OAK RIDGE
NATIONAL LABORATORY

MANAGED BY UT-BATTELLE
FOR THE DEPARTMENT OF ENERGY

ORNL/TM-2003/204

FLUXNET: Database of Fluxes, Site Characteristics, and Flux-Community Information

February 2004

Prepared by
R. J. Olson
S. K. Holladay
R. B. Cook
Environmental Sciences Division
Oak Ridge National Laboratory

E. Falge
Universität Bayreuth
95440 Bayreuth, Germany

D. Baldocchi
University of California
Berkeley, CA 94704

L. Gu
Environmental Sciences Division
Oak Ridge National Laboratory

UT-BATTELLE

ORNL-27 (2-03)

DOCUMENT AVAILABILITY

Reports produced after January 1, 1996, are generally available free via the U.S. Department of Energy (DOE) Information Bridge.

Web site http://www.osti.gov/bridge

Reports produced before January 1, 1996, may be purchased by members of the public from the following source.

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22161
Telephone 703-605-6000 (1-800-553-6847)
TDD 703-487-4639
Fax 703-605-6900
E-mail info@ntis.fedworld.gov
Web site http://www.ntis.gov/support/ordernowabout.htm

Reports are available to DOE employees, DOE contractors, Energy Technology Data Exchange (ETDE) representatives, and International Nuclear Information System (INIS) representatives from the following source.

Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831
Telephone 865-576-8401
Fax 865-576-5728
E-mail reports@adonis.osti.gov
Web site http://www.osti.gov/contact.html

ORNL/TM-2003/204

Environmental Sciences Division

FLUXNET: Database of Fluxes, Site Characteristics, and Flux-Community Information

R. J. Olson
S. K. Holladay
R. B. Cook
Environmental Sciences Division
Oak Ridge National Laboratory

E. Falge
Universität Bayreuth
95440 Bayreuth, Germany

D. Baldocchi
University of California
Berkeley, CA 94704

L. Gu
Environmental Sciences Division
Oak Ridge National Laboratory

Date Published: February 2004

Prepared for
U.S. Department of Energy
This work was funded by the Terrestrial Ecosystem Program and
Earth Observing System Date and Information System (ESDIS) of the
U.S. National Aeronautics and Space Administration
(NASA Reference Number 46WR41201 under
Interagency Agreement number 2013-M164-A1 with the U.S. Department of Energy)

Prepared by
OAK RIDGE NATIONAL LABORATORY
P.O. Box 2008
Oak Ridge, Tennessee 37831
managed by
UT-BATTELLE, LLC
for the
U.S. DEPARTMENT OF ENERGY
under contract DE-AC05-00OR22725

CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS AND ACRONYMS

AET	actual evapotranspiration
ANPP	aboveground net primary productivity
ASCII	American Standard Code for Information Interchange
AVHRR	advanced very-high-resolution radiometer
DAAC	Distributed Active Archive Center
DIS	Data and Information System
EOS	Earth Observing System
ETM	enhanced thematic mapper
FLUXNET	Flux Network
FTP	file transfer protocol
GIS	geographic information system
LAI	leaf area index
MODIS	moderate resolution imaging spectroradiometer
NASA	National Aeronautics and Space Administration (USA)
NDVI	Normalized Difference Vegetation Index
NEE	net ecosystem exchange
NEP	net ecosystem productivity
NOAA	National Oceanic and Atmospheric Administration (USA)
NPP	net primary productivity
ORNL	Oak Ridge National Laboratory (USA)
PAR	photosynthetically active radiation
PI	Principal Investigator
PPFD	photosynthetic active radiation
QA	quality assessment
QC	quality control
RDMS	Relational Database Management System
SD	standard deviation
TEM	Terrestrial Ecosystem Model
Terra	Earth Observation Satellite - Land
TM	thematic mapper
URL	Uniform Resource Locator
UTC	Coordinated Universal Time

ABSTRACT

R. J. Olson, S. K. Holladay, R. B. Cook, E. Falge, D. Baldocchi, and L. Gu. 2003. FLUXNET: Database of fluxes, site characteristics, and flux-community information. ORNL/TM-2003/204. Oak Ridge National Laboratory, Oak Ridge, Tennessee.

FLUXNET is a "network of regional networks" created by international scientists to coordinate regional and global analysis of observations from micrometeorological tower sites. The flux tower sites use eddy covariance methods to measure the exchanges of carbon dioxide (CO_2), water vapor, and energy between terrestrial ecosystems and the atmosphere. FLUXNET's goals are to aid in understanding the mechanisms controlling the exchanges of CO_2, water vapor, and energy across a range of time (0.5 hours to annual periods) and space scales.

FLUXNET provides an infrastructure for the synthesis and analysis of world-wide, long-term flux data compiled from various regional flux networks. Information compiled by the FLUXNET project is being used to validate remote sensing products associated with the National Aeronautics and Space Administration (NASA) Terra and Aqua satellites. FLUXNET provides access to ground information for validating estimates of net primary productivity, and energy absorption that are being generated by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. In addition, this information is also used to develop and validate ecosystem models.

The FLUXNET project is funded by NASA. The FLUXNET Data and Information System (DIS) component compiles, documents, archives, and distributes flux, meteorological, plant, and soil data to the scientific community. The flux data, site ancillary observations, and flux community information are available from the FLUXNET-DIS website, http://www.daac.ornl.gov/FLUXNET.

The FLUXNET-DIS database consists of interrelated tables of information, some that contain measurements and others that contain links to independent data sets, imagery, or external Web sites. For example, each new site is registered in a site table that includes site name, location, flux tower description, site investigator, climate, biome type, and vegetation type. Both original (as provided by investigators) and harmonized half-hour data and gap-filled products (e.g., estimates of annual net ecosystem exchange for sites) are available through the FLUXNET-DIS FTP server area. The FLUXNET-DIS provides the following types of additional information to support the flux community: general information on the FLUXNET project, contact list with email server, lists of new publications and searchable bibliography of flux related citations, announcements of meetings and resulting meeting reports, job announcements, and community news and opportunities for collaborative research.

FLUXNET builds upon the scientific initiatives of regional networks of flux sites in South, Central, and North America (AmeriFlux, Fluxnet-Canada), Europe (CARBOEUROFLUX, which incorporated EUROFLUX and MedFlu), Asia (AsiaFlux and Koflux), and Australia and New Zealand (OzFlux), as well as independent sites. At present, over 200 sites worldwide are operating on a long-term and continuous basis. Sites exist on five continents and their latitudinal distribution ranges from 70 degrees north to 30 degrees south. Vegetation under study includes temperate conifer, and broadleaved (deciduous and evergreen) forests, tropical and boreal forests, crops, grasslands, chaparral, wetlands, and tundra.

1. FLUXNET BACKGROUND

FLUXNET is a "network of regional networks" created by international scientists to coordinate regional and global analysis of observations from micrometeorological tower sites (Table 1). The flux tower sites use eddy covariance methods to measure the exchanges of carbon dioxide (CO_2), water vapor, and energy between terrestrial ecosystems and the atmosphere. FLUXNET's goals are to understand the mechanisms controlling the exchanges of CO_2, water vapor, and energy across a spectrum of time and space scales. The primary objective of FLUXNET is to promote the synthesis and analysis of long-term carbon, water, and energy flux data that are being acquired world-wide by various regional flux networks. The FLUXNET supports the secondary use of flux data, that is, use by investigators who may not have been associated with the initial collection and analysis of the data. FLUXNET provides both documentation and source information so that secondary users can understand the data and also give credit to the original collectors of the data.

The FLUXNET project consists of two closely related projects funded within the National Aeronautic and Space Administration (NASA) Earth Observing System (EOS) Validation Program and Terrestrial Ecosystem Program (TEP): (1) FLUXNET: Unifying A Global Array of Tower Flux Networks For Validating EOS Terrestrial Carbon, Water and Energy Budgets (Principal Investigator: Dennis Baldocchi, University of California Berkeley, California) and (2) FLUXNET-DIS: A Global Flux Data and Information System to Support EOS Product Validation [Principal Investigator: Robert Cook (formerly Richard Olson, 1997-2003), Oak Ridge National Laboratory (ORNL), Tennessee].

Information compiled by the FLUXNET project is being used by the EOS validation community to validate remote sensing products associated with the NASA Terra and Aqua satellites. FLUXNET provides access via the Mercury System (http://mercury.ornl.gov/ornldaac/) to ground information for validating satellite-derived estimates of net primary productivity and energy absorption that are being generated by the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. In addition, this information is used to develop and validate ecosystem models.

FLUXNET-DIS has several functions. First, it provides infrastructure for compiling and distributing carbon, water, and energy flux measurement, meteorological, plant, and soil data. Data and information are available from the FLUXNET-DIS website, http://www.daac.ornl.gov/FLUXNET. Second, the project supports calibration and flux inter-comparison activities by providing consistent and complete data products so data from the regional networks are inter-comparable. And FLUXNET-DIS supports the synthesis, discussion, and communication of ideas by providing specific flux data products for project scientists, workshop participants, and visiting scientists. To understand flux measurements at a site or among sites at broader scale studies, FLUXNET provides information on instruments, site characteristics, off-tower measurements of vegetation and soil dynamics, and remote sensing imagery. FLUXNET also provides information about site investigators, publications, meetings, and other flux community activities.

Table 1. Regional networks of flux towers associated with FLUXNET (July 2003)

Network	Geographic extent	Year established	No. of towers	Notes
AmeriFlux	North and South America	1996	71	
CARBOEUROFLUX	Europe	1996	39	Includes data EUROFLUX and MedeFlu/
OzNet	Australia and New Zealand	2002	6	
Large-Scale Biosphere-Atmosphere Experiment (LBA)	South America	2002	14	Some sites are also members of AmeriFlux, CARBOEUROFLUX
AsiaFlux	Japan, Korea, China, Malaysia, Thailand, Indonesia, Siberia	1998	14	Initially called JapanNet
KoFlux	South Korea	2002	4	
Safari2000	Southern Africa	2002	6	
TropiFlux	Panama		2	Savannah Systems
CARBOMONT		2002	3	
Fluxnet-Canada	Canada	2002	21	Some sites are also members of AmeriFlux
TCOS-Siberia	Siberia	2001	8	
Other			9	
Inactive			19	Not currently active, but had previously provided flux data
All towers			216	

This document describes the FLUXNET Data and Information System (DIS) component. It defines the parameters stored in the FLUXNET database; describes the processing, quality assurance checks, and documentation performed by FLUXNET; and defines the products available from the FLUXNET Web site. The document provides new investigators and networks guidelines for data formats, processing, management, and distribution. These guidelines are intended to encourage investigators to submit data in more complete and consistent formats. Chapter 2 describes the DIS components, including the various file formats and parameter definitions. Chapter 3 describes the process to register new flux tower sites, including requirements for standard site information to characterize the location and environment of a tower. Chapter 4 outlines the data QA checks that are done by FLUXNET, and the gap-filling procedure and temporal aggregation process are described in Chapter 5. The expanding collection of remote sensing products for flux tower sites is described in Chapter 6.

Data compiled by FLUXNET are being used to quantify and compare magnitudes and dynamics of annual ecosystem carbon, water, and energy balances, to quantify the response of stand-scale carbon dioxide and water vapor flux intensities to controlling biotic and abiotic factors, and to validate a hierarchy of soil-plant-atmosphere trace gas exchange models (Baldocchi et al. 2002). Findings so far include (1) net CO_2 exchange of temperate broadleaved forests increases by about 5.7 g C m^{-2} per day for each additional day that the growing season is extended; (2) the sensitivity

5.7 g C m^{-2} per day for each additional day that the growing season is extended; (2) the sensitivity of net ecosystem CO_2 exchange to sunlight intensity doubles if the sky is cloudy rather than clear; (3) spectral analysis of CO_2 flux intensities show that highest intensities occur at time scales of days, weeks, and year, and a spectral gap occurs at the month time scale; (4) the optimal temperature of net CO_2 exchange varies with mean summer temperature; and (5) stand age affects carbon dioxide and water vapor fluxes (Baldocchi et al. 2001).

At present, over 200 sites worldwide are operating on a long-term and continuous basis (Table 1; Fig. 1). FLUXNET builds upon the scientific initiatives of regional networks of flux sites in South and North America (AmeriFlux), Europe (CARBOEUROFLUX, which incorporated EUROFLUX and MedFlu), Asia (AsiaFlux and Koflux), Australia and New Zealand (OzFlux), and Canada (Fluxnet-Canada), as well as independent sites (Fig. 1). Sites exist on five continents and their latitudinal distribution ranges from 70 degrees north to 30 degrees south. New fluxtower sites are being added at the rate of 10–30 sites a year (Fig. 2). Vegetation under study includes temperate conifer and broadleaved (deciduous and evergreen) forests, tropical and boreal forests, crops, grasslands, chaparral, wetlands, and tundra (Fig. 3). The flux towers also cover a broad range of the global climate. Figure 4 shows the global array of temperature-precipitation combinations for 0.5 ° grid cells (Cramer et al. 2001) with the flux towers superimposed in black dots. Researchers also collect data on site vegetation, soil, hydrologic, and meteorological characteristics. Criteria for being included in the FLUXNET network are use of the eddy covariance method, continuous flux measurements, and a willingness to share data with other scientists.

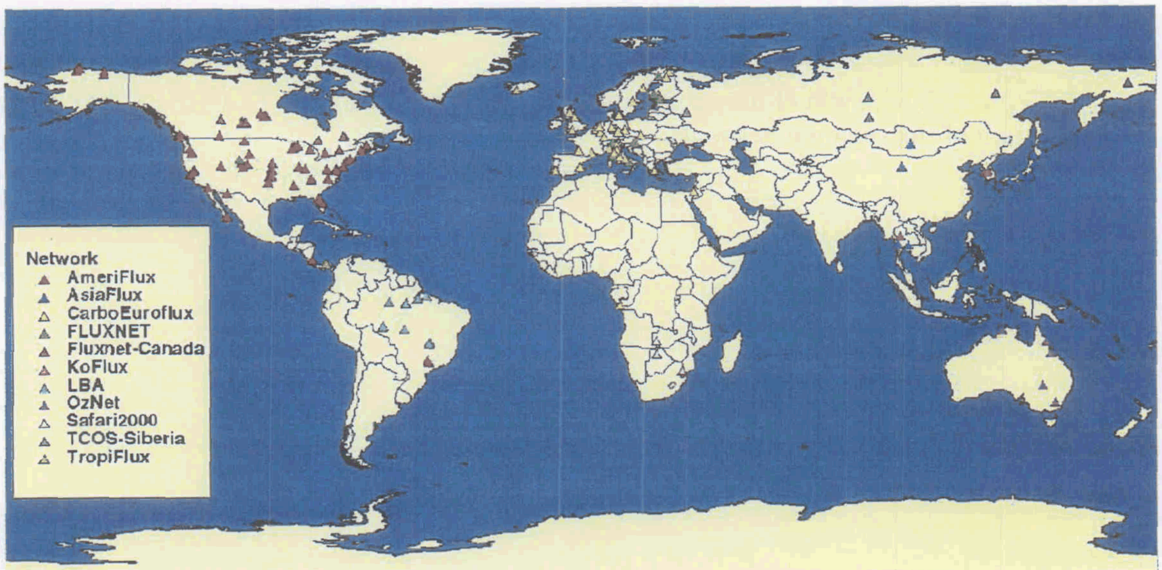

Figure 1. Distribution of towers by regional network affiliation that are registered in FLUXNET-DIS (total of 216 towers as of July 2003).

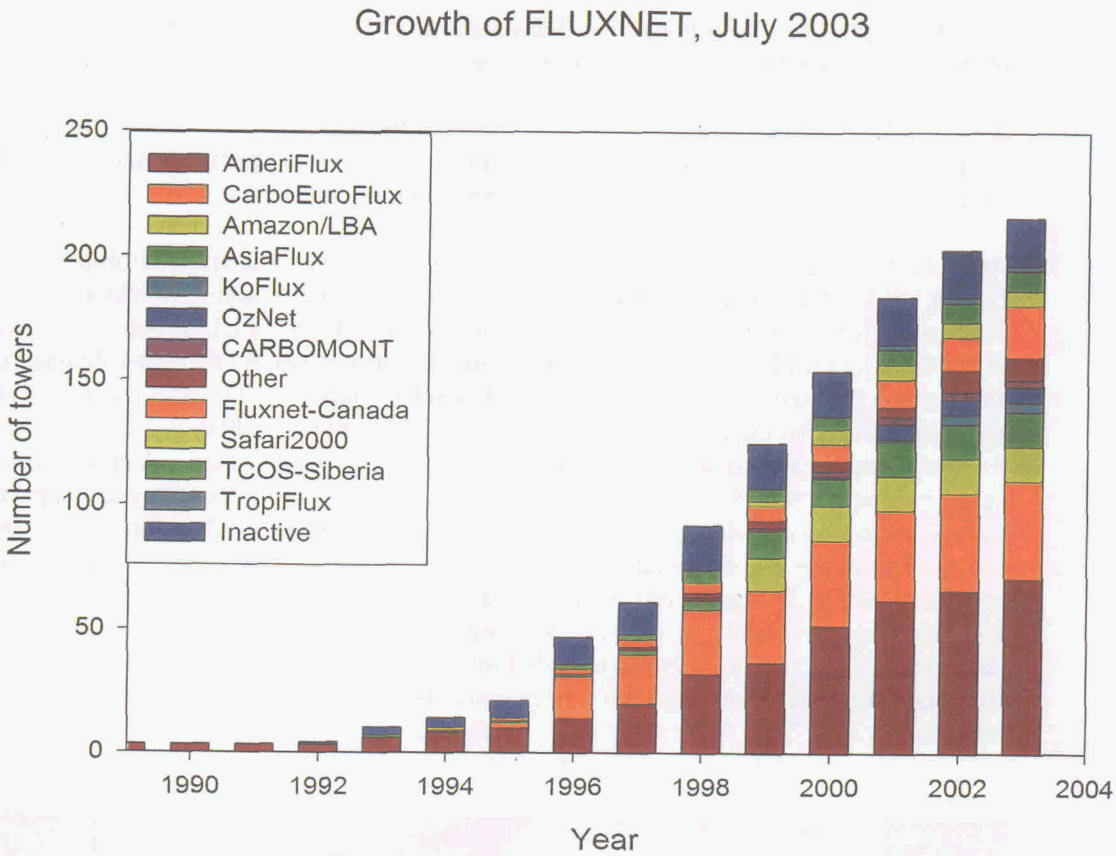

Figure 2. Growth of the number of flux towers registered in FLUXNET-DIS by year for each of the regional networks.

