



**Technical Report Series on the
Biosphere-Atmosphere Study (BOREAS)**

Volume 99, Editor

99

**BOREAS Level-3s Landsat TM Imagery:
Radiance in LGSOWG**

by D. Knapp, J.A. Newcomer, and J. Cihlar

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

Forrest G. Hall, Editor

Volume 99

BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format

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BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format

Jaime Nickeson, David Knapp, Jeffrey A. Newcomer, Josef Cihlar

Summary

For BOREAS, the level-3s Landsat TM data, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. CCRS collected and supplied the level-3s images to BOREAS for use in the remote sensing research activities. Geographically, the bulk of the level-3s images cover the BOREAS NSA and SSA with a few images covering the area between the NSA and SSA. Temporally, the images cover the period of 22-Jun-1984 to 30-Jul-1996. The images are available in binary, image-format files.

Note that the level-3s Landsat TM data are not contained on the BOREAS CD-ROM set. An inventory listing file is supplied on the CD-ROM to inform users of the data that were collected. See Sections 15 and 16 for information about how to acquire the data.

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1. Data Set Overview

1.1 Data Set Identification

BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format

1.2 Data Set Introduction

The BOREal Ecosystem-Atmosphere Study (BOREAS) Staff Science effort covered those activities that were BOREAS community-level activities, or required uniform data collection procedures across sites and time. These activities included the acquisition of the relevant satellite data. Data from the Landsat Thematic Mapper (TM) instruments on the Landsat satellites were acquired by the Canada Centre for Remote Sensing (CCRS) and provided for use by BOREAS researchers.

1.3 Objective/Purpose

For BOREAS, the Landsat TM imagery, along with the other remotely sensed images, was collected in order to provide spatially extensive information over the primary study areas. This information includes detailed land cover and biophysical parameter maps such as biomass, Fraction of Photosynthetically Active Radiation (FPAR), and Leaf Area Index (LAI).

1.4 Summary of Parameters

Landsat TM level-3s data in the BOREAS Information System (BORIS) contains the following parameters:

Original image header information, image coordinates, gains and offsets for each band for at-sensor radiance derivations, image bands 1 to 7 processed with systematic spatial corrections.

1.5 Discussion

Use and distribution of the level-3s Landsat TM images are subject to copyright restrictions. CCRS and Radarsat International (RSI) granted permission to BOREAS to place a subset of the level-3a Landsat TM images on the BOREAS CD-ROM series; however, none of the level-3b images are included. The level-3s images may not be available for public access. Please see Sections 15 and 16 for further details.

BORIS staff processed the Landsat TM level-3s imagery by:

- Extracting pertinent header information from the level-3s image product and placing it in an American Standard Code for Information Interchange (ASCII) file on disk.
- Reading the information in the ASCII disk file and loading the online data base with pertinent information.

1.6 Related Data Sets

BOREAS Level-3a Landsat TM Imagery: Scaled At-sensor Radiance in BSQ Format

BOREAS Level-3b Landsat TM Imagery: At-sensor Radiances in BSQ Format

BOREAS Level-3p Landsat TM Imagery: Geocoded and Scaled At-sensor Radiance

BOREAS Level-3s SPOT Imagery: Scaled At-sensor Radiance in LGSOWG Format

2. Investigator(s)

2.1 Investigator(s) Name and Title

BOREAS Staff Science

2.2 Title of Investigation

BOREAS Staff Science Satellite Data Acquisition Program

2.3 Contact Information

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3. Theory of Measurements

The Landsat series of satellites began with the Earth Resources Technology Satellite (ERTS) launched in July 1972. This satellite was renamed Landsat 1 in 1975 to reflect its primary use as a land resource observatory. Through its onboard instruments, Landsat monitors Earth's mountain ranges, deserts, forests, and crops by measuring the light waves they reflect.

The second generation of Landsat satellites (4 and 5) marked a significant advance in remote sensing through the addition of the more sophisticated TM sensor, with higher spectral and spatial resolution, and faster data processing at a highly automated data processing facility at the National Aeronautics and Space Administration (NASA) Goddard Space Flight Center (GSFC) in Greenbelt, MD. For BOREAS, the CCRS receiving station in Prince Albert, Saskatchewan, collected the raw data. Processing of the raw data to the level-3p images was performed with the Geocoded Image Correction System (GICS; Friedel, 1992) at the CCRS facility in Ottawa.

As Landsat's instrument mirrors scan Earth's surface, light enters the instrument optics, where it is focused on specially calibrated detector arrays. Onboard electronics encode the detector voltage as binary digits or bits. These digital image data are then relayed back to Earth to be processed into film and Computer-Compatible Tape (CCT) products, which are subsequently used for Earth resources analysis.

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 and cloud differentiation. |

| | | |
|---|-----------------|---|
| 6 | 10.450 - 12.460 | Plant heat stress measurement, other thermal mapping. |
| 7 | 2.083 - 2.351 | Hydrothermal mapping. |

4.1.1 Collection Environment

The BOREAS Landsat TM level-3s images were acquired through the CCRS. Radiometric corrections and systematic geometric corrections are applied to produce the images in a path-oriented and systematically corrected (level-3s) 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 images were processed through the CCRS GICS. The Landsat satellite orbits Earth at an altitude of 705 km.

