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Map comparison using spatial autocorrelation: an example using AVHRR derived land cover of Canada

Michael A. Wulder, Barry Boots, David Seemann, and Joanne C. White

Abstract. Any given geographic area is often subjected to numerous mapping efforts over the course of time. Similar end products may be generated from the same data source with similar target attributes. For instance, two maps representing the land cover of Canada were produced in 1995 and 1997 with data from the advanced very high resolution radiometer (AVHRR) satellite: the Northern Biosphere Observation and Modeling Experiment (NBIOME) product produced by Natural Resources Canada, and the International Geosphere–Biosphere Programme Data and Information System (IGBP DISCover) product. The thematic and spatial agreement of the forested classes of the map area representing Canada are considered in this study. A difference image was generated for each of two scenarios, where one product identified forest and the other identified non-forest and vice versa. Standard area summaries and per-pixel analyses were used to initially identify and quantify the differences between the two map products. To enable a more comprehensive comparison of the two map products, a 50 km × 50 km grid extending over the entire area of Canada was used as a framework for analyzing the spatial autocorrelation in the difference images. Differences that are not spatially autocorrelated are considered random; conversely, differences that are spatially autocorrelated may be systematic and reflect differences in classification legends and methodologies, and in image-processing methods. The total estimates of forest area from both maps are similar, varying by 6%, yet the area of agreement between the two maps (i.e., where both mapping processes have the same result in the same location) represents 62% of the total area classified as forest in both maps, or 35% of Canada. The spatial distribution of these classification differences is captured through the introduction of ancillary data (ecozones) and the consideration of spatial autocorrelation. Predominantly, spatially autocorrelated differences are found to occur within ecozones that are transition areas between forest and non-forest and at ecozonal interfaces. These differences appear related to the heterogeneous nature of the land cover and the small size of contiguous forest stands. In this research we demonstrate a range of approaches to map comparison. These approaches enable end users of map products to make informed decisions regarding various large area land cover products and to understand the implications of using these different products as inputs for subsequent applications or models.

Résumé. Toute zone géographique donnée est souvent soumise à des efforts de cartographie multiples à travers le temps. Des produits finaux similaires peuvent être générés à partir de la même source de données avec des attributs semblables au niveau de la cible. Par exemple, deux cartes représentant le couvert du Canada ont été produites en 1995 et 1997 à l'aide des données du capteur AVHRR (« advanced very high resolution radiometer ») : le produit NBIOME (« Northern Biosphere Observation and Modeling Experiment ») généré par Ressources Naturelles Canada et le produit IGBP DISCover (« International Geosphere–Biosphere Programme Data and Information System »). Dans cette étude, on fait référence à la concordance thématique et spatiale entre les classes forestières de la zone de la carte représentant le Canada. Une image des différences a été générée pour chacun des deux scénarios où un produit a identifié la forêt et l'autre a identifié des zones non-forestières et vice versa. Des sommaires standards de la zone et des analyses par pixel ont été utilisés pour identifier et quantifier initialement les différences entre les deux produits cartographiques. Pour permettre une comparaison plus complète des deux produits cartographiques, on a utilisé une grille de 50 km × 50 km couvrant tout le territoire du Canada comme cadre pour analyser l'autocorrélation spatiale dans les images des différences. Les différences qui ne sont pas spatialement autocorrélées sont considérées comme aléatoires; inversement, les différences qui sont spatialement autocorrélées peuvent être systématiques et reflètent des différences dans les légendes et les méthodologies de classification et dans les méthodes de traitement d'images. Les estimations de surface forestière totale à partir des deux cartes sont semblables, variant de 6 %. Toutefois, la zone de concordance entre les deux cartes (i.e., où les deux procédures de cartographie donnent le même résultat dans la même zone) représente 62 % de l'ensemble de la zone classifiée comme forêt sur les deux cartes, ou 35 % du Canada. La distribution spatiale de ces différences de classification est capturée par le biais de l'introduction de données auxiliaires (écozones) et de la considération de l'autocorrélation spatiale. De façon prédominante, les différences

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M.A. Wulder,[1] D. Seemann, and J.C. White. Pacific Forestry Centre, Canadian Forest Service, Natural Resources Canada, 506 West Burnside Road, Victoria, BC V8Z 1M5, Canada.

B. Boots. Department of Geography and Environmental Studies, Wilfrid Laurier University, Waterloo, ON N2L 3C5, Canada.

[1]Corresponding author (e-mail: mwulder@nrcan.gc.ca).

spatialement autocorrélées se manifestent à l'intérieur des écozones qui sont des zones de transition entre la forêt et les zones non-forestières et à l'interface des écozones. Ces différences semblent reliées à la nature hétérogène du couvert et à la petite dimension des peuplements forestiers contigus. Dans cette recherche, nous montrons une gamme d'approches pour la comparaison cartographique. Ces approches permettent aux utilisateurs de produits cartographiques d'arriver à des décisions informées concernant divers produits du couvert à grande échelle et de comprendre les implications de l'utilisation de ces différents produits en tant que données d'entrée dans les applications ultérieures ou aux modèles.
[Traduit par la Rédaction]

Introduction

The classification of land cover over large geographic areas with remotely sensed data is increasingly common. An overview of the status and research priorities for large area mapping with satellites is found in Cihlar (2000). Regions (Homer et al., 1997), nations (Cihlar and Beaubien, 1998; Loveland et al., 1991; Fuller et al., 1994), continents (Stone et al., 1994), and the globe (Loveland and Belward, 1997; Loveland et al., 2000; Hansen et al., 2000) have been mapped with a range of satellite data inputs and spatial resolutions. Unsupervised classification approaches are the most common for large area land cover projects (Franklin and Wulder, 2002).

The characterization of the land cover of large areas presents many unique challenges for the validation and comparison of map products. Inconsistency in derived map products is expected when the various components of map production are considered: data inputs, preprocessing techniques (compositing, geometric, radiometric), classification methods, ancillary data, and thematic legends. Disparity among these components will ultimately lead to differences in the final thematic map. In addition, statistically rigorous accuracy assessment for large area land cover classification is constrained by the lack of suitable ground data, logistical realities, and high monetary costs (Merchant et al., 1994; Muchoney et al., 1999). Furthermore, with coarse-resolution remote sensing data such as those obtained from the advanced very high resolution radiometer (AVHRR) satellite, the cross-referencing of a single validation ground point to the contents of a single pixel (nominally 1 km × 1 km spatial resolution) is challenging (Scepan, 1999).

When comparing two maps, the overall and individual class accuracies may be similar (when compared with the project-specific ground validation data), and the total amount of area represented by each class may also be similar, but the spatial distribution of the classes may differ (based on a per-pixel analysis). The impacts of these differences are most significant when considered in the context of the applications within which the land cover data are utilized (DeFries and Los, 1999; Xiao et al., 2003). Large area land cover maps are often developed with the goal of providing an input information source to complex models of earth systems. The modeled outcomes will differ based on the land cover inputs to the model. For instance, consider land cover input to a carbon budget or productivity model; differing land cover classes will invoke differing outcomes from the model.

In 1995, two land cover maps encompassing the terrestrial extent of Canada were produced with data from the AVHRR. One was produced under the auspices of the Northern Biosphere Observation and Mapping Experiment (NBIOME) project by Natural Resources Canada (Cihlar and Beaubien, 1998). Another was produced as part of the National Aeronautics and Space Administration (NASA) Earth Observing System Pathfinder Program and the International Geosphere–Biosphere Programme Data and Information System (IGBP DIS) through the collaboration of the US Geological Survey, the University of Nebraska-Lincoln, and the European Commission's Joint Research Centre (Loveland et al., 2000; Belward et al., 1999). The purpose of this paper is to compare the thematic and spatial agreement of the forest and non-forest components of these two classifications.

The nature of map comparison

In the comparison of two different maps created to represent the same feature (land cover) over the same geographic area (Canada), it is important to note that both maps may be considered as correct and accurate by objective measurements. Identifying which map is the most accurate is often not possible because the quality and accuracy of a given map must be considered in relation to its intended use. Regardless, differences between maps will inevitably result from the aforementioned factors associated with map production. As differing maps may be used in further analysis such as modeling, the nature of the differences that are occurring, as well as the location of these differences, are important issues for the end users of these products. Therefore, an approach is required for addressing and quantifying the locations and magnitude of these differences. Because of the inherent ambiguity associated with map comparison, it is important for end users to fully understand the differences between map products to make informed decisions on how to use the maps appropriately (Loveland and Brown, 1999).

Differences in classification legends inevitably result in coarse differences between maps (Hansen and Reed, 2000) and represent the greatest challenge to meaningful map comparison. Often designed for specific purposes, the usefulness of thematic legends is limited when considered outside their intended context. In addition, class definitions can vary from map to map, as may the method or criteria used to assign spectral clusters to land cover classes (Loveland and Brown, 1999). Beyond these fundamental differences between thematic legends, the spatial distribution of the differences between maps is also important; broad regional differences or areas where class labeling is problematic may be indicated by the comparison. At a finer level, the internal nature of the map differences may be addressed. For instance, the differences may be random (processing, mapping algorithm) or systematic (input imagery, clouds, burns, manual labeling choices).

The use of absolute measures of overall accuracy as a basis for map comparison is not recommended. Foody (2002) reports several issues specific to the accuracy assessment of large area mapping from coarse-resolution remotely sensed data. The primary issue is the reporting of invalid accuracy statements derived from standard error matrix analysis, notwithstanding many of the assumptions associated with this type of analysis being violated. There is growing acceptance that traditional means of validating classifications generated from remotely sensed data are not automatically transferable to coarser scales (Merchant et al., 1994; Foody, 2002). Moreover, there exist no standards, nor even any consensus within the remote sensing community, regarding appropriate accuracy assessment methods for large area land cover mapping (Loveland et al., 1999). In this context, the use of absolute measures of accuracy to characterize the differences between maps of large area land cover is futile. The accuracy assessments of the NBIOME and IGBP datasets were produced using different approaches, and the comparison of these measures of accuracy fails to provide a complete story regarding the nature of the differences between these two maps.

