

NASA/TM—2000—209891, Vol. 57



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

Forrest G. Hall and Jaime Nickeson, Editors

Volume 57

**BOREAS RSS-10 TOMS Circumpolar
One-Degree PAR Images**

D.G. Dye and B. Holben

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

August 2000

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BOREAS RSS-10 TOMS Circumpolar One-Degree PAR Images

Dennis G. Dye, Brent Holben

Summary

The BOREAS RSS-10 team investigated the magnitude of daily, seasonal, and yearly variations of PAR from ground and satellite observations. This data set contains satellite estimates of surface-incident PAR (400-700 nm, MJ/m²) at 1-degree spatial resolution. The spatial coverage is circumpolar from latitudes of 41 to 66 degrees N. The temporal coverage is from May through September for years 1979 through 1989. Eleven-year statistics are also provided: mean, standard deviation, and coefficient of variation for 1979-89. The PAR estimates were derived from the global gridded ultraviolet reflectivity data product (average of 360, 380 nm) from the Nimbus-7 TOMS. Image mask data are provided for identifying the boreal forest zone, and ocean/land and snow/ice-covered areas. The data are available as binary image format data files.

Note that some of the data set 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 RSS-10 TOMS Circumpolar One-Degree PAR Images

1.2 Data Set Introduction

This data set contains circumpolar satellite-based estimates of monthly total photosynthetically active radiation (PAR, 400-700 nm) incident at Earth's surface for latitudes between 41° N and 66° N. The spatial resolution is 1 degree. The estimation procedure employed gridded ultraviolet (UV) reflectivity data (average of 360, 380 nm) from the Nimbus-7 Total Ozone Mapping Spectrometer (TOMS) to account for the effects of clouds on a predicted clear-sky PAR irradiance. The TOMS

gridded reflectivity data were produced by the National Aeronautics and Space Administration (NASA) Ozone Processing Team (OPT) as part of the ozone monitoring procedure. PAR estimates for the months of May through September for years 1979 through 1989 are provided. Measurement units are megajoules per square meter (MJ/m²). Image data masks are provided for identifying data values associated with ocean or land areas, and the boreal forest zone. Additional data masks for snow and ice covered surfaces are provided to aid in identifying locations where the accuracy of the PAR estimates may be reduced. PAR estimates represent individual months in the active growing season (May through September), and 3-month and 5-month time periods (June-August, and May-September, respectively). Corresponding 11-year statistics are included (mean, standard deviation, and coefficient of variation for 1979-89).

1.3 Objective/Purpose

The purpose of the data set is to provide information on the spatial distribution and temporal dynamics of PAR within the circumpolar boreal forest zone. The data may be used for calculating vegetation-absorbed PAR, modeling primary production and associated processes, and scaling those processes from the local scale to the biome scale.

1.4 Summary of Parameters and Variables

PAR (400-700 nm) incident at Earth's surface during active growing season months (May through September), and corresponding 11-year statistics (mean, standard deviation, coefficient of variation).

1.5 Discussion

PAR (400-700 nm) provides the energy that supports primary production, and is a major determinant of the exchange of carbon dioxide and water between vegetation and the atmosphere. A full assessment of boreal ecosystem processes requires data and information on the amount, spatial distribution, and seasonal and interannual variability PAR in the boreal forest biome.

The satellite remote sensing method introduced by Eck and Dye (1991) has proven effective for estimating surface-incident PAR on a global scale (Dye, 1992; Dye and Shibasaki, 1995). Early successes in applying the method to UV reflectivity data from Nimbus-7 TOMS led to elements of the BOREal Ecosystem-Atmosphere Study (BOREAS) Remote Sensing Science (RSS)-10 project aimed at refining the original algorithm and performing validations at the BOREAS sites. An additional objective for RSS-10 was the creation of a retrospective time-series PAR data set for the boreal forest zone from the Nimbus-7 TOMS data archive. The data set described here fulfills that objective. The failure of Nimbus-7 TOMS in 1993 and subsequent delays in the launch of a follow-on instrument hindered pursuit of the original objectives for algorithm refinement and validation because suitable UV reflectivity data concurrent with the BOREAS field experiment were not available. Consequently, the present data set contains PAR estimates from our original algorithm applied to Version 6 reflectivity data from Nimbus-7 TOMS (Eck and Dye, 1991, Dye, 1992; Dye and Shibasaki, 1995). Although Nimbus-7 TOMS data are available through early 1993, the instrument exhibited a significant calibration drift during its latter years from 1990 to 1993. This calibration drift had not been fully corrected in the Version 6 reflectivity data set. The years 1990-93 were therefore excluded from the PAR data set. As this data set is submitted, we have proposed a research plan for an improved TOMS PAR data set that combines an enhanced PAR algorithm with corrected Version 7 TOMS reflectivity data.

