TERRA CORE PRODUCTS

Below is a brief summary of each Terra core data product. The summaries include the Terra products' data record time duration, primary users and distribution location. Table A-1 shows each product's contribution to the National Objectives and Applications and the Science Focus Areas. The table also summarizes the product maturity and indicates each product's source of funding. In the following text a "blue font" section denotes a new or significantly enhanced product (since 2013 Senior Review).

ASTER

ASTER has been acquiring and archiving about 450–550 images per day since March 2000. ASTER archives only the Level 1A data product, and the new Global DEM; all other data products are produced on demand when requested by a user. Some of the products directly use inputs from other instruments for optional processing inputs: MODIS water vapor profile, TOAST ozone product, NCEP profiles. These selections are available upon user request. ASTER data are archived both at the US LPDAAC and Japan Ground Data System. Users can search and order data from either site. In 2015, the LPDAAC offered users the option of ordering all higher level products in orthorectified format. All algorithms are at Validation Stage 3.

No new products are planned for the next funding period.

Level 1A AST01 – Reconstructed, unprocessed instrument data

This Level 1 product is reconstructed, unprocessed instrument data. This product is generated from Level 0 data by applying parallax correction and geometric correction and is segmented into scenes. Radiometric corrections and projection parameters are computed but not applied to the data. The values are appended in the metadata files.

Level 1B AST03 – Registered radiance at sensor

This Level 1 product is radiance at the sensor. This product is generated from Level 1A data by applying radiometric correction and resampling using a specific map projection method. This is the most popular ASTER product requested by users. It is the first geophysical product ASTER provides, and is suitable for many applications.

Level 2 AST09 – Surface radiance – VNIR, SWIR

The Level 2 surface radiance data set (AST09) contains surface radiance for each of the nine VNIR and SWIR bands at 15 m and 30 m resolutions, respectively. The results are obtained by applying an atmospheric correction to radiances reported by the ASTER sensor. The atmospheric correction removes effects due to changes in satellite-sun geometry and atmospheric conditions. The atmospheric correction algorithm is applied to clear-sky pixels only and the results are reported as a number between 0 and 1.

Level 2 AST09T– Surface radiance – TIR

This product provides surface leaving radiance, in W/(m^2 sr μm), for the five ASTER TIR channels at 90 m spatial resolution. In addition, the down welling sky irradiance in W/(m^2 μm) for the five ASTER TIR channels is also provided. Atmospheric correction has been applied and the surface leaving radiance is valid for the clear sky portion of scenes. This radiance includes both surface emitted and surface reflected components. The surface radiance is only of known accuracy for cloud free pixels since insufficient information is available about cloud properties for a valid correction of cloudy pixels.

Level 2 AST07 – Surface reflectance – VNIR, TIR

The Level 2 surface reflectance data set (AST07) contains surface reflectance for each of the nine VNIR and SWIR bands at 15 m and 30 m resolutions, respectively. The results are obtained by applying an atmospheric correction to radiances reported by the ASTER sensor. The atmospheric correction removes effects due to changes in satellite-sun geometry and atmospheric conditions. The atmospheric correction algorithm is applied to clear-sky pixels only and the results are reported as a number between 0 and 1.

Level 2 AST08 – Surface kinetic temperature

The Level 2 land surface kinetic temperature product contains surface temperatures at 90 m resolution generated only over the land from ASTER's five thermal infrared channels. Land surface temperatures are

determined from Planck's Law, using the emissivities from AST05 to scale the measured radiances after correction for atmospheric effects. Surface temperatures are important in studies of surface energy and water balance. They are also useful in studies of volcanism and thermal pollution.

Level 2 AST05 – Surface emissivity

The Level 2 land surface emissivity product contains surface emissivity at 90 m resolution generated only over the land from ASTER's five thermal infrared channels. Surface emissivity is required to derive land surface temperature (AST08) data, also at a resolution of 90 m. The emissivity product is critical for deriving accurate land surface temperatures. It is therefore important in studies of surface energy and water balance. The emissivity product is also useful for mapping geologic and land-cover features.

Level 3 AST14 – Digital elevation model

This data set contains topographic information derived from the along-track, 15 m ASTER optical stereo data acquired in near infrared bands 3N and 3B. These high spatial resolution DEMs (up to 7 m absolute horizontal and vertical accuracy with appropriate ground control, and up to 10 m relative accuracy without ground control) can be used to derive absolute slope and slope aspect good to 5° over horizontal distances of more than 100 m. ASTER DEMs should meet 1:50,000 to 1:250,000 map accuracy standards.

Level 3 AST14OTH – Orthorectified radiance

This produce takes the Level 1B radiance channels, and applies a ASTER-derived DEM to orthorectify the 15 bands. The resulting images have elevation-produced parallax removed, resulting in Images where every pixel appears as if viewed from directly overhead. The data are ordered in Geo-TIFF format, are UTM projected and have north "up".

