Name: LAI and FPAR

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Description

LAI is Leaf Area Index, defined as the one-sided green leaf area per unit ground area in broadleaf canopies and as half the total needle surface area in coniferous canopies. FPAR is the Fraction of Photosythetically Active Radiation (400-700 nm) absorbed by vegetation. LAI and FPAR are key biophysical variables controlling the exchange of energy, mass (e.g. water and CO_2) and momentum between the Earth surface and atmosphere. LAI and FPAR Earth System Data Records (ESDRs) have been generated globally from various sensors (AVHRR, MODIS, MISR, POLDER, SPOT-VGT, etc.) data at different spatial resolutions (250m to 1 degree) and temporal frequencies (4-day, 8-day and monthly).

Scientific rationale, importance of measurement, and expected end uses

Large-scale ecosystem modeling is used to simulate a range of terrestrial responses to variability and changes in climate. Land surface models such as the Biosphere-Atmosphere Transfer (BATS) model, Simple Biosphere (SiB) model, and Community Land Model (CLM), ecosystem productivity models such as the NASA-Carnegie Ames Stanford Approach (NASA-CASA), Biome-BioGeochemical Cycles model (Biome-BGC), Terrestrial Ecosystem Model (TEM), and models in hydrology, crop production etc. all require a set of land-surface variables that include land cover, LAI, FPAR, roughness length, and albedo. The estimation of land surface parameters, including LAI and FPAR, at regional and especially global scale is feasible only through remote sensing.

The models typically use satellite data based estimates of LAI and FPAR in one of three ways-forcing the model, validation of model output and model assimilation. A recent model study with the NCAR Community Climate Model (CCM3) forced with AVHRR-derived LAI reported that the use of satellite derived fields lead to a notable warming and decreased precipitation over large parts of the northern hemisphere lands during the boreal summer. Such warming and drying reduced discrepancies between the simulated and observed near-surface temperature and precipitation fields (Buermann et al., 2001). An inter-comparison of seasonal and spatial variations of global LAI and FPAR from MODIS and the Common Land Model (CLM) revealed consistency between the two during snow-free periods but model underestimates in the presence of snow, especially over evergreen forests (Tian et al., 2004). LAI/FPAR data, in addition to climate, are key inputs to carbon cycling models such as Biome-BGC and CASA. While climate influences interannual variability in net primary production and heterotrophic respiration, long-term changes in LAI/FPAR indicate significant changes in vegetation biomass and carbon sequestration. These and several other studies indicate the critical role of LAI and

FPAR in climate simulations and the need for high quality time series of global LAI and FPAR ESDRs.

The development of LAI and FPAR ESDRs supports investigation of the following NASA's Earth System Enterprise (ESE) research questions:

. • How are global ecosystems changing?

. • How do ecosystems respond to and affect global environmental change and the carbon cycle?

. • What changes are occurring in global land cover and land use, and what are their causes?

. • How will carbon cycle dynamics and terrestrial and marine ecosystems change in the future?

. • What are the consequences of land cover and land use change for human societies and the sustainability of ecosystems?

The community of LAI and FPAR users includes at least the following three classes: a) Scientific: modelers of climate, primary production, ecology, hydrology, crop production; b) Public: meteorological organizations, deforestation and desertification monitoring organizations, rapid response systems, pest risk evaluation companies, governments (for the implementation of international treaties such as Kyoto protocol, etc.); c) Private: international agriculture and forestry companies, insurance companies, traders, etc.

Scientific Requirements for the Measurement

The standard LAI and FPAR products from Terra and Aqua MODIS sensors are generated as 8day composites at 1-km spatial resolution. The accuracy of those products has been documented through comparison with a large number of ground measurements performed by multiple international teams over range of vegetation types (biomes) and climatic conditions. Every effort has been made to utilize existing measurements, registered at various frameworks (i.e., FLUXNET, LTER, ORNL Mercury system). Based on feedback from the user community and the accumulated research experience, we propose the following specifications for global LAI and FPAR products:

. • LAI accuracy of 0.5 LAI units, FPAR accuracy of 0.1, to be achieved for corresponding global averages over individual biomes;

. • Spatial resolution depends on application: from 250-m (local ecological studies) to 0.25 degree (global climate studies);

. • Temporal frequency from 4-days to monthly;

. • Length of record starting from the beginning of AVHRR measurements (July 1981) and continuing into the future.

