Spatial and temporal variation in vegetation land cover albedo in Finland

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Surface albedo, which is the fraction of reflected radiant energy by earth's surface to incoming solar energy, plays an important role in earth energy budget and energy equilibrium. Different features of the earth's surface have different reflectivity rates which affect albedo. Vegetation land-covers covering vast areas of earth's surface such as agricultural land, forest, grassland and so on, have great impact on land surface albedo. The species composition, geographical distribution, and seasonal phenology of different vegetation land-covers have an impact on surface albedo and earth's energy budget and, consequently, on climate change.

The boreal zone covering latitudes between 60º – 70º N is one of the largest vegetation biomes on earth and has a significant impact on surface albedo. The boreal region is mostly covered by coniferous forests which are optically very dark and absorb most of the incoming solar energy. This low reflectivity is very influential during the times that earth's surface is snow covered by masking the high reflectivity of the snow covered land surface. This has caused most studies to focus on the boreal vegetation land-cover albedo during the snow covered periods of the year.

In this study, the effects of five different vegetation classes (agricultural, deciduous, coniferous, mixed forest and shrubland), three different latitudinal gradients (northern, middle and southern Finland), and the vegetation phenology during the growing season on surface albedo of vegetated areas of Finland for the year 2009 has been investigated. The results of the study showed that there is a significant difference between the albedo of different vegetation land-cover classes. The albedo of agricultural lands tends to be systematically the highest in all conditions while coniferous are the lowest. The vegetation land-cover albedo is generally lower in northern Finland compared to middle and south. There is a gradual increase in vegetation albedo until mid-July and after reaching a maximum level it starts to decrease towards the end of the growing season. The peak in albedo is reached about two weeks earlier in the north compared to the south possibly due to and longer days during its shorter growing season.

Avainsanat – Nyckelord – Keywords

Surface Albedo, vegetation land-cover, Boreal zone, vegetation classes, growing season

Säilytyspaikka – Förvaringsställe – Where deposited

Helsingin yliopiston kirjasto – Helda / E-thesis (opinnäytteet) *ethesis.helsinki.fi*

Preface

This project has been conducted with data retrieved from open source data providers, NASA’s MODIS project and Finland’s IT center for science (CSC). These kinds of organizations play an important role by providing free access to scientific data for the progression and advancement of science and human knowledge in general. Fortunately, there are a lot of organizations like these which are providing open access to scientific materials and findings in different areas of science.

I am especially grateful to my supervisors, Professor Pauline Stenberg, DR. Petr Lukes and DR. Miina Rautiainen. I would also like to thank DR. Jarkko Salojärvi, who helped with statistical analysis and everyone else who helped and supported me in the process of conducting this research. The accomplishment of this project was only possible with their help and support.

In the end, I dedicate this project and offer my deepest gratitude to my lovely wife who has patiently supported and helped me throughout my studies.

Pezhman Safdari

May 6, 2015, Helsinki

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1 Introduction

1.1 Definition of albedo

The albedo of a surface can be described as fractions of radiant energy from all wavelengths which are diffused by a body or surface in all directions to the downwelling incident irradiance upon that body or surface (Professor Crystal Schaaf's Lab, 2015). In other words, it is the percentage of sun-radiated energy which reaches a surface and is reflected back by that surface. Due to its dimensionless nature, albedo is expressed as a percentage between zero, meaning a perfect black surface with no reflection, and one, meaning a perfect, diffusely-reflecting surface which reflects back all of the incident radiation (a Lambertian surface).

Albedo is a combined property of the surface and all illumination conditions. It changes based on the properties of a surface and during elapsed time. Albedo depends on the solar zenith angle and quantity and qualities of atmospheric components (gas molecules, clouds and aerosols) (Global Climate Observing System, 2009).

The albedo of a surface covered with fresh snow can reach up to 95 percent while for a coniferous forest it can be as low as 5 percent. For water bodies, on the other hand, albedo strongly depends on the solar zenith angle. This means that if the sun is radiating on a water body with a low zenith angle, albedo can drop to 3 percent and water absorbs almost all of the radiation. But, if the solar zenith angle is high, the water body can reflect more than 90 percent of the incident solar radiation.

As solar radiation passes earth's atmosphere, it goes through four different situations. Most of the radiation passes the atmosphere and reaches the earth's surface. However, clouds and atmospheric constituents absorb, reflect and scatter portions of the solar radiation. Clouds and air components reflect about 30 percent of the total incoming solar energy back to space (Ahrens, 2006).

The amount of solar radiation which reaches the earth’s surface is a function of direct and diffused components. Based on the source of the illumination, albedo can be defined in different ways. Black-sky albedo (directional hemispherical reflectance, Figure 1a) assumes that there is no diffused illumination source and is a function of solar zenith angle. White-sky albedo (bihemispherical reflectance, Figure1b) assumes that there is no source of direct illumination and all radiation comes from diffused sources. The black-sky and white-sky albedo are just extreme assumptions and the actual albedo, or blue sky albedo, is an interpolation between these two (Professor Crystal Schaaf's Lab, 2015).

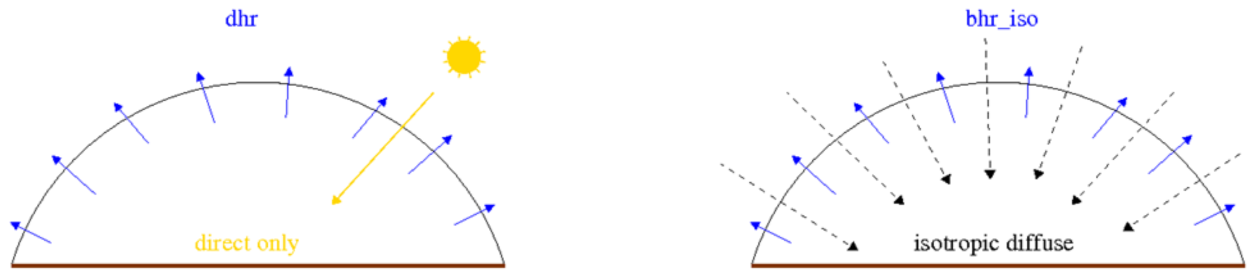


Figure 1 black-sky albedo (a) and white-sky albedo (b), Source: radiation Transfer Model Intercomparison, European commission website

The actual albedo is a joint property of the surface albedo and the atmosphere above it. This means the actual albedo is not a pure property of the surface. To peruse the earth surface albedo, one must study black-sky albedo, assuming direct solar radiation and no diffuse irradiance.

Based on the FAO's "Terrestrial essential Climate Report", albedo is one of the essential climate variables (ECV) (Schaaf, 2009). Albedo controls the planetary radiative energy budget. In order to calculate the energy balance of the atmosphere, weather and climate models have to consider evaluating surface albedo. Albedo, at different spatial resolutions, is also required for hydrological, biogeochemical, agricultural, etc. modeling.

Albedo can be measured by fixing spectroradiometers in site above the vegetation canopy, on air born platforms, or on earth orbiting satellites. While in-situ and airborne measurements are suitable for small scale, short term studies, satellite imagery seems to be the only applicable way to conduct long term national to global albedo measurements. The Moderate-Resolution Imaging Spectroradiometer (MODIS) instrument installed on NASA's Terra and Aqua satellite platforms is an example of long term albedo retrievals with the spatial resolution of the whole globe. In this study, the MODIS BRDF/Albedo Product (MCD43) is used as the source for albedo data.

1.2 The impact of the planetary albedo on earth and climate energy balance

There is a delicate equilibrium between the amount of energy that the earth surface receives from the sun, and energy that earth emits back to space. The transmission of energy from earth to outer space occurs through atmospheric radiation, thermal radiation of the earth's surface, and reflectance of a fraction of the incoming solar energy directly back to space (Marshal and Plumb, 2008). Perturbation of any of these energy transmittances can disturb the earth's energy balance and lead to cooling or warming of the earth's climate. (Hansen et al., 2005; Lindsey, 2009). Recently, this balance has been disturbed and earth is getting warmer. This is, most probably, due to anthropogenic interferences like CO_2 emissions and land-cover change. CO_2 emissions decrease the amount of energy radiation from earth to space which consequently warms the climate. This warming reduces the amount of ice and snow covered areas on earth, causing a reduction in albedo. Albedo reduction in return acts as a climate forcing factor and increases warming. This magnifying process will continue until the CO_2 emissions stops and a new equilibrium is reached (Hall, 2004; Hansen et al., 2005; Ingram et al., 1989).

Hall (2004) has discovered that the presence of albedo as a factor in climate models can cause 5 to 2 K global temperature fluctuation. This shows that albedo is playing an important role in climate modeling and the earth's energy budget. Clouds and atmospheric particles account for most of the earth's albedo (about 23 percent). Ice- and snow-cover, along with land-cover, account for 6 to 7 percent of the earth's albedo. Anthropogenic activities have changed land-cover during human existence on earth. Based on Betts (2000) and Feddema et al. (2005), human land-cover change activities might have reduced the northern mid-latitude temperatures by 1-2 K. This has been caused by changing previously forested lands into pasture and agricultural lands, which in return increases the surface albedo by almost 0.1 during snow-covered times. This is an indication of the importance of land-cover dynamics and consequently its albedo on the earth's climate.

1.3 The impact of vegetation land-cover and vegetation land-cover albedo on climate

Plants and vegetation affect the climate through evapotranspiration, volatile organic compounds, albedo and hydrological cycle. In global studies of climate, vegetation land-covers are basically classified as forest, agricultural and grasslands. The earth is also divided into tropical, temporal and boreal regions. In general, forest land-cover is considered darker with lower albedo. Forests cover about 42 million km^2 of the land surface. The species composition or conversion of the forest to other types of land-cover can have significant effects on the earth's climate. A number of studies (Betts, 2000; Bounoua et al., 2002; Feddema et al., 2005; Gordon, 2008; Jackson et al., 2008; Myhre and Myhre, 2003; Schwaiger and Bird, 2010; Snyder et al., 2004) have shown that land-cover and its probable changes can have a meaningful effect on the earth's climate.

Forests in tropical regions have a cooling effect on the climate because they are very efficient carbon sinks, and through massive evapotranspiration. These factors offset the low reflectivity of forest in the tropics. Removal or conversion of forest in these areas will lead to a warmer, drier environment and less precipitation in the tropical regions (Feddema et al., 2005; Gordon, 2008; Mahmood et al., 2014; Snyder et al., 2004).

Historical land use conversion from forest to croplands by humans in temperate regions may have led to about 1K cooling in the climate temperature throughout history (Bounoua et al., 2002). Pastures and croplands have higher albedo compared to forest land-cover. Crops also have much lower resistance to evapotranspiration, which in return causes more cooling and precipitation. In drier regions on the other hand, trees have access to deep ground water supplies and have higher evapotranspiration compared to crops and grasslands (Gordon, 2008). In general, the effect of land-cover seems to be a slightly negative forcing of global warming in temperate regions (Mahmood et al., 2014).

1.4 Vegetation land-cover albedo of boreal zone

The boreal zone is the circumpolar area between 50^{o} and 70^{o} in the northern hemisphere. This area is mostly covered by forest, although lakes, rivers, heath- and grasslands, as well as peat-lands, are also common landscapes throughout this region. The boreal region is about 1478 million hectares, of which 920 million hectares is forest covered (Hagner, 1995; Kuusela, 1992). The characteristics of this region are very cold winters, cool summers, and a low to medium amount of precipitation (400 – 800 mm per year), most of which is in the form of snow. The dominant tree genera are Pine (*Pinus*), Spruce (*Picea*), Larch (*Larix*), Poplar (*Poplus*) and Birch (*Betula*). The area is mostly dominated by coniferous trees. According to Snyder et al. (2004), boreal forests are the most influential earth biome on global average annual temperatures. Boreal land-cover is also affected by climate change. Based on Kauppi et al. (2014), climate warming has more than doubled the annual growth of Finnish forests. It seems that boreal forests and climate warming have a reciprocal effect on each other.

