NASA/TM—2000–209891, Vol. 56

Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS)

Forrest G. Hall and Jaime Nickeson, Editors

Volume 56

BOREAS RSS-8 Snow Maps Derived from Landsat TM Imagery

D. Hall, A. Chang, J. Foster, and J.Y.L. Chien

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

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Dorothy Hall, Al Chang, and Jim Foster, Goddard Space Flight Center, Greenbelt, Maryland
Janet Y.L. Chien, GSC

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BOREAS RSS-8 Snow Maps Derived from Landsat TM Imagery

Dorothy K. Hall, Alfred T.C. Chang, James L. Foster, Janet Y.L. Chien

Summary

The BOREAS RSS-8 team utilized Landsat TM images to perform mapping of snow extent over the SSA. This data set consists of two Landsat TM images that were used to determine the snow-covered pixels over the BOREAS SSA on 18-Jan-1993 and on 06-Feb-1994. 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.

Table of Contents

1. Data Set Overview

1.1 Data Set Identification

BOREAS RSS-08 Snow Maps Derived from Landsat TM Imagery

1.2 Data Set Introduction

The Landsat Thematic Mapper (TM) sensor was used to create maps of snow-covered pixels within two winter scenes acquired over the BOReal Ecosystem-Atmosphere Study (BOREAS) Southern Study Area (SSA) in 1993 and 1994. An automated technique for detecting snow-covered pixels using TM image-band ratios and reflectance thresholds was used.

1.3 Objective/Purpose

The objective of obtaining this data set was to use an automated technique to map snow in the BOREAS SSA. The algorithm selected to do this, called SNOMAP, has been developed to map snow using future Earth Observing System (EOS) Moderate-Resolution Imaging Spectroradiometer (MODIS) data. A secondary objective was to compare the results of snow mapping using the Landsat

TM and MODIS Airborne Simulator (MAS) sensors in order to determine the relative accuracy of the snow maps. However, very little MAS data were available for comparison.

Although the Landsat TM sensor can be used as a prototype for the MODIS sensor, it is not ideal as a prototype for MODIS because it does not have the same spectral bands as MODIS and its Field-Of-View (FOV) angle is only ±8°, while that of the MODIS sensor is ±55°. Nevertheless, until receipt of significant MAS data, the TM was the most appropriate prototype sensor available for developing a snow-mapping algorithm for MODIS.

For investigators who are using snow maps in their modeling efforts, the SNOMAP-derived snow maps may be useful.

1.4 Summary of Parameters

Snow in the TM scene and in the BOREAS SSA test site is the parameter of interest.

1.5 Discussion

The experiment was conducted in order to determine the accuracy of snow mapping using the MODIS snow-mapping algorithm, SNOMAP, in different forest types; specifically, deciduous and coniferous forests. Field measurements were acquired simultaneously with the Landsat TM test data. In addition, a National Aeronautics and Space Administration (NASA) ER-2 overflight was flown on 08-Feb-1994. MAS data were acquired using the MAS when it had only seven spectral bands available; only two scenes of MAS data were acquired, and clouds contaminated one of the scenes.

1.6 Related Data Sets

BOREAS HYD-02 Estimated Snow Water Equivalent (SWE) from Microwave
BOREAS Level-2 MAS Imagery: Reflectance and Temperatures in BSQ Format
BOREAS Level-3a Landsat TM Imagery: Scaled At-sensor Radiance in BSQ Format

2 Investigator(s)

2.1 Investigator(s) Names and Title

Principal Investigator:
Dorothy K. Hall Scientist

Co-Investigators:
Alfred T. C. Chang Scientist
James L. Foster Scientist

2.2 Title of Investigation

Automated Snow Mapping in the Southern BOREAS Test Site

2.3 Contact Information

Contact 1:
Dorothy K. Hall
Hydrological Sciences Branch
Code 974
NASA GSFC
Greenbelt, MD 20771
(301) 286-6892
(301) 286-1758 (fax)
Dorothy.K.Hall@gsfc.nasa.gov

Contact 2:
Alfred T.C. Chang
Hydrological Sciences Branch
Code 974
NASA GSFC
Greenbelt, MD 20771
(301) 286-8997
(301) 286-1758 (fax)
Alfred.T.Chang@gsfc.nasa.gov

