1. TITLE

1.1 Data Set Identification

ISLSCP II FASIR-adjusted NDVI, 1982-1998.

1.2 File Name(s)

The files in this data set are named using the following naming convention:

fasir_ndvi413_xx_YYYYmm.asc

where:

fasir_ndvi413	identifies the data set and the version number (4.13).
xx	identifies the spatial resolution of the data set where 1d, hd, and qd stand for a spatial resolution of 1, 1/2 and 1/4 degrees in both latitude and longitude, respectively.
YYYY	is the four-digit year from 1982 to 1998.
mm	is the two-digit month from 01 to 12.

1.4 Revision Date of this Document

March 31, 2010

2. INVESTIGATOR(S)

2.1 Investigator(s) Name and Title

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2.2 Title of Investigation

Monitoring Seasonal and interannual variations in Land-Surface Vegetation from 1982-1998 using FASIR-adjusted NDVI.

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* Providing information on these data is not part of our daily routine; Please read this document and descriptions first and/or refer to the publications listed below. Allow for some delay in our response. For general questions regarding the data contact the NASA Oak Ridge National Laboratory Distributed Active Archive Center (ORNL DAAC) first (see Section 13).

2.4 Data Set Citation

Sietse, O.L. 2010 ISLSCP II FASIR-adjusted NDVI, 1982-1998. In Hall, Forrest G., G. Collatz, B. Meeson, S. Los, E. Brown de Colstoun, and D. Landis (eds.). ISLSCP Initiative II Collection. Data set. Available on-line [http://daac.ornl.gov/] from Oak Ridge National Laboratory Distributed Active Archive Center, Oak Ridge, Tennessee, U.S.A.
doi: 10.3334/ORNLDAAC/972

2.5 Requested Form of Acknowledgment

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

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

Los, S.O., G.J. Collatz, P.J. Sellers, C.M. Malmström, N.H. Pollack, R.S. DeFries, L. Bounoua, M.T. Parris, C.J. Tucker, and D.A. Dazlich, 2000, A global 9-year biophysical land-surface data set from NOAA AVHRR data. *J Hydrometeor*., 1, 183-199.

Los, S.O., G.J. Collatz, P.R.J. North, D.A. Dazlich and P.J. Sellers, in preparation, A global 17-year biophysical land-surface data set from NOAA AVHRR data.

3. INTRODUCTION

3.1 Objective/Purpose

The Fourier-Adjusted, Sensor and Solar zenith angle corrected, Interpolated, Reconstructed (FASIR) adjusted Normalized Difference Vegetation Index (NDVI) data sets were generated to provide a 17-year, satellite record of monthly changes in the photosynthetic activity of terrestrial vegetation. FASIR-NDVI data are also used in climate models and biogeochemical models to calculate photosynthesis, the exchange of CO_2 between the atmosphere and the land surface, land-surface evapotranspiration and the absorption and release of energy by the land surface. FASIR adjustments concentrated on reducing NDVI variations arising from atmospheric, calibration, view and illumination geometries and other effects not related to actual vegetation change. FASIR NDVI was also generated to provide inputs for computing a 17-year time series of associated biophysical parameters, provided as a separate data set in this data collection. The production of the FASIR NDVI data set and its associated biophysical parameters was funded by NASA's Land Surface Hydrology program and the Higher Education Funding Council for Wales (HEFCW) as a core component of the International Satellite Land Surface Climatology Project (ISLSCP) Initiative II Data Collection.

3.2 Summary of Parameters

Global, composited, monthly, Normalized Difference Vegetation Index (NDVI) over land areas for the period 1982 to 1998. NDVI is the difference (in reflectance) between the Advanced Very High Resolution Radiometer's (AVHRR) near-infrared and visible bands divided by the sum of these two bands.

3.3 Discussion

Because NDVI is a ratio of differences between two bands, it is *insensitive* to variations in illumination affecting both bands equally. However, NDVI ***is sensitive*** to effects that differ between bands. Band calibrations for example changed frequently between the five NOAA AVHRR series that acquired the NDVI record for the 17-year period included in this ISLSCP Initiative II collection. In addition, natural variability in atmospheric aerosols and column water vapor affected the NDVI record. Over the period of record there were two major volcanic eruptions, El Chichon in 1982 and Mt. Pinatubo in 1991, that injected large quantities of aerosols into the Earth's stratosphere. These aerosols, along with smoke from biomass burning and dust from soil erosion and other factors, introduced significant variability in the AVHRR NDVI record. These constituents have significantly different effects on AVHRR band's 1 and 2.

NDVI is also sensitive to the periodic variations in solar illumination angle and sensor view angles induced by the orbits of the NOAA satellite platforms. Their polar, sun-synchronous orbits permitted daily coverage of each point on earth, although at time-varying viewing and illumination geometries. The drift in local crossing time of the satellite during its operation causes data to be observed at later times of the day, e.g., at the equator shifts in crossing time from 1:30 PM to 4:30 PM (and later) have occurred.

