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Forrest G. Hall and Jeffrey A. Newcomer, Editors

Volume 17

BOREAS AFM-12 1-km AVHRR Seasonal Land Cover Classification

L. Steyaert, F.G. Hall, and T.R. Loveland

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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BOREAS AFM-12 1-km AVHRR Seasonal Land Cover Classification

Lou Steyaert, Forrest G. Hall, Thomas R. Loveland

Summary

The BOREAS AFM-12 team's efforts focused on regional scale SVAT modeling to improve parameterization of the heterogeneous BOREAS landscape for use in larger scale GCMs. This regional land cover data set was developed as part of a multitemporal 1-km AVHRR land cover analysis approach that was used as the basis for regional land cover mapping, fire disturbance-regeneration, and multiresolution land cover scaling studies in the boreal forest ecosystem of central Canada (Steyaert et al., 1997). This land cover classification was derived by using regional field observations from ground and low-level aircraft transits to analyze spectral-temporal clusters that were derived from an unsupervised cluster analysis of monthly NDVI image composites (April-September 1992). This regional data set was developed for use by BOREAS investigators, especially those involved in simulation modeling, remote sensing algorithm development, and aircraft flux studies. Based on regional field data verification, this multitemporal 1-km AVHRR land cover mapping approach was effective in characterizing the biome-level land cover structure, embedded spatially heterogeneous landscape patterns, and other types of key land cover information of interest to BOREAS modelers.The land cover mosaics in this classification include:

- wet conifer mosaic (low, medium, and high tree stand density)
- mixed coniferous-deciduous forest (80% coniferous, codominant, and 80% deciduous)
- recent visible burn, vegetation regeneration, or rock outcrops-bare ground-sparsely vegetated slow regeneration burn (four classes)
- open water and grassland marshes
- general agricultural land use/grasslands (three classes)

This land cover mapping approach did not detect small subpixel-scale landscape features such as fens, bogs, and small water bodies. Field observations and comparisons with Landsat TM suggest a minimum effective resolution of these land cover classes in the range of 3 to 4 km, in part, because of the daily to monthly compositing process. In general, potential accuracy limitations are mitigated by the use of conservative parameterization rules such as aggregation of predominant land cover classes within minimum horizontal grid cell sizes of 10 km. More detailed discussion is provided by Steyaert et al. (1997). The data are stored in binary image format files.

Note that some of the data files on the BOREAS CD-ROMs have been compressed using the Gzip program. See Section 8.2 for details.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS AFM-12 1-km AVHRR Seasonal Land Cover Classification

1.2 Data Set Introduction

This regional land cover classification is based on the use of multitemporal 1-km Advanced Very High Resolution Radiometer (AVHRR) National Oceanic and Atmospheric Administration (NOAA) data that were analyzed in combination with selected Landsat Thematic Mapper (TM) and extensive field observations within a 619-km by 821-km subset of the 1,000-km by 1,000-km BOReal Ecosystem-Atmosphere Study (BOREAS) region (Steyaert et al., 1997). Following the approach developed by Loveland et al. (1991) for 1-km AVHRR land cover mapping in the conterminous United States, monthly Normalized Difference Vegetation Index (NDVI) image composites (April-September 1992) of this subset in the BOREAS region were used in an unsupervised image cluster analysis algorithm to develop an initial set of seasonal land cover classes. Extensive ground data with Global Positioning System (GPS) georeferencing, observations from low-level aerial flights over remote areas, and selected Landsat image composites for the study areas were analyzed to split, aggregate, and label the spectral-temporal clusters throughout the BOREAS region. Landsat TM image composites (bands 5, 4, and 3) were available for the 100-km by 100-km Northern Study Area (NSA) and Southern Study Area (SSA). This AVHRR land cover product was compared with Landsat TM land cover classifications for the BOREAS study areas (Steyaert et al., 1997). This experimental land cover data set was developed for test and evaluation as part of regional modeling and field experiments in BOREAS.

1.3 Objective/Purpose

A major objective of this study was to develop a regional 1-km AVHRR land cover classification for use by BOREAS investigators. The development and intercomparison of advanced multiresolution land cover mapping techniques based on Landsat TM and AVHRR data was a secondary objective of this research.

1.4 Summary of Parameters

The types of forest land cover classes required for input to BOREAS Terrestrial Ecology (TE) models were identified at a joint meeting of TE modelers and Remote Sensing Science (RSS) algorithm developers held in Columbia, MD, during June 1993. These general forest land cover classes, subsequently endorsed by other BOREAS modeling groups (Airborne Fluxes and Meteorology (AFM), Tower Fluxes (TF), and Trace Gas Biogeochemistry (TGB)), include Wet Conifer, Dry Conifer, Mixed Forest (Coniferous and Deciduous), Deciduous, Disturbed, Fen, Water, Regeneration (young, medium, and old age categories), and recent burn areas. Landsat TM 30-m data were used in the BOREAS TE-18 investigation to develop a land cover classification for this classification scheme in both the NSA and SSA in the BOREAS region (see F. Hall and D. Knapp, TE-18 documentation).

