Land Cover Mapping with MERIS at the BOREAS Study Area

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ABSTRACT

The objective of this study is to validate the MERIS vegetation land cover classification product. The full resolution MERIS radiance data sets obtained over the BOREAS (Boreal Ecosystem-Atmosphere Study) South Study Area in May and August 2003 were used. The MERIS radiance data were first converted to at-canopy reflectance data, which were compared to CASI data obtained during BOREAS (1994), followed by unsupervised classification performed based on seasonal variation of pigments as inferred from visible and near-infrared spectral bands. Three modified normalized Difference Vegetation Indices (mNDVI), sensitive to relative proportions among pigments and pigment content, and a red-edge spectral parameter, the wavelength at the reflectance minimum (λ_0) were used in the unsupervised classification. Accuracy assessments of the derived vegetation classification maps were performed using a forest inventory map provided by the Saskatchewan Environment and Resource Management Forestry Branch-Inventory Unit (SERM-FBIU). The forest vegetation classification using seasonal changes in optical indices (mNDVIs and λ_0), derived from the MERIS imagery in May and August revealed a reasonably high overall classification accuracy for all vegetation cover types identified: conifer, mixed stands, and fen. The classification results also demonstrated that classification using reflectance parameters sensitive to pigment absorption outperformed that using reflectance itself and the classification using seasonal information was better than that using information obtained in a single MERIS image, which were consistent with that achieved using multi-date CASI imagery. Implications of MERIS spatial resolution on the data product classification accuracy are discussed by comparison with results obtained with CASI.

INTRODUCTION

Distribution of forest vegetation types is one of the most important surface parameters from both scientific and management points of view. From the scientific perspective, forest cover characteristics influences the exchanges of water, energy and carbon dioxide between the land surface and the atmosphere. As a result, it has effects on climate. Forest cover classification is a starting point to parameterize land cover functioning. Forests also directly affect our daily life as an economic good or as an environment regulator. Careful planning, management and monitoring are therefore, needed by foresters and decision-makers to ensure that forest resources are being utilized efficiently and wisely. Gathering this type of information must be based on up-to-date forest cover information. Therefore, forest cover classification from remote sensing data has been one of the important topics since the beginning of mapping with remote sensing, and it has benefited from the evolution of remote sensing technologies and methodologies [1] [2] [3] [4]. The recently-developed hyperspectral sensors promise a considerable improvement in identifying forest vegetation types, because they have fine spectral resolution which gives the advantage of potential discrimination between elements with similar spectral signatures. The high spectral resolution, on the other hand, makes the hyperspectral data highly redundant, which poses challenges in developing a methodology suited to forest cover classification. It is well recognized that using a smaller number of spectral bands can probably produce better classification accuracies than the use of all of the bands. As a result, feature selection including band selection is very important for forest cover classification using hyperspectral data as well. Much effort is currently focused on statistical approaches to represent the data by a few basic components and a number of methods have been developed [5]. The commonly used approaches include principal component analysis (PCA) and its variants, and the minimum noise fraction (MNF) transformation [6]. The components obtained by the statistical approaches exhibit poor physical significance. Even though some satisfactory classification results were reported using these methods, it is more likely that some information important in identifying forest species may be lost or submerged by other unimportant information. To overcome this problem, it is preferable to derive the features sensitive to forest parameters that are systematically different by cover type or by species and explicitly use them in the classification. The challenge is to find the diagnostic features of forest cover types from remote sensing data, since a large number of factors affect the forest canopy reflectance.

A new paradigm for the land cover classification has recently emerged, which exploits systematic differences by cover type or by species of the reflectance sensitive to pigments, water, and foliar chemistry [7] [8] [9]. The differences in the reflectance in the absorption bands sensitive to foliar chemistry have been used and reported [7]. Further, the red-edge parameters sensitive to chlorophyll content [8] and optical indices sensitive to pigments and water content [9] were used in recent studies to map land cover in the BOREAS (Boreal Ecosystem-Atmosphere Study) south study area (SSA). These three studies show that the forest cover classification accuracies were improved by using parameters sensitive to the absorption features instead of using reflectance itself. By using such parameters, it is expected that the information needed to identify forest species is not be masked by other information contained in the reflectance spectrum. However, these three studies show that there are still considerable mis-classifications such as between wet conifers and dry conifers, and between the coniferous species and mixed conifers and deciduous forests. Even though different parameters were used in the three classification approaches, they have something in common; that is, all of the three classification approaches are based on the information obtained on one single date.