Level 3 AST14DMO – Orthorectified radiance plus Digital elevation model

This product packages AST14 (Digital elevation model) and AST14OTH (Orthorectified radiance) into a single product.

Level 3 AST-GDEM – Global DEM

This is a new product released in June, 2009. It is a Global Digital Elevation Model (DEM), produced by stereocorrelation of the entire ASTER daytime archive of Level 1 scenes, approximately 1,400,000 scenes. Each image was cloud screened, pixel-by-pixel, and then a DEM created for the individual scenes. All scenes covering a given output pixel were stacked and averaged to produce the DEM value. Where holes exist due primarily to persistent cloud cover, SRTM 90 m data, or other DEMs were used to fill in. The GDEM is distributed as 1° × 1° tiles with 30 m postings.

Level 3 AST-WBD - Waterbody data base

This is a new product released in September 2015, accompanying Version 3 of the GDEM. Produced at 30m, it is a raster data set identifying land versus water. In addition, water bodies are identified as either ocean, lakes, or rivers.

ASTER Product User Contacts:

Brenda K. Jones, Disaster Response Coordinator, USGS EROS Center, bkjones@usgs.gov

Teresa Howard, MAGIC Coordinator/Research Associate, Center for Space Research, University of Texas at Austin, howard@csr.utexas.edu

CERES

All CERES data products are available from the Atmospheric Science Data Center (ASDC) at NASA Langley Research Center (LaRC). The primary CERES data users are the U.S. and international general scientific communities (universities and government laboratories). The main U.S. federal agencies that use CERES data are NASA, Department of Energy (DoE), National Science Foundation (NSF)-National Center for Atmospheric Research (NCAR), and NOAA. All CERES data products have been substantially validated.

CERES Bidirectional Scans (BDS) (Level 1B)

The BiDirectional Scans (BDS) product is a core-mission data product containing 24 hours of instantaneous Level 1B CERES data for a single scanner instrument. The BDS contains instantaneous radiance measurements recorded every 0.01 seconds for views of space, internal calibration, solar calibration, and Earth footprints. The BDS is primarily used as input to the Level 2 CERES data products.

Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Single Scanner Footprint TOA/Surface Fluxes, Clouds and Aerosols (SSF) (Level 2)

The SSF product is a core-mission data product that contains instantaneous CERES footprint data for a single scanner instrument, produced in hourly files. The SSF merges instantaneous CERES radiances and radiative fluxes with cloud and aerosol information from MODIS on Terra or Aqua and meteorological parameters from the NASA GSFC Global Modeling and Assimilation Office (GMAO) GEOS Data Assimilation System (DAS) Version 5.0.3.1 product. Radiative fluxes are inferred from measured radiances using new CERES Angular Distribution Models (ADMs) developed from rotating azimuth plane scan CERES measurements.

Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES, MODIS.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Gridded Instantaneous TOA/Surface Fluxes, Clouds and Aerosols (SSF1deg-Hour) (Level 3)

The SSF1deg-Hour product is a core-mission data product that contains spatially averaged flux, cloud and aerosol parameters in a 1° nested grid, written to daily files for a single platform. The SSF product is input to the SSF1deg-Hour product. Only cross-track data is processed.

Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES, MODIS.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Time-Interpolated TOA Fluxes, Clouds and Aerosols (SSF1deg–Day, -Month) (Level 3)

The SSF1deg product is a core-mission product that contains daily and monthly 1° regional, zonal, and global averages of the clear-sky and all-sky TOA, LW, SW and net fluxes together with the associated MODIS-derived cloud and aerosol properties, and GMAO meteorological properties. Temporal interpolation completes the diurnal cycle by assuming constant meteorology between satellite observation times.

Duration of data record: Processing pending (3/2000–present), software delivery in testing.
Instruments required: CERES, MODIS.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES and GEO-Enhanced TOA, Within-Atmosphere, and Surface Fluxes, Clouds and Aerosols (SYN1deg-1Hour, -3Hour, -Day, -Month) (Level 3)

The SYN1deg product is a core mission product that contains CERES TOA and Fu-Liou radiative transfer model surface and within-atmosphere fluxes, together with the associated MODIS-derived cloud properties, MATCH assimilated aerosols, and GMAO meteorological input data. Fluxes are computed hourly with and without aerosols along with photosynthetically active radiation and UV fluxes. Inputs are from a merged Terra/Aqua-CERES/MODIS and hourly geostationary (GEO) multi-satellite cloud and flux data stream. Temporal averaging relies on GEO observations to fill in the diurnal cycle between Terra and Aqua observation times. These data are provided at 1-hourly, 3-hourly, daily and monthly intervals at the CERES 1° grid resolution as well as at 1° zonal and global scales.