Coniferous trees are very efficient in evapotranspiration and evaporate between 25 to 75 percent of the equilibrium evaporation compared to deciduous, which is almost 100 percent (Baldocchi et al., 2000). Due to low annual temperatures, a lack of precipitation, and unfertile soils, boreal forests are not very efficient carbon sequestration sources. Coniferous trees are one of the darkest land-covers of the earth's surface. This low reflectivity affects the albedo of boreal forests, particularly during winter and early spring when there is snow on the ground. The albedo of snow-covered, coniferous forest can drop to less than 0.3 due to the low reflectivity of coniferous trees. In snow-covered grasslands, albedo can reach up to 0.8 (Betts and Ball, 1997). This can significantly affect the surface temperature of boreal regions. Most climate and land-cover studies are in agreement that removing coniferous boreal forests and replacing them with more reflective vegetation, such as deciduous forests or grass and agricultural, will have considerably negative effect on global warming (Bala et al., 2007; Betts and Ball, 1997; Betts, 2000; Feddema et al., 2005; Gordon, 2008; Jackson et al., 2008; Schwaiger and Bird, 2010).

According to Betts and Ball (1997), the albedo of coniferous trees is significantly lower than grass even during the summer. Rautiainen et al. (2012) believe that the changes in leaf area index or green biomass are a key factor for studying forest land-cover reflection in boreal regions. This is because the green biomass of the trees changes during the phenological circle of vegetation life. They have reported that in boreal forests, deciduous and mixed stands reach their maximum leaf area index in mid-July while the leaf-area index of coniferous stands continues increasing until the end of August. On the other hand, Heiskanen et al. (2013) believe that the difference between the reflectance of deciduous trees and coniferous trees is significant until May, after which it is not statistically significant. Lukeš et al. (2013a) think that adding a mixture of deciduous trees to coniferous stands from 20% to 90% can increase the average albedo from 0.1 to 0.18. They have also suggested that managing a stand towards having low stand density throughout the rotation period might increase albedo.

1.5 Objectives and structure of the study

So far, most of the studies of boreal forest albedo have investigated the effect of forest land-cover on albedo in winter and early spring when there is snow on the ground. This is a rational approach because snow has dramatic effect on surface albedo. Reducing or covering snow effect can have a great impact on the atmosphere and surface temperature. A few studies (Betts and Ball, 1997; Lukeš et al., 2014; Lukeš et al., 2013a) have however suggested that there could be significant differences between different vegetation land-cover albedos even during the growing season. These differences are caused by the different reflection properties of different vegetation land-covers and also vegetation phenology during the growing season.

This study has been conducted to investigate the level of albedo difference between five vegetation land-cover classes during the growing season. The study area is the country of Finland, excluding the

Åland islands. CORINE Land-Cover data of Finland from the year 2006 was used as the source of the land-cover information. MODIS BRDF/Albedo Product MCD43 for the year 2009 was used as the source of albedo data. The vegetation land-cover classes which have been studied are Agricultural, Shrubland, Deciduous Forest, Coniferous Forest, and Mixed Forest. The albedo of the mentioned vegetation land-cover classes were compared on days 161 (10^{th} of June) at the beginning, day 209 (28th of July) in the middle and day 257 (14th of September) at the end of the growing season. In southern and middle Finland, the growing season starts in early May. Day 161 was selected as the beginning of the growing season as significant areas of northern Finland remain snow covered in early May, affecting albedo and meaning that they could not be used in this analysis. Also, there is insufficient data for most of the land-cover types in northern Finland and day 161 is selected to optimize the number of data points. The albedos of the five vegetation land-cover classes were also compared as a time-series comparison for the whole growing season. To take the effect of latitudinal gradient on vegetation into consideration, the comparisons were performed in three different geographical locations: northern, middle and southern Finland.

This study was conducted to test the following hypotheses:

1. The albedo of different vegetation land-cover classes in Finland are significantly different during the growing season
2. Latitudinal gradient has a meaningful impact on vegetation land-cover albedo
3. The albedo of the vegetation land-covers changes during the growing season

This study is expected to improve our understanding of land-cover albedo during the growing season in Finland in particular, and in the boreal region in general. The results can help future modeling of albedo for the boreal region and its application in climate modeling and global climate change.

The work flow of the study is shown in the figure 2.

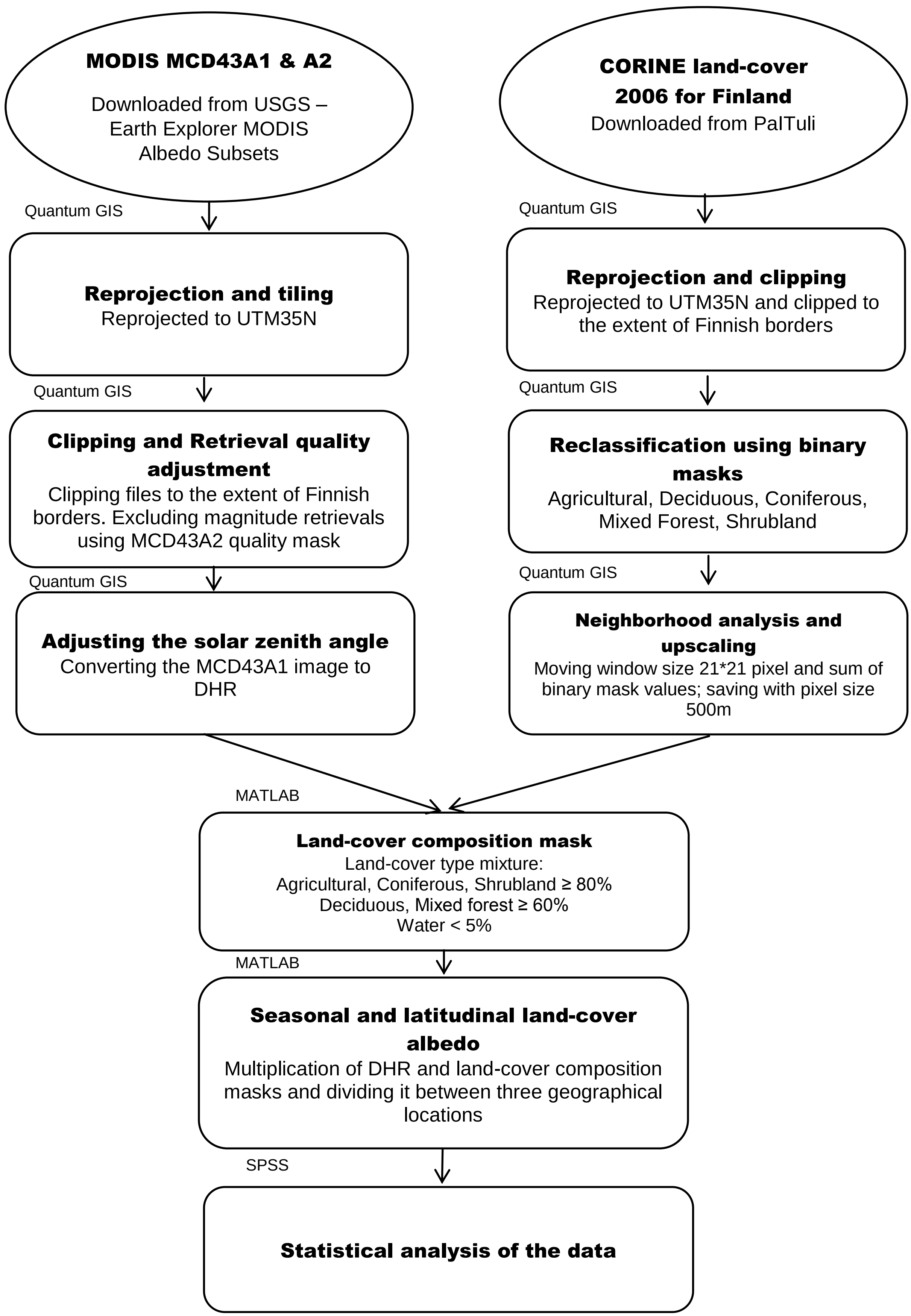


Figure 2 an overall flowchart of the study process

1.6 Application of MODIS albedo and CORINE land-cover products in land-cover radiation studies

Gao et al. (2005), in a global-scale study of albedo of major vegetation types, concluded that MODIS albedo products have temporal and spatial patterns in concordance with their underlying land-cover classes. This means that land-cover types and their temporal phenological changes have a detectable effect on the observed albedo. In their study, grasslands, shrubland and agricultural lands show the highest albedo variation compared to other land-cover classes. Stathopoulou et al. (2007), by combining CORINE Land-Cover (CLC) data and Landsat satellite data, reported that there is a statistically significant difference in emissivity in different CORINE Land-Cover classes. Their results also show that there is a strong correlation between CORINE Land-Cover classes and emissivity which can quantitatively link them together. Finally, Lukeš et al. (2014), using MODIS albedo products, CORINE Land-Cover data and the national forest inventory of Finland, concluded that the albedo of all land-cover classes start to increase from the beginning of the growing season until mid-July when it starts to decrease. Coniferous land-cover has the lowest and agricultural lands have the highest albedo during this time. They also did not observe a relationship between latitude and albedo during the growing season, which suggests latitude may not have any effect on albedo during the growing season.

2 Materials and methods

2.1 Materials

2.1.1 The area of the study

The whole area of Finland is the subject of this study. Finland is one of the so called Nordic countries (Finland, Denmark, Norway, Iceland and Sweden) and is located in the Eurasian boreal zone which stretches from Norway to eastern Russia. The boreal zone (50^o – 70^o N) is a coniferous-tree-dominated forest biome and is one of the biggest biomes of the plant.

Finland is the most forested country in this region with 73 percent of its land-covered by forest. The length of the growing season (when the average temperature is above 5^o C) is about 180 days in southern Finland, and 120 days in northern parts of Finland. The dominant tree species in Finland are Scots pine (*Pinus sylvestris,* 50%), Norway spruce (*Picea Abies*, 30%) and Silver birch (*Btula pendula*, 17%). Based on Stenberg (1996), the approximate median of the incoming solar radiation of Finland during the growing season is 60^o. Figure 3 shows the 2006 CLC for Finland (Finnish Environment institute 2009).

Figure 3 Land-cover map of Finland

To study the possible effect of the spatial gradient on albedo, the study area was equally divided into three regions from north to south.

