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Research into different forest cover measurement techniques and clarification when what method is used.

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Summary

There are multiple institutions measuring forest cover, for different reasons and using different definitions of forest cover. This thesis aims to give an explanation for the differences in these methods, find out whether there is a best method and give advice on when to use what method.

This was done by exploring five case studies as varied as possible to give an overview of the methods used, including references to similar techniques. Also, different data obtainment methods, European satellites, American satellites, drones, and aircraft are outlined. The method used for two global land cover maps are described to get insight into the forest cover aspects of these methods; the GLOBCOVER initiative, and the MODIS Land Cover Dynamics product. Both of these methods use different data and different classification systems. A case study that studied land use in the eastern United States was examined — also applying different ways to come to their results. Different satellites, different classification techniques are used in this method. An experiment using drones that could potentially in the future study forest fires (thus tracking the loss of forest cover) was examined. And finally, a method involving LiDAR and the use of an aeroplane was discussed.

The main reason methods differ is that most techniques are designed or are a result of a specific situation. For example, bigger areas are better mapped using satellites, and when there is not much capital available, more straightforward processing techniques are used. Also, when there is a dangerous situation like a forest fire, drones are the better choice. Some methods are better in specific ways than others, but it seems more important to fit the right method in the right situation. What method fits what situation has been made insightful using a decision tree. When looking at future detection techniques drones seems really promising.

Abbreviation list

FAOSTAT = The Food and Agriculture Organization Corporate Statistical Database
GLOBCOVER = Land cover product from the ESA
ESA = European Space Agency
NASA = National Aeronautics and Space Administration
MODIS = Moderate Resolution Imaging Spectrometer
NIRS = Near-infrared Spectroscopy
SWIR = Short wave infrared
TIR = Thermal Infrared
ASAR = Advances Synthetic Aperture Radar
AMORGOS = Accurate MERIS Ortho-Rectified Geo-Location Operational Software
RMS = Root mean square
BRDF = Bidirectional Reflection Distribution Function
LCSS = Land Cover Classification System
CPU = Central Processing Unit
MLCT = MODIS Land Cover Dynamics product
ISODATA = Iterative Self-Organizing Data Analysis Techniques
UAV = unmanned aerial vehicle
UA = unmanned aircraft
RPA = Remotely piloted aircraft
RGB camera = A camera where information is taken that is represented in the colour red green and blue
CIR = Color Infrared Detection
SWIR = Shortwave Infrared
LiDAR= Light detection and ranging

Introduction

In the past, forest cover had to be determined using aerial footage from aeroplanes or by doing surveys at the ground. These techniques could never cover the entire forest cover and always had to rely on sampling techniques. With the arrival of remote sensing techniques done from satellites in the 90s (Hansen, 2000) forest cover determination became easier to apply with total satellite coverage of all areas worldwide. In the present, however, researchers still use different techniques. Researchers, for example, use drones, aircraft and a variety of different scanners as will be made clear in this research. This variety in methods can suggest that satellite imaging is maybe not the *one size fits all technique.*

This variety in methods happens for different reasons, such as availability of capital, what size of forest is to be measured or what information researchers want from the forest (fire location, canopy height, forest spread). For example, forest cover in the MODIS map, a land cover map created by NASA is measured differently compared to, GLOBCOVER. GLOBCOVER is a land cover product from a collaboration of the University of Leuven and the ESA (European Space Agency).

From a science perspective, there is a knowledge gap that needs further clarification. More insight into the use of different techniques is necessary. What methods are used when, for forest cover determination? However, not many descriptive comparative studies are conducted into different forest cover determination methods. Comparative research that focuses on land cover alone are done, but not specifically to forest cover. Providing a clear overview of these methods give more insight into the limitations of these techniques. And whether some ways might be better than others. It is also offering more transparency to the process. Moreover, the reasons for these method-differences are used to understand how these method differences occur (financial, area size that is to be measured, dangers, etcetera). Besides the scientific relevance of this phenomenon, it is also essential to study from a society and sustainability perspective.

From a society and sustainability perspective, it is also essential to have more insight into these methods. More clarity into why some ways might be better is necessary, as forest cover determination guide an array of different important decisions. And if there is no certainty in the forest cover, problems can occur. If there is no consensus about forest cover, illegal logging activities will be hard to monitor, policies like forest preservation will be hard to implement. Moreover, will it be unclear how much greenhouse gasses will be taken up by the biomass through photosynthesis fighting the greenhouse effect. If there is knowledge about forest cover, but this knowledge is not realistic, then this will lead to problems regarding the feasibility of projects and other enterprises dependent on forest cover data.

An overview of remote sensing and land cover classification is given first to provide background information because these terms are used many times in this thesis. Different forest cover determination techniques are outlined. The reasons for different existing measurement techniques are explored after the analysis. Leading to the following aim: This thesis aims to explain and illustrate various methods of forest area measurement techniques, and clarification when what method is used. Moreover, a prediction for future methodologies is given. This will be examined by an investigation in the methods and assumptions taken by organizations such as, ESA (GLOBCOVER initiative), NASA (MODIS land cover product) and other (smaller) institutions that measure forest cover. Also, the possibilities of drone remote sensing will be taken a look into.

Concepts

All methods that are described and analysed in this thesis use a form of remote sensing and data processing. And they are organised in these two concepts. Because of this, this section provides a background of the main principles and concepts of remote sensing and data processing. The reason for this is to help the reader understand these concepts and to make clear what part of the method description belongs to what concept.

Remote sensing

As the name remote sensing suggests, the sensor *senses* an object a fair distance away (*remote)* from the sensor. This sensing is mostly done through satellites, although other aircraft like hot air balloons, drones or aeroplanes are also used in this process. (Tang and Lao, 2015) (Congalton and Green, 2002). Used satellites are, for example, the MERIS satellites from the ESA and the MODIS satellite from the NASA (Arino et al., 2007).

Different sorts of radiation emitted by the ground (or emitted by the satellite and reflected to the satellite) are processed by the sensors. The kind of radiation used depends on the equipment available in the aircraft doing the remote sensing. One of the ranges used in satellite imagery is the solar reflective range (MERIS satellite, GLOBCOVER) ranging from wavelengths of 400 nm (nanometer) to 3000 nm (ESA, 2019) Multiple other imaging techniques, and terms corresponding to wavelength bands, are mentioned in this thesis and these are clarified in the following section. Figure 1 shows how the detected wavelengths are related to the visible spectrum.

