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New Methods to Quantify Canopy Structure of Leafless Boreal Birch Forest from Hemispherical Photographs

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Hemispherical photography has been used for many years to measure the physical characteristics of forests, but most related image processing work has focused on leafy canopies or conifers. The boreal forest contains large areas of deciduous trees that remain leafless for over half the year, influencing surface albedo and snow dynamics. Hemispherical photographs of these sparse, twiggy canopies are difficult to acquire and analyze due to bright bark and reflections from snow. This Note presents new methods for producing binary images from hemispherical photographs of a leafless boreal birch forest. Firstly, a thresholding method based on differences between colour panes provides a quick way to remove bright sunlit patches on vegetation. Secondly, an algorithm for joining up fragmented pieces of tree after thresholding ensures a continuous canopy. These methods reduce the estimated hemispherical sky view fraction by up to 6% and 3%, respectively. Although the processing remains subjective to some degree, these tools help to standardize analysis and allow the use of some photographs that might have previously been considered unsuitable for scientific purposes.

Keywords: Hemispherical Photography; Image Processing; Leafless Canopies; Boreal Forest; Snow; Abisko

Introduction

Forest canopies strongly affect the radiation balance at the Earth's surface. One well-established technique for quantifying this effect is to take hemispherical photographs (hemiphotos) looking upwards from the forest floor. Hemiphotos can be analyzed to estimate forest parameters such as sky view fraction and plant area index van Gardingen 1999, but the first important step involves applying thresholds of brightness to produce a binary map of black (trees/horizon) and white (sky) pixels. The thresholding is usually done manually, and has been criticised for being subjective, prompting the development of automatic methods Nobis 2005, Ishida 2004. Sky conditions are also important, and overcast skies are preferable for their homogeneous quality. Zhang 2005 suggest measuring a reference exposure for the open sky before lengthening exposure time to increase contrast between sky and vegetation, while Pueschel 2012 suggest taking five photographs on different exposure settings. However, such complicated approaches are not always practical in remote, challenging field environments. It is beneficial to take photos quickly, with minimal equipment and simple protocols that can be performed by different operators, including students.

Moreover, most papers on hemiphoto analysis have focussed on leafed deciduous trees or needleleaf conifers. The motivetion for this Note arose during fieldwork in March 2011 in an area of leafless mountain birch forest in Abisko National Park, Sweden. Hemiphotos taken in this region present considerable challenges; homogeneous overcast conditions are rare or accompanied by blizzard conditions, and the high albedo snow cover, low solar elevations and white birch bark cause considerable light scattering.

This Note describes new techniques that can aid processing of hemiphotos of sparse, leafless Arctic canopies. Section 3 describes a method of manipulating the colour panes of a hemiphoto to identify sunlit parts of the canopy that are too bright to be distinguished from the sky through a simple threshold. Section 4 describes a branch-joining algorithm that acts to repair hemiphotos in which branches with heterogeneous colour characteristics have become broken-up during the thresholding process. These new concepts are easy to use, and remove some subjectivity from the processing of hemiphotos. They would provide useful additions to popular existing software packages such as Gap Light Analyzer, or GLA Frazer 1999, which don't tend to include special settings or functions for leafless canopies.

Hemiphoto Acquisition and Thresholding

All photographs were taken using a Nikon Coolpix 4300 digital camera with a Nikon FC-E8 fisheye converter lens on an automatic exposure setting, under the mountain birch canopy around 3 km south of Abisko village (68.32˚ N, 18.83˚ E). Images were saved as JPEGs with resolution that gave a hemi-

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spherical view of radius 1704 pixels. Algorithms were encoded using IDL (Interactive Data Language©, 2011 Exelis Visual Information Solutions). Canopy metrics-hemisphere-averaged sky view fraction v_s and effective plant area index P were calculated by first obtaining values of gap fraction, v_{θ}, as the ratio of sky pixels to total pixels in nine concentric 10 bands of elevation angle (θ) in the hemisphere. v_s was calculated by summing the weighted individual v_{θ} values according to Essery 2008, and P was calculated from logarithms of v_{θ} according to van Gardingen 1999.