Contact 3:
James L. Foster
Hydrological Sciences Branch
Code 974
NASA GSFC
Greenbelt, MD 20771
(301) 286-7096
(301) 286-1758 (fax)
James.L.Foster@gsfc.nasa.gov

Contact 4:
Jaime Nickeson
Raytheon ITSS
NASA GSFC
Code 923
Greenbelt, MD 20771
(301) 286-3373
(301) 286-0239 (fax)
Jaime.Nickeson@gsfc.nasa.gov

3. Theory of Measurements

The normalized-difference snow index (NDSI) is useful for the identification of snow and ice and for separating snow/ice and most cumulus clouds to improve identification of snow/ice and decrease reliance on single-band, "universal" thresholds. The NDSI is a measure of the relative magnitude of the characteristic reflectance difference between the visible and short-wave infrared (IR) reflectance of snow. The NDSI is insensitive to a wide range of illumination conditions, is partially normalized for atmospheric effects, and does not depend on reflectance in a single band. The NDSI is analogous to the normalized-difference vegetation index (NDVI). Various other techniques employing band ratio techniques have been used previously to map snow, as discussed in Section 1. For Landsat TM data, the NDSI is calculated as:

NDSI = (TM Band 2 - TM Band 5) /(TM Band 2 + TM Band 5)

Pixels with 50% or greater snow coverage have been found to have NDSI values greater than or equal to 0.4. Separation of snow and water is done by a TM band 4 reflectance test. If the reflectance of TM band 4 is greater than 11%, and the NDSI is greater than or equal to 0.40, snow covers 50% or more of the pixel. The NDSI threshold has been determined from detailed analysis of numerous TM scenes and comparisons with supervised-classification techniques.

4. Equipment

4.1 Sensor/Instrument Description

The TM sensor system records radiation from seven bands in the electromagnetic spectrum. It has a telescope that directs the incoming radiant flux obtained along a scan line through a scan line collector to the visible and near-infrared focal plane, or to the mid-infrared and thermal-infrared cooled focal plane. The detectors for the visible and near-infrared bands (1 to 4) are four staggered linear arrays, each containing 16 silicon detectors. The two mid-infrared detectors are 16 indium-antimonide cells in a staggered linear array, and the thermal-infrared detector is a four-element array of mercury-cadmium-telluride cells. The spectral regions, band widths, and primary use of each channel are given in the following table:

Channel	Wavelength (µm)	Primary Use
1	0.451 - 0.521	Coastal water mapping, soil vegetation differentiation, deciduous/coniferous differentiation.
2	0.526 - 0.615	Green reflectance by healthy vegetation.
3	0.622 - 0.699	Chlorophyll absorption for plant species differentiation.
4	0.771 - 0.905	Biomass surveys, water body delineation.
5	1.564 - 1.790	Vegetation moisture measurement, snow cloud differentiation.
6	10.450 - 12.46	Plant heat stress measurement, other thermal mapping.
7	2.083 - 2.351	Hydrothermal mapping.

4.1.1 Collection Environment

Data were collected on 06-Feb-1994 when the temperatures were very cold (approximately -20 °F). There was generally some cloud cover. The ground was continuously snow covered except for tree branches, stems, and canopies. Coniferous tree canopies were typically snow free, although there was some snow in the canopies. No ground measurements were available for the January 1993 scene.

The BOREAS Landsat TM level-3s and -3p images were acquired through the Canada Centre for Remote Sensing (CCRS). Radiometric corrections and systematic geometric corrections are applied to produce the images in a path-oriented, systematically corrected (level-3s) or precision-corrected (level-3p) form. A full TM image contains 6,920 pixels in each of 5,728 lines. Before any geometric corrections, the ground resolution is 30 m for bands 1, 2, 3, 4, 5, and 7 and 120 m for band 6 at nadir. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single byte field. The level-3s and level-3p images were processed through the CCRS Geocoded Image Correction System (GICS).

4.1.2 Source/Platform

Landsat 4 and/or 5.

4.1.3 Source/Platform Mission Objectives

The Landsat TM is designed to respond to and measure both reflected and emitted Earth surface radiation to enable the investigation, survey, inventory, and mapping of Earth's natural resources.

4.1.4 Key Variables

Reflected radiation, emitted radiation, temperature.