1.6 Related Data Sets

BOREAS RSS-14 Level-3 Gridded Radiometer and Satellite Radiation Images

AVHRR Land Pathfinder Climate Data Set (Normalized Difference Vegetation Index, 10-day composites, 1 degree resolution).

http://daac.gsfc.nasa.gov/CAMPAIGN_DOCS/LAND_BIO/GLBDST_main.html

2. Investigator(s)

2.1 Investigator(s) Name and Title

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2.2 Title of Investigation

Satellite Estimation of PAR and UV-B Irradiances and Long Term Estimates of Trends of UV-B from Ozone Depletion and Cloud Variability at the BOREAS Sites

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3. Theory of Measurements

Modeling PAR

Surface irradiance in the PAR band (400-700 nm) was estimated by accounting for the reduction in potential (clear sky) irradiance due to the backscatter of PAR to space by clouds and aerosols. The equation is:

$$I_p = I_p^*[1-(r-0.05)/0.90]$$

where I_p is PAR irradiance (MJ/m²/day). I_p^* is the potential (clear sky) PAR irradiance, and r is the TOMS-observed reflectivity averaged for the 360 nm and 380 nm channels on Nimbus-7 TOMS (henceforth referred to simply as 370 nm). The constants account for the variable contribution of the Earth surface background to the observed value of r as r varies between 0.05 (reflectivity for cloudless sky conditions) and 0.50 (reflectivity for 100% cloud-filled pixel). If the UV reflectivity of Earth's surface was zero, the expression $(1-r)$ could be used to adjust I_p for all measurements of r . Since this is not the case, we must account for the contribution of the background reflectance. We adopted a constant reflectivity threshold of 0.05 for the TOMS measured reflectivity for a cloudless pixel. This 0.05 value is the median of the 0.02-0.08 reflectance range exhibited by the majority of Earth's surfaces. As cloud reflectance increases, it is necessary to account for a decrease in the Earth surface contribution to total scene reflectance. We assumed a reflectivity threshold of 0.5 for the underlying surface contribution to total pixel reflectance, which is approximately equal to the mean UV reflectance for a 100% cloud-filled field of view. For reflectivities greater than 0.50, the contribution of surface background reflectance to the measured total reflectance is assumed to be zero or negligible, and I_p is multiplied by $(1-r)$ instead of $[1-(r-0.05)/0.90]$. We used the model of Goldberg and Klein (1980) to predict daily I_p (MJ/m²/day). Additional details are presented in Sections 9.1.1 and 9.2 and by Eck and Dye (1991).

The Version 6 Ultraviolet Reflectivity Measurement (from McPeters et al., 1996).

The reflectivity values account for an "effective" reflectivity, which is the reflectivity of a Lambertian reflective surface that would explain the observed backscattered radiance. The algorithm used for the Version 6 reflectivity is based on the treatment of Dave (1978), who represented the contribution of clouds and aerosols to the backscattered intensity by assuming that radiation is reflected from a particular pressure level called the "scene pressure" with a Lambert-equivalent "scene reflectivity" R .

Version 6 reflectivity data incorporated a correction for an observed downward drift in the TOMS ozone values relative to those measured by the ground-based Dobson network. The drift was the result of an error in the correction for diffuser plate degradation. A correction referred to as the Pair Justification Method (PJM) was applied to account for the differential sensitivity to instrument degradation between wavelengths that should measure the same ozone value. Details on the Version 6 data set are contained in the "Nimbus-7 Total Ozone Mapping Spectrometer Data Product User's Guide" (McPeters et al., 1993, 1996).

4. Equipment

4.1 Sensor/Instrument Description

The Nimbus-7 TOMS measured solar irradiance and the radiance backscattered by Earth's atmosphere in six 1-nm bands in the UV, located at approximately 380, 360, 340, 331, 317, and 312 nm. The sensor used a single monochromator and scanning mirror to sample the backscattered solar UV radiation at 35 sample points at 3-degree intervals along a line perpendicular to the orbital plane. In normal operation, the scanner measured 35 scenes (pixels), one for each scanner view angle, stepping from right to left. It would then quickly return to the first position, not making measurements on the retrace. Eight seconds after the start of the previous scan, another would begin. (from McPeters et al.,

1996). A complete technical description of the TOMS instrument and its initial calibration are provided by Heath et al. (1975).

4.1.1 Collection Environment

Not applicable.

4.1.2 Source/Platform

The data source was the Nimbus-7 TOMS Gridded Reflectivity Data Product (monthly averages) produced by the NASA OPT.

4.1.3 Source/Platform Mission Objectives

The Nimbus-7 platform carried sensors that supported a number of experiments related to pollution control, oceanography, and meteorology (see also

http://jwocky.gsfc.nasa.gov/data_access.html#n7m3 and McPeters et al. (1996)):

- To observe gases and particulates in the atmosphere for the purpose of determining the feasibility of mapping sources, sinks, and dispersion mechanisms of atmospheric pollutants.
- To observe ocean color, temperature, and ice conditions, particularly in coastal zones, with sufficient spatial and spectral resolution to determine the feasibility of applications such as:
 - Detecting pollutants in the upper level of the oceans.
 - Determining the nature of materials suspended in the water.
 - Continuing to make baseline measurements of variations in longwave radiation fluxes outside the atmosphere and of atmospheric constituents for the purpose of determining the effect of these variations on Earth's climate.

Our application of the averaged 360- and 380-nm reflectivity data from Nimbus-7 TOMS to estimate surface-incident PAR was not part of the original TOMS mission objectives. Recognition of the utility of the TOMS reflectivity data for purposes other than ozone monitoring has led to additional applications. In addition to PAR monitoring, TOMS data are now being employed in global monitoring of UV-B surface irradiance and atmospheric aerosol distributions (Herman et al., 1996, 1997).