The land cover classes defined as part of this regional 1-km AVHRR land cover classification are in general conformance with the types of land cover classes developed from Landsat TM classifications for the NSA and SSA. The differences between the classifications are, in part, associated with the different resolutions of the satellite sensors; that is, the 1-km AVHRR pixel size versus the 30-m Landsat TM pixel size. For example, this regional land cover mapping approach did not detect subpixel fens, bogs, and small lakes. There are also additional land cover classes that are in the BOREAS region, but not in the study areas. These 1-km AVHRR-derived land cover classes for BOREAS generally represent mosaics of various vegetation species as described in Section 7.3.2. The 1-km AVHRR land cover classes for BOREAS include:

Class ID	Class Name
1	Wet Conifer (Low Stand Density)
2	Wet Conifer (Medium Stand Density)
3	Wet Conifer (High Stand Density)
4	Upland Conifer/Fen
5	Rock Outcrops/Bare Ground/Sparse Vegetation/Slow Regeneration Burn Areas
6	NA
7	Open Water
8	NA
9	Regeneration (North: Within Canadian Shield Zone)
10	NA
11	Recent Visible Burn
12	Rangeland/Pasture/Hay/Aspen Patches
13	Mixed Agriculture/Predominately Grains
14	Mixed Agriculture/Predominately Pasture/Hay
15	Grassland Marshes
16	Mixed Forest (80% Coniferous)
17	Mixed Forest (50% Coniferous)
18	Mixed Forest (80% Deciduous)
19	Regeneration (South: generally south of Shield Zone)
20	Unknown

1.5 Discussion

This experimental land cover data base for BOREAS was developed from multitemporal 1-km AVHRR data that were supplemented by field observations and selected Landsat TM image composites for the two study areas in BOREAS (Steyaert et al., 1997). The preprocessing of the daily 1-km AVHRR data and the monthly NDVI unsupervised cluster analysis followed procedures outlined by Eidenshink (1992a, b), Loveland et al. (1991), and Brown et al.(1993). Field observations, collected during the pre-BOREAS operations in 1993 and BOREAS Intensive Field Campaigns (IFCs) of 1994, were the primary source of information to analyze, combine, and interpret the clusters according to land cover class. These field data were the primary source of information for the analysis of regional forest fire disturbance-regenerating vegetation patterns. The 1-km AVHRR land cover classification was compared with both high- and coarse-resolution land cover data bases generated from 30-m Landsat TM and AVHRR data, respectively.

1.6 Related Data Sets

BOREAS TE-18 Landsat TM Physical Classification Image of the NSA
BOREAS TE-18 Landsat TM Physical Classification Image of the SSA
BOREAS TE-18 Landsat TM Maximum Likelihood Classification Image of the NSA
BOREAS TE-18 Landsat TM Maximum Likelihood Classification Image of the SSA

2. Investigator(s)

2.1 Investigator(s) Name and Title

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2.2 Title of Investigation

Modeling Biosphere-Atmosphere Interactions at Various Scales in Support of BOREAS (AFM-12, PI: Dr. R.A. Pielke, Sr.)

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3. Theory of Measurements

The AVHRR is a four- or five-channel scanning radiometer capable of providing global daytime and nighttime information about ice, snow, vegetation, clouds, and the sea surface (Newcomer, 1992; Los et al., 1995). These data are obtained on a daily basis primarily for use in weather analysis and forecasting; however, a variety of other applications are possible. The AVHRR data are from instruments onboard the NOAA polar orbiting platforms. The radiometers onboard more recent satellites such as NOAA-11 measure emitted and reflected radiation in two visible, one middle infrared, and two thermal channels.

Channel	Wavelength [micrometers]	Primary Use
1*	0.58 - 0.68	Daytime Cloud and Surface Mapping
2	0.725 - 1.10	Surface Water Delineation
3	3.55 - 3.93	Vegetation Cover Sea Surface Temperature (SST)
4**	10.5 - 11.5	Nighttime Cloud Mapping Surface Temperature, Day/Night Cloud
5***	11.5 - 12.5	Mapping Surface Temperature

* Channel 1 wavelength for Television and Infrared Observation Satellite (TIROS)-N flight model was 0.55 - 0.90 micrometers.
** For NOAA-7 and -9 Channel 4 was 10.3 - 11.3 micrometers.
*** For TIROS-N, NOAA-6, -8, and -10, Channel 5 is a duplicate of Channel 4.