4.1.2 Source/Platform

Although the majority of the BOREAS Landsat TM imagery was acquired by the instrument onboard Landsat 5, some imagery was obtained with the TM sensor on the Landsat 4 platform.

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 MultiSpectral 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 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 Santa Barbara Remote Sensing (SBRS)
Goleta, CA

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 field-of-view (FOV).

The calibration signals for bands 1-5 and 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

| Band | Radiometric 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 degrees |
| Orbital nodal period | 98.88 minutes |
| Scan width | 185 km |
| Scan angle | 14.9 degrees |
| 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 Kelvins.

4.2.1.1 Tolerance

The TM channels were designed for a 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 located between the telescope and the detectors that 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. Because of the absolute accuracy and relative precision of this calibration scheme, it is assumed 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 were in turn 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 if there was an inconsistency within or between bands, a change in the inherent dynamic range of the sensors, or a desire to make quantized and calibrated values from one sensor match those from another.

5. Data Acquisition Methods

The BOREAS Landsat TM level-3s imagery was acquired through the CCRS. Radiometric corrections and systematic geometric corrections are applied to produce the images in a path-oriented, systematically corrected spatial form. A full level-3s TM image contains 6,920 pixels in each of 5,728 lines (see Section 11.2). Before any geometric corrections, the ground resolution is 30 m for bands 1-5 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 images were processed through the CCRS GICS system.

6. Observations

6.1 Data Notes

None.

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

7.1.1 Spatial Coverage

The BOREAS level-3s Landsat TM images primarily cover the Southern Study Area (SSA) and the Northern Study Area (NSA). Some of the imagery covers the transect area between the SSA and the NSA or the Prince Albert National Park (PANP) west of the SSA. The SSA and the NSA are located in the southwest and northeast portions of the overall region. A full TM scene covers approximately 31,000 square kilometers.

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 corner coordinates of the NSA are:

| | Latitude | Longitude |
|-----------|----------|-----------|
| | ----- | ----- |
| Northwest | 56.249 N | 98.825 W |
| Northeast | 56.083 N | 97.234 W |
| Southwest | 55.542 N | 99.045 W |
| Southeast | 55.379 N | 97.489 W |

7.1.2 Spatial Coverage Map

Not available.

7.1.3 Spatial Resolution

Before any geometric corrections, the spatial resolution is 30 m for bands 1-5 and 7 and 120 m for band 6 at nadir. These values increase with scan angle away from the nadir path. The level-3s Landsat TM images have had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands. These level-3s images have a high level of internal spatial integrity but the actual geographic coordinates contained in the image header can be offset from their actual positions by as much as 20 km (personal communication with CCRS personnel, 1994).

7.1.4 Projection

The level-3s Landsat TM images are placed in a Universal Transverse Mercator (UTM) projection based on NAD83. Detailed projection parameter information for the individual images is contained in the leader file(s).

7.1.5 Grid Description

The pixel/grid spacing for each pixel in the level-3s Landsat TM images is 30 m in the UTM projection. Detailed grid parameter information for the individual images is contained in the leader file(s).

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The BOREAS level-3s Landsat TM acquisitions cover 22-Jun-1984 to 30-Jul-1996. Imagery acquired before the BOREAS field campaigns were conducted is included in the BOREAS archive with imagery collected during the project. Historical Landsat data have been acquired by CCRS routinely since the launch of Landsat 1 and are kept in the CCRS archive. Since the mid-1980s, CCRS has been acquiring and archiving all Landsat data over Canada during the growing season; however, during the winter, only requested data were obtained. For BOREAS, this policy was modified to obtain data throughout the year over the BOREAS region. The acquired data are archived by CCRS and can be interrogated to ascertain which scenes were archived and their characteristics.

