1. TITLE

1.1 Data Set Identification

ISLSCP II Leaf Area Index (LAI) from Field Measurements, 1932-2000

1.2 File Name(s)

There is only one data file in this particular data set and two associated companion files. The data file is named **ornl_point_lai.dat** and is provided in its original tab-delimited tabular format. This file contains Leaf Area Index (LAI) data for 1008 worldwide point measurements compiled from the literature with associated ancillary information (See Section 8.2 for a full description of column headings and file contents).

The two companion files are named **ornl_lai_refs.txt** and **LAI_TM.pdf**. The **ornl_lai_refs.txt** file contains a bibliography of over 300 references used in the compilation of this data set, in ASCII, or text format. The **LAI_TM.pdf** file is a copy of an Oak Ridge National Laboratory (ORNL) Technical Memorandum which contains additional information on data set production and graphics that the user will find useful. This file is in Portable Document Format (PDF).

1.3 Revision Date of this Document

April 9, 2010

2. INVESTIGATOR(S)

2.1 Investigator(s) Name and Title

Drs. J. M. O. Scurlock., G. P. Asner, and S. T. Gower.

2.2 Title of Investigation

Worldwide Historical Estimates of Leaf Area Index 1932-2000.

2.3 Contacts (For Data Production Information)

	Contact 1	Contact2
2.3.1 Name	Dr. G. P. Asner	Dr. J. M. O. Scurlock
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City/St. **Zip Code** **Country**	Stanford, CA 94305 U.S.A.	Warwickshire CV8 2TZ
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2.4 Data Set Citation

Scurlock, J.M.O., G.P. Asner, and S.T. Gower. 2010. ISLSCP II Leaf Area Index (LAI) from Field Measurements, 1932-2000. In Hall, Forrest G., G. Collatz, B. Meeson, S. Los, E. Brown de Colstoun, and D. Landis (eds.). ISLSCP Initiative II Collection. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A. doi:10.3334/ORNLDAAC/971

2.5 Requested Form of Acknowledgment

Users of the International Satellite Land Surface Climatology (ISLSCP) Initiative II data collection are requested to cite the collection as a whole (Hall et al. 2006) as well as the individual data sets. Please cite the following publications when these data are used:

Hall, F.G., E. Brown de Colstoun, G. J. Collatz, D. Landis, P. Dirmeyer, A. Betts, G. Huffman, L. Bounoua, and B. Meeson, The ISLSCP Initiative II Global Data sets: Surface Boundary Conditions and Atmospheric Forcings for Land-Atmosphere Studies, *J. Geophys. Res.*, 111, doi:10.1029/2006JD007366, 2006.

3. INTRODUCTION

3.1 Objective/Purpose

Leaf Area Index (LAI) data from the scientific literature, covering the period from 1932-2000, have been compiled at the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC) to support model development and validation for products from the MODerate Resolution Imaging Spectroradiometer (MODIS) instrument. Like Net Primary Productivity (NPP), Leaf Area Index (LAI) is a key parameter for global and regional models of biosphere/atmosphere exchange. Modeling and validation of coarse scale satellite measurements both require field measurements to constrain LAI values for different biomes (typical minimum, maximum values, phenology, etc.). Maximum values for point measurements are unlikely to be approached or exceeded by area-weighted LAI, which is what satellites and true spatial models are measuring or modeling.

3.2 Summary of Parameters

This International Satellite Land Surface Climatology Project (ISLSCP) Initiative II data set contains approximately 1000 published estimates of leaf area index (LAI) from over 450 unique field sites worldwide, covering the period 1932-2000 that have been compiled into a single data set, along with a variety of ancillary information (See Section 8.2 for file description). The LAI data are linked to a bibliography of over 300 original-source references (see **ornl_lai_refs.txt** file).

3.3 Discussion

Published estimates of LAI were compiled at the ORNL DAAC into a single data set to support model development and MODIS product validation. Like NPP, LAI is a key parameter for global and regional models of biosphere/atmosphere exchange of carbon dioxide, water vapor, etc. This data set provides a benchmark of typical values and ranges of LAI for a variety of biomes and land cover types, in support of model development and validation of satellite-derived remote sensing estimates of LAI and other vegetation parameters. It should be noted however that values for point measurements are unlikely to be approached or exceeded for area-weighted LAI, which is what satellites and spatial models are measuring or modeling.