The thresholding of images in this paper is all done manually. The automated threshold method of Nobis 2005 was tested on Abisko hemiphotos, but it resulted in binary images that looked far from the reality; large parts of trees were lost, perhaps because their software was developed for leafed canopies and has difficulty detecting sky-tree edges in the leafless canopy.

Colour Pane Manipulation

Previous studies have highlighted the benefit of selecting the blue colour pane of an RGB image to separate canopy and sky, because blue is enhanced in the sky and reduced on trees Frazer 1999, Nobis 2005. The method presented here expands on this concept, and that of Normalized Difference Vegetation Index (NDVI), which indicates the presence of vegetation via the difference in intensities at certain spectral ranges Kriegler 1969. **Figure 1** shows that a similar argument can be applied to mountain birch forest. A spectrophotometer (Analytical Spectral Devices, Inc. (ASD)) was used to measure reflectivity spectra of snow, white bark and darker copper-coloured bark in the area where hemiphotos were taken in 2011 (Richardson and Sandells, unpublished); these are similar to spectra measured by Ovhed 1995. On applying these reflectivities to a typical sky spectrum for the Abisko region (replicated from Ovhed 1995), white bark produces a flatter spectrum in the visible region (400 to 700 nm) than the sky, which gives considerably higher irradiance at the blue end. This supports the argument for using the blue pane ($\approx$ 400 to 500 nm). However, the irradiance reflected from white bark is often higher than from blue sky and even some clouds. In this Note the shapes of the graphs are exploited, taking the red pane into account. This involves subtracting a proportion of the red (R) pixel values (with digital number (DN) between 0 and 255) from the blue (B) pixel values to produce a new grayscale image I_g, defined as:

$$I_g = B - f_r R \quad (1)$$

where f_r is a number between 0 and 1. If I_g is then normalized back to the range 0:255, the difference between sky and tree is magnified. Finally, a suitable threshold t_b (=0 to 255) should be chosen and applied to I_g, producing a binary image.

Figure 2 shows an example hemiphoto in which the sunlit white bark produces many bright patches on trees. In the blue-pane-only image (upper row) these were too bright to remove through simple thresholding without starting to turn many sky pixels black as well. On applying the new method with a value of $f_r = 0.5$, a subjectively better binary image was produced. The trunks come out black at a lower threshold and the vegetation as a whole is filled out to more accurately represent

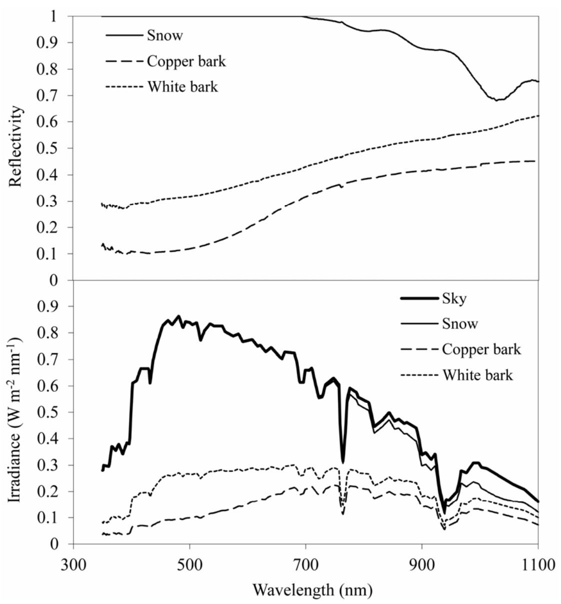

Figure 1.
Reflectivity spectra of snow, copper-coloured birch bark and white birch bark measured in Abisko in 2010 (upper panel). Lower panel shows a typical sky irradiance spectrum for Abisko replicated from Ovhed and Holmgren (1995), and the irradiance expected from snow, copper bark and white bark, where each is calculated by multiplying the sky irradiance by the relevant reflectivity.