Comprehensive map comparisons of large area land cover products are rare in the literature. Hansen and Reed (2000) undertook a comparison between the IGBP DISCover product and the University of Maryland global land cover product. Their comparison provides a description of the methodologies associated with the production of each classification as well as area and per-pixel measures of correspondence. The two classification legends were assimilated into seven common land cover classes, and area summaries were generated that indicated general agreement between the two products, with the exception of the grass–shrub class. However, a per-pixel comparison between the two products signified that the level of agreement between the two products was not as great as the area summary alone would suggest. The internal arrangement of the classes, as represented in a per-pixel comparison, indicated that 74% of pixels corresponded between the two products. The seven generalized classes were further simplified into tall (forest and woody savanna – woodlands) and short–no (all other classes) vegetation and overlaid to create a difference map. The total global area of tall vegetation reported by each product differs by less than 4%; however, the per-pixel agreement for this generalized class is only 84%. The per-pixel agreement for the nongeneralized classes is 48%, pointing to substantial differences in the classification legends. Hansen and Reed conclude that, although there is overall agreement for the core areas of broad vegetation types, individual classes have low per-pixel agreement (particularly in the noncore transition areas), and there is significant regional variability. Differences between the maps were attributed to the use of dissimilar ancillary data sources and artifacts associated with the preprocessing of the input imagery (presence of clouds, data gaps, misregistrations, noisy data, and other anomalies).

Loveland and Brown (1999) compared the six global land cover products generated from the NASA Pathfinder and IGBP programs (of which DISCover is one of the products) in an effort to identify the impact of different thematic legends on product output. In this comparison, the various classes of the six legends were collapsed into 13 common land cover classes, and area summaries were generated for each of the maps. Estimates of area for forest cover were the most consistent between all of the maps (varying by only 5.1 million square kilometres), and urban, tundra, and wetlands differed the most. Loveland and Brown then proceeded to conduct a spatial comparison by simplifying the maps into four general vegetated landscapes (agriculture, tree-covered, shrub-covered, and grass-covered) and overlaying them to create difference maps for each of the four generalized vegetated landscapes. Tree-covered lands included both forest and woodland classes, and the authors noted significant differences in the definition of the woodland class among the six products. The difference map indicated that there was more variability in the classification of tree-covered lands than the area summaries alone would suggest. Similar to the findings of Hansen and Reed (2000), the core forest lands were in agreement among all the products, with the major discrepancies found on the margins of these core areas. Disagreements in these marginal areas were attributed to variability in the treatment of forest density among the six thematic legends. In their conclusions, Loveland and Brown cite the variability in land cover patterns, as depicted through different land cover legends, as a significant issue and suggested that the selection of which land cover dataset to use must be rooted in a strong understanding of the application.

Fuller et al. (2003) provide another view of map comparison, specifically designed for the purpose of identifying change over time. In their example they compare the 1990 Land Cover Map of Great Britain with the 2000 UK Land Cover Map. Their comparison assumes that the errors in each of the maps are distributed randomly and independently. As per the findings of the other studies reviewed in this paper, however, they note that many of the differences between the two maps are not random but rather are found on the margins of land cover zones, where misclassification is common. In addition, they report that other systematic differences (manifesting as change) occur when errors coincide spatially but not thematically (representing changes that are spurious in location and type), and when errors coincide spatially and thematically (spurious patterns of change may be more limited, but characteristics of static areas are confused). In their conclusion, Fuller et al. recommend that end users of map products need to draw upon information regarding the directions, patterns, and scale of change to identify change correctly. The methods of describing map differences presented in this paper represent one approach for characterizing the spatial relationships of differences between map products, whether they are generated by different methods or at different points in time.

In this paper we present an approach for addressing accuracy in a relative, rather than absolute manner. The result of this method is that agreement between the maps can act as confirmation or refutation of expectation. Areas of disagreement between the maps may be looked upon as requiring additional information or may be treated with less confidence. Similar to the comparisons of Hansen and Reed (2000) and Loveland and Brown (1999), we compare the NBIOME and IGBP DISCover products by aggregating the two products into areas of forest and non-forest and subsequently examine them on both an area and per-pixel basis to discern the nature and magnitude of the discrepancies between the products in representing the forested area of Canada. In an effort to go beyond describing the differences between the two products, however, we present methods for identifying and characterizing nonrandom differences. Nonrandom differences are indicated through a grid-based assessment of spatial autocorrelation using join-count statistics and their associated *Z* scores. Although area and per-pixel summaries provide a broad account of the differences between the two products, more subtle differences appear when the association of the pixels is observed.

Data and methods

Advanced very high resolution radiometer (AVHRR)

The National Oceanic and Atmospheric Administration (NOAA) series of polar-orbiting satellites carry the AVHRR, a broadband scanning radiometer capable of providing complete global coverage twice per day. The AVHRR instrument has been deployed on 10 different NOAA satellites since June 1979 and provides four to six bands of multispectral data in the visible, middle infrared, and thermal portions of the electromagnetic spectrum. The spatial resolution of the sensor at nadir is 1.1 km; at the extremes of the swath, however, the instantaneous field of view is an ellipse with dimensions 2.5 km × 6.8 km. AVHRR data with a reduced resolution of 4.4 km are also available (global area coverage).

The AVHRR sensor “has unique characteristics of spectral response, image geometry, frequency of coverage, and accessibility that make it useful for applications in oceanography, terrestrial sciences, and meteorology” (Hastings and Emery, 1992). Although designed primarily to provide data for meteorological monitoring and forecasting, the utility of the AVHRR data has extended far beyond this initial application (Cracknell, 2001). In recent years, the capability of using AVHRR data to monitor vegetation dynamics has been demonstrated (Lu et al., 2003; Kogan and Wei, 2000; Senay and Elliott, 2000). The application of AVHRR data for large area land cover characterization has been the subject of extensive investigation for approaching 20 years (McGinnis and Tarpley, 1985; Loveland et al., 1991; 2000; Hirosawa et al., 1996; Raptis et al., 2003).

Canadian terrestrial ecozones

An ecozone is defined as an area where organisms and their physical environment endure as an ecosystem (Wiken, 1986). The Canadian terrestrial ecozones (Environment Canada, 1996) were designed to serve as a “national ecological framework to provide a consistent, national spatial context within which ecosystems at various levels of generalization can be described, monitored, and reported on” (Marshall et al., 1996). For the purposes of this study, the Canadian terrestrial ecozones provide a useful framework for reporting and analyzing the differences between the NBIOME and IGBP map products. A priori knowledge of the ecological characteristics within these zones facilitates inference regarding the possible causes of the differences between the maps.

NBIOME land cover classification data

Through collaboration between the Canadian Forest Service and the Canada Centre for Remote Sensing, a national land cover map was produced from AVHRR data (Cihlar and Beaubien, 1998). The land cover map, a component of the NBIOME project, is derived from AVHRR data collected from instruments on NOAA-14 between April and October 1995. The radiometer measures emitted and reflected radiation in two visible, one middle infrared, and two thermal channels. The NBIOME map is composed of 1 km^2 pixels. The land cover of Canada is placed into 31 land cover classes as outlined in **Table 1**.

The goal of the NBIOME program is to “improve the understanding of the relationship between climate and northern ecosystems, including their seasonal interannual dynamics and their role in the global carbon cycle” (Cihlar and Beaubien, 1998). The objective behind production of the land cover product was to generate an up-to-date and consistent (spatially and temporally) land cover map of Canada for subsequent use by NBIOME scientists and other users interested in land cover at a national scale (Cihlar and Beaubien, 1998).

Image processing was completed in three phases: conversion of raw AVHRR data into a 10-day composite product, transformation of the 10-day composite into a refined product, and extraction of land cover information from the refined product. The first phase was completed using the NOAA AVHRR Geocoding and Compositing System (GEOCOMP) (Cihlar et al., 1997). This system supports the full radiometric resolution of the sensor (10 bit). The compositing algorithm replaces each cloudy pixel in an image with a cloud-free pixel that covers the same ground area but is taken from a slightly later or earlier image. This process is combined with a mosaicking process. Twenty composite products (level 2) were generated and subsequently preprocessed according to the steps outlined in **Table 2**. The third phase involved classification and postprocessing, which are also outlined in **Table 2**. It should be noted that AVHRR channels 1 and 2 were used (and not the normalized difference vegetation index (NDVI)), as previous work had shown that these two channels contain useful

Table 1. NBIOME land cover legend.

Value	Class description
Forest	
1	Evergreen needleleaf forest – high density
2	Evergreen needleleaf forest – medium density (southern forest)
3	Evergreen needleleaf forest – medium density (northern forest)
4	Evergreen needleleaf forest – low density (southern forest)
5	Evergreen needleleaf forest – low density (northern forest)
6	Deciduous broadleaf forest
7	Mixed needleleaf forest
8	Mixed intermediate uniform forest
9	Mixed intermediate heterogeneous forest
10	Mixed broadleaf forest
Non-forest	
11	Burns – low green vegetation cover
12	Burns – green vegetation cover
13	Open land – transition treed shrub land
14	Wetland/shrub land – high density
15	Wetland/shrub land – medium density
16	Grassland
17	Barren land – lichen and others
18	Barren land – shrub/lichen dominated
19	Treeless – heather and herbs
20	Treeless – low vegetation cover
21	Treeless – very low vegetation cover
22	Treeless – bare soil and rock
23	Cropland – high biomass
24	Cropland – medium biomass
25	Cropland – low biomass
26	Mosaic land – cropland–woodland
27	Mosaic land – woodland–cropland
28	Mosaic land – cropland–other
29	Urban and built up
30	Water
31	Snow/ice

information on northern land cover types (Beaubien and Simard, 1993; Cihlar et al., 1996).

Three sources of error were identified: imperfect corrections of the AVHRR data, pixel mixing caused by the large pixel size (increasing at off nadir angles), and confusion among various cover types caused by a lack of spectral separability. The quality assessment of the land cover product included both qualitative and quantitative methods as outlined in **Table 3**. The evaluations lead to the conclusion that the NBIOME map was relatively accurate at representing the overall distribution of land cover types. However, the map was not considered accurate or reliable at assigning individual pixels to the correct class. The latter was attributed to the large number of land cover classes, the heterogeneous distribution of the cover classes relative to the spatial resolution of the satellite data, the spectral variability of cover types and satellite data over an area as large as Canada, and errors in the Landsat thematic mapper (TM) data used as reference data (Cihlar and Beaubien, 1998).

Table 2. NBIOME land cover product methodological summary.