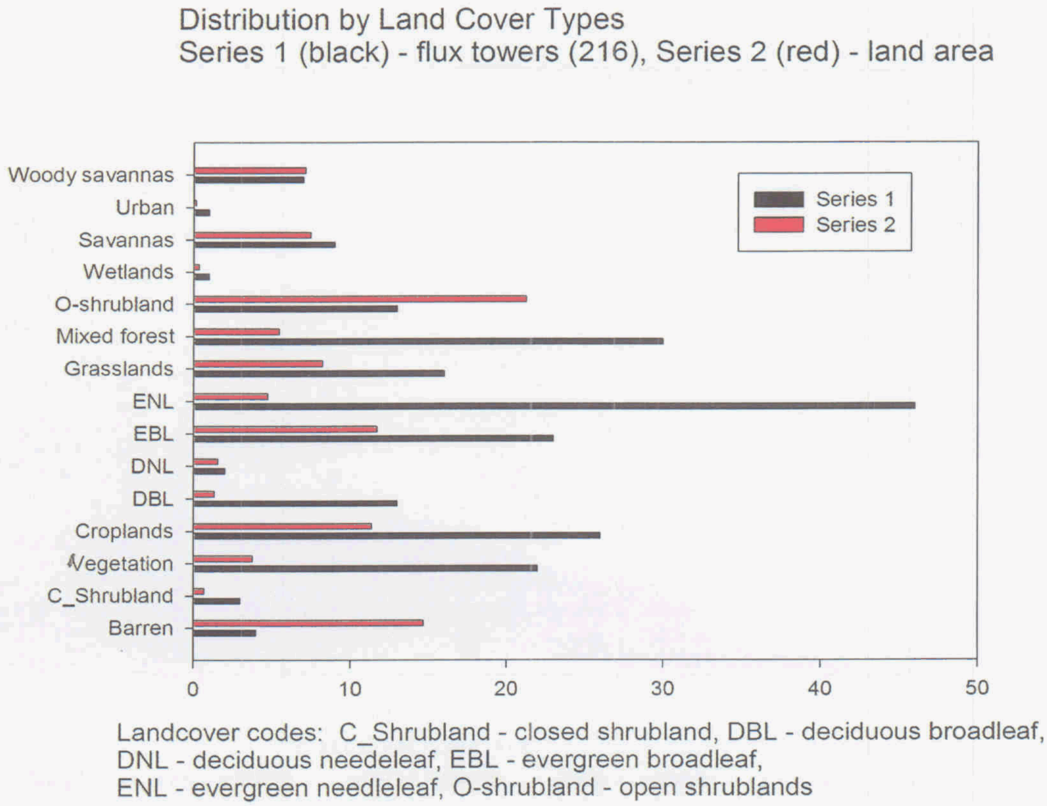

Figure 3. Distribution of flux towers by land cover (black) derived from the MODIS land cover product (MOD12Q1; Collection 3) for 2002 at 1-km resolution. Landcover codes: C_Shrubland – closed shrubland, DBL – deciduous broad leaf, DNL – deciduous needle leaf, EBL – evergreen broadleaf, ENL – evergreen needle leaf, O_shrubland – open shrubland. For comparison, the land cover classes for global land pixels (red) are provided, normalized to the same scale as the numbers of flux towers. The percentage of land cover classes for all land pixels is calculated and then multiplied by the total number of towers (216).

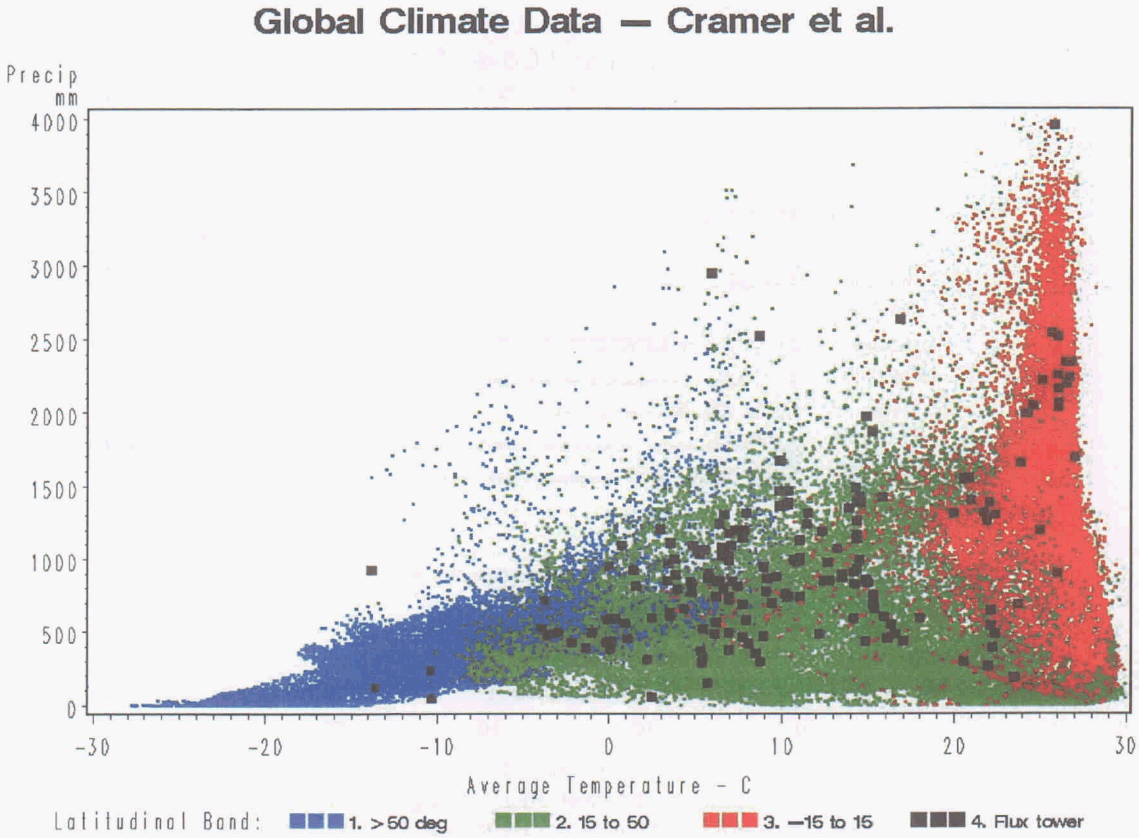

Figure 4. Distribution of flux towers within global climate based on precipitation and temperature for 0.5° grid cells. This figure shows the global array of temperature-precipitation combinations for 0.5° land grid cells based on Cramer et al. (2001) with the blue representing grid cells at high latitudes (greater than 50° or less than -50°), green representing mid-latitudes (15° to 50° or -50° to -15°), and red representing tropical latitudes (-15° to +15°). Flux towers are superimposed (black dots) based on their long-term climate.

1.1 Origin and Scope of FLUXNET

Study of the Earth's biogeochemistry and hydrology involves quantifying the flows of matter in and out of the atmosphere with an array of methods (Canadell et al. 2000). Contemporary investigators apply the eddy covariance technique to acquire nearly continuous measurements of carbon exchange between the atmosphere and biosphere. The eddy covariance method, a micrometeorological technique, provides a measure of net carbon and water fluxes between vegetated canopies and the atmosphere (Baldocchi et al. 1988; Aubinet et al. 2000). With the eddy covariance method, ecosystem responses to environmental forcings are measured at the stand scale, and their temporal variability is quantified. Data may be aggregated to monthly and annual time periods. This method is able to estimate fluxes quasi-continuously with minimal disturbance to the underlying vegetation. In effect, measurements at the flux tower represent ecosystem processes over a relatively large area of land ($> 1\ km^2$) depending on the height of the tower and meteorological conditions.

The concept of a global network of long-term flux measurement sites had a genesis as early as 1993, as noted in the Science Plan of the IGBP/BAHC (International Geosphere-Biosphere Program/Biospheric Aspects of the Hydrological Cycle). Formal discussion of the concept among the international science community occurred at the 1995 La Thuile workshop (Baldocchi et al. 1996). Regional collections of eddy covariance flux towers were formalized into the EUROFLUX and AmeriFlux networks in 1996. Although some towers had been in operation for many years, the La Thuile meeting was the start of flux community efforts to understand the controls on carbon fluxes across sites.

The FLUXNET project was established in 1997 to compile the long-term measurements from the regional networks into consistent, quality assured, documented data sets for a variety of worldwide ecosystems (Baldocchi et al. 1996; Running et al. 1999). FLUXNET is a "partnership of partnerships" that was formed initially by linking AmeriFlux, EUROFLUX, and independent sites. New sites and regional networks are continually being added to FLUXNET (Fig. 2). Criteria for being included in the FLUXNET network are use of the eddy covariance method, continuous flux measurements, and a willingness to share data with other scientists.

FLUXNET is an umbrella organization that facilitates the interaction, coordination, cooperation and organization of regional flux measurement networks to form a global network for measuring and assessing carbon, water, and energy exchange between ecosystems and the atmosphere (Valentini et al. 1999). Its mission is

- to identify and quantify temporal and spatial patterns of carbon, water, and energy fluxes on the global scale, that may not be detectable by individual sites or regional networks;
- to produce value-added products on stand-scale CO_2, water, and energy fluxes by synthesizing data at the biome, cross-biome, continental, and global scales;
- to sponsor a central database for the archiving, documenting, and disseminating of flux data and supporting metadata on climate, site, vegetation, and soil characteristics for the global ecological and biogeochemical research community; and
- to support validation of remote sensing land products and models.

The FLUXNET project serves as a mechanism for uniting the activities of several regional and continental networks (Table 1) into an integrated global network. Research sites are operating across the globe in North, Central and South America, Europe, Scandinavia, Siberia, Asia, and Africa.

FLUXNET is a collection of networks of flux towers. The placement of individual field sites has often been decided by the investigator, due to funding and investigator opportunities, rather than following a network-wide geostatistical design. Generally, individuals join FLUXNET because they want to share experiences, methodologies, and data. With the current network configuration, we are not capable of estimating representative fluxes from every unique environment on Earth. On the other hand, this coordinated network of sites is able to deduce certain information on spatial patterns of fluxes from research sites across a range of climates and biomes. Eddy flux measurements in combination with ecosystem and biophysical models and satellite products can be used to construct spatially integrated fluxes of carbon and water vapor.

The global nature of FLUXNET extends the diversity of climates, biomes, and methods that are associated with the regional networks. For example, sites in the original EUROFLUX network consisted of conifer and deciduous forests and Mediterranean shrubland. The European networks used a standard methodology, based on closed-path infrared spectrometers. By contrast, the American network, AmeriFlux, had more diversity in terms of the number of biomes and climates studied and methods used. The American regional network includes sites in temperate conifer and deciduous forests, tundra, cropland, grassland, chaparral, boreal forests, and tropical forests. Sites use open or closed-path infrared spectrometers to measure CO_2 and water vapor fluctuations. Another unique dimension of AmeriFlux is its inclusion of a tall (400-m) tower for study of CO_2 flux and concentration profiles and boundary layer dynamics. By combining the results from both networks, the broader diversity of sites and methods provides data to confirm and extend the results based on the separate networks.

FLUXNET does not fund tower sites directly, but depends upon institutional support associated with the funding of the AmeriFlux, CARBOEUROFLUX, AsiaFlux, OzFlux, and other networks. Funding for the numerous scientists, students, and technicians responsible for the day-to-day gathering of the flux data at individual field sites is provided by a variety of government agencies and organizations (see box).

Many Agencies Sponsor Flux Measurements

Funding flux activities includes, but is not limited to the following:

AmeriFlux (the Americas network) – United States Departments of Energy (Terrestrial Carbon Program and National Institutes of Global Environmental Change), Commerce (NOAA), Agriculture (USDA/Forest Service), and Interior (USGS); NASA; the National Science Foundation; and the Smithsonian Institution

CARBOEUROFLUX (European sites, including sites in the earlier EUROFLUX, Medeflu, and EcoMont projects) – European Commission Directorate General Vth Framework Programme Key Action Global Change, Climate and Biodiversity)

Fluxnet-Canada – Canadian collaborators, Natural Sciences and Engineering Research Council of Canada

AsiaFlux (Japanese and Asian sites) – Ministry of Agriculture, Forest and Fisheries, the Ministry of Industrial Trade and Industry, and Ministry of Education, Science, Sports and Culture

FLUXNET project science and data components – NASA's EOS Validation Program, Terrestrial Ecology Program, and Earth Observing System Data and Information System

1.2 FLUXNET-DIS Mission and Objectives

FLUXNET provides long-term carbon, water, and energy flux data (Baldocchi et al. 2001). The emphasis throughout FLUXNET is high quality, reliable and credible information, and value-added products. Measurements and terminology from disparate sites and networks are brought together into a common framework and harmonized, thereby increasing substantially the usage and value of the flux data and information for the global change research community. The core variables for the FLUXNET database include net ecosystem exchange (NEE), sensible heat flux, and latent heat flux from eddy correlation, photosynthetic active radiation, net radiation, air temperature, precipitation, relative humidity, wind speed and direction above the canopy, barometric pressure, soil temperature, soil heat flux, soil moisture, and carbon dioxide concentration. Individual sites may measure other parameters based on site-specific research objectives. Associated site information includes vegetation, edaphic, hydrologic, and meteorological characteristics.

FLUXNET has two operational components, a project office and a data office (FLUXNET-DIS). The project office houses the principal investigator, a postdoctoral scientist, and, periodically, visiting scientists. Specific duties of the FLUXNET project office include

- communicating with participants to ensure the timely submission of data and documentation to the data archive;
- organizing workshops for data synthesis and model testing activities;
- constructing and analyzing integrated data sets for synthesis of field data and for the development and testing of soil-atmosphere-vegetation-transfer (SVAT) models;
- preparing peer-reviewed research papers and reports on FLUXNET activities and analyzes;

- funding the planning, implementation, and analysis of site inter-comparison studies;
- providing scientific guidance to the FLUXNET-DIS;
- supporting travel expenses for scientists traveling to regional workshops or for extended stays at the FLUXNET project office to conduct data analysis projects; and
- creating databases, with FLUXNET-DIS, on site metadata (DEM, IKONOS images, soil carbon content, climate data, leaf physiological parameters, etc.) in order to form a FLUXNET GIS.

The FLUXNET-DIS office is responsible for

- compiling and documenting eddy covariance data, including:
  - data files as submitted,
  - harmonized data to achieve consistency and completeness for variable names, units of measure, missing value codes, and formats (see Chapter 4),
  - value-added products as submitted, and
  - flux and site ancillary data in consistent formats;
- developing data guidelines of the FLUXNET-DIS;
- examining data sets with standard quality control and assurance procedures;
- providing data and support for activities sponsored by the FLUXNET project office as listed above;
- maintaining the FLUXNET Web page for communications and data exchange (http://www.daac.ornl.gov/FLUXNET/); and
- transferring flux data and metadata to a long-term archive, currently designated as the Oak Ridge National Laboratory (ORNL) Distributed Active Archive Center (DAAC).

Back up of data and long-term accessibility of the data, provided by FLUXNET-DIS, ensures the protection and extended use of the data by project scientists, as well as the flux and other global change communities, well into the future.

1.3 Flux Measurement Methods

The eddy covariance method is used to assess trace gas fluxes between the biosphere and atmosphere at each site within the FLUXNET community. Vertical flux intensities of CO_2 (Fc), latent (LE), and sensible heat (H) between vegetation and the atmosphere are proportional to the mean covariance between vertical velocity and the respective scalar fluctuations (e.g., CO_2, water vapor, and temperature). Turbulent fluctuations are computed as the difference between instantaneous and mean scalar quantities.

Typical instrumentation at flux tower sites includes a three-dimensional sonic anemometer, to measure wind velocities and virtual temperature, and a fast responding sensor to measure CO_2 and water vapor. Scalar concentration fluctuations are measured with open or closed-path infrared gas analyzers. Sampling frequencies between 10 and 20 Hz ensure complete sampling of the high frequency components of the flux signal. Standardized data processing routines are used by the individual site investigators to compute flux covariances to produce flux estimates for either 30- or 60-minute averaging period. FLUXNET-DIS stores and distributes the 30- or 60-minute summary data.

Application of the eddy covariance method requires site scientists to address issues relating to the tower site, instrument placement, sampling duration and frequency, calibration, and post-processing. Ideally the field site should be flat, with an extensive fetch of uniform vegetation. In practice many of the flux tower sites are on undulating or gently sloping terrain, as this is where native vegetation exists. Sites on extreme terrain can have complex air flow and may not be readily analyzed by the eddy covariance method. The degree of uniformity of the underlying vegetation varies across the network, too. Some sites consist of monospecific vegetation (e.g., agricultural or forest plantations), others contain a mixture of species, and a third grouping possesses different plant functional types in different wind quadrants. All sites have sufficient fetch to generate an internal boundary layer where concentrations are constant with height.

Agricultural scientists mount their sensors on small poles, while forest scientists use either walk-up scaffolding or existing radio or TV towers. The height of the sensors depends on the height of the vegetation, the extent of fetch, the range of wind velocity and the frequency response of the instruments. To minimize tower interference on scaffold towers, investigators place their instruments on booms that point several meters up-wind or at the top of the tower. Spatial separation between anemometry and gas analyzers depends on whether one uses a closed- or open-path gas sensor. With the closed-path systems, the intake is often near or within the volume of the sonic anemometers. A delay between gas sample collection and analysis occurs as air flows through the tubing to the sensor. Corrections for this delay are made during post-processing. Some investigators place their gas transducer on the tower in a constant environment box to minimize the lag time from the sample port and the sensor. Others draw air down long tubes to instruments housed in a climate-controlled hut at the base of the tower. In either circumstance, flow rates are high (6 L/min) to ensure that gas collected at time t will minimally mix with gas collected at time t +1. Open-path gas sensors are typically placed within a 0.5 m of a sonic anemometer, a distance that minimizes flow distortion and lag effects.

Calibration frequencies of gas instruments vary from team to team. With closed-path sensors, investigators are able to calibrate frequently and automatically, such as hourly or daily. Teams using open-path sensors calibrate with less frequency (e.g. every few weeks). However, a body of accumulating data indicates that calibration coefficients of both types of instruments remain steady over a few weeks (± 5%). Scientists using open-path sensors also compare their instrument responses to an independent measure of CO_2 concentration and humidity; however, they do not currently use a uniform standard for calibrating CO_2. But many use CO_2 gas standards that are traceable to the standards at the Climate Monitoring and Diagnostics Laboratory (http://www.cmdl.noaa.gov/index.html) of the National Oceanic and Atmospheric Administration standards for the global flask network.