7.2.2 Temporal Coverage Map

| Date | Study Area | Date | Study Area |
|-------------|------------|-------------|------------|
| ----- | ----- | ----- | ----- |
| 11-Jul-1984 | SSA | 22-Jun-1984 | NSA |
| 12-Aug-1984 | SSA | 19-Aug-1985 | NSA |
| 07-Jul-1985 | SSA | 15-Aug-1986 | NSA |
| 11-Aug-1986 | SSA | 01-Jun-1988 | NSA |
| 18-Aug-1986 | SSA | 20-Aug-1988 | NSA |
| 30-Aug-1987 | SSA | 05-Sep-1988 | NSA |
| 20-Jun-1988 | SSA | 07-Aug-1989 | NSA |
| 06-Jul-1988 | SSA | 25-Jul-1990 | NSA |
| 23-Aug-1988 | SSA | 28-Jul-1991 | NSA |
| 02-Jul-1989 | SSA | 06-Aug-1992 | NSA |
| 04-Sep-1989 | SSA | 02-Aug-1993 | NSA |
| 06-Aug-1990 | SSA | 10-Feb-1994 | NSA |
| 06-Aug-1990 | SSA | 09-Jun-1994 | NSA |
| 29-Aug-1990 | SSA | 13-Feb-1995 | NSA |
| 05-May-1991 | SSA | 09-Apr-1995 | NSA |
| 06-Jun-1991 | SSA | 11-May-1995 | NSA |
| 24-Jul-1991 | SSA | 21-Jun-1995 | NSA |
| 09-Aug-1991 | SSA | 22-May-1996 | NSA |
| 10-Sep-1991 | SSA | 09-Jul-1996 | NSA |
| 15-Jun-1992 | SSA | | |
| 18-Jan-1993 | SSA | Date | Study Area |
| 29-Jul-1993 | SSA | ----- | ----- |
| 06-Feb-1994 | SSA | 23-Aug-88 | PANP |
| 20-Apr-1994 | SSA | 12-Jul-90 | PANP |
| 07-Jun-1994 | SSA | | |
| 29-Mar-1995 | SSA | Date | Study Area |
| 03-Jul-1995 | SSA | ----- | ----- |
| 21-Sep-1995 | SSA | 05-Aug-89 | Transect |
| 27-Jan-1996 | SSA | 23-Jul-90 | Transect |
| 02-May-1996 | SSA | | |
| 30-Jul-1996 | SSA | | |

7.2.3 Temporal Resolution

The Landsat TM satellite revisit frequency is 16 days for each path/row; however, in the BOREAS region the overlap between adjacent scene paths is about 50%.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The main parameter contained in the image data files is scaled at-sensor radiance. The parameters contained in the inventory listing file on the CD-ROM are:

```

      Column Name
-----
SPATIAL_COVERAGE
DATE_OBS
START_TIME
END_TIME
PLATFORM

```

INSTRUMENT
 NUM_BANDS
 BAND_QUALITY
 CLOUD_COVER
 PATH_NUM
 ROW_NUM
 NW_LATITUDE
 NW_LONGITUDE
 NE_LATITUDE
 NE_LONGITUDE
 SW_LATITUDE
 SW_LONGITUDE
 SE_LATITUDE
 SE_LONGITUDE
 PLATFORM_ALTITUDE
 MIN_SOLAR_ZEN_ANG
 MAX_SOLAR_ZEN_ANG
 MIN_SOLAR_AZ_ANG
 MAX_SOLAR_AZ_ANG
 CRTFCN_CODE

7.3.2 Variable Description/Definition

For the image data files:

Scaled at-sensor radiance - The scaled value representing the quantized DN derived by the TM scanning system radiant energy incident on the sensor aperture at the time of data collection in the specific TM wavelength regions.

The descriptions of the parameters contained in the inventory listing file on the CD-ROM are:

| Column Name | Description |
|------------------|---|
| SPATIAL_COVERAGE | The general term used to denote the spatial area over which the data were collected. |
| DATE_OBS | The date on which the data were collected. |
| START_TIME | The starting Greenwich Mean Time (GMT) for the data collected. |
| END_TIME | The ending Greenwich Mean Time (GMT) for the data collected. |
| PLATFORM | The object (e.g., satellite, aircraft, tower, person) that supported the instrument. |
| INSTRUMENT | The name of the device used to make the measurements. |
| NUM_BANDS | The number of spectral bands in the data. |
| BAND_QUALITY | The data analyst's assessment of the quality of the spectral bands in the data. |
| CLOUD_COVER | The data analyst's assessment of the cloud cover that exists in the data. |
| PATH_NUM | For Landsat and SPOT, the sequential number given to the orbital paths trending from northeast to southwest and extending around the earth. |
| ROW_NUM | For Landsat and SPOT, the sequential number given to the nominal scene acquisition points |

along the orbital paths which trend from northeast to southwest.

NW_LATITUDE The NAD83 based latitude coordinate of the northwest corner of the minimum bounding rectangle for the data.

NW_LONGITUDE The NAD83 based longitude coordinate of the northwest corner of the minimum bounding rectangle for the data.

NE_LATITUDE The NAD83 based latitude coordinate of the northeast corner of the minimum bounding rectangle for the data.

NE_LONGITUDE The NAD83 based longitude coordinate of the northeast corner of the minimum bounding rectangle for the data.

SW_LATITUDE The NAD83 based latitude coordinate of the southwest corner of the minimum bounding rectangle for the data.

SW_LONGITUDE The NAD83 based longitude coordinate of the southwest corner of the minimum bounding rectangle for the data.

SE_LATITUDE The NAD83 based latitude coordinate of the southeast corner of the minimum bounding rectangle for the data.

SE_LONGITUDE The NAD83 based longitude coordinate of the southeast corner of the minimum bounding rectangle for the data.

PLATFORM_ALTITUDE The nominal altitude of the data collection platform above the target.

MIN_SOLAR_ZEN_ANG The minimum angle from the surface normal (straight up) to the sun during the data collection.

