Moderate Resolution Imaging Spectroradiometer (MODIS) Downward Shortwave Radiation (MCD18A1) and Photosynthetically Active Radiation (MCD18A2) User Guide

Collection 6

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1. Introduction

Incident solar radiation over land surfaces, either photosynthetically active radiation (PAR) in the visible spectrum (400-700nm) or downward shortwave radiation (DSR) in the shortwave spectrum (300-4000nm), is a key variable required by almost all land surface models. Satellite DSR and PAR products are in great need to address a variety of scientific and application issues related to climate trends, hydrologic, bio-physical and bio-chemical modeling, solar energy applications, and agriculture. These products with high spatial resolution are especially needed for land applications, such as generating high-resolution terrestrial gross and net primary production (GPP/NPP) Earth Science Data Record (ESDR), evapotranspiration (ET) ESDR. However, there is no high-resolution global land surface DSR or PAR ESDR available, although high-resolution global ocean PAR ESDR (9.3km) has been generated through the NASA MEaSUREs Program.

The current global satellite products of surface radiative fluxes usually have much coarser spatial resolutions, such as the Clouds and the Earth's Radiant Energy System (CERES) product at a spatial resolution of 140km from 1997 to present, the International Satellite Cloud Climatology Project (ISCCP) product on a 280 km equal-area global grid from 1983-2008, the Global Energy and Water Cycle Experiment (GEWEX) surface radiation budget (SRB) product at a spatial resolution of 1° x 1° from 1983-2007. Besides, few land surface global PAR products exist because most global radiative flux datasets do not include PAR, so users have to empirically convert DSR to PAR. The conversion itself is a source of uncertainties.

Funded by NASA, a suite of global high-resolution (5km) DSR and PAR products over land surfaces are generated from MODIS data. The new product suite is consisted of two gridded L3 products: MCD18A1 (Downward Shortwave Radiation) and MCD18A2 (Photosynthetically Active Radiation). MCD18A1 and MCD18A2 are combined Aqua and Terra MODIS products. This user guide will document the technical details of data files and scientific data sets of the products. It will also briefly describe the theoretical basis and practical consideration of the retrieval algorithm.

2. Algorithm summary

The basic framework of the algorithms was presented by Liang et al. (2006) for estimating PAR. The algorithm first estimates surface reflectance from multi-temporal imagery and then appraises PAR flux for each imagery. The major procedure is composed of two steps: (1) determination of the surface reflectance from observations under the “clearest” atmospheric conditions in a temporal window; and (2) calculation of incident PAR from the determined surface reflectance and TOA radiance/reflectance using the LUT approach. The LUTs consider different types and loadings of multiple aerosols and clouds at a variety of illumination/viewing geometry. The key concept of this algorithm is use of multi-temporal signatures of MODIS data (Figure 1).

In the follow-up studies, a series of refinements and improvements have been made. For example, MODIS surface reflectance product (MOD09) was used to map PAR over China from MODIS data (Liu et al. 2008). It has been extended to estimate PAR from GOES data (Zheng et al. 2008) by taking into account topographic effects. It was also extended to estimate DSR over China from Geostationary Meteorological Satellite (GMS) 5 imagery by considering water vapor and the surface elevation (Lu et al. 2010). (Huang et al. 2011) further extended the LUT scheme to estimate DSR by combining the Multifunctional Transport Satellite (MTSAT) data and MODIS data products.