These LAI data are mostly from natural and semi-natural (managed) ecosystems, although some agricultural estimates are also included. Caution is advised in using these data, which were collected using a wide range of methodologies and assumptions that may not allow valid comparisons among sites. However, some attempts have been made to detect and flag the outliers in this data set, according to different biome/land cover classes.

Needleleaf (coniferous) forests are by far the most commonly measured biome/land cover types in this compilation, with 22% of the measurements from temperate evergreen needleleaf forests, and boreal evergreen needleleaf forests (9%). Crops are the next most common class (9%). About 40% of the records in the data set were published in the past 10 years (1991-2000), with a further 20% from between 1981 and 1990.

4. THEORY OF ALGORITHM/MEASUREMENTS

Scurlock et al. (2001) provide a Technical Memorandum (see **LAI_TM.pdf** file) which includes a brief definition of leaf area index and methods for its measurement (ranging from leaf weight/litterfall to optical instruments such as the LI-COR 2000). According to Barclay (1998), there are at least five common measures of LAI, which partly reflect the different purposes for which LAI is determined (determination of vegetation growth, estimation of potential physiological activity, study of light attenuation under plant canopies, etc.). The four most common of these are defined.

Definition (1): Total LAI is based on the total outside area of the leaves, taking leaf shape into account, per unit area of horizontal land below the canopy.

Definition (2): One-sided LAI is usually defined as half the total LAI, even if the two sides of the leaves are not symmetrical.

Definition (3): Horizontally projected LAI is the area of "shadow" that would be cast by each leaf in the canopy with a light source at infinite distance and perpendicular to it, summed up for all leaves in the canopy.

Definition (4): Inclined projected LAI, or "silhouette" LAI, represents the projected area of leaves taking into account individual leaf inclinations. An additional fifth definition, according to Barclay (1998), is a variation on this approach, counting overlapping leaf areas only once.

Most published values of LAI appear to use definition (2) or definition (3), with an increasing number of definition (4) in the recent literature (Barclay 1998). Definition (1) is relatively rarely used (see discussion following description of methodologies). Definition (2) suffers from the problem that the meaning of "one-sided" is unclear for coniferous needles, highly clumped foliage, or rolled leaves (Chen and Black 1992). Chen and Black (1992) suggest that the LAI of non-flat leaves should be defined as half the total intercepting area per unit ground area, and that definition (3) should be abandoned. LAI according to definition (2) may exceed LAI according to definition (3) by a factor ranging from 1.28 (hemi-circular cylinders representing conifer needles), through 1.57 (representing cylindrical green branches) to 2.0 (spheres or square bars representing highly clumped shoots and some spruce needles) (Chen and Cihlar 1996). Regrettably, many individual reports of LAI in the literature fail to provide any details of the LAI definition assumed, and a significant fraction do not even describe the methodology used.

Scurlock et al. (2001) also discuss why the older literature tends to contain higher values of LAI than later reports (methodologies are not strictly comparable, and there is a noticeable decline in reported values over time). High values have been reported previously for double-sided or all-sided LAI in wetlands and coniferous forest (as opposed to one-sided LAI commonly reported for broad-leaved forests, crops, etc.), and the high numbers reported for needle-leaf stands such as ponderosa pine are probably more suitable for modeling gas exchange across all leaf surfaces than for comparing canopy light scattering between needle-leaved and broad-leaved "planophile" canopies.

5. EQUIPMENT

5.1 Instrument Description

Methodologies for ground-based estimation of LAI include:

(A) destructive harvesting and direct determination of one-sided leaf area, using squared grid paper, weighing of paper replicates, or an optically based automatic area measurement system;

(B) collection and weighing of total leaf litterfall, converted to leaf area by determining specific leaf area (leaf area/leaf mass) for sub-samples;

(C) allometry using species-specific or stand-specific relationships based on simple physical dimensions, such as stem diameter at breast height from detailed destructive measurement of a sub-sample of leaves, branches, or whole individuals;

(D) indirect contact methods, such as plumb lines and inclined point quadrats;

(E) indirect noncontact methods, such as the Decagon Ceptometer (Decagon Devices, Inc., Pullman, Washington), the LICOR LAI-2000 (Li-Cor, Inc., Lincoln, Nebraska), and analysis of hemispherical photographs.