MAX_SOLAR_ZEN_ANG The maximum angle from the surface normal (straight up) to the sun during the data collection.

MIN_SOLAR_AZ_ANG The minimum azimuthal direction of the sun during data collection expressed in clockwise increments from North.

MAX_SOLAR_AZ_ANG The maximum azimuthal direction of the sun during data collection expressed in clockwise increments from North.

CRTFCN_CODE The BOREAS certification level of the data. Examples are CPI (Checked by PI), CGR (Certified by Group), PRE (Preliminary), and CPI-??? (CPI but questionable).

7.3.3 Unit of Measurement

The units for the scaled at-sensor radiance values vary by band. To obtain at-sensor radiance values in Watts/(m² * sr * μm) use the formula:

$$\text{At-sensor Radiance} = \text{Scaled Value} * \text{Gain} + \text{Offset}$$

where the gain and Offset values are contained in the ASCII header file. The measurement units for the parameters contained in the inventory listing file on the CD-ROM are:

| Column Name | Units |
|-------------------|-------------|
| SPATIAL_COVERAGE | [none] |
| DATE_OBS | [DD-MON-YY] |
| START_TIME | [HHMM GMT] |
| END_TIME | [HHMM GMT] |
| PLATFORM | [none] |
| INSTRUMENT | [none] |
| NUM_BANDS | [counts] |
| BAND_QUALITY | [none] |
| CLOUD_COVER | [none] |
| PATH_NUM | [unitless] |
| ROW_NUM | [unitless] |
| NW_LATITUDE | [degrees] |
| NW_LONGITUDE | [degrees] |
| NE_LATITUDE | [degrees] |
| NE_LONGITUDE | [degrees] |
| SW_LATITUDE | [degrees] |
| SW_LONGITUDE | [degrees] |
| SE_LATITUDE | [degrees] |
| SE_LONGITUDE | [degrees] |
| PLATFORM_ALTITUDE | [meters] |
| MIN_SOLAR_ZEN_ANG | [degrees] |
| MAX_SOLAR_ZEN_ANG | [degrees] |
| MIN_SOLAR_AZ_ANG | [degrees] |
| MAX_SOLAR_AZ_ANG | [degrees] |
| CRTFCN_CODE | [none] |

7.3.4 Data Source

The data contained in the level-3s Landsat TM data files come from various portions of the Landsat satellite, the TM instrument, and the ground processing components. The level-3s Landsat TM images were supplied to BOREAS by the CCRS. The sources of the parameter values contained in the inventory listing file on the CD-ROM are:

| Column Name | Data Source |
|------------------|--|
| SPATIAL_COVERAGE | [Determined by BORIS software from latitude and longitude information contained on the level-3s data files.] |
| DATE_OBS | [Determined by BORIS software from data and time information contained on the level-3s data files.] |
| START_TIME | [Determined by BORIS software from data and time information contained on the level-3s data files.] |
| END_TIME | [Determined by BORIS software from data and time information contained on the level-3s data files.] |

| | |
|-------------------|--|
| | information contained on the level-3s data files.] |
| PLATFORM | [Determined by BORIS software from platform information contained on the level-3s data files.] |
| INSTRUMENT | [Constant software value] |
| NUM_BANDS | [Determined by BORIS software from processing of the data files.] |
| BAND_QUALITY | [Assessed by BORIS personnel from viewing the image.] |
| CLOUD_COVER | [Assessed by BORIS personnel from viewing the image.] |
| PATH_NUM | [Determined by BORIS software from location information contained on the level-3s data files.] |
| ROW_NUM | [Determined by BORIS software from location information contained on the level-3s data files.] |
| NW_LATITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| NW_LONGITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| NE_LATITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| NE_LONGITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| SW_LATITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| SW_LONGITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| SE_LATITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| SE_LONGITUDE | [Determined by BORIS software from location information contained on the level-3s data files.] |
| PLATFORM_ALTITUDE | [Determined by BORIS software from platform information contained on the level-3s data files.] |
| MIN_SOLAR_ZEN_ANG | [Calculated with software from latitude and longitude and time information] |
| MAX_SOLAR_ZEN_ANG | [Calculated with software from latitude and longitude and time information] |
| MIN_SOLAR_AZ_ANG | [Calculated with software from latitude and longitude and time information] |
| MAX_SOLAR_AZ_ANG | [Calculated with software from latitude and longitude and time information] |
| CRTFCN_CODE | [Assigned by BORIS based on processing.] |

7.3.5 Data Range

The maximum range of scaled at-sensor radiance values in each level-3s Landsat TM image band is limited from 0 (zero) to 255 so that the values can be stored in a single 8-bit (1-byte) field. The following table gives information about the parameter values found in the inventory table on the CD-ROM.