The wavelength ranges at 50% Relative Spectral Response (in micrometers) of the bands for each platform are:

Band	NOAA-9	NOAA-10	NOAA-11
1	0.570 - 0.699	0.571 - 0.684	0.572 - 0.698
2	0.714 - 0.983	0.724 - 0.984	0.716 - 0.985
3	3.525 - 3.931	3.554 - 3.950	3.536 - 3.935
4	10.334 - 11.252	10.601 - 11.445	10.338 - 11.287
5	11.395 - 12.342	10.601 - 11.445	11.408 - 12.386

The AVHRR is capable of operating in both real-time or recorded modes. Direct readout data can be transmitted to ground stations of the automatic picture transmission (APT) class at low resolution (4 x 4 km) and to ground stations of the high-resolution picture transmission (HRPT) class at high resolution (1 x 1 km), such as the HRPT receiving and processing station at the United States Geological Survey (USGS) Earth Resources Observation System (EROS) Data Center (EDC), Sioux Falls, SD. Data recorded onboard are available for processing after downlinking to groundstations such as at the USGS-EDC or at the Naval Research Laboratory (NRL) Satellite Data Receiving and Processing Facility. These recorded data include global area coverage (GAC) data, with a resolution of 4 x 4 km, and local area coverage (LAC) data recorded from selected portions of each orbit with a 1 x 1 km resolution.

4. Equipment

4.1 Sensor/Instrument Description

The AVHRR onboard NOAA-11 is a cross-track scanning system featuring two visible, one middle infrared, and two thermal channels.

4.1.1 Collection Environment

The daily NOAA-11 AVHRR data were collected by the USGS EDC during the period 01-April - 30-September-1992. Field study trips were made to various sites in the BOREAS region during 19-July-1993, 19-July-1994, 19-August-1994, and 19-July-1996.

4.1.2 Source/Platform

AVHRR data used for this BOREAS data set were collected onboard the NOAA-11 polar orbiting platform. The NOAA-11 is an afternoon pass satellite with northbound Equatorial crossing directly after launch of 1340 LST. However, during the time of operation of the satellite, the Equatorial crossing time gradually shifted to a later time in the afternoon.

4.1.3 Source/Platform Mission Objectives

The AVHRR is designed for multispectral analysis of meteorological, oceanographic, and hydrologic parameters. The objective of the instrument is to provide radiance data for investigation of clouds, land-water boundaries, snow and ice extent, ice or snow melt inception, day and night cloud distribution, temperatures of radiating surfaces, and SST. It is an integral member of the payload on the advanced TIROS-N spacecraft and its successors in the NOAA series, and as such contributes data required to meet a number of operational and research-oriented meteorological objectives. Although not its primary purpose, the AVHRR was found to be suitable for vegetation monitoring studies, in part because of its high temporal resolution and global coverage.

4.1.4 Key Variables

Emitted radiation. Reflected radiation (used to calculate the NDVI).

4.1.5 Principles of Operation

The AVHRR is a four- or five-channel scanning radiometer that detects emitted and reflected radiation from Earth in the visible, near-infrared, and far-infrared regions of the spectrum. A fifth channel has been added to the follow-on instrument designated AVHRR/2 and flown on NOAA-7, NOAA-9, and NOAA-11 to improve the correction for atmospheric vapor. Scanning is provided by an elliptical beryllium mirror rotating at 360 rpm about an axis parallel to Earth's axis. A two-stage radiant cooler is used to maintain a constant temperature for the infrared detectors of 95 K. The operating temperature is selectable at either 105 or 110 K. The telescope is an 8-inch afocal, all-reflective Cassegrain system. Polarization is less than 10 percent. Instrument operation is controlled by 26 commands and monitored by 20 analog housekeeping parameters.

4.1.6 Sensor/Instrument Measurement Geometry

The AVHRR is a cross-track scanning system. The instantaneous field-of-view (IFOV) of each sensor is approximately 1.4 milliradians giving a resolution of 1.1 km at the satellite subpoint. There is about a 36 percent overlap between IFOVs (1.362 samples per IFOV). The scanning rate of the AVHRR is six scans per second, and each scan spans an angle of +/- 55.4 degrees from the nadir.

4.1.7 Manufacturer of Sensor/Instrument

ITT Aerospace/Communications Division
P.O. Box 3700
Fort Wayne, IN 46801-3700

4.2 Calibration

NOAA provides calibration parameters on tape that relate the data in the visible and near-infrared channels to a preflight standard (preflight calibration). However, during the time of operation of the satellite, the sensitivity of the red and near-infrared has gradually decreased. This decrease is not accounted for by the preflight calibration, and no in-flight visible channel calibration is performed. The calibration coefficients for AVHRR thermal channels 3, 4, and 5 are derived onboard the satellite using a view of a stable blackbody and deep space as a reference. The radiance values for all channels are stored with 10-bit precision. The procedures used by the USGS EDC to radiometrically calibrate the visible and near-infrared channels as well as other methods used by EDC to process these data are described by Eidenshink (1992a, 1992b). Specific details are provided in Section 4.2.2.