Methodologies (A) and (B) are commonly used in conjunction with definition (2) of LAI, whereas methodologies (D) and (E) are used with definitions (3) and (4), respectively. Methodology (C) may be used with any of the LAI definitions, including definition (1), depending upon the details of the calibration of the allometric equations. Whereas all of these methodologies may be used for forest canopies, (A) tends to be the most common for grasslands and crops, and (D) or (C) for irregularly shaped canopies, such as shrublands. In many cases, the choice of methodology is a matter of ease of use in a particular field situation.

The user of LAI data should note that almost all of these methodologies are subject to limitations, such as sampling error (small plots, etc.) for direct determination and non-random leaf distribution and inclination in the case of the indirect methods. For example, specific leaf area in an experimental stand of sweetgum (*Liquidambar styraciflua*) may vary by a factor of more than two between sun and shade leaves, making it difficult to use an annual average value for the determination of LAI by methodology (B) above (Norby et al. 2001; Norby, R. J., Oak Ridge National Laboratory, personal communication, July 2001). The wide range of leaf turnover times, from less than 12 months to about 6 years, may also present problems for this methodology. Some knowledge of the dynamics of leaf area production and abscission is really required to estimate LAI (Norby, R. J., Oak Ridge National Laboratory, and S. T. Gower, University of Wisconsin-Madison, personal communication, July 2001). Leaf spatial distribution, leaf angle distribution, and the contribution of non-photosynthetic tissue to light attenuation are all complicating factors in methodology (E), the optical determination of LAI, which was originally developed for crop canopies (Chen 1996). Strictly speaking, this methodology estimates “plant area index” (sometimes abbreviated to PAI), which includes projected stem area as well as leaves. For certain types of vegetation, instruments such as the LAI-2000 have also been found to systematically underestimate LAI compared with other methodologies (Deblonde et al. 1994; Kucharik et al. 1998; Gower et al. 1999).

5.1.1 Platform (Satellite, Aircraft, Ground, Person)

Ground.

5.1.2 Mission Objectives

To compile published estimates of leaf area index (LAI) from nearly 400 unique field sites, covering the period 1932–2000 into a single data set.

5.1.3 Key Variables

Leaf Area Index, biome/vegetation type.

5.1.4 Principles of Operation

See Section 5.1.

5.1.5 Instrument Measurement Geometry

Not applicable to this data set.

5.1.6 Manufacturer of Instrument

Several.

5.2 Calibration

5.2.1 Specifications

5.2.1.1 Tolerance

Not applicable to this data set.

5.2.2 Frequency of Calibration

Not applicable to this data set.

5.2.3 Other Calibration Information

Not applicable to this data set.

6. PROCEDURE

6.1 Data Acquisition Methods

All of the data were accumulated from the published literature (see **ornl_lai_refs.txt** and **LAI_TM.pdf**).

6.2 Spatial Characteristics

6.2.1 Spatial Coverage

The spatial coverage for this data set is NOT global. Values are given for 1,008 point measurements that are located throughout the world. The latitude of the sites varies from 71.30 degrees N to 54.50 degrees S and the longitude from 172.75 degrees E to 156.67 degrees W.

6.2.2 Spatial Resolution

These are all point measurements of LAI, normalized to square meters.

6.3 Temporal Characteristics

6.3.1 Temporal Coverage

The point measurements included here cover the period from 1932 to 2000. This coverage does NOT include all years for all sites.

6.3.2 Temporal Resolution

Usually annual peak LAI.

7. OBSERVATIONS

7.1 Field Notes

Not applicable to this data set.

8. DATA DESCRIPTION

8.1 Table Definition with Comments

The available data consist of a spreadsheet table, together with a bibliography of more than 300 original-source references, and several companion files. Although the majority of measurements are from natural or semi-natural ecosystems, some LAI values have been included from crops (limited to a sub-set representing different crops at different stages of development under a range of treatments).