4.1.4 Key Variables

Monthly total surface irradiance in the PAR band (400-700 nm).

4.1.5 Principles of Operation

Not applicable.

4.1.6 Sensor/Instrument Measurement Geometry

The Nimbus-7 satellite was maintained in a near polar, sun-synchronous orbit at an altitude of 955 km. Equatorial crossings are local noon for ascending and local midnight for descending nodes. Spacecraft inclination was 99.1 degrees, with a maximum poleward latitude of 80.77 degrees. The orbital period was 104.16 minutes. Equator crossings on consecutive orbits are separated by 26.1 degrees longitude. TOMS scanned in 3-degree steps to 51 degrees on each side of the subsatellite point, in a direction perpendicular to the orbital plane. Consecutive cross-scans overlapped, providing contiguous spatial coverage, and full global coverage on a daily basis. (NASA, 1978).

4.1.7 Manufacturer of Sensor/Instrument

The TOMS instrument was built by Beckman Instruments, Inc., of Anaheim, CA, USA.

4.2 Calibration

Portions of the following section on TOMS calibration were quoted from McPeters et al. (1996).

An onboard wavelength monitor tracked changes in the wavelength scale between calibration and launch. Radiometric calibration was performed using the ratio of backscattered radiance to incident solar irradiance, $I(t)/F(t)$. An aluminum diffuser plate was used to reflect sunlight into the instrument to

measure solar irradiance. The diffuser plate was normally deployed once per week for TOMS solar irradiance measurements. Version 6 reflectivity data included corrections for time-dependent degradation of the diffuser plate (Herman et al., 1991). Errors associated with sea-glint contamination and spacecraft attitude were also corrected in Version 6. Details on the wavelength and radiometric calibration for Nimbus-7 TOMS is given by McPeters et al. (1993, 1996), and Herman et al. (1991).

4.2.1 Specifications

Refer to Heath et al. (1975).

4.2.1.1 Tolerance

Refer to Heath et al. (1975).

4.2.2 Frequency of Calibration

The diffuser plate was normally deployed once per week for the TOMS solar irradiance measurements used in radiometric calibration (McPeters et al., 1993). The Nimbus-7 TOMS data archive was reprocessed in Version 6 to account for effects of diffuser plate degradation on the measured irradiance (Herman et al., 1991). (Note: Subsequent analysis revealed remnant calibration-related errors. See Section 10.1.1.)

4.2.3 Other Calibration Information

None given.

5. Data Acquisition Methods

In normal operation, the TOMS scanner measured 35 scenes (pixels), one for each scanner view angle, stepping from right to left. It then quickly returned to the first position, not making measurements on the retrace. Eight seconds after the start of the previous scan, another would begin (from McPeters et al., 1996).

6. Observations

6.1 Data Notes

None given.

6.2 Field Notes

Not applicable.

7. Data Description

7.1 Spatial Characteristics

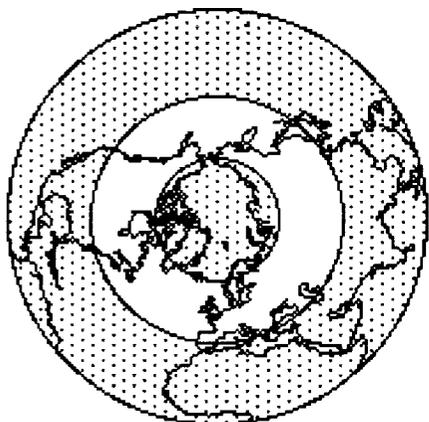
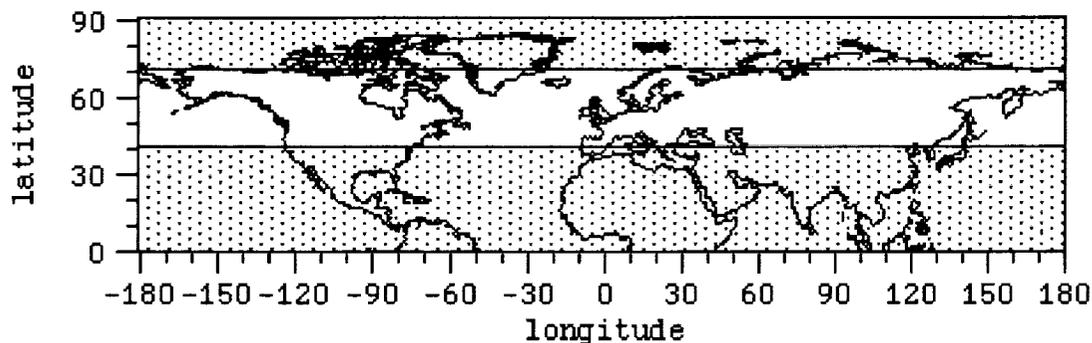
7.1.1 Spatial Coverage

The data array with dimensions of 25 rows by 360 columns covers the circumpolar region bounded by 41 and 66 degrees north latitude. The geographic coordinates of the upper-left and lower-right grid cells are indicated in the table below. The North American Datum of 1983 (NAD83) coordinates refer to the center point of the grid cell.

grid cell position	coordinates (decimal degrees)
Northwest corner	179.5 W, 65.5 N
Southeast corner	179.5 E, 41.5 N

7.1.2 Spatial Coverage Map

The spatial coverage of the data set corresponds to the non-stippled areas in the two Northern Hemisphere maps shown below. The top map has the same Plate Carree projection as the PAR data grid. The bottom map depicts the same region with a Lambert equal-area projection centered on the North Pole.