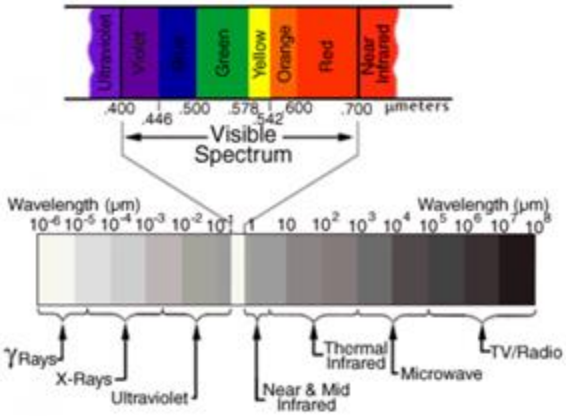


Figure 1, this figure shows how wavelength bands used in remote sensing correspond to the visible light spectrum. (Nijland, 2019, slide 4)

Other ranges that are used in remote sensing are the NIR range (Near-infrared radiation, ranging from 780 nm to 2500 nm) (Lisein et al., 2013), the SWIR range (Shortwave infrared radiation, ranging from 1100 nm to 3000 nm) (Ambrosia et al. 2011b; Hinkley and Zajkowski 2011) and the TIR range (Thermal infrared radiation, ranging from 8000nm to 15000 nm) (Ambrosia et al. 2011b; Hinkley and Zajkowski 2011). And the LiDAR technique is used. This technique uses the reflections of laser beams to the surface (Dubayah and Drake, 2000). There are also remote sensing techniques that measure multiple wavelength values simultaneously, typically three to fifteen, called multispectral imaging (Friedl et al., 2010). Another similar range is hyperspectral imaging, where continuous bands of wavelength values are measured (Arino et al., 2007)

All data mentioned in this section is called spectral data.

Data Processing

This section will give a short explanation of all the data processing possibilities. That is all the operations that are done on raw data to yield forest cover information. This processing is mostly done on computers. This includes the creation of classes, the re-allocation of classes. And also, the geolocation of data, as explained in the GLOBCOVER method, is a form of data processing. Mosaic creation and algorithms using training data are a form of data processing. Also, the creation of temporal data out of spectral data is a form of data processing as well as expert labelling of classes. Temporal data is the change of spectral data over time.

All of the data processing mentioned in this section is explained in more detail in the results section.

Methods

The research method chosen for this research is a method that combines a descriptive methodology and a comparative methodology. First, literature research has been conducted into the current literature about forest cover detection methods. The approach described by Pautasso (2013), who explains ten rules on how to do a useful literature review is taken in this thesis for the literature review. When the literature review was done as described above, there was decided to focus on five methods only. There are a couple of reasons for this decision.

To describe every method that has ever been applied in forest cover research covers too much space to include this in a single thesis. Too many studies have been conducted into forest cover. Moreover, is this approach too repetitive, some methods are really similar, and this would not contribute much to the research. To address these objections, an approach has been chosen to study only five methods in a case study manner. These case studies have been selected on mutual variety. This variety was based on project size (availability of money and equipment), equipment used, study area size, classification techniques, and goal of the detection method. (Of course, is forest cover always the goal, but the context in which forest cover is studied differs. For example, forest cover decrease-detection methods that are used in forest fires and forest cover detection methods used for global land use maps.) These five case studies were divided in a “remote sensing” part, and a “data processing” part. This is mentioned in the concept section.

Besides these case studies, other methods were shortly described or referred to in the section describing the most similar case study, resulting in a total of twelve techniques. This was done to make the method descriptions more complete without the loss of conciseness. After the description of the five case studies, including similar methods, an analytical section was added containing the discussion, conclusion. The objective of this section was gaining more insight into the reason for the differences between methods (to answer the research question). Then a section was added only focusing on methods that use drones. This was done because, while doing the analysis described in the previous paragraph, drones were found to be really promising for the future.

Schematic overview of structure research

Descriptive part	
Method 1 description + similar methods	**...**
Method 2 description + similar methods	**...**
Method 3 description + similar methods	**...**
Method 4 description + similar methods	**...**
Method 5 description + similar methods	**...**

Analytical part	
Discussion	
Decision tree	**….**
Conclusion	**….**

Results: Five case studies of forest cover detection methods

In the following section, five methods are described all measuring forest cover. First, the creation of two global land cover maps are described, GLOBCOVER and the MLCT map both using satellites. Then methods used to find forest cover on a location in the eastern US is looked at using an automated algorithm for classification (ISODATA). Methods involving drones and aircraft are described afterwards. In the end, an application of the LiDAR technique is given for forest cover detection. The focus on these methods has been decided because a focus on these five case studies give, in my opinion, the best representation of all different available methods. Satellites, aircraft and drones are described. Global regional and local maps are described. Different remote sensing techniques are described. As well as different classification systems (LCSS, IGBP, UMD etc.) By focusing on such a diverse group of methods, the research aim *Research into different forest cover measurement techniques and clarification when what technique is used* can be best answered. Other available methods are described alongside the five presented methods in **bold style**. In the analysis section, an explanation will be given for the variety in methods presented here, a decision tree guiding when to use what method will be presented and will a prediction for the future be done.

Method one (Creation GLOBCOVER Map using European Satellites)

The first method is the GLOBCOVER initiative, as mentioned in the introduction, a collaboration between the University of Leuven and the ESA. The goal of GLOBCOVER was to produce a land cover map for the year 2005/2006. This part will explore how this map has been created. Although the GLOBCOVER doesn't only focus on total forest cover but on multiple land covers, this investigation is still useful when studying forest cover detection methods. Because the classes that are created in the GLOBCOVER initiative contain several forest classes as will be made clear below. Also, similar methods will be mentioned and/or shortly described. All information given in this section unless mentioned otherwise has been taken from (Arino et al., 2007)

Remote Sensing-Satellite imaging ESA

The creation of the GLOBCOVER map starts with the making of satellite images. These images are taken using the MERIS (Medium Resolution Imaging Spectrometer) between the 1st of December 2004 and 30th of June 2006. The MERIS is attached to a satellite and is used by the ESA. The MERIS has the following specifications: The MERIS is programmable from the ground, meaning commands can be given from the earth. The MERIS has a medium -spectral resolution, operating in the solar reflective solar range, radiation from 0,4 micrometre to three micrometres (Sh. Fifteen spectral bands can be observed depending on the needs of the person commanding the satellite (multispectral imaging) (Schowengerdt, 2006). And the physical width of the bands that can be observed while orbiting the earth has a width of 1150 km due to having five cameras in a fan shape configuration.