2.1.2 MODIS Albedo/BRDF Product MCD43

MODIS albedo products are a database of globally modeled surface albedo started in early 2000. Version 5 of the products, which have been used in this study, are produced every 8 days based on multi-spectral, multi-angular and multi-day surface reflectance measurements by the MODIS instruments on board the Terra and Aqua satellites. This data is cloud free and atmospherically corrected to measure only the reflectance properties of the surface. The data is produced at 500m to 1km pixel resolution. It is an average of 16 days of reflectance retrievals for each pixel per each day, weighted based on the observation coverage, retrieval quality, and time distance from the day of interest. MODIS data retrievals are in 16 days rotation in order to gather sufficient cloud-free, multi-angular observation for use in the model. The MODIS Albedo and Reflectance Anisotropy Algorithm uses a linear kernel-driven semi-empirical model to estimate the Bidirectional Reflectance Distribution Function (BRDF) (formula 1). In the formula, *fiso* is the isotropic and *fvol* and *fgeo* are the volume-scattering and geometric-optical contributions to the BRDF; g_{iso}, g_{vol} and g_{geo} are constant weights that describe the current observed data in the best way and Θ is the sun-zenith angle in radian. This model is formed based on the two functions of viewing and illumination geometry and the weighted sum of an isotropic parameter (a Ross-ThickLiSparse-Reciprocal model). These selected parameters are the ones that best fit the atmospherically-corrected, cloud-free available reflectance over a period of 16 days for each location. (Professor Crystal Schaaf's Lab, 2015; Schaaf et al., 2010; Strahler A. H., 1996).

$$\begin{aligned}\alpha_{bs}(\Theta,\lambda) = {} & f_{iso}(\lambda)\,(g_{0iso} + g_{1iso}\,\Theta_i^{2} + g_{2iso}\,\Theta_i^{3}) + \\ & f_{vol}(\lambda)\,(g_{0vol} + g_{1vol}\,\Theta_i^{2} + g_{2vol}\,\Theta_i^{3}) + \\ & f_{geo}(\lambda)\,(g_{0geo} + g_{1geo}\,\Theta_i^{2} + g_{2geo}\Theta_i^{3})\end{aligned}$$

Formula 1 MODIS Ross-ThickLiSparse-Reciprocal BRDF model. Source: MODIS User Guide

After retrieving a suitable anisotropy estimate of the BRDF, integrating this estimation over all possible viewing angles will result in Directional hemispherical reflectance, or black-sky albedo (DHR), for a specific illumination direction. Integrating all the possible illumination angles will result in bihemispherical reflectance or white-sky albedo (BHR). The assumption for the white-sky albedo is that the illumination is isotropic. This procedure is carried out for all seven spectral and three broad bands of MODIS instrument which will be combined as a final, single albedo product. Whenever there are insufficient high quality retrievals for a full conversion to be made, a magnitude conversion is employed based on land-cover classification and historical high-quality conversions (Professor Crystal Schaaf's Lab, 2015; Schaaf et al., 2010).

2.1.2.1 MCD43A1 and MCD43A2

The MCD43A1 BRDF/Albedo product is the measured anisotropic weighting parameters of the Ross ThickLiSparse Reciprocal model (*fiso*, *fvol* and *fgeo*), which describes each pixel in the best way. The reason for producing this dataset is to enable users to compute their own integrated black-sky or white-sky albedo with their desired sun-zenith angle. The constants to be used in formula 1 are provided in the MODIS User Guide web page (Professor Crystal Schaaf's Lab, 2015). By using similar sun-zenith angles for all of the pixels in an image, one can eradicate the effect of latitude or temporal difference on sun-zenith angle between different pixels and images.

The MCD43A2 BRDF/Albedo Quality product is comprehensive quality information for each pixel of each produced albedo product. It contains a per-pixel flag stating if the algorithm has produced a full conversion for that pixel or not, and also if the result is the best quality or not. It also contains the period of the observation, land/water mask data, time of retrieval, mean sun-zenith angle of the observation, sun-zenith angle of the local solar noon, and presence of snow in the pixel.

2.1.2.2 MODIS Black-Sky Albedo Data

The MODIS black-sky albedo images can be downloaded from different MODIS data providers such as Reverb, USGS earth explorer, GloVis and so on. For the purpose of this study, the data was downloaded from USGS earth explorer website (http://earthexplorer.usgs.gov). The steps to download data from the website are as follows:

- Define the geographical extents of the area of interest. This can be done in two ways: by graphically selecting the intended area by mouse click, or by providing the coordinates of the area.
- Select the time period of interest. In this case, because the vegetation growing season was the intention of the study, days 161 until 265 of year 2009 were selected (from 10 June until 22 September, 14 days in total). It was anticipated that land-cover had not undergone significant changes at MODIS albedo images resolution level.
- Choose the data set. USGS earth explorer web site offers different kinds of geospatial data produced by NASA. The albedo data is stored under NASA LPDAAC Collections, MODIS BRDF and Albedo. For the purpose of this study MCD43A1, the shortwave black-sky albedo, and MCD43A2, the quality images, were chosen.
- Download the images. After following the above steps, a list of available images for the chosen criteria will be provided by the website. The images can be downloaded from this list.
- In order to cover the whole of Finland, four image tiles were downloaded for each day. The images are available every eight days.

2.1.3 CORINE Land-Cover Data

2.1.3.1 European CORINE2006 Land-Cover (CLC2006)

Coordinated Information on the Environment (CORINE) is a project which has been constituted by the European Commission to compile standardized and comparable spatial environmental information between European countries since 1990. The year 1990 was established as the baseline for the geographical distribution of land-cover across Europe. Since then, it has been updated by members of the European Commission countries for years 2000, 2006 and 2012.

The CORINE Land Cover project is a segment of the CORINE programme designed to produce homogenous localized geographical land-cover information for the 12 participating member countries.

This information can be used in national and European environmental policy making, as well as in a wide range of scientific studies.

The CLC maps are produced in 1:100,000 scale and the surface area of the smallest unit is 25 hectares. The maps are produced in three levels; level 1 consists of 5 subcategories, level 2 consists of 15 and level 3 consists of 44 subcategories. The raster format of the products is 100m and 250m. A complete table of the levels and subcategories of CLC is given in appendix 1. Figure 4 shows the CLC 2006 for all the European Commission countries involved in the program.

2.1.3.2 CORINE Land-Cover 2006 project in Finland

Finland joined the CLC 2000 program and has been updating Finland's CLC maps for years 2006 and 2012 since then. The Finnish Environment Institute (SYKE) is responsible for the project, with the help of the Finnish Forest Research Institute (Metla), which is responsible for the national forest inventory (NFI) in Finland. The CLC 2006 for Finland is the result of automated satellite image interpretation in combination with existing nationally produced digital maps. In CLC 2006, manual interpretation has been applied for some of the classes. For national level purposes, the Finnish CLC was produced with the pixels size of 25m which was later converted to 100m and 250m for European Commission level applications. SPOT satellite images of Finland, provided by the European Commission, were the source for satellite images for 2006. The available digital national maps used in CLC 2006 were The Finnish Land Parcel Identification System (FLPIS), topographic database, digital elevation model, vegetation zones, land use and forest classification, soil extraction sites, building and dwelling register 2000 and 2006, agricultural and forestry statistics 2000-2006, biotope maps of Metsähallitus (Finnish Forestry Service), and SLICE land use element 1999 and 2005. This data was provided to the project by Finnish organizations such as the National Land Survey, Ministry of Agriculture and Forestry, Agency for Rural Affairs and Population Register Center.

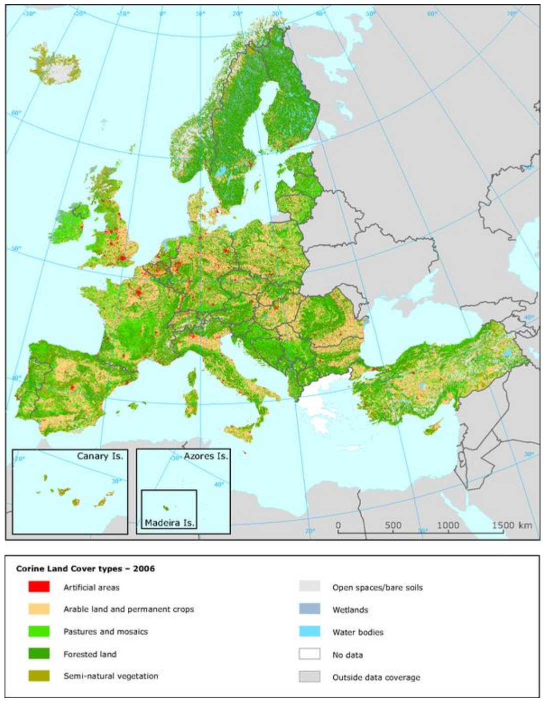


Figure 4 CORINE Land-Cover map of all European Commission countries. Source: European Environment Agency

Land-cover data was downloaded from CSC – IT Center for Science website (https://www.csc.fi/en). CSC is a non-profit governmental company administered by the Finnish Ministry of Education and Culture. CSC is maintaining and developing a centralized IT infrastructure to provide IT services for different research and educational institutions in Finland. The data was downloaded from the E-services section of the website via PaITuli spatial data service (https://sui.csc.fi/applications/paituli/PaITuli/index_eng.html). The CLC Land-Cover image of Finland, for the purpose of national studies, comes as 25×25m raster image with several ancillary files.

2.1.4 Finnish borders map

This map (figure 5), was also downloaded from PaITuli spatial data service of CSC — IT Center for Science website.

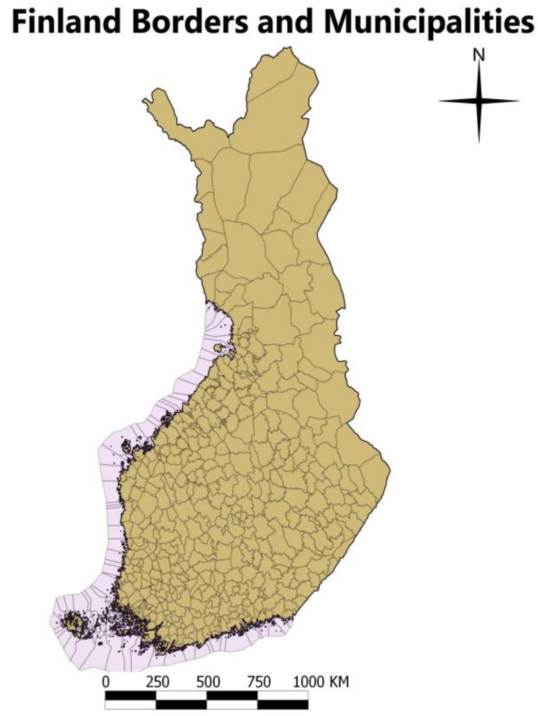


Figure 5 Finnish borders

2.2 Methods

2.2.1 MODIS black-sky albedo data processing

Raster images are basically matrices of cells. Some information is stored in number form in each of these cells with a specific meaning. For instance, in the case of albedo images, each cell contains a number between zero and one thousand. These numbers are the calculated albedo for the corresponding area that the pixel covers for a specific time multiplied by one thousand. In the case of the land-cover image, each number represents the type of land-cover existing in the covered area of that pixel. In this project, the goal is to make two raster matrices with exactly the same dimensions which completely lay on top of each other. This means that pixels with the same coordinates will point to the same area of land. In other words, pixels on land-cover and albedo images should have one-to-one correspondence. Then, the correlation between the numbers stored in these pixels will be further studied.

2.2.1.1 Tiling and reprojection of albedo images

In order to compare albedo images with the land-cover image, several steps were needed. First, the four image tiles for each day needed to be tiled together and reprojected to a more commonly used projection (MODIS spatial land products come in sinusoidal (SIN) projection). This step was carried out using MODIS Reprojection tool (MRT). MRT enables users to read MODIS images and conduct some further processing on them. It can be used through command line and graphical user interface (https://lpdaac.usgs.gov/tools/modis_reprojection_tool). In this study, the graphical user interface was used.

The four images for each day were loaded into the tool first. Then, the image band to be processed, which is only one band in MODIS images case, was selected. In the next steps, the output file name and type (GEOTIFF) and resampling type were selected. The images were resampled to WGS 84 / UTM zone 35N projection system which best represents Finland's land surface. The 500m pixel size was also defined for the output images. This process was executed for all the representative data for fifteen days for both albedo and quality MODIS images.

2.2.1.2 Clipping albedo images to Finnish borders

The outcome of the tilling process was a set of images covering the whole of Finland with WGS 84 / UTM zone 35N projection. These groups of images also cover some parts of neighboring countries and surrounding seas. These areas were not of interest to this study. In order to get only Finland's land surface area, the images were clipped using Finnish borders map downloaded from PaiTuli web site (figure 5).