7.1.3 Spatial Resolution

The nominal spatial resolution is 1 degree x 1 degree. This resolution was produced by resampling PAR estimates computed at 1 degree x 1.25 degree (latitude x longitude), which is the resolution of the monthly gridded reflectivity data product from the NASA OPT. The resampling was performed by computing the spatially weighted mean of the 1- x 1.25-degree PAR values occurring within each 1- x 1-degree cell in the target grid.

7.1.4 Projection

The data grid is in a Plate Carree (equal-angle) projection.

7.1.5 Grid Description

Each pixel is a 1- x 1-degree cell of latitude, longitude.

7.2 Temporal Characteristics

7.2.1 Temporal Coverage

The PAR data correspond to discrete calendar months, and account for differences in the number of days in each month with adjustments for leap years. For example,

$$(\text{monthly total PAR}) = (\text{daily total PAR}) \times (\text{number of days in the month})$$

The data set covers the months of May, June, July, August, and September for years 1979 to 1989.

7.2.2 Temporal Coverage Map

Not available.

7.2.3 Temporal Resolution

The base PAR data set has a temporal resolution of 1 month. This is equal to the temporal resolution of the gridded reflectivity data employed in the estimation procedure (monthly averages of daily reflectivities). Data for the 3-month (Jun/Jul/Aug) and 5-month (May/Jun/Jul/Aug/Sep) PAR sums are also provided.

7.3 Data Characteristics

7.3.1 Parameter/Variable

The types of files provided in the data product are:

parameter	data type
-----	-----
par1m	2-byte
par3m	2-byte
par5m	2-byte
par1mav	2-byte
par3mav	2-byte
par5mav	2-byte
par1msd	2-byte
par3msd	2-byte
par5msd	2-byte
par1mcv	2-byte
par3mcv	2-byte
par5mcv	2-byte
sm1m	1-byte
sm1m11y	1-byte
sm3m11y	1-byte
sm5m11y	1-byte
veg2mask	1-byte
veg3mask	1-byte
oceanmask	1-byte

Equations for scaling from 2-byte integers (int) to floating point numbers (val) can be found in Section 9.1.

7.3.2 Variable Description/Definition

The following are descriptions of the file types provided:

Parameter	Description
par1m	Monthly total PAR (irradiance)
par3m	Total PAR for June, July, Aug
par5m	Total PAR May, Jun, Jul, Aug., Sep
par1mav	11-yr. mean of par_1m
par3mav	11-yr. mean of par_3m
par5mav	11-yr. mean of par_5m
par1msd	11-yr. std. dev. of par_1m
par3msd	11-yr. std. dev. of par_3m
par5msd	11-yr. std. dev. of par_5m
par1mcv	11-yr. coeff. of var. of par_1m
par3mcv	11-yr. coeff. of var. of par_3m
par5mcv	11-yr. coeff. of var. of par_5m
sm1m	Monthly snow/ice mask; data values indicate number of weeks in month with snow or ice in grid cell
sm1m1ly	Monthly snow/ice mask, 1979-89; masked if snow/ice indicated for given month in one or more years
sm3m1ly	3-month snow/ice mask, 1979-89; masked if snow/ice indicated for one or more of the 3 months in one or more years
sm5m1ly	5-month snow/ice mask, 1979-89; masked if snow/ice indicated for one or more of the 5 months in one or more years
veg2mask	Vegetation mask, Class 2 coniferous evergreen forest and woodland
veg3mask	Vegetation mask, Class 3 high latitude deciduous forest and woodland
oceanmask	Ocean/land mask

7.3.3 Unit of Measurement

The following describe the units for the various file types:

Parameter	Units
par1m	MJ/m ²
par3m	MJ/m ²
par5m	MJ/m ²
par1mav	MJ/m ²
par3mav	MJ/m ²
par5mav	MJ/m ²
par1msd	MJ/m ²
par3msd	MJ/m ²
par5msd	MJ/m ²
par1mcv	unitless
par3mcv	unitless
par5mcv	unitless
sm1m	weeks
sm1m1ly	unitless
sm3m1ly	unitless
sm5m1ly	unitless
veg2mask	unitless
veg3mask	unitless
oceanmask	unitless

7.3.4 Data Source

The following describe the source of the data file values:

Parameter	Source
par1m	TOMS
par3m	TOMS
par5m	TOMS
par1mav	TOMS
par3mav	TOMS
par5mav	TOMS
par1msd	TOMS
par3msd	TOMS
par5msd	TOMS
par1mcv	TOMS
par3mcv	TOMS
par5mcv	TOMS
sm1m	Northern Hemisphere Weekly Snow Cover and Sea Ice Extent EOSDIS Distributed Active Archive Center, University of Colorado National Snow and Ice Data Center, 1978-1995
sm1m1ly	same as above
sm3m1ly	same as above
sm5m1ly	same as above
veg2mask	1 degree global landcover map of DeFries and Townshend (1994) Class 2 = coniferous evergreen forest and woodland
veg3mask	1 degree global landcover map of DeFries and Townshend (1994) Class 3 = high latitude deciduous forest and woodland
oceanmask	Ocean mask based on identification of non-land grid cells in 1 degree global landcover map of DeFries and Townshend (1994)

7.3.5 Data Range

The following are the range of values that can be expected after applying the equations given in Section 9.1:

Parameter	Range of Values
par1m	-1.0 to variable
par3m	-1.0 to variable
par5m	-1.0 to variable
par1mav	-1.0 to variable
par3mav	-1.0 to variable
par5mav	-1.0 to variable
par1msd	-1.0 to variable
par3msd	-1.0 to variable
par5msd	-1.0 to variable
par1mcv	-1.0 to 1.000
par3mcv	-1.0 to 1.000
par5mcv	-1.0 to 1.000
sm1m	0 to 5
sm1m1ly	0 or 1
sm3m1ly	0 or 1
sm5m1ly	0 or 1
veg2mask	0 or 1
veg3mask	0 or 1
oceanmask	0 or 1

7.4 Sample Data Record

Not applicable to image data.

8. Data Organization

8.1 Data Granularity

The smallest orderable unit is the entire 11-year data set of 163 files.

8.2 Data Format(s)

8.2.1 Uncompressed Data Files

All data files are binary encoded, stored as either 1- or 2-byte unsigned integers (integer*1 or integer*2). The 2-byte data have IEEE byte ordering. Variables originally computed as floating point numbers were scaled to 2-byte unsigned integers. Equations for reverting to floating point numbers are given in Section 9.1.

The data set includes a total of 163 discrete files. Each data file is a binary image containing 360 samples in each of 25 lines. The data storage type for each variable is indicated in the table in Section 7.3.1. All the file type names that begin with "par" are 2-byte integer images (files 1-99). The remainder of the files (files 100-163) are single-byte images. The files were each written in a single record; files 1 to 99 have a blocksize of 18,000 bytes ($18,000 = 360 * 2 * 25$), and files 100-163 have a blocksize of 9,000. The 2-byte integer data must be scaled to floating point numbers, using the equations provided in Section 9.1.

The list of individual files is given below. The order follows the listed variables in Section 7.3, which gives the root names of the files. The root of the file name is followed by the last two digits of the year and/or the number corresponding to the month, for each variable set, if applicable.

```
file 1: par1m7905.bin
file 2: par1m7906.bin
file 3: par1m7907.bin
file 4: par1m7908.bin
file 5: par1m7909.bin
file 6: par1m8005.bin
file 7: par1m8006.bin
file 8: par1m8007.bin
file 9: par1m8008.bin
file 10: par1m8009.bin
file 11: par1m8105.bin
file 12: par1m8106.bin
file 13: par1m8107.bin
file 14: par1m8108.bin
file 15: par1m8109.bin
file 16: par1m8205.bin
file 17: par1m8206.bin
file 18: par1m8207.bin
file 19: par1m8208.bin
file 20: par1m8209.bin
file 21: par1m8305.bin
file 22: par1m8306.bin
file 23: par1m8307.bin
file 24: par1m8308.bin
file 25: par1m8309.bin
file 26: par1m8405.bin
file 27: par1m8406.bin
```

file 28: parlm8407.bin
file 29: parlm8408.bin
file 30: parlm8409.bin
file 31: parlm8505.bin
file 32: parlm8506.bin
file 33: parlm8507.bin
file 34: parlm8508.bin
file 35: parlm8509.bin
file 36: parlm8605.bin
file 37: parlm8606.bin
file 38: parlm8607.bin
file 39: parlm8608.bin
file 40: parlm8609.bin
file 41: parlm8705.bin
file 42: parlm8706.bin
file 43: parlm8707.bin
file 44: parlm8708.bin
file 45: parlm8709.bin
file 46: parlm8805.bin
file 47: parlm8806.bin
file 48: parlm8807.bin
file 49: parlm8808.bin
file 50: parlm8809.bin
file 51: parlm8905.bin
file 52: parlm8906.bin
file 53: parlm8907.bin
file 54: parlm8908.bin
file 55: parlm8909.bin
file 56: par3m79.bin
file 57: par3m80.bin
file 58: par3m81.bin
file 59: par3m82.bin
file 60: par3m83.bin
file 61: par3m84.bin
file 62: par3m85.bin
file 63: par3m86.bin
file 64: par3m87.bin
file 65: par3m88.bin
file 66: par3m89.bin
file 67: par5m79.bin
file 68: par5m80.bin
file 69: par5m81.bin
file 70: par5m82.bin
file 71: par5m83.bin
file 72: par5m84.bin
file 73: par5m85.bin
file 74: par5m86.bin
file 75: par5m87.bin
file 76: par5m88.bin
file 77: par5m89.bin
file 78: parlmav05.bin
file 79: parlmav06.bin
file 80: parlmav07.bin
file 81: parlmav08.bin