The standard data acquisition used by the ESA had to be improved to facilitate the GLOBCOVER initiative because some regions are not covered regularly enough. This was done by improving how ASAR (A synthetic aperture) and the MERIS work together. How a synthetic aperture operates is illustrated down below. Because of the area covered in an instant by for example a MERIS scanner, points remain in focus for a longer time. Because of this, more time can be taken to take imagery of an object, resulting in a bigger (synthetic) aperture. They are opposed to big physical lenses that can be too big and expensive to put into space. So, after this adjustment, the MERIS satellites were able to provide data to the GLOBCOVER initiative. What was done to this data is explained in the data processing section.

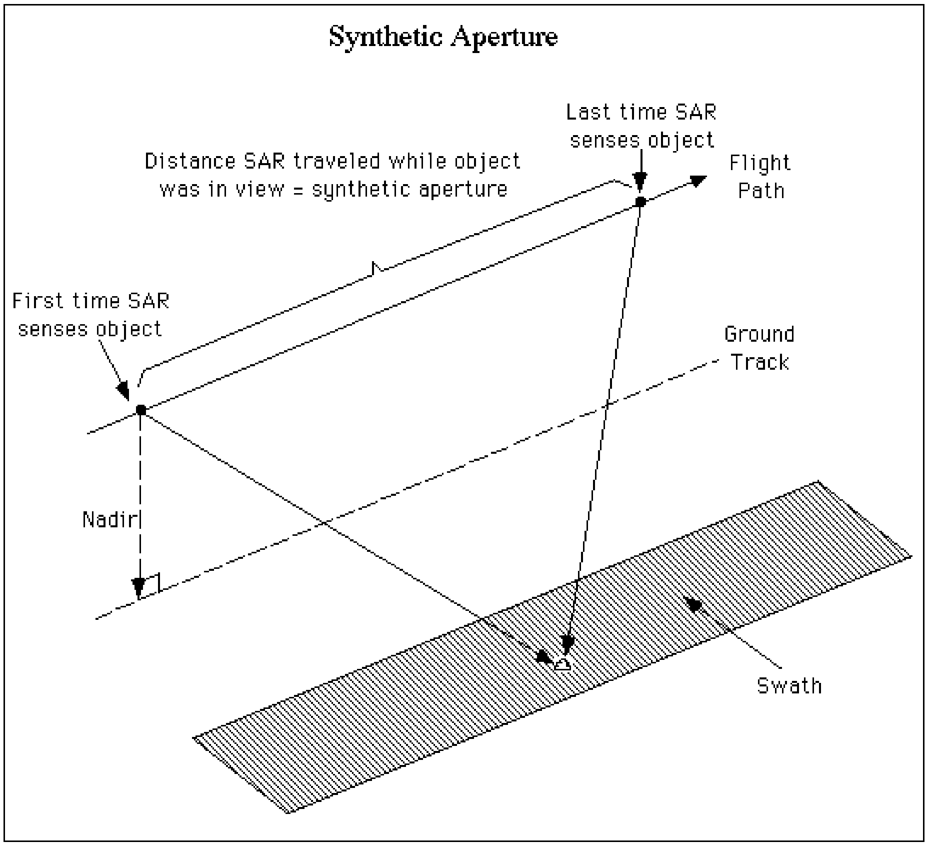


Figure 2: This figure illustrates the principle of Syntetic Aperture (ESA, n.d.).

Data Processing-Improvement Geolocation satellite imaging

When all satellite imaging had been acquired, the first step of the processing was to improve the geolocation. This means that the observed imaging had to allocated to the right geographical location on the earth. The GLOBCOVER strived for a precision of 150 m as because this was the wanted precision by the land science community. To achieve this, the ESA used the AMORGOS (Accurate MERIS Ortho-Rectified Geo-location Operational Software) tool (ESA, 2012). This tool makes sure data is allocated to the right location. The input for this tool is the MERIS attitude and orbit information file (The satellite images mentioned above).

Data Processing-Improving quality satellite images and creation of bimonthly mosaics

The following is applying the BRDF (Bidirectional Reflection Distribution Function). This function does two things: It creates maps, two for every month while at the same time correcting differences in reflectance. This reflectance happens due to images being taken at different times of the year and under different viewing angles. Also, corrections for clouds, gaseous absorption, Rayleigh scattering and aerosol effects have been taken into account. Besides annual and seasonal mosaics are created, this is done by averaging the bimonthly mosaics for the desired period.

Data Processing-Class determination process

Then the classes are determined. The world is split up into 22 regions to make calculations less difficult (mosaics). Then the classes are calculated in the following five steps. First, the mosaics are split up into classes based on their spectral characteristics. These classes are then classified based on temporal characteristics determined in the previous step (e.g. the length of the vegetation period). The following step puts classes together that have similar spectral and temporal characteristics (the previous two steps). Then in the next step, these classes are transformed into the LCSS land cover classes. The fifth step is the labelling done by experts, who improve the interpretation of the spectral-temporal classes. Thus, finally yielding different classes, one of which is forest.

Data Processing-LCSS

The LCSS classification system, as mentioned above, is a standardized classification system consisting of classes that have been created before the creation of a map. Taken from Di Gregorio et al. (2000), this classification system uses a set of diagnostic criteria (the classifiers). Any existing classification can be incorporated into this system. This works in the following way: First, eight major land uses have to be distinguished before the classifiers can be applied; this is called the Dichotomous phase. Then the so-called Modular-Hierarchical Phase is started where a set of hierarchically ordered classifiers are applied to achieve the desired classes. Then the classes are created having a unique name and numerical code that can be linked to a name in any language.