To ensure intercomparability, the AmeriFlux project circulates a set of reference sensors to members in the network (http://public.ornl.gov/ameriflux/Standards/roving-system/roving_system.cfm) and the FLUXNET project sponsors the circulation of this set of instruments to sites in Europe, Asia, and Australia. CO_2 fluxes measured by the two systems agree within 5% of one another on an hour-by-hour basis. A similar level of agreement has been found by comparing open and closed-path CO_2 sensors. Side-by-side comparisons between open- and closed-path water vapor sensors, on the other hand, are not as good. The absorption and desorption of water vapor on tubing walls can cause estimates of water uptake to have an uncertainty of up to 20%.

FLUXNET-DIS provides quality-assured, qualified flux data to scientists and policymakers dealing with global change issues, and modelers interested in regional scaling or validation of soil-vegetation transfer models and biogeochemical cycling models (Running et al. 1999). These users have identified the need to have estimates of net ecosystem exchange (NEE) for monthly and annual time periods from a variety of ecosystems. Data from eddy covariance towers are usually reported by half-hour with the objective to collect data 24 hours a day and 365 days a year. However, the average data coverage during a year is only 65% due to system failures or data rejection (Falge et al. 2001a,b). Therefore, gap-filling procedures have been developed for providing complete data sets (Falge et al. 2001a,b), and development of more robust methods is under way. Community acceptance of standard gap-filling procedures will allow the creation of comparable data sets, thereby enabling intersite comparisons.

1.4 Progress to Date

There are over 200 towers registered in FLUXNET-DIS associated with 11 active regional networks (Tables 1 and 2). The number of networks and sites continues to expand (Fig. 2 and Table 3). Other collections of towers with common interests are forming thematic networks such as LBA flux towers and TropiFlux.

Site characteristics for the flux towers are organized in a relational database management system (RDBMS) that has component tables to organize information on investigators, projects, flux towers, and associated measurement sites, measurement methods, supporting literature, and data. The ancillary or ecological data are stored in the RDBMS so that each value can be documented as to its source and methods used. Flux tower measurements are available from the ORNL DAAC FTP area (ftp://daac.ornl.gov/data/fluxnet/) – either one-hour or half-hour products containing daily, weekly, monthly or annual values. In addition, selected MODIS products are available for many of the flux tower sites (http://public.ornl.gov/fluxnet/modis.cfm).

A bibliography of key papers has been compiled by the FLUXNET-DIS project in part to document the source of ancillary site information. Often information such as leaf area index (LAI), net primary productivity (NPP), soil properties, etc., is published in papers by ecologists at the site and extracted for the FLUXNET database.

Table 2. FLUXNET database statistics as of July 2003

FLUXNET statistics	Count
Regional Networks: AmeriFlux, CARBOEUROFLUX, AsiaFlux, KoFlux, Fluxnet-Canada, OzNet, CARBOMONT, TropiFlux, TCOS-Siberia, Safari2000, LBA	11
Towers registered	216
Active towers (that have submitted data or defined start year)	197
Years of observations for towers	880
Site-years of data submitted to FLUXNET or regional networks	300
Maximum years of record at a tower (Harvard)	11
Sites with gap-filled, aggregated data available from FLUXNET	36
Site-years of gap-filled, aggregated data available from FLUXNET	150
Site ancillary data records (climate, vegetation, LAI, NPP, etc.)	3,300
Number of parameters reported	183
Flux related bibliographic citations	5,000
Flux scientists on FLUXNET email server	555

Table 3. Number of operating flux tower sites within regional networks by year

	Year											
Network	87	89	94	95	96	97	98	99	00	01	02	03
AmeriFlux	1	3	8	10	14	20	32	37	52	62	66	71
EUROFLUX/MedeFlu/CARBOEUROFLUX				2	17	20	26	29	34	36	39	39
OzNet									1	6	6	6
Amazon/LBA								13	14	14	14	14
JapanNet / AsiaFlux			1	1	1	2	4	11	11	14	14	14
KoFlux										1	4	4
Safari2000								2	6	6	6	6
CARBOMONT							1	1	2	3	3	3
TropiFlux										2	2	2
Fluxnet-Canada			1	1	2	3	4	6	7	11	13	21
TCOS-Siberia					2	2	5	5	5	6	8	8
Other						1	2	3	4	4	9	9
Inactive			4	7	11	13	18	18	18	19	19	19
All towers	1	3	14	21	47	61	92	125	154	184	203	216
Cumulative site-years of data	1	2	10	24	45	86	138	196	313	458	611	800

Note: A total of 216 towers were registered as of July 2003. Towers may be included in more than one network; e.g., towers in Canada that have been part of AmeriFlux also became part of FLUXNET-Canada in 2002.

2. FLUXNET DATA AND INFORMATION SYSTEM DESIGN

Data are gathered at research sites on variables chosen to help answer specific questions posed by researchers operating the sites.

The FLUXNET-DIS can be viewed as information to

- understand the site observations,
- allow sets of sites to be analyzed together, and
- support the flux community (methodology descriptions, parameter definitions, gap-filling algorithms, meeting announcements, and meeting summaries).

The FLUXNET-DIS is designed to provide these diverse types of information in a way to understand processes at a site or patterns associated with groups of sites. The underlying information tool is a relational database management system (RDBMS). The RDBMS is especially appropriate to storing, retrieving, and manipulating diverse types of data. That is, an LAI value for a site can be stored with detailed metadata documenting the source of the value, measurement method, date of measurement, and units of measure; however, the LAI value can be extracted from the RDBMS and inserted into summary tables or cross-site queries to enable comparing multiple sites.

2.1 Data and Information Strategy

Before FLUXNET-DIS receives the data, scientists at the individual sites compile, quality assure, analyze, and document the half-hour or hourly flux and micrometeorology data based on the unique focus of each site. Typically an entire year's worth of data is processed as a unit so that the annual pattern can be reviewed. These data are submitted to regional networks [e.g., AmeriFlux, CARBOEUROFLUX, etc. (Fig. 1)], some of which review the data and metadata, convert to common formats, and distribute to the user community through an FTP or Web server. Often members of the flux community will assemble collections of flux data to perform cross-site studies. Synthesis and modeling projects (often associated with FLUXNET) may process a set of flux data to produce a standardized gap-filled, aggregated flux product (e.g., Falge et al. 2001a,b).

Flux data typically flow from individual sites to regional networks and synthesis projects to FLUXNET-DIS and eventually to a long-term data archive. FLUXNET-DIS compiles site characteristics (Chapter 3), conducts quality assurance checks (Chapter 4), distributes value-added products (Chapter 5), and provides access to the data. FLUXNET-DIS distributes flux data and ancillary information through the ORNL DAAC (http://daac.ornl.gov/FLUXNET/) and the final data sets are currently being archived there.

Given this sequence of processing, the flux data sets are assigned levels by FLUXNET-DIS as they are processed as defined below:

1. collected and reviewed by site investigators,
2. submitted to a regional network or to FLUXNET,
3. harmonized into common formats and units of measure,

4. night-time adjustments and gap filling performed,
5. publication of annual sums by flux investigators, and
6. submitted to long term archive.

Value-added role. Value-added functions are carried out at several levels of the data processing scheme. For example, site investigators and networks, (e.g., AmeriFlux) may develop data products associated with their research interests, such as estimates of annual net ecosystem productivity (Baldocchi et al. 2001) or validity of MODIS products. FLUXNET-DIS distributes consistent data products across all the networks and sites. Participation in FLUXNET adds to the value and use of data and information obtained from individual networks by providing complementary information from the other networks on the principle that two bits of related data have more information value when they are considered together than when they are apart. Integration of networks within the FLUXNET framework also enables protocols and standards to be more widely applied thus greatly facilitating intercomparisons and synthesis studies. Linking networks together within FLUXNET, for example, widens the range of studies possible (e.g., climate, soils, and plant functional types), fosters multidisciplinary research, extends spatial and temporal coverage, and, through inter-comparison exercises and model testing, greatly improves predictive power.

Data distribution policy. In general, data and information generated or supplied through FLUXNET are readily available to potential users with no restrictions and at no cost within two years after the date of collection. Checked and verified data are placed in the public domain and made readily accessible through direct access to the FLUXNET-DIS through the World Wide Web (http://www.daac.ornl.gov/FLUXNET/). FLUXNET also has a data policy that governs use of FLUXNET data, as shown in the box.

FLUXNET Data Policy

Kindly inform the appropriate the Principal Investigator of the flux tower how you are using site data and of any publication plans. If the Principal Investigator feels that they should be acknowledged or offered participation as authors, they will let you know and we assume that an agreement on such matters will be reached prior to publishing and/or use of the data for publication. If your work directly competes with the Principal Investigator's analysis, he or she may ask that they have the opportunity to submit a manuscript before you submit the one that uses their data. In addition, when publishing a paper using flux data, please acknowledge the agency that supported the flux tower research. (http://www.fluxnet.ornl.gov/fluxnet/fairuse.cfm)

2.2 Flux Community Data and Information

To support the flux community, the FLUXNET Web site (http://www.daac.ornl.gov/FLUXNET/) provides the following types of information:

- general information on the FLUXNET project,
- site characteristics,
- flux and ancillary data,
- contact list associated with an email server,
- new publications and searchable bibliography of flux related citations,
- announcements of meetings and meeting reports,

- job announcements, and
- community news and opportunities for collaborative research.

The FLUXNET Web Site has a menu bar that provides further access to **General** information, information on **Sites, Maps, Map Server, Data**, the FLUXNET **Mailing List**, publications **(Pubs)**, and **Contacts**. Tables 1 and 2 in Appendix A provide more specific information on the content of each Webpage and links to additional levels of information. A secondary menu bar provides access to the Web sites of regional networks which are part of FLUXNET such as AmeriFlux, CARBOEUROFLUX, AsiaFlux, KoFlux, OzFlux, and Fluxnet-Canada.

- The **General** information page provides access to overviews of the FLUXNET Project, as well as presentations, reports, news, registration of new sites, and job, meeting, and workshop announcements. New publications, a publication search tool, parameter definitions, journals, and other links are also provided.

- The **Sites** information page provides access to a pick list and table of FLUXNET sites. When the chosen site is selected, a web page is displayed dynamically from the RDBMS which then summarizes all the ancillary data for that site, presents a picture of the site if available, lists the personnel associated with the site, tabulates any instrumentation that has been registered for the site, and summarizes the publications that have been identified as being applicable to the site.

- The **Maps** page provides access to various maps of the FLUXNET tower sites, such as the Bailey ecoregions. Maps are provided in several formats (e.g., .jpg and .tiff) and resolutions appropriate for use in Web pages, PowerPoint applications, or publications.

- The **Map Server** page allows users to select from more than 200 sites in the FLUXNET global network and to retrieve information about site characteristics as well as retrieve flux data, if available. To access the map server, see http://www.daac.ornl.gov/FLUXNET/fluxnet.html and click on "Map Server" in the bar at the top.

- The **Data** page provides access to cross tabulations of the FLUXNET ancillary data, such as average air temperature and precipitation, stand characteristics, vegetation parameters, carbon and nitrogen content, terrain, flux and productivity data, and radiation parameters. Links to network data for the EUROFLUX and AmeriFlux programs are provided. Other related data such as long-term climate data (Thornton and Running 1999), the Arctic Tundra Flux Study (Chapin et al. 2002), Net Carbon Flux Data (Buchmann and Schulze 1999), and can be found here. Data from the relational database can be queried by site or by parameter. Published NEE estimates are presented in tabular fashion. Links are also provided to gap-filled flux data products, the field-image-model intercomparisons pages, and the MODIS ASCII (American Standard Code for Information Interchange) subset data. A web form and an excel spreadsheet are provided for users to submit data. A subheader provides links to the FLUXNET data use policy and data updates. The user can also access the "Best Practices for Preparing Data" (Cook et al. 2001).

- The publications page **(Pubs)** provides access to an index of publications related to carbon flux science and publications which have been authored by network scientists. The main publication file is maintained in Endnote.

- The FLUXNET listserver on the **Mailing List** page is a mailing list of people in the FLUXNET community (fluxnet@ornl.gov). The list currently serves over 500 participants around the world. The FLUXNET mailing list is for use by people interested in long-term measurements of carbon dioxide, water vapor, and energy exchange from a variety of worldwide ecosystems. The contact list includes site affiliation, address, email, and phone numbers for individuals associated with flux activities. Individuals can distribute information or ask for assistance using the FLUXNET email server that is based on the contact list. Information, such as upcoming meetings or position openings, distributed through the email server or other sources, is also added to the FLUXNET web page of announcements.

- The **Contacts** page provides access information to the FLUXNET science leader, steering committee members, programmatic committee members, network contacts and data, and information system members.

The flux and meteorology measurements are available via anonymous (File Transfer Protocol FTP) from the DAAC FTP site, ftp://daac.ornl.gov/fluxnet/. Data are typically formatted as ASCII space or tab delimited (.txt), or comma delimited (.csv). The FLUXNET-DIS FTP area is divided into seven subdirectories (Table 4) according to the source of data and level of processing.

Table 4. Description of the FLUXNET FTP server (ftp://daac.ornl.gov/fluxnet/) subdirectories

FTP subdirectory	Description
Arctic_flux	Collection of flux data from roving towers in the Arctic region (Chapin et al. 2002)
Climate	Monthly climate data for U.S. sites from the DayMet data set
Gap_filled_EUROFLUX	EUROFLUX Gap-Filled Flux and Meteorology Data
Gap_filled_fluxnet	Gap-filled data submitted to the FLUXNET project
Gap_filled_marconi	Marconi Gap-Filled Flux and Meteorology Data
Harmonized data	Harmonized flux data files containing a subset of 30 parameters
Net carbon data	Net CO_2 and H_2O fluxes (Buchmann and Schulze 1999)
Preliminary data	Flux data sets available as contributed to FLUXNET without additional harmonization or QA checks.

2.3 FLUXNET Database Considerations

Flux parameters. An underlying basis of FLUXNET is that data are compiled and presented with comprehensive parameter definitions developed in collaboration with the participating networks and scientists. Current definitions are presented in Table 5 for the core flux tower measurements and in Table 6 for the site characteristics parameters. The tables include parameters and definitions found in the AmeriFlux Science Plan, the EUROFLUX parameter files, the Large Scale Biosphere Atmosphere Experiment in Amazonia (LBA) list, and the International Geosphere-Biosphere Programme (IGBP) Global Analysis, Interpretation and

Modelling Task Force (GAIM) initial model parameterization list. The lists are continually undergoing review, and additional comments are welcome.

Table 5. Core variables for the FLUXNET database

Meteorological model-driving inputs
Air temperature
Barometric pressure
Carbon dioxide concentration
Global solar radiation
Photosynthetic active radiation
Precipitation
Relative humidity
Soil temperature
Wind speed and direction above the canopy
Flux model checking variables
Latent heat flux from eddy correlation
Net ecosystem exchange from eddy correlation - CO_2 flux
Net radiation
Sensible heat from eddy correlation
Soil heat flux

Note: See Table 8 and Appendices B, C, and D for more information on specific variables.

Table 6. Site characteristics information, usually representing long-term status (information contained in the Site table in the Access relational database)

Site Characteristic	Picklists or description
IDENTIFICATION	
Site name	
Country	
State	Two-character code
Information provided by	
Email of provider	
Sources of information (publications, web sites, etc.)	
Objectives/research topics	
Sponsors	
Comments	
Additional comments	
Network assigned code	
Network	AmeriFlux, AsiaFlux, CARBOEUROFLUX, OzFlux, KoFlux, Fluxnet-Canada, etc.
LOCATION	
Country/Nearby City/Landmarks	
Latitude, degrees	
Latitude, decimal	
Longitude, degrees	
Longitude, decimal	
Elevation, meters	
TOWER	
Year began	
Month began	
Status	Continuous, Intermittent, Summer operation only, Roving, Inactive, Retired from use, Planned, Under construction
Measurement frequency	Half-hourly, Hourly
Measurement period	
Type of tower	
Tower height, m	
Canopy height, m	
Fetch, m	
Fetch length, m	
Fetch width, m	
Site type	Meteorological, Flux
Instruments	Open-path, Closed-path or Multiple instruments
SITE	
Limitations	Good for annual sums, Good for process studies, Good for daytime measurements, Challenged by complex terrain, Influenced by nearby disturbances
History	
Area	
Site terrain	

Table 6 (continued)

VEGETATION	
Dominant species	
Biome	Crops, Pasture, Plantation, Wetland, Deciduous broad-leaf forest / boreal, Deciduous broad-leaf forest / temperate, Deciduous broad-leaf forest / tropical, Desert, Deciduous needle-leaf forest / boreal, Evergreen broad-leaf forest / temperate, Evergreen broad-leaf forest / tropical, Evergreen needle-leaf forest / boreal, Evergreen needle-leaf forest / temperate, Grassland / C3, Grassland / C4 temperate, Grassland / C4 tropical, Mediterranean, Mixed forest, Savanna / temperate, Savanna / tropical, Tundra
IGBP class	
Vegetation type	
Stand age, years	
Stand age, year began	
Typical start of the growing season	
Typical end of the growing season	
Typical length of the growing season	
LONG-TERM NORMAL CLIMATE	
Climate class	Tropical wet, Topical wet/dry, Tropical/subtropical semi-arid, Tropical/subtropical arid, Temperate arid, Subtropical dry summer, Humid subtropical, Temperate, oceanic, Temperate, continental, warm summer, Temperate, continental, cool summer, SubArctic-Boreal, Polar-Tundra
Average air temperature, °C	
Average annual precipitation, mm	
SOIL	
Soil type	
STAND	
Stand area description	
Leaf area index	
ANPP	$g\ C\ m^{-2}\ yr^{-1}$
CONTACTS	
Primary investigator	
Function	
Address	
Address	
Street	
City	
State	
Country	
Zip code	
E-mail	
Phone	
Fax	
Affiliation	
Comments	

Parameter tables. Appendix B includes definition tables with names, acronyms/short names, formats, and definitions for approximately 100 parameters/variables. Literature references provide additional information about the parameters. The parameters are organized by logical groups within tables for the flux, meteorology, and soil efflux (Appendix B, Table B.1), site stand information (Appendix B, Table B.2), and calculated annual estimates (Appendix B, Table B.3). Customized information for each flux tower site is included in the FLUXNET database to indicate which parameters are measured and which instruments are used at the site. The expected range for each parameter may be revised for specific sites and comments may be added as needed to further define how parameters are being measured at that site.

NEE flux sign convention. Eddy covariance observations in the FLUXNET database are represented using the atmospheric scientist's sign convention with a negative flux indicating a net downward transport of CO_2. This is the opposite of the sign convention used by many ecologists, where photosynthesis is considered a positive flux. Using the atmospheric scientist's convention, a site that is a CO_2 sink in a specific year have a negative NEE and those that are a CO_2 source have positive NEE.