Duration of data record: 3/2000–7/2014, with 8/2014-present pending processing.
Instruments required: Terra/Aqua CERES, Terra/Aqua MODIS, Meteosat-5 and 7-10, GMS-5, GOES-8-15, MTSAT-1R and 2.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Energy Balanced and Filled TOA/Surface Fluxes (EBAF–TOA and EBAF–Surface) (Level 3B)

The EBAF product is a core-mission product that contains CERES TOA fluxes with consistent Fu-Liou radiative transfer model-based surface fluxes. It is derived from the CERES SSF1deg and SYN1deg products. Fluxes are adjusted within uncertainty to ensure a 5-year global average of Earth's energy imbalance consistent with that from Argo in-situ ocean measurements and estimates of deep ocean heat storage, ice warming and melt, and atmospheric and lithospheric warming. It also includes CERES and imager-based high-resolution clear-sky fluxes. These data are provided at monthly intervals and at 1° grid resolution, 1° zonal, and global scales.

Duration of data record: TOA: 3/2000-10/2014, with 11/2014–present pending processing. *Surface*: 3/2000–5/2014, 6/2014–present pending processing.
Instruments required: Terra/Aqua CERES, Terra/Aqua MODIS, Meteosat-5 and 7-10, GMS-5, GOES-815, MTSAT-1R and 2.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Cloud Type Histogram (CldTypHist) (Level 3)

The CldTypHist product is a core-mission product that contains histograms of Terra/Aqua MODIS and hourly geostationary imager cloud properties stratified by cloud types that are defined by cloud top pressure, optical depth, and phase. The cloud properties are gridded onto 1°x1° regions and averaged over monthly and monthly hourly time scales. CldTypHist is produced using the same cloud properties that are input to SYN1deg.

Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: Terra/Aqua CERES, Terra/Aqua MODIS, Meteosat-5 and 7-10, GMS-5, GOES-8-15, MTSAT-1R and 2.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES TOA Flux-by-Cloud-Type (FluxByCloudTyp) (Level 3)

The FluxByCloudTyp product is a core-mission product that contains instantaneous gridded CERES TOA fluxes and associated MODIS-derived cloud properties stratified into 42 cloud types according to cloud top pressure and optical depth. Imager-based high-resolution fluxes are derived for the clear-sky and cloud layer portions of each CERES footprint. The product is available in daily files for 1° regions between 60°S-60°N during daytime.

Duration of data record: New product.
Instruments required: CERES, MODIS.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Near Real-Time TOA/Surface Fluxes and Clouds (FLASH_SSF) (Level 2)

The FLASH_SSF product is a core-mission product that contains instantaneous footprint CERES TOA fluxes, parameterized surface radiative fluxes, and imager cloud properties in the SSF format, produced within 1 week of observation and processed prior to official CERES calibration updates.

Duration of data record: Near-Real Time.
Instruments required: CERES, MODIS.
Maturity of algorithms: Mature.

Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

CERES Near Real-Time Time-Interpolated TOA/Surface Fluxes and Clouds (FLASH_TISA) (Level 3)

The FLASH_TISA product is a core-mission product that contains temporally interpolated daily averaged CERES TOA fluxes, parameterized surface radiative fluxes, and imager cloud properties, produced within 1 week of observation and processed prior to official CERES calibration updates. These data are provided in daily files at 1° grid resolution.
Duration of data record: Near-Real Time.
Instruments required: Terra/Aqua CERES, Terra/Aqua MODIS.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

ERBE-like Footprint TOA Fluxes (ES-8) (Level 2)

The ES-8 product is a core-mission data product that provides a continuation of the ERBE S-8 product record of TOA radiative fluxes, analyzed using the same scene identification algorithm and Angular Distribution Models (ADMs) that produced the ERBE data. The ES-8 product contains 24 hours of instantaneous unfiltered radiances and radiative fluxes for a single scanner instrument.
Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

ERBE-like Gridded Instantaneous TOA Fluxes (ES-9) (Level 3)

The ES-9 product is a core-mission data product that provides a continuation of the ERBE S-9 product record of TOA radiative fluxes, analyzed using the same algorithms that produced the ERBE data. The ES-9 product contains a month of instantaneous spatially averaged CERES TOA fluxes on a 2.5° grid for crosstrack data only.
Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

ERBE-like Time-Interpolated TOA Fluxes (ES-4) (Level 3)

The ES-4 product is a core-mission data product that provides a continuation of the ERBE S-4 record of TOA radiative fluxes analyzed using the same algorithms that produced the ERBE data. Daily average, hourly average over the month, as well as monthly average TOA radiative fluxes are given in 2.5°, nested 5°, and nested 10° regions. Zonal and global monthly average fluxes are also included.
Duration of data record: 3/2000–8/2014, with 9/2014–present pending processing.
Instruments required: CERES.
Maturity of algorithms: Mature.
Primary NASA and/or operational agency users: NASA, DoE, NSF-NCAR, NOAA.
Availability and location of the product: LaRC ASDC.