Global coverage, point data: About 1000 LAI values from 0.1-0.18 (minimum; desert and tundra) to 47.0 (maximum; a peculiarity of one allometric method for estimating all-sided LAI in coniferous tree stands). Units are m^2/m^2 or dimensionless. However, only 14% of the records have LAI greater than 8.0 (a more typical maximum value for one-sided or projected LAI, unlikely to be exceeded except with peculiar conditions or methodology).

The LAI data set includes table headings such as site name, country, latitude, longitude, LAI, and many supporting variables, not all of which are available for all records. Associated variables: time of measurement, methodology, biome/land cover, dominant species, leaf type/ leaf angle, author, year, year of measurement, ANPP (above-ground NPP), BNPP (below-ground NPP), TNPP (total [above+below-ground] NPP), elevation, stand age, remarks [N.B. not all these variables are available for all points]. More details are available in Scurlock et al. (2001) (file **LAI_TM.pdf**).

8.2 Type of Data

8.2.1 Parameter/ Variable Name	8.2.2 Parameter/ Variable Description	8.2.3 Data Range	8.2.4 Units of Measurement	8.2.5 Data Source
Sitename	Unique common name for study site, where reported.	N/A	N/A	See **ornl_lai_refs.txt** file
Country	Country of study.	N/A	N/A	
Latitude	Latitude of study site	71.30°N To	decimal	

	(south is negative by convention).	54.50°S No Data= -99.99	degrees
Longitude	Longitude of study site (west is negative by convention).	172.75°E To 156.67°W No Data= -99.99	decimal degrees
LAI*	Leaf area index, as reported.	0.1-47.0	m^2/m^2 or dimensionless
Time of measurement	Season, month, occasionally exact date.	N/A	N/A
Year_LAI	Year of original study, where reported (otherwise assumed to be equal to Year_pub).	1932-2000	Year
Methodology/ Remarks	Method of LAI measurement: A – destructive harvest B – litterfall C – allometry D – point quadrat/plumb line E – Indirect noncontact (LAI-2000 or other) X – unknown	A-X	See 8.2.2
Biome	Biome/land cover type, as reported.	N/A	N/A
Biomecover	Biome/land cover type assigned to one of 15 classes.	1-15	(see Table 1 in Scurlock et al. 2001)
Dominant species	Major species, genus, family, where reported.	N/A	N/A
Author	Name of first author of original reference	N/A	N/A
Year_pub	Year of publication.	1932-2000	Year
ANPP	Aboveground net primary productivity.	10-2180 No Data= -999	g dry matter/m^2/year
BNPP	Below ground net primary productivity.	10-2770 No Data= -999	g dry matter/m^2/year
TNPP	Total net primary productivity (ANPP + BNPP).	10-3100 No Data= -999	g dry matter/m^2/year
Elevation*	Elevation of study site, as reported.	0-3476 No Data=	m

		-999	
Age	Age of vegetation stand in years (mostly reported for forests).	N/A	N/A
Remarks/original source	Additional remarks about peculiarities of the study; references to previous or related studies	N/A	N/A

*** The entries for the LAI and elevation columns can contain a range of values as opposed to one single value.**

8.3 Sample Data Record

```
Sitename | Country | Latitude | Longitude | LAI | Time of Measurement |
Year_LAI | Methodology/remarks |Biome | Biomecover | Dominant species |
Author | Year_pub | ANPP |BNP | TNPP | Elevation (m)| Age |Remarks/original
source
Point Barrow, AK | USA | 71.3 | -156.67 | 1.00 | July | N/A | D; max value |
Tundra/arctic | Tundra | Dupontia | Caldwell et al. | 1978 | 69| 42| 111| 5|
1|
N/A | USA | 68.6 | -149.57 | 1.39 | N/A | 1991 | X | TUNDRA | Tundra | N/A |
Shaver, G.R. & F.S. Chapin | 1991 | 480| 300| 780| 760| -999|shrub tundra
N/A | USA | 68.63 | -149.57 | 1.20 | N/A | 1991 | X | TUNDRA | Tundra | N/A |
Shaver, G.R. & F.S. Chapin | 1991 | 280| 150| 430| 760| -999|tussock tundra
N/A | USA | 68.63 | -149.57 | 0.39 | N/A | 1991 | X | TUNDRA | Tundra | N/A |
Shaver, G.R. & F.S. Chapin | 1991 | 100| 100| 200| 760| -999|wet tundra
```

Note: the "|" character above represents a "tab" in the data file.