Temporal scales. Aggregating flux data temporally is difficult because of inherent problems in acquiring continuous flux measurements. Typically, the site investigators calculate hourly or ½-hourly flux values from the instantaneous raw flux data. Instrument problems and complying with quality control criteria may result in data gaps. Currently there are no standard methods for estimating missing data that would allow aggregating data into daily, monthly, and annual time periods. FLUXNET-DIS strives to reflect a consensus of the flux community on how to produce temporal data aggregations.

Spatial scales. Flux observations are made at towers that measure exchanges for a range of footprint areas. Thus flux data may represent areas ranging from square meters to square kilometers. The *in situ* site measurements of ecological parameters are made at finer resolutions still. No single scale is adequate for all FLUXNET activities and it is likely that studies may require extrapolation across spatial scales. Integrated models that can be used at multiple scales are unlikely to be developed so that, for example, in global analyses it is more probable that layered models will be used to provide inputs into other models in a hierarchical approach.

2.4 FLUXNET Data and Information System

The FLUXNET-DIS encompasses several areas of data integration:

- ancillary data collection and storage in a relational database,
- Web-based interface to the relational database,
- user input through Web interfaces,
- web site management and data presentation,
- flux and meteorological data files, and
- organization of data files in an FTP site.

FLUXNET relational database. The FLUXNET ancillary data and information system is based on a relational database management system (RDBMS) using Microsoft Access. The Webpages are dynamically produced from the RDBMS through use of Macromedia's ColdFusion server-side web technology and the ColdFusion Markup Language.

The FLUXNET RDBMS consists of interrelated tables of information, some that contain measurements and others that contain World Wide Web links to independent data sets, imagery, or external Web sites. For example, each new site is registered in a site table that includes site name, location (latitude, longitude, elevation, and country), flux tower description (type of instrument, height of tower), site investigator, climate, biome type, and vegetation. World Wide Web addresses are included to provide direct links to an investigator's Web site containing additional information for the tower site. Complete investigator information of institutional address, phone, and email is included in the investigator table. Additional site characteristics are added to the data table, including source of the observation and other metadata. The RDBMS is then used to provide a description of data for a site or to generate summary tables for groups of sites or to allow users to query the database. To maintain a workable size of the RDBMS, most of the large data files (including the 0.5-hr flux and meteorology data sets of 17,520 values per year per site and large images) are stored outside of the RDBMS in individual files in an FTP area.

The RDBMS **(FLUXNET_DEV)** contains five tables of data associated with the flux sites, two tables associated with the MODIS subsetting activity, seven lookup tables for standard values of climate and biome classes, etc., a parameter definitions table, and five tables used to control web site programming. Table 7 lists the tables, and Appendix C provides a more complete description. The data dictionary listing field names, field descriptions, valid values, constraints, and data types is included in Appendix C.

Table 7. Description of the FLUXNET relational database (FLUXNET_DEV) tables

Type[a]	Table name	Description
Data	testsite	FLUXNET site ID, physical descriptors
Data	sitepis	Identifies site investigators, main contacts
Data	pi	Identifies participants' names, addresses, etc.
Data	data	Ancillary data, containing 20 items describing the time, location, methods, source, and comments associated with each value
Definitions	define	Parameter definitions
Lookup	BAILEY_C	Lookup table for Bailey ecoregions
Lookup	BIOME	Lookup table for biome categories
Lookup	CLIMATE	Lookup table for climate categories
Lookup	IGBP	Lookup table for IGBP land cover classes
Lookup	LIMITATION	Lookup table for site limitations
Lookup	TIMECODES	Lookup table for time codes
Lookup	UMD_CLSS	Lookup table for Univ. of Maryland classes
MODIS	modiscoord	Coordinates of MODIS subset grids
MODIS	modisstatus	Status of MODIS subsetting
MODIS	modissubsets	MODIS subsets
Web site	gapdata2	Gap-filled EUROFLUX data
Web site	publications	Publications table from Endnote
Web site	server	FLUXNET server list loaded from majordomo
Web site	status	Status of flux file processing
Web site	suppdata	AmeriFlux table used in web programming
Web site	library	Hyperlinks to documents, maps, announcements, etc.

[a]Table types are as follows: Data—contains observation values; Definitions—defines terms; Lookup—provides names for codes; MODIS—information associated with MODIS products; Web site—information associated with FLUXNET web pages. See Appendix C for descriptions of the contents of each table.

FLUXNET user input. A second relational database accumulates user input and statistical information from the Web site. Fluxnet_input contains five tables which collect information from user input that is added to the main relational database after review by the FLUXNET-DIS staff. These are as follows:

NEWSITEINFO	Collects information input from http://www.fluxnet.ornl.gov/fluxnet/allrev3.cfm and http://www.fluxnet.ornl.gov/fluxnet/allrev2.cfm?KEYID=?
TEMPDATA	Collects information input from http://www.fluxnet.ornl.gov/fluxnet/dataform2.cfm
VISITOR	Collects information input from http://www.fluxnet.ornl.gov/fluxnet/guestform.cfm
TEMPINSTR	Collects information input from http://www.fluxnet.ornl.gov/fluxnet/instrumentform.cfm
Statistics	Collects user information such as IP (Internet Protocol) address, web page URL (Uniform Resource Locator), date/time

FLUXNET data and imagery files. In addition to the flux data and site measurements taken at or near the flux tower, the following data are provided from the ORNL DAAC FTP site as files for downloading:

- MODIS imagery files – Many of the flux tower sites are included in a set of sites for which NASA extracts products generated from images from the MODIS sensor on the Terra satellite. FLUXNET provides access to these data for selected sites.
- Other imagery/photos/DEM, etc. – Often TM, IKONOS, or other images, photos, and digital elevation models (DEM) are available for sites. FLUXNET provides links to these data sets.
- Climate for sites – Many of the flux towers are located at sites with a long history of ecological or atmospheric research. When available, these data are compiled in a common format for either daily or monthly periods and provided.
- Climate for U.S. sites – the Daymet program (Thornton et al. 1997, Thornton and Running 1999) was used to estimate daily temperature and precipitation for the 18-yr period, 1980-1997.
- Model development and validation – Many of the flux tower sites are ideal for model development and validation using flux measurements, meteorology observations, and site characteristics as model inputs.

Data archive. Finalized flux data and documentation will be archived (i.e., stored at permanent data center for long-term storage and maintenance). Regional networks (e.g., AmeriFlux) may assume this responsibility or FLUXNET-DIS may ensure that data are placed in a long-term archive. For example, periodically copies of finalized data will be submitted to an archive (e.g., ORNL DAAC for FLUXNET data or the ORNL Carbon Dioxide Information Analysis Center for Ameriflux data). The archives provide long-term data and metadata storage, open and free data access, and user support.

3. FLUX TOWER SITE CHARACTERIZATION

The Flux Community has identified information that is necessary to characterize the location and environmental context for each tower. Information includes the tower's identification, contact person, location, operation, site, vegetation, long-term climate, and average soil, vegetation, and stand properties (Table 6). This information is useful for individuals doing synthesis or modeling activities who want to look at the distribution of towers in environmental space. It can be used to promote the scope and scientific value of the flux networks.

The FLUXNET-DIS Web site provides a Site Registration Tool to either enter information for a new flux tower site into the FLUXNET-DIS relational database or to update information for an exiting site. Entries, either new or edits, are identified as to the date and person entering the information. Entries are placed in a temporary data set to be reviewed for consistency prior to replacing current site information with the new values. The tool is designed to capture static information or long-term averages. However, measurements, such as leaf area index or litter fall, for a specific year must be entered into the relational database as new data with specific dates, locations, methods, units of measure, notes, and citation.

Pick-lists are provided for several of the items in the Site Registration Tool (Table 6) to encourage consistency across the networks. Descriptions of the items are provided in an online glossary. Often a site may experience an unusual event within a year, such as a nearby fire, insect infestation, unusual weather, etc. The tool provides a way to add comments describing these specific events. Each set of notes or comments are stored and displayed with the site information.

Assigning site names and ID. The site ID is used internally within FLUXNET-DIS to identify sites and link tables within the relational database. In 2002, the following scheme was implemented to make sure the site IDs were concise and consistent.

Flux Site Name/Identifier Scheme:
Country.site-abbreviation.tower-code
(e.g., US.WALK.01)

Rules for assigning the site abbreviations are based on the need for a concise and unique site ID that can be recognized by the flux community. Therefore, the rules are flexible and can be applied as needed:

1. Use an existing convention, if it is concise (e.g., HARVARD).
2. If there are multiple words that make up a long common site name (Walker Branch Watershed), use first letters of each word (e.g., WBW).
3. If there are multiple words that make up a long common site name (Tomakomai National Forest), select the most descriptive and unique word (Tomakomai National Forest – TOMAKOMAI).
4. If there are single or multiple words that make up a long common site name, use either the first four letters (e.g., Fedorovskoje - FEDO) or use the first letter plus the next three consonants, except use only one of a double consonant. (e.g., Fedorovskoje – FDRV).

Examples of sites and towers that may need special consideration when assigning site names and IDs. Some towers may be close to each other (e.g., similar climatic and atmospheric conditions and similar tower instrumentation) such that towers can be considered either treatments or separate towers (e.g., Sky Oaks or Metolius).

Sites with replicate towers at a site

- Howland
- Niwot Ridge

Towers with multiple sets of sensors

- WLEF tall tower
- Wind River (advection studies)
- Instruments on an LBA tower that moves up and down

Sites with multiple treatments or land surface studies

- Bondville (soybeans and corn)
- Sky Oaks (old and young)
- Slashpine FL (clearcut, old)
- Metolius (old and young pine)
- Howland (fertilizer/harvest)
- Ione (savanna/grassland)

Sites with roving towers

- CARBOEUROFLUX: CarboAge – 7 sites

Sites with unique studies

- Planetary Boundary Layer (PBL) studies (WLEF, WBW, Florida, etc.)
- Understory Flux Studies (Wind River, Walker Branch, Ione, Metolius, etc.)

Site table. Site identifier information is stored within the site table (Table 6). The site table includes

- Site ID – concise identifier, unique for site, tower, and treatment
- Site name – up to 80-character expanded name
- Site code – 2- to 3-character code used in graphics, tables, dataset names, etc., that may be combined with 2-digit year for specific year of measurement

4. FLUX QA AND DATA PROCESSING

FLUXNET-DIS is responsible for storing and distributing flux data in consistent and documented formats (Section 1.2). Currently, flux sites may measure a variety of parameters to meet their specific research objectives; however, most sites measure a basic set of parameters. FLUXNET-DIS receives the preliminary flux measurements from regional networks or individual sites in a variety of forms. This chapter discusses the steps that FLUXNET-DIS undertakes to create consistent data files of the basic flux measurements. This process, called harmonization, includes assigning standard variable names, converting to common units of measure, assigning standard missing values, storing in a common file format, performing basic QA checks, and assembling documentation. The 30- or 60-minute measurement step is maintained and no gap-filling (see Chapter 5) is performed.

Significant effort has been devoted by the flux community to defining flux parameters to achieve consistency within the database. A FLUXNET-DIS parameter list (Appendix B) was compiled from lists developed by regional networks associated with measuring the fluxes and characterizing the surrounding area in 1999 and more recently. Parameter names, definitions, units of measure, typical methods and instruments, and ranges were defined. Lists have been distributed at the FLUXNET, AmeriFlux and the EUROFLUX meetings for review and confirmation of site-specific parameters. However, as the flux measurement technology evolves, new parameters or revisions to the original parameter definitions may be needed.

Caveat: The FLUXNET-DIS summary tables provide a list of site characteristics from a variety of sources. We suggest that users check site-specific sources to determine the appropriateness of this information for specific applications. For example, annual climate values or growing season length may represent observations for different years and leaf area index may not be measured by methods that allow intercomparisons among sites. The FLUXNET database is constantly being expanded and updated. Please let the FLUXNET-DIS project know if you see questionable values or if you have suggestions as to the content of the summary table.

Quality assurance and quality control (QA/QC). Data quality assurance programs, including quality control, are applied at different levels in the data gathering process by the site PIs, the regional networks, synthesis activities, and FLUXNET-DIS. These include statistical and graphical evaluations to check the validity and representativeness of the acquired data (Aubinet et al. 2000). For example, site investigators and the network (e.g., AmeriFlux Science Team) are responsible for quality of primary measurements and data products. The regional network (AmeriFlux) has responsibility for assuring quality of data sets as they are made available to the science community and other users. FLUXNET-DIS reviews cross-network data conventions for consistency. Application of QA/QC procedures to flux data give international and scientific credibility, indicate their reliability, and ensure their acceptance by users in both the scientific research and assessment communities.

The data processing strategy for sites is that the 30- or 60-minute flux and micrometeorology data are compiled, processed, and reviewed prior to being submitted to regional networks. FLUXNET-DIS acquires copies of the processed data from regional networks and occasionally directly from individual flux towers. FLUXNET-DIS processes the data to produce standard set of flux parameters that were selected by the flux community (Table 8). The data are distributed on the ORNL DAAC FTP site. The following describes the QA checks that FLUXNET-DIS performs.

Quality assurance checks. FLUXNET-DIS gets data and metadata from regional networks, compiles site characteristics if needed, reviews data/metadata, standardizes data/metadata if needed, generates value-added products, links to more detailed data in regional networks, and makes the data available to the community. FLUXNET-DIS compiles site information from that entered using the online Site Registration Tool, from published papers or from site Web pages. FLUXNET-DIS uses the information to create tables of site characteristics and adds the data to the RDBMS. Some non-network sites may submit their data directly to FLUXNET-DIS and the processing and distribution equivalent to the regional networks will be provided. At each step, data and metadata are reviewed and processed in cooperation with the site PIs and according to the principles outlined above. The initial processing uses routines written in SAS to perform the following steps.

- Read data from each site in site-specific format:
  - check for NEE/NEP, CO_2 storage signs,
  - convert to standard units of measure,
  - check for missing values and convert to -9999,
  - check and adjust time stamp to include solar time,
  - convert to standard variable names,
  - check that Ustar values are reasonable and whether fluxes with low Ustar values were adjusted, and
  - check that energy balance is reasonable for the site.
- Examine x-y time series plots and other special plots of key parameters to check for unusual patterns or missing values,
- Calculate percentage of data missing for each parameter by 30- or 60-minute periods and entire 14-day periods,
- Compare individual values with typical minimum and maximum values for each parameter (Table 8); if values are outside the normal range, check for correct units of measure or other causes,
- Document all the conversions and changes made by FLUXNET-DIS, usually by saving a copy of the batch SAS code, or assembling a text file.
- Output data in standard ASCII, .csv, or .txt-formatted file.

Additional quality checks are described for the time-stamp, integrity of the file, and frequently confused units and parameter names.

QA checks of time stamp: Plots of measures of radiation energy against time can help to confirm that the time stamp that is provided correctly relates to solar noon (solar elevation max at 12 noon). The goals of this check are to (1) make sure time of day is local time (not daylight savings/summer time or UTC) and (2) provide a solar time variable.

- Calculate solar elevation and solar time for lat/long/day/time,
- Calculate global solar radiation – top of the atmosphere,
- Calculate plot ratio (measured Rg/potential Rg) vs. solar elevation.
- Visually inspect plot.

QA checks and plots: The following checks provide a way to quickly check for corruption of incoming data during transfer, switched or mislabeled columns, or other problems.

- Start and stop dates
- Percentage of ½ hr gaps, by month, annual
- Percentage of 14-day gaps by month, annual
- Statistics – mean, standard deviation, skewness, kurtosis for all variables
- QA plots:
  - x-y for selected pairs of variables, including
    - NEE vs PPFD
    - NEE vs wind direction
    - Cumulative precipitation vs time
    - Energy balance [(= (H+LE) – (Rn+G (+other storage terms)))] vs time
    - VPD (or RH) vs time
  - fingerprint plot for NEE, LE, temperature, radiation energy index; a "fingerprint plot" provides a quick view of an entire year of data (17,520 ½-hr values) by producing a plot parameter of interest classified into 4-6 classes and displayed as hours (y axis) vs. days (x axis) for full year

Check frequent units/name mix-ups: Based on processing flux data, the following variables are examined to ensure that they are reported in the correct units.

- Carbon equivalent, g C –convert g CO_2 to g C
- Relative humidity – convert "fraction" to percentage
- Vapor pressure deficit –convert hPa to kilopascals (kPa)
- Air pressure – convert millibars to kilopascals
- Radiation – check possible mixing of incoming, outgoing, and net radiation variables
- Precipitation – convert inches to millimeters

Table 8. FLUXNET variables, units of measure, and typical minimum and maximum values

Parameter	Name	Units	Min	Max
Air temperature	TA	°C	-50	50
Atmospheric stability	ZI	ratio	-1000000	1000000
Barometric pressure	Pa	kPa	70	120
Bole temperature	Tbole	°C	-50	50
CO_2 concentration	Ca	ppm	220	770
CO_2 flux	Fc	$\mu mol\ m^{-2}\ s^{-1}$	-40	40
Friction velocity	Ustar	$m\ s^{-1}$	0	6
Global solar radiation	Rg	$W\ m^{-2}$	0	1200
Latent heat flux	LE	$W\ m^{-2}$	-100	700
Latent heat flux inside the canopy	Sw	$W\ m^{-2}$	-60	60
Momentum flux	Tau	$kg\ m^{-1}\ s^{-2}$	-100	100
NEE	NEE	$\mu mol\ m^{-2}\ s^{-1}$	-60	30
NEE+FC	NEE	$\mu mol\ m^{-2}\ s^{-1}$	-60	30
Net radiation	Rn	$W\ m^{-2}$	-200	1000
Photosynthetic active radiation	PPFD	$\mu mol\ m^{-2}\ s^{-1}$	0	2200
Precipitation	P	mm	0	50
Relative humidity	RH	%	10	100
Sensible heat flux	H	$W\ m^{-2}$	-300	700
Sensible heat storage in canopy	Sa	$W\ m^{-2}$	-160	160
Soil CO_2 efflux	Fcsoil	$\mu mol\ m^{-2}\ s^{-1}$	0	10
Soil H_2O efflux	Esoil	$mmol\ m^{-2}\ s^{-1}$	-1	4
Soil heat flux	G	$W\ m^{-2}$	-110	220
Soil moisture, H_2O 0-30 cm	SWC	$mg\ mg^{-1}$ (or vol %)	0	0.6
Soil temperature	TS	°C	-20	50
Solar elevation	Solel	deg	-91	91
Vapor pressure deficit	VPD	kPa	-0.2	7
Water vapor flux	ee_mes	$mmol\ m^{-2}\ s^{-1}$	-2	14
Wind direction	Wd	deg N	0	360
Wind speed	Ws	$m\ s^{-1}$	0	40

Note: With the extension of sites into less temperate regions, some of the limits may need to be revised (e.g., air temperature, precipitation, soil CO_2 efflux, soil moisture, wind speed, and CO_2 concentration).