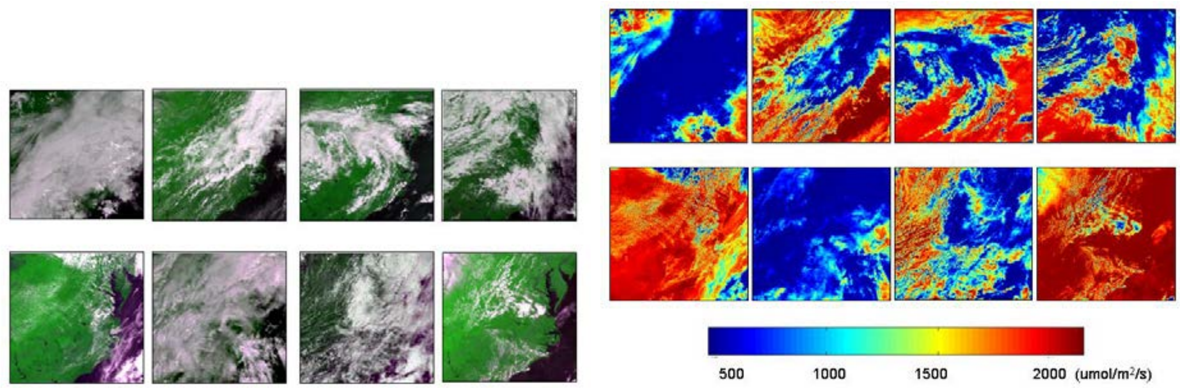

Figure 1. Time series of MODIS observations of TOA radiance and the derived surface incident PAR results.

Based on these studies, the extensive prototyping has also been carried out for producing global DSR and PAR products (Zhang et al. 2014). The key feature of the prototyping algorithm is the use of DSR and PAR LUTs for different types and loadings of aerosols and clouds. It consists of several key steps:

1) The satellite TOA radiance/reflectance for different sensors is calculated based on the digital numbers (DN values) using the calibration coefficients.
2) The surface reflectance is derived for different sensors. The MODIS land surface reflectance product is used as the input parameter for the MODIS sensor. However, for geostationary and AVHRR satellite data, the minimum TOA reflectance method is employed to derive the surface reflectance.
3) TOA radiance is estimated for each atmospheric condition from the clearest condition to the cloudiest conditions (high cloud extinction coefficient) based on the first LUT in Figure 2. Then, the actual TOA radiance calculated from the sensors is compared to the series of the simulated radiance for different atmospheric conditions to retrieve the atmospheric index.
4) DSR and PAR from each sensor are estimated by searching the second LUT in Figure 2 using the estimated atmospheric condition index and surface reflectance.

5) A Bayesian procedure is used to integrate estimates of MODIS and geostationary satellite data and the probability is determined based on extensive validation using in-situ measurements.