Clipping was conducted in QGIS software. QGIS is a Free and Open Source Geographic Information System for creating, editing, visualizing and analyzing geospatial information, available for different operating systems (QGIS Development Team, 2012). The module Clipper in QGIS software was used for clipping the images. There are two options for obtaining the desired extent. First is to select the extent by dragging on the canvas or inserting the coordinates. The second one, which was used, is to provide a mask layer. This way, your image will be clipped to the extent of the provided mask layer (Finnish borders map).

After clipping the images, each image contained 1316 columns and 2289 rows. This is important to know since the land-cover image must have the same number of columns and rows in order to be compared with the albedo images.

2.2.1.3 Extracting best quality albedo inversions

In this study, only the fully inverted pixels were used and magnitude inverted pixels were filtered out. This was done with the help of the quality images. Quality images have one to one pixel correspondence with the albedo images. The fully inverted pixels are represented by number zero and magnitude inverted pixels by one.

The easiest way to apply the quality images was to reclassify them in a way that fully inverted pixels were represented by value one and magnitude inverted pixels were represented by value zero. Then the result was multiplied by the albedo images. This way, the values of magnitude inverted pixels were changed to zero and filtered out, while fully inverted pixels contained the albedo image values.

The reclassification was done with GRASS software. GRASS (Geographic Resources Analysis Support System) is a free and open source Geographic Information System (GIS) software suite used for geospatial data management and analysis, image processing, graphics and maps production, spatial modeling, and visualization. It can be used as a standalone program or as a module in QuantumGIS. Usually, GRASS comes as part of the package when QuantumGIS is installed (GRASS Development Team, 2012).

A new map set was built and the Albedo quality images were imported to GRASS (Mapset is a database for storing GRASS data and information). This is because the format of the data in QGIS is different from GRASS. The command ***r.in.gdal*** was used for importing the data to the GRASS database and the ***r.reclass*** command was used to reclassify the images. The reclassification rules are presented in Table 1.

Table 1 Reclassification rules for reclassifying quality images.

Conversion type	Original value	Reclassified value
Full conversion	0	1
Magnitude conversion	1	0

After reclassification, the quality images were exported back to QGIS environment using the command ***r.out.gdal.*** The next step was to multiply these reclassified quality images with the albedo images. This was done using the Raster calculator module. The corresponding albedo image and quality image were selected and the multiply function was applied. This function multiplies the values of pixels with the same coordinates and stores the results in a new raster image. In the resulting image, the magnitude converted pixels were changed to zero and the fully inverted pixels contained their original values.

2.2.1.4 Converting MCD43A1 images to black-sky albedo with SZA 60^o

The final step in processing the albedo images was to deal with the different incoming solar-zenith angles due to the different geographical latitudes of each pixel, and the seasonal variations of the sun's zenith angle. The MODIS BRDF is estimated with the Ross ThickLiSparse Reciprocal model shown in formula 1. The Θ symbol in this equation represents the sun-zenith angle which could be set to any desired solar-zenith angle. For the purpose of this study the 60^o solar zenith angle was selected which, based on Stenberg (1996), is a good average representation for the whole of Finland. The parameters used in this equation to calculate black-sky albedo can be found in appendix 2.

2.2.2 CORINE Land-Cover data

2.2.2.1 Reprojection and reclassification of land-cover image

In order to be compared with the albedo images, the Land-Cover file was reprojected to ETRS89 / TM35FIN (E, N) – Finland – EPSG: 3067 (Projected coordinate system for Finland – onshore and offshore) which best describes Finland. The Reprojection was conducted through the GDAL raster Reprojection module (Wrap) in QGIS software.

The CORINE land-cover consists of 44 different land-cover classes at its third level. This means each pixel in the land-cover image is assigned a number between 1 and 44. The meaning of these numbers was provided as a separate excel file which is presented in appandix1. For the purpose of the study, the land-cover image had to be reclassified into classes of interest.

In order to process the land-cover image in GRASS, a new mapset was built. Since the format of the data in GRASS is different from QuantumGIS, the data was imported to the GRASS mapset with ***r.in.gdal*** command (Import GDAL supported raster file into a binary raster map layer). In the next step, the 44 subcategories were reclassified into 9 new classes, shown in table 2.

From these 9 classes, 6 of interest to this study were then further reclassified into six different land-cover binary masks. The six land-covers of interest were agricultural, deciduous forest, coniferous forest, mixed forest, shrubland and water. In this step, with the use of the same GRASS command, ***r.reclass,*** six land-cover binary masks were created so that the agriculture pixels for instance (containing number 2) were converted to one and everything else was converted to zero. By this method, a land-cover binary mask was created containing only agricultural land-cover data. The same process was applied for each of the land-covers of interest and binary land-cover masks were created in the same fashion for deciduous forest, coniferous forest, mixed forest, shrubland and water. Since the purpose of this project is to study the vegetation albedo, the binary masks for manmade objects, open areas and wetland pixels were not created. The use of a binary mask for water pixels is described later.

Table 2 Reclassification rules for reclassifying land-cover image.

New class name	Original class value	New class value
Man made	1 to 13	1
Agricultural	14 to 17	2
Deciduous	18 and 19	3
Coniferous	20 to 22	4
Mixed forest	23 to 25	5
Shrubland	26 to 33	6
Open area	34 and 35	7
Wetlands	36 to 41	8
Water	42 to 44	9

2.2.2.2 Upscaling land-cover image pixels to match albedo image pixels

The pixel size of the MODIS albedo images is 500×500m while the land-cover image pixel size is 25×25m. This means each pixel in MODIS albedo image encompass 400 land-cover pixels. In order to compare these two, the land-cover pixels had to be upscaled to match the corresponding albedo pixel. The problem here is that not all of the 400 land-cover pixels in each upscaled land-cover pixel necessarily come from the same land-cover class. This means there can be coniferous, deciduous, water and so on pixels in one upscaled pixel. My aim here was to study the effect of different land-cover types on albedo so I needed to know what percentage of each upscaled pixel is made up of which classes of land-cover.

In order to address this problem I used neighborhood analysis. In neighborhood analysis, the GRASS software moves an imaginary window over every single pixel in a raster image. This window must have equal odd dimensions. This way, there will always be one pixel at the center of the widow. The

GRASS software then analyses the neighboring pixels of that central pixel inside the moving window and does a selected function on the values. Then, the result of this analysis will be stored in the central pixel. The outcome of this process is a raster file with each pixel containing a number representing the result of the analysis of the value the pixel and its neighboring pixels. A small scale example of how neighborhood analysis with sum function over the central pixel works is shown in figure 6.

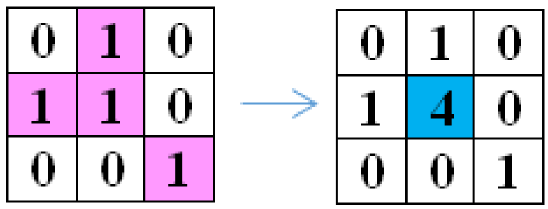


Figure 6 Neighborhood analyses with sum function over the central pixel.

In the GRASS software, the command for executing this analysis is ***r.neighbors***. Two important options which should be set for this command are neighborhood moving window size and neighborhood analysis function to be used.

The first option was neighborhood size. This is the intended moving windows size. As mentioned before, the land-cover pixel size had to match the albedo so the window size should have been 20×20 but, because the dimensions of the window had to be an odd number, a 21×21 window was defined to cover the intended pixel size.

The second option was neighborhood function. This is the operation that one intends to do on the neighboring pixels. There are several options available like average, sum, minimum and maximum. For the purpose of this study the sum option was used. This is because the land-cover masks consisted of zeroes and ones. By using sum function, each pixel was assigned a number between zero and four hundred and forty one. In the up-scaling process later, the QGIS program will make an average of these numbers and assign it to the upscaled pixels. This process was applied to all six land-cover masks.

After this, for example if the value of a pixel in an upscaled coniferous mask is 352, it means that eighty percent of the sub-pixels in this upscaled pixel were coniferous pixels (352/441 = 0.8) and the rest of the sub pixels belonged to other land-cover classes.

Next, the produced raster images were exported from GRASS environment format to GDAL (QGIS) environment format. The command for exporting raster files from GRASS to GDAL environment is ***r.out.gdal.***

In order to match the pixel size of the albedo images, the exported land-cover mask files were upscaled to 500×500m pixels using gdalwarp (image Reprojection and warping utility). In the graphical user interface, there is no option to resize the pixels. But, this module has a –tr option which can be used to define the output pixel size. In this case the –tr options for xres and yres (x and y resolution for each pixel) were set to five hundred, the same as MODIS albedo images pixel size. All of the land-cover binary masks were upscaled and stored as new files with 500m pixel size using this command. An overall view of the span of different land-covers in Finland based on land-cover masks can be seen in figure 7.

2.2.2.3 Clipping the binary masks to Finnish borders

The final step in preprocessing the land-cover images was clipping them to the extent of the Finnish borders map (downloaded from PaiTuli website). This process was conducted the same as described for the albedo images. The resulting land-cover images also contained 1316 columns and 2289 rows with 500×500m resolution, the same as the albedo images.

At this point the preprocessing of the data was completed and the MODIS albedo and CORINE land-cover images had the same dimensions and resolution. Corresponding albedo and land-cover pixels of each image were compared to each other to retrieve the land-cover albedo as it is described in the next section.

2.2.3 Correlating MODIS albedo images and CORINE land-cover images

In order to compare the two sets of images, MATLAB software was used. MATLAB is a high-level language and interactive environment for numerical computation, visualization, and programming. MATLAB can be used for analyzing data, developing algorithms, and creating models and applications. MATLAB is capable of signal processing and communications, image and video processing, control systems, test and measurement, computational finance, and computational biology (MATLAB and Statistics Toolbox 2012a).

Tagged Image File Format (TIFF) images can be directly loaded into MATLAB as matrices. The format of the MODIS albedo and land-cover images were TIFF. This created the possibility of directly importing the albedo and land-cover images to MATLAB for further analysis and data manipulation.

The idea here was to multiply the land-cover masks with the albedo images to get the corresponding albedo of each land-cover class for each day of the year (DOY). Later on, these land-cover albedos were studied and compared against each other to find out if there were significant differences between the albedo of different land-covers. In order to get the land-cover albedo of each DOY, some criteria had to be defined before proceeding further.

To study the effect of specific land-cover on albedo, the minimum number of land-cover sub-pixels in each 500m pixel was set to eighty percent coverage for coniferous and agricultural and shrubland and sixty percent coverage for deciduous and mixed forest pixels. The reason for the lower threshold for deciduous and mixed forest pixels was that there were not enough pixels with more than eighty percent coverage of these types of land-cover in middle and northern Finland.