5. GAP-FILLING, NIGHTTIME FLUX CORRECTION, AND AGGREGATION

One of the goals of FLUXNET is to provide uninterrupted time series and annual estimates of NEE. Estimating annual NEE for a site involves adjusting nighttime fluxes for site-specific micrometeorology conditions, filling gaps in the record, and aggregating the 30- or 60-minute flux estimates into daily, weekly, monthly, and annual time periods. A set of common gap-filling algorithms based on response functions (to temperature and radiation) and mean diurnal patterns have been applied to the harmonized data for many of the sites (Falge et al. 2001a,b; Falge et al. in press).

The development of robust methods for producing flux products is an ongoing research area within the flux community. For example, the GLOFLUX project (http://www.fluxnet.ornl.gov/fluxnet/gloflux.cfm) is using an artificial neural network system approach to perform gap-filling and examine carbon and energy flux patterns at global scales. This approach has the advantage of being able to preserve temporal variability in flux data. The following section describes some of the issues and products. FLUXNET-DIS stores and distributes additional gap-filled flux products when new collections are contributed by the flux community.

It is the intent of the micrometeorological community to collect eddy covariance data continuously throughout the year. However, missing data are a common feature of the measurements. The average data coverage during a year is between 65 % and 75%, that is 25-35% gaps due to system failures or data screening (Falge et al. 2001a). Tests show that this observed level of data acquisition and acceptance provides a statistically robust and over-sampled estimate of the ensemble mean. The filling of missing data does not provide a significant source of bias for estimating annual values, if there are no large gaps (>2 months) (Falge et al. 2001a).

Gaps in the data record are attributed to system or sensor breakdown, periods when instruments are off-scale, when the wind direction is such that the tower itself influences the measurements, when spikes occur in the raw data if the vertical angle of the wind vector at the tower is too severe, or are due to calibration and maintenance operations. Data might be rejected when stationary tests or integral turbulence characteristics fail (Foken and Wichura 1995) or when precipitation limits the performance of open-path sensors. If the wind is coming from a non-preferred direction as may occur over patchy stands, a certain portion of the data may be screened and flagged. In addition, rejection probability for some sites is higher during nighttime because of calm wind conditions. Other criteria used to reject data include applications of biological or physical constraints. Missing data may arise from farming operations and other management activities (e.g., prescribed burn of grasslands). Rejection criteria applied to the data vary among the flux tower groups.

Although flux scientists may perform gap-filling for their site, the FLUXNET community acknowledges the need to also use common approaches for processing data when flux data from multiple sites are to be compared (Falge et al. 2001 a, b). Four gap-filling algorithms were programmed in PV-Wave® based on Falge et al. (2001 a, b) and have been used to fill gaps less than 14 days in length. Gap-filled data are archived and available from the ORNL DAAC for the EUROFLUX collection of 54 site-years covering 15 sites and the period 1996-2000 (Falge et al. in press). A second collection of gap-filled data called the Marconi data set was compiled for a series of synthesis papers (see Gu and Baldocchi 2002 and others). This collection of 100 site-years for 33 sites covers the period 1996-1999. There is some overlap of the same site-years of flux data between the EUROFLUX and Marconi collections. In addition, gap-filled fluxes provided by sites are maintained. Additional research is needed to perform night-time corrections and gap-filling that addresses unique conditions at sites.

A description of the variable names, descriptions, and units of measure for the gap-filled data products (both EUROFLUX and Marconi data sets) are provided in Appendix D.

The gap-filling algorithms described by Falge et al. (2001 a, b) typically require key parameters to successfully process a year of flux data. Some of the meteorological parameters are strongly correlated such that the gap filling routines need only a subset of them. Specific pairs of alternative parameters include Ta and Ts and Rg and PPFD. The mean diurnal course algorithm for gap filling does not need any meteorological drivers. Parameters needed for the other algorithms (Falge et al. 2001 a, b) include

- Short-wave global radiation – Rg
- Photosynthetic photon flux density –PPFD (photosynthetically active radiation)
- Ambient air temperature – Ta
- Ambient relative humidity – RH
- Soil temperature at 5 cm depth – Ts
- Momentum flux – Tau
- Net ecosystem CO_2 flux – Fc
- Latent heat flux – LE
- Sensible heat flux – H

Eddy covariance system typically underestimates CO_2 fluxes during nighttime under stable atmospheric conditions. Most researchers screen their nighttime data by examining scatter plots of NEE vs. friction velocity (Ustar). A cutoff friction velocity is selected, above which there is no clear pattern between NEE and Ustar. A statistical approach is now being developed to determine the cutoff friction velocity.

After gaps have been filled and nighttime adjustments applied, estimates for annual NEE for a site can be determined. Typically the 30- or 60-minute flux estimates are aggregating into daily, weekly, monthly, and annual time periods. NEE estimates have been published for over 40 sites by individual investigators and are available from FLUXNET-DIS (http://www.fluxnet.ornl.gov/fluxnet/nee.cfm). In addition, gap-filled flux products and aggregation sums based on the gap-filling procedures developed by Falge et al. (2001a, b) are available from FLUXNET-DIS http://www.fluxnet.ornl.gov/fluxnet/gapzips.cfm).

6. REMOTE SENSING

The FLUXNET-DIS project provides remote sensing products for sites, or links to site Web pages that contain such imagery. The ORNL DAAC provides access to MODIS products as they become available from NASA. The goal of the MODIS ASCII Subset activity is to prepare summaries of selected MODIS Land Products for the community to use for validation in conjunction with FLUXNET and other field data. The Subsets include pixel values of selected land products for a 7 x 7-km area around the flux towers or field sites. Data are available from the ORNL DAAC's FTP area.

Nine MODIS products (Table 9) are available for many flux sites, primarily as 8-day composites for 7x7-km subsets around the flux towers (http://www.fluxnet.ornl.gov/fluxnet/modis.cfm).

Table 9. MODIS products currently available in ASCII format and subsetted (7 × 7 km) for selected sites

Product	Acronym	Spatial resolution	Temporal frequency	Product number
Surface reflectance	SREF	500 m	8-day composites	MOD09A1
Land surface temperature and emissivity	TEMP	1 km	8-day composites	MOD11A2
Land cover	LC	1 km	96-day	MOD12Q1
Normalized Difference Vegetation Index (NDVI) and Enhanced Vegetation Index (EVI)	NDVI / EVI	1 km	16-day composites	MOD13A2
Leaf Area Index and Fraction of Photosynthetically Absorbed Radiation (FPAR)	LAI / FPAR	1 km	8-day composites	MOD15A2
Photosynthesis (PSN)	PSN	1 km	8-day composites	MOD17A2
Net primary productivity (NPP)	NPP	1 km	Yearly	MOD17A3
MODIS/Terra BRDF/Albedo Model-1 16-Day L3 Global 1km ISIN Grid		1 km	16-day composites	MOD43B1
Reflectance Nadir BRDF-Adjusted (NBAR)	NBAR	1 km	16-day composites	MOD43B4

ORNL posts these subsets (7x7 km) in a single expanding ASCII table for each site-product with rows representing dates and columns values for the pixels surrounding flux towers (http://public.ornl.gov/fluxnet/modis.cfm).

The Field Data-Image-Model Intercomparison Activity (http://public.ornl.gov/ameriflux/Analysis/Model_Evaluation/index.html) is a task in which MODIS products are being compared to field measurements, flux tower observations, and model simulations.

7. ACKNOWLEDGMENTS

The Terrestrial Ecology Program within NASA's Office of Earth Science (U.S. National Aeronautics and Space Administration, Office of Earth Science, Terrestrial Ecology Program, Activity No. 46WM16401) supported the FLUXNET-DIS project. We especially appreciate Dr. Diane Wickland's support during this project.

We thank Mac Post for helpful review comments.

This data compilation depended on the contributions of many individuals. We are grateful to the following individuals and others who are willing to not only share their data but also to provide the documentation to ensure that others can use the data: P. Bakwin, R. Ceulemans, H. J. Dolman, J. Fuentes, H. L. Gholz, A. Grelle, D. Hollinger, P. Jarvis, N. O. Jensen, G. Katul, B. E. Law, G. Matteucci, W. Munger, W. Oechel, K. Pilegaard, R. Valentini, S. Verma, T. Vesala, K. Wilson, and S. Wofsy.

8. REFERENCES

Aubinet, M., A. Grelle, A. Ibrom, U. Rannik, J. Moncrieff, T. Foken, A. Kowalski, P. Martin, P. Berbigier, Ch. Bernhofer, R. Clement, J. Elbers, A. Granier, T. Grunwald, K. Morgenster, K. Pilegaard, C. Rebmann, W. Snijders, R. Valentini and T. Vesala. 2000. Estimates of the annual net carbon and water exchange of European forests: The EUROFLUX methodology. Advances of Ecological Research 30:113–175.

Baldocchi, D. D., B. B. Hicks, and T. P. Meyers. 1988. Measuring biosphere-atmosphere exchanges of biologically related gases with micrometeorological methods. Ecology 69:1331–1340.

Baldocchi, D., R. Valentini, S. Running, W. Oechels, and R. Dahlman. 1996. Strategies for measuring and modelling carbon dioxide and water vapour fluxes over terrestrial ecosystems. Global Change Biology 2:159–168.

Baldocchi, D. D., Falge, E., Gu, L., R. Olson, D. Hollinger, S. Running, P. Anthoni, Ch. Bernhofer, K. Davis, J. Fuentes, A. Goldstein, G. Katul, B. Law, X. Lee, Y. Malhi, T. Meyers, J. W. Munger, W. Oechel, K. Pilegaard, H. P. Schmid, R. Valentini, S. Verma, T. Vesala, K. Wilson and S. Wofsy. 2001. FLUXNET: A new tool to study the temporal and spatial variability of ecosystem-scale carbon dioxide, water vapor and energy flux densities. Bulletin of the American Meteorological Society 82(11): 2415–2434.

Buchmann, N. and E. D. Schulze. 1999. Net CO_2 and H_2O fluxes of terrestrial ecosystems. Global Biogeochemical Cycles 13(3):751–760.

Chapin, F. S., III, W. Eugster, and J. P. McFadden. 2002. Arctic tundra flux study in the Kuparuk River Basin (Alaska), 1994–1996. Data set. Available online at [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tenn.

Cook, R. B., R. J. Olson, L. A. Hook, and P. Kancurik. 2001. Best practices for preparing ecological data sets to share and archive. Bulletin of the Ecological Society of America 82(2): 138–141.

Cramer, W. P. and R. Leemans. 2001. Global 30-Year Mean Monthly Climatology, 1930–1960, Version 2.1 (Cramer and Leemans). Available online [http://www.daac.ornl.gov] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tenn.

Falge, E., D. Baldocchi, R. Olson, P. Anthoni, M. Aubinet, C. Bernhofer, G. Burba, R. Ceulemans, R. Clement, H. Dolman, A. Granier, P. Gross, T. Grunwald, D. Hollinger, N. O. Jensen, G. Katul, P. Keronen, A. Kowalski, C. T. Lai, B. E. Law, T. Meyers, H. Moncrieff, E. Moors, J. Munger, K. Pilegaard, Ü. Rannik, C. Rebmann, A. Suyker, J. Tenhunen, K. Tu, S. Verma, T. Vesala, K. Wilson, and S. Wofsy. 2001a. Gap-filling strategies for defensible annual sums of net ecosystem exchange. Agricultural and Forest Meteorology 107(1):43–69.

Falge, E., D. Baldocchi, R. Olson, P. Anthoni, M. Aubinet, C. Bernhofer, G. Burba, R. Ceulemans, R. Clement, H. Dolman, A. Granier, P. Gross, T. Grunwald, D. Hollinger, N. O. Jensen, G. Katul, P. Keronen, A. Kowalski, C. T. Lai, B. E. Law, T. Meyers, H. Moncrieff, E. Moors, J. Munger, K. Pilegaard, Ü. Rannik, C. Rebmann, A. Suyker, J. Tenhunen, K. Tu, S. Verma, T. Vesala, K. Wilson, and S. Wofsy. 2001b. Gap-filling strategies for long-term energy flux data sets. Agricultural and Forest Meteorology 107(1):71–77.

Falge, E., R. Valentini , G. Matteucci, R. Valentini, A. Granier, P. Berbigier, D. Loustau, N. O. Jensen, K. Pilegaard, A. Lindroth, C. Rebmann, Ch. Bernhofer, A. J. Dolman, E. J. Moors, J. Moncrieff, Paul Jarvis, M. Aubinet, R. Ceulemans, H. Thorgeirsson, and T. Vesala. In press. EUROFLUX Gap-Filled Flux and Meteorology Data, 1996–2000. CD-ROM. CARBODATA Product, University of Bayreuth, Bayreuth, Germany. Available from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tenn. at [http://www.daac.ornl.gov].

Foken, Th. and B. Wichura. 1995. Tools for quality assessment of surface-based flux measurements. Agricultural and Forest Meteorology 78:83–105.

Gu, L., D. Baldocchi, and N. Kiang. 2000. FLUXNET 2000 Synthesis Workshop Report. Available online at [http://www.daac.ornl.gov/FLUXNET/news.html].

Gu, L. H. and D. Baldocchi. 2002. FLUXNET 2000 Synthesis—Foreword. Agricultural and Forest Meteorology 113:1–2.

Running, S. W., D. D. Baldocchi, D. P. Turner, S. T. Gower, P. S. Bakwin, and K. A. Hibbard. 1999. A global terrestrial monitoring network integrating tower fluxes, flask sampling, ecosystem modeling and EOS satellite data. Remote Sensing Environment 70:108–127.

Thornton, P. E. and S. W. Running. 1999. An improved algorithm for estimating incident daily solar radiation from measurements of temperature, humidity, and precipitation. Agriculture and Forest Meteorology 93:211–228.

Thornton, P. E., S. W. Running, and M. A. White. 1997. Generating surfaces of daily meteorology variables over large regions of complex terrain. Journal of Hydrology 190:214–251.

Valentini, R., P. de Angelis, G. Matteucci, R. Monaco, S. Dore, and G. E. Scarascia-Mugnozza. 1996. Seasonal net carbon dioxide exchange of a beech forest with the atmosphere. Global Change Biology 2:199–208.

Valentini, R., D. Baldocchi, and R. Olson. 1999. FLUXNET: A challenge that is becoming reality. Global Change Newsletter, IGBP 37:15–17.

Valentini, R., G. Matteucci, A. J. Dolman, E.-D. Schulze, C. Rebmann, E. J. Moors, A. Granier, P. Gross, N. O. Jensen, K. Pilegaard, A. Lindroth, A. Grelle, C. Bernhofer, T. Gr.Dcnwald, M. Aubinet, R. Ceulemans, A. S. Kowalski, T. Vesala, Dc. Rannik, P. Berbigier, D. Loustau, J. Guethmundsson, H. Thorgeirsson, A. Ibrom, K. Morgenstern, R. Clement, J. Moncrieff, L. Montagnani, S. Minerbi, and P. G. Jarvis. 2000. Respiration as the main determinant of carbon balance in European forests. Nature 404:861–865.

Valentini, R., ed. 2003. Fluxes of carbon, water and energy of European forests. Ecological Studies 163:300.

APPENDIX A

FLUXNET Web Site Descriptions

Table A.1. FLUXNET Web Pages

Page	Description	Links	Description
Home	Brief description and goals of the FLUXNET Project with links to regional networks	AmeriFlux	Regional Network
		CarboEUROFLUX	Regional Network
		AsiaFlux	Regional Network
		KoFlux	Regional Network
		OzFlux	Regional Network
		FLUXNET-Canada	Regional Network
General	Overviews of the FLUXNET project and links to dynamic information for the flux community	FLUXNET Architecture FLUXNET Components FLUXNET Overview FLUXNET Diversity Why a coordinated, long-term flux network?	Overview material compiled during the initial planning and organization of the FLUXNET project
		Presentations	Presentations and posters from various flux meetings
		Reports	Annual project reports and workshop proceedings
		News	Items submitted by the flux community
		Registration of new sites	Online tool to enter basic information for a new site or to update site information
		FLUXNET Data Analysis Opportunities	Links to synthesis and modeling activities
		Job announcements	Job descriptions as submitted by the flux community
		Meeting and workshop announcements	Announcements

Table A.1 (continued)

Page	Description	Links	Description
		New Publications	List of flux publications for past 12 months
		Search the List of FLUXNET Publications	Search the FLUXNET bibliographic database of over 5,000 citations
		Journals	List of major journals containing flux papers
		Parameter Definitions	Descriptions of parameters, units of measure, suggested names
		Other links	Links to useful Web sites
Sites	Pick list and table of all sites registered in FLUXNET with links to site information	Summary of the ancillary data, including site location, picture of the site, personnel, instrumentation, publications, and field measurements.	
Maps	Maps of the FLUXNET tower locations with various background maps, such as the Bailey ecoregions		Low resolution files for use on the Web or in PowerPoint presentation and higher resolution versions for publications
Data	Variety of links information about data and links to flux data	Parameter Definitions	
		Data Use Policy	
		Data Updates	
		Best Practices for Preparing Data	
		FLUXNET Data	See Table A.2
		Site Information	See Table A.2
		Network Data	See Table A.2
		Other Data	See Table A.2
		Other Activities	

Table A.1 (continued)

Page	Description	Links	Description
Mailing List	List of names, mail, and email addresses for over 500 individuals in the flux community		
Pubs	Search screen of over 5,000 citations by author, title, or keywords in title.		
Contacts	Individuals associated with the FLUXNET project, funding agencies, and Science Steering Committee		

Table A.2. FLUXNET Web Pages Associated with Data

Pick list	Choices	Description
FLUXNET Data	Published NEE estimates	NEE estimates extracted from peer-reviewed publications
	Gap-filled flux data products	
	Query by site	Dynamic user-defined queries for individual sites
	Query by parameter	Dynamic user-defined queries for specific parameters
Site Information	Site Contacts	Predefined reports from RDBMS
	Site locations	Predefined reports from RDBMS
	Average air temperature and precipitation	Predefined reports from RDBMS
	Stand characteristics (age, elevation, etc.)	Predefined reports from RDBMS
	Vegetation parameters	Predefined reports from RDBMS
	Carbon and nitrogen content	Predefined reports from RDBMS
	Terrain, slope, fetch, soil type, soil water holding capacity	Predefined reports from RDBMS
	Flux and productivity data	Predefined reports from RDBMS
	Radiation parameters	Predefined reports from RDBMS
Network Data	Euroflux data	Euroflux data
	Ameriflux data	Ameriflux data
Other Data	Long-term climate data	Long-term climate data
	Arctic Tundra Flux Study, 1994-1996	Arctic Tundra Flux Study, 1994-1996
	Net Carbon Flux Data	Net Carbon Flux Data
Other Activities	Field Image Model Intercomparison	Field Image Model Intercomparison
	MODIS ASCII Subsets: Overview and Links to Data	MODIS ASCII Subsets: Overview and Links to Data