MISR

All MISR products are publicly available for 2/2000–present from the Atmospheric Sciences Data Center (ASDC) at the Langley DAAC. Changes since the 2013 Senior Review include (a) a refined Level 2 Cloud Classifiers Product and an improved Level 3 Cloud Classifiers by Altitude Product, (b) expansion of the Level 3 Plume Height Climatology Product to include global smoke plume data for the year 2008, (c) initial use of the MISR Near-Real Time Cloud Motion Vector product by operational weather forecast numerical modelers. Two dynamic external to Terra data sources are used for MISR data product generation. One is the SSM/I as the source of monthly averaged ocean surface wind speeds, which are

required as input to Level 2 Aerosol processing. The other is a monthly snow/ice mask obtained from NSIDC. As MISR is a PI-led investigation, only Terra continuation funds are used to support MISR Project activities such as generation of the core data products. No other sources of funding (e.g., ROSES) are relied upon for this purpose.

Level 1 Georectified Radiance Product

Radiometrically and geometrically calibrated, Earth projected multiangle imagery. Radiometric uncertainty estimates are ±4% absolute, ±1-2% relative. Radiances from all 4 bands and 9 angles are mapped to a Space Oblique Mercator (SOM) projection. Camera-to-camera co-registration meets the < 1 pixel (275 m) specification. Radiometric calibration and stability are verified and maintained through bimonthly deployments of the on-board calibrator. Ongoing assessments of image geolocation and co-registration are performed to ensure quality. Product is Stage 3 validated (Diner et al., 2002; Bruegge et al., 2002, 2007, 2014; Chrien et al., 2002; Abdou et al., 2002; Jovanovic et al., 2002, 2007).

Primary users: Researchers in Climate Variability and Change, Atmospheric Composition, Water and Energy Cycle, Carbon Cycle and Ecosystems, Weather, Earth's Surface and Interior Structure.

Example users: Frank Evans, University of Colorado, evans@nit.colorado.edu; Paquita Zuidema, University of Miami, pzuidema@rsmas.miami.edu.

Level 2 Stereo Product

Stereoscopically-derived cloud top heights (CTH), aerosol plume-top heights, and cloud motion vector (CMV) winds. Geometric parallax and computationally fast image matching yields instantaneous CTH uncertainty of < 1 km and CMV uncertainty of a few m/sec. Stereo CTH measurements are insensitive to atmospheric temperature profile, emissivity, and radiometric calibration drifts, providing climate diagnostics independent of common error sources. The CTH and CMV are Stage 3 and Stage 2 validated, respectively (Naud et al., 2002, 2004, 2005a, b; Seiz et al., 2006; Marchand et al., 2007; Davies et al., 2007; Genkova et al., 2007; Chapman and DiGirolamo, 2008; Garay, et al., 2008; Hinkelman, 2009; Harshvardan et al., 2009).

Primary users: Researchers in Climate Variability and Change, Atmospheric Composition, and Weather.

Example users: Mike Fromm, Naval Research Laboratory, mike.fromm@nrl.navy.mil; Johnny Luo, City College of NY, z.johnny.luo@gmail.com.

Level 2 Cloud Product

Stereoscopically-derived CTH, aerosol plume-top heights, CMV winds. Product rationale is similar to the Stereo Product. Compared to the Stereo Product, the Cloud Product has increased coverage for all parameters and higher resolution (17.6 km) CMV winds with reduced bias and improved quality control, as well as a high resolution (1.1 km) cross-track wind field. The CTH and CMV are Stage 3 and Stage 1 validated, respectively (see references cited above). This product will replace the L2 Stereo Product once validation is completed. Beginning in September 2014, a Near-Real Time version of the CMV parameters of this product has been made public, with 90% of the wind data available within 2.5 hours of on-orbit data acquisition

Primary users: Researchers in Climate Variability and Change, Atmospheric Composition, and Weather.

Example users: Nancy Baker, Naval Research Laboratory, nancy.baker@nrlmry.navy.mil; Claudia Stubenbach, GEWEX Cloud Assessment Group; Joel Norris, Scripps Institute of Oceanography, jnorris@ucsd.edu; Mary Forsythe, International Winds Working Group, mary.forsythe@metoffice.gov.uk.

Level 2 Cloud Masks/Level 2 Cloud Classifiers Product

Three independently-derived cloud masks. The Radiometric Camera-by-camera Cloud Mask (RCCM) uses spectral and spatial measures to provide a separate mask for each of the 9 MISR cameras. The Stereoscopically-Derived Cloud Mask (SDCM) detects clouds as a result of their elevation above the surface terrain, and is part of the Level 2 Stereo Product. The Angular Signature Cloud Mask (ASCM) is part of the Level 2 Cloud Classifiers Product, and is derived from a band differenced angular signature. SSM/I-based snow/ice mask, available from NSIDC, is used to generate climatologies to support production. The RCCM is Stage 3 validated (Zhao and DiGirolamo, 2004, 2006; Zhao, 2006; Yang, 2007; Yang et al., 2007). Over ice-free ocean it has a classification accuracy of 94% (96% excluding sunglint) for the nadir camera, and increases slowly with view angle to a classification accuracy of 96% (98% excluding

sunglint) for the most oblique cameras. RCCM over snow-free land has a classification accuracy of 92% for all cameras, averaged over all land surface types. The SDCM/ASCM are Stage 2 validated (Shi et al., 2007; Di Girolamo and Wilson, 2003).