4.1.5 Principles of Operation

The TM is a scanning optical sensor operating in the visible and infrared wavelengths. It contains a scan mirror assembly that directly projects the reflected Earth radiation onto detectors arrayed in two focal planes. The TM achieves better image resolution, sharper color separation, and greater in-flight geometric and radiometric accuracy for seven spectral bands simultaneously than the previous generation sensor, the Multi-Spectral Scanner (MSS). Data collected by the sensor are beamed back to ground receiving stations for processing.

4.1.6 Sensor/Instrument Measurement Geometry

The TM sensor depends on the forward motion of the spacecraft for the along-track scan and uses a moving mirror assembly to scan in the cross-track direction (perpendicular to the spacecraft). The instantaneous field-of-view (IFOV) for each detector from bands 1-5 and band 7 is equivalent to a 30-m square when projected to the ground at nadir; band 6 (the thermal-infrared band) has an IFOV equivalent to a 120-m square at nadir.

4.1.7 Manufacturer of Sensor/Instrument

NASA GSFC
Greenbelt, MD 20771

Hughes Aircraft Company
Santa Barbara Remote Sensing (SBRS)
75 Coromar Drive
Goleta, CA 93117

4.2 Calibration

The internal calibrator, a flex-pivot-mounted shutter assembly, is synchronized with the scan mirror, oscillating at the same 7-Hz frequency. During the turnaround period of the scan mirror, the shutter introduces the calibration source energy and a black direct-current restoration surface into the 100 detector FOV. The calibration signals for bands 1-5 and band 7 are derived from three regulated tungsten-filament lamps.

The calibration source for band 6 is a blackbody with three temperature selections, commanded from the ground. The method for transmitting radiation to the moving calibration shutter allows the tungsten lamps to provide radiation independently and to contribute proportionately to the illumination of all detectors.

4.2.1 Specifications

```
                          Radiometric
Band                   Sensitivity [NE(dP)]*
----                   --------------------
 1                          0.8%
 2                          0.5%
 3                          0.5%
 4                          0.5%
 5                          1.0%
 6                          0.5 K [NE(dT)]
 7                          2.4%
Ground IFOV                30 m (Bands 1-5, 7)
                           120 m (Band 6)
Avg. altitude              699.6 km
Data rate                   85 Mbps
Quantization levels         256
Orbit angle                  8.15°
Orbital nodal Period       98.88 minutes
Scan width                 185 km
Scan angle                 14.9°
Image overlap               7.6%
```

Note: The radiometric sensitivities are the noise-equivalent (NE) reflectance differences for the reflective channels expressed as percentages [NE(dP)], and temperature differences for the thermal-infrared bands [NE(dT)] in Kelvin.

4.2.1.1 Tolerance

The TM channels were designed for an NE differential represented by the radiometric sensitivity shown in Section 4.2.1.

4.2.2 Frequency of Calibration

The absolute radiometric calibration between bands on the TM sensor is maintained by using internal calibrators that are physically located between the telescope and the detectors and are sampled at the end of a scan.

4.2.3 Other Calibration Information

Relative within-band radiometric calibration, to reduce "striping," is provided by a scene-based procedure called histogram equalization. The absolute accuracy and relative precision of this calibration scheme assumes that any changes in the optics of the primary telescope or the "effective radiance" from the internal calibrator lamps are insignificant in comparison to the changes in detector sensitivity and electronic gain and bias with time, and that the scene-dependent sampling is sufficiently precise for the required within-scan destriping from histogram equalization.

Each TM reflective band and the internal calibrator lamps were calibrated prior to launch using lamps in integrating spheres that in turn were calibrated against lamps traceable to calibrated National Bureau of Standards lamps. The absolute radiometric calibration constants in the "short-term" and "long-term" parameter files used for ground processing were modified after launch only when inconsistency existed within or between bands, changes occurred in the inherent dynamic range of the sensors, or it was desirable to make quantized and calibrated values from one sensor match those from another.

5. Data Acquisition Methods

The BOREAS Landsat TM level-3s and -3p images were acquired through the CCRS. Radiometric corrections and systematic or precision geometric corrections are applied to produce the images in a path-oriented form. A full TM image contains 6,920 pixels in each of 5,728 lines. Before any geometric corrections, the ground resolution is 30 m for bands 1-5 and band 7 and 120 m for band 6 at nadir. The pixel values of the images can range from 0 to 255. This allows each pixel to be stored in a single-byte field.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

During the Landsat TM overflight that occurred on 06-Feb-1994, a team of scientists was on the ground in Prince Albert National Park (PANP), Saskatchewan. Observations indicated that the ground was continuously snow covered except for tree stems, canopies, and trunks, which were largely snow free. Some snow, but not very much, was present on the coniferous tree canopy.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The BOREAS level-3a Landsat TM images used for these products were World Reference System (WRS) path/row 37/22-23 and cover the entire SSA and more.