APPENDIX B

FLUXNET Parameter Definitions

Table B.1. Flux, Meterological, and Soil Measurements

	Name	Format	Definition
Biosphere-atmosphere interface CO_2, water vapor, and energy flux			
CO_2 flux	**Fc**	±##.##	Rate of vertical transfer of CO2 calculated from measurements above the canopy in μmol m^{-2} s^{-1}
Sensible heat flux	**H**	±###.##	Rate of vertical transfer of heat (energy) in units of W m^{-2} from measurements above the canopy (NOTE sensible heat is the heat absorbed or transmitted by a substance during a change of temperature that is not accompanied by a change of state)
Water vapor flux	**E**	±#.###	(Footnote 1) Rate of vertical transfer of water vapor (water vapor is the density of water molecules in vapor phase to the density of dry air at the same temperature and pressure)
Latent heat flux	**LE**	±###.##	Rate of vertical transfer of latent heat {heat (energy) released by evapotranspiration or absorbed by the condensation or frost of water)} in units of W m^{-2} from measurements above the canopy (NOTE latent heat is the heat released or absorbed per unit mass by a system in a reversible isobaric-isothermal phase change)
Momentum flux	**TA**	±#.###	Rate of vertical transfer of momentum in units of kg $m^{-1}s^{-2}$ (ecor.html) NOTE momentum defined at Harvard Forest in units of cm^2 s^{-2} from measurements above the canopy
Meteorological data and consequences (e.g. wetness)			
Air temperature	**Ta**	±##.##	Measure of the thermal energy of the atmosphere measured above the canopy Degrees C
Relative humidity	**Rh**	+###.##	Relative humidity describes the degree of water saturation of the air, and is the ratio of the quantity of water vapor actually present to the saturation vapor pressure, the greatest amount possible at the given temperature. It is expressed in %.
Net radiation	**Rn**	±###.##	Net radiation is the difference between the incoming and outgoing total radiation. Total radiation includes both the global radiation as well as the long-wave radiation emitted by the atmosphere, the earth's surface, the vegetation, etc. Net radiation is expressed in units of W m^{-2}. (Pearcy 1991)

Table B.1 (continued)

	Name	Format	Definition
Global Solar Radiation	**Rg**	±###.#	Global (solar) radiation is the amount of solar radiation received on a horizontal plane at the earth's surface. It includes both the direct radiation from the sun and the indirect or diffuse radiation from the sky, which is due to scattering by molecules in the atmosphere and scattering and reflection from clouds and pArcticulates. It is given in units of W m^{-2}. (Pearcy 1991) NOTE solar radiation is the total electromagnetic radiation emitted by the sun with 99% of the total found between wavelengths of 0.2 and 4.0 μm, the part of the spectrum, which includes UV, PAR, and near-IR radiation. NOTE during scatter there is no change in wavelength and no energy transformation NOTE Pearcy (1991) give 0.3-3.0 μm as range for total short-wave radiation.
Short-wave Radiation	**Rgs**	±###.#	Radiation of wave-lengths between 0.285 and 2.800 um (in the visible and near ultraviolet wavelengths) in units of W m^{-2}. In general flux measurements don't distinguish between global solar radiation and shortwave radiation. NOTE Pearcy (1991) give 0.3-3.0 μm as range for total short-wave radiation.
Long-wave Radiation	**Rgl**	+###.#	Radiation emitted by the earth's surface due to thermal emission. It includes wavelengths between 4 and 100 μm, the far-IR radiation expressed in units of W m^{-2}. (Pearcy 1991)
Reflected Radiation	**Rr**	±###.#	Part of the incident global radiation, which is reflected by the surface. The flux is defined going backward in the atmosphere. It is expressed in units of W m^{-2}. (Pearcy 1991) NOTE The reflection coefficient for solar radiation of natural surfaces is called albedo.
Direct Radiation	**Rb**	±###.#	Part of global radiation, which is due to the relatively unmodified parallel radiation in the direct beam W m^{-2}. (Pearcy 1991)
Diffuse Radiation	**Rd**	±###.#	Part of global radiation, which includes reflected and scattered radiation from all portions of the sky in units of W m^{-2}. (Pearcy 1991)
UV Radiation	**Ru30 or Ru60**	+##.##	Radiation of wave-lengths between 0.1 and 0.4 μm. In units of mW m^{-2} nm^{-1}.

Table B.1 (continued)

	Name	Format	Definition
Photosynthetic Active Radiation (Photosynthetic active Photon Flux Density, Incident PAR)	**PPFD**	±####.#	PAR is the radiation in the 0.4-0.7 μm waveband. **Photosynthetic active Photon Flux Density** (PPFD) PPFD is the incident photon flux density of PAR: the number of photons (0.4-0.7 μm) incident per unit time on a unit surface. It is expressed in units of μmol photons (quanta) m^{-2} s^{-1}. **Incident PAR** (IPAR) is considered as a synonym for PPFD. (Footnote 2) (Pearcy 1991)
Absorbed PPFD	**APAR**	±####.#	Part of PPFD, that is absorbed by the vegetation during the observation time in units of μmol $m^{-2}s^{-1}$
Percent (Fraction) Intercepted Radiation	**FIPAR**	+###.## (+#.####)	Percent of PPFD, that is absorbed by the vegetation during the observation time in %
Wind speed	**WS**	+##.##	Speed of wind in the direction of the wind in m s^{-1}
Wind direction	**WD**	+##.##	Wind direction in degrees clockwise from the North
Friction Velocity	**UStar**	±#.####	Calculated (Footnote 3)
Atmospheric stability parameter	**ZL**	±######.# #	(Footnote 4) Calculated, provides information about atmospheric stability, which in needed to compute footprints
Barometric pressure	**Pa**	+##.##	Averaged barometric pressure (the pressure exerted by the weight of air above a given point) during the observation period in units of kPa
Precipitation	**P**	+##.##	Total precipitation during the observed time period in mm/time period
Throughfall	**TF**	+##.##	Precipitation reaching the ground level during the observed time period in mm/time period
Stem flow	**SF**	+##.##	Precipitation collected in bottles around the tree trunk in mm/time period

Table B.1 (continued)

	Name	Format	Definition
Snow depth	**SNOW D**	+####.	Depth of the snow at the ground, averaged over the observed time period in mm
Canopy wetness	**CW**	+#.###	A measure of the wetness of surfaces in the canopy. It helps to diagnose, whether sensors are wet and measures questionable, and affects interpretation of canopy evaporation.
Within canopy data, e.g. profiles			
CO_2 concentration profile	**Co**	±###.##	CO_2 concentration profile in units of μmol mol^{-1}
Canopy air temperature profile	**Tap**	±##.##	Temperature profile in degrees C
Bole temperature	**Tbole**	±##.##	Temperature of the tree trunk (measured usually in several depths) averaged over the observed time period in Degrees C
Relative humidity profile	**Rhp**	+###.##	Relative humidity profile in %
Humidity	**Ho**	+###.##	H_2O concentration of the air in units of mmol mol^{-1}
Dew-point temperature	**Tdew**	±##.##	Dewpoint temperature or wetbulb temperature; in deg K The temperature to which air must be cooled for saturation to occur (given a constant pressure and water vapor content). The temperature at which dew begins to form.
Light profile/tram data	**Rprof**	±###.# ±####.#	in W m^{-2}
Soil Albedo	**SAlb**	+###.#	Soil albedo is the reflection coefficient for solar radiation of the soil, the fraction of the solar radiation (in %) reflected by the soil. NOTE Albedo is the ratio of the amount of electromagnetic radiation reflected by a body to the amount incident upon it OR the reflectivity of a body compared to that of a perfectly diffusing surface at the same distance from the sun, and normal to the incident radiation.
Litter Albedo	**LAlb**	+###.#	Reflection coefficient for solar radiation of litter, the fraction of the solar radiation (in %) reflected by litter.
Canopy Albedo	**CAlb**	+###.#	Reflection coefficient for solar radiation of the canopy, the fraction of the solar radiation (in %) reflected by the canopy.
Within canopy process parameters			
Pre-dawn water potential	**PSI**	-#.##	(Note time of day: dawn, pre-dawn) in units of MPa
Leaf water potential	**LWP**	-#.##	In units of MPa

Table B.1 (continued)

	Name	Format	Definition
Stomatal conductance	**Gs**	+###.##	(minimum, spring) (vpd response, vpd in kPa at stomatal closure) The gas exchange measurement systems usually provide temperature, humidity, and light.
Leaf net photosynthesis	**Psat**	±##.##	Light response curves (maximum photosynthetic rate at light saturation, A/Ci curves) The gas exchange measurement systems usually provide temperature, humidity, and light.
Foliar respiration	**RLD**	±##.##	In units of μmol m^{-2} leaf area s^{-1}
Bole respiration	**RB**	±##.##	In units of μmol m^{-2} bole area s^{-1}
Xylem sapflow	**TR**	+#.####	(transpiration) in units of mm hr^{-1}
Derived variables: CO_2, water vapor and energy storage			
CO_2 storage in canopy air layer	**Sc**	±##.##	In units of μmol mol^{-1} s^{-1} Calculated by integrating changes in CO_2 profiles
CO_2 Drift	**FcD**	±##.##	
Heat storage in canopy air layer	**Sa**	±###.##	In units of W m^{-2} Calculated by converting changes in air temperature into heat transfer by multiplying with the specific heat of air and the canopy volume (layer volume when profile data are used)
Heat storage in canopy biomass	**Sb**	±###.##	In units of W m^{-2} Calculated by converting changes in bole temperature into heat transfer by multiplying with the specific heat of canopy biomass and the biomass volume
Latent heat in canopy air layer	**Sw**	±###.##	In units of W m^{-2} Calculated by converting changes in air humidity into heat transfer by multiplying with the specific heat of water and the canopy volume (layer volume when profile data are used)
Soil efflux of CO_2, water vapor, and energy in addition to soil moisture and temperature profiles			
Soil CO_2 flux, Soil respiration	**FCSOIL**	+##.##	The averaged soil CO_2 efflux (root respiration and heterotrophic respiration) in μmol $m^{-2}s^{-1}$
Soil heat flux	**G**	±##.##	The averaged soil heat flux density in W m^{-2}
Soil water vapor flux	**ESOIL**	±#.###	The averaged soil water vapor flux in mmol $m^{-2}s^{-1}$

Table B.1 (continued)

	Name	Format	Definition
Soil temperature (profile) (5/10/20 etc cm)	**Tscm**	±##.##	The averaged temperature (thermal energy) of the soil at different depths in degrees C (cm for depth)
Soil moisture (0-30cm/ etc)	**SWCcm**	+##.##	The soil moisture based on the difference between the soil wet and dry weight, measured once per time period in % by volume (Rundel and Jarrell 1991 give an overview of measurement systems for both, soil water content and soil water potential) (cm for depth)
Soil water potential	**SWP**	-##.##	In units of MPa

Table B.2. Stand data: Vegetation, Litter and Soils

Parameter/ Variable	**Name**	**Definition**
Physical vegetation characteristics		
Species composition (canopy and understory)	**Spp**	
Vegetation type	**Vegt**	(Footnote 5)
Species phenology	**Spphen**	(Footnote 6)
Standing crop/grass biomass	**BCG**	
Standing wood (bole) biomass	**BWt**	Wood biomass is the total quantity, at a given time, of wood of one or more species per unit area
Standing twig/branch biomass	**BWb**	
Standing leaf biomass	**BL**	(Note time period or maximum) Leaf biomass is the total quantity, at a given time, of leaf of one or more species per unit area
Crop/grass increment	**BCGI**	
Wood biomass increment	**WI**	
Branch/Twig biomass increment	**BI**	
Leaf biomass increment (conifers)	**LBI**	
Stem density (#/ha) by species	**N**	
Canopy height	**H**	

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Crown length	**Cl**	Crown can be defined as the upper part of a tree or shrub, including the branches and foliage, above the level of the lowest branch
Stand age (add year of investigation)	**Age**	(add year of investigation)
Diameter at Breast Height	**DBH**	(Footnote 7)
Stand basal area	**SBA**	Calculated from DBH by species
Sapwood area by species	**SAAsp**	
Leaf Area Index (LAI) (canopy / understory)	**LAI**	
LAI profile	**LAIPRcm**	(cm from soil surface)
Clumping index	**CI**	The clumping index of a canopy describes the relative gap frequency in the canopy. The basic exponential light extinction theory for a canopy assumes random distribution of the leaves. As this is normally not the case for (tree) canopies, the clumping index is introduced as an additional factor in the exponent of the extinction equation. A clumping index of 1 indicates random distribution, values less than 1 indicate various degrees of clumping, and values greater than 1 regular distribution of the leaves.
Leaf area density	**LAD**	
Stem area index	**SAI**	
Specific leaf area SLA (canopy / understory) (profile) Specific leaf weight SLW (canopy / understory) (profile)	**SLA** **SLW**	**SLW = Specific leaf weight = 1/SLA** cm^2 g^{-1} d.w. (SLA) g d.w. cm^{-2} (SLW)
Chemical Vegetation characteristics		
Woody tissue carbon content	**WTCC**	

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Woody tissue nitrogen content	**WTNC**	
Woody tissue non-structural carbohydrate content	**WTNS**	
Leaf carbon content	**LCC**	
Leaf nitrogen content	**LNC**	
Leaf nitrogen pool	**Nleaf**	
Leaf tissue non-structural carbohydrate content	**LNCCC**	
Leaf lignin content Leaf lignin/nitrogen ratio	**LLC** **LLNRC**	
Leaf phosphorus	**LPC**	
Sap wood carbon content	**SWCC**	
Sap wood nitrogen content	**SWNC**	
Tissue $^{13}C/^{12}C$ ratios, or $\delta^{13}C$, or discrimination Δ	**TCIS**	
Tissue $^{15}N/^{14}N$ ratios, or $\delta^{15}N$	**TNIS**	
Tissue $^{18}O/^{16}O$ ratios	**TOIS**	
Litter characteristics		
Litter fall (seasonal)	**LL**	
Litter carbon content	**LiCC**	

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Litter nitrogen content	**LiNC**	
Litter lignin content Litter lignin/nitrogen ratio	**LiLC** **LiLNR**	
Litter leaf C/N	**LiLCNR (C/N)**	
Decomposition rate	**DecR**	Breakdown rate of matter by bacteria and fungi, changing the chemical makeup and physical appearance of materials
Soil characteristics		
Soil type	**SoilTy**	The FAO soil classification system arranges the soil units in 26 primary classes based on inherent soil profile properties. (Footnote 7) The ISSS soil classification system defines 11 soil orders (entisols, inceptisols, andisols, spodosols, mollisols, alfisols, ultisols, oxisols, aridisols, vertisols, histosols).
Soil depth (depth to bedrock)	**TotDB** **SoilDA01** **SoilDA02** **SoilDA03** **SoilDA1** **SoilDA2** **SoilDB** **SoilDC**	Soil depth (TotDB) is the sum of the depths of the soil horizons A, B, and C. Soil horizons are defined as the topsoil layer or humidification zone A, (subdivided into A01 litter, A02 duff, A03 leaf mold, A1 humus, A2 leached zone), mineralization zone B, and the parent material zone C (http://www.csc.noaa.gov/otter/htmls/ecosys/physical/soil_def.HTM)
Humus layer depth	**SoilDA1** (see above)	Depth of the A horizon of the soil.
Depth to water table	**TotDW**	Depth to seepage in m
Bulk density	**BDSOIL (DSOIL)**	The dry bulk density ρb is obtained from the mass of solids in the soil sample (oven dry soil, in kg) ms, and the volume of the undisturbed soil cylinder (V): ρb = ms / V. Soils with high bulk density have limited water holding capacity and often restricted drainage. The parameter is required for converting between soil data based on weight or volume.