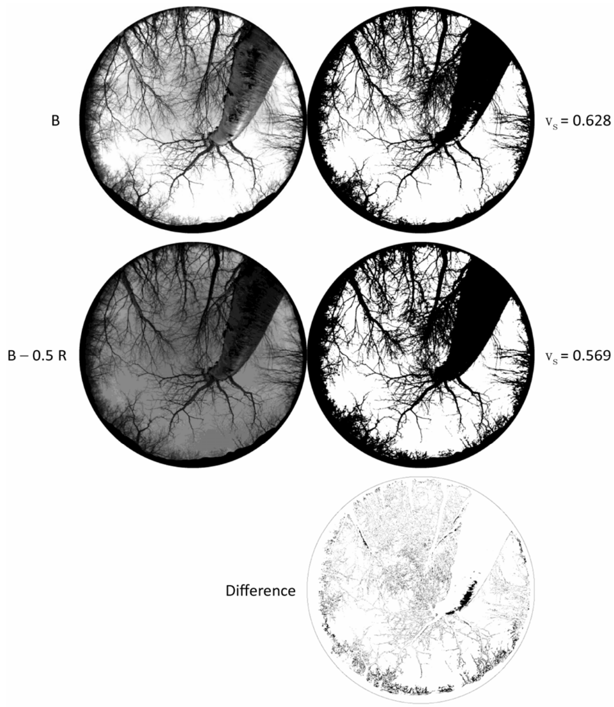

Figure 2.
Blue colour pane from an Abisko birch hemiphoto (top left) and the subjectively best binary image (top right) acquired by manually increasing the threshold until just before some sky pixels began turning black. By subtracting a fraction of the red pane (see Equation (1)) and renormalising (centre left), it is easier to correctly classify bright areas of bark without affecting the sky. This produces a different value of sky view fraction (v_s).

the real canopy. This causes a reduction in v_s from 0.628 to 0.569.

Incorporating this colour pane manipulation in a graphical user interface, using sliding bars to choose the best combinations of f_r and t_b, has proven useful for analyzing several hundred hemiphotos from the Abisko region. Such functionality is not included in packages such as GLA, which allows users to select an individual colour pane but doesn't allow panes to be combined in more complex ways. The implementation of Equation (1) or variations on it would be very straightforward and possibly beneficial for other forest situations.

This Note presents no automated method for removing snow-covered topography from hemiphotos. Snow could be removed by calculating horizon angles from a DEM Dozier 1990. Alternatively one could use a camera sensitive to near-infrared radiation (NIR) Chapman 2007, because as **Figure 1** shows there is a difference between visible and NIR reflectance for snow. For this Note, snowy horizons were shaded by hand, which can be done quite quickly and accurately.

Branch Joining Algorithm

It is reasonable to assume that there should be no flying twigs in a hemiphoto, and all dark areas of tree should be connected to the ground forming one continuous dark object in the image. When applying a brightness threshold to a gray colour pane, the priority is to remove all the sky pixels, but even with additional measures such as those described in Section 3, some brighter tree pixels will be saturated to the extent that they will be wrongly classified as sky. This means that the thresholded image has many twigs and branches appearing fragmented. This problem is enhanced for canopies with bright, reflective bark such as mountain birch.

For these reasons a branch joining algorithm (BJA) was developed to connect the disjointed parts of thresholded images. **Figure 3** illustrates this process. A connected-component algorithm was used to identify individual blobs in the image. For each blob, the BJA identifies the two furthest-apart pixels (pixels 1 and 2 in **Figure 3**), representing the extreme ends of a branch section, and performs searches in increasing radii around both those points to find out which of the two is closest to part of a different blob (pixel 3). The pixel is then joined to the other blob by a line; the width of this line is determined by the width of the original blob, defined as the number of pixels in the blob divided by its length in pixels, rounded to the nearest whole number. If it turns out that the blob is further than a specified maximum distance from the nearest other blob, the blob is deleted. For Abisko hemiphotos 30 pixels was chosen as the maximum separation, but this could be adjusted for different circumstances.