4.2.1 Specifications

```
IFOV          1.4 mRad
RESOLUTION    1.1 km
ALTITUDE      833 km
SCAN RATE     360 scans/min
              1.362 samples per IFOV
SCAN RANGE    -55.4 to 55.4 degrees
SAMPLES/SCAN  2,048 samples per channel per Earth scan
```

4.2.1.1 Tolerance

The AVHRR infrared channels were designed for a Noise Equivalent Differential Temperature (NEdt) of 0.12 Kelvin (at 300 Kelvin, and a signal-to-noise ratio of 3:1 at 0.5 percent albedo.

4.2.2 Frequency of Calibration

NOAA provides calibration parameters on tape that relate the data to a preflight standard (preflight calibration). These parameters generally do not change during the time of operation of a satellite (with the exception of NOAA-11). The preflight calibration does not take degradation of the sensors into account. Degradation of AVHRR sensors after launch is well documented (e.g., Rao, 1987; Price, 1987; Holben et al., 1990). These studies have used a variety of approaches such as ground-based measurements from stable sites (e.g., homogeneous desert targets) to monitor the degradation of the sensors. Corrections to these 1992 data for sensor degradation were made by using coefficients developed from a study by Teillet and Holben (1991, unpublished report) and Teillet and Holben (1994). Their calculation takes into account the desert calibration approach (Holben et al., 1990) to develop a set of time-dependent calibration coefficients for the AVHRR sensor on NOAA-11. Use of calibration coefficients involves extrapolation of the most recent calibration results for processing data on a near-real-time basis. Therefore, the time-dependent coefficients are based on a piecewise linear fit of the desert results. A piecewise linear fit is recommended for operational use because, unlike polynomial fits, it will not change retroactively when new data are added to the end of the time series (Eidenshink, 1992a, 1992b).

4.2.3 Other Calibration Information

See Eidenshink (1992a, 1992b).

5. Data Acquisition Methods

The primary data source for this 1-km AVHRR land cover classification was monthly NDVI image composites derived from daily NOAA-11 AVHRR polar orbiting satellite data. Daily 1-km AVHRR data were received and processed by the USGS EDC during the period April through September 1992. Monthly NDVI composites were processed for a 619-km by 821-km subset (approximately 52-57 N and 96-108 W) of the 1,000-km by 1,000-km BOREAS region. The methods for processing the daily NOAA-11 AVHRR data into monthly NDVI image composites is described by Eidenshink (1992a, 1992b). These processing steps include radiometric calibration, atmospheric correction, computation of the NDVI, geometric registration, and image compositing. Other than the maximum NDVI compositing, no cloud screening algorithm was used. The AVHRR data were not atmospherically corrected for water vapor and aerosols. These processing procedures are very analogous to the procedures established for processing the 1-km AVHRR Pathfinder data as described by Eidenshink and Faundeen (1994).

Landsat imagery and field observations were essential data inputs to the development of this land cover classification. Hardcopy Landsat TM image composites (bands 5, 4, and 3) for the NSA and the SSA were acquired from TE-18 to help understand and identify 1-km AVHRR spectral-temporal clusters in the study areas and as a guide to help interpret field observations in the study areas.

Extensive field observations of vegetation type and composition along with associated GPS georeferencing data were obtained throughout many portions of the BOREAS region. A four-wheel drive vehicle was used to collect more than 350 sets of ground observations with GPS positional fixes, mainly along the road networks within the boreal forested areas of the BOREAS region during field visits (July 1993; July and September 1994). In addition, several low-level aircraft reconnaissance flights within Saskatchewan and Manitoba, including the BOREAS transect from Prince Albert National Park (PANP) to Thompson, were used to photograph vegetation patterns (some GPS) and verify preliminary classes. These aircraft flights by both USGS and NASA investigators were especially useful in analysis of land cover conditions in remote regions. A follow-up field visit including three separate low-level aircraft flights in Manitoba was made during July 1996.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Extensive field observations of land cover type composition were made during 1993 and 1994 with a follow-up visit in 1996.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The regional 1-km AVHRR land cover data are located in a 672-row by 862-column raster image. This image contains the actual land cover classes (pixel values 1-20) for the 619-km by 821-km subset of the BOREAS region, plus a set of zero-value pixels that form the boundary of the raster image. The subsetted land cover classification has a domain of approximately 52-57 deg. N and 96-108 deg. W, which includes the BOREAS SW-NE transect from southwest of Saskatoon, Saskatchewan, to northeast of Gillam, Manitoba. The corner coordinates (kilometers from the origin) of the data set in the Albers Equal-Area Conic (AEAC) projection (see Section 7.1.4) are:

Corner	X	Y
Upper Left	174.0707	785.4531
Upper Right	1036.0707	785.4531
Lower Left	174.0707	113.4531
Lower Right	1036.0707	113.4531

7.1.2 Spatial Coverage Map

None.