We know that forest canopies change over time. Normally, new leaves come out in spring. Plants reach their growth peak during summer months. The plant pigments change across the growing season both in terms of the proportions of pigments and pigment content. A separate study being carried out in our research group clearly demonstrates that the chlorophyll content of Jack Pine increases significantly from spring to summer in new needles (Inian Moorthy, York University, personal communication). The seasonal changes in plant pigments are different by species, due to either the seasonality of pigments in the overstory leaves or in the understory vegetation. Therefore, for some species, if we cannot identify them based on the absorption features in one season, we may be able to identify them by looking at the change in the absorption features from one season to another. This inspires our research to exploit systematic difference by cover type of reflectance sensitive to the seasonality of pigment concentrations in forest cover classification. This research first focused on data collected with Compact Airborne Spectrographic Imager (CASI) for the BOREAS SSA in May and in July 1994, and the results demonstrated that classification using reflectance parameters sensitive to pigment absorption outperforms that using reflectance itself, and the classification using seasonal information is better than that using information obtained in one single date [10]. In the present study, we performed MERIS vegetation cover classification using the same approach with CASI data in [10], and the results were validated against the ground truth and those obtained using CASI data.

DATA DESCRIPTION AND DATA PRE-PROCESSING

Three data sets from the BOREAS southern study area were used in the present study on forest vegetation cover classification: (1) forest cover data for detailed validation of the classification results, provided by Saskatchewan Environment and Resource Management, Forestry Branch-Inventory Unit (SERM-FBIU) as derived from infrared aerial photography and field reconnaissance notes; (2) Surface reflectance data from CASI collected at 2 m spatial resolution and in 15 narrow spectral bands obtained in May and July 1994; and (3) MERIS full resolution radiance data in May and August, 2003.

SERM-FBIU Forest Cover Data Set

A forest cover data set covering the BOREAS south study area was prepared by the BOREAS science staff by processing the original vector data into raster images with a cell size of 30 m. It includes four images providing information on species association (cover type), crown closure, height class, and the year of origin or disturbance. The original maps were first produced using infrared aerial photography taken in 1988 and field reconnaissance notes, but maintained and updated based on fires, cuttings, and other disturbances by SERM-FBIU until 1993 when they were acquired by BORIS (BOREAS Information System).

The SERM-FBIU classification included twenty cover types. BOREAS scientists grouped the twenty cover types into nine ecologically significant classes, in order to meet the needs of modelling boreal forest ecosystem [11] [3]. Based on the groupings and the existence status of these classes in our study area, we used six categories shown in Fig.1. They are (1) wet conifer (black spruce, spruce/pine, and tamarack), (2) dry conifer (white spruce and jack pine), (3) mixed conifer and deciduous (mix spruce-fir/broadleaf, mix jack pine/broadleaf, mix broadleaf/spruce-fir, mix broadleaf/jack pine), (4) deciduous (aspen), (5) fen (treed muskeg and clear muskeg) and the disturbed areas (clearing, burned, disturbed/cut/burn, disturbed/jack pine regeneration, experimental area). The SERM-FBIU classification map was used to assess the classification accuracy.

CASI Reflectance Data

The CASI instrument was flown in May and July 1994 over the BOREAS flux tower sites of old jack pine (OJP), young jack pine (YJP), fen, and old black spruce (OBS) in the southern study area as part of the BOREAS project field deployment. The four CASI images obtained over the four flux tower sites (OJP, YJP, Fen, and OBS) for each season (May or July) were processed to at-sensor radiance and then to at-canopy reflectance. The reflectance retrieval accuracies reported in the validation experiments performed during similar CASI deployments in 1994 were 0.005 and 0.008 absolute errors in the visible and 0.013 and 0.022 in the near-infrared for two forest targets, black spruce and tamarack, respectively. The four CASI reflectance images were geo-referenced and mosaicked. The spatial resolution of the CASI images originally was 2 m by 2 m and has been resampled to 30 m by 30 m. The CASI images, as shown in Fig.2 were used to validate the MERIS reflectance data and the conclusions obtained from MERIS data.