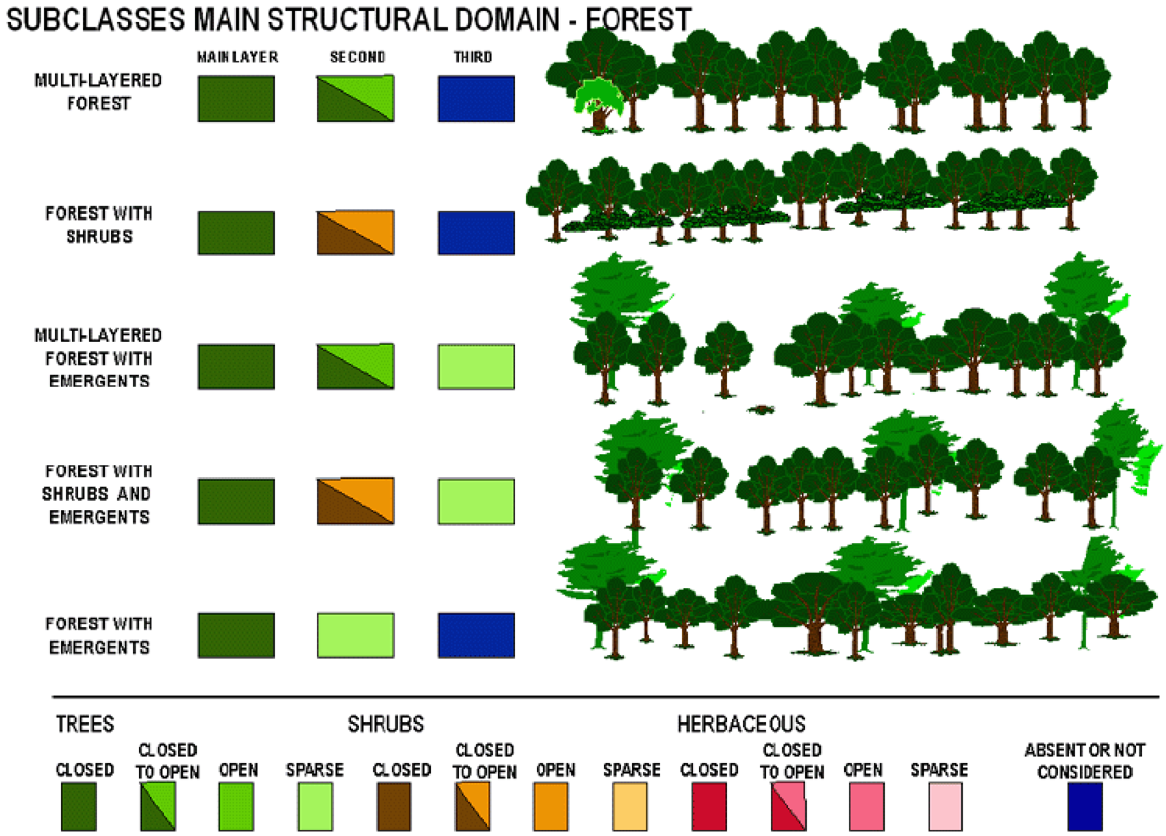


Figure 3. This figure shows an example of classes created using the LCSS approach (FAOSTAT, n.d.).

Data Processing- Processing time

The total time taken to process all the data for this project was 127 days, and when 24 CPUs are used instead of 12, 64 days are needed. The total data used per year for the project was 46 TB. This information.

Similar methods

A map of similar magnitude also containing the category “forest” was created by the ESA CCI Land Cover Team for the year 2016. **This map covered entire Africa using a resolution of twenty-meter resolution.** Using freely available satellite data (Lesiv et al., 2017).

Method two (Creation of the Collection 5 MODIS map using American Satellites)

The next method that is described is the creation of the Collection 5 MODIS (Moderate resolution imaging spectroradiometer). This is a land cover product with a 500-meter pixel resolution made between the year 2005 and 2008. Created using satellite imagery from NASA. this land cover product supplies five different classification systems, and thus contains multiple definitions of forest cover. This makes this method interesting for the analysis because also five different definitions of forest are used in this method. The details of the creation of this map is the subject of this section. All information given in this section unless mentioned otherwise has been taken from (Friedl et al., 2010)

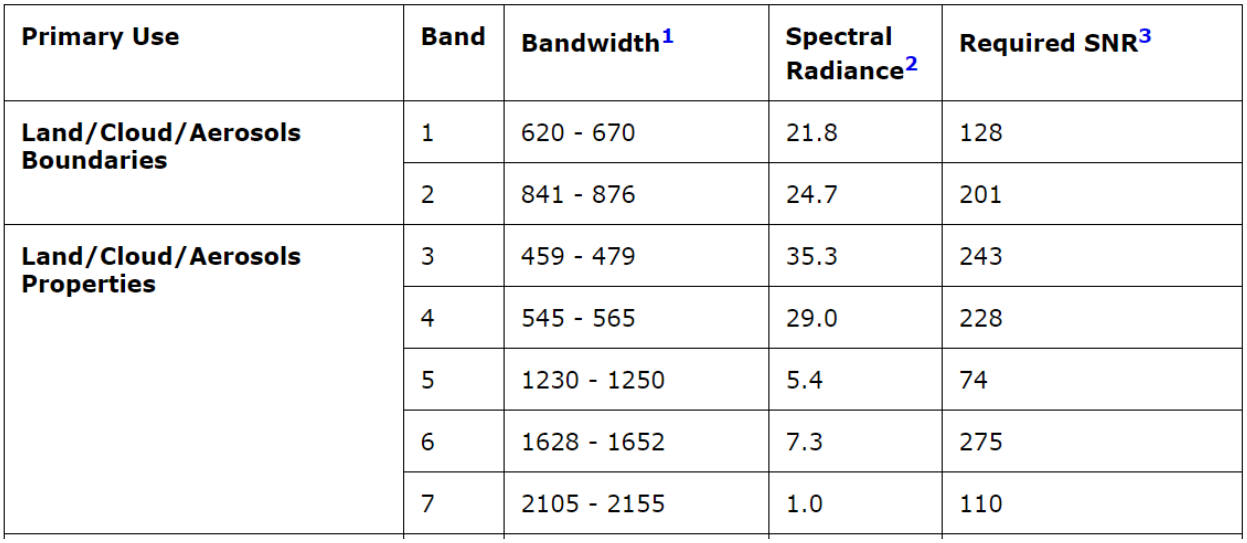
Remote Sensing-Input data

As mentioned above, the data used for this map are obtained from NASA. The satellites used for obtaining this data are the MODIS satellites. This imagery was taken in the period 2005-2008. The Bands (each band corresponds to a certain bandwidth in nanometer that is being imaged) used for the input data are shown in figure 4. This is multispectral imaging. Also, the strength of the obtained radiation is outlined in this figure, as well as the required ratio between background radiation and the desired bandwidth. This figure also makes clear why these wavelengths are chosen. Besides the MODIS satellites also information from the enhanced vegetation index (a standard index giving information about the amount of vegetation at a certain location) (Jian et al., 2008) was used to produce the MLCT product. Other input data include MODIS LST (land surface temperature).

Data processing-algorithm using training data other data processing

Before this data was put into the processing algorithm, the data was first transformed into temporal data. Data was created for 32-day periods totalling a year, where each period also contained information about the minimum, maximum and average values of a measured pixel. Moreover, was the MODIS BRDF added (Bidirectional reflectance distribution function), a function that defines how light is reflected at a certain location on earth under a certain angle. This is useful to correct for albedo effects.

