surface, Size and Security.

This research led to an automated and fast method that uses more recent 3D data (WorldDEM) and delivers faster results (validated on the Edesche Heide) than using the current method. The automated procedure has been restricted to two of the five aspects (Slope and Shoots). The aspects Size and Security are discussed in the research but not integrated in the automated method.

The Slope aspect is about the size of the slope combined with the direction of the slope. The requirements for both the direction and the size of the slope depend on factors like the time of day and the type of helicopter used during the mission. The Shoots aspect is about the incoming and outgoing flying angles. These angles and the distance over which the angles must be measured depend on the type of mission, the time of day and the availability of night vision equipment.

Starting from the 5 aspects (5S), this research focused on the available data sources that enable digital analysis of these aspects in ArcGIS Pro. ArcGIS Pro is the standard software package used by 11 AMB. With a Digital Surface Model we can solve at least the aspects Slope, Shoots and Security and the first step of the Size aspect. To cover the most aspects, the research is limited to the use of Digital Surface Models.

	Slope	Surface	Shoots	Size	Security
Digital Surface Model	■		■	□	■
Multispectral data		■		□	
Polarimetric radar data		■		□	
Wind data			■	□	
Precipitation data		■		□	
Temperature data		■		□	
Infrastructure data				□	■

A lot of different digital surface models are available. It is important to have a worldwide coverage with the Digital Surface Model for the military planning process. Comparing the characteristics of these different Digital Surface Models, WorldDEM comes out best looking at the spatial resolution and the time of acquisition.

The Netherlands army is working on their own digital surface model, TREx, with the same specifications as WorldDEM since it is based on the same raw data. TREx, however, is not worldwide available until it will be completed in 2025. Therefore it has been decided to use WorldDEM for this research.

To check whether WorldDEM is an appropriate input for the new method, validations tests are performed. The WorldDEM is validated by comparing the results of the new method for WorldDEM, the AHN DSM and a DSM build with the help of a drone for two areas. From the comparison with the AHN DSM can be concluded that the WorldDEM is not suitable for finding potential landing zones in areas with freestanding trees, thinly forested areas, areas with forest with equal canopy height and areas with a sudden height differences (larger than 30 centimeters) over a distance smaller than the pixel size of the WorldDEM (12 meter). From the comparison with the drone DSM can be concluded that the WorldDEM is, in addition to the remarks above, missing actuality due to the difference in time of acquisition. Also the height registered in the DSMs differ due to the use of different acquisition techniques (InSAR and photogrammatry).

A second validation is performed empirically by the Pathfinders. The Pathfinders conclude that the results of the new method using WorldDEM is correct in almost all areas, only in areas with freestanding trees, bushes and large height differences over a smaller distance than the WorldDEM pixel size it is not good enough. Here local information will still be needed. For this the researches showed that the use of a drone will help the pathfinders in the field.

The use of drone data improves the results of the new method compared to the use of WorldDEM due to the fact that drone data is more actual and the drone data has a smaller pixel size. By using a drone the Pathfinders can cover a larger area in less time, because they don't have to walk. The Pathfinders can control the drone from a covered position which makes the time in the field saver.

To conclude, it is possible to find potential landing zones with the help of a Digital Surface Model. The results generated with the DSM are not correct in all cases. Adding drone data of the potential landing zone to the new method leads to more correct potential landing zones. Using the new automated and faster method to find potential landing zones, Pathfinders are better prepared for their mission and a more targeted deployment of the Pathfinders is possible. The results can be used to exclude areas and therefore reduces the areas to be investigated by the Pathfinders.

7

Recommendations and future work

The full potential of the new method isn't reached. Only the Digital Surface Model is used as input while there are many more data types, which can deliver potential useful information for the new method. In this chapter, some potential sources are discussed for future research. Furthermore, recommendations are given to improve the new method regarding the Digital Surface Model part.

7.1. Adding more data types

In chapter 2.2 data types are given which can deliver potential information to better locate potential landing zones. For the shoots requirement, it would be very useful to add wind data. For now, the flight direction can be manually selected, but if the wind data is added a better supported potential landing zone can be generated. Besides determining the flight direction of the air crafts the wind data can be used for more. The Pathfinders are very much interested in wind speed and wind direction on different heights. This can be very useful to bring in aircraft and make it possible to safely deploy paratroopers. The wind data can be acquired by using a weather model. Research must show which weather model is working best in which area or situation.

To improve the new method and have better wind data available at the exact location where the Pathfinders are preparing the landing zone in the field, the drone might be used. In the future drones might collect the wind direction and wind speed while flying. This data is much more specified to the potential landing zone instead of a whole weather model cell. Furthermore, the wind direction and wind speed can now be collected at different heights while flying the drone. Nowadays weather balloons are deployed to collect this type of data. Not only are the weather balloons easily visible for the enemy, the Pathfinders also need to bring more equipment for the mission. If it turns out these tasks can be combined using the drone it saves weight and can be safer.