Frequent cloud cover also created numerous gaps in the daily AVHRR record eliminating roughly 2/3 of the useable data. In order to construct periodic cloud-free views of the Earth, ***composite*** images were constructed at regular intervals by selecting pixels with the maximum NDVI during regularly spaced intervals. Choosing pixels with maximum NDVI reduces cloud cover and water vapor effects since both strongly reduce NDVI. Compositing can be done over any time interval, but 9 days is generally selected as the minimum period since the NOAA orbit repeats at that frequency. The monthly FASIR data record constructed here is based on 10-day composites. There are three 10-day composites per month, the first for days 1-10, the second for days 11-20 and the third for the remainder of the month. After the FASIR corrections were applied to the 10-day composites, we took the middle composite (days 11-20) to represent the month.

4. THEORY OF ALGORITHM/MEASUREMENTS

Live vegetation has a higher reflectance in the AVHRR near infrared band (band 2) than in the visible band (band 1), primarily because of differences in leaf absorption between the two bands. Leaf chlorophyll absorbs strongly in the red around 670 nm, spanned by AVHRR band 1. Leaf tissue strongly reflects in the near infrared (> 700 nm) spanned by AVHRR band 2. Thus, the difference in vegetation reflectance between the near infrared and visible bands increases with vegetation density, hence chlorophyll concentration. The ratio of the difference between band 2 and band 1 and their sum, NDVI, is an index that ranges between -1 and +1; the observed range is usually smaller: Non-vegetated materials generally have a much lower NDVI (around 0) than dense vegetation (around 0.7 or 0.8), since their near infrared and visible reflectances are more nearly equal.

5. EQUIPMENT

5.1 Instrument Description.

The Advanced Very High Resolution Radiometer (AVHRR) acquired data in 5 spectral bands; one visible, one near infrared and three thermal bands with 1024 quantizing levels. The thermal bands are not used in FASIR. AVHRR has the capability to transmit data to the ground at spatial resolutions of 1.1 and 4 km. The 4-km product or global area coverage (GAC) product is derived from the 1-km product by onboard sampling. The 4-km product is available globally from August 1981 until the present. The 1-km record is not continuous. Its availability depends upon prior arrangements made by NOAA, or on the proximity of a local receiving station that can capture the data directly from the satellite.

5.1.1 Platform (Satellite, Aircraft, Ground, Person)

The NOAA AVHRR satellite series 6,7,9, 11 and 14 used to compile the NDVI record flew in sun-synchronous polar orbits with a nominal 1:30 PM local overpass time at launch. However, the overpass times drifted by as much as 4 1/2 hours later in the day creating variable illumination and view angles over the period of record. The 55-degree sensor swath width permitted a daily view of each pixel on Earth although at different illumination and view angles during the 9-day repeat cycle. Maximum value NDVI data compositing tends to select pixels acquired in a near-nadir mode with minimum atmospheric effects. Even so, view, illumination and atmospheric effects remain. Reducing these effects is the aim of FASIR processing.

5.1.2 Mission Objectives

The NOAA AVHRR satellite sensor series was originally designed as weather satellites. However from the early 1980s, AVHRR data have been used increasingly to monitor the type and condition of land vegetation. AVHRR vegetation data archives extend back to August 1981.

5.1.3 Key Variables

The AVHRR measures top of the atmosphere radiance in 5 spectral bands. Band 1 covers the 500 to 700 nm region, band 2 the 700 to 1100 nm region, with three thermal bands one covering the middle infrared region around 3 microns and two thermal infrared bands in the 10 to 11 micron region. The FASIR NDVI product uses as input, radiance in bands 1 and 2 provided by the Pathfinder AVHRR Land (PAL) effort (James and Kalluri, 1994).

5.1.4 Principles of Operation

The NOAA satellite series, NOAA 6, 7, 9, 11 and 14 were in polar, sun-synchronous orbits with nadir afternoon overpass times. NOAA 6 data span the years 1980,1981, NOAA 7, 1982 -1985, NOAA 9, 1986-1989, NOAA 11, 1989-1995, NOAA 14, 1995-2000. Gaps in the AVHRR record exist from September 1994 until December 1994 when NOAA 11 started to malfunction and its replacement, NOAA 13, failed shortly after launch. Each AVHRR sensor has different and variable calibration and overpass time.

5.1.5 Instrument Measurement Geometry

The AVHRR is a scanning, imaging radiometer, scanning ± 55 degrees, providing a 2800 km swath width. The orbital configuration permits daily coverage at a maximum spatial resolution of 1 km of each point on earth, although at different viewing and illumination geometries on subsequent days. The orbit repeats its ground track each 9 days.

5.1.6 Manufacturer of Instrument

ITT.