The data is then put into an algorithm that connects the corresponding pixel, to the corresponding land cover class. This is done by comparing pre-processed data, as described in the above section, to data located in the MODIS land cover training site database. This training data is obtained from 1860 sites across the world, covering a variety of land uses, see figure 5. This variety is guaranteed by taking samples from ecoregions as described by Olson et al. (2001).



Primary Use	**Band**	**Bandwidth**[1]	**Spectral Radiance**[2]	**Required SNR**[3]
Land/Cloud/Aerosols Boundaries	1	620 - 670	21.8	128
	2	841 - 876	24.7	201
Land/Cloud/Aerosols Properties	3	459 - 479	35.3	243
	4	545 - 565	29.0	228
	5	1230 - 1250	5.4	74
	6	1628 - 1652	7.3	275
	7	2105 - 2155	1.0	110

Figure 4: This figure shows the used imaging bandwidths and their uses for the MLCT product (Friedl et al, 2010).

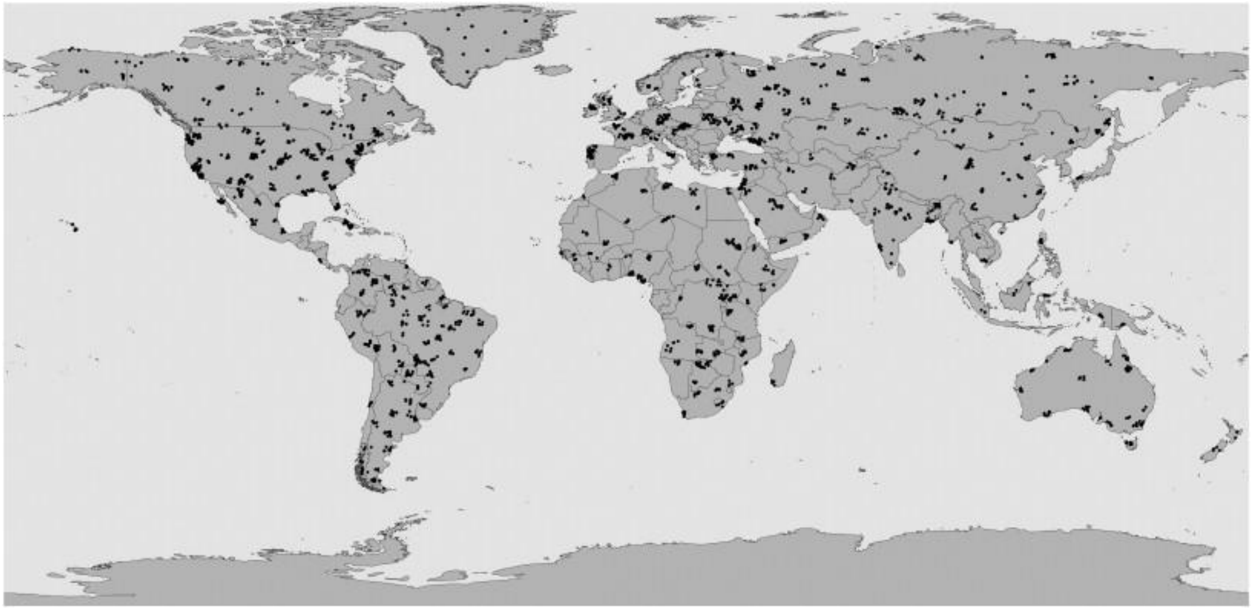


Figure 5: This figure shows the spread of areas where training data has been taken from, used for the MLCT product (Friedl et al., 2010).

Data Processing-Multiple output classes

The following classes are an output of the MLCT product: The International Geosphere-Biosphere Program classification system (IGBP) consisting of seventeen used for the program with the same name. The University of Maryland classification (UMD) consisting of fourteen classes, used by the University of Maryland. An out of ten consisting classes system used by the MODIS LAI/FPAR algorithm. And two unnamed classification systems. The first having eight classes from (Running et al., 1995), and the second has twelve classes used to describe existing plant functions from (Bonan et al., 2002). Besides these outputs using the 500-meter resolution. A lower spatial output consisting of 0.05° resolution is created called the MCD12C1 product, using the same classifications. These classifications are shown in figure 6.

	IGBP	UMD	LAI/FPAR	BGC	PFT
Forests	Evergreen needleleaf forest (1)	Evergreen needleleaf forest	Evergreen needleleaf forests	Evergreen needleleaf vegetation	Evergreen needleleaf tree
	Deciduous needleleaf forest (2)	Deciduous needleleaf forest	Deciduous needleleaf forests	Deciduous needleleaf vegetation	Needleleaf deciduous tree
	Evergreen broadleaf forest (3)	Evergreen broadleaf forest	Evergreen broadleaf forests	Evergreen broadleaf vegetation	Broadleaf evergreen tree
	Deciduous broadleaf forest (4)	Deciduous broadleaf forest	Deciduous broadleaf forests	Deciduous broadleaf vegetation	Broadleaf deciduous tree
	Mixed forests (5)	Mixed forest			
Woodlands	Woody savannas (8)	Woody savannas	Savanna		
	Savannas (9)	Savannas			
Grasses/cereals	Grasslands (10)	Grassland	Grasses/cereal crops	Annual grass vegetation	Grass
Shrublands	Closed shrublands (6)	Closed shrublands	Shrublands		Shrub
	Open shrublands (7)	Open shrublands	Shrublands		Shrub
Croplands and mosaics	Croplands (12)	Croplands	Broadleaf crops	Annual broadleaf vegetation	Cereal crop
	Cropland/natural vegetation mosaics (14)				Broadleaf crop
Seasonally or permanently inundated	Permanent wetlands (11)				
Unvegetated	Urban and built-up land (13)	Urban and built-up land	Urban	Urban	Urban
	Barren or sparsely vegetated (16)	Barren or sparsely vegetated	Unvegetated	Unvegetated	Barren or sparsely vegetated
	Water (17)	Water	Water	Water	Water
	Permanent snow and ice (15)				Snow and ice

Figure 6: This figure shows all the classification system for the MLCT product and the MCD12C1 product (Friedl et al., 2010).

Data Processing-Definitions of forest in different classification systems

As can be seen in figure 6, forest cover, the subject of this thesis, is represented in various categories in this product. Some names are: Evergreen needle leaf forest, Deciduous broadleaf forest, broadleaf deciduous tree, mixed forests etc. All categories contain at least four different forest categories, making for a precise description of global forest cover.