7.1.3 Spatial Resolution

The IFOV of each sensor is approximately 1.4 milliradians, leading to a resolution of about 1.1 km by 1.1 km at nadir for a nominal altitude of 833 km. The AVHRR and land cover data were gridded to a cell size of 1.0 km from the original nominal resolution of 1.1 km. However, as discussed by Steyaert et al. (1997), the effective resolution of these 1-km AVHRR land cover classes is more realistically in the 3- to 4-km range, in part, because of the maximum NDVI compositing and multitemporal analysis over the April-September time period.

7.1.4 Projection

The area mapped is projected in the AEAC projection. The projection has the following parameters:

```
Datum: None
Ellipsoid: Sphere
Origin:    111.000° W 51.000° N
Standard Parallels: 52° 30' 00" N
                    58° 30' 00" N
Units of Measure: kilometers

Note: Each pixel is 1,000 m by 1,000 m in size.
```

It is important to emphasize that this image is projected using a Sphere as the Earth model and not the WGS84 ellipsoid used for most other BOREAS data sets. The other projection parameters listed above are the same as many other BOREAS georeferenced data sets. This difference in ellipsoid models can result in spatial misregistration of approximately 2 to 4 pixels. This difference should be considered when comparing this classification to other georeferenced imagery.

7.1.5 Grid Description

None.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

Monthly NDVI image composites for the period April-September 1992 were used to develop this 1992 1-km AVHRR/land cover data set.

7.2.2 Temporal Coverage Map

None.

7.2.3 Temporal Resolution

Monthly NDVI image composites for the period April-September 1992 were used to develop this 1992 1-km AVHRR/land cover data set.

7.3 Data Characteristics

7.3.1 Parameter/Variable

Land Cover Type.

7.3.2 Variable Description/Definition

The 1-km AVHRR land cover classes listed in Section 1.4 can be grouped into broad vegetation categories consisting of: (1) wet conifer mosaic; (2) mixed coniferous-deciduous forest; (3) recent burn, regeneration, or rock outcrops-bare ground-sparsely vegetated slow regeneration burn; (4) open water and grassland marshes; and (5) general agricultural land use. This grouping facilitates the understanding and descriptive characterization of these 1-km AVHRR land cover classes, especially in terms of the vegetation associations within each class. Qualitative descriptions of these land cover classes are essential for interpreting class attributes and estimating biophysical parameters for land surface parameterizations. The land cover class descriptions within these vegetation categories are given in the following subsections:

Wet Conifer Mosaic

The wet conifer mosaic is the dominant conifer class within this classification. This wet conifer mosaic consists of black spruce (Picea mariana) and various embedded subpixel fens and bogs, scattered tamarack (Larix laricina), mixed water-vegetation pixels, small pockets of dry jack pine

(Pinus banksiana) on sandy hilltops, and scattered deciduous trees. This mosaic is characterized by the very consistent vegetation patterns in the "lowlying" areas (black spruce, fens, bogs) as opposed to more upland terrain (more productive black spruce in combination with jack pine on sandy soils and scattered deciduous trees) environments throughout the entire BOREAS region. This classification does not resolve in all cases these "lowland" versus "upland" components of the wet conifer mosaic. The subpixel fens, bogs, and small water bodies are also not resolved in this classification. Based on extensive field data, the 1-km AVHRR spectral-temporal clusters do permit the characterization of the wet conifer mosaic into "low," "medium," and "high" tree density levels (Classes 1-3, respectively).

There is also a small upland conifer/fen class (Class 4) that is characterized by isolated patches of mature jack pine or black spruce/fen mosaics. This class is in part due to the lack of spectral separation between dense black spruce and jack pine classes with AVHRR. To the east of Lake Winnipeg, this mixed conifer mosaic consists of black spruce (with some jack pine) on small, "upland" hummocks that are embedded in large tamarack fens.

Mixed Coniferous-Deciduous Forest Mosaic

There are three AVHRR mixed forest classes that, based on field observations, are estimated to consist of 80 percent conifer-20 percent deciduous (Class 16), codominant mixed forest (Class 17), and 80 percent deciduous-20 percent conifer (Class 18). These mixed forest classes are generally distributed along a southwest-northeast gradient ranging from deciduous dominant in the south to coniferous dominant in the north. The effects of forest succession are evident in this mixed class, especially in stands with mature deciduous trees and successional spruce under the deciduous canopy. In the northern extremes, this AVHRR mixed forest (Class 16) is predominantly upland black spruce with scattered jack pine on sandy soils and approximately 20 percent aspen trees (populus tremuloides) with scattered birch (betula papyrifera) and balsam poplar (populus balsamifera) trees. These trees are typically on rocky hills throughout the central and northern portions of the BOREAS region. The mixed forest class in the central region (Class 17) consists of codominant coniferous and deciduous trees that are quite well developed. The conifers are dominated by tall jack pine, black spruce, and some white spruce (Picea glauca), while the deciduous trees consist of mature aspen and birch. The mixed forest in the southern boreal ecosystem (Class 18) is dominated by well-developed aspen trees that grow either in pure stands or in mixed forest stands with birch, balsam poplar, and some conifers. The deciduous trees account for at least 80 percent of the mixed forest composition. In some cases, the aspen is near maturity with well-developed conifers growing under the canopy.