Step	Description
Preprocessing (input level 2 products)	
1	Top-of-the-atmosphere reflectance
2	Atmospheric correction of AVHRR channels 1 and 2
3	Identification of contaminated pixels
4	Corrections for bidirectional reflectance effects in channels 1 and 2
5	Replacement of contaminated pixels for AVHRR channels 1 and 2
6	Computation of surface temperature
7	Identification of the growing season
8	Derivation of mean seasonal values
Classification (input level 2B products)	
1	Contrast enhancement
2	Image quantization
3	Image filtering
4	Selection of spectral clusters
5	Clustering
6	Cluster agglomeration and labeling
Postprocessing	
1	Incorporation of built-up areas from the Atlas of Canada
2	Reassigning classes where confusion existed between cropland and natural vegetation by isolating cropland
3	Reassignment of needleleaf forest areas in eastern Quebec, New Brunswick, and Nova Scotia using Landsat TM data
4	Reassigned isolated forest burn pixels to water class
5	Identification of snow and ice class by identifying all land pixels that did not belong to any other class
6	Identification of water class using water mask from World Data Bank database

IGBP DIScover land cover classification data

The US Geological Survey, the University of Nebraska-Lincoln, and the European Commission Joint Research Centre collaborated to produce a 1-km global land cover characteristics database, by continent, based on AVHRR data collected from instruments on NOAA-11 between April 1992 and March 1993 (Loveland et al., 2000). The radiometer measures emitted and reflected radiation in two visible, one middle infrared, and two thermal channels (identical to the instrument on NOAA-14). The continental databases were combined to produce seven different global datasets (based on seven classification schemes). The dataset examined in this study is based on the initial version (version 1.2) of the International Geosphere–Biosphere Programme Data and Information System (IGBP DIS) global 1-km land cover dataset (DISCover), which has 17 land cover classes as outlined in **Table 4**. This version has been subjected to a formal accuracy assessment (Scepan, 1999; Scepan et al., 1999).

The IGBP is a research program built around the study of global biogeochemistry. The objective of the IGBP program is

Table 3. NBIOME land cover product quality assessment methods.

Method

- Comparison to enhanced Landsat TM images (105 images) in which cover types can be visually distinguished
- Review by scientists familiar with land cover characteristics in various parts of Canada using existing forest inventory data
- Quantitative accuracy assessment compared the NBIOME product to a Landsat TM derived classification of a 14 000 km^2 area in Alberta; accuracy varied from 1.3% to 66.7% and was complicated by the heterogeneous nature of the land cover
- Quantitative accuracy assessment was conducted using a mosaic of Landsat TM scenes covering an area of 136 432 km^2 in Saskatchewan and Manitoba (Beaubien et al., 1999) that was coregistered to the AVHRR, and the following comparisons were carried out:

(1) Pixel-by-pixel accuracy — overall accuracy of 29.7%, with a range of 17.1%–76.6%

(2) Accuracy as a function of pixel purity — results from (1) were reexamined to account for the heterogeneity of land cover in the area; pixels were reassigned according to their dominant cover type using two purity thresholds of 50% and 75%; the revised overall accuracy assessment for the 50% threshold was 37.8% (ranging from 24.4% to 78.9%) and for the 75% threshold was 43.9% (ranging from 37.7% to 83.5%)

(3) Accuracy in relation to class limits — results from (1) were reexamined to account for subtle differences between particular classes (i.e., high-density coniferous versus medium-density coniferous); when combined with the purity thresholds outlined in (2), the overall accuracy was reported as 56.4% (without pixel purity included), 68.4% at a 50% purity threshold, and 70.7% at a 75% purity threshold

(4) Weighted overall accuracy — results for (3) were weighted by class size and the resulting overall accuracy was 61.9% (without pixel purity included), 72.5% at a 50% purity threshold, and 78.3% at a 75% purity threshold

Conclusion

- The NBIOME map portrays the distribution of land cover types quite accurately (in terms of overall distribution); the map is not consistently accurate or reliable at assigning an individual pixel to the correct class

Table 4. DISCover land cover legend.

Value	Class description
Forest	
1	Evergreen needleleaf forest
2	Evergreen broadleaf forest
3	Deciduous needleleaf forest
4	Deciduous broadleaf forest
5	Mixed forest
Non-forest	
6	Closed shrub lands
7	Open shrub lands
8	Woody savannas
9	Savannas
10	Grasslands
11	Permanent wetlands
12	Croplands
13	Urban and built up
14	Cropland/natural vegetation mosaic
15	Snow and ice
16	Barren or sparsely vegetated
17	Water bodies

"to describe and understand the interactive physical, chemical and biological processes that regulate the total Earth System, the unique environment that it provides for life, the changes that are occurring in this system, and the manner in which they are influenced by human actions" (http://www.igbp.kva.se). The DISCover product was designed to provide an improved global land cover product to support IGBP core science projects in the areas of atmospheric chemistry, biogeochemical cycles, and land cover change.

Image processing involved the creation of AVHRR NDVI monthly composites and an unsupervised classification followed by extensive post-classification refinement using ancillary data. It is notable that Hansen and Reed (2000) cite the lack of a complete preprocessing system as one of the shortcomings in the DISCover product (in contrast to the NBIOME product, which was generated using the GEOCOMP system (Adair et al., 2002; Cihlar et al., 2002)). The classification methodology involved a sequence of steps summarized in **Table 5**. The postclassification process was critical to the creation of the final land cover products. Seasonal land cover regions were the fundamental units, characterized by homogenous land cover associations that exhibit distinctive phenology. In an intermediate processing step, these regions were first translated into Olson's global ecosystems (Olson, 1994) and then subsequently converted into seven different land cover products, based on seven different land cover

Table 5. IGBP DISCover product methodological summary.

Step	Description
Preprocessing	
1	Recompositing of 10-day composites into monthly composites using maximum value compositing
2	Quality assessment of monthly composites to identify correctable deficiencies: (*i*) gross image misregistration, (*ii*) gross radiometric anomalies, (*iii*) gaps from missing data, (*iv*) presence of mosaic or composite lines, (*v*) problems associated with the inclusion of images outside of the composite period, and (*vi*) excessive cloud contamination
3	Mask preparation to exclude NDVI of nonvegetated areas prior to classification
Classification	
1	Clustering
2	Generation of cluster attributes
3	Preliminary “greenness” class interpretations developed (corresponding to homogenous patterns of seasonality and related to relative patterns of productivity)
Postprocessing	
1	Stratify preliminary “greenness” classes into seasonal land cover regions using one of four possible methods: (*i*) selected ancillary data (elevation, ecoregions) used to split heterogeneous greenness classes into smaller homogenous seasonal land cover regions, (*ii*) user-defined polygons were used where ancillary data were not helpful in splitting the heterogeneous classes, (*iii*) ancillary data were combined with user-defined polygons, and (*iv*) spectral reclustering using different clustering parameters or a smaller set of NDVI composites to partition heterogeneous greenness classes
2	Formulate final land cover attributes for final (961) seasonal land cover regions
3	Relate seasonal land cover regions to the global ecosystems of Olson (1994) and then cross-walk into the other seven land cover legends
4	Replace urban land cover with data from the populated places’ data layer in the defense mapping agency’s digital chart of the world
5	Consolidation of the continental datasets generated from the aforementioned processing steps into a database with seven global land cover characteristics

classification legends. The DISCover product was one of the seven outputs generated.

Several factors were identified as impacting upon the accuracy of the final DISCover product. These include atmospheric contamination of the NDVI composites, temporal–spectral relationship between natural or seminatural vegetation and agriculture, and agricultural complexity and seasonal land cover regions. Of particular relevance to this study, the forest classes had the highest percentage of land area contaminated by atmospheric effects (Loveland et al., 2000). The DISCover product was the only product out of the seven that has been subjected to a formal accuracy assessment (**Table 6**) (Scepan, 1999; Scepan et al., 1999). Interpreters examined subscenes from 379 Landsat TM and SPOT images in 15 of the 17 DISCover land cover classes. The globe was divided into 13 separate validation regions, with three interpreters per region validating the complete set of regional samples. Confidence in interpretations for North America – Canada were lower than average, with only 29.3% of the samples in this area being correctly classified compared with the global average of 54.5%. On a land cover class basis, the average class accuracy for the DISCover product was 59.4%, and the area weighted accuracy was determined to be 66.9%.

Data processing

To enable the map comparison at a common level of information, both of the image classifications were aggregated to binary forest–non-forest maps. As noted in **Table 1**, 10 of the 31 NBIOME classes were considered as forest and the remainder as non-forest. The class listing for the IGBP DISCover dataset is presented in **Table 4**; for this product, five of the 17 classes were considered forest and the remainder as non-forest. These binary maps of forest and non-forest were subsequently compared to determine for each pixel if that location is mapped similarly or differently. Two scenarios were considered: (*i*) where NBIOME is forest and DISCover is non-forest, and (*ii*) where NBIOME is non-forest and DISCover is forest.

Area and per-pixel comparisons for both these scenarios were completed. The examination of the spatial autocorrelation associated with the two scenarios was completed in two steps. First, two difference images were generated from the comparison of the NBIOME and DISCover classifications that represented each of these scenarios. Where the scenario evaluated to true (e.g., where the NBIOME map coded forest and the DISCover map coded non-forest), the difference image was coded as “1” or “black”; conversely, where the scenario evaluated to false, the difference image was coded as “0” or “white”. Second, these codings of black and white formed the basis for the analysis of spatial autocorrelation of the differences using join-count statistics (Upton and Fingleton, 1985).

Measuring spatial autocorrelation with join counts

Spatial autocorrelation exists where there is a systematic spatial variation in values across a map (Cliff and Ord, 1981).

Table 6. IGBP DIScover product quality assessment methods.

Formal accuracy assessment using Landsat TM imagery as the validation source (Scepan, 1999; Scepan et al., 1999):

- 379 samples selected with a stratified random sampling procedure
- A minimum of 25 samples per DISCover class for 13 of the 15 classes validated
- Globe divided into 13 regions, and three "expert image interpreters" from each region validated all the samples within the region (majority decision rule was used to determine class accuracy)
- 15 of the 17 classes were validated (snow and ice and water were not validated)
- Average class accuracy was 59.4%, and overall area-weighted accuracy of the dataset was 66.9%

Accuracy assessment for Western Europe (De Wit et al., 1999):

- Cross-correlated IGBP DISCover with an aggregated and resampled version of the Coordination of Information on the Environment (CORINE) database (derived from Landsat TM, SPOT HRV-XS, and ancillary data at a scale of 1 : 100 000)
- Based on incompatibilities between the two datasets, the validation method is not considered comprehensive
- Overall accuracy can be regarded as poor, and there was very poor correspondence between DISCover and CORINE forest classes (ranging from 0% to 12%)
- Overall reliability (commission errors) can be regarded as "rather good" for many classes; user's accuracy was 59% for evergreen needleleaf forest, 87% for deciduous broadleaf forest, and 63% for mixed forest
- Overall characterized as poor accuracy and high reliability, a trend most strongly demonstrated by forest classes

The emphasis is on the patterns in the values recorded at specific locations and not on the patterns of the locations themselves (Upton and Fingleton, 1985). The mosaic of black (B) and white (W) areas for each of the scenarios is used to determine if neighbouring locations are more likely to display opposite colours or the same colours. This is accomplished by classifying the joins as BB, WW, or BW (where BB indicates a join between two black pixels or, in the context of this analysis, between two pixels classified differently by the NBIOME and DISCover maps). Although BW joins are considered to be marginally more informative (Cliff and Ord, 1981), in our analysis we are more interested in the joins between pixels representing the differences in the two scenarios of forest and non-forest as captured by two map products under consideration (i.e., the BB joins). Congalton (1998) used a similar approach to characterize errors in a classified remotely sensed image.