However, this variety in classes can make it hard to speak about such a thing as a forest, as the segmentation of these classes leads to different definitions of forest and makes distinctions between different types. This can make it hard to compare maps from different producers among each other. The creators of the MLCT product aim to create in the next product a classification congruent with the LUCC classification, as described in the first method description, to make this comparison easier. On the other hand, this variety in classification system is also beneficial. Different uses require different products. E.g. the PFT classification (Global plant functional classification) the classification based on the use of a land cover requires different categories as for example, the UMD classification, as the conventions in Maryland are different. However, more standardization could be useful.

Method three (Post-classification technique)

The method described here, although very useful for this study, doesn’t only focus on forest cover determination techniques. But it focusses on the following covers: dense urban, residential, turf & grass, agriculture, deciduous forest, coniferous forest, water, non-forested wetland, and barren. These covers are studied in four assigned regions in the eastern part of the US, see figure 7. Despite the fact that this methodology uses satellites like the first two described methods, the scale (a much smaller scale) adds to the variety among the five studied methods. All information given in this section unless mentioned otherwise has been taken from (Civco et al., 2002)

Figure 7: This figure shows where data was taken from for the described post-classification technique (Civico et al., 2002).

Remote Sensing- Data from Landsat

Between the 23rd of September 1999 and 4th of May 2000, satellite data was taken for the blue parts in eastern regions in the US, shown in figure 7. This data was multispectral data, consisting of fourteen different bands. They were taken by the Landsat satellites, satellites used by NASA (NASA, n.d.). A fourteen band multi-seasonal composite was created using this data. This means that data using a multispectral scanning radiometer was used taken from the Landsat satellite.

Data Processing – ISODATA algorithm

Then an algorithm called the ISODATA (Iterative Self-Organizing Data Analysis Technique) algorithm was used. This algorithm creates classes on its own. First cluster centres are randomly created, and pixels are assigned to the nearest cluster centre resulting in different classes. This process is illustrated in figure 8. Thus, categories are created only based on visual aspects, and afterwards, labels can be attributed to these categories. This method has according

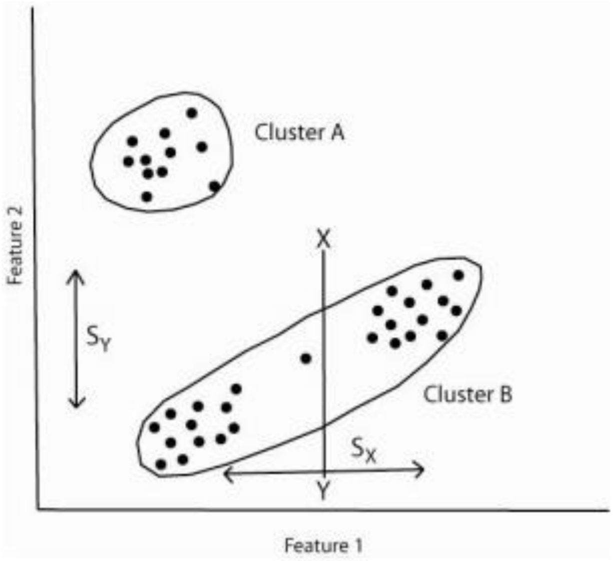


Figure 8: This figure shows how cluster are created bases spectral characteristics in the ISODATA algorithm (Vasilaros, n.d.)

In the research of Zhang et al. (2000) 75 spectral clusters were created using the ISODATA algorithm out of which 47 were labelled into a land cover, and 28 were classified as unknown. Then these 28 classes were again organised using an ISODATA algorithm yielding 33 labelled classes and 25 unknown classes. Then this process (*cluster busting)* was done a third time until all pixels were assigned to a class. Then the final classes were put into the wanted nine categories. Two of these classes were related to forest cover, the deciduous forest, coniferous forest.

Other methods on the same land area

Other similar methods that are applied to the same piece of land are shortly described/mentioned here. The first one is **correlation analysis**. This method is focused on finding how an area of land changes over time (Koeln and Bissonnette, 2000). In this method, changed pixels, compared to earlier obtained spectral data are given high statistic values. The second method is called **neural networks**. This method works by training algorithms to link specific characteristics of a pixel to a particular land cover, so this method is similar to the method used for the MLCT product; however, applied at a smaller scale. The last method described is **image segmentation and object-oriented classification**. This method operates using an algorithm that recognizes land covers not on pixel characteristics but based on segment characteristics such as region homogeneity.

Method four (Drone remote sensing, Automated detection forest fire)

The method that is described here is a cooperative perception system. This system is used to determine the amount of forest that is on fire (and thus being destroyed) in real-time, to inform firefighters. This system has however not been employed in real forest fires, only in controlled forest fire. The system operates using three vehicles: two autonomous vehicles and a blimp. Because the amount of forest on fire is monitored, loss of forest cover is measured. Thus, this is a way of measuring forest cover. All information given in this section unless mentioned otherwise has been taken from (Merino et al., 2006)

Remote Sensing - Sensors

The system described in Merino et al. (2006) describes the method of how unmanned drones and a blimp can discover and observe forest fires. The system consists of two UAVs. They have the following sensors: Differential Global Positioning System (DGPS), gyroscopes and sensors required for navigation. The sensors that perceive the environment are visual, infrared cameras and a fire sensor (only mounted on one drone). Which is a photodiode set up, that can perceive wavelengths between 185 nm and 260 nm (these are the wavelengths fires usually emit). The drone carrying the fire sensor also has a Canon S40 digital photo camera. The other drone has, besides the navigation sensors an infrared and visual camera. Both drones also carry tilt units to allow the cameras to move without the drone moving. The blimp carries two optical cameras to allow for event monitoring.

Data Processing - Fire confirmation and Observation

The drones are programmed to hover a predetermined area, in this case, an airfield in Portugal (310x 400 meters), (this could be bigger areas. E. g. Big forest fires where hectares of forest are demolished.) At this stage, no cooperation between the two drones is taking place. Both are hovering the airport. While scanning the environment, data from the entire airfield is obtained — a combination of visual data and fire sensor data. Using algorithms described in Merino et al. (2006), fire probabilities are calculated for every square meter. When a set of scanned cells all having a high fire probability is found, the drones are given a new assignment. Both drones are sent to the place having a high fire probability. The drone having the infrared sensor concludes whether there is a fire or not based on algorithms described in Merino et al. (2006).

When a fire has been found, both drones are given the assignment to hover around the fire to observe it — sending imagery from the fire to an observer to obtain information on the size of the fire. Then when needed, the blimp is sent to the fire to observe the fire.