Primary users: Researchers in Water and Energy Cycle, Climate Variability and Change, and Atmospheric Composition.

Example users: Tao Shi, Ohio State University, taoshi@stat.osu.edu; Seiji Kato, NASA Langley Research Center, seiji.kato-1@nasa.gov.

Level 2 Top-of-atmosphere Albedo Product

Spectral bidirectional reflectance factors (BRFs) and albedos projected to cloud-top altitudes for cloudy scenes and to the surface elevation for clear scenes. MISR generates local albedos at 2.2 km resolution. Two coarse resolution albedos, defined over 35.2 km regions, are also defined. For comparative purposes, especially with products from CERES, the "restrictive" albedo entails angular integration of the observed BRFs over a given region only, and the "expansive" albedo integrates over all surrounding regions influencing the TOA radiative flux, simulating what a pyranometer would observe. MISR is unique in the sense that its high-resolution spectral BRFs and albedos cannot be compared directly with other products; therefore, progression to higher validation stages is limited by availability of independent data sources. Given the maturity level of the precursor data products (radiances and stereo heights), the BRFs are Stage 3 validated. Based on a global comparison with CERES (including narrow-to-broadband conversions) for overcast ocean, spectral albedos are Stage 1 validated (Sun et al., 2006).

Primary users: Researchers in Water and Energy Cycle, and Climate Variability and Change.

Example users: Constantine Lukashin, NASA Langley Research Center, Constantine.Lukashin-1@nasa.gov.

Level 2 Aerosol Product

Ocean and land aerosol optical depth (AOD), Ångström exponent, single scattering albedo (SSA), and optical depth due to small, medium, large, spherical, and nonspherical particles. Applications are to air quality and aerosol-climate forcing. Global comparisons of MISR and ground-based AERONET sun photometer data shows that 63% of the mid-visible AODs fall within 0.05 or 20% * AOD of AERONET, and about 40% are within 0.03 or 10% * AOD. AOD is Stage 3 validated; particle properties are Stage 2 validated (Liu et al., 2004; Martonchik et al., 2004; Redemann et al., 2005; Abdou et al., 2005; Kahn et al., 2005; 2007, 2009, 2010).

Primary users: Researchers in Atmospheric Composition, and Climate Variability and Change.

Example users: Stefan Kinne, Max Planck Intitut für Meterologie, stefan.kinne@zmaw.de (use of MISR in the aerosol model comparison AEROCOM project); Sundar Christopher, University of Alabama at Huntsville, sundar@nsstc.uah.edu; Stephanie Weber (use of MISR data in EPA's AirQuest system), Battelle Memorial Institute, WeberS@batelle.org.

Level 2 Surface Product

Atmospherically-corrected land surface spectral directional reflectance factors and associated hemispherical reflectances (albedos), bidirectional reflectance model (Rahman-Pinty-Verstraete) parameter fits to retrieved surface BRFs (which characterize surface reflectance angular anisotropy), leaf area index (LAI), and fractional amount of PAR (FPAR) absorbed by green vegetation. Compensation for atmospheric effects uses MISR aerosol retrievals. Validation shows typical albedo errors of ±0.005, and BRF errors of ±0.01. Surface albedos and BRFs are Stage 3 validated; other parameters are Stage 2 (Abdou et al., 2006; Lyapustin et al., 2006; Lavergne et al., 2006; Pinty et al., 2007; Pocewicz et al., 2007; Hu et al., 2007; Chen et al., 2008; Schaaf et al., 2008; Taberner et al., 2010).

Primary users: Researchers in Climate Variability and Change, and Carbon Cycle and Ecosystems.

Example users: Jing Chen, University of Toronto, chenj@geog.utoronto.ca; Alexei Lyapustin (use of MISR in the AERONET-based Surface Reflectance Validation Network processing), Goddard Space Flight Center, alexei.i.lyapustin@nasa.gov.

Level 3 Component Radiation and Climate, Cloud, Aerosol, and Surface Products

Includes: monthly, seasonal, and annual summaries of the above Level 1 and Level 2 input data products, globally gridded at 0.5° resolution. Modelers use the global statistics to improve, tune, and validate their models, examples of which include those dealing with cloud-climate and aerosol-climate interactions,

aerosol transport, and ecosystem productivity. As part of the verification process the MISR science team collaborates with members of the modeling community to ensure that product content, utility, and accessibility are consistent with their needs. Product maturity levels and user communities track the Level 1 and Level 2 inputs.

Example users: Stefan Kinne, Max Planck Intitut für Meterologie, stefan.kinne@zmaw.de; Claudia Stubenrauch (use of MISR in GEWEX cloud climatology intercomparison), Laboratoire de Météorologie Dynamique - École Polytechnique, stubenrauch@lmd.polytechnique.fr.