8.4 Data Format

All of the files in the ISLSCP Initiative II data collection are in the standard ArcGIS ASCII Grid format. The data file **ornl_point_lai.dat** has a total of 1,009 rows and 19 columns all separated by a single tab character. Both numerical and text fields are included as described in Section 8.2. A value of –999 denotes a missing numerical value (-99.99 for Latitude and Longitude fields). “N/A” means that a particular text field was not available.

The ORNL Technical Memorandum **LAI_TM.pdf** is in Portable Document Format (PDF). The user will require the Acrobat Reader Software to view this file. The Version 5 reader is available on this DVD-ROM. Newer versions are available free from the Adobe Web site (http://www.adobe.com).

8.5 Related Data Sets

See http://daac.ornl.gov/ISLSCP_II/islscpii.html for other data sets.

9. DATA MANIPULATIONS

9.1 Formulas

9.1.1 Derivation Techniques/Algorithms

See Scurlock et al. (2001) or **LAI_TM.pdf** for more information.

9.2 Data Processing Sequence

The process of compiling the data included identifying sites and sources of data; acquiring the data, metadata (information about the data), and other documentation; performing quality assessment checks; reformatting the data; and writing documentation for the entire data set. The data and documentation were then reviewed before final release for public access.

The sites included in this data set represent mostly natural or seminatural stands; however, some data from crops are included for comparison, and intensively managed pastures and tree plantations have been labeled where possible to distinguish them from natural or seminatural (minimally managed) grasslands and forests. As far as possible, the minimum criteria for inclusion of data in this compilation were the following:

- a geographical or place-name reference to the site of measurement (data related to vegetation types only were not considered)
- at least some ancillary data on vegetation type, stand age, etc., and preferably other physiological parameters such as aboveground NPP, etc.
- a citation to the source of the data

Where the geographical coordinates of the measurement site were not included in the original literature, coordinates were selected from national or regional maps, based upon site descriptions. A variety of published maps, road atlases, online maps, and online nationwide mapping software were used for this purpose.

The authors contributed different parts of the data set. Gower contributed a substantial data set with LAI, NPP, and references for about 700 sites. About 200 records of LAI, with references, were already available at the ORNL DAAC as a by-product of preparing the "Osnabrück" data set on NPP. Asner provided a data set and references for about 80 recent LAI measurements from his own work and other studies. Additional records were added as further citations and published tables of data came to light during the data compilation and quality-checking process.

After elimination of duplicate data and doubtful or incomplete records, the data were condensed into a table of 1008 unique records from 339 known field sites (geographical coordinates available), with a further 69 records for which coordinates could not be estimated Each record represents a unique value reported for a particular vegetation type, treatment, or vegetation condition (e.g., maximum or minimum LAI) at an individual study site. The vast majority of records (98%) have been matched to a bibliography of over 300 original literature references, which forms a useful resource in its own right.

9.2.1 Processing Steps and Data Sets

See Section 9.2.

9.2.2 Processing Changes

None.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None.

9.4 Graphs and Plots

See Scurlock et al. (2001) or **LAI_TM.pdf** for a map of the distribution of locations of LAI measurements and other graphics.

10. ERRORS

10.1 Sources of Error

The primary source of error (inconsistency in LAI values) is associated with the variety of sources used to compile the data, that is, often source publications to not adequately describe the methods that would allow the LAI values to be harmonized within this data set.

10.2 Quality Assessment

10.2.1 Data Validation by Source

Criteria for consistency in the data included the use of common systems of names, units, etc., including names of countries and assignment of biome/land cover to a consistent set of 15 classes, in addition to the original biome designation, where available. They represent a compromise between biome and land cover classes that are meaningful to ecologists, ecosystem modelers and users of satellite remote sensing data. By sorting and re-sorting the table of records in order of each variable, it was possible to check for out-of-range values and to crosscheck many suspect records against the original primary literature. Geographical coordinates were converted to decimal degrees (ddd.dd), and mapped using Geographical Information System software to check for erroneous coordinates located in water bodies or other unlikely areas.