5.2 Calibration

NOAA provides preflight calibration coefficients that relate the digital counts measured by the satellite to reflectances. The preflight calibration coefficients for the visible and near infrared channel are of the form:

$$\text{reflectance} = \text{gain}*(\text{digital counts} - \text{offset}) \qquad (1)$$

The gain and the offset are determined on the ground prior to launch of the satellite; The gain and offset are referred to as preflight calibration coefficients. The preflight calibration coefficients change for each satellite. In some cases preflight coefficients were updated during the time of operation of a satellite.

Preflight calibration coefficients do not take into account the degradation of the AVHRR sensor during its time of operation. Several techniques exist to correct for the change in sensitivity of the AVHRR. For the Pathfinder data, the coefficients by Rao and Chen (1994) are used to correct the visible and near infrared reflectances for in-flight sensor degradation. The Rao and Chen calibration reduces the relative error in the gain as a result of sensor degradation to about 5 %. In the FASIR NDVI data the relative degradation error in the gain is further reduced to below 1 %. See section 9.2.1 for details.

5.2.1 Specifications

5.2.1.1 Tolerance

See Rao and Chen (1994) and Section 9.2.1 for more details.

5.2.2 Frequency of Calibration

See Rao and Chen (1994) and Section 9.2.1 for more details.

5.2.3 Other Calibration Information

See James and Kalluri (1994), Rao and Chen (1994) and Section 9.2.1.

6. PROCEDURE

6.1 Data Acquisition Methods

FASIR NDVI data sets were compiled using band 1, band 2, solar zenith angle, scan angle, and relative azimuth angle values from the Pathfinder AVHRR Land (PAL) data set (James and Kalluri 1994) for the period of 1982-1998. We determined that the Pathfinder radiances were more appropriate for FASIR Bidirectional Reflectance Distribution Function (BRDF) adjustments than top of the atmosphere measurements from the AVHRR sensors because the Pathfinder data set contains band 1 and band 2 radiances corrected for atmospheric (Ozone) absorption and (Rayleigh) scattering. The BRDF functions used for the FASIR correction of illumination and viewing angle effects (see section 9.2.1) were derived for surface-measured reflectance. The Pathfinder data set is also well-documented and is currently available from the NASA Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC) (see http://daac.gsfc.nasa.gov/).

6.2 Spatial Characteristics

6.2.1 Spatial Coverage

The spatial coverage is global for all land areas except Antarctica, Greenland and small islands. Data in files are ordered from North to South and from West to East beginning at 180 degrees West and 90 degrees North.

6.2.2 Spatial Resolution

The data are given in an equal-angle latitude longitude grid at three different spatial resolutions of 1, 1/2 and 1/4 degrees in both latitude and longitude.

6.3 Temporal Characteristics

6.3.1 Temporal Coverage

The data set spans the period from January 1982 through December 1998. Gaps in the AVHRR record do exist from September 1994 until December 1994 because NOAA 11 started to malfunction and its replacement, NOAA 13, failed shortly after launch. Data for this period have been interpolated using a climatological mean and the Fourier Adjustment (see Section 9.0).

6.3.2 Temporal Resolution

The temporal resolution is monthly; The FASIR data record constructed here is based on 10-day composites (there are three 10-day composites per month, the first for day 1-10, the second for day 11-20 and the third for the remainder of the month). After the FASIR corrections were applied to the 10-day composites, we used the middle composite (days 11-20) to represent the month.

7. OBSERVATIONS

7.1 Field Notes

Not applicable to this data set.

8. DATA DESCRIPTION

8.1 Table Definition

Not applicable to this data set.

8.2 Type of Data

8.2.1 Parameter/ Variable Name	8.2.2 Parameter/ Variable Description	8.2.3 Data Range[1]	8.2.4 Units of Measurement	8.2.5 Data Source
FASIR NDVI	FASIR-adjusted* Normalized Difference Vegetation Index calculated from AVHRR channel 1 and 2 digital count data.	Min=-0.0499 Max=0.8957 Permanent Ice = -77 No data over land = -88 Water = -99	Unitless	Pathfinder AVHRR Land (PAL)

*Normalized Difference Vegetation Index corrected for:

- residual sensor degradation and sensor intercalibration differences
- distortions caused by persistent cloud cover in tropical evergreen broadleaf forests
- solar zenith angle and viewing angle effects
- volcanic aerosols
- missing data in the Northern Hemisphere during winter
- short-term atmospheric aerosol effects, atmospheric water vapor effects, and cloud cover

1 The theoretical range of NDVI is between -1 and 1.

8.3 Sample Data Record

Not applicable to this data set.