file 82: parl mav09.bin
file 83: par3mav.bin
file 84: par5mav.bin
file 85: parlmsd05.bin
file 86: parlmsd06.bin
file 87: parlmsd07.bin
file 88: parlmsd08.bin
file 89: parlmsd09.bin
file 90: par3msd.bin
file 91: par5msd.bin
file 92: parlmcv05.bin
file 93: parlmcv06.bin
file 94: parlmcv07.bin
file 95: parlmcv08.bin
file 96: parlmcv09.bin
file 97: par3mcv.bin
file 98: par5mcv.bin
file 99: smlm7905.bin
file 100: smlm7906.bin
file 101: smlm7907.bin
file 102: smlm7908.bin
file 103: smlm7909.bin
file 104: smlm8005.bin
file 105: smlm8006.bin
file 106: smlm8007.bin
file 107: smlm8008.bin
file 108: smlm8009.bin
file 109: smlm8105.bin
file 110: smlm8106.bin
file 111: smlm8107.bin
file 112: smlm8108.bin
file 113: smlm8109.bin
file 114: smlm8205.bin
file 115: smlm8206.bin
file 116: smlm8207.bin
file 117: smlm8208.bin
file 118: smlm8209.bin
file 119: smlm8305.bin
file 120: smlm8306.bin
file 121: smlm8307.bin
file 122: smlm8308.bin
file 123: smlm8309.bin
file 124: smlm8405.bin
file 125: smlm8406.bin
file 126: smlm8407.bin
file 127: smlm8408.bin
file 128: smlm8409.bin
file 129: smlm8505.bin
file 130: smlm8506.bin
file 131: smlm8507.bin
file 132: smlm8508.bin
file 133: smlm8509.bin
file 134: smlm8605.bin
file 135: smlm8606.bin

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file 136:smlm8607.bin
file 137:smlm8608.bin
file 138:smlm8609.bin
file 139:smlm8705.bin
file 140:smlm8706.bin
file 141:smlm8707.bin
file 142:smlm8708.bin
file 143:smlm8709.bin
file 144:smlm8805.bin
file 145:smlm8806.bin
file 146:smlm8807.bin
file 147:smlm8808.bin
file 148:smlm8809.bin
file 149:smlm8905.bin
file 150:smlm8906.bin
file 151:smlm8907.bin
file 152:smlm8908.bin
file 153:smlm8909.bin
file 154:smlm11y05.bin
file 155:smlm11y06.bin
file 156:smlm11y07.bin
file 157:smlm11y08.bin
file 158:smlm11y09.bin
file 159:sm3m11y.bin
file 160:sm5m11y.bin
file 161:veg2mask.bin
file 162:veg3mask.bin
file 163:oceanmask.bin

```

8.2.2 Compressed CD-ROM Files

On the BOREAS CD-ROMs, all the files listed above have 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

Equations for scaling from 2-byte integers to floating point numbers (val).

variable	equation
par1m	val = (int/100.)-1.
par1mav	val = (int/100.)-1
par3m	val = (int/10.)-1.
par5m	val = (int/10.)-1.
par3mav	val = (int/10.)-1.
par5mav	val = (int/10.)-1.

```

par3msd      val = (int/100.)-1.
par5msd      val = (int/100.)-1.