MERIS Data Set

The MERIS full resolution radiance data (L1) in May and August, 2003 were first converted to reflectance data and then geo-referenced. In order to correct the MERIS data to at-ground reflectance from at sensor radiance, the CAM5S radiative transfer model was used. CAM5S is the Canadian Advanced Modified 5S [12] based on H5S [13], and it incorporates some of the advanced features of 6S [14] without the substantial increase in time required to run the latter model. Used extensively at York University to correct airborne CASI imagery over the last 10 years the procedure was slightly modified to correct the MERIS data. While unsuited to correct the full MERIS image without extensive changes the methodology was considered appropriate for the small region of interest used here. As an initial validation the model was run with no aerosol content and compared to the ESA provided level 2 “top of the aerosol layer” product, and the comparison for a pixel is shown in Fig. 1 as an example. The outlier lies in the oxygen absorption band. The outlier point was discarded in later processing and the reflectance in this band was interpolated using the reflectance values in its neighboring bands.

The inputs required for the CAM5S correction procedure are: aerosol optical depth, date, solar and sensor geometry and atmospheric model (mid latitude summer, continental aerosols). Values for aerosol optical depth were taken from the AEROCAN sun-photometer at Bratt’s Lake Sask. AEROCAN is a sub net of the larger AERONET [15] network of sun-photometers. If sun-photometer measurements where not available on the day of image acquisition, an historical monthly average value was used. The MERIS reflectance images in May and August are shown in Fig. 1. The MERIS reflectance spectra were compared with CASI reflectance spectra. In the MERIS data, the flux tower sites in the BOREAS south study area, old back spruce (SOBS), old jack pine (SOJP), young jack pine (SYJP), and fen (Sfen), were identified and the reflectance spectra of a pixel were derived for each site; the areas in the CASI image corresponding to the selected pixel in the MERIS image were then determined and the average reflectance spectra were calculated. The comparison results, as shown in Fig.4, indicate the reflectance spectra shapes and the seasonal change trends are similar, although there are differences in the absolute values. In this study, the reflectance ratios were used, as a result, the uncertainties in the atmospheric correction of MERIS, which may cause the discrepancy in the absolute value, do not significantly affect the classification results. In addition, the importance to be drawn on spectra differences between CASI and MERIS needs to be tempered by the fact of a 9 year time interval between the image acquisitions.

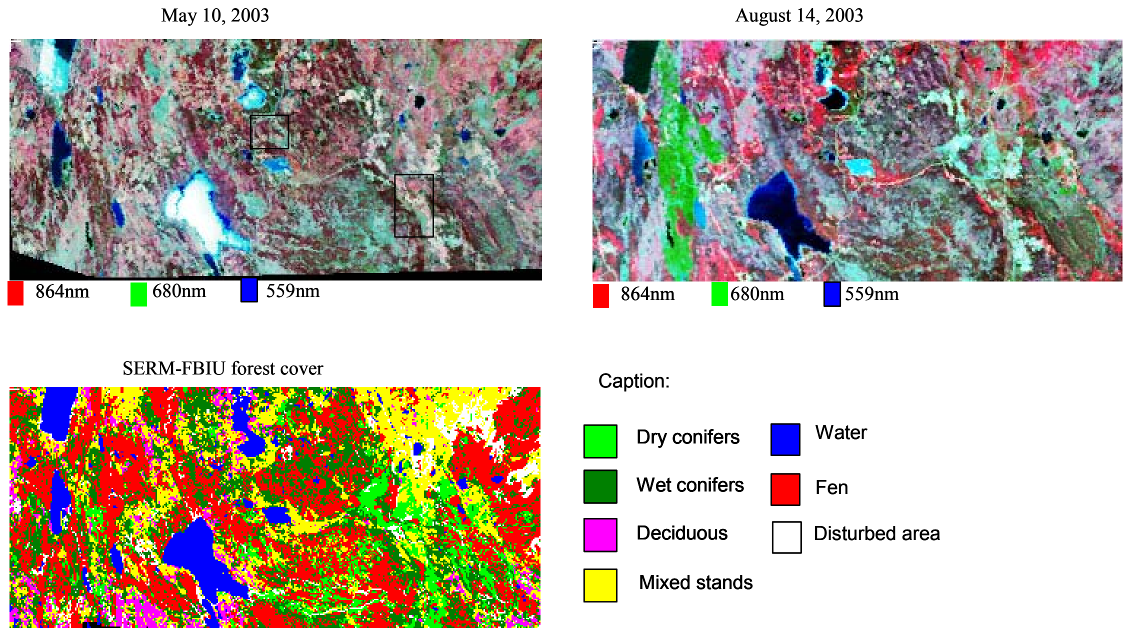


Fig. 1. MERIS full resolution reflectance images and the SERM-FBIU forest cover image. The rectangular areas in the MERIS image in May include the BOREAS SSA and are covered by the CASI images shown in Fig.2. The SERM-FBIU original forest cover classification was aggregated into 7 functional classes.