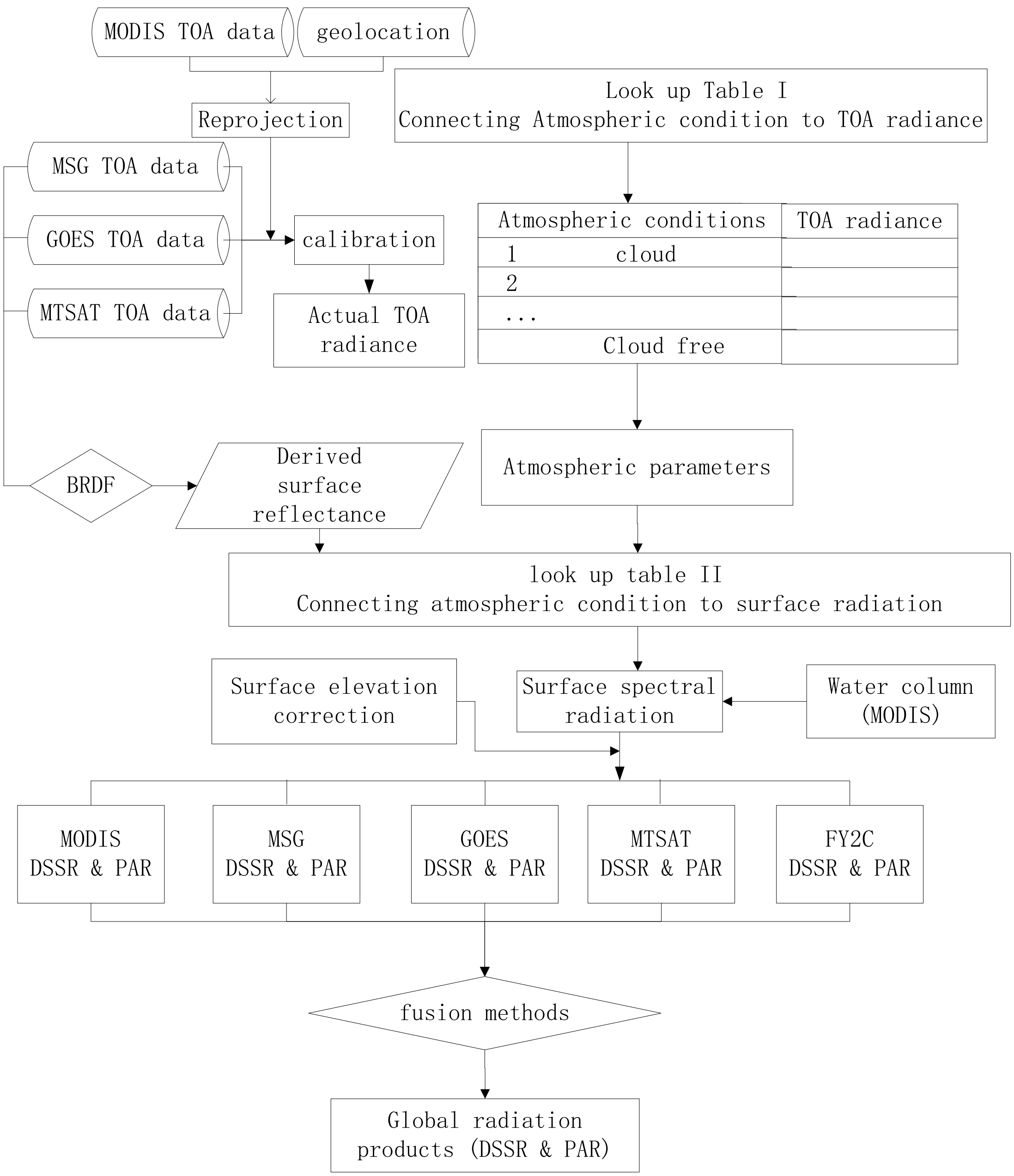

Figure 2. Flowchart to generate global DSR and PAR products from MODIS and geostationary satellite data

Although data of geostationary satellites were included in the prototype system, the current version DSR and PAR products (Collection 6) use only MODIS data because of practical consideration. MODIS/Terra and MODIS/Aqua data are used, which provide a daily coverage over most of the world (Figure 3). The geostationary data will be added in the future version.