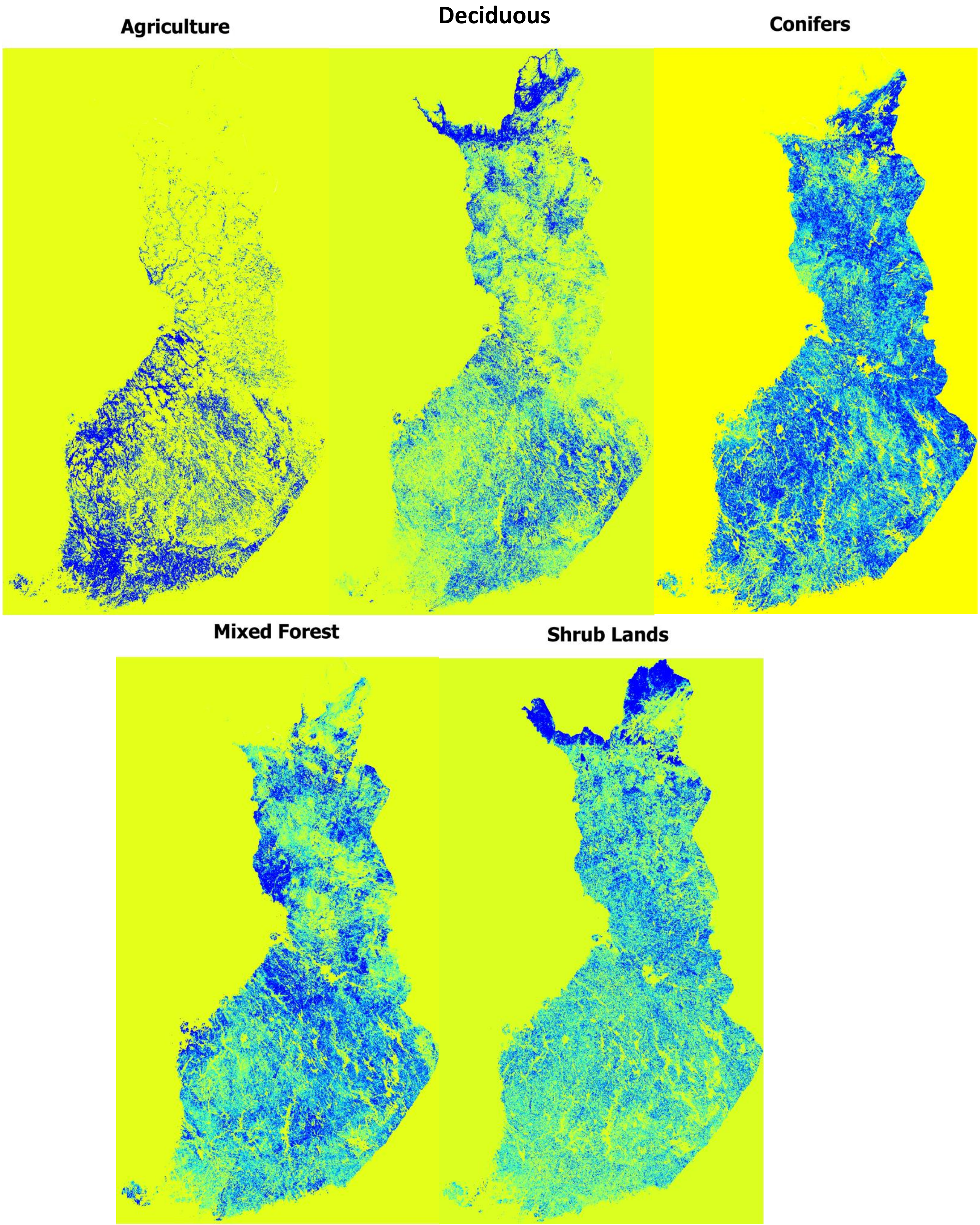


Figure 7 an overall view of the span of different land-covers in Finland based on land-cover masks

2.2.3.1 Filtering pixels with more than 5 percent water bodies

Since water bodies are very dark and have very low albedo during the day with low sun-zenith angles, even a small amount of water body sub-pixels in an upscaled pixel can bias the albedo measurement for that pixel. A maximum of five percent water body sub-pixels per each upscaled pixel was defined. This decision is based on Muster et al. (2013) who observed water bodies smaller than five percent are not detectable in 250m resolution MODIS albedo pixels. After this step, if an upscaled pixel contains more than five percent water body sub-pixels, that pixel will be filtered out and not considered in the calculations.

All the steps which are explained here were applied to all six different land-cover mask matrices. In all of the land-cover matrices, the values indicating the no data pixels, which are usually a very big positive or negative number (-32768, 32768), were turned into zero. The reason for changing the unwanted pixel values to zero is that these big numbers bias the calculations and zero values will be considered as no data later in the statistical analysis.

The first step after importing the images to MATLAB was filtering out the land-cover mask pixels containing more than five percent water body sub-pixels. In the water land-cover mask, the value of pixels containing five percent or more (pixels containing a value greater than 22) water body sub-pixels were turned into zero and the values of the rest of the pixels were turned into one.

2.2.3.2 Applying percentage thresholds to different land-cover masks

In the next step, previously explained coverage thresholds were applied to each land-cover mask matrix. This was done in a way that the pixels containing a value of less than the desired threshold for the intended land-cover were turned into zero and the value of the rest of the pixels were turned into one (pixels containing values greater than 352 for agricultural, coniferous and shrubland and greater than 264 for deciduous and mixed forest). Then, the water land-cover mask matrix was multiplied to all the other land-cover mask matrices to filter out pixels containing more than five percent water. The result of multiplication of a cell containing zero with a cell containing a value is zero.

2.2.3.3 Removing irrelevant pixels in albedo images and calculating land-cover albedo

Next, for the albedo matrices, pixels containing values equal to zero or more than one thousand were turned into zero and for the rest of the pixels, the original value of the pixels were retained.

The final step was to multiply the albedo matrix to all five land-cover matrices. The results are five land-cover-albedo matrices for the whole of Finland for each day.

2.2.3.4 Finalizing the land-cover albedo tables

To be used later in the statistical analysis, each of the five land-cover mask matrices where transposed and reshaped in such a way that the result was a one column vector with each line of the matrix coming after another from north to south. This means that the upper-left cell of the matrix is the first point and the lower-right cell is the last point of the new array. The ASCII value corresponding to the lower case initial letter of each land-cover was replaced with pixel values equal to 1 for each land-cover mask vector (as shown in table 3.3). This is because of ease of access in later format changes to the files and transfer of data between different computer programs. All of these vectors were concatenated together to make a single north-to-south land-cover array. The procedure was applied to all of the five land-cover-albedo matrices to get one final five land-cover-albedo matrix per day.

As Finland is a big country and it is particularly stretched in geographical latitude, different parts of Finland have different ecological and morphological characteristics. This could bias the results if we compare the land-cover albedos throughout the whole country.

To account for this problem, Finland was divided into three areas; northern Finland, middle Finland and southern Finland. Since the total number of the pixels in the matrices are 3012324 (2289*1316), a vertical vector of 1004108 for each of North, Middle and South was created to be used as a location vector later in the statistical analysis. Each vector contained the ASCII value of the corresponding initial capital letters of each geographical location (as shown in table 3).

All of these vertical vectors were concatenated together in a way that the first column was the land-cover vector, the second was the location vector, and the albedo vectors came in a timely manner after that. Day 161 was the first and day 265 was the last.

The final step conducted in MATLAB was to store the data as a coma separated format (csv) file to be used in later statistical analysis in SPSS software.

Table 3 initial letters of land-cover types and geographical locations and their corresponding ASCII numbers used in the final data table

	Land-Cover					Geographical location		
Full name	Agricultural	Deciduous	Coniferous	Mixed forest	Shrubland	North	Middle	South
Initial letter	a	b	c	m	s	N	M	S
ASCII value	97	98	99	109	115	78	77	83

2.2.4 The statistical analysis

Three days, day 161 at the beginning (10 June), day 209 in the middle (28 July), and day 257 at the end of the growing season (14 September), were selected to study the relationship between albedo and land-cover and geographical location. In order to study this relationship, a two-way ANOVA test was conducted in the Statistical Package for the Social Sciences (SPSS) software package. SPSS is used for statistical analysis. It is an integrated family of products that addresses the entire analytical process, from planning to data collection to analysis, reporting, and deployment (SPSS Inc, 2013).

The two-way ANOVA test compares the mean differences between groups which are split on two independent variables (called factors). The primary purpose of a two-way ANOVA is to understand if there is an interaction between the two independent variables on the dependent variable. The land-cover type and the geographical location were the independent, and albedo was the dependent variable in this study.

The steps taken in performing the two-way ANOVA in SPSS software package are taken from Two-Way ANOVA – SPSS educational video from how2stats YouTube channel (https://www.youtube.com/channel/UCr3OHuCSrwAO2KYP2CJB6zg).

2.2.4.1 Two-way ANOVA test on three DOY data

The CSV file resulting from MATLAB software was imported to the SPSS software package for statistical analysis. A Univariate test was conducted with albedo columns for each of the three days (days 161, 209 and 257) as dependent variable, and geographical location and land-cover columns as independent variables. The option estimated marginal means of the factors was used instead of descriptive statistical means because the sample size across different levels of the data was different. The option 'Compare main effects' were also selected. This way, if we get a statistically different ANOVA, that will be followed by pairwise comparisons between the factors. In the plot section, geographical locations were selected as the separate lines and land-cover was selected for the horizontal axis. Another plot with land-cover as separate lines and geographical location as horizontal axis was also selected.

2.2.4.2 Conducting a two-way ANOVA test on all 14 days of data

The next step was to analyze the albedo and its fluctuations during all fourteen days of the year representing the growing season. To conduct this analysis, the 'Repeated Measures' option was selected. Time, with fourteen levels, was defined as the within-subject factor and albedo as the measure. Then the fourteen albedo measurements were defined as the within- subject variables and land-cover and location as between-subject factors. In plot section, time was selected as the horizontal axis and land-cover as separate lines. Location was selected as separate plots. Two other options that were defined for drawing plots were time as horizontal axis and land-cover as separate lines, and time as horizontal axis and location as separate lines.

3 Results

3.1 The three day comparison of albedo based on land-cover and location

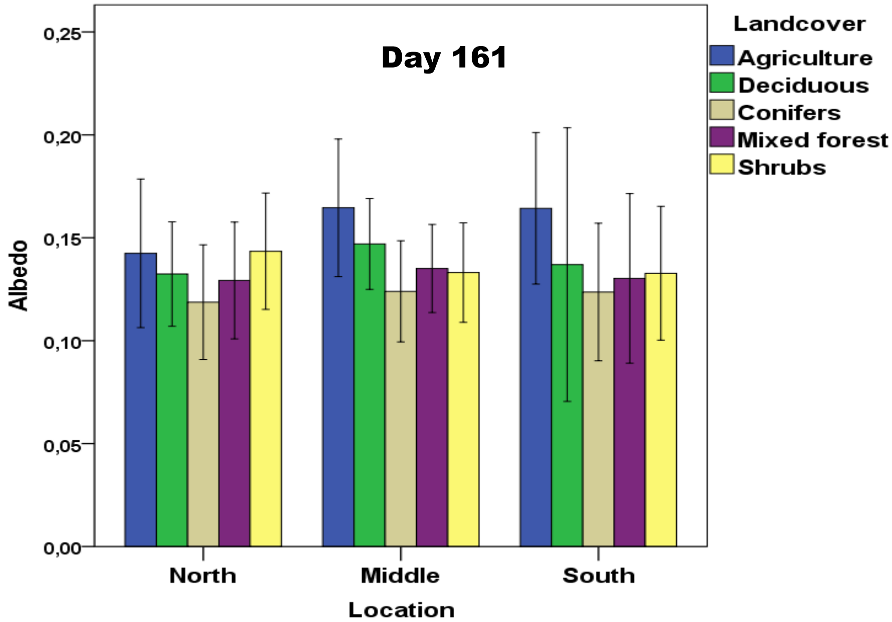
To answer the research question that if the albedo of different vegetation land-covers are different, the two way ANOVA statistical analysis of MODIS albedo measurements for the days 161 (10 June) at the beginning, day 209 (28 July) in the middle and day 257 (14 September) at the end of the growing season were conducted in SPSS for five different land-covers (agricultural, deciduous, coniferous, mixed forest and shrubland) in three different geographical locations (north, middle and south) of Finland.