par1msd      val = (int/1000.)-1.
par1mcv      val = (int/1000.)-1.
par3mcv      val = (int/1000.)-1.
par5mcv      val = (int/1000.)-1.

```

9.1.1 Derivation Techniques and Algorithms

The PAR estimation technique described by Eck and Dye (1991) consists of two main components: (1) estimation of the potential amount of PAR that would reach the surface under clear sky conditions, and (2) estimation of the actual amount of PAR incident at the surface under observed conditions using TOMS reflectivity.

Potential (clear sky) Incident PAR

Daily potential (clear sky) PAR at the surface was calculated using the spectral model described by Goldberg and Klein (1980), parameterized for the 400 - 700 nm band. The model is given as

$$I_p^* = I_{op} \cos z [0.5(1 + e^{-m^*R})e^{-m^*(t-ac)} + 0.05]$$

where: I_p^* = potential PAR incident at the surface (kJ/m²/day)
 I_{op} = PAR at top of atmosphere (kJ/m²/day)
 m^* = effective air mass for computing daily total irradiance
 R = Rayleigh scattering coefficient (0.131)
 t = aerosol scattering and absorption coefficient (0.02)
 a = ozone absorption coefficient for 400-700 nm band (0.053)
 c = ozone amount (300 Dobson Units)

Actual Incident PAR

Estimation of actual surface-incident PAR (I_p , daily total, kJ/m²/day) is based in part on the the PAR reflectance inferred from the monthly average TOMS reflectivity (r). Refer to Eck & Dye (1991) for details regarding the underlying rationale.

For $r < 0.5$,

$$I_p = I_p^* [1 - (r - .05)/.90]$$

For $r > 0.5$,

$$I_p = I_p^* (1-r).$$

Monthly total PAR is calculated as the sum of the daily total PAR values for all days in the month, with units conversion to MJ/m².

Snow/Ice Masks

The snow/ice masks are intended to aid in identifying grid cells with PAR estimates that are not contaminated by snow and ice reflectance. The snow/ice image masks were created by reducing the spatial resolution of the Northern Hemisphere Weekly Snow Cover and Sea Ice Extent data product from NSIDC from 25 km to 1 degree, and their temporal resolution from 1 week to 1 month. This was achieved in two steps. First, a binning procedure was employed in which the 25-km weekly data were "mapped" onto a 1-degree grid. These 1-degree weekly data were then combined within monthly periods.

For latitudes below 66 degrees north, typically between 8 and 20 input cells (25 km resolution) were associated with each output cell on the 1 degree target grid. If snow or ice cover was indicated by three or more of the input cells, the output cell was tagged accordingly as either snow or ice. When both snow and ice occurred in the same output cell, the category with greater number of occurrences was selected, and snow was selected in the case of equal occurrences. Each weekly file was assigned to a calendar month based on the calendar date of the end day in its weekly coverage period. If the end date was 3 or less, the weekly file was assigned to the preceding month. Consequently, the temporal resolution of the monthly PAR data has a uncertainty of ± 3 days at the beginning and end of the month. The mask data values indicate the number of weeks during the month in which snow or ice was present in a significant area of the 1 degree PAR grid cell. Eleven-year snow/ice masks were created by compositing the individual months over 11-year period. A given grid cell is assigned a mask value if snow or ice is indicated for one or more years in the 11-year time series. The 11-year snow/ice masks may be applied to the 11-year PAR statistics data.

Vegetation and Ocean/Land Masks

The image masks for vegetation type and ocean/land areas were extracted from the 1 degree global map described by DeFries and Townshend, 1994 (see also <http://www.inform.umd.edu/GEOG/landcover/1d-map.html>).

9.2 Data Processing Sequence

9.2.1 Processing Steps

The RSS-10 team used the following processing steps:

- Compute monthly total PAR irradiances at the surface for grid cell center points using (see Section 9.1.1).
- Resample 1 x 1.25 degree monthly grid values to 1 x 1 degree grid based on spatially weighted averages.
- Compute 11 year statistics (mean, standard deviation, coefficient of variation) for 1 degree monthly PAR data
- Compute 11 year statistics (mean, standard deviation, coefficient of variation) for 1 degree monthly data.

BOREAS Information System (BORIS) personnel processed the data by:

- Viewing randomly selected images on a display screen.
- Using the supplied information to inventory the data in the online data base.
- Compressing the data files for distribution on CD-ROM.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.3.2 Calculated Variables

PAR at the top of the atmosphere (I_{op}) was calculated according to the model of McCollough (1968):

$$I_{op} = 0.378[A_0 + A_1 \cos(d) + A_2 \cos(2d) + B_1 \sin(d) + B_2 \sin(2d)]$$

where A_0 , A_1 , A_2 , B_1 , and B_2 are latitude-dependent coefficients given by McCollough (1968) and d is day of year. The constant 0.378 accounts for the fraction of extraterrestrial solar flux in the PAR band and includes a correction for McCollough's (1968) assumed solar constant as adopted by

Goldberg and Klein (1980).

The effective daily total air mass (m^*) was calculated using the equation of Goldberg and Klein (1980):

$$m^* = 0.179 + 130836m + 0.39482m^2$$

where: $m = (\sin\phi \sin\delta + \cos\phi \cos\delta) - 1$

ϕ = latitude

δ = solar declination

9.4 Graphs and Plots

None given.

10. Errors

10.1 Sources of Error

Errors in Version 6 Reflectivity

The Version 6 reflectivity for non-ozone-absorbing wavelengths was found to exhibit a wavelength dependence correlated with partially clouded scenes. Results from a quantitative assessment of the impact on PAR estimation accuracy is not available at this time.

After 1989, Nimbus-7 TOMS sensor degradation introduced significant errors that were not fully corrected in the Version 6 reflectivities. PAR estimates for years 1990-93 were excluded from the data set.

Effects of Snow/Ice Surfaces

The PAR estimates may be lower than actual PAR irradiance in locations where the surface was covered by snow or ice during the month(s) observed by the TOMS instrument. Results from a quantitative examination of this effect are not yet available; however, such error may be expected to decrease as the snow/ice-free period within the month increases. The user can assess the potential for snow/ice related effects at each grid cell location by referring to the snow/ice information provided with the data set.

10.2 Quality Assessment