To facilitate the analysis of join counts for the large land area of Canada, the country was partitioned into a grid of 50 km × 50 km cells. This cell size was chosen as a reasonable tradeoff between the nominal 1 km resolution of the AVHRR and the large area to be analyzed. These 50-km^2 cells served as the analysis units (AU) within which the join-count statistics were generated. A total of 4968 AU cover the entire country. Counts for the BB joins were determined through an automated procedure in a raster-based geographical information system (GIS).

The expected number of BB joins under the hypothesis of no spatial autocorrelation is given by

$$E(\mathrm{BB}) = 2b(b-1)/c(c+1) \qquad (1)$$

where b is the black count, and c is the number of columns = 50 (for a 50 cell × 50 cell grid). Equation (2) is used to determine the variance of the BB joins:

$$\mathrm{var(BB)} = S_1T_1/2n^{(2)} + (S_2 - 2S_1)(T_2 - 2T_1)/4n^{(3)} + (S_0^2 + S_1 - S_2)(T_0^2 + T_1 - T_2)/n^{(4)} - [E(\mathrm{BB})]^2 \qquad (2)$$

where $T_0 = b(b-1)$, $T_1 = 2T_0$, $T_2 = 4b(b-1)^2$, $S_0 = 4c(c-1)$, $S_1 = 2S_0$, $S_2 = 16(4c^2 - 7c + 2)$, n is the number of grid cells = 2500 (for a 50 cell × 50 cell grid), $n^{(2)} = n(n-1)$, $n^{(3)} = n(n-1)(n-2)$, and $n^{(4)} = n(n-1)(n-2)(n-3)$. Lastly, since the join counts are asymptotically normal, a Z score can be calculated for the BB joins as follows:

$$Z = [\mathrm{BB} - E(\mathrm{BB})]/\ \mathrm{var(BB)}^{1/2} \qquad (3)$$

Results and discussion

Figure 1 illustrates the differences and similarities between the NBIOME and DISCover maps. The green area represents agreement in forest classification between the two products. The green and the red indicate the extent of the NBIOME forested area. The green and the blue combine to indicate the extent of the DISCover forested area. White areas are non-forest in both classification products. Red and blue areas represent areas of difference. The total area classified as forest in both products is the combination of red, green, and blue areas.

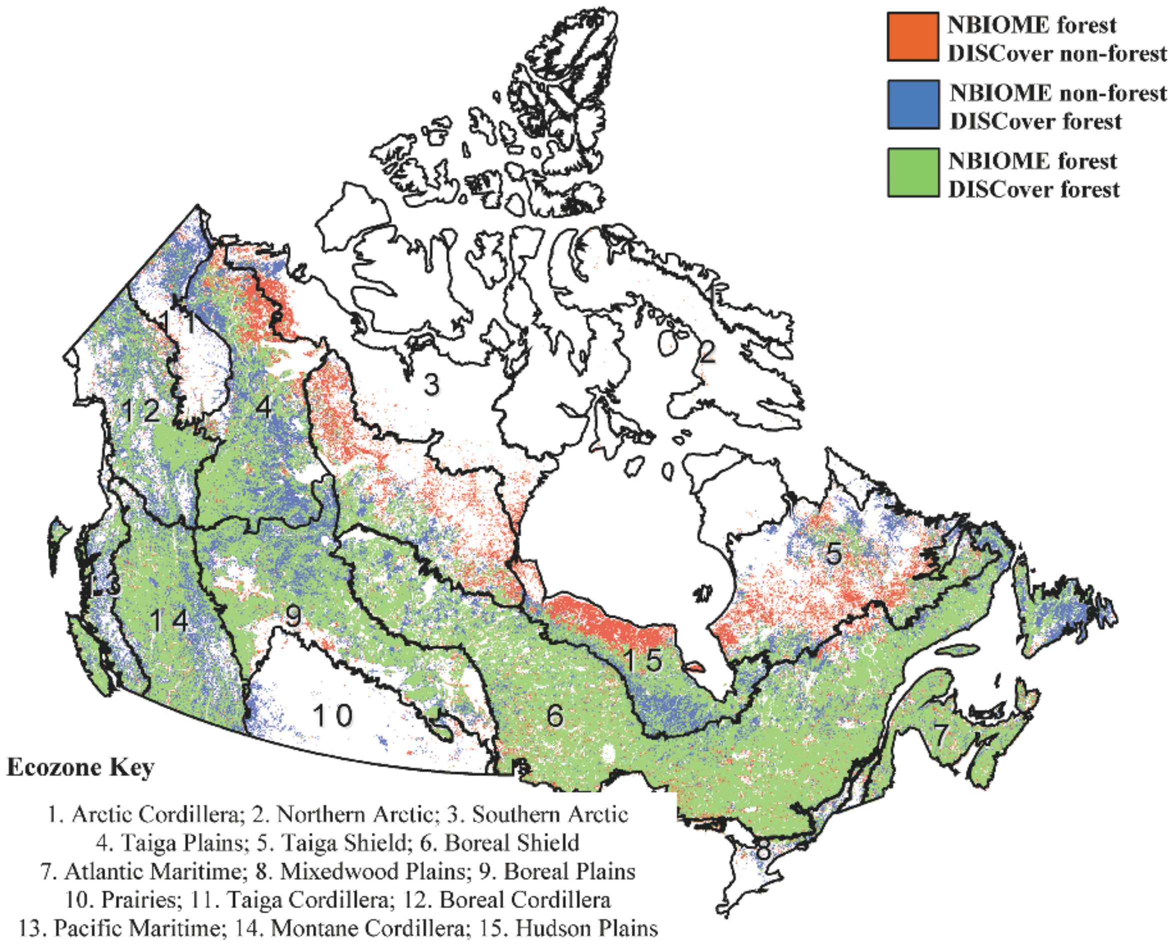

Figure 1. Difference and similarity map of forested area derived from land cover maps depicting Canada, including ecozones and provincial boundaries.

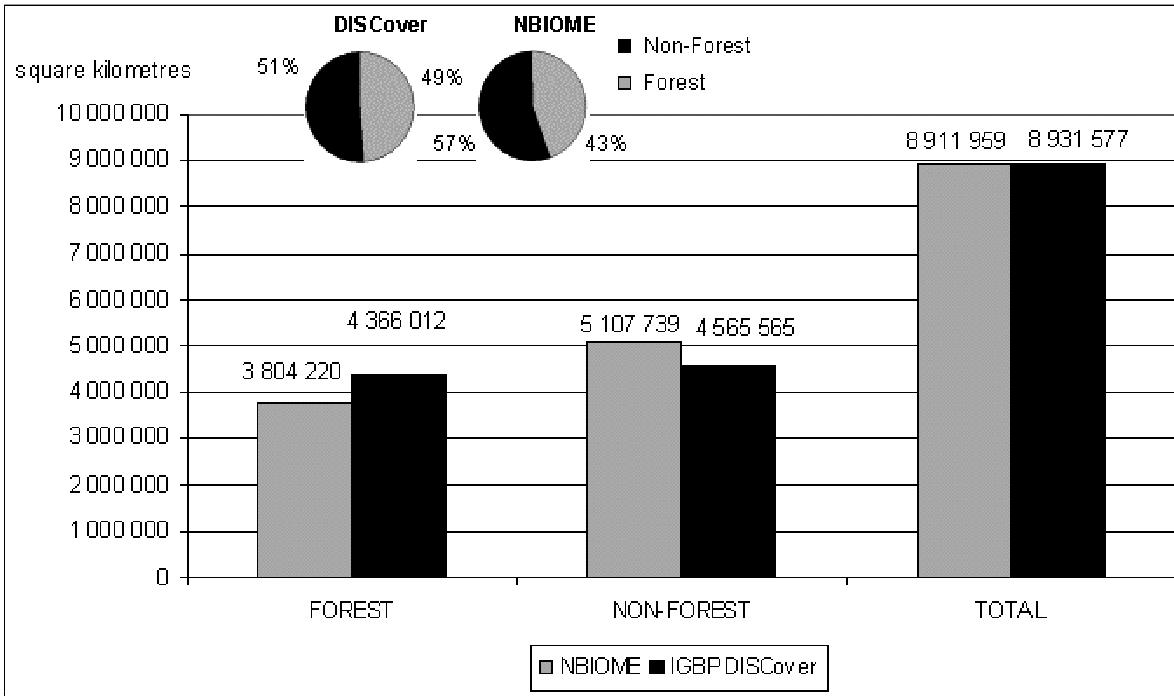

Figure 2. Comparison of estimates of area for forest and non-forest.

Area comparisons

In 1991, the total forest area of Canada was estimated to be 4 175 800 km^2 (Lowe et al., 1996). The NBIOME product estimates the total forest area at approximately 3 803 432 km^2, and the IGBP DISCover product estimates the total area of forest in Canada to be 4 244 936 km^2. Relative to the total area classified by the two products, the following summarizes the differences and similarities between them:

(*i*) There are 713 265 km^2 where NBIOME is forest and IGBP is non-forest (approximately 8% of the total classified area in both products)

(*ii*) There are 1 154 769 km^2 where NBIOME is non-forest and IGBP is forest (approximately 13% of the total classified area in both products)

(*iii*) There are 3 090 167 km^2 where NBIOME is forest and IGBP is forest (approximately 35% of the total classified area in both products, or 62% of the area classified as forest in both products)

As illustrated in **Figure 2**, the estimates of area for forest and non-forest are very similar, particularly when considered in proportion to total area (note that the two classifications differ slightly in the total area classified). The similarities in total area, however, mask the differences in the spatial distribution of these two classes across the country. To examine the spatial distribution, a per-pixel comparison was conducted.