Level 3 Plume Height Climatology Product

The Plume Height Climatology (Diner et al., 2008; Nelson et al., 2008) has been generated since the 2007 Senior Review, and is a publicly-available repository for stereoscopically-derived smoke plume injection heights from MISR and MODIS radiative power to support wild fire, climate change and air quality studies. Plume heights are retrieved using the MISR INteractive eXplorer (MINX) tool(Nelson et al., 2013). Since the 2013 Senior Review, the database has now been expanded to include global data for 2008 (nearly 16,000 plumes), increasing the archived inventory to approximately 38,000 plumes. The MINX code was updated to include both blue-band and red-band height/wind retrievals, geographic region and IGBP biome type, and provides improved estimates of maximum plume height and retrieval quality using new algorithms. In particular, the blue band allows retrieving heights for low optical-density plumes over bright backgrounds, unlike the red band and provides better estimates of height in most cases. In addition, a new web interface has been implemented, providing a tabbed graphical user interface that allows narrowing searches for plumes by filtering on parameters such as start and end dates, latitude/longitude, geographic region, biome type, height above terrain, data quality, fire radiative power, retrieval band, wind correction, and database version.

Example users: Jennifer Logan, Harvard University, jlogan@seas.harvard.edu; James Randerson, University of California at Irvine, jranders@uci.edu; Simona Scollo, Istituto Nazionale di Geofisica e Vulcanologia, simona.scollo@ct.ingv.it.

Level 3 Cloud Fraction by Altitude Product

The MISR Level 3 Cloud Fraction by Altitude product offers the highest vertical resolution cloud climatology available from a passive instrument, providing the frequency of cloud occurrence partitioned into different cloud top height bins at a global and monthly scale with a spatial resolution of 0.5° × 0.5° latitude/longitude and vertical resolution of 500 m. For each height bin, the frequency of cloud occurrence of a region over a time period is represented by the temporal mean of the spatial coverage of cloud tops. The spatial coverage of clouds is referred to as cloud fraction, which is defined in this document as the ratio of the number of cloudy pixels to the total number of cloudy and cloud-free pixels observed by the instrument. Clouds are assigned to height bins based on their top height as retrieved by the MISR stereoscopic technique. This product makes use of several unique strengths of multiangle observation: multiple cloud detection methodologies (dynamic radiance thresholding, stereoscopy, and angular signature); use of stereoscopic height retrieval, which is insensitive to radiometric calibration and atmospheric thermal structure; and sunglint avoidance. In the 2009 Senior Review, a pre-public release eight-year (2000–2007) average for the month of December was shown, which demonstrated good sensitivity to low- and mid-level clouds, revealing, for example, a trimodal vertical cloud distribution in the tropics that is consistent with shipboard and ground-based radar data (Johnson et al., 1999; Hollars et. al, 2004). This product has now been publicly released, along with an Algorithm theoretical Basis Document (Di Girolamo et al., 2010). Cloud fractions are calculated using the three MISR cloud masks (see Level 2 Cloud Masks/Cloud Classifiers, above). Product maturity tracks those of the MISR Stereo Product and Cloud Masks/Classifiers Products.

Example users: Stefan Kinne, Max Planck Institut für Meteorologie, stefan.kinne@zmaw.de; Claudia Stubenrauch (use of MISR in GEWEX cloud climatology intercomparison), Laboratoire de Météorologie Dynamique –École Polytechnique, stubenrauch@lmd.polytechnique.fr; Joel Norris,University of California, San Diego, jnorris@ucsd.edu.

Level 3 Cloud Motion Vector Product

The Cloud Motion Vector Product (CMVP) contains retrievals of cloud motion determined by geometrically triangulating the position and motion of cloud features observed by MISR from multiple perspectives and times during the ~7 minute overpass of Terra over each cloud scene. Cloud motion vectors

(CMVs) are a valuable proxy observation of the horizontal atmospheric wind field at the retrieved altitude of the cloud. MISR CMVs have been and continue to be operationally produced as part of the publicly available Level 2 Stereo product. The CMVP provides users a complete global list of the highest quality CMVs extracted from the standard Stereo product, distributed as monthly, seasonal, and annual netCDF files that are neither gridded nor averaged. The annual files, the largest of these, are a manageable 160MB, facilitating scientific applications requiring CMV information spanning multiple months or years. An ATBD has been released (Mueller, et al, 2010).

Example users: Michelle Rienecker, Global Modeling and Assimilation Office—Goddard Space Flight Center, michele.m.rienecker@nasa.gov; Wesley Ebisuzaki, Climate Prediction Center- National Centers for Environmental Prediction, wesley.ebisuzaki@noaa.gov.

Level 3 Aerosol Joint Product

The Joint Aerosol Product contains maps of probability distributions of aerosol particle types. These maps are provided as monthly global statistical summaries of MISR Level 2 aerosol optical depth retrievals as a function of particle type on a 5° x 5° geographic grid. It will be used as input the Aerosol Airmass Type Product, currently in development, which will provide probability distributions of aerosol mixtures.