The North American Datum of 1983 (NAD83) corner coordinates of the SSA are:

	Latitude	Longitude
Northwest	54.321 °N	106.228 °W
Northeast	54.225 °N	104.237 °W
Southwest	53.515 °N	106.321 °W
Southeast	53.420 °N	104.368 °W

The NAD83 nominal scene corner coordinates of the scenes used were:

	Latitude	Longitude
Northwest	54.78147 °N	106.23289 °W
Northeast	54.37192 °N	103.44300 °W
Southwest	53.28872 °N	106.91269 °W
Southeast	52.89536 °N	104.21175 °W

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

The images derived here have the same spatial resolution as the Landsat TM level-3a product. The level-3s and -3p Landsat TM images have had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands.

7.1.4 Projection

The two TM scenes processed for this data set were registered to each other. The 06-Feb-1994 scene was used as the reference scene in this case. These products, like the level-3a Landsat TM image, are in a Universal Transverse Mercator (UTM) projection based on the NAD83.

7.1.5 Grid Description

The pixel/grid spacing for each pixel in these images is 30 m in the UTM projection.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The data submitted are snow maps derived from the 18-Jan-1993 and 06-Feb-1994 TM scenes.

7.2.2 Temporal Coverage Map

Not available.

7.2.3 Temporal Resolution

Two Landsat TM winter scenes from 1993 and 1994 were selected to create these snow map products.

7.3 Data Characteristics

7.3.1 Parameter/Variable

Snow cover.

7.3.2 Variable Description/Definition

A snow-covered pixel.

7.3.3 Unit of Measurement

Coded but unitless value.

7.3.4 Data Source

The level-3a Landsat TM images used to create the snow maps were supplied to BOREAS by CCRS.

7.3.5 Data Range

The derived map is binary. Each pixel is considered to be either snow covered or not snow covered. If a pixel is approximately 50% snow covered, it will be mapped as snow. Snow-covered pixels are mapped to a Digital Number (DN) of 1, all others are zero.

7.4 Sample Data Record

Not applicable to image data.

8. Data Organization

8.1 Data Granularity

The smallest unit of this data set tracked by the BOREAS Information System (BORIS) is each individual snow map image.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

Three files comprise the Landsat TM snow map product, one 80-byte American Standard Code for Information Interchange (ASCII) header file and two binary image files. The image files contain one image line per physical record. Each record has 6,930 bytes (image samples) of image data for each of 5,728 records (image lines) on tape. There are no header records in the image files.

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, the image files been compressed with the Gzip (GNU zip) 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 uses the Lempel-Ziv algorithm (Welch, 1994) also used in the zip and PKZIP programs. The compressed files may be uncompressed using gzip (with the -d option) or gunzip. Gzip is available from many Web sites (for example, the 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

The following formula is used to map snow cover:

If (TM2-TM5)/(TM2+TM5) >= 0.4, and RTM4 >= 11%, then the pixel is snow covered.

TM2, TM4, and TM5 are Landsat TM bands 2, 4, and 5, respectively. RTM4 is reflectance of band 4.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff copied the ASCII and compressed the binary files for release on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

The derived map is binary. Each pixel is considered to be either snow covered or not snow covered based on the formula in Section 9.1.

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

There may be errors caused by thin cloud cover being mapped as snow cover, particularly on the 06-Feb-1994 image. In addition, errors could exist where any ground cover was obscured by tree canopies, stems, and trunks.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Data have not been validated.

10.2.2 Confidence Level/Accuracy Judgment

The level-3a TM image data used were of good quality. The quality of the snow maps, however, has not been ascertained.

10.2.3 Measurement Error for Parameters

Percentage of snow mapped in coniferous and deciduous forests has been calculated for the 06-Feb-1994 scene. Approximately 72% of the coniferous forests were mapped as snow covered, while only 14% of the deciduous forests were mapped as snow covered. Though the snow was continuous, areas existed that did not have snow because of tree stems, branches, and trunks. It is not understood why more snow is mapped in the coniferous forests than in the deciduous forests; it may relate to grain-sized differences between scenes.