Per-pixel comparisons

A per-pixel accounting of the differences between the two map products is provided in **Tables 7** and **8**. In **Table 7** a summary, by ecozone, is presented for the locations that the DISCover classification was labeled forest and the NBIOME was labeled non-forest (represented as blue in **Figure 1**). For each ecozone, the proportion of pixels assigned to a class is reported relative to the total number of pixels within that ecozone. For example, 73.4% of the pixels within the Taiga Shield ecozone were classed as mixed forest in the DISCover product. In the NBIOME classification, 34.92% of these same pixels were classed as shrub and lichen, 17.13% were classed as open land, 15.97% were classed as low-vegetation burns, 13.4% were classed as burns, 8.84% were classed as lichen and others, and the remaining 9.74% of pixels are distributed among other non-forest classes. The row and column counts (*N*) allow for determination of the actual land area mapped differently by classification map, by category, and by ecozone (as each pixel represents 1 km^2). In **Table 8**, a summary by ecozone is presented for the locations that the DISCover classification was labeled non-forest and the NBIOME was labeled forest (represented as red in **Figure 1**). In the Taiga Shield ecozone, 49.6% of the pixels were classified as low-density (southern forest) evergreen needleleaf forest and 38.45% as medium-density (southern forest) evergreen needleleaf forest in the NBIOME map, whereas 39.06% of the pixels in this ecozone were classified as closed shrub land and 33% as woody savannas in the DISCover map.

For the scenario where NBIOME is forest and DISCover is non-forest (red in **Figure 1**, see also **Table 8**), the ecozone

Table 7. Summary of class membership for the DISCover and NBIOME classification by ecozone, where NBIOME is non-forest and DISCover is forest.

	Arctic Cordillera	Northern Arctic	Southern Arctic	Taiga Plains	Taiga Shield	Boreal Shield	Atlantic Maritimes
DISCover classification							
Evergreen needleleaf forest	100.00	100.00	0.09	22.11	23.92	68.05	27.91
Deciduous broadleaf forest	0.00	0.00	90.44	23.96	2.61	0.77	16.88
Mixed forest	0.00	0.00	9.47	53.93	73.47	31.18	55.21
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	947	9	14 852	158 071	152 166	230 792	16 855
NBIOME classification							
Burns	0.42	0.00	0.01	10.91	13.40	7.78	0.20
Low vegetation burns	0.00	0.00	0.16	5.43	15.97	9.08	0.53
Green vegetation cover open land	0.52	0.00	20.89	41.19	17.13	38.90	5.51
Wetland/shrubland	0.95	0.00	35.97	22.73	5.55	25.37	13.47
High-density wetland/shrubland	12.57	0.00	26.06	3.41	1.34	4.67	0.00
Medium-density lichen and others	3.70	0.00	1.55	7.53	8.84	1.74	0.10
Shrub and lichen	74.13	0.00	13.54	6.45	34.92	8.96	0.00
Cropland	0.00	0.00	0.00	0.03	0.00	0.37	24.78
High-biomass mosaic land	0.00	0.00	0.00	0.20	0.00	1.43	49.75
Woodland–cropland others		100.00	1.82	2.12	2.85	1.70	5.66
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	947	9	14 852	15 8071	152 166	230 792	16 855

containing the greatest degree of difference is the Taiga Shield, with 268 841 km^2 of non-correspondence (19% of the total area of this ecozone). The Taiga Shield ecozone covers 12.6% of Canada's total land area and is characterized by "cool temperatures, a short growing season, frequent forest fires, and thin, acidic soils covering permafrost" (Wiken, 1986). The forests of the Taiga Shield are dominated by black spruce (*Picea mariana*) and jack pine (*Pinus banksiana*), which are adaptable to the challenging conditions. Bogs and other wetlands are common, interspersed with scattered stands of deciduous trees and rocky outcrops. Forest fires play a significant role in this ecosystem (Wiken, 1986) and result in a patchy distribution of species and ages across the landscape. Turner et al. (1993) found that the level of agreement between US Forest Service data and AVHRR-derived estimates of forest cover was best in areas with large, contiguous patches of forest cover. These large contiguous patches are characteristic of core areas, whereas the Taiga Shield represents an area on the margin of these core areas with small patches of forest cover. This effect is complicated by the coarse resolution of AVHRR pixels, combined with factors that further reduce the effective resolution of the sensor, such as off-nadir viewing geometry and the modulation transfer function. These factors result in large mixed pixels, exceeding 1 km^2 in size, which are very difficult to assign to a single class, particularly when the landscape is heterogeneous, as in the Taiga Shield.

The ecozone with the second largest area of difference for the scenario where NBIOME is forest and DISCover is non-forest is the Boreal Shield, with 117 405 km^2 of noncorrespondence (6% of the total area of this ecozone). The Boreal Shield covers 17.9% of Canada's total land area and is similar to the Taiga Shield with its short growing season, frequent forest fires, and acidic soils (Wiken, 1986). This ecozone is 88% forested with tree species such as black spruce, jack pine, white spruce (*Picea glauca*), and balsam fir (*Abies balsamea*). Bogs and wetlands are intermixed with the forest and cover nearly 20% of the ecozone. There are no other ecozones with more that 100 000 km^2 of noncorrespondence for this scenario.

For the scenario where NBIOME is non-forest and DISCover is forest (blue in **Figure 1**, see also **Table 7**), the ecozone containing the greatest degree of difference is the Boreal Shield with 230 792 km^2 (11% of the total area of this ecozone), followed by the Taiga Plains (5.8% of Canada's land area) with 158 071 km^2 (25% of the total area of this ecozone), the Taiga Shield with 152 166 km^2 (11% of the total area of this ecozone), the Boreal Plains (6.8% of Canada's land area) with 115 776 km^2 (16% of the total area of this ecozone), and the Montaine Cordillera (4.8% of Canada's land area) with 110 840 km^2 (23% of this ecozone's total area). The Taiga Plains is Canada's sixth largest ecozone and is dominated by low-lying shrubs and herbs. Tree species are similar to those found in the Taiga Shield and Boreal Shield areas previously discussed. The Boreal Plains ecozone is characterized by the extensive boreal forests covering 84% of the ecozone area. The Montaine Cordillera ecozone is Canada's most diverse ecozone, with ecosystems ranging from alpine tundra to dense conifer forests to dry sagebrush and grasslands; most of the ecozone is rugged and mountainous.

Based on the descriptions of these ecozones, it is clear that the Taiga Shield, Taiga Plains, and Boreal Shield have certain ecological traits in common and serve as transition ecozones

Table 7 (*concluded*).

Mixedwood Plains	Boreal Plains	Prairies	Taiga Cordillera	Boreal Cordillera	Pacific Maritime	Montaine Cordillera	Hudson Plains	Total (%)	*N*
5.12	43.19	8.81	1.18	11.81	55.48	50.89	87.10	39.56	456 778
83.14	0.81	58.61	70.70	8.68	2.42	4.32	0.01	12.89	148 902
11.74	56.00	32.58	28.12	79.51	42.10	44.79	12.89	47.55	549 160
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
19 826	123 738	24 989	57 773	115 776	48 782	110 840	79 424		
0.03	1.64	0.00	0.28	1.34	0.01	0.02	0.08	5.15	59 451
0.00	2.82	0.00	0.09	0.98	0.00	0.20	1.55	5.20	60 083
0.81	36.09	0.40	23.80	41.33	14.94	24.24	64.53	32.64	376 896
8.37	28.09	2.40	34.63	28.53	20.91	21.42	26.75	22.15	255 805
0.00	0.58	0.00	21.07	7.34	33.12	17.99	5.93	7.31	84 404
0.04	0.43	0.00	2.85	2.16	0.79	3.06	0.10	3.31	38 178
0.00	0.78	0.00	14.44	16.45	19.48	20.94	1.03	12.87	148 604
23.89	6.21	48.79	0.00	0.00	1.71	0.92	0.00	2.73	31 542
57.39	10.35	7.20	0.00	0.00	0.45	0.90	0.00	3.40	39 214
9.47	13.01	41.21	2.84	1.87	8.59	10.31	0.03	5.24	60 663
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
19 826	123 738	24 989	57 773	115 776	48 782	110 840	79 424		

Table 8. Summary of class membership for the DISCover and NBIOME classifications by ecozone, where NBIOME is forest and DISCover is non-forest.

	Arctic Cordillera	Northern Arctic	Southern Arctic	Taiga Plains	Taiga Shield	Boreal Shield	Atlantic Maritimes
DISCover classification							
Closed shrubland	0.23	0.00	0.44	7.46	39.06	17.60	0.05
Open shrubland	24.54	19.85	0.01	0.53	0.00	0.10	0.00
Woody savannas	1.39	3.96	26.85	6.28	33.29	6.83	3.72
Permanent wetlands	0.00	0.00	48.14	75.11	16.02	3.48	0.00
Cropland/natural	0.00	0.00	0.00	1.58	0.06	22.04	61.36
Vegetation mosaic barren or sparsely vegetated	50.46	68.49	18.13	2.51	7.14	1.03	0.00
Water bodies	3.70	4.13	6.43	6.52	4.40	46.29	29.18
Others	19.68	3.57	0.00	0.01	0.03	2.63	5.69
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	432	5 710	53 711	68 353	268 841	117 405	18 006
NBIOME classification							
Evergreen needleleaf forest	78.01	56.97	1.00	2.20	3.84	28.04	17.58
High-density evergreen needleleaf forest	3.94	1.93	1.75	9.86	7.41	14.72	10.48
Medium-density (southern forest) evergreen needleleaf forest	5.09	13.71	32.51	46.11	38.45	8.38	0.53
Medium-density (northern forest) evergreen needleleaf forest	0.00	0.49	0.71	1.03	0.68	7.58	0.09
Low-density (southern forest) evergreen needleleaf forest	9.26	24.68	64.00	39.40	49.60	13.19	1.08
Low-density (northern forest) mixed intermediate	2.31	0.96	0.01	0.59	0.02	11.53	16.03
Heterogeneous forest mixed broadleaf forest	0.69	0.58	0.01	0.75	0.00	10.05	32.70
Others	0.70	0.68	0.01	0.06	0.00	6.51	21.51
Total (%)	100.00	100.00	100.00	100.00	100.00	100.00	100.00
N	432	5 710	53 711	68 353	268 841	117 405	18 006

from areas of primarily forest to areas of non-forest in more northern latitudes. Similarly, the southern reaches of the Boreal Plains ecozone may also be considered a transition zone between the boreal forest and the prairie grasslands. As per Hansen and Reed (2000) and Loveland and Brown (1999), transition zones are found to be problematic areas for land cover classification. Transition zones result in differing map outcomes as a result of the different ways forest is defined between the two classifications and (or) the way the two classifications deal with forest density. The Montaine Cordillera ecozone is very diverse and is characterized by extreme topographic variability, thereby explaining why this area has a high level of classification disagreement as well.