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Porosity	**SPOR**	The ratio between the total pore space (space between the soil pArcticles or soil interstices) of the soil to the total volume of the soil. The volumetric soil water content at saturation indicates the fraction of total pore space.
Soil texture (percent of sand, silt, and clay)	**SOILT (SOIL-PROP)**	The relative proportions of sand, silt, and clay separates in a soil, which are defined by the pArcticle size. (% clay, silt, fine sand, coarse sand; Classification of soil separates < 2.0mm according to ISSS, International Society of Soil Science)
Soil organic matter	**SOM**	Soil organic matter contributes to soil structure and improves the drainage of soil.
Soil water capacity or Field Capacity	**SFC (Fc2)**	The pressure head (in cm) in a soil after a few days of free drainage, following a period of thorough wetting. It is the moisture content of the soil after gravitational water has been drained from the soil, and capillary pores are still filled with water. More information on the soil water dynamics is provided by the soil-water retention curve, which describes the relationship between pressure head and soil water content.
Hydraulic conductivity or Unsaturated Hydraulic conductivity	**HYDC**	HYDC* is the most important parameter affecting water movement in the unsaturated zone. During unsaturated flow part of the pores are filled with air and do not pArcticipate in the flow. HYDC* should be measured as a function of h, the soil-water retention, or θ, the volumetric soil water content (see Rundel and Jarrell 1991; Van Genuchten et al. 1989; Wösten and Van Genuchten 1988; Van Genuchten 1980)
Thermal conductivity	**THERC**	An important parameter affecting soil heat exchange. One way for the heat flow is by thermal conduction due to molecular exchange of energy in the direction of decreasing temperature. It can vary considerably, predominantly with water content and soil structure. (see Beneke and Van der Ploeg 1981)
Soil chemistry		
Soil carbon	**Ctot**	
Soil nitrogen	**Ntot**	
Soil NH_4^+	**NH4S**	
Soil NO_3^-	**NO3S**	

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Soil organic P	**PorgS**	
Soil isotopes	**Siso**	
Soil nitrogen mineralization rate	**SnminR**	
Cation exchange capacity (CEC)	**CEC**	Total negative charge of a soil, that attracts and holds cations dissolved in the soil solution, expressed as meq/100g or cmol(+)/kg of soil. Assuming equal molar concentrations in the initial soil solution cations are held and displace one another in the sequence $Al^{3+} > H^+ > Ca^{2+} > Mg^{2+} > K^+ > NH_4^+ > Na^+$ on cation exchange sites. As long as there is sufficient base saturation CEC acts to buffer soil acidity. Acid soils with low CEC, as in the humid tropics, are buffered by various geochemical reactions involving aluminum. (Schlesinger 1991)
Soil Aluminum	**AlS**	
Soil pH	**PhS**	For measuring the soil pH a soil sample is mixed with a solution of water or dilute salt in a ratio of one part soil weight to one part solution. After stirring and 10 minutes equilibration, the pH is measured by an electrode inserted to the solution. Soil high in organic matter often need ratios of 1:5 to form a suspension. (Binkley and Vitousek 1991)
Root characteristics		
Rooting depth	**RD**	
Root biomass (profile)	**RbioPrcm** (cm for depth)	
Root biomass increment	**RBioIn**	
Pollution and trace gas data		
Rain fall chemistry, (Ca^{2+}, Mg^{2+}, K^+, Na^+, H^+, NH_4^+, NO_3^-, Cl^-, SO_4^{2-})	**PChem**	
Atmospheric N deposition	**AtNdep**	
O_3		ppb (nmol mol^{-1})
NO_2		ppb (nmol mol^{-1})

Table B.2 (continued)

Parameter/ Variable	Name	Definition
NO		ppb (nmol mol^{-1})
N_2O		ppb (nmol mol^{-1})
SF_6		ppb (nmol mol^{-1})
SO_2		ppb (nmol mol^{-1})
CH_4		ppm (mmol mol^{-1}) / nmol m^{-2} ground area s^{-1}
CO		ppb (nmol mol^{-1})
VOC C_2-C_6 hydrocarbons		
Halocarbons	**HCar**	ppb (nmol mol^{-1})
Atmospheric $^{13}C/^{12}C$ ratios, or $\delta^{13}C$	**AtCIs**	unitless / ‰ (per mil)
Atmospheric $^{15}N/^{14}N$ ratio	**AtNIs**	unitless / ‰ (per mil)
Atmospheric $^{18}O/^{16}O$ ratios, or $\delta^{18}O$	**AtOIs**	unitless / ‰ (per mil)
Additional Site Characteristics (historical, geographical and aerodynamic characteristics)		
Site History	**SHIST**	(Footnote 9)
Geographic coordinates	**LOC**	(Footnote 10)
Elevation	**ELV**	
Slope	**Slp**	The degree of deviation of a surface from horizontal that is measured as a percentage, a numerical ratio, or in degrees.
Exposure	**Exp**	
Aerodynamic roughness length	**ADR**	
Zero plane displacement height	**ZLDH**	(see Footnote 4)

Table B.2 (continued)

Parameter/ Variable	Name	Definition
Measurement height/Tower height	**MH** **TH**	
Homogeneous fetch (length, width)	**HFL** **HFW**	
Homogeneous fetch in prevailing wind direction	**HFWD**	

Table B.3. Annual calculated Flux Data

Parameter/Variable	Name	Definition
Annual summed day-time CO_2 flux	**ACO2F**	
Annual summed night-time CO_2 flux	**ACO2NF**	
Annual summed respiration (CO_2 flux)	**ACO2R**	
Annual Net Ecosystem Carbon Exchange (NEE)	**ANEE**	
Annual Above-ground Net Primary Production	**ANPP**	
Annual Evapo-transpiration	**AET**	The loss of water by evaporation from the soil and by transpiration from plants
Total Annual precipitation	**APT**	
Annual mean air temperature	**AMT**	
Annual mean bole temperature	**AMBT**	
Annual mean soil temperature	**AMST**	
Annual net radiation	**ANR**	
Annual solar radiation	**ASR**	
Max IPAR(Annual)	**MaxAPAR**	

Footnote 1. E (water vapor) is the measured variable, multiplied by λ (specific heat of vaporization, J kg^{-1}) and MW_{H2O} (molecular weight of water, g mol^{-1}), and divided by 10^6 mg kg^{-1} gives LE (in W m^{-2})

Footnote 2. PAR == incident PAR

IPAR == intercepted PAR, FIPAR == Fraction intercepted PAR

IPAR = FIPAR*PAR

FIPAR=1-fraction of incident PAR (PAR) that was transmitted through the canopy

Footnote 3. is Friction velocity, calculated as the square root of momentum

Footnote 4, is calculated, and equals Z / L, where Z is the measurement height, and L the „Monin-Obukhov"-length, $L = -(u^*)^3 / (k\ ß\ H_0)$, where u* is the friction velocity, k is the von Karman constant, ß is g / T_0 (gravity divided by surface temperature T_0), and H_0 is the surface heat flux. Over tall vegetation in stead of Z, (Z – zero plane displacement height) is more appropriate.

Footnote 5. ecological functional types:

Mixed forest
Temperate broad-leaved forest
Temperate conifer forest
Boreal broad-leaved forest
Boreal conifer
Semi-arid woodland
Alpine
Arctic
Grassland
Crop
Tropical forest
Wetland

Footnote 6. Phenology descriptions may include (some of these are from Harvard Forest publications): time period of initial bud break (begin and end date), date when leaves are at 75% and 95% of full expansion, period (begin and end date) of shoot elongation, period (begin and end date) of flowering, date of first observation of autumn color, dates of leaves-off (for deciduous, begin and end date), dates when 10-25% and 98% of leaves have been shed, dates for insect attacks, high mast (i.e. indicate a year of high seed production), and all other usual or unusual events (as shoot drops due to drought, etc.)

Footnote 7. Tree diameter at breast height is measured at 1.35 m, indicate mean and standard deviation.

Footnote 8. The FAO soil classification has two levels: the upper level with 26 soil classes, and a lower with 106. The 26 primary soil classes are

Fluvisols, Arenosols, Solonchaks, Kastanozems, Gleysols, Rendzinas, Solonetz, Chernozems, Rankers, Regosols, Andosols, Yermosols, Phaeozems, Lithosols, Vertisols, Xerosols, Greyzems, Cambisols, Podzoluvisols, Acrisols, Histosols, Podzols, Nitosols, Luvisols, Planosols, Ferralsols. (http://www.fao.org/waicent/FaoInfo/Agricult/AGL/agls/key2soils.HTM).

Footnote 9. Using text description including: site type (natural or plantation, management goal), indicate disturbances (date of fires, storms, flooding, etc.) if applicable, date of planting, thinning, fertilization if applicable

Footnote 10. Example: 50° 09' 30" N, 11° 52' 47" E

Literature Cited in Appendix B

Beneke, P., and R. R. Van der Ploeg. 1981. The soil environment. In: O. L. Lange, P. S. Nobel, C. B. Osmond, and H. Ziegler (eds.), Physiological Plant Ecology, Part I: Responses to the Physical Environment. Springer, Berlin; Heidelberg, New York.

Binkley, D., and P. Vitousek. 1991. Soil nutrient availability. In: R. W. Pearcy, J. Ehleringer, H. A. Mooney, and P. W. Rundel (eds.), Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall, London. Pp. 75–96.

Pearcy, R. W. 1991. Radiation and light measurements. In: R. W. Pearcy, J. Ehleringer, H. A. Mooney, and P. W. Rundel (eds.), Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall, London. Pp. 97–116.

Rundel, P. W., and W. M. Jarrell. 1991. Water in the environment. In: R. W. Pearcy, J. Ehleringer, H. A. Mooney, and P. W. Rundel (eds.). Plant Physiological Ecology: Field Methods and Instrumentation. Chapman and Hall, London. Pp. 29–56.

Schlesinger, W. H. 1991. Biogeochemistry: An Analysis of Global Change. Academic Press, San Diego. P. 83.

Van Genuchten, M. T. 1980. A closed-form equation for predicting the oil hydraulic conductivity of unsaturated soils. Soil Sci. Soc. Am. J. 44:892–898.

Van Genuchten, M. T., F. Kaveh, W. B. Russel, and S. R. Yates. 1989. Direct and indirect methods for estimating the hydraulic properties of unsaturated soils. In: J. Bouma and A. K. Bregt (eds.), Land qualities in space and time. PUDOC, Wageningen. Pp. 61–73.

Wösten, J. H. M., and M. T. Van Genuchten. 1988. Using texture and other soil properties to predict the unsaturated soil hydraulic functions. Soil Sci. Soc. Am. J. 52:1762–1770.

APPENDIX C

FLUXNET Relational Database Management System Description

Table C.1

BAILEY_C

Field Name	Description	Data Type	Field Size	Valid Values	Comments
Bailey_c	Bailey_c as defined from Bailey's Ecoregions	Text	50	Lookup list	Primary Key

BIOME

Field Name	Description	Data Type	Field Size	Valid Values	Comments
Biome	Biome categories as defined at the EMDI I Workshop and based on IGBP Land Cover and Models needs	Text	50	Lookup list	Primary Key

CLIMATE

Field Name	Description	Data Type	Field Size	Valid Values	Comments
Climate	Climate - based on Koppen, 24 subclassifications from six major climate regions	Text	50	Lookup list	Primary Key

DATA

Field Name	Description	Data Type	Field Size	Valid Values	Comments
OLDKEYID	Site identifier prior to January 22, 2002	Text	255	Lookup list	
SUBSITE	Identifies site partition	Text	255		
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
DATEADDED	Date value was entered into table	Date/Time	8	Any valid date/time	
PARAMETER	Measured variable	Text	255		
CHECK	Marker for identifying values that require review	Text	255		
ADDEDBY	Initials of person entering the data	Text	50	Initials	
VALUE	Measured variable result	Text	255		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
UNITS	Units for measured variable	Text	255		
SOURCE	Source of the data, such as a publication, web page, email	Text	255		
FLAG	Flag assigned	Text	255	*, ?, ~, +, <, >, >=	
VALUESTATUS	Status of value, "yes" means use the value, "no" means the value has been determined to be unusable	Text	50		
SUM	If sum=yes, then value is used in summary tables	Text	50	Yes or No	
COMPUTE	If compute=yes, then this is an artificial entry created to summarize other single entries, regardless of timeperiod	Text	50	Yes or No	
SUMMARY	Indicates whether the values is a range or average	Text	255	Max, mean, min, range, sum total	
SPATIAL	Indicates the spatial extent where the value was measured	Text	255	5 min, 1 km	
HEIGHT	Height of instrument or vertical stratum of measurements relative to ground level	Text	255	subcanopy, canopy, above crown closure, * m, * cm, A1 for soil horizon	May be negative if a subsurface stratum
GROUPING	Indicates any grouping levels that are applicable to the value	Text	255	May indicates species, DBH>30 cm, DBH>12, DBH<=30 cm, exclusions, all sided, shaded, subcanopy, trees, leaves, etc.	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
TIMEPERIOD	Year/Month/Day measurement was made (Combines year, month, and day fields)	Text	50	season, month, year or range of months or years	
TEMPORAL	Indicates any temporal constraints for the value such as length of sampling or averaging time	Text	255	Day(s), month, old, seasonal, single, summer, winter, year, young	
COMMENTS	Comment field	Memo	-		
YEAR	Year measurement was made	Text	50		
MONTH	Month measurement was made	Text	50		
DAY	Day measurement was made	Text	50		
ERROR	Estimate of measurement error or uncertainty	Text	255	Confidence interval, standard error, standard deviation	
ERRTYPE	Measurement error type	Text	255	STD, Range, Max, SE=standard error, SD=standard deviation, 95CI=95% confidence interval, CV=coefficient of variation	
METHOD	A reference to document how the measurement was made	Text	255	Statistical model, tower flux data, open-path, chamber, radius plots	
INSTRUMENT	Instrumentation used to obtain the measurement value	Text	255	Examples are LI6200, minirhizotron, open-path, soil cores	
CATEGORY	AmeriFlux program classification variable for use in web programming	Text	255		

Table C.1 (continued)

DEFINE					
Field Name	**Description**	**Data Type**	**Field Size**	**Valid Values**	**Comments**
ID	Record number	Long Integer	4	1, 2, 3 …	
CATEGORY	Category of variable	Text	255	Annual flux data, meteorological data, site characteristics, soil characteristics, soil chemistry, vegetation, etc.	
SORTCAT	Secondary variable category	Text	50	Carbon, flux, gas, inst, met, productivity, radiation, site, soil, vegetation	
MODEL	Identifies model that uses variable	Text	50	1, 2, 3	
PARAMDEF	Parameter definition	Text	255		
PARAMETER	Measured variable	Text	255	Examples: PAR, ELEV, FETCH…	Primary Key
UNITS	Units for measured variable	Text	255		
COMMENTS	Comment field	Memo	-		
TIMESTEP	Timestep	Text	255	hourly, half-hourly	
INSTRU	Instrumentation used to make measurement	Memo	-		
RANGE	Range of values for parameter	Text	255		
FORMAT	Format of value, such as +/- ##.##	Text	255		
DEFINE	Detailed parameter definition	Memo	-		
DATE	Date value was entered into table	Text	50		
SOURCE	Source of the data, such as a publication, web page, email	Text	50		
LASTUPDATE	Date of last update	Text	255		

Table C.1 (continued)

GAPDATA2

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	Long Integer	4	1, 2, 3 …	
SITECODE	Site two letter code	Text	255	BV, HV, …	
YEAR	Year data was collected	Text	255	1992-	
LETTER	Indicates - e or n	Text	50	e or n	
METHOD	Indicates method of gapfilling	Text	255	re, dc, lu	
USTAR	Indicates USTAR correction	Text	255	u0 or u1	
TIMEPERIOD	Indicates timeperiod	Text	255	mm, yy, hh, dd, ww	
FILETYPE	File type -	Text	255	flx, met, zip	
FILENAME	File name	Text	255	AB97_dc_u0_dd.flx, AB97.zip, AB97_dd.met	
STATUS	Indicates status of data	Text	255	New, removed at request of PI, old	
DATEADDED	Date value was entered into table	Date/Time	8	Any valid date/time	
ADDEDBY	Initials of person entering the data	Text	255	Initials	

IGBP

Field Name	Description	Data Type	Field Size	Valid Values	Comments
IGBPclss	Land cover class, based on IGBP (International Geosphere Biosphere Programme) Land Cover Classification	Text	50	Lookup list	Primary Key

LIBRARY

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	Long Integer	4	1, 2, 3 …	
ORIGINATOR	Person who submitted the information	Text	50		
ORIGEMAIL	Email of submitter	Text	255		
CONTACT1	Contact person	Text	255		

Field Name	Description	Data Type	Field Size	Valid Values	Comments
EMAIL1	Email of contact person	Text	255		
CONTACT2	Additional contact person	Text	255		
EMAIL2	Email of additional contact person	Text	255		
ANNLINK	Hyperlink to additional information	Text	255	Hyperlink	
ANNLINK2	Hyperlink to additional information	Text	50	Hyperlink	
AUTHOR	Author of information	Text	255		
OTHERINFO	Other information	Text	255		
ANNTYPE	Type of document	Text	255	Maps, presentation, proposal, report, course, image, job announcement, journal, link, meeting, workshop	
ANNDESC	Document description	Text	255		
IMPTDATES	Important dates such as deadline for abstract, meeting registrations, etc.	Text	255		
DATEORIG	Date the document originated	Date/Time	8	Any valid date/time	
DATEDUE	Date the document will expire	Date/Time	8	Any valid date/time	
DATEREMOVED	Date the document should be removed	Date/Time	8	Any valid date/time	
DATEADDED	Date value was entered into table	Date/Time	8	Any valid date/time	
ADDEDBY	Initials of person entering the data	Text	255	Initials	

Table C.1 (continued)

LIMITATIONS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
Limitations	Limitations of flux site	Text	255	Good for annual sums, good for process studies, good for daytime measurements, challenged by complex terrain, influenced by nearby disturbances	Primary Key

MODISCOORD

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	Long Integer	4	1, 2, 3 ...	
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
LAT	Latitude, decimal degrees	Double	8	-90 to 90 decimal degrees	
LON	Longitude, decimal degrees	Double	8	-180 to 180 decimal degrees	
VTILE	Vertical tile - A tile is the smallest unit of MODIS Land data processed at any one time for Levels 2G, 3 and 4. Each tile has fixed Earth-locations covering an area of approximately 1200 x 1200 km.	Double	8	The range of vertical tiles depends on the projection and the tile size.	
HTILE	Horizontal tile - A tile is the smallest unit of MODIS Land data processed at any one time for Levels 2G, 3 and 4. Each tile has fixed Earth-locations covering an area of approximately 1200 x 1200 km.	Double	8	The range of horizontal tiles depends on the projection and the tile size.	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
SAMP		Double	8		
LINE		Double	8		
point	Location of point	Text	255	NE, NW, SE, SW, tower, center	

MODISSTATUS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	Long Integer	4	1, 2, 3 …	
Satellite	Satellite	Text	255	Aqua, Terra	
Collection	Collection	Text	255	Collection 3, 4, …	
Date	Applicable dates	Text	255		
Products	Applicable products	Text	255		
Sites	Applicable sites	Text	255		
Event	Event	Memo			

MODISSUBSETS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	Long Integer	4	1, 2, 3 …	
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
MODIS	Indicates set of MODIS sites for Collection 4	Text	5	Yes or No	
MODIS_PENDING	Indicates pending sites for MODIS products	Text	50		
MODISCUT2	Identifies Collection 3 MODIS sites	Text	5	Yes or No	
FILENAME	MODIS Cutouts site/filename identifier	Text	255		'MODISKEYID
FILENAME_ORIG	MODIS Cutouts site/filename identifier-Collection 3	Text	255		
ADDEDBY	Initials of person entering the data	Text	255	Initials	
GRAPHICS	Indicates filename for addition graphics	Text	255		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
MOD13A2	Indicates file name for this product	Text	255		
MOD15A2	Indicates file name for this product	Text	255		
MOD17A2	Indicates file name for this product	Text	255		
COMMENTS	Comment field	Memo			

PI

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	AutoNumber	Long Integer	1, 2, 3 …	
FSERVER	Designates people associated with FLUXNET listserver - Yes/No	Text	5	Yes or No	
AMERLIST1	Designates people associated with Ameriflux network - Yes/No	Text	5	Yes or No	
PIFIRST	Investigator's first name	Text	255		
PILAST	Investigator's last name	Text	255		
PIMID	Investigator's middle initial	Text	255		
FLUX_CONTACT	FLUXNET contact	Text	255	Yes or No	
FLUX_ROLE	FLUXNET role	Text	255	Co-Principal Investigator, Data and Information System, Former Project Scientist, Programmatic Steering Committee, Science Component Leader, Science Steering Committee	
TEMAIL	Investigator's email address	Text	255		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
EMAILORG	Email address after the @ sign- helps identify individuals of same organization	Text	255		
COUNTRY	Country where pi is located	Text	255		
ADD1	Address	Text	255		
ADD2	Address	Text	255		
STREET	Street	Text	255	Yes or No	
CITY	City	Text	255		
STATE	State	Text	255		Restricted to 2 characters because of Ameriflux java applets
ZIP	Zip code	Text	255		
PHONE	Phone number	Text	255		
FAX	Fax number	Text	255		
ASSOCIATION	Assocation	Text	255		
TITLEADD	Title	Text	255		
TITLE	Job title	Text	255		
COMMENTS	Comment field	Text	255		
TWEBSITE	Investigator's homepage	Text	255		
LASTCHANGEDATE	Date entry last changed	Date/Time	8	Any valid date/time	
LASTCHANGEBY	Person's intials who made the last change	Text	255	Initials	
DATEADDED	Date individual was added to the FLUXNET listserver for the first time	Date/Time	8	Any valid date/time	
DROPPED	Indicates date when person has been dropped from the FLUXNET Listserver	Date/Time	8		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
UNSUBSCRIBED	Indicates date and/or reason individual unsubscribed to the list	Text	255		