8.4 Data Format

All of the data files in the ISLSCP Initiative II data collection are in the standard ArcGIS ASCII Grid format. The file format consists of six lines of header information followed by numerical fields of varying length, which are delimited by a single space and arranged in columns and rows. The files at different spatial resolutions each contain the following numbers of columns and rows:

1 degree: 360 columns by 180 rows
1/2 degree: 720 columns by 360 rows
1/4 degree: 1440 columns by 720 rows

All files are gridded to a common equal-angle lat/long grid, where the coordinates of the upper left corner of the files are located at 180 degrees W, 90 degrees N and the lower right corner coordinates are located at 180 degrees E, 90 degrees S. Data in the files are ordered from North to South and from West to East beginning at 180 degrees West and 90 degrees North. The files have all had the ISLSCP II land/water mask applied to them. All values in these files are written as real numbers. Water bodies are assigned the value of -99, missing data over land are assigned the value of -88, and permanent ice is listed as -77.

8.5 Related Data Sets

This data set is based on data from the 8 km Pathfinder AVHRR Land (PAL) data set (James and Kalluri, 1994), available at the GSFC DAAC at: http://daac.gsfc.nasa.gov/

This data set forms the basis for a 17-year data set of biophysical parameters that is also included in this ISLSCP II data collection. The biophysical parameters include monthly total and green Leaf Area Index (LAI), fraction of photosynthetic active radiation absorbed by the vegetation canopy (FAPAR), roughness length, zero plane displacement, and fixed maximum vegetation (canopy) cover fraction. In addition, this data set was used to produce a 1-degree global monthly snow free Surface Albedo data set. This data set and related data sets can be obtained from the Oak Ridge National Laboratory Distributed Active Archive Center (DAAC) at: http://daac.ornl.gov/ISLSCP_II/islscpii.html.

The EROS Data Center (EDC) global land cover classification product using the Simple Biosphere (SiB) legend was used in the production of this data set (see Section 9.0). Finally, users may wish to compare the NDVI data from this data set with those of the Global Inventory Modeling and Mapping Studies (GIMMS) NDVI data set, which is also available in this collection.

9. DATA MANIPULATIONS

9.1 Formulas

9.1.1 Derivation Techniques/Algorithms

See Section 9.2.1

9.2 Data Processing Sequence

9.2.1 Processing Steps and Data Sets

The following layers of the 8-km Pathfinder AVHRR Land data set (James and Kalluri 1994) were used:

- band 1 reflectance
- band 2 reflectance
- solar zenith angle
- scan angle
- relative azimuth angle

The EDC global land cover classification using the SiB 1 classification scheme was also used. However, the SiB 1 land cover classification was modified; wetlands were treated as grasslands and dry coastal complexes were treated as shrubs and bare soil. Wetlands and dry coastal complexes are not defined in the SiB 1 classification.

The FASIR NDVI data sets were compiled to correct the Pathfinder NDVI data for:

1. Residual sensor degradation effects and residual intercalibration differences among subsequent AVHRRs that remained in the Pathfinder 1 data.
2. Changes in the NDVI as a result of variations in solar zenith angle and view zenith angle.
3. Data drop outs occurring fewer than three months in a row. Data dropouts are caused by cloud cover, atmospheric constituents -- aerosols, molecules, gases, water vapor -- and discontinuous data coverage.
4. Effects on the NDVI caused by volcanic aerosols from the El Chichon and Mt. Pinatubo eruptions that occurred in April 1982 and June 1991 respectively.
5. Low and missing values for evergreen needleleaf vegetation types, occurring for the most part in the Northern Hemisphere during winter.
6. Persistent cloudiness over tropical forests.

These processing steps are described in detail below:

1. AVHRR Sensor Recalibration

The Pathfinder band 1 and 2 data are corrected for sensor degradation using the technique documented in Rao and Chen (1994); The Rao and Chen calibration reduces the relative error in the AVHRR gain as a result of sensor degradation to about 5 %. We further reduce the sensor degradation error in the gain with the technique described below, and in Los (1993, 1998). To evaluate the Pathfinder calibration, we established 1000 reflectance-invariant sites globally (e.g. deserts) and used these to examine the residual variation in Pathfinder band 1, band 2 and NDVI. Our analysis showed systematic residual variations that could be reduced. To do so, we assumed that there was no residual error in the AVHRR calibration offset, thus adjusted only the Pathfinder gain values. This assumes that the difference between the AVHRR deep space count and the offset correction by Rao and Chen (1994) is negligible.

With these assumptions, the apparent rate of sensor gain degradation is given by:

r'_1 = rho1_s / rho1_d (2)

where: r'_1 = apparent sensor gain degradation in band 1[1]
rho1_d = band 1 reflectance of desert sites
rho1_s = reference band 1 long-term average reflectance

We don’t know the actual value of reflectance for our reflectance - invariant sites, so we assumed that the band 1 reflectance of a site is the 17-year mean value of the AVHRR Pathfinder band 1 reflectance for that site.

We could in a similar manner compute the degradation in the band 2 gain by

r'_2 = rho2_s / rho2_d (3)

[1] We refer to it as “apparent” sensor gain degradation because its value is estimated assuming that the “true” reflectance is given by the long-term average of Pathfinder band 1 reflectance.