Join-count statistics

Three measures are examined: the total count of blacks, the number of BB joins, and the significance of the number of BB joins (when compared with a completely random distribution) as indicated by the *Z* score. Counting the number of blacks or difference pixels within each 50 km^2 AU indicates gross differences, which are most likely attributable to differences in classification legends. To identify where more subtle differences are evidently appearing in a systematic fashion, join counts and their associated *Z* scores are utilized. **Figure 3** illustrates the relationship between the total count of blacks and the number of BB joins and the distribution of *Z* scores relative to the total count of blacks. This figure demonstrates that the *Z* score is sensitive to the count of blacks within an AU and that the majority of *Z* scores are significant at the 5% significance level. Based on the distributions of the *Z* scores shown in **Figure 3**, a heuristic was selected (top 5% of *Z* scores) to facilitate the examination of only those AUs with extremely significant *Z* scores. **Figures 4** and **5** show the distribution of BB joins and *Z* scores for the entire country for both scenarios considered. The boxes highlighted in blue in the bottom image of Canada in both these figures represent the top 5% of *Z* scores. These figures capture the essence of the join-count analysis and provide useful visualizations of where systematic differences are occurring between the two products.

If we examine the scenario represented in **Figure 4** where NBIOME is forest and IGBP is non-forest, the most significant *Z* scores highlight ecozone interfaces and areas of transition between forest and non-forest. Specifically, there are three areas of interest: (*i*) the northeastern border of the Taiga Plains ecozone, (*ii*) the transition between the Boreal Plains and Prairies along the southern border of the Boreal Plains ecozone, and (*iii*) areas proximal to the northern edge of the Hudson Plains ecozone. **Figure 6** illustrates specific examples for each of these areas. Along the northeastern border of the Taiga Plains ecozone, this area is identified in the NBIOME classification as

Table 8 (*concluded*).

Mixedwood Plains	Boreal Plains	Prairies	Taiga Cordillera	Boreal Cordillera	Pacific Maritime	Montaine Cordillera	Hudson Plains	Total (%)	*N*
0.05	1.96	0.54	0.29	1.45	4.56	13.11	49.55	25.67	174 739
0.00	0.01	0.00	23.21	13.30	6.60	5.54	0.00	1.18	8 048
0.13	1.25	0.00	49.91	63.77	9.53	15.75	46.57	25.75	175 271
0.00	0.01	0.02	22.70	11.42	0.37	1.39	0.01	18.98	129 167
76.91	59.24	64.89	0.00	1.21	2.46	9.72	0.10	10.32	70 260
0.00	0.00	0.00	0.51	0.04	0.11	0.01	0.06	0.53	36 121
18.84	27.34	6.71	3.38	8.49	72.19	39.64	3.65	15.83	107 727
4.07	10.19	27.84	0.00	0.32	4.18	14.84	0.05	1.74	11 888
100.00	100.00	100.00	100.00	100.00	100.00	100.00	99.99	100.00	
9 337	34 550	4 232	11 914	16 676	9 681	12 259	82 114		
2.91	3.79	0.07	0.75	5.22	44.06	24.24	1.04	8.79	62 672
3.31	9.11	0.28	5.76	13.87	8.46	10.10	0.86	7.87	56 145
1.54	3.71	1.21	12.91	14.89	1.86	8.70	0.40	23.86	170 141
4.11	8.79	0.92	7.13	7.47	6.67	8.06	11.43	3.99	28 434
3.02	9.94	6.05	72.75	54.87	5.83	14.62	86.24	43.01	306 734
17.92	12.19	10.78	0.55	1.98	10.04	13.28	0.02	3.69	26 306
61.91	49.68	77.76	0.15	1.45	8.89	12.61	0.01	6.61	47 161
5.28	2.79	2.93	0.00	0.25	14.19	8.39	0.00	2.18	15 628
100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00	
9 337	34 550	4 232	11 914	16 676	9 681	12 259	82 114		

primarily evergreen needleleaf forest, whereas in the IGBP classification this same area is considered wetland – shrub land. Along the southern boundary of the Boreal Plains ecozone, this area is identified in the NBIOME classification as a complex of mixed forest, cropland, mosaic land, and wetland – shrub land. In the IGBP classification, the same area is identified as mosaic land with some deciduous broadleaf forest interspersed throughout. In the Hudson Plains ecozone, the area is classified in the NBIOME map as a complex of evergreen needleleaf forest and open land, whereas in the IGBP classification the area is classified as striations of vegetation, which moving away from the bay itself include savannah, wetland – shrub land, and evergreen needleleaf forest.

Conversely, if we examine the scenario presented in **Figure 5** where NBIOME is non-forest and IGBP is forest, the most significant *Z* scores highlight interior areas of transition ecozones (e.g., Boreal Shield and Taiga Plains), as opposed to the edges, and the eastern coast of Newfoundland. There are four areas of interest: (1) the southeast corner of the Taiga Plains, (2) the northwest area of the Boreal Plains, (3) the central areas of the Boreal Plains, and (4) the coast of Newfoundland. **Figure 7** illustrates each of these examples. In the southeast corner of the Taiga Plains, the area is classified in the IGBP DISCover classification as a mixture of evergreen needleleaf forest and broadleaf deciduous forest, whereas in the NBIOME classification it is classified as a complex of wetland – shrub land, open land, and evergreen needleleaf and mixed forests. In the area in the northwest of the Boreal Plains, areas are identified as burn in the NBIOME classification and evergreen needleleaf forest and wetland – shrub land in the IGBP DISCover classification. The areas identified as burn in the NBIOME are commonly identified as highly significant differences because of their unique spatial pattern. In the central area of the Boreal Plains ecozone the NBIOME classification has identified a complex mixture of evergreen needleleaf forest, wetland – shrub land, open land, and mosaic land. In the DISCover classification, the same area is characterized as a mixture of evergreen needleleaf forest and deciduous broadleaf forest. The nature of the classification differences is very similar in Newfoundland, where the NBIOME presents a complex arrangement of five classes and the DISCover classification has a simpler, three-class representation of the same area.

Overall, there are several possible reasons for the differences between these two maps. First, the classification schemes are different, with the NBIOME schema having 31 classes compared with the 17 classes of the IGBP DISCover schema. This greater number of classes facilitates the more refined and detailed classification of the NBIOME map, and several examples of this are included in **Figure 7**. Second, many of the

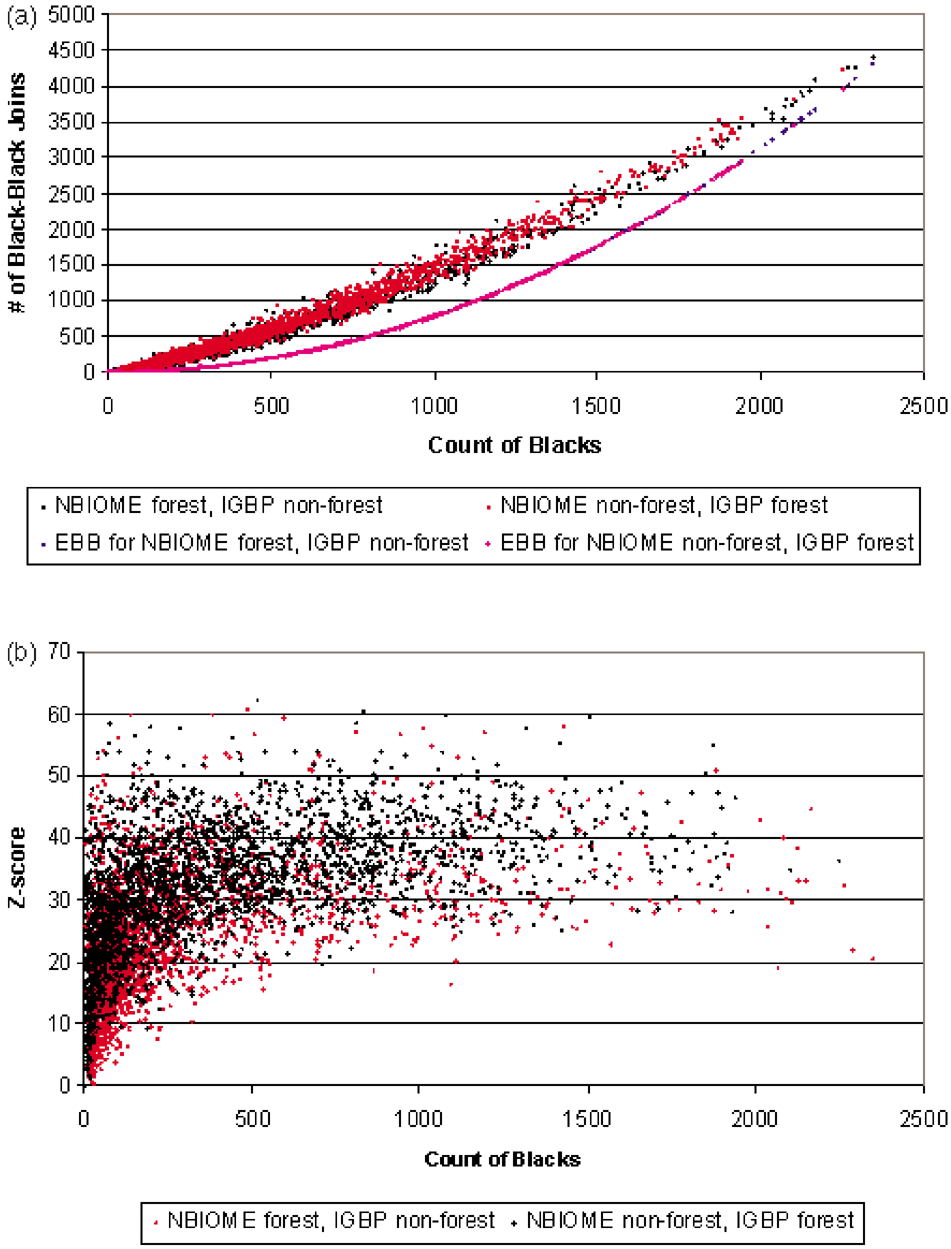

Figure 3. Count of blacks versus number of BB joins and expected BB (EBB) joins (a) and *Z*-score distribution (b).

differences are concentrated in transition areas between forest and non-forest where land cover is more heterogeneous, and contiguous patches of forest cover are small, rendering accurate classification more difficult, as noted by Hansen and Reed (2000). Third, the image data used in the creation of these two products were subjected to different levels of preprocessing. The data used for the NBIOME map were the product of a complex image compositing process used to generate the best possible cloud-free image. In addition, the composite images underwent extensive atmospheric and radiometric correction prior to classification, whereas the IGBP DISCover data did not. As was previously noted, this lack of atmospheric correction was cited as one of the major factors impacting on the accuracy of the DISCover product (Scepan, 1999) and that forest classes had the highest percentage of land contaminated by atmospheric effects (Loveland et al., 2000). This difference in preprocessing could contribute to the differences in the discrimination of wetland and other classes.