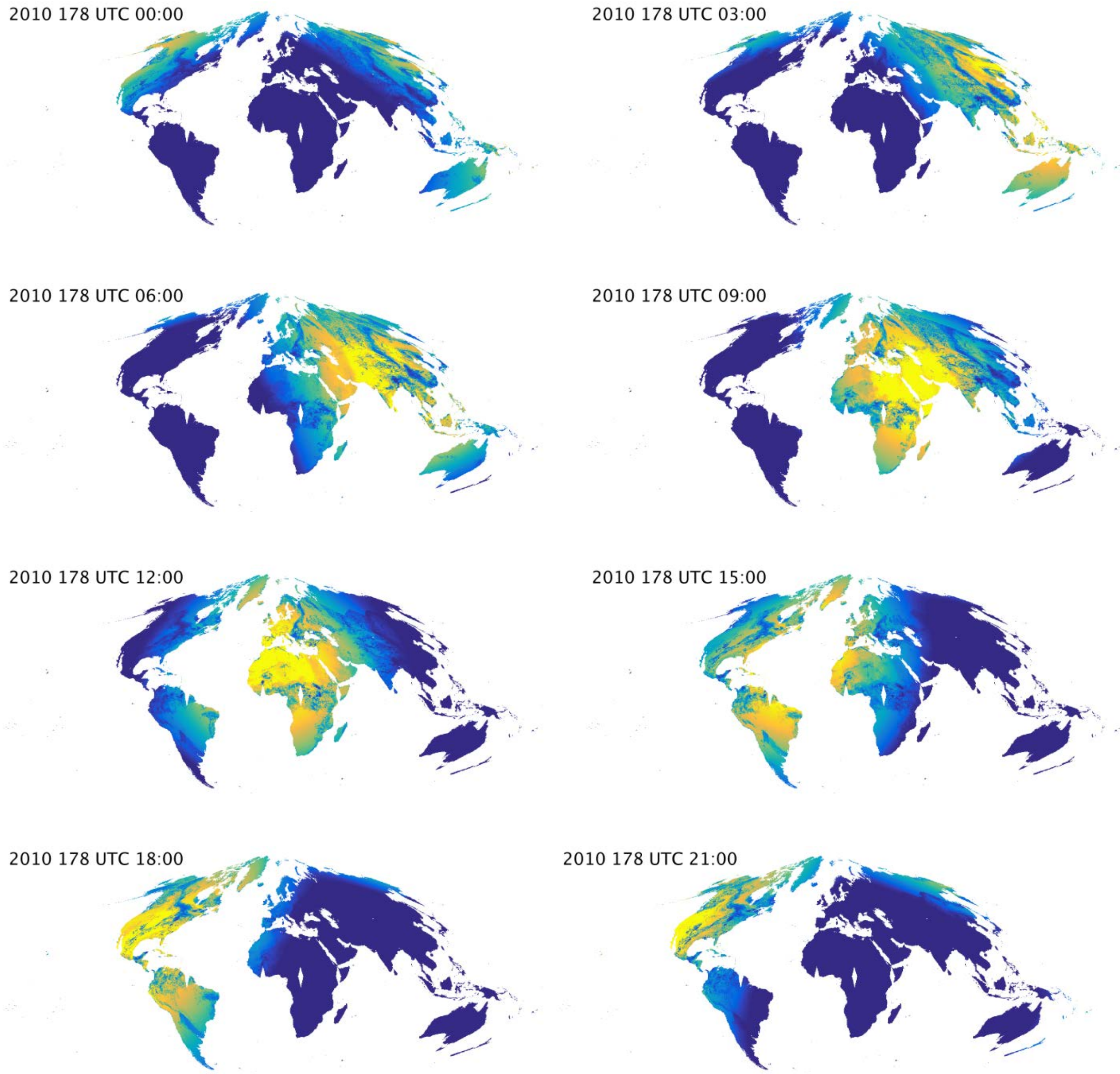

Figure 3. Global maps of 3-hourly PAR of Day 178 of Year 2010 generated from MODIS/Terra and MODIS/Aqua.

3. Product description

The DSR and PAR products are available in two separate datasets: MCD18A1 (DSR) and MCD18A2 (PAR). MCD18A1 and MCD18A2 are gridded L3 products in MODIS sinusoidal map projection with 5km resolution. One product file is produced for one day over one MODIS sinusoidal land tile. Names of MCD18A1 and MCD18A2 follow file naming convention of standard MODIS products:

```
MCD18AX.AYYYYDDD.hHHvVV.006.PPPPPPPPPPPPP.hdf
where
X =1: DSR, 2: PAR
YYYY = year
DDD = day of year
HH = horizontal tile coordinate
VV = vertical tile coordinate
PPPPPPPPPPPPP = production date
```

3.1 MCD18A1 DSR product

MCD18A1 files are archived in Hierarchical Data Format V4 - Earth Observing System (HDF-EOS) format files. Each file contains global attributes (metadata) and scientific data sets (SDSs, data layers).

3.1.1 Metadata

MCD18A1 contains several global metadata attributes. The attributes include some basic information, such as `HDFEOSVersion`, `identifier_product_doi`, `identifier_product_doi_authority`. They also contain three global attributes used by standard MODIS products, known as EOS Data Information System (EOSDIS) Core System (ECS), namely, `CoreMetadata.0`, `ArchiveMetadata.0` and `StructMetadata.0`.