Approach to generating the measurement (i.e., data product)

The approaches to generating LAI/FPAR fields from satellite data can be grouped into

three broad categories: a) Empirical methods, which utilize vegetation indices; b) Physical methods, based on Radiative Transfer theory; c) Artificial intelligence based computer methods. While the implementation details may vary, the following core concepts are common to all: use passive remote sensing data at optical and infrared (NIR and SWIR) bands; strict requirements on atmospheric correction, especially in the case of high sensitivity of parameters to surface reflectances (i.e. retrievals of LAI under saturation condition); use of compositing to minimize the impact of atmosphere; cloud and snow screening.
Historically, LAI/FPAR retrievals from satellite data were first implemented with empirical methods applied to NOAA AVHRR data. Los et al. at NASA generated one year (1987) of global NDVI data at 1x1 degree spatial resolution for characterization of spatial and temporal variation of vegetation cover in climate models. This data set was further processed by Seller et al. at NASA to correct for atmospheric, view/illumination geometry and other effect to generate the FASIR-NDVI data set (FASIR stands for Fourier wave Adjustment, Solar zenith angle adjustment, Interpolation of missing data, and Reconstruction of NDVI data over tropical evergreen broadleaf forests). The FASIR-NDVI data set was converted to LAI/FPAR using empirical relationships derived from available field surveys.

James and Kalluri at NASA implemented the Pathfinder AVHRR Land (PAL) data set at 8 km spatial resolution, 10-days composites for the period July 1981 to September 1994. The processing included improved navigation, calibration and partial atmospheric correction (Rayleigh scattering and ozone absorption). Independently, Tucker et al. at NASA implemented the Global Inventory Monitoring and Modeling Studies (GIMMS) NDVI data set at 8 km spatial resolution, 15-days composites for period January 1982 to December 2004. GIMMS NDVI data were calibrated and processed by the Principal Component Analysis (PCA) technique to minimize atmospheric effects and to interpolate missing data. The PAL and GIMMS NDVI time series were processed by Myneni et al. at Boston University to generate corresponding LAI/FPAR data sets. Biome-specific LAI-NDVI and FPAR-NDVI relationships were derived based on Radiate Transfer (RT) simulations and field surveys.

The researchers at the Canadian Center for Remote Sensing (CCRS: Chen, Cihlar, Leblank and Fernandes) derived Canada-wide time series of LAI/FPAR from AVHRR (10-days composites during the growing season of various years, 2-3 km spatial resolution) and SPOT-VGT (10-days composites during April-October in year 1998-2000, 1.25 km resolution) data. Satellite data were atmospherically corrected with the Simple Model for Atmospheric Correction (SMAC). Biome-dependant empirical relationships of LAI/FPAR and vegetation indices were established: Infrared Simple Ratio (ISR=NIR/SWIR) was used for woody vegetation and Simple Ratio (SR=NIR/Red) for herbaceous. Multiple spatially distributed ETM scenes were utilized to establish regression between vegetation indices and field measured LAI/FPAR and also for products validation.

The physically-based algorithms were implemented within the following major efforts. Roujean and Lacase from CNES (France) developed global LAI/FPAR data set from

POLDER/ADEOS-1 measurements (8-months from September 1996 through June 1997, 15-days composites, 8-km resolution). POLDER data were geo-coded, calibrated, cloud screened and partially corrected for atmospheric effects. A kernel based model was used and the coefficients were obtained as the result of linear inversion from multiangular POLDER measurements.