Recent Burn, Regeneration, or Rock Outcrops-Bare Ground-Sparsely Vegetated-Burn

This grouping includes individual land cover classes for recent visible burns (Class 11), fire disturbance-regenerating vegetation in the north (Class 9) and south (Class 19), and a rock outcrops-bare ground-sparsely vegetated class (Class 5) that is frequently associated with slow regeneration burned areas of various ages. The recent visible burns (Class 11) represent areas that were burned within the past 5 or 6 years, relative to this 1992 data analysis. This burn class is distinguishable by its charred background of partially burned trees and moss in black spruce areas or other intensely burned areas where little or no vegetation survived. These recent burn areas are much more frequent and widespread within the Canadian Shield Zone. The regenerating vegetation patches in the north (Class 9) are located within the Canadian Shield Zone and are typically associated with old burns of various ages. This mixed vegetation class consists of jack pine, aspen, and young black spruce trees. The stand density and tree sizes depend on the age of the burn and the soil conditions. The jack pine and aspen trees are taller than young black spruce. The regenerating vegetation patches in the south (Class 19) that are located to the south of the Canadian Shield Zone are the result of old burns or previously logged or cleared areas, especially along the southern ecotone between the boreal forest and grasslands/agriculture land cover types. The class is dominated by a mixture of regenerating young aspen trees and various herbaceous bushes and grasses with scattered jack pine. The rock outcrops-bare ground-sparsely vegetated areas (Class 5) are frequently associated with slow regeneration burn areas of various ages, especially within the north. Based on field data analysis, this mixed class has examples of recent and older burns. The estimated vegetation cover for Class 5 is less than 30 percent.

Open Water and Grassland Marshes

The open water Class 7 includes water bodies such as small lakes and streams. For AVHRR, this class also includes water/vegetation mixed pixels. In the north, there were some cases of definite spectral confusion between dark water bodies and recent, dark burns. The grassland marshes (Class 15) are mainly located in western Manitoba, near The Pas.

General Agricultural Land Use

There are three general agricultural land use classes. A mixed class (rangeland, pasture, hay, and aspen patches) consists of aspen patches (typically around "pothole" water bodies) embedded in grasslands (rangeland, pasture, and hay fields) in the southwest portion of the BOREAS region (Class 12). The aspen trees are estimated to represent 30 percent of the land cover. A mixed agricultural, predominantly grains class represents the major agricultural grain-producing area in the BOREAS region (Class 13). This class also includes fallowed fields. A mixed agricultural class consists predominantly of pasture and hay fields with some grain cropping (Class 14).

7.3.3 Unit of Measurement

Pixel values represent different land cover types.

7.3.4 Data Source

AVHRR imagery was received from EDC, Sioux Falls, SD. Pixel values range from 0 to 20, where the land cover classes have pixel values of 1-20 and the raster-filler boundary pixels have values of zero.

7.3.5 Data Range

Pixel values range from 0 to 20, where the land cover classes have pixel values of 1-20 and the raster-filler boundary pixels have values of zero.

7.4 Sample Data Record

Not applicable to image data.

8. Data Organization

8.1 Data Granularity

The smallest amount of data that can be ordered from this data set is the entire data set.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

This BOREAS AFM-12 regional 1-km AVHRR/land cover classification product contains two files as follows:

- File 1: (80-byte American Standard Code for Information Interchange (ASCII) text records). Header file on tape.
- File 2: (672 records of 862 bytes each) (1 byte per pixel). Classified image with values from 1 to 20 with zero values(0) used as fillers for the boundaries of the image.

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, the ASCII header file for this image is stored as ASCII text; however, file 2 has been compressed with the Gzip compression program (file name *.gz). These data have been compressed using gzip version 1.2.4 and the high compression (-9) option (Copyright (C) 1992-1993 Jean-loup Gailly). Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (-d option) or gunzip. Gzip is available from many Web sites (for example, ftp site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

9. Data Manipulations

9.1 Formulae

None.

9.1.1 Derivation Techniques and Algorithms

None.