| Column Name | Minimum Data Value | Maximum Data Value | Missng Data Value | Unrel Data Value | Below Detect Limit | Data Not Cllctd |
|-------------------|--------------------|--------------------|-------------------|------------------|--------------------|-----------------|
| SPATIAL_COVERAGE | N/A | N/A | None | None | None | None |
| DATE_OBS | 22-JUN-84 | 30-JUL-96 | None | None | None | None |
| START_TIME | 1638 | 1735 | None | None | None | None |
| END_TIME | 1638 | 1735 | None | None | None | None |
| PLATFORM | LANDSAT-5 | LANDSAT-5 | None | None | None | None |
| INSTRUMENT | THEMATIC MAPPER | THEMATIC MAPPER | None | None | None | None |
| NUM_BANDS | 7 | 7 | None | None | None | None |
| BAND_QUALITY | N/A | N/A | None | None | None | None |
| CLOUD_COVER | N/A | N/A | None | None | None | None |
| PATH_NUM | 33 | 38 | None | None | None | None |
| ROW_NUM | 20 | 23 | None | None | None | None |
| NW_LATITUDE | 54.00009 | 60.00021 | None | None | None | None |
| NW_LONGITUDE | -108.08837 | -98.75538 | None | None | None | None |
| NE_LATITUDE | -106.98707 | 57.82097 | None | None | None | None |
| NE_LONGITUDE | -105.45392 | -95.82957 | None | None | None | None |
| SW_LATITUDE | 52.52631 | 56.77072 | None | None | None | None |
| SW_LONGITUDE | -108.75375 | 54.95387 | None | None | None | None |
| SE_LATITUDE | 52.13967 | 56.33999 | None | None | None | None |
| SE_LONGITUDE | -106.10096 | -96.68568 | None | None | None | None |
| PLATFORM_ALTITUDE | 705300 | 705300 | None | None | None | None |
| MIN_SOLAR_ZEN_ANG | 35.2 | 77.9 | None | None | None | None |
| MAX_SOLAR_ZEN_ANG | 35.2 | 77.9 | None | None | None | None |
| MIN_SOLAR_AZ_ANG | 132.5 | 154.6 | None | None | None | None |
| MAX_SOLAR_AZ_ANG | 132.5 | 154.6 | None | None | None | None |
| CRTFCN_CODE | CPI | CPI | None | None | None | None |

- Minimum Data Value -- The minimum value found in the column.
- Maximum Data Value -- The maximum value found in the column.
- Missng Data Value -- The value that indicates missing data. This is used to indicate that an attempt was made to determine the parameter value, but the attempt was unsuccessful.
- Unrel Data Value -- The value that indicates unreliable data. This is used to indicate an attempt was made to determine the parameter value, but the value was deemed to be unreliable by the analysis personnel.
- Below Detect Limit -- The value that indicates parameter values below the instruments detection limits. This is used to indicate that an attempt was made to determine the parameter value, but the analysis personnel determined that the parameter value was below the detection limit of the instrumentation.
- Data Not Cllctd -- This value indicates that no attempt was made to determine the parameter value. This usually indicates that BORIS combined several similar but

not identical data sets into the same data base table but this particular science team did not measure that parameter.

Blank -- Indicates that blank spaces are used to denote that type of value.
N/A -- Indicates that the value is not applicable to the respective column.
None -- Indicates that no values of that sort were found in the column.

7.4 Sample Data Record

A sample data record for the level-3s Landsat TM images is not available here. The following are wrapped versions of the first few records from the level-3s Landsat TM inventory table on the CD-ROM:

```
SPATIAL_COVERAGE, DATE_OBS, START_TIME, END_TIME, PLATFORM, INSTRUMENT, NUM_BANDS,  
BAND_QUALITY, CLOUD_COVER, PATH_NUM, ROW_NUM, NW_LATITUDE, NW_LONGITUDE, NE_LATITUDE,  
NE_LONGITUDE, SW_LATITUDE, SW_LONGITUDE, SE_LATITUDE, SE_LONGITUDE, PLATFORM_ALTITUDE,  
MIN_SOLAR_ZEN_ANG, MAX_SOLAR_ZEN_ANG, MIN_SOLAR_AZ_ANG, MAX_SOLAR_AZ_ANG, CRTFCN_CODE  
'NSA', 22-JUN-84, 1701, 1701, 'LANDSAT-5', 'THEMATIC_MAPPER', 7, 'GOOD', '50%', 33, 21,  
56.84831, -98.92454, 56.4284, -96.0968, 55.36081, -99.67174, 54.94405, -96.84661,  
705300.0, 36.5, 36.5, 142.8, 142.8, 'CPI'  
'SSA', 11-JUL-84, 1732, 1732, 'LANDSAT-5', 'THEMATIC_MAPPER', 7, 'GOOD',  
'20% CLOUD COVER', 38, 22, 55.0951, -107.49632, 54.69609, -104.78902, 53.60613,  
-108.1927, 53.2059, -105.47743, 705300.0, 37.0, 37.0, 140.0, 140.0, 'CPI'
```

8. Data Organization

8.1 Data Granularity

The smallest unit of data for level-3s Landsat TM imagery is a full TM scene.