10.2.1 Data Validation by Source

None at this time for boreal sites. Eck and Dye (1991) and Dye (1995) present validation results for selected sites at middle and tropical latitudes.

10.2.2 Confidence Level/Accuracy Judgment

PAR estimation accuracy is potentially reduced in areas covered by snow or ice. Model parameters for UV reflectivity and atmospheric ozone amount therefore do not account for potential geographic and temporal variations. See Sections 10.2.2 and 10.2.3.

10.2.3 Measurement Error for Parameters

The present version of the PAR data set assumes constant values for atmospheric ozone amount (300 Dobson units). This assumption introduces a maximum potential error in the PAR estimates of approximately -0.5% to +1% during June at boreal latitudes (Dye, 1992). Likewise, the background surface UV reflectivity is assumed constant at 5%. For a "true" background surface reflectivity between 4% and 7%, the predicted maximum PAR estimation error is less than approximately +/- 2% (Dye, 1992).

10.2.4 Additional Quality Assessments

Results from an intercomparison of global-coverage TOMS PAR data with other satellite-derived PAR data sources are presented by Dye and Shibasaki (1995).

10.2.5 Data Verification by Data Center

The data center has browsed samples of the image files.

11. Notes

11.1 Limitations of the Data

None reported at this time.

11.2 Known Problems with the Data

None.

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

The data may be useful in the analysis and modeling of the spatial and temporal dynamics of PAR energy receipt and capture by vegetation at middle to high latitudes, and for application in process models of primary production.

13. Future Modifications and Plans

A research plan for a second-generation PAR data set for the globe using reprocessed (Version 7) Nimbus-7 TOMS reflectivity data has been proposed. The improved data set will account for spatiotemporal variation in model parameters for surface UV reflectivity, ozone amount, and aerosol optical depth. The proposed project includes an extensive validation component involving comparisons to contemporaneous ground-based measurements.

14. Software

14.1 Software Description

The software used to process the TOMS PAR data was prepared in Fortran, with each program addressing a specific task in the processing and analysis sequence. Fortran Transform software in conjunction with LS Fortran software was employed for creation, manipulation, and analysis of the image data. Gzip (GNU zip) uses the Lempel-Ziv algorithm (Welch, 1994) used in the zip and PKZIP commands.

14.2 Software Access

For information on the software used in processing this data set, contact:

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Assistant Professor
Dept. of Geography and Center for Remote Sensing
Boston University
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Boston, MA 02215 USA
(617) 353-4807
(617) 353-8311 (fax)
ddye@bu.edu

Gzip is available from many Web sites across the Internet (for example, FTP site [prep.ai.mit.edu/pub/gnu/gzip-*. *](http://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 PAR 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 data 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.

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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
AVHRR	- Advanced Very High Resolution Radiometer
BOREAS	- BOREal Ecosystem-Atmosphere Study
BORIS	- BOREAS Information System
CD-ROM	- Compact Disk-Read-Only Memory
DAAC	- Distributed Active Archive Center
EOS	- Earth Observing System
EOSDIS	- EOS Data and Information System
GIS	- Geographic Information System
GSFC	- Goddard Space Flight Center
IEEE	- Institute of Electrical and Electronics Engineers
NAD83	- North American Datum of 1983
NASA	- National Aeronautics and Space Administration
NSA	- Northern Study Area
OPT	- Ozone Processing Team
ORNL	- Oak Ridge National Laboratory
PANP	- Prince Albert National Park
PAR	- Photosynthetically Active Radiation
PJM	- Pair Justification Method
RSS	- Remote Sensing Science
SSA	- Southern Study Area
TOMS	- Total Ozone Mapping Spectrometer
URL	- Uniform Resource Locator
UV	- Ultraviolet

20. Document Information

20.1 Document Revision Date(s)

Written: 18-Jul-1997

Last Updated: 02-Aug-1999

20.2 Document Review Date(s)

BORIS Review: 10-Sep-1997

Science Review: 29-Jan-1998

20.2 Document Review Date(s)

20.3 Document ID

20.4 Citation

When using these data, please acknowledge Dennis G. Dye (Boston Univ.) and Thomas F. Eck (NASA GSFC/Raytheon ITSS) for providing TOMS PAR data and include citations of relevant papers in Section 17.2.

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

Holben, B., T. Eck, D. Dye, and P.K. Bhartia, "Satellite Estimation of PAR and UV-B Irradiances and Long Term Estimates of Trends of UV-B from Ozone Depletion and Cloud Variability at the BOREAS Sites." 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 PAGE			Form 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 August 2000	3. REPORT TYPE AND DATES COVERED Technical Memorandum	
4. TITLE AND SUBTITLE Technical Report Series on the Boreal Ecosystem-Atmosphere Study (BOREAS) BOREAS RSS-10 TOMS Circumpolar One-Degree PAR Images			5. FUNDING NUMBERS 923 RTOP: 923-462-33-01	
6. AUTHOR(S) Dennis G. Dye and Brent Holben Forrest G. Hall and Jaime Nickeson, Editors				
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. 57	
11. SUPPLEMENTARY NOTES D.G. Dye: Boston University; J. Nickeson: Raytheon ITSS				
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) The BOREAS RSS-10 team investigated the magnitude of daily, seasonal, and yearly variations of PAR from ground and satellite observations. This data set contains satellite estimates of surface-incident PAR (400-700 nm, MJ/m ²) at 1-degree spatial resolution. The spatial coverage is circumpolar from latitudes of 41 to 66 degrees N. The temporal coverage is from May through September for years 1979 through 1989. Eleven-year statistics are also provided: mean, standard deviation, and coefficient of variation for 1979-89. The PAR estimates were derived from the global gridded ultraviolet reflectivity data product (average of 360, 380 nm) from the Nimbus-7 TOMS. Image mask data are provided for identifying the boreal forest zone, and ocean/land and snow/ice-covered areas. The data are available as binary image format data files.				
14. SUBJECT TERMS BOREAS, remote sensing science, PAR, TOMS.			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	