9.2 Data Processing Sequence

9.2.1 Processing Steps

The primary data source for this 1-km AVHRR land cover classification was monthly NDVI image composites derived from daily NOAA-11 AVHRR polar orbiting satellite data. Daily 1-km AVHRR data were received and processed by the USGS EDC during the period April through September 1992. Monthly NDVI composites were processed for a 619-km by 821-km subset of the BOREAS region (approximately 52-57 N and 96-108 W). The methods for processing the daily NOAA-11 AVHRR into monthly NDVI image composites is described by Eidenshink (1992a, 1992b). These processing steps include radiometric calibration, atmospheric correction, computation of the NDVI, geometric registration, and image compositing. Other than the maximum NDVI compositing, no cloud screening algorithm was used. The AVHRR data were not atmospherically corrected for water vapor and aerosols. These processing procedures are very analogous to the procedures established for processing the 1-km AVHRR Pathfinder data as described by Eidenshink and Faundeen (1994).

This regional land cover classification was then based on the use of these multitemporal 1-km AVHRR (NOAA-11) data that were analyzed in combination with selected Landsat TM and extensive field observations within a 619-km by 821-km subset of the BOREAS region (Steyaert et al., 1997). Following the approach developed by Loveland et al. (1991) for 1-km AVHRR land cover mapping in the conterminous United States, monthly NDVI image composites (April-September 1992) of this subset in the BOREAS region were used in an unsupervised image cluster analysis algorithm to develop an initial set of seasonal land cover classes. Extensive ground data with GPS georeferencing, observations from low-level aerial flights over remote areas, and selected Landsat image composites for the study areas were analyzed to split, aggregate, and label the spectral-temporal clusters throughout the BOREAS region. Landsat TM image composites (bands 5, 4, and 3) were available for the 100-km by 100-km NSA and SSA. This AVHRR land cover product was compared with Landsat TM land cover classifications for the BOREAS study areas (Steyaert et al., 1997).

BOREAS Information System (BORIS) staff copied the ASCII and compressed the binary files for release on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

None.

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

None.

9.4 Graphs and Plots

None.

10. Errors

10.1 Sources of Error

The sources of error in this classification could be the result of a number of factors. Error could be the result of spectral mixing of various features that fall within a 1-km pixel. The spectral signature of one feature could also be similar to that of another feature, resulting in confusion. The similarity in spectral signatures could be the result of similar background components and variations in tree density. The locational accuracy of this image may be off by as much as 3 or 4 pixels based on the compositing of the multitemporal data.

10.2 Quality Assessment

10.2.1 Data Validation by Source

The imagery was spot checked at various locations, and the image class was compared to Landsat TM-derived land cover classifications developed for the NSA and SSA under TE-18.

10.2.2 Confidence Level/Accuracy Judgment

Although efforts have been made to make this classification as accurate as possible, there is bound to be some confusion between classes. The most noticeable problem is confusion between dense jack pine and dense black spruce. Spectrally, they look very similar.

10.2.3 Measurement Error for Parameters

Not applicable.

10.2.4 Additional Quality Assessments

None.

10.2.5 Data Verification by Data Center

This image was viewed to make sure that it matched the product description.

11. Notes

11.1 Limitations of the Data

This product is intended to be used to characterize the land cover over a large region at least at a 1-km pixel resolution or greater. It should not be used to determine land cover at a few specific pixels.

11.2 Known Problems with the Data

The AVHRR data were not atmospherically corrected for water vapor and aerosols. This could have affected the NDVI values that were derived from the data, and thus this classification.

11.3 Usage Guidance

Before uncompressing the Gzip files on CD-ROM, be sure that you have enough disk space to hold the uncompressed data files. Then use the appropriate decompression program provided on the CD-ROM for your specific system.

11.4 Other Relevant Information

None.

12. Application of the Data Set

This data set would be useful for regional modeling of the ecosystem.

13. Future Modifications and Plans

None given.

14. Software

14.1 Software Description

Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Gzip is available from many Web sites across the Internet (for example, FTP site prep.ai.mit.edu/pub/gnu/gzip-*.*) for a variety of operating systems in both executable and source code form. Versions of the decompression software for various systems are included on the CD-ROMs.

15. Data Access

The AFM-12 1-km AVHRR seasonal land cover classification data are available from the Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

15.1 Contact Information

For BOREAS data and documentation please contact:

ORNL DAAC User Services
Oak Ridge National Laboratory
P.O. Box 2008 MS-6407
Oak Ridge, TN 37831-6407
Phone: (423) 241-3952
Fax: (423) 574-4665
E-mail: ornldaac@ornl.gov or ornl@eos.nasa.gov

15.2 Data Center Identification

Earth Observing System Data and Information System (EOSDIS) Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) for Biogeochemical Dynamics http://www-eosdis.ornl.gov/.

15.3 Procedures for Obtaining Data

Users may obtain data directly through the ORNL DAAC online search and order system [http://www-eosdis.ornl.gov/] and the anonymous FTP site [ftp://www-eosdis.ornl.gov/data/] or by contacting User Services by electronic mail, telephone, fax, letter, or personal visit using the contact information in Section 15.1.