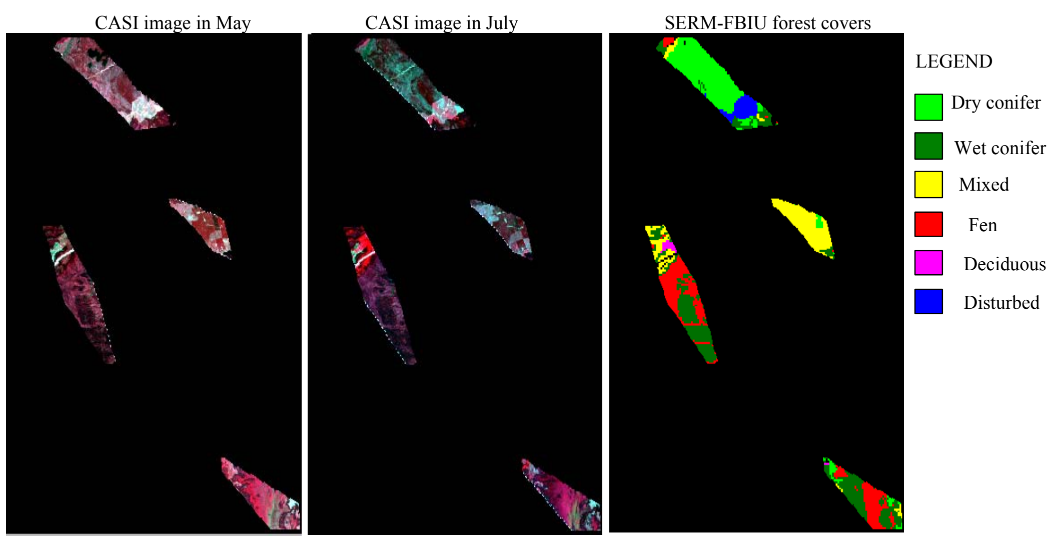


Fig. 2. The colour composite CASI images in May and in July and the SERM-FBIU forest cover image (aggregated into six functionally dominant categories). Please note that the actual location of OBS site is far from the OJP, YJP, and Fen sites, located to the west but has been re-positioned together with the other sites for display purposes only.

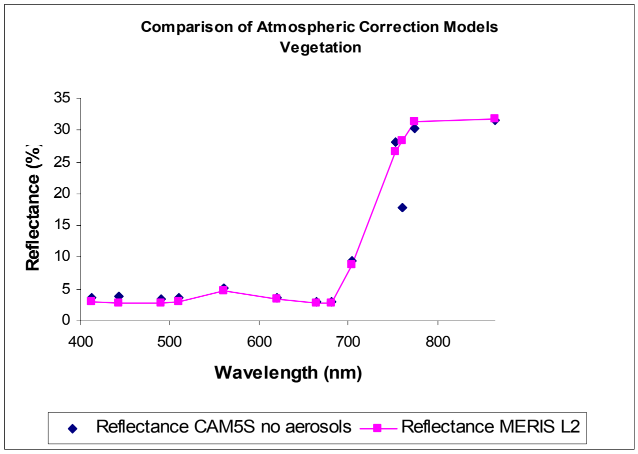


Fig.3. Comparison between the reflectance obtained by CAM5S without aerosols and ESA L2 reflectance.