8.2 Data Format(s)

The CD-ROM inventory listing file consists of numerical and character fields of varying length separated by commas. The character fields are enclosed within single apostrophe marks. There are no spaces between the fields.

The level-3s Landsat TM imagery from CCRS is stored in either a band sequential (BSQ) or band interleaved by line (BIL) form. General information on these two formats is provided in the subsequent sections. Detailed information on these can be obtained from the CCRS document referenced in Section 17.1.

8.2.1 Band Sequential Format

The files associated with a band sequential TM scene are as follows:

```
File 1  volume directory  
File 2  leader file band 1  
File 3  TM band 1  
File 4  trailer file band 1  
File 5  leader file band 2  
File 6  TM band 2  
File 7  trailer file band 2  
       and so on...  
File 21 TM band 7  
File 22 trailer file band 7  
File 23 null volume file
```

If there are multiple scenes on a tape, the next scene would occupy files 24-46, 23 files exactly as above. Up to four TM scenes (92 files) are contained on one 8-mm tape. There are multiple-volume directory files on one tape media because the 8-mm tapes were generated by copying the original 9-track tapes, and each one of the 9-track tapes had its own volume directory. Each image file in BSQ format contains data for one spectral band.

8.2.1.1 BSQ Leader Files

The contents of Leader files have been defined in detail by the LGSOWG Technical Working Group (LTWG). The contents of the Leader files are as follows:

File descriptor record; Scene header record; Map projection (scene-related) ancillary record; Radiometric transformation ancillary record.

All leader files contain fixed length records 4,320 bytes in length and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.1.2 BSQ Imagery File

The BSQ image files have 5,729 records, with each record containing 7,020 bytes. The first record in this file is a header record, followed by 5,728 image records.

The contents of the Scene Header record are specified by LTWG standards and contain information relating to the mission, sensor parameters, processing options, and geometric parameters for the sensor.

Each image record contains 32 bytes of prefix data, 6,920 bytes of image data, and 68 bytes of suffix data ($32 + 6920 + 68 = 7020$). Each image is oriented so that pixel 1, line 1 is in the upper left-hand (i.e., northwest) corner of the screen display. Pixels and lines progress left to right and top to bottom so that pixel n , line n is in the lower right-hand corner.

8.2.1.3 BSQ Trailer File

The trailer file contains information associated with the image data not always available before writing the image data, such as data and recording quality and data summaries. Each trailer file contains a file descriptor record and trailer records for all bands of imagery in the associated imagery file. All trailer files contain fixed-length records of 4,320 bytes and contain both ASCII and binary data. For specific details, see the CCRS documentation referenced in Section 17.1.

8.2.2 Band Interleaved by Line Format

The files associated with a BIL TM scene are as follows:

```
File 1  volume directory
File 2  leader file bands 1-7
File 3  TM bands 1-7 (first 1/3 of scene - 1910 lines)
File 4  volume directory
File 5  TM bands 1-7 (second 1/3 of scene - 1909 lines)
File 6  volume directory
File 7  TM bands 1-7 (final 1/3 of scene - 1909 lines)
File 8  trailer
File 9  null volume file
```

If there are multiple scenes on a tape, the next scene would occupy files 10-18, 9 files exactly as above. Up to four TM scenes (36 files) are contained on one 8-mm tape. There are multiple volume directory files on one tape media because the 8-mm tapes were generated from copying the original 9-track tapes, and each one of the 9-track tapes had its own volume directory. The image files in BIL format contain image data for one or more spectral bands.

8.2.2.1 BIL Leader Files

See BSQ leader files.

8.2.2.2 BIL Imagery File

The three BIL image files have 13,371, 13,363, and 13,363 records, respectively, with each record containing 7,020 bytes. The first record in the first imagery file is the header record, followed by 13,370 image records for a total of 1,910 lines of the scene for all seven bands (1910 lines x 7 bands = 13370 records). The second two imagery files each contain 13,363 image records for a total of 1,909 lines of the scene for all seven bands (1909 lines x 7 bands = 13370 records). In a BIL image file, the first seven image records are line 1, bands 1-7, respectively; the next seven image records are line 2, bands 1-7, respectively; and so on. Each image record contains 32 bytes of prefix data, 6,920 bytes of image data, and 68 bytes of suffix data (32 + 6920 + 68 = 7020).

Each image is oriented so that pixel 1, line 1 is in the upper left-hand (i.e., northwest) corner of the screen display. Pixels and lines progress left to right and top to bottom so that pixel n, line n is in the lower right-hand corner.

8.2.2.3 BIL Trailer File

See BSQ trailer file.

9. Data Manipulations

9.1 Formulae

None.

9.1.1 Derivation Techniques and Algorithms

Not applicable.

9.2 Data Processing Sequence

9.2.1 Processing Steps

BORIS staff processed a level-3s Landsat TM image by:

- Extracting pertinent header information from the level-3s image product and writing it to a disk file.
- Reading the information in the disk file and loading the online data base with needed information.