15.4 Data Center Status/Plans

The ORNL DAAC is the primary source for BOREAS field measurement, image, GIS, and hardcopy data products. The BOREAS CD-ROM and data referenced or listed in inventories on the CD-ROM are available from the ORNL DAAC.

16. Output Products and Availability

16.1 Tape Products

These data can be made available on 8-mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

16.2 Film Products

None.

16.3 Other Products

These data are available on the BOREAS CD-ROM series.

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

AEAC	- Albers Equal-Area Conic
AFM	- Airborne Fluxes and Meteorology
APT	- Automatic Picture Transmission
ASCII	- American Standard Code for Information Interchange
BOREAS	- Boreal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
BPI	- Bytes Per Inch
CCRS	- Canadian Centre for Remote Sensing
CD-ROM	- Compact Disk-Read-Only-Memory
DAAC	- Distributed Active Archive Center
DAT	- Digital Archive Tape
DEM	- Digital Elevation Model
EDC	- EROS Data Center
EOS	- Earth Observing System
EOSAT	- Earth Observing Satellite Company
EOSDIS	- EOS Data and Information System
EROS	- Earth Resources Observation System
GAC	- Global Are4a Coverage
GCM	- Global Circulation Model
GIS	- Geographic Information System
GMT	- Greenwich Mean Time
GPS	- Global Positioning System
GRS80	- Geodetic Reference System of 1980
GSFC	- Goddard Space Flight Center
HRPT	- Higher Resolution Picture Transmission
IFC	- Intensive Field Campaign
IFOV	- Instantaneous Field of View
LAC	- Local Area Coverage
LST	- Local Standard Time
MSA	- Modeling Sub-Area
NAD27	- North American Datum 1927
NAD83	- North American Datum 1983
NASA	- National Aeronautics and Space Administration
NDVI	- Normalized Difference Vegetation Index
NeDT	- Noise Equivalent Differential Temperature
NOAA	- National Oceanic and Atmospheric Administration
NRL	- Naval Research Laboratory
NSA	- Northern Study Area
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
RSS	- Remote Sensing Science
SSA	- Southern Study Area
SST	- Sea Surface Temperature
SVAT	- Surface Vegetation and Atmosphere
TE	- Terrestrial Ecology
TF	- Tower Fluxes
TGB	- Trace Gas Biogeochemistry

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TIROS       - Television and Infrared Observation Satellite
TM          - Thematic Mapper
URL         - Uniform Resource Locator
USGS        - United States Geological Survey
UTM         - Universal Transverse Mercator
WGS84       - World Geodetic System of 1984
WRS         - Worldwide Reference System
WWW         - World Wide Web
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Steyaert, L.T., F.G. Hall, and T.R. Loveland, "Modeling Biosphere-Atmosphere Interactions at Various Scales in Support of BOREAS (AFM-12, PI: Dr. R.A. Pielke, Sr.)." In Collected Data of The Boreal Ecosystem-Atmosphere Study. Eds. J. Newcomer, D. Landis, S. Conrad, S. Curd, K. Huemmrich, D. Knapp, A. Morrell, J. Nickeson, A. Papagno, D. Rinker, R. Strub, T. Twine, F. Hall, and P. Sellers. CD-ROM. NASA, 2000.

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13. ABSTRACT *(Maximum 200 words)*
The BOREAS AFM-12 team's efforts focused on regional scale SVAT modeling to improve parameterization of the heterogeneous BOREAS landscape for use in larger scale GCMs. This regional land cover data set was developed as part of a multitemporal 1-km AVHRR land cover analysis approach that was used as the basis for regional land cover mapping, fire disturbance-regeneration, and multiresolution land cover scaling studies in the boreal forest ecosystem of central Canada (Steyaert et al., 1997). This land cover classification was derived by using regional field observations from ground and low-level aircraft transits to analyze spectral-temporal clusters that were derived from an unsupervised cluster analysis of monthly NDVI image composites (April-September 1992). This regional data set was developed for use by BOREAS investigators, especially those involved in simulation modeling, remote sensing algorithm development, and aircraft flux studies. Based on regional field data verification, this multitemporal 1-km AVHRR land cover mapping approach was effective in characterizing the biome-level land cover structure, embedded spatially heterogeneous landscape patterns, and other types of key land cover information of interest to BOREAS modelers.The land cover mosaics in this classification include:
• wet conifer mosaic (low, medium, and high tree stand density), • mixed coniferous-deciduous forest (80% coniferous, codominant, and 80% deciduous), • recent visible burn, vegetation regeneration, or rock outcrops-bare ground-sparsely vegetated slow regeneration burn (four classes), • open water and grassland marshes, • general agricultural land use/ grasslands (three classes)

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