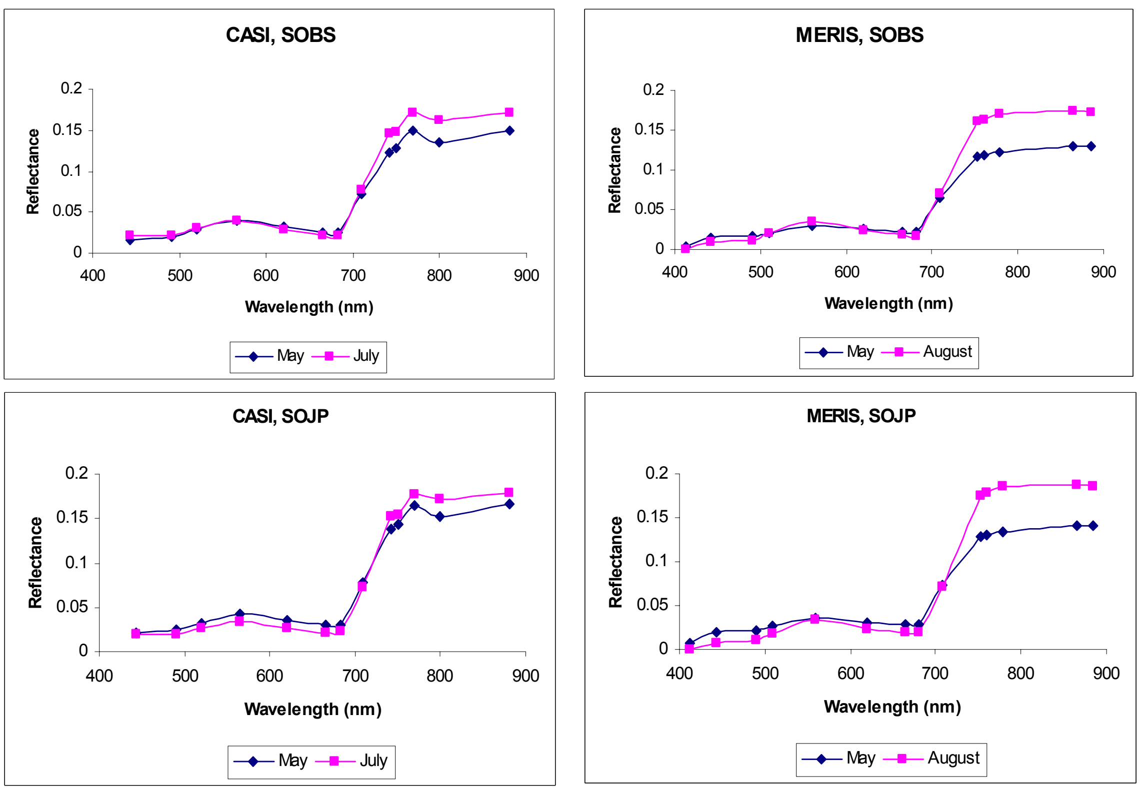


Fig.4. Reflectance spectra derived from MERIS and CASI data in the SOBS and SOJP sites.

METHODS AND RESULTS

Feature Selection

The spectral signatures of plants in the visible and near-infrared regions are dominated by the absorption of blue and red light by pigments for photosynthesis and high reflection of the near-infrared radiation [16]. Since vegetation is composed of the same pigment constituents, the reflectance spectra from widely differing plants will look similar. However, either seasonal variation or vegetation stress can lead to differences in proportions among pigments and /or pigment content, and therefore the spectral details of the associated absorption features. Different plants grow in different environment and may experience different level of stress. Different plants also have different seasonality due to either the overstory canopy or the understory vegetation. These physical considerations suggest that the absorption features derived from the at-canopy reflectance across the growing season differentiate between plant types or associations.

In this study, we used three modified normalized difference vegetation indices (NDVIs) and the spectral position of the reflectance minimum at the red-edge (λ_0), called optical indices for convenience. Their formulation and functions are listed in Fig. 5 Since the absorption bands of pigments are different and are focused in the blue and red spectral regions, we used the first two mNDVIs to characterise the absorption features by calculating the slope of the reflectance change from the blue absorption to the green peak and from the green peak to the red absorption, respectively. The third mNDVI and λ_0 have been demonstrated to be sensitive to chlorophyll content (refer to [17] for a review). The four optical indices were calculated for each pixel from the MERIS reflectance data for May and August and are shown in Fig.6 Evident spatial patterns are exhibited in all of the images in Fig.6, and the spatial patterns are consistent with those shown in the cover type map in Fig.1 We can also notice temporal changes (from May to August) of these optical indices, which also vary with cover types.