PUBLICATIONS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	AutoNumber	Long Integer	1, 2, 3 …	
ENDNOTENO	Endnote reference number	Text	255		
REFTYPE	Reference type - journal, book	Text	255	journal, book	
HAVEPAPER	Indicates whether paper is in FLUXNET library	Text	255	Yes or No	
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
AUTHORS	Publication authors	Memo	-		
JOURNAL	Journal name	Text	255		
YEAR	Year of publication	Text	255		
TITLE	Job title	Memo	-		
VOLUME	Volume of journal	Text	255		
ISSUE	Issue of the journal	Text	255		
PAGES	Pages of journal where Arcticle is located	Text	255		
CUSTOM3	Custom variable for later use	Text	255		
CUSTOM4	Indicates whether publication has been reviewed for data	Memo	-		
CUSTOM5	Custom variable for later use	Text	255		
CUSTOM6	Indicates program, such as AmeriFlux or FLUXNET	Text	255	Used in web site programming to generate publication lists for AmeriFlux, FLUXNET	

Table C.1 (continued)

SITEINSTRUMENTATION

Field Name	Description	Data Type	Field Size	Valid Values	Comments
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
ORIGPARAMETER	Original parameter description	Text	255		
INSTRUMENTATION	Instrumentation type	Text	255		
MODEL	Instrument model	Text	255		
NOUNITS	Number of instrument units measuring this parameter	Long Integer	4		
DATASOURCE	Source of instrumentation information	Text	255		
DATEADDED	Date information added to table	Date/Time	8	Any valid date/time	
ADDEDBY	Initials of person entering the data	Text	255	Initials	
PARAM	Parameter	Text	255		
MEASUREMENTTYPE	Measurement type	Text	255	Ancillary, continuous, core, periodic	
UNITS	Units for measured variable	Text	255		
LEVEL	Height at which measurement is taken	Text	255		
TIMEPERIOD	Year/Month/Day measurement was made (Combines year, month, and day fields)	Text	255		
FREQUENCY	Frequency of measurements	Text	255		
INSTCOMMENT	Comment field	Text	255		
INSTCOMMENT2	Additional comments	Text	255		
CATEGORY	Category of instrumentation	Text	255	Eddy correlation method, gradient method, heat balance method, micrometeorology, etc.	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
RANGE	Range of values measured by instrumentation	Text	255	Example: 0-360 degrees or 400-700 nm	

SITEPIS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
PRIMARY	Indicates primary investigator	Text	50	Yes/No, multiples per site are possible	
SITECONTACT	Indicates primary site contact	Text	255	Yes or No	Must choose only one per site
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
PIFIRST	Investigator's first name	Text	255		
PILAST	Investigator's last name	Text	255		
FUNCTION	Function	Text	255	Collaborator, Primary Investigator, Site Scientist, etc.	
DATEADDED	Date value was entered into table	Date/Time	8	Any valid date/time	
ADDEDBY	Initials of person entering the data	Text	255	Initials	
OLDKEYID	Site identifier prior to January 22, 2002	Text	255	Lookup list	
USERLOGIN	User login for site changes	Text	50		
USERPASSWORD	User password for site changes	Text	50		

SUPP

Field Name	Description	Data Type	Field Size	Valid Values	Comments
PARAMETER	Measured variable	Text	255		
PARAMDEF	Parameter definition	Text	255		
SUPP	Supplemental variable - used by AmeriFlux in web programming	Text	50	Yes or No	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
VAR	Core variable - used by AmeriFlux in web programming	Text	50	Yes or No	

STATUS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
ID	Record number	AutoNumber	Long Integer	1, 2, 3 …	
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
NETWORK	Network	Text	255	Ameriflux, AsiaFlux, CarboEurope, FLUXNET, Fluxnet-Canada, KoFlux, LBA, OzNet, Safari2000, TCOS-Siberia, TropiFlux	
STATUS	Status of file processing	Text	255	1-Collected, 2-Submitted, 3-QA Review, 4-Processed, 5-GapFilled, 6-Reprocess, 9-Inactive	
YEAR	Year data generated	Double	8	1989 through present	
SOURCE	Source of data	Text	255	EUROFLUX, Marconi, rjo1004, rjo1204	
RECEIVED	Date data file was received	Text	255		
INGROUP	Group	Text	255	EUROFLUX, EUROFLUX CD Falge, Falge Marconi, MA96.csv, Marconi, RJO-Dec2001, RJO-Oct2002	
LOCATION	Location of data file	Text	255	Example: /data/fluxnet/gap_filled_marconi/data/ZIP	
FILENAME	Filename	Text	255		
COMMENTS	Comments	Text	255		

Table C.1 (continued)

TESTSITE					
Field Name	**Description**	**Data Type**	**Field Size**	**Valid Values**	**Comments**
ID	Record number	Long Integer	4	1, 2, 3 …	
USE	Designates whether site is to be used	Text	5	Yes or No	
NetworkComments	Network comments	Text	255	Aerocarb, AmeriFlux, AsiaFlux, CARBOEUROFLUX, etc. This field contains all the networks that a site may be associated with that we know about.	
KEYID	Site identifier (assigned by FLUXNET)	Text	255	Lookup list	
SITENAMEA	Site descriptive name	Text	255		
COUNTRY	Country where site is located	Text	255		
STATE	State where site is located.	Text	2		Restricted to 2 characters because of AmeriFlux java applets
FLUXNET	Designates towers that are part of the FLUXNET network	Text	5	Yes or No	
AMERIFLUX	Designates towers that are part of the AmeriFlux network	Text	5	Yes or No	
SAFARI2000	Designates towers that are part of SAFARI2000	Text	5	Yes or No	
SYNCODE	Designates two letter synthesis code	Text	5		
SYNCODE2	Designates two letter synthesis code- alternate	Text	5		
EOSLANDVAL	Designates sites that are part of EOS Land Validation	Text	5	Yes or No	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
OZFLUX	Designates towers that are part of the OzFlux network	Text	5	Yes or No	
FLUXNET_CANADA	Designates towers that are part of the FLUXNET-Canada network	Text	5	Yes or No	
KOFLUX	Designates towers that are part of the KoFlux network	Text	5	Yes or No	
ASIAFLUX	Designates towers that are part of the AsiaFlux network	Text	5	Yes or No	
SAVAFLUX	Designates towers that are part of the SavaFlux network	Text	5	Yes or No	
CARBOEUROFLUX	Designates towers that are part of the CARBOEUROFLUX network	Text	5	Yes or No	
TROPIFLUX	Designates towers that are part of the TropiFlux network	Text	5	Yes or No	
LOCLAT	Latitude in degrees	Text	255	-90 to +90	
LOCLG	Longitude in degrees	Text	255	0 to 180 degrees -180 to +180	
DATECOORDINATES	Date that the coordinates last changed (field added January 7, 2003)	Text	50		
STATUS	Status of flux measurements	Text	255	Continuous, intermittent summer operation only, roving, inactive, retired from use	
YEARBEGAN	Year flux measurements began	Text	255		
MONTHBEGAN	Month flux measurements began	Text	255		
YEAREND	Year flux measurements ended	Text	255		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
MONTHEND	Month flux measurements ended	Text	255		
INSTRUMENTS	Flux tower instrumentation	Text	255	Open-path, closed-path, multiple instruments	
LIMITATIONS	Limitations of flux site	Text	255	Good for annual sums, good for process studies, good for daytime measurements, challenged by complex terrain, influenced by nearby disturbances	
MEASUREMENTFREQUENCY	Frequency of flux measurements	Text	255	half/hourly, hourly	
MEASUREMENTPERIOD	Time period of flux measurements	Text	255		
HISTORY	Site history	Memo	-	Description of land disturbances	
COMMENTS	Comment field	Memo	-		
SOURCE	Source of the data, such as a publication, web page, email	Memo	-		
NETWORKCODE	Network site code (may be non-unique)	Text	50		
NETWORKNODE	Network site node	Text	255	FLUXNET, OzNet, LBA, …	
CLUSTER	Cluster name - identifies towers in collocated stations	Text	255		
SITETYPE	Site type -	Text	255		
BIOME	Biome - based on modelers input, see lookup list	Text	255	Lookup list	
BIOMESOURCE	Source of biome assignment	Text	255		
CLIMATESOURCE	Source of climate assignment	Text	255		

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
CLIMATE	Climate - based on Koppen, 24 subclassifications from six major climate regions	Text	255	Lookup list	
CLASSSOURCE	Source of IGBP, Bailey, UMD classes - may be determined by geographical programming or assigned by investigators	Text	255		
IGBPclss	Land cover class, based in IGBP types/MODIS	Text	255	Lookup list	
BAILEY_C	Bailey_C	Text	2	Lookup list	
UMD_CLSS		Text	255	Lookup list	
FUNDING	Funding	Text	255		
SPONSORS	Sponsors	Memo	-		
RESEARCHTOPICS	Research topics	Memo	-		
DATEADDED	Date value was entered into table	Date/Time	8	Any valid date/time	
ADDEDBY	Initials of person entering the data	Text	255	Initials	
COORD_TYPE_PROVIDED	Coordinate type provided as degrees or decimal degrees	Text	255		
LATDIR	Latitude, direction	Text	2	N or S	
LATDEGR	Latitude, degrees	Double	8	0 to 90 degrees	
LATMIN	Latitude, minutes	Double	8	0 to 60	
LATSEC	Latitude, seconds	Double	8	0 to 60	
LONGDIR	Longitude, direction	Text	2	E or W	
LONGDEG	Longitude, degrees	Double	8	0 to 180 degrees	
LONGMIN	Longitude, minutes	Double	8	0 to 60	
LONGSEC	Longitude, seconds	Double	8	0 to 60	
Link1	Applicable link to site information	Text	255	Hyperlink	

Table C.1 (continued)

Field Name	Description	Data Type	Field Size	Valid Values	Comments
Link2	Applicable link to site information	Text	255	Hyperlink	
Link3	Applicable link to site information	Text	255	Hyperlink	
Image1	Site image	Text	255	Image address, such as /images/image1.gif	
Image2	Site image	Text	255	Image address, such as /images/image1.gif	
Image3	Site image	Text	50	Image address, such as /images/image1.gif	
Image4	Site image	Text	50	Image address, such as /images/image1.gif	
Image5	Site image	Text	50	Image address, such as /images/image1.gif	
Data1	Data link	Text	255		
Data2	Data link	Text	255		

TIMECODES

Field Name	Description	Data Type	Field Size	Valid Values	Comments
TIMECODE	Monthly, daily, halfhourly, weekly, yearly	Text	255	Monthly, daily, halfhourly, weekly, yearly	
TIMEPERIOD	mm,dd,hh,ww,yy	Text	255	mm, dd, hh, ww, yy	Primary Key

UMD_CLSS

Field Name	Description	Data Type	Field Size	Valid Values	Comments
UMD_CLSS	University of Maryland land cover classification system	Text	255	Lookup list	Primary Key

APPENDIX D

FLUXNET File Content

Table D.1. Variables in meteorology data files for monthly gap-filled, aggregated flux data

Variable*	Description	Units**
Siteid	2-4 letter code	
Year	"Year"= 4-digit number	
Time	"Month"=1-12 or 0 for "yy" annual values	
GapMethod	Gap-filling method; "lookup" using U* corrected NEE	
Interval	"tot","day", "night" refer to total day, daytime only, nighttime only	
Rg	Sum of Global radiation for time period	MJ m^{-2} month-1 (or year-1)
Rg_g	Percent gaps filled for period	%
Rg_s	S.D.	MJ m^{-2} day-1
PAR	Sum of Photosynthetic active radiation for time period	mol m^{-2} month-1 (or year-1)
PAR_g	Percent gaps filled for period	%
PAR_s	S.D.	mol m^{-2} day-1) (for monthly, yearly)
Ta	Average Air temperature (height of instruments-tower top) of time period	deg. C
Ta_g	Percent gaps filled for period	%
Tami	Minimum Air temperature of time period	deg. C
Tamx	Maximum Air temperature of time period	deg. C
Ta_s	S.D.	deg. C
Ts	Average Soil temperature (5 cm depth) of time period	deg. C
Ts_g	Percent gaps filled for period	%
Tsmi	Minimum Soil temperature of time period	deg. C
Tsmx	Maximum Soil temperature of time period	deg. C
Ts_s	S.D.	deg. C
RH	Average relative humidity (height of instruments-tower top) of time period	%
RH_g	Percent gaps filled for period	%
RHmi	Minimum relative humidity of time period	%
RHmx	Maximum relative humidity of time period	%
RH_s	S.D.	%
VPD	Average vapor pressure deficit (height of instruments-tower top) of time period	kPa
VPD_g	Percent gaps filled for period	%
VPDmi	Minimum vapor pressure deficit of time period	kPa
VPDmx	Maximum vapor pressure deficit of time period	kPa

Table D.1 (continued)

Variable*	Description	Units**
VPD_s	S.D.	kPa
Ca	Average CO_2 concentration in air (height of instruments-tower top) of time period	ppm
Ca_g	Percent gaps filled for period	%
Cami	Minimum CO_2 concentration in air of time period	ppm
Camx	Maximum CO_2 concentration in air of time period	ppm
Ca_s	S.D.	ppm
Rn	Sum of Net radiation for time period	MJ m^{-2} month-1 (or year-1)
Rn_g	Percent gaps filled for period	%
Rn_s	S.D.	MJ m^{-2} day-1 (for monthly or yearly)
PPT	Sum of precipitation	mm month-1 (or year-1)
PPT_g	Percent gaps filled for period	%
PPT_s	S.D.	mm day-1 (for monthly, yearly)
SWC	Average Soil water content	cm3 H2O cm-3 soil
SWC_g	Percent gaps filled for period	%
SWC_s	S.D.	cm3 H2O cm-3 soil
WS	Average wind speed	m s-1
WS_g	Percent gaps filled for period	%
WS_s	S.D.	m s-1
Pa	Average air pressure	kPa
Pa_g	Percent gaps filled for period	%
Pa_s	S.D.	kPa
U*	Average Friction velocity	m s-1
U*_g	Percent gaps filled for period	%
U*_s	S.D.	m s-1

*This column defines order of variables (i.e., the header row) for the data sets (csv files).

**Units for the "tot" (daytime plus nighttime) are as given. Units for daytime and nighttime separately are per "time period", i.e. the values added give the "total").

Table D.2. Variables in flux data files for monthly gap-filled, aggregated flux data

Variable*	Description	Units**
Siteid	2-4 letter code	
Year	"Year"= 4-digit number	
Month	"Month"=1-12 or 0 for "yy" annual values	
GapMethod	Gap-filling method; "lookup" using U* corrected NEE	
Interval	"tot","day", "night" refer to total day, daytime only, nighttime only	
NEE	Sum of net ecosystem exchange (FC + storage + correction if applied) for time period	g C m^{-2} month-1 (or year-1)
NEE_e	Error (+/-) introduced by filling for NEE	+/- g C m^{-2} month-1 (or year-1)
NEE_g	Percent gaps filled for period	%
NEE_s	S.D.	g C m^{-2} day-1 (for month or year)
LE	Sum of latent heat for time period	MJ m^{-2} month-1 (or year-1)
LE_e	Error (+/-) introduced by filling for LE	+/- MJ m^{-2} month-1 (or year-1)
LE_g	Percent gaps filled for period	%
LE_s	S.D.	MJ m^{-2} day-1 (for monthly or yearly:)
H	Sum of sensible heat for time period	MJ m^{-2} month-1 (or year-1)
H_e	Error (+/-) introduced by filling for H	+/- MJ m^{-2} month-1 (or year-1)
H_g	Percent gaps filled for period	%
H_s	S.D.	MJ m^{-2} day-1 (for monthly or yearly)
G	Sum of soil heat flux for time period	MJ m^{-2} month-1 (or year-1)
G_e	Error (+/-) introduced by filling for G ("zero" in this version)	+/- MJ m^{-2} month-1 (or year-1)
G_g	Percent gaps filled for period	%
G_s	S.D.	MJ m^{-2} day-1 (for monthly or yearly)

*This column defines order of variables (i.e., the header row) for the data sets (csv files).

**Units for the "tot" (daytime plus nighttime) are as given. Units for daytime and nighttime separately are per "time period", i.e. the values added give the "total").

ORNL/TM-2003/204

INTERNAL DISTRIBUTION

1-20.	R. B. Cook	27.	R. C. Mann
21.	T. A. Boden	28-32.	R. J. Olson
22.	D. E. Fowler	33.	W. M. Post
23.	L. Gu	34.	L. D. Voorhees
24.	S. K. Holladay	35.	S. Wullschleger
25.	G. K. Jacobs	36-37.	ESD Library
26.	A. King	38.	ORNL Laboratory Records-RC

EXTERNAL DISTRIBUTION

39 Dennis Baldocchi, Ecosystem Science Division and Berkeley Atmospheric Science Center Department of Environmental Science, Policy and Management, 151 Hilgard Hall, University of California, Berkeley, Berkeley, CA 94720

40 Roger C. Dahlman, U.S. Department of Energy, SC-74, 19901 Germantown Road, Germantown, MD 20874-1290

41 Jerry Elwood, Acting Director, Environmental Sciences Division, ER-74, Department of Energy, 19901 Germantown Road, Germantown, MD 20874

42 E. Falge, Universität Bayreuth, 95440 Bayreuth, Germany

43 Beverly E. Law 328 Richardson Hall College of Forestry Oregon State University Corvallis, OR 97331

44 Office of Assistant Manager for Energy Research and Development, Department of Energy, Oak Ridge Operations, P.O. Box 2001, Oak Ridge, TN 37831-8600

45 Office of Scientific and Technical Information, P.O. Box 62, Oak Ridge, TN 37831

46 Steve Running, School of Forestry, University of Montana, Missoula, MT 59812

47 Diane E. Wickland, Manager, Terrestrial Ecology Program, NASA Code YS, 300 E Street, SW, Washington, DC 20546