Besides, there are two attributes specifically used by MCD18A1: `Orbit_amount` and `Orbit_time_stamp`. Orbit_amount stores the count of the MODIS overpass covering the current day and tile. Orbit_time_stamp contains time information of each overpass in the format of `YYYYDDDHHMM`:

```
where YYYY = year
DDD = day of year
HH = hour
MM = minute
```

3.1.2 Data layers

Each MCD18A1 file contains two major types of scientific data sets: instantaneous DSR array for each individual MODIS overpass and 3-hour DSR array. The data sets are archived in 11 SDSs (Table 1).

Table 1. Summary of scientific data sets (data layers) in MCD18A1

Name	**Content**	**Dimension**	**Data type**	**Unit**	**Fill value**	**Valid range**

DSR	Instantaneous total DSR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-1400
Direct	Instantaneous direct DSR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-1400
Diffuse	Instantaneous diffuse DSR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-1400
GMT_0000_DSR	Total DSR at GMT 00:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_0300_DSR	Total DSR at GMT 03:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_0600_DSR	Total DSR at GMT 06:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_0900_DSR	Total DSR at GMT 09:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_1200_DSR	Total DSR at GMT 12:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_1500_DSR	Total DSR at GMT 15:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_1800_DSR	Total DSR at GMT 18:00	240*240	32bit floating	W/m^2	-1	0-1400
GMT_2100_DSR	Total DSR at GMT 21:00	240*240	32bit floating	W/m^2	-1	0-1400
DSR_Quality	Quality flag	240*240	8bit unsigned integer	N/A	N/A	N/A

n: the count of MODIS overpass, available from global attribute “Orbit_amount”

SDSs directly store DSR values. Scale and offset factors are not needed.

DSR_Quality is currently used to indicate the input source of surface reflectance data. 0: no valid surface reflectance data ; 01: from the MCD43 product, 10: from the climatology data

3.2 MCD18A2 PAR product

MCD18A2 files are organized in a manner similar to MCD18A1. The difference is that MCD18A2 contains PAR values instead of DSR values (Table 2).

Table 2. Summary of scientific data sets (data layers) in MCD18A2

Name	**Content**	**Dimension**	**Data type**	**Unit**	**Fill value**	**Valid range**
PAR	Instantaneous total PAR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-700
Direct	Instantaneous direct PAR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-700
Diffuse	Instantaneous diffuse PAR at MODIS overpass	n*240*240	32bit floating	W/m^2	-1	0-700
GMT_0000_PAR	Total PAR at GMT 00:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_0300_ PAR	Total PAR at GMT 03:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_0600_ PAR	Total PAR at GMT 06:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_0900_ PAR	Total PAR at GMT 09:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_1200_ PAR	Total PAR at GMT 12:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_1500_ PAR	Total PAR at GMT 15:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_1800_ PAR	Total PAR at GMT 18:00	240*240	32bit floating	W/m^2	-1	0-700
GMT_2100_ PAR	Total PAR at GMT 21:00	240*240	32bit floating	W/m^2	-1	0-700
PAR_Quality	Quality flag	240*240	8bit unsigned integer	N/A	N/A	N/A

n: the count of MODIS overpass, available from global attribute “Orbit_amount”

SDSs directly store PAR values. Scale and offset factors are not needed.

PAR_Quality is currently used to indicate the input source of surface reflectance data. 0: no valid surface reflectance data ; 01: from the MCD43 product, 10: from the climatology data

4. Obtaining MODIS DSR and PAR products

The MODIS DSR (MCD18A1) and PAR (MCD18A2) products are available to users free of charge. The products are archived at the Land Processes Distributed Active Archive Center (LP-DAAC). They can be ordered and downloaded through the EOS Reverb web interface (http://reverb.echo.nasa.gov/reverb).

5. Known issue and status

Due to a programming error, the C6 dataset before year 2017 suffers from the serious overestimation in the winter season and is not appropriate as the basis for quantitative scientific publications. The data products after Jan 1 2018 are generated with the bug-fixed software and free of the overestimation issue.

6. References

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