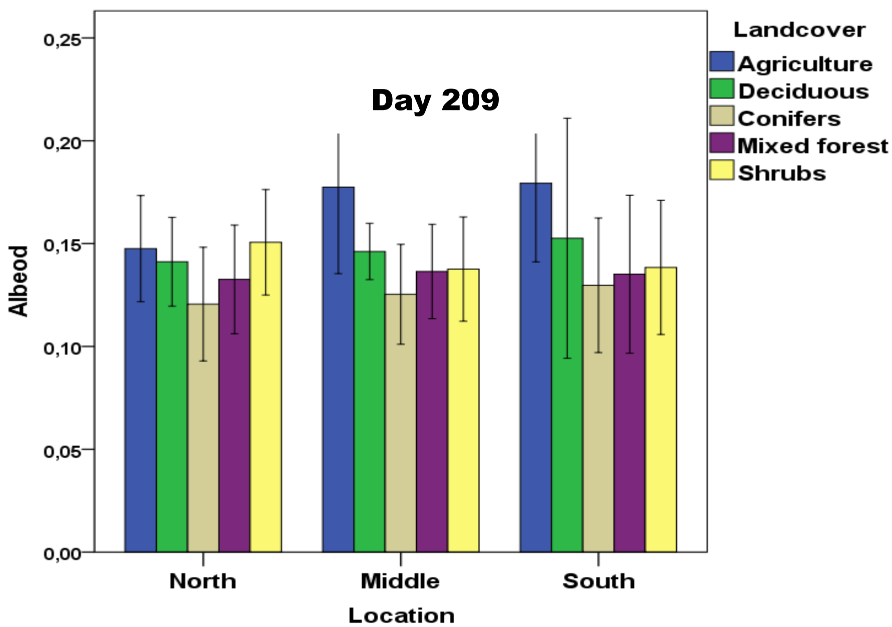
The results of the test indicate that there was a significant main effect of land-cover type in each location on the surface albedo of the subjected land-cover for all three days. There was also a significant main effect of location on the surface albedo in all three days between northern, middle and southern Finland for different land-cover types. The results also indicate that the interaction between land-cover and location significantly affected albedo. The results of the test are illustrated in table 4.

Table 4 Results of the two-way ANOVA test for land-cover albedo of three days of the year

	Day 161	Day 209	Day 257
Land-Cover	$F(4,129439)=400.9$, $p< 0.005$	$F(4,130268)=509.9$, $p< 0.005$	$F(4,139863)=578.1$, $p< 0.005$
Location	$F(2,129439)=14.8$, $p< 0.005$	$F(2,130268)=15.2$, $p< 0.005$	$F(2,139863)=34.9$, $p< 0.005$
Land-Cover * location	$F(8,129439)=60.4$, $p< 0.005$	$F(8,130268)=91.9$, $p< 0.005$	$F(8,129439)=198.9$, $p< 0.005$

The results show that on all three days, agricultural land had the highest rates of albedo. Deciduous had the second highest followed by shrubland and mixed forest respectively. On the other hand, coniferous land-cover showed the lowest rate of albedo in all cases. In all cases shrubland was even more reflective than agricultural land-cover in the north but ranked third in middle and southern Finland, figure 8.





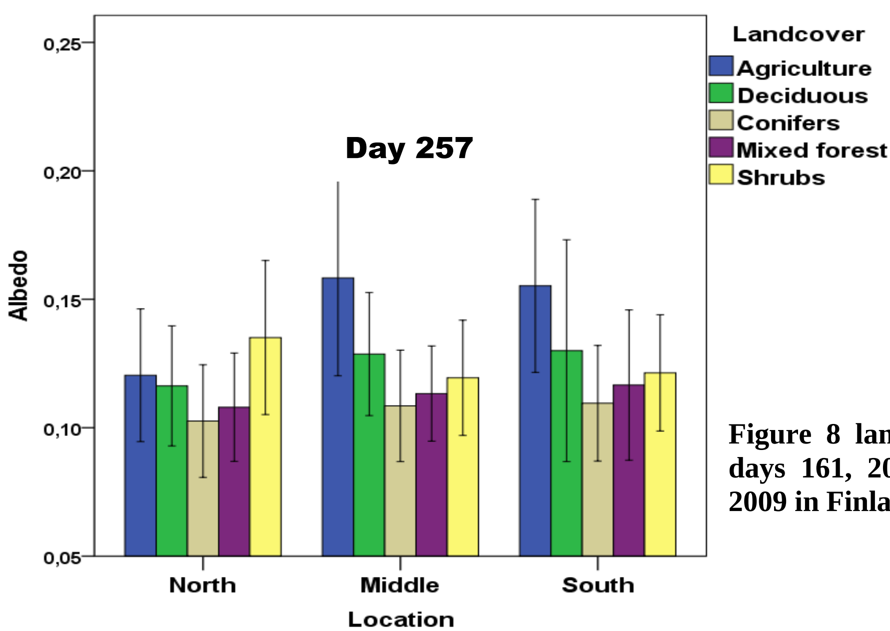


Figure 8 land-cover albedos on days 161, 209 and 257 of year 2009 in Finland

Based on geographical location, it seems that the albedo is slightly lower in northern Finland for all the land-cover types except shrubland. Shrubland albedo is higher on all three days in northern Finland. Considering the albedo of the other land-covers, the middle and southern albedos are slightly different to northern albedo measurements. The albedos of northern land-cover types are slightly lower than the same types in middle and southern Finland. This is illustrated in figure 9.

3.2 The time series analysis of the land-covers albedo during the growing season

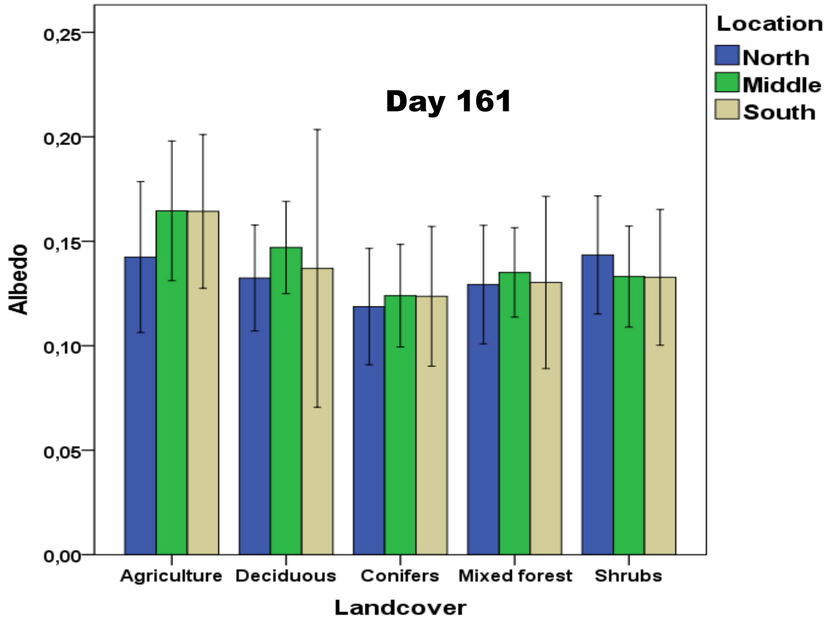
In order to observe the effect of land-cover and geographical location on albedo during the vegetation growing season, the repeated measures ANOVA statistical analysis of MODIS albedo measurements for days 161 (10 June) until 265 (22 September), every eight days, was conducted in SPSS for five different land-covers (agricultural, deciduous, coniferous, mixed forest and shrubland) in three different geographical locations (north, middle and south of Finland).

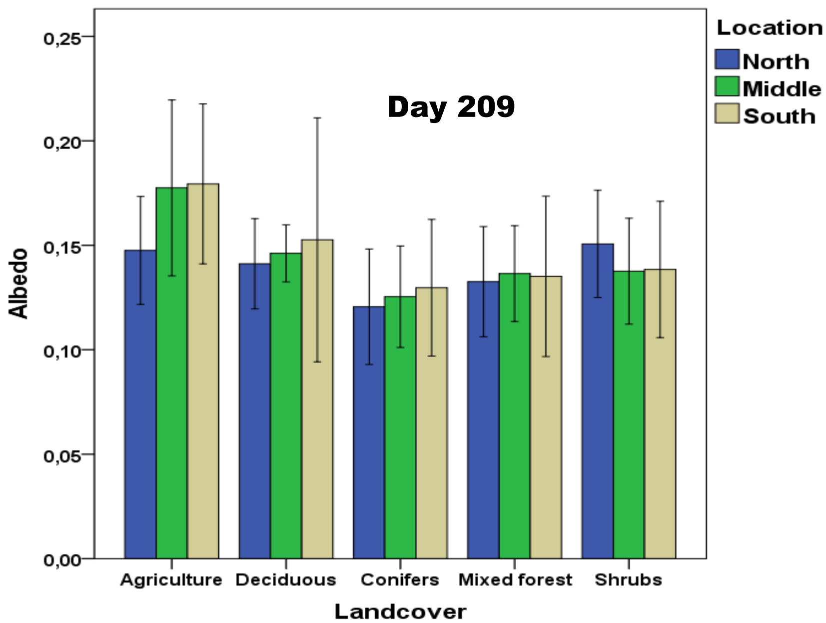
3.2.1 Test of Within-Subject effects

The results of the Within-Subject effects showed that there was a significant main effect of time on land-cover albedo. There was also a significant main effect of interactions between time and land-cover types and geographic location. The interaction of time with all the factors together was also significant. The results of the test are illustrated in table 5.

Table 5 Results of the Within-Subject analysis of the land cover albedo during the growing season

Source	Test results
Time	$F(13,101894) = 166.8$, $p<0.05$
Time*land-cover	$F(52,101894) = 4.2$, $P<0.05$
Time*location	$F(26,101894) = 2.5$, $p<0.05$
Time*land-cover*location	$F(104,101894) = 13.2$, $P<0.05$





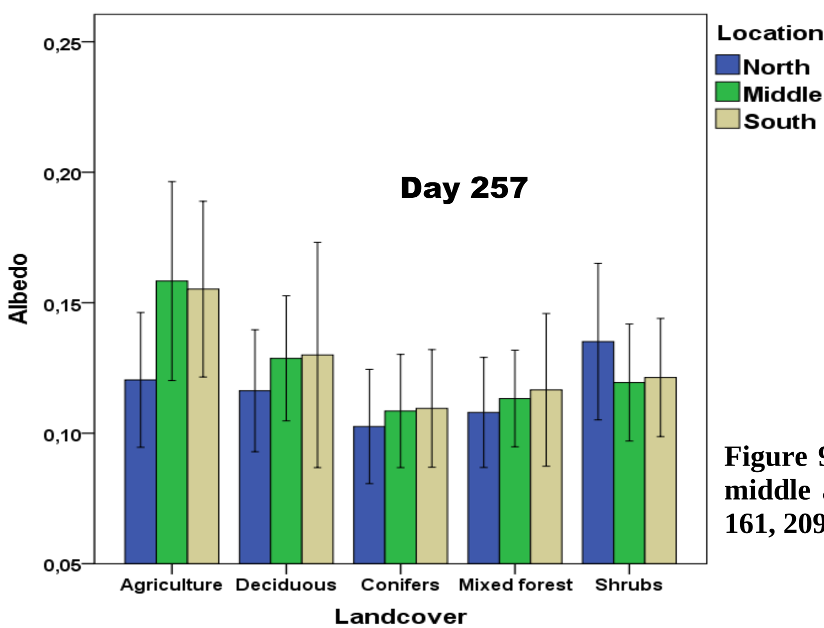


Figure 9 land-cover albedos in north, middle and south of Finland on days 161, 209 and 257 of year 2009

3.2.2 Test of Between-Subject effects

The results of the Between-Subject effects indicated that there was a significant main effect of land-cover type in each location on the surface albedo of the subjected land-cover during the whole growing season. There was also a significant main effect of location on the surface albedo between northern, middle and southern Finland for different land-cover types. Although, the significance level for the location was 0.012 which is very close to our significance interval (0.05). The results also indicated that the interaction between land-cover and location significantly affects the albedo. The results of the test are illustrated in table 6.