Researchers at the Joint Research Center, Italy (JRC: Gobron, Pinty, Verstrate) developed LAI/FPAR date sets from MERIS (March 2002-present, monthly composites, 1-km resolution) and SeaWiFS (from September 1997 to December 2004, monthly composites, 2-km to 0.5 degrees resolution). The algorithm utilized Blue, Red and NIR bands (retrievals are performed form Red and NIR bands; the Blue band provides ancillary information to account for atmospheric effect). A coupled atmosphere-vegetation radiation model was used to account for atmospheric effects and simultaneously retrieve biophysical parameters of vegetation.

Knyazikhin and Myneni at Boston University implemented a synergistic MODIS and MISR LAI/FPAR algorithm. The retrievals are performed with the RT algorithm which finds LAI and FPAR values given sun and view directions, Bidirectional Reflectance Factor (BRF) for each MODIS band, band uncertainties, and 8-biome land cover classes. The retrieval technique compares observed and modeled BRFs for a suite of canopy structures and soil patterns that represent an expected range of typical conditions for a given biome type. All canopy/soil patterns for which modeled and observed BRFs differ within a specified uncertainties level are considered as acceptable solutions. The mean values of LAI averaged over all acceptable solutions are reported as the output of the algorithm (Knyazikhin et al., 1998; Shabanov et al., 2005). This physically-based LAI and FPAR algorithm was developed for operational use with the MODIS data and over six years of Terra MODIS and about 4 years of Aqua MODIS LAI/FPAR products have been generated with this algorithm. These products have been validated in a host of vegetation types representative of all the major biome types. The products have the following characteristics based on nearly 10 years of research: a) LAI accuracy of 0.5 LAI units (uncertainty of 0.66 LAI), FPAR accuracy of 0.1; b) spatial resolution from 250-m to 1-km; c) temporal frequency from 4-days to monthly (Yang et al., 2006a,b).

The last groups of the algorithms, artificial intelligence based computer algorithms, were implemented with neural networks (Weiss et al. at INRA, France) and genetics algorithm (Liang et al. at University of Maryland). Once the architecture of the algorithm is specified (i.e., number of input channel data, hidden layers and outputs) and the algorithm has been trained with ground measurements, classification of the image is performed to derive LAI/FPAR. At the present time, the computer algorithms were implemented only at the site scale in Europe and North America with fine resolution ETM/SPOT satellite data.

Intended sources for the measurement

Current LAI and FPAR retrieval techniques rely mostly on optical remote sensing data, namely Red and NIR channels. The potential for incorporating SWIR channels is being explored. Data from the following sensors constitute the major potential for LAI and FPAR retrievals:

a) Heritage data sets from AVHRR (channel data, GIMMS and PAL reprocessing)
b) Current data sets from MODIS, MISR, SPOT-VGT
c) Data from future missions (VIIRS)

In addition ancillary data sources, namely, fine resolution ETM+, IKONOS, ASTER data and ground measurements are needed for algorithm refinement and product validation purposes.

Necessary supporting activities, tasks

There are three major groups of activities with respect to development of the highest possible quality LAI and FPAR ESDRs: a) algorithm refinement; b) products validation; c) reprocessing. Algorithm refinement includes theoretical work on radiative transfer theory to better account for spatial heterogeneity of vegetation in retrievals, exploring the potential for incorporation of additional data channels (SWIR), adjustment of algorithm parameters to a particular sensor and joining AVHRR and MODIS time series data. The objective of future validation work is to compile an extensive database of field measurements and fine resolution LAI and FPAR maps to further assess the accuracy of the products. Vegetation over the 8 biome types should be sampled extensively through the range of geographical locations and climatic conditions. Additional FPAR measurements are of special interests as this database is currently under-populated. New measurements of LAI and FPAR should better sample the seasonal cycle. Research advances in product validation and algorithm refinement should be implemented in future reprocessing of LAI and FPAR ESDRs.

Key citations

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