Figure 4 shows the BJA applied to an Abisko hemiphoto. On applying the BJA, the binary image is filled out considerably. For comparison, a small cropped part of the photo was processed by manually (laboriously!) shading in black all the branches seen in the original image. This manual shading is also subjective to some extent, but at least gives individual attention to every part of the image, so it is arguably the closest attainable representation of the truth. Counting the sky pixels in the three cropped images showed that the threshold-only approach provides a sky view fraction 3.5% higher than the hand-drawn method. On applying the BJA, the difference is only

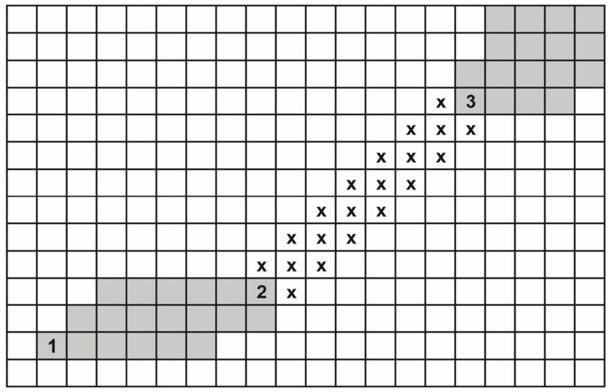

Figure 3.
Schematic illustration of the branch-joining algorithm. For each isolated blob (e.g. bottom left), the two furthest-apart pixels are identified (marked 1 and 2). The algorithm then finds out which of 1 or 2 are closest to a pixel of another blob-in this case it is pixel 2, which is joined to pixel 3 with a line (pixels marked with x) whose width is determined by the width of the original blob.

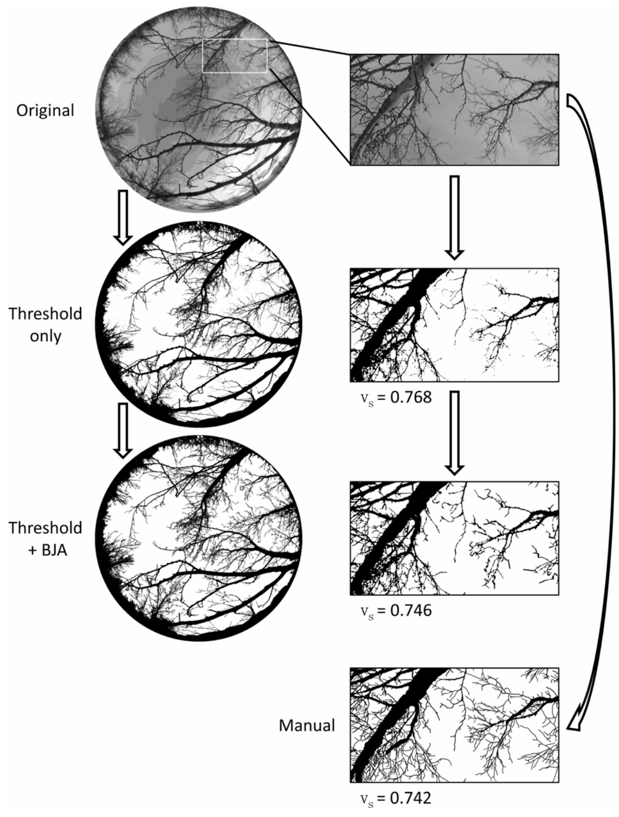

Figure 4.
Blue pane of an example hemiphoto (top row) processed by thresholding (second row) then by the BJA (third row). The close-up region in the right column was also subjected to a separate manual approach with twigs hand-drawn in black on the original image before thresholding (bottom right).