Some cloud cover and image quality assessment information is generated when BORIS processes the level-3s images to level-3a products. This information is entered into the BORIS data base but is not included with the images on tape. To obtain this information, see Section 15.1.

9.2.2 Processing Changes

None.

9.3 Calculations

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

Errors could arise in the acquired imagery from location inaccuracy, distortion of lengths, anisomorphism, the instrument's local coherence, and multispectral registrability. Other errors could arise from inherent radiometric imperfections of the sensors.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Whatever the processing level, the geometric quality of the image depends on the accuracy of the viewing geometry. Spectral errors could arise from image-wide signal-to-noise ratio, saturation, cross-talk, spikes, and response normalization due to change in gain.

10.2.2 Confidence Level/Accuracy Judgment

Assessment of accuracy of the absolute radiometric constants is difficult. The uncertainties in prelaunch and postlaunch updates of the absolute calibration constants are nominally specified to be less than 10%. A root mean square (rms) summing of known errors in the prelaunch calibration suggests that this may be a reasonable estimate of overall uncertainty in the prelaunch calibration.

There are also known, but as yet uncorrected, effects associated with temperature-dependence of the TM internal calibrator that may be contributing to apparent discontinuous changes at launch and to the continuous changes of gain while in orbit. Additional uncertainties for exoatmospheric reflectances are probably less than 2% in the visible/near-infrared and less than 5% in the shortwave infrared portion of the spectrum as judged by the current differences in estimates of the solar irradiance.

The level-3s Landsat TM imagery has had geometric corrections applied so that the spatial resolution for all pixels is 30 m in all bands. The level-3s imagery has a high level of internal spatial integrity, but the geographic coordinate information contained on the tape can be offset from the actual positions by as much as 20 km.

10.2.3 Measurement Error for Parameters

None given.

10.2.4 Additional Quality Assessments

The reproducibility of ground measurements at White Sands, NM, at times of Landsat TM overpass to about 5% for five dates for bands 1-4 suggests a potential for monitoring sensor change for the whole system with time. Images are screened for level of cloud cover before BORIS processing.

10.2.5 Data Verification by Data Center

BORIS staff used developed software to extract information for logging the data into a relational data base. In addition, the software read through the records of the files checking for proper record sizes.

11. Notes

11.1 Limitations of the Data

To date, no discrepancies/problems have been noted in the data.

11.2 Known Problems with the Data

To date, the following discrepancies/problems have been noted in the data:

- Some header files refer to Level-1S rather than Level-3S or to L1S rather than L3S since they were created by software prior to BORIS finalization of data categories..

11.3 Usage Guidance

None.

11.4 Other Relevant Information

None.

12. Application of the Data Set

The level-3s Landsat TM images are useful for anyone interested in high spatial resolution imagery over the entire NSA or SSA.

13. Future Modifications and Plans

None.

14. Software

14.1 Software Description

BORIS staff developed software and command procedures for:

- Extracting header information from level-3s Landsat TM images on tape and writing to ASCII files on disk.
- Reading the ASCII disk file and logging the level-3 Landsat TM image products into the Oracle data base tables.
- Converting coordinates in the leader file(s) between the geographic systems of (latitude, longitude), UTM (northing, easting), and BOREAS (x,y) grid locations.

The software mentioned under items 1 and 2 is written in the C language and is operational on VAX 6410 and MicroVAX 3100 systems at GSFC. The primary dependencies in the software are the tape I/O library and the Oracle data base utility routines.

The geographic coordinate conversion utility (BOR_CORD) has been tested and used on Macintosh, IBM PC, VAX, Silicon Graphics, and Sun workstations.

14.2 Software Access

All of the described software is available upon request. BORIS staff would appreciate knowing of any problems discovered with the software, but cannot promise to fix them.

15. Data Access

The level-3s Landsat TM images 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: ornl~~daac~~@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

Although the BOREAS level-3s Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office to get the most recent information.

Users may obtain information about the 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 Landsat TM level-3s data can be made available on 8 mm, Digital Archive Tape (DAT), or 9-track tapes at 1600 or 6250 Bytes Per Inch (BPI).

Although the BOREAS level-3s Landsat TM images are being held in a public archive, copyright restrictions limit the distribution and use of the data. The BOREAS CD-ROM series is publicly available and contains some of the level-3a Landsat TM images. However, other Landsat TM image products in the collection are available only to official BOREAS project personnel. Please contact the ORNL DAAC User Services office (see Section 15.1) to get the most recent information.

16.2 Film Products

None.

16.3 Other Products

Although the image inventory is contained on the BOREAS CD-ROM set, the actual level-3s Landsat TM images are not. See Section 15 for information about how to obtain the data.