Table 6 Results of Between-Subject analysis of land-cover albedo of northern, middle and southern Finland

Factors	Test results
Land-Cover	$F(4,7838) = 84.6$, $p < 0.005$
Location	$F(2,7838) = 4.4$, $p < 0.05$
Land-Cover * location	$F(8,7838) = 4.3$, $p < 0.005$

Based on the figures separated by location (figure 10) for different land-covers, the general trend of the measured albedo for northern and middle Finland was a decrease from agricultural land, deciduous, shrubland, mixed forest and coniferous forest respectively. There were some fluctuations between deciduous and shrubland on some days. The general trend of the measured albedo was an increase for all different land-covers between days 185 (4 July) and 193 (12 July). On these days, the measured albedo reached a peak and started decreasing towards the end of the growing season. The measured albedo at the end of the growing season tended to be lower than that measured at the beginning of the growing season.

For southern Finland on the other hand, the ranking of measured albedo for different land-cover types seemed to be the same with one exception; the mixed forest measured albedo seemed to be the same and at some points even lower than coniferous land-cover. The measured albedo peak also came several days later, between days 201(20 July) and 217 (28 July). Deciduous in this case was an exception and the albedo peak for it came at the same time as in northern and middle Finland.

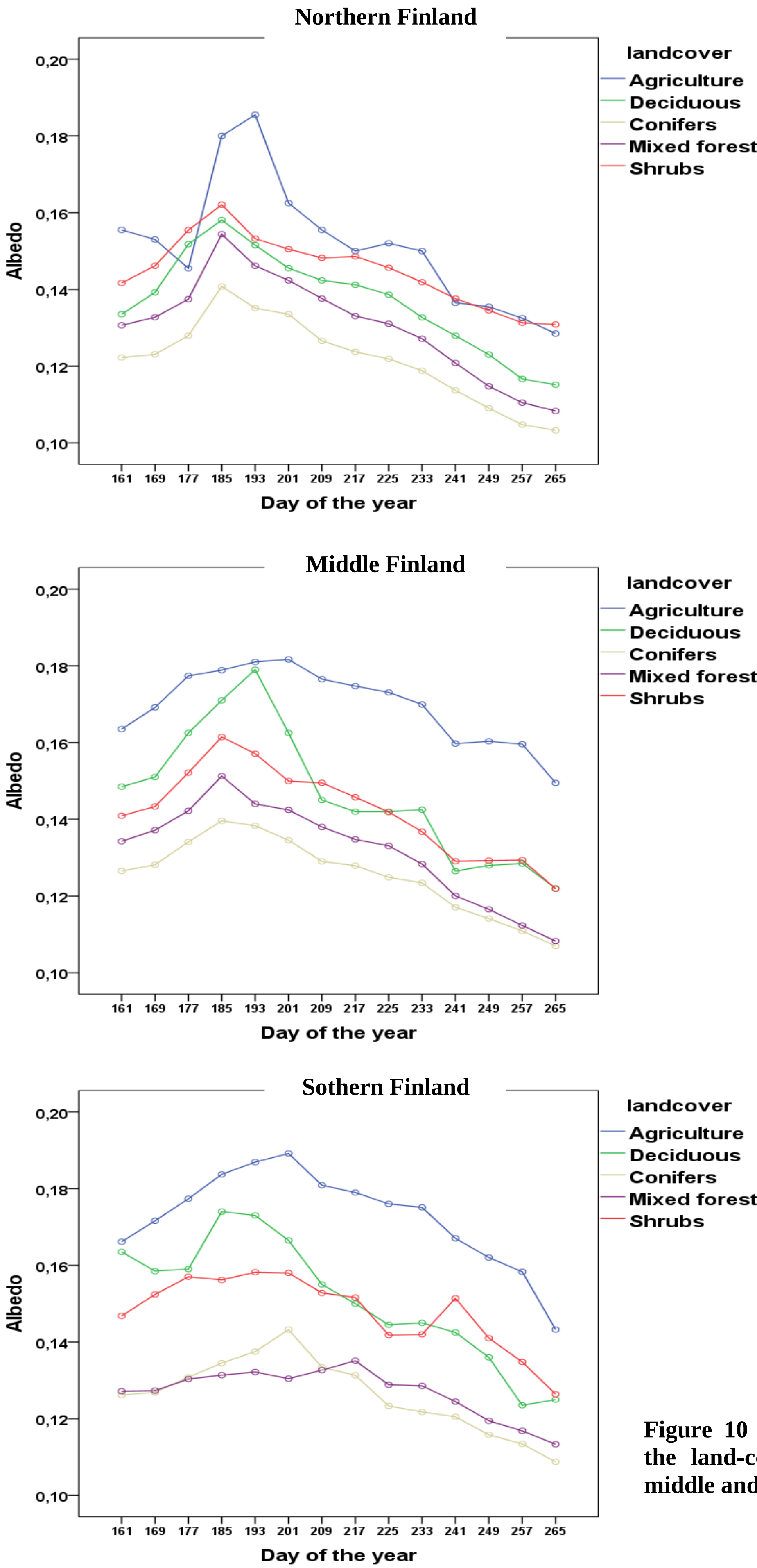


Figure 10 the time series analysis of the land-cover albedo for northern, middle and southern Finland

Figure 11 shows an overview of the time series analysis of albedo for 14 days of year 2009. Figure 11a shows the land-cover albedo of the five different land-covers regardless of their geographical location (all geographical data combined) and figure 11b shows the land-cover albedo of three different geographical locations ignoring their land-cover type (all land-cover types combined).

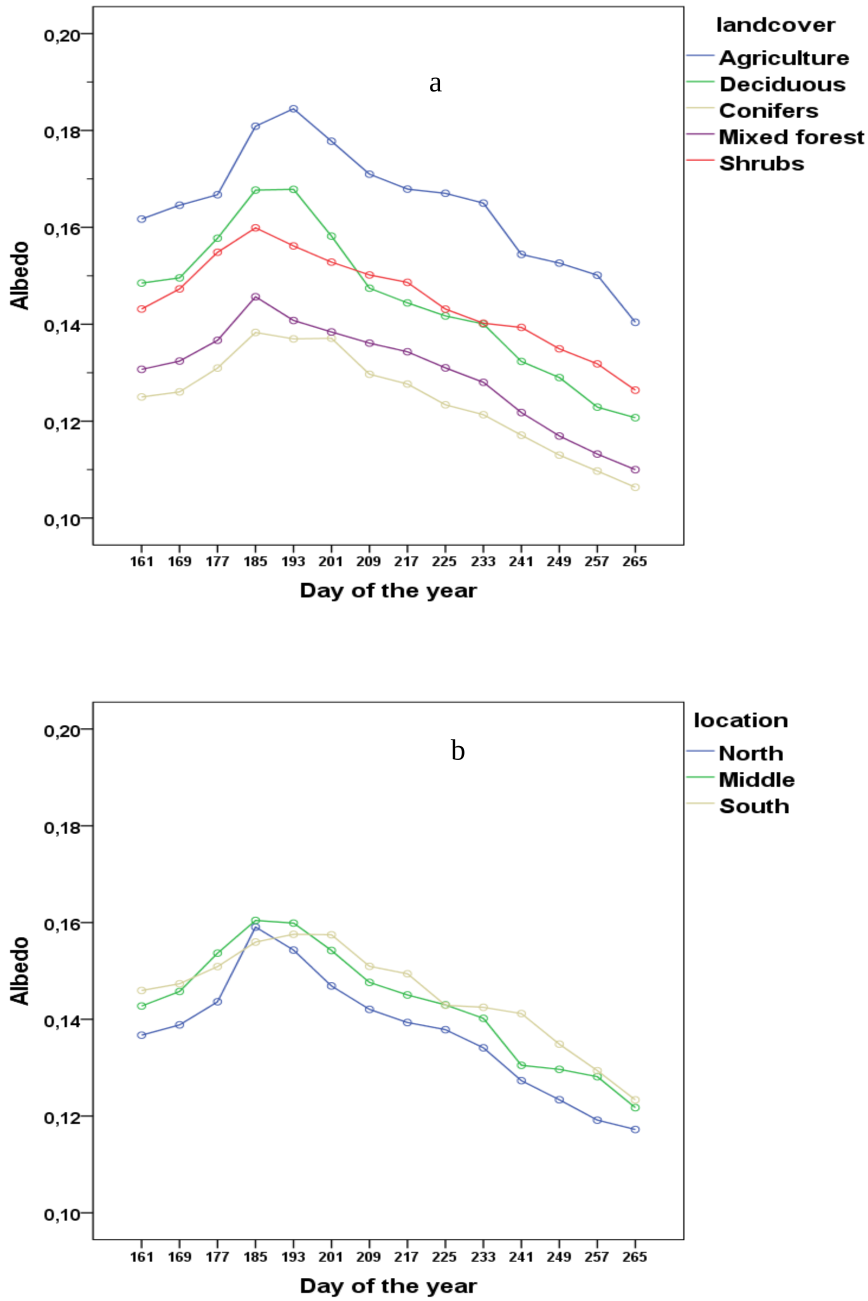


Figure 11 Time series land-cover albedo of Finland regardless of the geographical location (a) and land-cover albedo of different geographical locations in Finland regardless of land type (b)

In agreement with previous analysis, figure 11a shows that agricultural land had the highest albedo throughout the entire growing season compared to other land-covers. Deciduous had higher albedo compared to shrubland and was ranked second at the beginning of the growing season, but became darker as time passed. Mixed forest and coniferous were the darkest, and their respective albedos were relatively close to each other, although coniferous was always the darkest type of land-cover throughout the whole growing season.

The albedo of all land-cover types increased until day 193, with the exception of coniferous. Coniferous albedos seemed to peak roughly one week later on day 201. All land-cover albedos began to decrease after these days towards the end of the growing season, and seemed to be at their lowest at the end of the growing season.

In figure 11b on the other hand, middle Finland seemed to have highest land-cover albedos at the beginning of the growing season, followed by southern Finland. This trend continued until the period between days 185 and 193 when middle and northern Finland reached their peak of land-cover albedo. For southern Finland, it took a bit longer, reaching this peak between days 201 and 209. After reaching peak albedo, southern Finland had the highest albedo level, followed by middle Finland, until the end of the growing season. Northern Finland had almost the lowest albedo levels throughout the growing season.

Tables of average land-cover albedos for different geographical locations can be found in appendix 3.

4 Discussion

By studying MODIS albedo products against CORINE Land Cover Map 2006 of Finland, this study has tried to investigate the relationships between vegetation land-cover types, geographical gradient, and growing season time transition on surface albedo.

4.1 Vegetation land-cover types and albedo

The results of this study suggest that there is significant difference between the land-cover albedo of different land-cover classes. This is in agreement with other studies (Bala et al., 2007; Betts and Ball, 1997; Betts, 2000; Feddema et al., 2005; Gordon, 2008; Jackson et al., 2008; Lukeš et al., 2014; Schwaiger and Bird, 2010). The study results indicated that agricultural land has the highest land-cover albedo, followed by deciduous, shrubland and mixed forest respectively. Coniferous land cover is the darkest land-cover type in all the examinations.