Example users: To be established, as this product has only recently been publicly released.

MODIS

*(see also **http://modis.gsfc.nasa.gov/data/dataprod/index.php**)*

Note: MOD is the standard designator for MODIS Terra products; MYD is for MODIS Aqua products; and MCD is the standard designator for MODIS Combined Terra and Aqua products.

Brief descriptions for the 36 data products are given below. All listed except those designated as "other products" are part of the core mission and are maintained/refined over the course of the mission by investigators selected by NASA Headquarters as part of the ROSES process. For MODIS there are now 23 of these algorithm refinement investigators with contracts to deliver algorithm and code for the products. The Terra MODIS data record extends from February 24, 2000 to the present. The Aqua MODIS data record extends from June 24, 2002 to the present. All the core products have been substantially validated over a widely distributed set of locations, conditions and time periods via several ground truth and validation efforts. The primary MODIS data users include the general scientific community and a wide variety of federal, state and local agencies not only in the United States but also in countries world-wide. The principal federal users are the Department of Defense, NOAA, U. S. Department of Agriculture, Department of Interior, and the EPA. There are an estimated 220 Direct Broadcast (DB) stations operating worldwide with an estimated 1000 separate entities routinely using the Aqua and Terra MODIS data.

MODIS Level-1 (radiance and reflectance) products

*(see also **http://www.mcst.ssai.biz/mcstweb/index.html**)*

MODIS Level-1A Radiance Counts (MOD 01)

This Level 1A data set contains counts for 36 MODIS channels, along with raw instrument engineering and spacecraft ancillary data. The Level-1A data are used as input for geolocation, calibration, and processing. Quality indicators are added to the data to indicate missing or bad pixels and instrument modes. Visible, SWIR, and NIR measurements are made during daytime only, while radiances for TIR are measured during both the day and the night portions of the orbit.

MODIS Level-1B Calibrated Geolocation Data Set (MOD 02)

The Level 1B data set contains calibrated and geolocated at-aperture radiances for 36 bands generated from MODIS Level 1A sensor counts (MOD 01). The radiances are in $W/(m^2\ \mu m\ sr)$. In addition, reflectance may be determined for the solar reflective bands (bands 1-19, 26) through knowledge of the solar irradiance (e.g., determined from MODIS solar-diffuser data, and from the target-illumination geometry). Additional data are provided, including quality flags, error estimates, and calibration data.

MODIS Geolocation Data Set (MOD 03)

The MODIS Geolocation product contains geodetic coordinates, ground elevation, and solar and satellite zenith, and azimuth angle for each MODIS 1 km sample. These data are provided as a companion data set to the Level 1B calibrated radiances and the Level 2 data sets to enable further processing. These

geolocation fields are determined using the spacecraft attitude and orbit, instrument telemetry, and a digital elevation model.

MODIS Atmosphere Products
*(see also **http://modis-atmos.gsfc.nasa.gov/products.html**)*

MODIS Aerosol Product (MOD 04)

The MODIS Aerosol Product provides column-integrated aerosol information globally over both the continents and oceans for cloud-free scenes. The primary data product is the aerosol optical thickness (AOT) at 550 nm, and it is obtained from three complementary algorithms. The Dark-Target (DT) algorithms provide coverage over "dark" surfaces that includes vegetated, dark-soiled and some urban surfaces over land (DT-land), as well as over large water bodies (oceans and large lakes, DT-ocean). In addition to AOT, the DT-ocean algorithm retrieves fine-mode fraction (FMF) and reports Angstrom Exponent (AE), which both indicate the proportion of 'fine-sized' (e.g. smoke and pollution from combustion) versus 'coarse-sized' (e.g. mineral dust and sea-salt) aerosol particles. The enhanced Deep-Blue (eDB) algorithm retrieves AOT and AE over all snow-free land surfaces (includes deserts and urban areas as well as vegetation). Daily Level 2 (MOD 04) data are produced at the spatial resolution of a 10 × 10 1 km (at nadir) pixel array for all three algorithms. In addition, MOD04 provides a 'combined' AOT dataset that draws from all three algorithms and provides more complete spatial coverage.

MODIS Total Precipitable Water (MOD 05)

The MODIS Precipitable Water product (MOD 05) consists of column water-vapor amounts. During the daytime, a near-infrared algorithm is applied over clear land areas of the globe and above clouds over both land and ocean. Over clear ocean areas, water vapor estimates are provided over the extended glint area. An infrared algorithm for deriving atmospheric profiles is also applied both day and night for Level 2. The Level 2 data are generated at the 1-km spatial resolution of the MODIS instrument using the near-infrared algorithm during the day, and at 1-km pixel resolution both day and night using the infrared algorithm.