10.2.2 Confidence Level/Accuracy Judgment

See Section 10.2.1.

10.2.3 Measurement Error for Parameters and Variables

See Section 10.2.1.

10.2.4 Additional Quality Assessment Applied

None.

11. NOTES

11.1 Known Problems with the Data

Because these data were compiled from a variety of sources, errors (assuming LAI's are equivalent when they may not be comparable) may be associated with different measurement methods and sampling designs used by the individual investigators.

11.2 Usage Guidance

Caution is advised in using these data, which were collected using a wide range of methodologies and assumptions that may not allow comparisons among sites.

11.3 Other Relevant Information

See Section 9.2 and Scurlock et al. (2001).

12. REFERENCES

12.1 Satellite/Instrument/Data Processing Documentation

Scurlock, J. M. O., G. P. Asner, S. T. Gower. 2001. *Worldwide Historical Estimates and Bibliography of Leaf Area Index, 1932-2000*. ORNL Technical Memorandum ORNL/TM-2001/268. Oak Ridge National Laboratory, Oak Ridge, Tenn. (File **LAI_TM.pdf**)

12.2 Journal Articles and Study Reports

Asner, G. P. 1998. Biophysical and biochemical sources of variability in canopy reflectance. *Remote Sens. Environ*. 64:234–53.

Asner, G. P., Scurlock, J. M.O., S. T. Gower, et al. 2001. Leaf Area Index across temporal and spatial scales. (in preparation).

Barclay, H. J. 1998. Conversion of total leaf area to projected leaf area in lodgepole pine and Douglas-fir. *Tree Physiol*. 18:185–93.

Chen, J. M. 1996. Optically-based methods for measuring seasonal variation in leaf area index in boreal conifer stands. *Agric. For. Meteorol*. 80:135–63.

Deblonde, G., M. Penner, and A. Royer. 1994. Measuring leaf area index with the Li-COR LAI-2000 in pine stands. *Ecology* 75:1507–11.

Gower, S. T., C. J. Kucharik, and J. M. Norman. 1999. Direct and indirect estimation of leaf area index, f_{APAR}, and net primary production of terrestrial ecosystems. *Remote Sens. Environ*. 70:29–51.

Kucharik, C. J., J. M. Norman, and S. T. Gower. 1998. Measurements of branch area and adjusting leaf area index indirect measurements. *Agric. For. Meteorol*. 91:69–88.

Norby, R. J., D. E. Todd, J. Fults, and D. W. Johnson. 2001. Allometric determination of tree growth in a CO2-enriched sweetgum stand. *New Phytol*. 150:477–87.

Scurlock, J. M. O., G. P. Asner, S. T. Gower. 2001. *Worldwide Historical Estimates and Bibliography of Leaf Area Index, 1932-2000*. ORNL Technical Memorandum ORNL/TM-2001/268. Oak Ridge National Laboratory, Oak Ridge, Tenn. (File **LAI_TM.pdf**)

13. DATA ACCESS

13.1 Data Access Information

The ISLSCP Initiative II data are archived and distributed through the Oak Ridge National Laboratory (ORNL) DAAC for Biogeochemical Dynamics at http://daac.ornl.gov.

13.2 Contacts for Archive

E-mail: uso@daac.ornl.gov
Telephone: +1 (865) 241-3952

13.3 Archive/Status/Plans

The ISLSCP Initiative II data are archived at the ORNL DAAC. There are no plans to update these data.

15. GLOSSARY OF ACRONYMS

ANPP	Aboveground Net Primary Productivity
BNPP	Belowground Net Primary Productivity
DAAC	Distributed Active Archive Center
ISLSCP	International Satellite Land Surface Climatology Project
MODIS	MODerate Resolution Imaging Spectroradiometer
NPP	Net Primary Productivity
LAI	Leaf Area Index
ORNL	Oak Ridge National Laboratory (USA)
PDF	Portable Document Format
TNPP	Total Net Primary Productivity