Instead, we employed an alternate method that expresses the degradation in the band 2 gain, r'_2, relative to the degradation in band 1 and the Simple Ratio, band 2/band 1. The advantage in using the SR to estimate the combined sensor degradation in band 1 and 2 is that residual calibration errors in the NDVI are about 1/3 smaller than when the NDVI is calculated from the calibrated component bands. This gain in accuracy can be derived from an analysis of the propagation of band 1 and 2 errors in the NDVI.

Let $r'_{1/2}$ denote the degradation in band 2 gain relative to that in band 1. That is,

$$r'_{1/2} = r'_1 / r'_2 \tag{4}$$

$r'_{1/2}$ can be expressed in terms of the simple ratio and its long-term mean, i.e.,

$$r'_{1/2} = (\rho1_s/\rho1_d)\,(\rho2_d/\rho2_s) = (SR_s) / (SR_d) \tag{5}$$

where: SR_s is the variation in simple ratio over the reference sites and
SR_d is the long-term average of Pathfinder simple ratio over the reference sites

Thus we may calculate the degradation in band 2 from r'_1 and measurements of simple ratio and its long-term average.

$$r'_2 = r'_1 \,(SR_d)/(SR_s) \tag{6}$$

The calibration method and derivation of the equations is published in Los (1993, 1998). The apparent calibration coefficients for the band 1 and 2 gains were calculated for every 10-day composite. A “smoother” was applied to these values to reduce noise (Friedman 1984). The smoothed 10-day calibration coefficients were applied to the individual bands using the inversions of the above equations.

After the additional calibration corrections, the relative RMS error as a result of sensor degradation and intercalibration differences in the channel 1 and 2 gains is estimated at about 1 %. The absolute calibration error is unknown, but the average calibration standard is similar to Rao and Chen (1994) and Holben et al (1990) who related their calibration standard to aircraft measurements. Vermote and Kaufman (1995) use a different calibration standard that is based on the radiative properties of the atmosphere. Because of this different calibration standard, the Vermote and Kaufman calibrated NDVI values are consistently higher than NDVIs from the other calibration methods.

2. BRDF correction

To correct for illumination and viewing angle effects in the AVHRR data, the Bi-directional Reflectance Distribution Function (BRDF) for each pixel is estimated from its 17-year NDVI anomaly time series by determining which of two functions (Ross Thick and the LiSparse kernels) best fit the time variation in the series. Thus, we assume that each pixel retains a constant BRDF over the 17-year series. Specifically:

(a) Ross Thick and Li Sparse Kernels were calculated for viewing and solar geometry concurrent with the collection of the NDVI data. In the LiSparse kernel both the h/b ratio and b/r ratio were varied iteratively to obtain a least squares best fit. The b is the vertical radius of the vegetation canopy; r is the horizontal radius of the vegetation canopy; and h is the height of the vegetation. The ratios calculated do not necessarily have any physical meaning, they were varied to obtain the optimum BRDF shape.

(b) Departures from the monthly mean were calculated (NDVI, Ross Thick and Li Sparse kernels); kernels were fitted through anomalies of 50 % of the highest NDVI values; high NDVI values are in general the most reliable in a time-series. Estimating an accurate BRDF shape from the Pathfinder AVHRR data is complicated by the relatively low sampling frequency. For operational purposes, we estimate an average BRDF shape for the entire period of 1982-1998 from the anomaly data:

$$\Delta NDVI = k\mathit{geo}' \, \Delta K(\mathit{LS}) + k\mathit{vol}' \, \Delta K(\mathit{RT}) \qquad (7)$$

where: Δ indicates the deviations from the 10-day mean
$k\mathit{geo}'$ = the coefficient for the geometric kernel
$K(\mathit{LS})$ = the Li Sparse kernel
$k\mathit{vol}'$ = the coefficient for the volumetric kernel
$K(\mathit{RT})$ = the Ross Thick kernel

This assumes that the BRDF does not change significantly, both seasonally and interannually, as a function of leaf area index (LAI). Simulations indicated that with this technique the BRDF effect was reduced to about 1/3 of its original magnitude.

(c) NDVI data (not the anomalies) were normalized to standard viewing geometry using the kernel weights calculated under (b) to 30 degrees solar zenith angle and 0 degrees view angle. The kernel weights from the anomalies were applied to the NDVI data. This simplifies the correction procedure, but introduces a random error of about 5 %.