0.5%.

Figure 5 shows v_s and P calculated for 50 Abisko hemiphotos with just a threshold applied, and the same images after applying the BJA. The branch-joining algorithm decreases v_s and increases P, with maximum changes of −0.03 in v_s

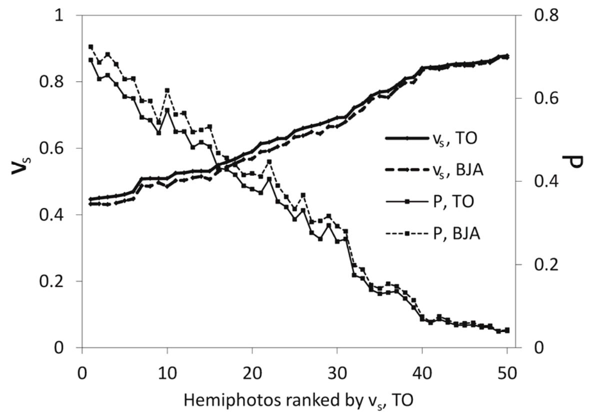

Figure 5.
v_s and p calculated for 50 hemiphotos from Abisko, numbered according to their sky view fraction. Solid lines show the results with image thresholding only (TO), and dotted lines are results after applying the branch-joining algorithm (BJA).

and +0.05 in P. As might be expected, the differences are larger when v_s is smaller, because such hemiphotos contain more vegetation to be processed by the BJA. A change in v_s of 3% may seem a small amount, but could have a significant effect on calculations of surface radiation balance, especially if conclusions were applied across large areas of forest.

It should be acknowledged that the BJA is rather ad-hoc in the way it accounts for canopy geometry. A more sophisticated BJA was trialled by preferentially attaching individual blobs to others that lay in the direction of the major axis of the original blob. This resulted in some twigs being drawn in strange places, because there are many small blobs of 5 pixels or less in which the major axis is not obvious. Overall, the simpler approach is usefully non-specific; further levels of sophistication might make the algorithm less generalizable to other canopies.

Conclusion

The techniques described in this Note address some of the difficulties encountered on analyzing hemiphotos of leafless Arctic canopies, and could provide useful additions to existing hemiphoto software. The manipulation of individual RGB colour panes has proven very useful for correctly classifying bright areas of canopy that would otherwise be missed out, and the BJA fills many of the gaps left by the thresholding process. Both techniques remain to be tested for different leafless forest types, but for at least the case of boreal birch, they help to standardize analysis across thresholded images.

The process of producing a binary image from a hemiphoto will always be subjective to some degree, but these new methods go some way to reducing that subjectivity. The colour pane manipulation provides a quick and easy way to correctly classify sunlit areas of bark, encouraging all users to pay special attention to those areas; meanwhile the repairs made by the BJA work to produce similar final results from binary images that may have had different levels of branch fragmentation resulting from thresholding by different users. The subjectivity could be further reduced in future by adapting existing automatic thresholding methods Nobis 2005, Ishida 2004 to work for leafless canopies.

Most usefully, these methods make it possible to use hemiphotos taken quickly under automatic camera settings and non-ideal light conditions—often the only possible way to conduct fieldwork in the Arctic winter. To improve on this study without increased effort in the field, images should be saved in raw format to avoid loss of detail on conversion to JPEG and allow more sophisticated processing Lang 2010. Future work could compare hemiphoto-based radiation transfer modelling to subcanopy radiometer measurements Link 2004 or terrestrial laser scanning Antonarakis 2009, Cote 2009 to assess the benefits of different image processing methods. Such independent verification would be highly beneficial for forest studies on the whole, because hemiphotos remain the fastest, cheapest and easiest way to record forest structure in the field.

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