There may be other reasons for the differences between the two products. Not only are the classification schemes dissimilar, but the methods by which the classifications were completed also differ. Furthermore, the definition of seemingly similar classes is also variable, with NBIOME incorporating density and latitudinal partitions into its evergreen needleleaf forest class. Another reason for the differences may be that the two products were constructed using different image dates.

Some of the most marked differences occur because the NBIOME map has captured burns from its 1995 image dates. The IGBP DISCover map does not capture burns; however, even if it did, the imagery for the IGBP classification was collected in 1992 and 1993, and 1994 and 1995 were extreme fire years in Canada, with over 13.7 million hectares burned

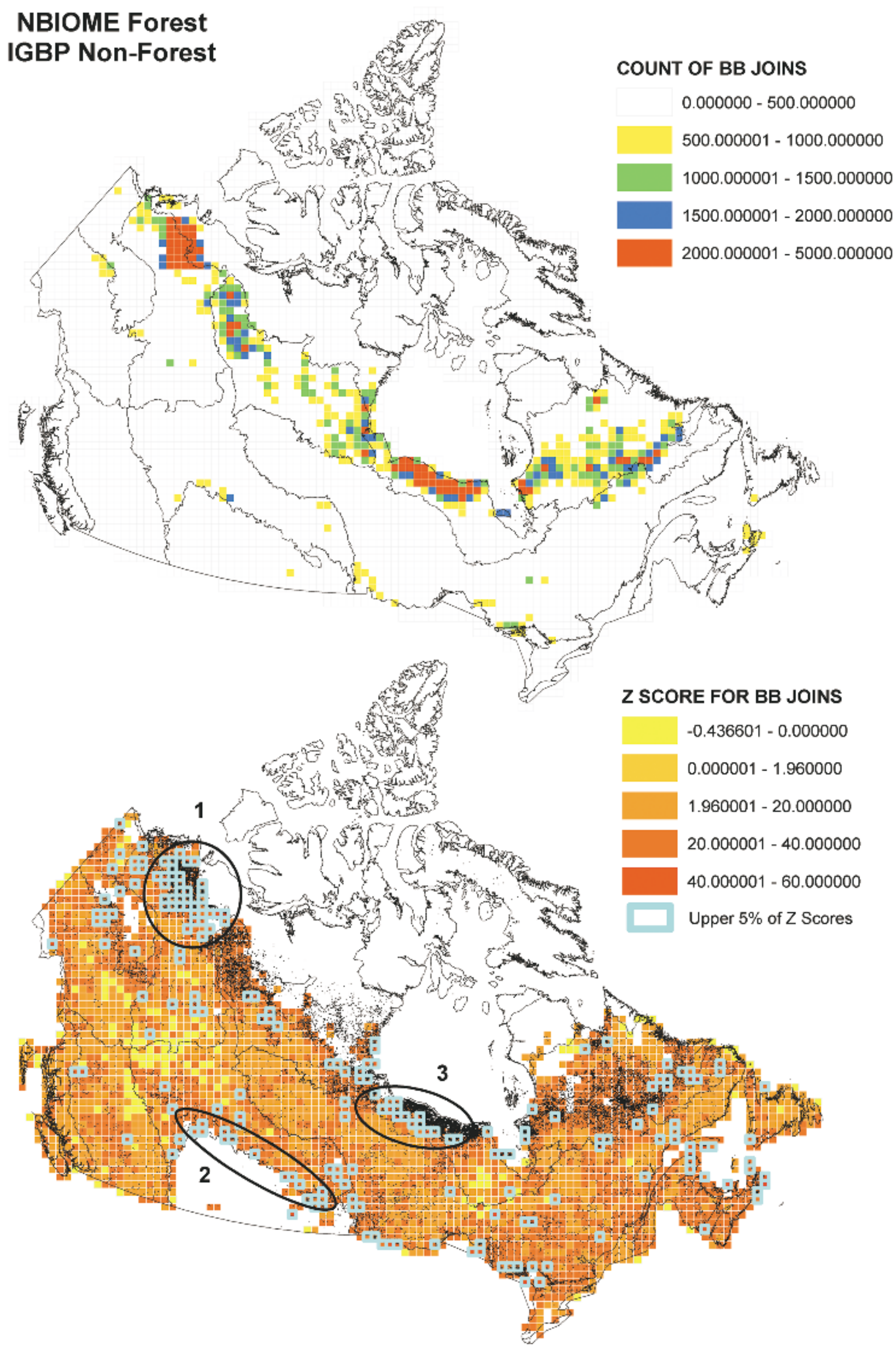

Figure 4. Illustration of map differences where NBIOME data are of a forest class and DISCover data are of a non-forest class. The most significant *Z* cores (top 5%, in blue) highlight ecozone interfaces and areas of transition between forest and non-forest. Specifically, there are three areas of interest: (1) the northeastern border of the Taiga Plains ecozone, (2) the transition between the Boreal Plains and Prairies along the southern border of the Boreal Plains ecozone, and (3) areas proximal to the northern edge of the Hudson Plains ecozone. See text for discussion and **Figure 6** regarding numbered areas of interest.

(Canadian Council of Forest Ministers, 2003). Therefore, the combination of image date and the inclusion of a specific disturbance class also accounts for some of the systematic differences between the two products.

For someone who plans to utilize a land cover product in another application or as input to a model or simulation, confidence surrounding the land cover classification is critical. If choosing between multiple products, the user should be able to make an informed decision based on the analysis framework

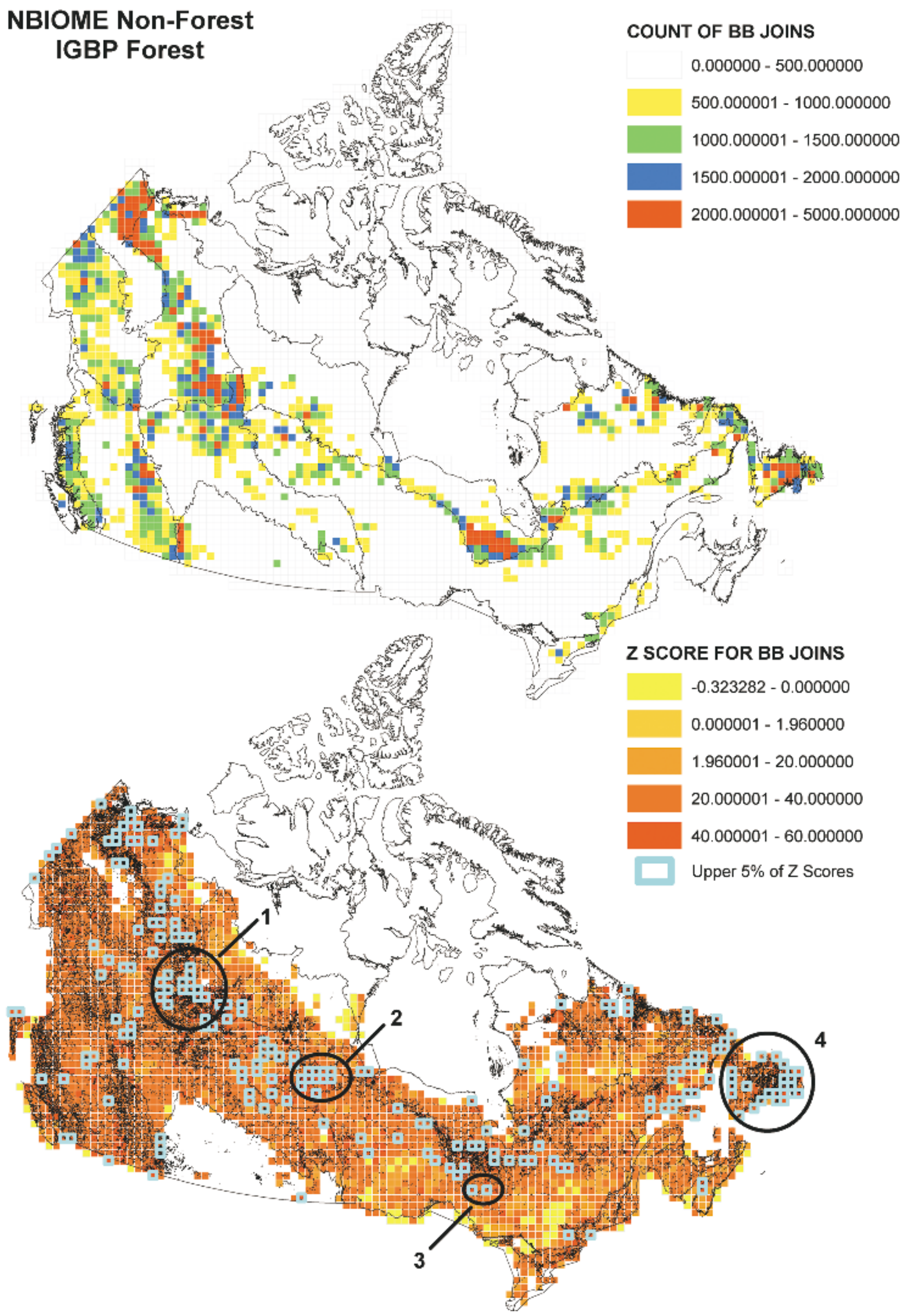

Figure 5. Illustration of map differences where NBIOME data are of a non-forest class and DISCover data are of a forest class. The most significant *Z* scores (top 5%, in blue) highlight interior areas of transition ecozones (e.g., Boreal Shield and Taiga Plains) as opposed to the edges, as well as the eastern coast of Newfoundland. There are four areas of interest: (1) the southeast corner of the Taiga Plains, (2) the northwest area of the Boreal Plains, (3) the central area of the Boreal Plains, and (4) the coast of Newfoundland. See text for discussion and **Figure 7** regarding numbered areas of interest.

presented in this paper. At the very least, an understanding of the differences between products and the spatial locations of systematic differences enables the user to interpret anomalous results from their own modeling efforts. The binary difference images generated for this analysis could also serve as a confidence layer that could be associated with the land cover product and identify those areas of agreement (higher confidence) and disagreement (lower confidence) between products. In the absence of standard measures of accuracy, this method provides the end user with valuable information.