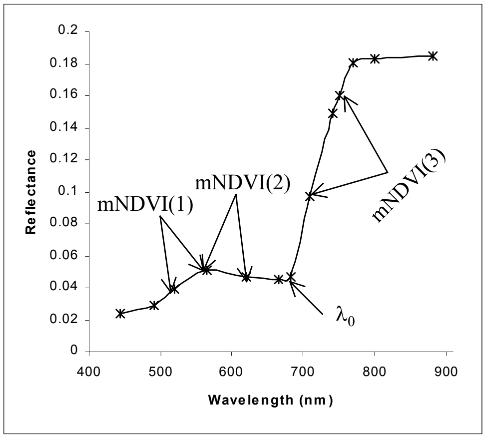
Unsupervised Classification and Results

The Isodata unsupervised classification (PCI software) was performed on the optical indices derived from MERIS reflectance data in May and August and the result is shown in Fig. 7. The spatial distribution of the cover type obtained from the classification is similar to that exhibited in the SERM-FBIU forest cover image. We also quantitatively analyzed the classification accuracy. From the SERM-FBIU cover type image, we randomly select a number of pixels for each class. Using these pixels, we tested the classification accuracy. The contingency matrix is shown in Table 1. The overall classification is 72 % and the producer's accuracies for all of the classes are larger than 65 % and the user's accuracies for the mixed stands and fen are larger than 80 %.

With the MERIS data, we also tried unsupervised classification using reflectance in August and using optical indices in August for comparison. The results and the producers' accuracies are shown in Fig.8. Comparing with the results in Fig.7 and Table 1, we can see that the classification using the parameters sensitive to pigment absorption features are better than the classification accuracy using reflectance itself, and adding seasonal information into classification can improve classification accuracy.

Table 1: The contingency matrix of the unsupervised classification using the optical indices in May and August

SERM-FBIU	Unsupervised classification			
	Conifers	Mixed	Fen	Producer's accuracy
Conifers	871	152	314	0.651458
Mixed	335	1191	271	0.662771
Fen	585	121	2550	0.78317
User's accuracy	0.48632	0.813525	0.813397	0.721753



Optical indices	Formulation	Functions
mNDVI (1)	$\frac{R_{565} - R_{520}}{R_{565} + R_{520}}$	Relative proportion among pigments and pigment content
mNDVI (2)	$\frac{R_{565} - R_{619}}{R_{565} + R_{619}}$	Relative proportion among pigments and pigment content
mNDVI (3)	$\frac{R_{750} - R_{710}}{R_{750} + R_{710}}$	Chlorophyll content
λ_0	Inverted Gaussian	Chlorophyll content

Fig. 5 Locations of the optical indices used (in the figure) and their formulation and functions (in the table). λ_0 was calculated using the inverted-Gaussian model in [18].