Other methods using drones

Research is also being done how this could be done in real-time and some studies (Merino et al., 2012) are exploring how this could be combined with **automated prediction** models to inform wildfire operators even better. Also, **bigger aeroplane shaped drones** are used to monitor forest fires (Ambrosia et al. 2011b; Hinkley and Zajkowski 2011). And of course, can drones be combined with most scanners discussed in this research. The potential for drones seems big in the future. This is explored in the discussion.

Method five (Aircraft remote sensing)

The following method has a different goal regarding forest cover compared to earlier described methods. The aim of this method is to estimate canopy height. This estimation has been done in the Aberfoyle forest district in Scotland, as shown in Figure 9. The technique used in this detection process is LiDAR. Although this method doesn't only focus on forest cover, this method has been included to show how different information types can be obtained from forest cover. It can be essential to know specifics of forest cover to say something about forest cover more confidently. Thus, also deemed relevant for this research. In contrast to the other methods, an aeroplane has been used in the remote sensing process. All information given in this section unless mentioned otherwise has been taken from (Suarez et al., 2005).

Remote Sensing- Data acquisition

The studied area covered an area of 20 km²; this is highlighted by the red rectangle in figure 9. Using an aeroplane, this area was completely scanned in one. Resulting in a map with a resolution of 25x25 cm. The scanner that was used was an Optech ALTM2033 scanner, which is using LiDAR technique (This technique is described in the concept and theory section. The estimated price per hectare was 5 English pounds.

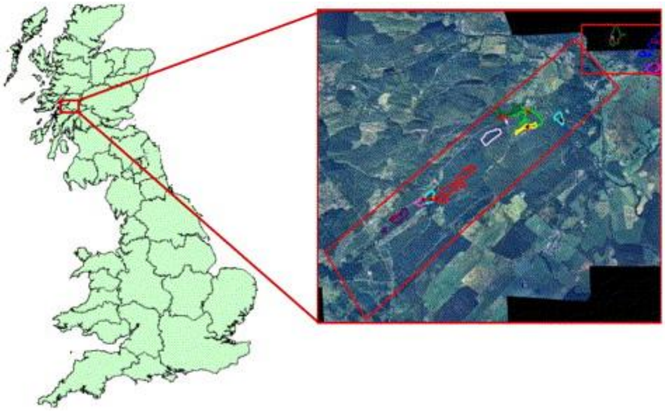


Figure 9: This figure shows the geographical location of the research, the Aberfoyle forest district in Scotland (Suarez et al., 2005).

Data Processing LiDAR technique

As described in the theory and concept section, LiDAR works similar to radar. Using lasers that are reflected back from the ground/trees, canopy height can be calculated using the time it takes for the laser to return. These lasers are continuously being emitted along the flight line of the aircraft. This is illustrated in figure 10. LiDAR techniques deployed from satellites are not present during the time of this research.

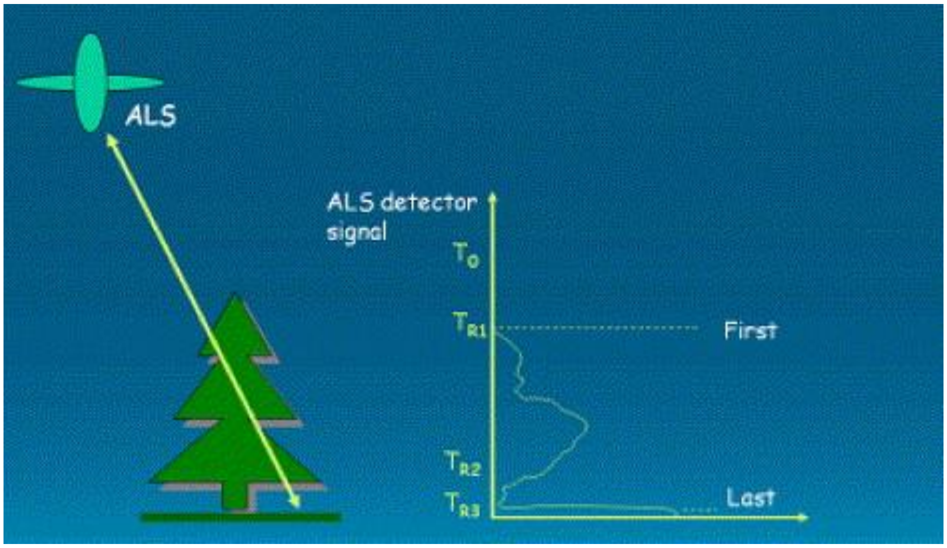


Figure 10: This Figure shows how LiDAR technique is applied (Suarez et al, 2005).

Other methods using LiDAR

Also, other LiDAR techniques are used. An example is a study **focusing on the number of branches present on studied trees**. This study was conducted in North America (Dubayah et al., 2000).

Discussion & Conclusion

Summary results

The discussed methods show that there is a wide variety of different forest cover detection methods. Different sensors (as mentioned in the theory and concept section) are used. Dependent on the size of a project, various remote sensing aircraft are used. They are ranging from satellite data from NASA to create global maps, to local drone installations looking for forest fires. There are methods almost entirely computer-based (ISODATA method), mostly based on the judgement of experts, and there are methods that combine all this (the GLOBCOVER initiative and the MLCT product). Moreover, some techniques use a variety of different classifications (MLCT product), and some methods use a more or less standardized classification (GLOBCOVER). Also, methods focusing more on the specifics of forest cover are available. The LiDAR methods described here, for example, only focus on canopy height and branch amount. Also, the size of these projects differs significantly. The first two case studies focus on a global map, whereas the project size of the last three case studies is much smaller. Consequently, also the needed time for a project and the required capital differs a lot.

Why do methods differ?

When returning to the aim of this research as mentioned in the introduction: "*this thesis aims to give an explanation for the differences in these methods and find out whether there is a best method.*". It seems that when forest cover is mapped on a global scale, satellite data is always the methodology. This can be the case because it is too much work to map the entire earth using other aircraft besides satellites. The use of drones has an advantage when forest cover has to be covered as fast as possible during, for example, forest fires. Also, the danger aspect that is present when assessing forest cover during a forest fires makes drone remote sensing a more suitable method. The difference between data processing techniques such as the ISODATA algorithm and the advanced processing techniques used in the first two case studies seems to be linked to the availability of capital. When more capital is available, more advanced techniques can be used. Moreover, it appears that when more specific information is needed regarding forest cover such as canopy height, or number of branches, LiDAR or a similar radar technique is the right method. The advantage of aircraft compared to drones is not completely clear out of these results. When the goal of forest cover detection is detecting change, it is best to choose an approach like correlation analysis. And finally, methods use different classification systems. It seems like it would be a good thing to achieve a generalised classifications system. And it seems like the LUCC classifications system is the best available option. However, as of today, there is not a generalised system.