Enriching the new method with the requirement regarding the surface of the landing zone requires adding different data types. The reason for this is the large variety of requirements. Multispectral data can be used for varies reasons. For instance, it can be used to calculate indices using different electromagnetic bands to find areas of water or areas of dense vegetation. By adding temperature data to the new method, the multispectral data can be used to check whether the surface of an area is flammable. Other research showed the potential of using polarimetric radar data combined with a simple threshold might be useful to detect areas with high risk of brownout conditions.

Then there is the requirement regarding the bearing capacity of the soil at a landing zone. To fulfill this requirement somehow the bearing capacity must be measured using remote sensing. Literature about this subject is scarce. In specific conditions, there is some progress using hyperspectral data and data about the humidity of the soil. Future work in this field could be very useful if the new method is fully expanded to locating potential landing zones for airplanes.

7.2. Improving the new method

This expansion of the new method, to be able to provide potential landing zones for airplanes and paratroopers is possible with further research. The modular setup of the new method can be expanded by selecting the type of deployment in one of the first steps. By selecting helicopter, airplane or paratrooper the requirements which must be met can be activated.

The functions in the new method can be optimized to work more efficiently. This can result in time savings. Not only the functions itself but also the order in which the steps inside the functions are executed can be optimized. In this research there is only discussed in which order the aspects must be ordered for optimized executing time.

Some functions can be optimized by increasing the customizability. For instance, the slope and aspect function is fixed to a given direction. The new method can be improved in terms of user friendliness by asking the direction as input. The new method must then adapt values to this input. Also, the option to give the time of day or the type of helicopter as an input option for the new method can improve the user-friendliness.

This is the same for the shoots section. The angels for which the shoots are calculated are fixed and not depending on the user input. The best option is to do this automatically by implementing a weather model for the wind direction.

Not only for the slopes, shoots and surface improvements are possible. There are many opportunities to implement the security aspect of the mission. First of all the flying route of the aircraft can be made safer. By using the Digital Surface Models as input and functions like the viewshed it is possible to calculate the safest route to the point of interest. Locations, where enemies are located, can be given and the new method then can calculate where to fly whit out being in a direct line of fire.

The other way around there are also possibilities. The suggestion above is to avoid an enemy line of fire, but it can also be used to make sure the enemy is in the line of fire. Snipers can be advised which position to take. From this position, the target will be visible, but the positions can also be selected such that the team can cover each other.

The whole topic of size is almost untouched. However, there are possibilities to implement solutions for requirements regarding the size. In the second chapter, the solution D3Plus is shortly introduced. With scripts like this, it is possible to search inside a polygon for the largest possible rectangle. This is not where the possibilities of this kind of script end. The script can be linked to for instance the wind direction. This way the largest rectangle can be oriented in the flying direction with a small margin to be turned off the flying direction according to the manuals. Furthermore, it is possible to make an input box for the type of mission, type of helicopter and amount of helicopters. This way the minimum size of the rectangle can be set. This can be done both for the minimum width, minimum length and for the ratio of the rectangle.

An easier solution to the problem might be using the build in size requirement in the ModelBuilder of ArcGIS Pro. Inside the ModelBuilder an option is present to only select the polygons with a given area. Because the shape of these polygons can be completely random, only selecting polygons by area might not be sufficient to fit rectangles inside. Therefore a ratio of area and circumference can be tried. The ratio will be different for compact polygons compared to stretched polygons with the same area. This method does not provide a watertight solution to the size requirements, but can provide a quick and dirty solution to reduce the total amount of polygons fast.

7.3. Other thoughts

ArcGIS pro proved to be useful for displaying the results of the research. Also, the ModelBuilder inside the ArcGIS Pro environment is convenient to work with. However, the speed of the calculations is not that good. While using the WorldDEM as input the execution time is still okay. Unlike using the drone or AHN Digital Surface Models as input. The execution time for the last two Digital Surface Models is very slow. On top of the slow processing, the program sometimes crashes completely while processing the AHN or drone Digital Surface Models. This might have to do with the specifications of the used computer.

The error messages and complete crashes of the program might be correlated to the amount of computational power available versus the computational power needed. By increasing the computational power the crashes will probably occur less or even stop occurring completely. The other way around, by dividing the created functions into more but smaller functions the computational demand might decrease. This will have probably have a negative effect on the computation time but will have a positive effect on the reliability of the new method.

Finding an alternative for executing the calculation might be profitable. For certain when the reliability of the new method becomes more important in real planning situations for the military. Both reliability and execution time can probably be improved. For the visualization of the results, ArcGIS Pro is suitable.

The new method is currently tested for different areas like dunes, heathland, grassland and semi-urban areas. For these areas, the performance is evaluated because these areas are the most likely deployment areas. However, there are more types of areas where the military might want to operate. Think of dessert, jungle or arctic environments. For these areas, further research must be done to see what the results are. Besides new environments also, similar environments but in other countries, are a point of future research. This new method is only tested for areas in the Netherlands. For usage of the new method abroad the new method must be tested more thoroughly.

8
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CGI eyefly ATMOS UAV

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