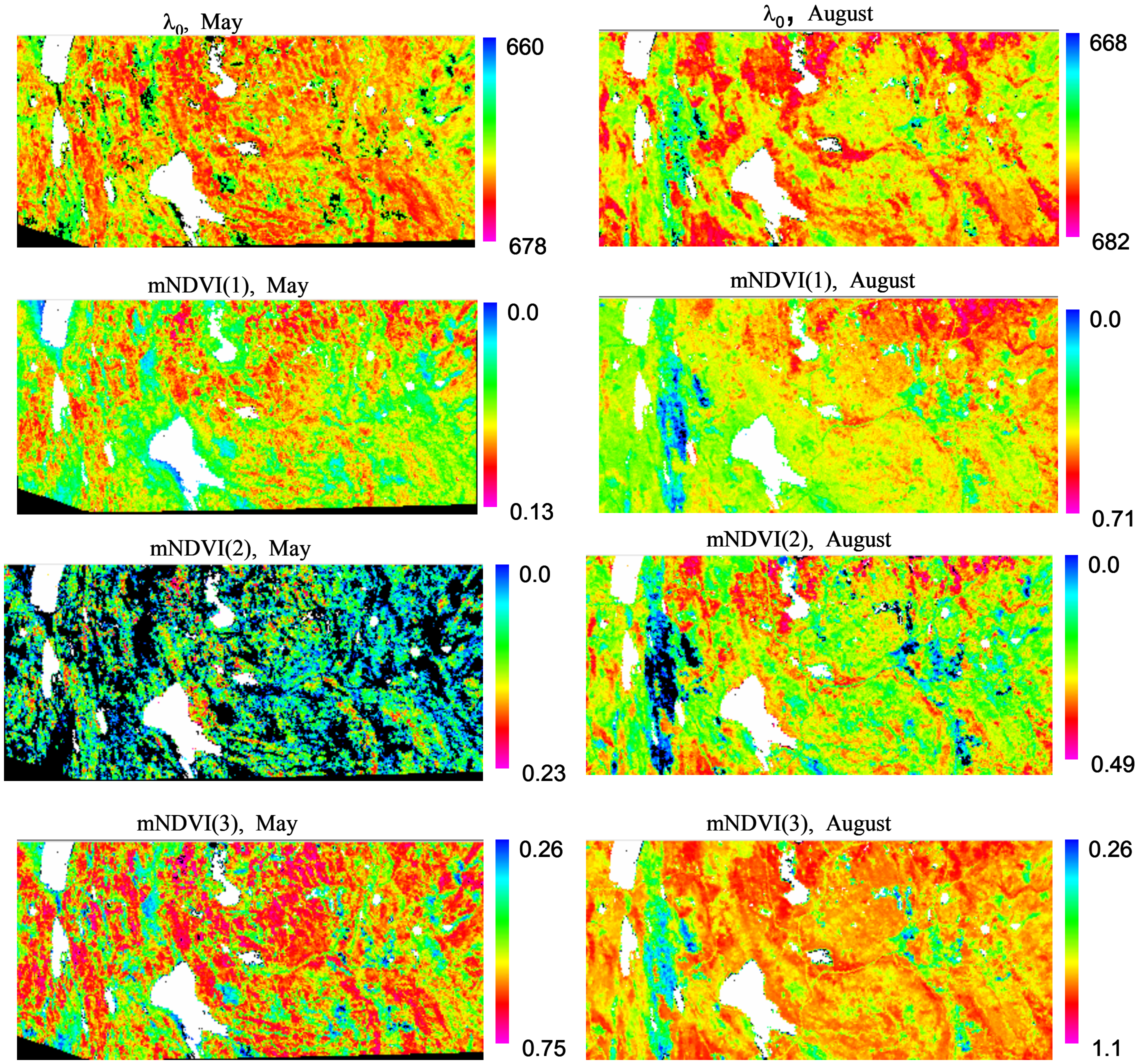


Fig. 6 The images of optical indices calculated from MERIS reflectance data in May and August, where the white areas are water bodies. Please note that the scale is varied.

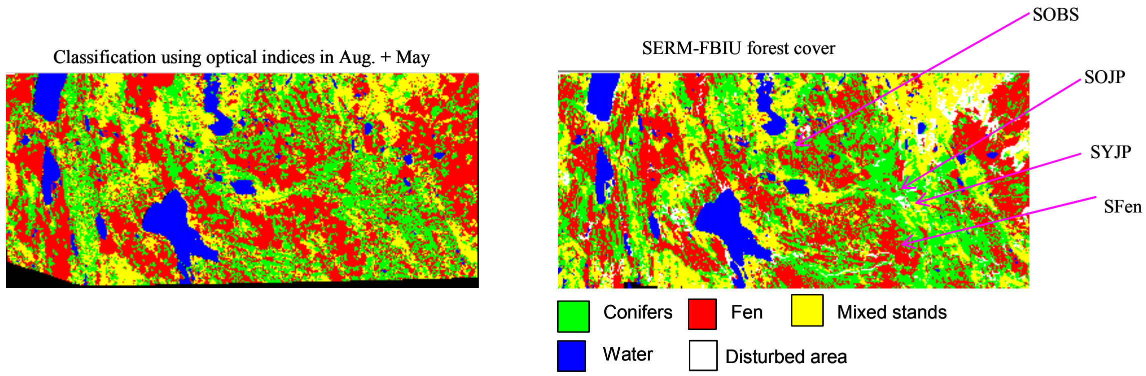
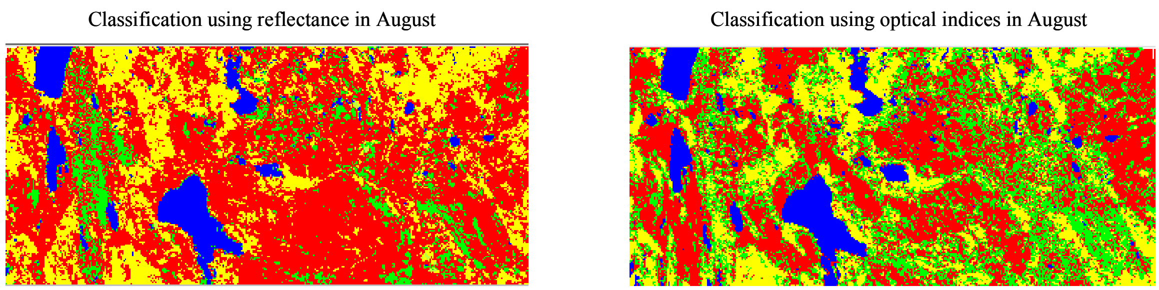


Fig.7. The classification image using the optical indices derived from MERIS data in May and August.