The explanations given above make clear that there cannot be spoken of the right method. Although, some methods seem more promising than other methods (more advanced data processing seems a better approach compared to a one algorithm (ISODATA) approach. And always having data using a 10x10 meter resolution seems ideal) But using the right technique for the right situation is a more realistic and useful way to think about it in my opinion. A suggestion for choosing is illustrated in the decision tree down below.

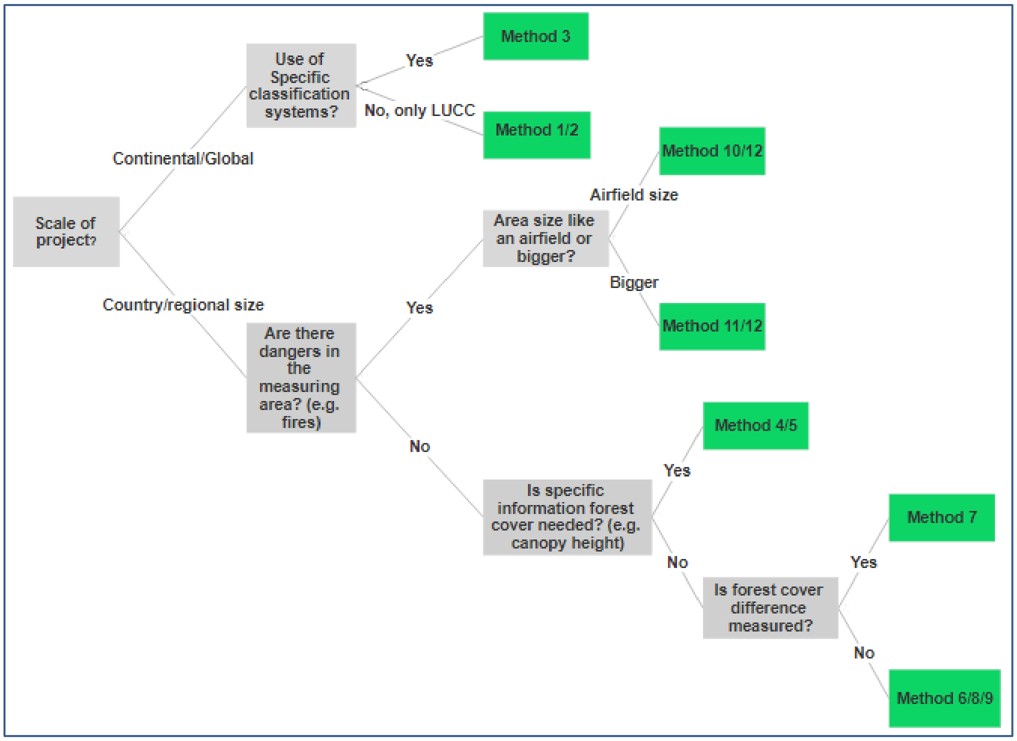


Figure 11: This figure gives a suggestion for the method choosing process based on methods mentioned in this thesis. Method 1: GLOBCOVER project (ESA), Method 2: ESA CCI team, Method 3: MODIS NASA, Method 4: LiDAR Canopy Height, Method 5: LiDAR Branches, Method 6: Post Classification, Method 7: Correlation Analysis,
Method 8: Neural Networks, Method 9: Image segmentation and Oriented classification, Method 10: Drone Remote sensing, Method 11: Aeroplane shaped drone remote Sensing, Method 12: Automated prediction methods (drones)

Future forest cover detection methods

When analysing the used methods and literature, some methods seemed more promising for the future than others. This section will argue that drones could be the future of forest cover detection techniques. This promising nature of drones is shown in the case study done in this thesis. Moreover, *Nature* has done research into this possible future use for drones. This has been stated in a research called *Drone remote sensing for forestry research and practices*. By Lina Tang and Guofan Shao (2015)

Drones can carry a variety of scanners, Koh and Wich (2012) used a simple camera to detect forest cover. Lisein et al. (2013) used NIR (Near-infrared imaging). Zarco et al. (2014) also used a cheap RGB camera (A camera where information is taken that can be represented in the colour red green and blue, a standard consumer camera) modified for CIR (Colour infrared detection) to detect tree height.
Also, bigger scanners are used for drones, such as the one mentioned in the results section (Ambrosia et al. 2011b; Hinkley and Zajkowski, 2011) Other scanners that can be put onto drones are (SWIR) shortwave infrared, TIR (Thermal Infrared) Radar and Lidar sensors.

Drones can, depending on the need for the detection use a variety of different power sources. This is important because depending on the power source the flight time is directly affected (Dudek et al. 2013) Drones used for military practices usually use combustion engines like aeroplanes (Tang and Shao, 2015). However, this is not a good option for smaller drones used for remote sensing. These engines are more economical and vibrate less, thus having a smaller distortion effect on the imaging. Solar cells would also be a good option to supply energy. But for larger drones that for example, monitor forest fire as mentioned in the previous section, combustion engines will be necessary.(Ambrosia et al. 2011b; Hinkley and Zajkowski 2011)

Scientific, Societal and Sustainability implications

The implications for this research are that there is now an overview for forest cover detection methods contributing to the scientific knowledge. As well as brief guidelines (decision tree) when to use what method. Moreover, are there also implications regarding society and sustainability, this links back to the reasons given in the introduction of why this research was deemed useful. More clarity in when to use what method will contribute to better knowledge about forest cover numbers. This certainty is important for a number of reasons. Illegal logging cannot be precisely monitored. Forest preservation policies are hard to implement. And like mentioned in the introduction, will it be hard to assess how many greenhouse gasses are taken up as a result of biomass.

Shortcomings and suggestions for future research

When looking at the research methodology taken in this research, some comments can be made. Due to limited space, it was not possible to accurately describe all available methods, and however, due to the methodology taken, this has mostly been solved.
Also, when focusing on forest cover detection methods, it became more a focus on land cover detection methods. This can make it seem like this research focuses on land cover techniques. However, to describe forest cover detection methods, a focus on the big picture is needed because forest cover detection is, in many cases done simultaneously with other land covers. In this research has been tried to keep the focus on forest cover as much as possible.

Recommendations for future research are looking more into the possibilities of forest cover mapping of drones as this technology looks very promising (Tang et al., 2015) And a more comprehensive description of forest cover detection methods could be added as this description is maybe somewhat short. Also, the same analysis for other land covers could be made. As there are not any of these analysis at the moment of other land covers.

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