17. References

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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 |
| BIL | - Band Interleaved by Line |
| 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 |
| EDC | - EROS Data Center |
| EOS | - Earth Observing System |
| EOSDIS | - EOS Data and Information System |
| EROS | - Earth Resources Observation System |
| ERTS | - Earth Resources Technology Satellite |
| FOLD | - Federally Owned Landsat Database |
| FOV | - Field of View |
| FPAR | - Fraction of Photosynthetically Active Radiation |
| GICS | - Geocoded Image Correction System |
| GIS | - Geographic Information System |
| GMT | - Greenwich Mean Time |
| GPS | - Global Positioning System |
| GSFC | - Goddard Space Flight Center |
| IFOV | - Instantaneous Field-of-View |
| I/O | - Input/Output |
| LAI | - Leaf Area Index |
| LGSOWG | - Landsat Ground Station Operations Working Group |
| LTWG | - LGSOWG Technical Working Group |
| MSS | - Multispectral Scanner |
| NAD27 | - North American Datum of 1927 |
| NAD83 | - North American Datum of 1983 |
| NASA | - National Aeronautics and Space Administration |
| NE | - Noise Equivalent |
| NSA | - Northern Study Area |
| ORNL | - Oak Ridge National Laboratory |
| PANP | - Prince Albert National Park |
| rms | - root-mean-square |
| SBRC | - Santa Barbara Research Center |
| SSA | - Southern Study Area |
| TIPS | - Thematic Mapper Image Processing System |
| TM | - Thematic Mapper |
| URL | - Uniform Resource Locator |
| UTM | - Universal Transverse Mercator |

20. Document Information

20.1 Document Revision Date

Written: 12-Apr-1995

Last Updated: 14-May-1999

20.2 Document Review Dates

BORIS Review: 20-Feb-1998

Science Review: 27-Feb-1998

20.3 Document ID

20.4 Citation

When using these data, please include the following acknowledgment as well as citations of relevant papers in Section 17.2:

The Landsat Thematic Mapper (TM) level-3s images were acquired by Canada Centre for Remote Sensing (CCRS) and processed by Radarsat International (RSI) under an agreement with CCRS.

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

BOREAS Staff Science, "BOREAS Staff Science Satellite Data Acquisition Program." 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.

Also, cite the BOREAS CD-ROM set as:

Newcomer, J., 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, eds. *Collected Data of The Boreal Ecosystem-Atmosphere Study*. NASA. CD-ROM. NASA, 2000.

20.5 Document Curator

20.6 Document URL

REPORT DOCUMENTATION PAGEForm Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

| | | | | |
|--|---|--|--|--|
| 1. AGENCY USE ONLY (Leave blank) | | 2. REPORT DATE September 2000 | 3. REPORT TYPE AND DATES COVERED Technical Memorandum | |
| 4. TITLE AND SUBTITLE Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS) BOREAS Level-3s Landsat TM Imagery: Scaled At-sensor Radiance in LGSOWG Format | | | 5. FUNDING NUMBERS 923 RTOP: 923-462-33-01 | |
| 6. AUTHOR(S) Jaime Nickeson, David Knapp, Jeffrey A. Newcomer, and Josef Cihlar Forrest G. Hall, Editor | | | | |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS (ES) Goddard Space Flight Center Greenbelt, Maryland 20771 | | | 8. PERFORMING ORGANIZATION REPORT NUMBER 2000-03136-0 | |
| 9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS (ES) National Aeronautics and Space Administration Washington, DC 20546-0001 | | | 10. SPONSORING / MONITORING AGENCY REPORT NUMBER TM—2000—209891 Vol. 99 | |
| 11. SUPPLEMENTARY NOTES J. Nickeson, D. Knapp, and J. A. Newcomer: Raytheon ITSS, NASA Goddard Space Flight Center, Greenbelt, Maryland; J. Cihlar, Canada Centre for Remote Sensing, Ottawa, Ontario, Canada | | | | |
| 12a. DISTRIBUTION / AVAILABILITY STATEMENT Unclassified—Unlimited Subject Category: 43 Report available from the NASA Center for AeroSpace Information, 7121 Standard Drive, Hanover, MD 21076-1320. (301) 621-0390. | | | 12b. DISTRIBUTION CODE | |
| 13. ABSTRACT (Maximum 200 words) For BOREAS, the level-3s Landsat TM data, along with the other remotely sensed images, were collected in order to provide spatially extensive information over the primary study areas. This information includes radiant energy, detailed land cover, and biophysical parameter maps such as FPAR and LAI. CCRS collected and supplied the level-3s images to BOREAS for use in the remote sensing research activities. Geographically, the bulk of the level-3s images cover the BOREAS NSA and SSA with a few images covering the area between the NSA and SSA. Temporally, the images cover the period of 22-Jun-1984 to 30-Jul-1996. The images are available in binary, image-format files. | | | | |
| 14. SUBJECT TERMS BOREAS, remote sensing science, Landsat TM data. | | | 15. NUMBER OF PAGES 23 | |
| | | | 16. PRICE CODE | |
| 17. SECURITY CLASSIFICATION OF REPORT Unclassified | 18. SECURITY CLASSIFICATION OF THIS PAGE Unclassified | 19. SECURITY CLASSIFICATION OF ABSTRACT Unclassified | 20. LIMITATION OF ABSTRACT UL | |