3. Reconstruction

Cloud effects in tropical forests as defined by the IGBP land cover data set were minimized by selecting the maximum NDVI value of a 3 x3 spatial window. In previous FASIR versions cloud effects were reduced by selecting the maximum NDVI of the year to represent the NDVI for the entire year. This eliminates seasonal information in the data over tropical forests; the maximum filter retains the seasonal information but effectively reduces the spatial resolution from 8 by 8 km to 24 by 24 km (about 0.25 degree at the equator)

4. Aerosol Correction

To correct the data for aerosol effects from the eruptions of Mt Pinatubo in 1991 and El Chichon in 1982, we used the aerosol optical depth data from Sato et al (1993). The Sato et al (1993) data extend further north and south (90 S to 90 N) than the data set by Vermote et al 1994 (50 S to 50 N) than was used to correct the ISLSCP Initiative I

FASIR NDVI. Data sets by Sato et al were interpolated to 0.5 degree latitude and 10 day intervals. Data prior to and 2 years after the eruptions were set to zero. The Sato et al (1993) data set contains optical depth for four different stratospheric layers. This information was reduced to 2 principal components per latitude. The first 2 principal components were fitted to the change in NDVI for each pixel:

$$\Delta NDVI \ / (\max (NDVI, 0.2) = a + b\ PC1 + c\ PC2 \quad (8)$$

where: ΔNDVI = the change in NDVI caused by aerosol scattering and absorption.
a, b, c = the regression coefficients.
PC1, PC2 = the first and second principal components of the aerosol optical depth fields for a particular latitude.

It takes several months after an eruption before aerosols are evenly distributed over a latitude band. As a result NDVI data are likely undercorrected during the start of the eruption. Comparison of the NDVI corrected with the Sato et al data and the NDVI corrected with the Vermote et al optical depth data showed close agreement between 50 degrees South and 50 degrees North.

5. Interpolation

The NDVI record, for various reasons, has missing values. In such cases some parameters require a best guess of a land surface value. Other cases can use a zero value instead. For example, missing NDVI data, when substituted by a zero value in needle bearing evergreen vegetation during winte, are not a problem for the calculation of photosynthetic rates, because these values will be close to zero during winter. However, zero NDVI values are a problem for the calculation of roughness length and albedo. Zero NDVI would translate to zero roughness length and high albedo, whereas evergreen forests in reality have higher roughness length and lower albedo values because of trees protruding through the snow. Thus an estimate of the greenness of vegetation in the boreal forests during winter is necessary to avoid erroneous estimates for the aerodynamic resistance and energy budget (Sellers et al 1994).

Interpolation was similar to the procedure described in Sellers et al (1996); we took the median of all October values (3 per year) for 1981-1999 for evergreen needle leaf classes. Values below the median October value were replaced. The same procedure was applied to data in the Southern Hemisphere but with a lag of six months.

6. Fourier Adjustment

Fourier adjustment was modified to take into account the occurrence of NDVI outliers with anomalously high values in the 8 km Pathfinder data. The Fourier adjustment requires an input of 36 dekadal (10-day) values at a time. In general, it is assumed that the effects of atmosphere, clouds, off-nadir viewing etc. will lower the value of the NDVI. It is further assumed that the development of NDVI-time series is smooth, i.e., sudden changes in the NDVI are not due to sudden changes in the target. Using these two assumptions, a technique was developed that fits a smooth series through an NDVI sequence for a year. The smoothed NDVI curve is compared with the values of the original series. Points below the fitted curve are likely to be unreliable (errors tended to decrease the NDVI). Based on the distance to the fitted curve weights were calculated and a new curve was fitted with strong emphasis on the reliable points (points above the first fitted curve). A threshold was used to assign a low weight to extreme outliers about the first fitted curve. This was necessary to remove anomalous high points that are most likely the result of interference during data transmission to the ground (Emery et al 1989).

Prior to the Fourier Adjustment missing data and extreme outliers were replaced with the long-term mean:

(a) Replace data point with the monthly mean if the deviation from the monthly mean is outside $-2k < u < 4k$, where $k = 2$, u = (y - y_avg) / M, M = median(abs(y-y_avg)), y_avg = average y for 10-day composite (= dekade) and y = element of NDVI time-series.

(b) The Fourier adjustment is described in Sellers et al (1996) and its application on multi-year data explained in Los et al (2000). The weighting in the Fourier adjustment was revised to account for the occurrence of outliers with high NDVI values in the 8 km data. For one year of data at a time solve the following matrix equation:

$$\mathbf{F}'\,\mathbf{F}\,\mathbf{c} = \mathbf{F}'\,\mathbf{y} \qquad (9)$$

where **F** = the matrix with the Fourier series:

1st column contains all values set to 1
2nd column contains terms with cos (phi)
3rd column contains terms with sin(phi)
4th column contains terms with cos(2*phi)
5th column contains terms with sin(2*phi)

phi = 2 * pi * (dekade - 1)/36
c = vector with coefficients to be solved
y = the NDVI time series (36 10-day composites or dekades)

The fitted NDVI series are calculated from the coefficient **c** and the Fourier series in matrix **F**. A weight is calculated for each fitted point:

If $0 < u < 2k$ then $w = 10$
else if $(-k) < u \le 0$ then $w = 1$
otherwise $w = 0.1$

where: u = (y - y_fit) / median (abs (y - y_fit)) (10)

Fourier series were fitted a second time but with each data point y weighted with w. The Fourier adjustment was applied to 36 decades (1 year of data) at a time. Fitting moved along the time series with intervals of 17 decades; the fitted data for the middle 17 decades were retained to form the corrected time series.