Conifers: 30; Mixed: 74; Fen: 80; overall: 68

Conifers: 45; Mixed: 69; Fen: 82; overall: 70

Fig.8 The classification images using the reflectance (left) and optical indices (right) derived from MERIS data in August.

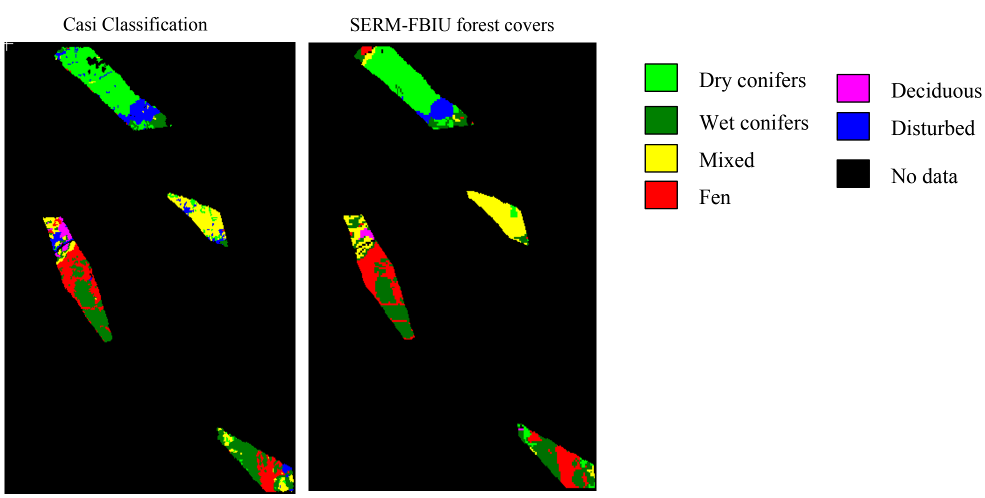


Fig. 9.The classification result using the optical indices derived from CASI reflectance data in May and in July. The overall accuracy is 84%.

DISCUSSION AND CONCLUSIONS

In this study, we exploited the use of parameters sensitive to the diagnostic absorption of forest cover types in forest cover classification. Four optical indices sensitive to relative proportions among plant pigments and pigment content derived from the MERIS images in May and in August were used to capture the seasonality of plant pigments, both overstory and understory depending on the cover type. The classification results demonstrate that the classification approaches using parameters sensitive to the absorption of plant pigments are better than those using reflectance itself. They also demonstrate that seasonal information about the parameters sensitive to plant pigments does improve forest cover classification. These conclusions are consistent with those achieved by using two-date CASI imagery in Fig.2 [10], even though the classification accuracy is much higher with the two-date CASI imagery than with the two-date MERIS imagery. For comparison, the classification image obtained by using the seasonal optical indices derived from the CASI imagery is shown in Fig. 9. The overall classification accuracy is 84%. The high classification accuracy using the CASI imagery may due to the following two facts: (1) the spatial resolution of the CASI images are 30 m by 30m (after re-sampling from 2 x 2 m), as a result, the pixels are more likely less mixed than the MERIS pixels. (2) The CASI images mainly cover relatively homogeneous flux tower areas. The differences in the signal-to-noise characteristics of the instruments may be another reason. The evident difference in the classification accuracies between using MERIS data and using CASI data indicates the effects of MERIS spatial resolution on the data product classification accuracy. In future study, we will exploit the fuzzy logic classification and spectral unmixing approaches to deal with the highly mixed MERIS pixels.

Right now, with both CASI and MERIS data, we simply used the optical indices in spring and in summer to do the classification. Although the classification result is very promising, the classification accuracy can be further improved if we use more detailed information about the seasonal changes of plant pigments. Further studies are also needed to develop parameters accurately describing the absorption features of plant pigments, water content, and foliar chemistry and to select an optimal set of optical indices for forest cover classification.

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