Conclusions

This study presents the use of spatial autocorrelation for exploring the thematic and spatial differences between two map products generated for the same area. Traditional methods of map comparison such as class area summaries and per-pixel agreement are presented. In addition, the use of spatial autocorrelation is introduced as a means of identifying and characterizing the differences between two map products.

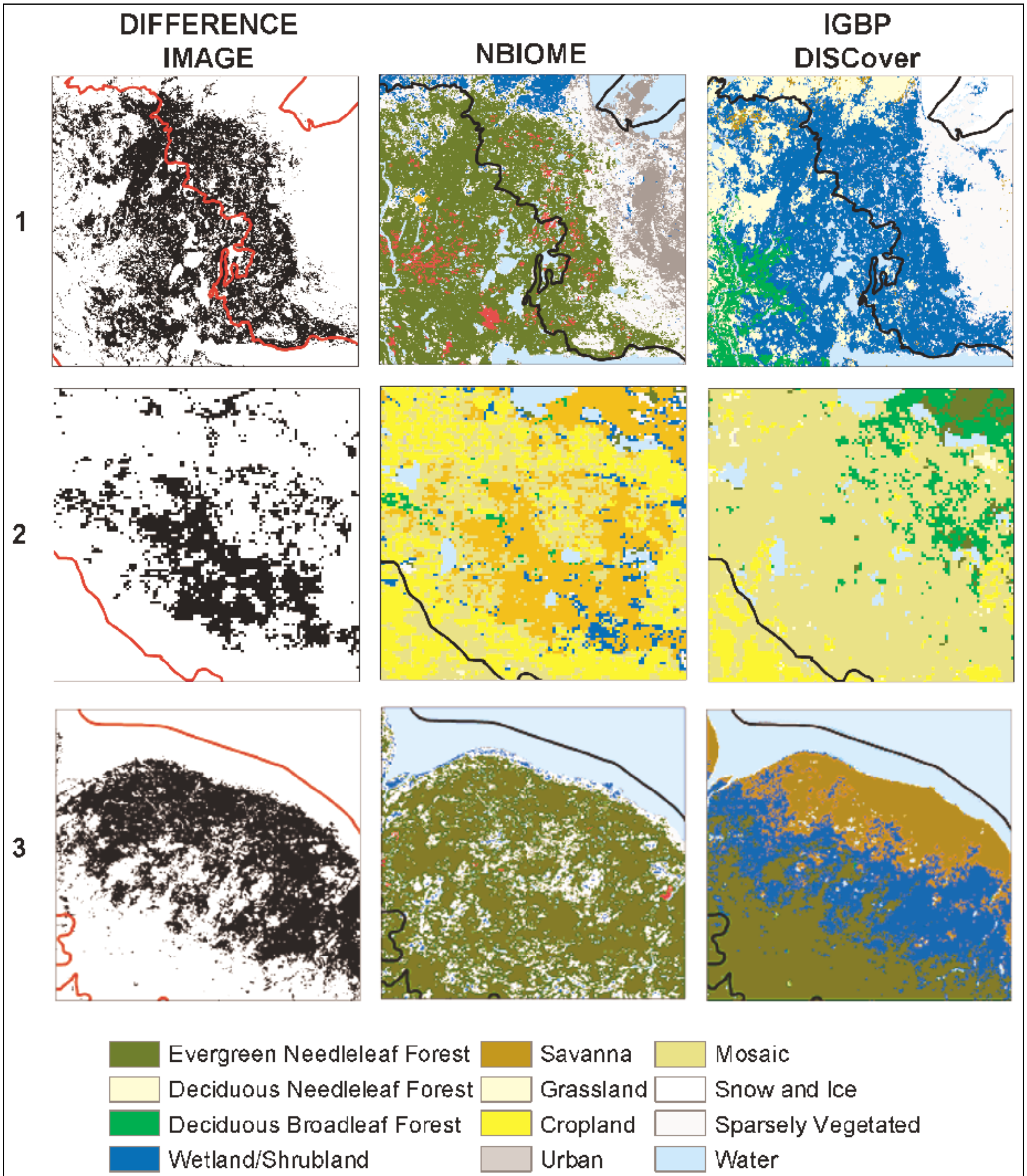

Figure 6. Samples of significant areas of spatial autocorrelation (top 5% of Z scores) where NBIOME is forest and DISCover is non-forest. The numbers 1–3 on the left correspond to areas of interest identified in **Figure 4**.

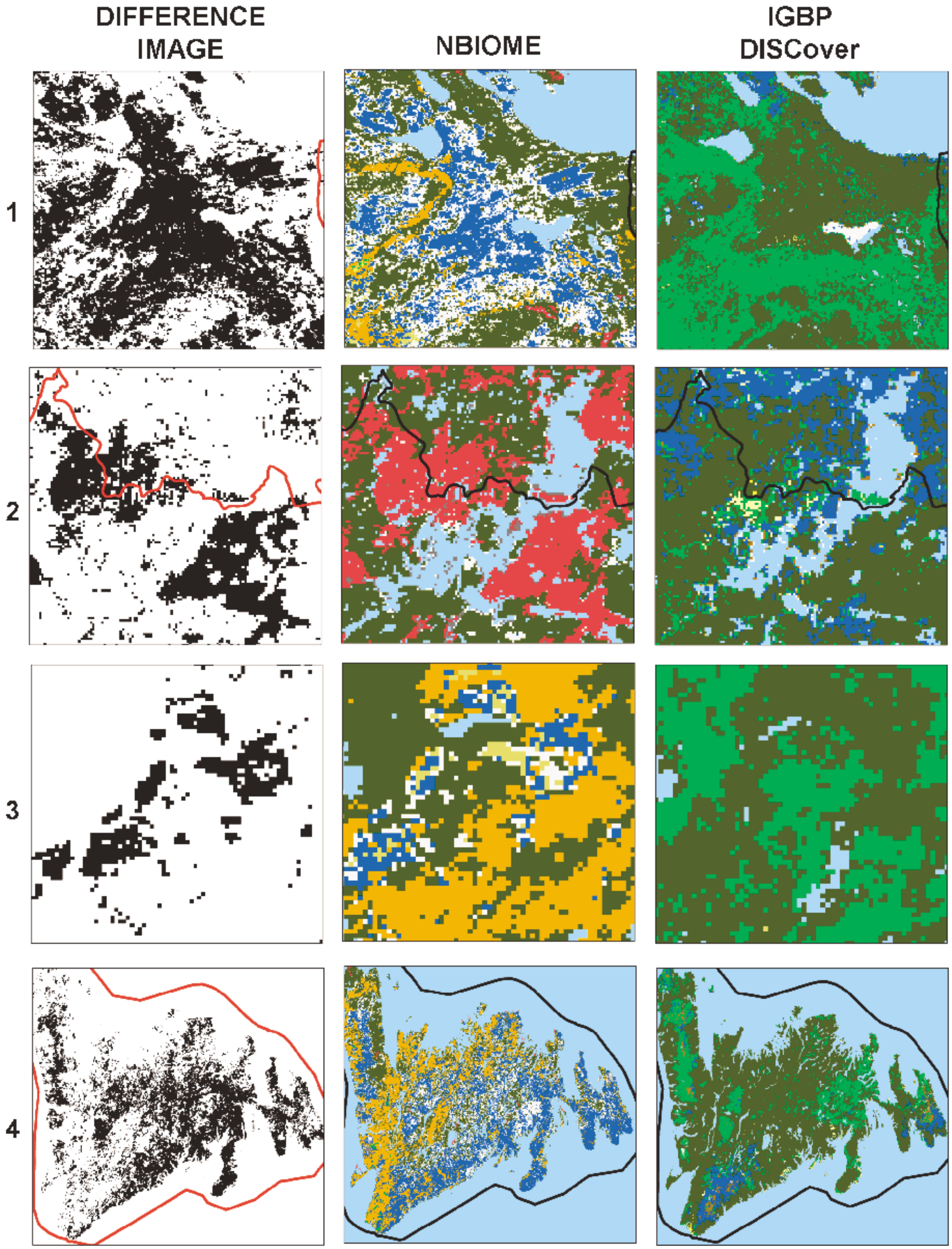

Figure 7. Samples of significant areas of spatial autocorrelation (top 5% of *Z* scores) where NBIOME is non-forest and DISCover is forest. The numbers 1–4 on the left correspond to areas of interest identified in **Figure 5**.

The results of the area summaries show that the two maps are very similar in their total area estimates of forest and non-forest. The per-pixel analysis considered within an ecozone framework, however, signifies that the two maps are not as comparable as the area summaries initially suggest. In particular, the differences between the map products appear to be concentrated in ecozones that are regarded as transition zones between areas that are predominantly forest and areas that are predominantly non-forest. An analysis of spatial autocorrelation using join-count statistics with a 50-km^2 grid covering the entire country points to specific areas where systematic differences exist between the two products. These systematic differences appear to be caused by four factors:

(1) Differences in classification schemes and methodologies

(2) Capture of disturbance classes and the differences in the image dates used to generate the products

(3) Heterogeneity of transition zones where contiguous forest patches are small and dispersed

(4) Image preprocessing, specifically compositing, and atmospheric and radiometric processing

A comparison between two map products that includes area summaries, a per-pixel evaluation within some broad ecological context, and an analysis of spatial autocorrelation provides the end user with useful insights into the differences between map products. These differences may be methodological or temporal. Based on this analysis, map users are better equipped to make an informed selection between the two products or, alternatively, opt for a synthesized hybrid product where class membership is confirmed in both products. In addition, end users are able to understand the nature of the differences between the outputs from their own subsequent applications, where these maps are used as inputs. Information regarding the locations and classes that exhibit the intermap differences is also valuable to the end user. In the absence of a standard validation process for large area land cover products, the methods for map comparison presented here may provide useful tools to end users who seek to understand the differences between map products and the implications these differences may have on their own applications and models.

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