Finally, two low pass filters were applied to the late 1994 data to estimate the interannual variation:

- A moving average was calculated for the entire time series, the span was -22 to + 22 dekades; low frequency data;
- A moving average was calculated for the corrected time series, the span was -5 to + 5 dekades; missing data for 1994 were replaced with the filtered data.

9.2.2 Processing Changes

With this update of FASIR (release 4.13) changes were made with respect to the description of FASIR in the Sellers et al (1996) paper and FASIR release 2.x; (Los et al 2000) published as part of the ISLSCP Initiative II collection. These changes are:

1. use of a different land cover classification (EDC SiB 1 classification).
2. estimation of BRDF from NDVI anomalies per pixel instead of solar zenith angle effect estimated per biome type.
3. use of Pathfinder AVHRR data instead of GIMMS data (Hence data are corrected for ozone absorption and Rayleigh scattering by the atmosphere).
4. Calibration of component channel 1 and 2 data in stead of the NDVI data.

9.2.3 Additional Processing by the ISLSCP II Staff

The ISLSCP II staff checked the FASIR NDVI data for consistency with the ISLSCP II land/water mask. Some inconsistencies between missing data flags were found and fixed in all data layers. Points in small islands (e.g. Hawaii) that were unclassified on the EDC land cover data set were set to –88, or missing data over land. Other points over land with no NDVI values for the entire record (e.g. Greenland, Antarctica) were also set to –88. Finally, some points had missing data over some months, typically winter, yet for other months the NDVI values were provided. For these points, we assigned the minimum value in NDVI for the particular year where the missing data were found. For all data layers, the water values were then assigned the water flag of –99. The ISLSCP "permanent ice mask" (derived from the EDC land cover classification) was then imposed on each map, flagging permanent ice as -77.

9.3 Calculations

9.3.1 Special Corrections/Adjustments

None other than those described in Sections 9.1 and 9.2 above.

9.4 Graphs and Plots

None given at this revision.

10. ERRORS

10.1 Sources of Error

Some sources of error in the NDVI data set are not accounted for with the FASIR corrections. These errors are caused by:

- soil background reflectance; this affects low NDVI values, but does not affect high NDVI values. Thus similar low NDVI values may indicate different amounts of vegetation.

- bias as a result of compositing; this bias is smaller in the current data set than previous versions because 10-day composites were used instead of monthly composites
- residual long-term atmospheric effects (e.g., after volcanic eruptions)

10.2 Quality Assessment

10.2.1 Data Validation by Source

Earlier versions of FASIR-NDVI data have been used in various models and seem to capture general patterns of vegetation well. Tests on sites showed reasonable agreement of interannual variation in FASIR NDVI and other measures of vegetation (crop yield variations, variations in tree-ring density (Malmstrom et al, D'Arrigo et al, Lobell et al). These tests show that the variation in FASIR NDVI is realistic on specific sites. Comparisons between climate signals and FASIR NDVI show realistic patterns in many semi-arid regions and temperate regions. Errors in the data are thought to be most significant in areas with snow cover for a large part of the year. The development of FASIR-NDVI data is an ongoing project, further evaluation of the data is anticipated.

The accuracy the FASIR BRDF approach was tested on data simulated with the FLIGHT model (North 1996). FLIGHT simulates the scattering and absorption of radiation in complex canopies. We used FLIGHT to generate NDVI timeseries for different vegetation types. All time-series were derived from seasonally and interannually varying LAI time-series and contained the effects of the observed variations in AVHRR solar and viewing geometry over 17 years as well. We estimated the BRDF effect on the simulated NDVI time-series with the LiSparse and Ross Thick Kernels. Synthetic NDVI time-series were calculated from simulated interannually varying LAI time-series for observed AVHRR viewing and illumination geometries. The effect of varying geometry was then estimated, and the synthetic NDVI data were then adjusted to standard viewing and illumination geometry and compared with the standard viewing geometry predicted by the FLIGHT model. In the simulations, the Root Mean Square Error (RMS) as a result of viewing and illumination geometry decreased to about 30 % of the RMS error in uncorrected data. Simulations testing solar zenith angle corrections previously used to correct for varying illumination revealed that the RMS error was reduced to only about 90% of that in the uncorrected data. BRDF corrections applied to component channel data instead of the NDVI lead to similar results when correction anomalies, however, residual errors were larger when the NDVI seasonality was calculated.

10.2.2 Confidence Level/Accuracy Judgment

The FASIR-NDVI data set is believed to give large improvements over the Pathfinder NDVI data set, especially for areas with persistent cloud cover and for needle bearing evergreen vegetation during winter. FASIR NDVI has reduced effects of orbital drift that are especially large near the end of the time of operation a satellite. Data from September 1994 - December 1994 are estimated by interpolation and should be treated with extreme caution. Corrections for atmospheric aerosols are likely to be too small from about one to three months after an eruption (May-Jul 1982 for El Chichon and Jul-Sep 1991 for Mt Pinatubo). See Table 1 below.