The higher albedo of agricultural land-cover could be explained by the biochemical properties and chlorophyll contents of the leaves in agricultural species. As Lukeš et al. (2013a) notes, deciduous species' leaves have higher chlorophyll contents and different chemical properties to coniferous trees. The low reflectance of coniferous trees can also be explained by their complex hierarchical clumped structure which traps photons within the shoots and crown (Rautiainen and Stenberg, 2005). The low reflectance can also be explained by the complex structure of the needles and needle clumping, as well as by low single scattering albedo of needles compared to leaves of deciduous species (Lukeš et al., 2013b).

4.2 Geographical gradient and vegetation land-cover albedo

The study results also indicate that there is a significant geographical influence on land-cover albedo. This can be observed at land-cover type level and overall. The general trend is that the land-cover albedo is lower in northern Finland compared to middle and southern Finland. The only exception to this general trend is shrubland, which has higher levels of albedo in northern Finland compared to the other two locations.

Based on DeFries et al. (1995), 50% of the Fennoscandia boreal forests have canopy cover of less than 0.5. This means that the land-cover albedo is heavily influenced by understory vegetation. In southern Finland, due to higher soil fertility and better atmospheric conditions, the dominant under story layer is composed of mesic and herb-rich types. In northern Finland the lack of fertile soil and unfavorable atmospheric conditions lead to lichen-dominant xeric understory types. In general, the fertile herb-rich sites have higher albedo compared to unfertile, lichen-rich sites. The openness of the canopy in northern parts magnifies this effect. This is a possible explanation for the general trend of lower albedo for different land-cover types in northern Finland compared to middle and southern Finland.

4. 3 Temporal albedo trends during the growing season

The results of this study are in agreement with previous studies (Heiskanen et al., 2013; Lukeš et al., 2014) about temporal changes of reflectance during the growing season. There seems to be a systematic significant difference between different land-cover albedos. Agricultural lands have the highest and coniferous have the lowest albedo during the growing season. There is also a consensus about gradual increase of land-cover albedo until mid-July. Although, contrary to Heiskanen et al. (2013), the systematic difference between reflectance of deciduous and coniferous land-covers continues until the end of the growing season.

The gradual increase in land-cover albedo at the beginning of the growing season can be explained by the phenology of the vegetation. Freshly sprouted leaves are brighter and thinner which makes them more reflective. The appearance of tree leaves and understory also covers the low reflective and usually wet (due to the abundance of precipitation and melting snow) and dark soil beneath them. This continues until the vegetation reaches its maximum leaf area index (LAI) which, based on Rautiainen et al. (2011), is reached in mid-July. After this point, based on the study of Oak by Boyer et al. (1988), the amount of chlorophyll content in leaves starts to decline and anthocyanin increasingly develops in the leaves, reducing their chlorophyll reflectance. In general, leaves start to become darker and thicker, and consequently less reflective, towards the end of the growing season. This could explain the decline of the land-cover albedo after mid-July.

The albedo peak is reached about two weeks earlier in northern Finland compared to the south. This despite of the fact that the growing season starts later in the north due to lower temperatures and the presence of snow. A possible explanation for this phenomenon could be the shorter period of the growing season (about 120 days in the north compared to 180 days in the south) and longer hours of daylight. The whole plant development and senescence seems to happen faster in northern Finland due to its shorter growing season.

4.4 Future improvements

This study considers only one of the contributing factors to the surface albedo (the vegetation land-cover). Including other influential factors like understory vegetation, forest inventory data, weather information, and topographical information can lead to a better understanding of surface albedo in the Finnish boreal region.

4.5 Uncertainties and shortcomings

The coarse resolution of the MODIS albedo images and uncertainties of MODIS products like performance of the conversion, topographic and atmospheric factors can affect the actual surface albedo. Although, Cescatti et al. (2012) showed that for homogenies areas MODIS DHR retrievals have a good performance for all plant types including boreal forest. The land-cover image is also not 100% correct and there is a possibility of single pixel errors. The upscaling of the land cover pixels to match the MODIS pixels also can be a cause of data loss and uncertainty.

By using only best quality MODIS DHR retrievals and setting minimum land-cover type composition percentages, this study has tried to reduce the effect of the above mentioned problems.

The lack of enough homogeneous pixels for agricultural land in northern Finland and deciduous and shrubland in middle and southern Finland can also bias the statistical analysis and flaw the normal distribution assumption of the ANOVA test.

In the end, it should be mentioned that dividing the whole study area just based on the number of the pixels from north to the south is not the best possible solution to study the geographical gradient effect on albedo. A model based on compositional gradients of the vegetation, as has been studied by Tonteri et al. (1990), would be a better solution to this problem.

5 Conclusion

Albedo is an important factor affecting the earth's surface energy budget. Land-cover types of different biomes on earth have an impact on surface albedo. The boreal region is one of the biggest biomes of our planet and also one of the most influential on surface albedo. An accurate estimation of boreal land-cover albedo can help to improve the regional and global prediction of earth's surface energy budget, improve our understanding of climate change, and improve climate modeling and weather forecasting. Through improved understanding of land-cover albedo we may be able to manage land-cover vegetation to mitigate the effects of climate change and minimize the impact of human intervention in nature.

In this study, the effect of different land-cover types and their geographical location as well as seasonal variation on the surface albedo of Finland was studied. The results showed that there is a significant difference between albedo of different land-cover types. Agricultural land cover had the highest and coniferous land cover had the lowest albedo between different land-covers. The study also suggested that in general, land-cover albedo is lower in northern Finland compared to middle and southern Finland. The albedo peak is also reached earlier in northern Finland compared with the south despite the fact that the growing season starts later. A seasonal effect on land-cover albedo was also observed. Considering the results of this study and the possible significant impact of the boreal zone albedo on climate change, the following land use managements are suggested to increase the vegetation land-cover albedo of Finland:

- The species composition of the forest sites should be administrated in favor of deciduous species such as birch.
- Considering the ongoing debate in Finland about even-aged versus uneven-aged forestry methods (Siiskonen, 2007; Tonteri et al., 1990), the current even-aged forestry method seems to be a better recommendation than the selection system. This is because the cleared area will have higher snow albedo during the winter and spring, and young forest stands may have higher albedo compared to mature stands.
- Shorter harvest rotation can also prevent the low albedo of mature stands.
- Afforestation, and reforestation of agricultural lands, peat-lands and grasslands, should be implemented with greater consideration.

It should be noted that this study investigates only the effect of vegetation land-cover albedo and the above mentioned suggestions are based on this fact. Considering the ecological, social and economic benefits of the vegetation land-covers will influence these suggestions and an overall combination of all these factors might lead to a completely different set of suggestions. All of these factors are equally important and must be considered in land use management and decision making.

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Appendices

Appendix 1. CORINE Land-Cover Classification

	1. Constructed areas
	1.1. Residential areas
1	1.1.1. Closely built residential areas
2	1.1.2. Loosely constructed residential areas
	1.2.Indusries, utilities and traffic areas
3	1.2.1. Industry and utility areas
4	1.2.2. Traffic areas
5	1.2.3. Port areas
6	1.2.4. Airport areas
	1.3. Soil extraction, waste disposal sites and construction areas
7	1.3.1. Composite material extraction areas
8	1.3.2. Landfills
9	1.3.3. Construction areas
	1.4. Recreation and leisure areas
	1.4.1. Green spaces in urban areas and parks
	1.4.2. Sport and leisure operation areas
10	1.4.2.1. Summer cottages
11	1.4.2.2. Sport and leisure areas
12	1.4.2.3 Golf field
13	1.4.2.4 Horse riding tracks
	2. Agricultural Areas
	2.1. Arable land
14	2.1.1.1. Fields
15	2.1.1.1. Discarded agricultural soils
	2.1.2. Irrigated fields
	2.1.3. Rice fields
	2.2. Trees and shrubs
16	2.2.2. Fruit and berry crops
	2.2.3. olive groves
	2.3. Pastures
17	2.3.1 Pastures
	2.4. Heterogeneous agricultural regions
	2.4.1. Agriculture combinations
	2.4.2. Fields and meadows on connection. mosaic
	2.4.3. Intricate mosaic of agricultural mosaic
	2.4.4. Wooded farmland and pastures
	3. Forest, sparse forest and rocky grounds
	3.1. Dense forests
	3.1.1. Deciduous Forests
18	3.1.1.1. Deciduous Forests on mineral soil
19	3.1.1.2. Deciduous Forests on peat soil
	3.1.2. Coniferous forests
20	3.1.2.1. Coniferous forests on mineral soil

21	3.1.2.2. Coniferous forests on peat soil
22	3.1.2.3. Coniferous forests on rocky land
	3.1.3. Mixed forests
23	3.1.3.1. Mixed forests on mineral soil
24	3.1.3.2. Mixed forests on peat soil
25	3.1.3.3. Mixed forest on rocky land
	3.2. Open heath forests, scrubs, moorlands and rocky grounds
26	3.2.1. Natural grasslands
27	3.2.2. Plants on the ground and heaths
	3.2.3. Sclerophyllous vegetation areas
	3.2.4. Open woodlands areas
28	3.2.4.1. Open heath regions cc <10%
29	3.2.4.2. Open woodlands areas, cc 10-30%, mineral soil
30	3.2.4.3. Open woodlands areas, cc 10-30%, peat land
31	3.2.4.4. Open woodlands areas, cc 10-30%, rocky land
32	3.2.4.5. Open woodlands areas
	3.2.4.6. Open woodlands areas, under the power lines
33	3.2.4.7 Open woodlands areas, disused farmland
	3.3. Sparse forest and rocky grounds
34	3.3.1. Sand banks and dunes
35	3.3.2. Rocky land
	3.3.3. Sparsely vegetated moorlands
	4. Wetlands and open marshes
	4.1. Inland wetlands and open mires
	4.1.1. Inland wetlands
36	4.1.1.1. Inland wetlands on land
37	4.1.1.2. Inland wetlands in water
	4.1.2. Open mires
38	4.1.2.1. Open mires
39	4.1.2.2. Peat extraction areas
	4.2. The coastal wetlands
	4.2.1. Seaside Wetlands
40	4.2.1.1. Seaside Wetlands on land
41	4.2.1.2. Seaside Wetlands in water
	4.2.2. Seaside Salt lands
	4.2.3. Tide Pools
	5. The waters
	5.1. Inland waters
42	5.1.1. Rivers
43	5.1.2. lakes
	5.2. Marine waters
	5.2.1. Coastal lagoons
44	5.2.2. Estuaries
	1.2.3. Sea

Appendix 2. Appropriate constants to be used for black-sky albedo generation

Term	Isotropic (iso)	RossThick (vol)	LiSparseR (geo)
g_0	1.0	-0.007574	-1.284909
g_1	0.0	-0.070987	-0.166314
g_2	0.0	0.307588	0.041840

Appendix 3. Average land-cover albedos with and without considering the geographical location

Appendix 3.1 Average land-cover albedo per land-cover during the whole growing season

Land cover type	Average albedo
Agricultural	164.6
Deciduous	144.8
Coniferous	124.4
Mixed forest	129.7
Shrubland	144.9

Appendix 3.2 Average land cover albedo per geographical location for all land cover groups during the whole growing season

Location	Average albedo
Northern Finland	137.1
Middle Finland	143
Southern Finland	144.9

Appendix 3.3 Average land cover albedo per land cover type per geographical location

Land cover type	Geographical location	Average albedo
Agricultural	North	151.6
	Middle	169.6
	South	172.6
Deciduous	North	136.9
	Middle	146.5
	South	151.1
Coniferous	North	121.7
	Middle	125.4
	South	126.2
Mixed forest	North	130.5
	Middle	131.6
	South	127
Shrubland	North	144.8
	Middle	142
	South	147.8