10.2.4 Additional Quality Assessments

None given.

10.2.5 Data Verification by Data Center

None.

11. Notes

11.1 Limitations of the Data

Data are currently useful only for assessing the ability of the MODIS SNOMAP algorithm to map snow in different forest-cover types.

11.2 Known Problems with the Data

None.

11.3 Usage Guidance

Cirrus clouds obscure much of the 06-Feb-1994 scene.

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

So far, the data set has been used to show that the conventional wisdom that more snow will be mapped in deciduous forests than in coniferous forests is not always true. The opposite of this was found in the case of the 06-Feb-1994 TM image. However, there was no measurable difference in the amount of snow mapped between forest-cover type in the 18-Jan-1993 TM image.

13. Future Modification and Plans

The MODIS algorithm is being modified to map more snow in forests than is currently possible.

14. Software

14.1 Software Description

Software to calculate snow cover from Landsat TM data was developed in-house and is available upon request. Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

Software to calculate snow cover from Landsat TM data can be obtained by contacting Dorothy Hall, Code 974, NASA GSFC, Dorothy.K.Hall@gsfc.nasa.gov. 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 RSS-08 snow map 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

The snow maps can be made available on 8-mm or Digital Archive Tape (DAT) media.

16.2 Film Products

None.

16.3 Other Products

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

17. References

17.1 Platform/Sensor/Instrument/Data Processing Documentation

Welch, T.A. 1984. A Technique for High Performance Data Compression. IEEE Computer, Vol. 17, No. 6, pp. 8-19.

17.2 Journal Articles and Study Reports

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17.3 Archive/DBMS Usage Documentation

None.

18. Glossary of Terms

None.

19. List of Acronyms

```
ASCII   - American Standard Code for Information Interchange
BOREAS  - BOReal Ecosystem-Atmosphere Study
BORIS   - BOREAS Information System
BPI     - Bytes Per Inch
BSQ     - Band Sequential
CCRS    - Canada Centre for Remote Sensing
CCT     - Computer Compatible Tape
CD-ROM  - Compact Disk-Read-Only Memory
DAAC    - Distributed Active Archive Center
DAT     - Digital Archive Tape
DN      - Digital Number
EOS     - Earth Observing System
EOSDIS  - EOS Data and Information System
FOV     - Field Of View
GICS    - Geocoded Image Correction System
GIS     - Geographic Information System
GSFC    - Goddard Space Flight Center
HYD     - Hydrology
IFOV    - Instantaneous Field-of-View
IR      - Infrared
MAS     - MODIS Airborne Simulator
MODIS   - Moderate-Resolution Imaging Spectroradiometer
MSS     - Multi-Spectral Scanner
NAD83   - North American Datum of 1983
NASA    - National Aeronautics and Space Administration
NDSI    - Normalized Difference Snow Index
NDVI    - Normalized Difference Vegetation Index
NE      - Noise Equivalent
NSA     - Northern Study Area
ORNL    - Oak Ridge National Laboratory
PANP    - Prince Albert National Park
RSS     - Remote Sensing Science
SBRS    - Santa Barbara Remote Sensing
SSA     - Southern Study Area
SWE     - Snow Water Equivalent
TM      - Thematic Mapper
URL     - Uniform Resource Locator
UTM     - Universal Transverse Mercator
WRS     - World Reference System
WWW     - World Wide Web
```

20. Document Information

20.1 Document Revision Dates
Written: 15-Dec-1996
Last Updated: 16-Jul-1999

20.2 Document Review Dates
BORIS Review: 10-Sep-1997
Science Review: 15-Nov-1997

20.3 Document ID

20.4 Citation

If this data set is referenced by another investigator, please acknowledge the paper by Hall et al., 1997, in Section 17.2.

If using data from the BOREAS CD-ROM series, also reference the data as:

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Dorothy Hall, Al Chang, Jim Foster, and Janet Y.L. Chien
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The BOREAS RSS-8 team utilized Landsat TM images to perform mapping of snow extent over the SSA. This data set consists of two Landsat TM images that were used to determine the snow-covered pixels over the BOREAS SSA on 18-Jan-1993 and on 06-Feb-1994. The data are stored in binary image format files.

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