10.2.4 Additional Quality Assessment Applied

NDVI data are increasingly being used to assess interannual variations in the biosphere; we would like to distinguish between the following types of temporal analyses (see also Gutman 1996):

- seasonal analysis: NDVI data should provide a realistic representation of seasonality of vegetation. The BRDF correction adjusts the seasonal cycle for solar zenith angle effects in temperate and high northern latitudes. These solar zenith angle effects tend to decrease the length of growing season in top of atmosphere data and tend to increase length of growing season in ground measured data. Not all seasonality displayed by the NDVI data reflects variation of land-surface vegetation, e.g., small seasonal cycles are observed in the Sahara, this seasonality is most likely caused by variations in atmospheric water vapor, not by variations in vegetation.

Table 1. Measurement Error for Parameters and Variables

Error Source	**RMS Error Pathfinder NDVI**	**RMS Error FASIR NDVI**
A) Dense vegetation (0.4 < NDVI < 0.85)		
Calibration (Los 1995)	0.007	0.001
Clouds (<= 2 months) (Los et al 2001)	0.200	0.005
Atmospheric effects (<= 2 months) (Los et al 2001)	0.100	0.005
Volcanic Aerosols (Los et al 2001)	0.200	0.020
Missing data (Los et al 2001)	0.6	0.050
BRDF (Los et al in preparation)	0.050	0.01-0.03
B) Sparse Vegetation. (0.05 < NDVI < 0.4)		
Calibration	0.014	0.002
Clouds	0.100	0.005
Atmospheric effects	0.050	0.005
Volcanic aerosols	0.005	0.005
Missing data	0.100	0.050
BRDF	0.010	0

Indication of magnitude of several errors in the Pathfinder NDVI and FASIR NDVI data sets; error estimates are provided for dense and sparse vegetation. The error estimates should be seen as an indication of the RSE over an extended region (e.g., for a 5-degree latitude band, or a tropical forest). The magnitude of the errors vary significantly over space and time; errors for local areas can be significantly higher or lower.

- interannual analysis: NDVI data have been used to look at year-to-year variations in desert margins (Tucker et al 1991) and to variations associated with climate oscillations (Myneni et al 1995, Los et al 2001). The interannual signal in semi-arid regions and temperate regions is in general larger than the residual errors in the data.

- trend analysis: This is in general the smallest interannual signal in the data; errors in the NDVI data are often as large or larger than the magnitude of trends, at this stage the trends in NDVI data is uncertain within an order of magnitude.

11. NOTES

11.1 Known Problems with the Data

Data from about September 1994 - December 1994 have limited reliability; they were interpolated because these data were missing in the Pathfinder record. Data at the end of NOAA 7 (1984) and NOAA 11 (1994) are possibly more problematic because of extreme solar zenith angles at which data were collected by the AVHRR.

11.2 Usage Guidance

FASIR NDVI presents generalized patterns which may result in poor representations of a specific locale, quantitative conclusions should be drawn with caution. Nevertheless, FASIR-NDVI should provide a large improvement over previously used land cover schemes (e.g. Dorman and Sellers 1989) and NDVI data sets, because the data are collected by one series of instruments, and they give a more realistic representation of the spatial and temporal variability of vegetation patterns over the globe. Users of the data are strongly encouraged to validate their results on independent data.

11.3 Other Relevant Information

None.

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13. DATA ACCESS

13.1 Data Access Information

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

13.2 Contacts for Archive

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

13.3 Archive/Status/Plans

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

14. GLOSSARY OF ACRONYMS

AVHRR	Advanced Very High Resolution Radiometer
BRDF	Bidirectional Reflectance Distribution Function
DAAC	Distributed Active Archive Center
DISC	Data and Information Service Center
DVD	Digital Video Disk
EDC	EROS Data Center
EOS	Earth Observing System
FASIR (NDVI)	Fourier Adjusted, Solar and view zenith angle correction, Interpolation, and Reconstruction of NDVI
FPAR/Fapar	Fraction of Absorbed Photosynthetically Active Radiation
GAC	Global Area Coverage
GCM	General Circulation Model

GES	Goddard Earth Sciences
GIMMS	Global Inventory Monitoring and Modeling Studies
GSFC	Goddard Space Flight Center
GVI	Global Vegetation Index
HEFCW	Higher Education Funding Council for Wales
IDS	Inter disciplinary Science
IFOV	Instantaneous Field Of View
ISLSCP	International Satellite Land Surface Climatology Project
LAC	Local Area Coverage
LAI	Leaf Area Index
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanographic and Atmospheric Administration
ORNL	Oak Ridge National Laboratory
PAL	Pathfinder AVHRR Land
RMS	Root Mean Square Error
SiB	Simple Biosphere model
SR	Simple Ratio