MODIS Cloud Product (MOD 06)

The MODIS Cloud Product combines infrared and shortwave techniques to determine physical and radiative cloud properties. Cloud particle phase, effective radius, cloud optical thickness, and cloud integrated water path are derived at 1-km pixel resolution using the MODIS visible, near-infrared, and shortwave infrared bands and are thus available during the sunlit portion of the day. Cloud height, cloud top pressure, effective emissivity, and cloud particle phase parameters are produced by infrared retrieval methods both day and night. Finally, the MODIS Cloud Product includes cirrus reflectance in the visible at 1 km pixel resolution, useful for removing cirrus scattering effects from the land surface reflectance product.

MODIS Atmospheric Profiles (MOD 07)

The MODIS Atmospheric Profiles product (MOD 07) consists of several parameters: they are total-ozone burden, atmospheric stability, temperature and moisture profiles, and atmospheric water vapor. The MODIS atmospheric profile algorithm is a statistical regression that accounts for surface emissivity. The retrievals are performed using clear sky radiances measured by MODIS within a 5 x 5 field of view (approximately 5 km resolution) over land and ocean for both day and night.

MODIS Level-3 Atmosphere Gridded Product (MOD 08)

There are three MODIS Level 3 Atmosphere Products, each covering a different temporal scale: Daily, 8-Day, and Monthly. Each of these Level 3 products contains statistics derived from over 100 science parameters from the Level 2 Atmosphere products: Aerosol, Precipitable Water, Cloud, and Atmospheric Profiles. A range of statistical summaries (scalar statistics and 1- and 2-dimensional histograms) are computed, depending on the Level 2 science parameter. Statistics are aggregated to a 1° × 1° equal-angle global grid. The daily product contains ~700 statistical summary parameters. The 8-day and monthly products contain ~900 statistical summary parameters.

MODIS Level-2 Atmosphere Joint Product (MOD ATML2)

The MODIS Atmosphere Level 2 Joint Product contains 91 key data sets gleaned from the complete set of standard Level 2 products: Aerosol, Water Vapor, Cloud, Atmospheric Profiles, and Cloud Mask. The Joint Atmosphere product was designed to be small enough to minimize data transfer and storage requirements, yet robust enough to be useful to a significant number of MODIS data users. Scientific data sets (SDSs) contained within the Joint Atmosphere product cover a full set of high-interest parameters produced by the MODIS Atmosphere group, and are stored at 5 km and 10 km (at nadir) spatial resolutions.

MODIS Cloud Mask (MOD 35)

The MODIS cloud mask product indicates whether a pixel is unobstructed between the surface and satellite. The product provides 48 bits of output per 1 km pixel that includes information on sets of multispectral test results (from 19 MODIS spectral bands), the decision tree used to arrive at the product, and limited ancillary information such as a land/ocean and snow/no snow flags. The first eight bits provide a summary sufficient for most applications. Additionally, the first two bits simply offer information in four categories: confident clear, probably clear, uncertain/probably cloudy, and cloudy.

MODIS Land Products

*(see also **http://modis-land.gsfc.nasa.gov/**)* Note: The majority of the land products are validated at Stage 2 (see Table A-1).

MODIS Surface Reflectance (MOD 09)

The MODIS Surface Reflectance products provide an estimate of the surface spectral reflectance as it would be measured at ground level in the absence of atmospheric scattering or absorption. Low-level data are corrected for atmospheric gases and aerosols, yielding a Level 2 basis for several higher order gridded products. In the 8-day product, each surface reflectance pixel contains the best possible observation during an 8-day period as selected on the basis of high observation coverage, low view angle, the absence of clouds or cloud shadow, and aerosol loading.

MODIS Land Surface Temperature and Emissivity (MOD 11)

The Land Surface Temperature (LST) and Emissivity daily data are retrieved at 1 km pixels by the generalized split-window algorithm and at 6 km grids by the day/night algorithm. In the split-window algorithm, emissivities in bands 31 and 32 are estimated from land cover types, atmospheric column water vapor and lower boundary air surface temperature are separated into tractable sub-ranges for optimal retrieval. In the day/night algorithm, daytime and nighttime LSTs and surface emissivities are retrieved from pairs of day and night MODIS observations in seven TIR bands. The product is comprised of LSTs, quality assessment, observation time, view angles, and emissivities.

MODIS Land Cover and Dynamics (MCD 12)

The MODIS Combined Terra and Aqua Land Cover product incorporates five different land cover classification schemes, derived through a supervised decision-tree classification method. The primary land cover scheme identifies 17 classes defined by the IGBP, including 11 natural vegetation classes, three human-altered classes, and three non-vegetated classes. The Land Cover Dynamics product includes layers on the timing of vegetation growth, maturity, and senescence that mark the seasonal cycles. Estimates of vegetation phenology are provided twice annually from the two 12-month focus periods, July-June, and January-December, allowing for hemispheric differences in the growing seasons, and enabling the product to capture two growth cycles if necessary.

MODIS Vegetation Indices (NDVI and EVI) (MOD 13)

MODIS vegetation indices, produced on 16-day intervals and at multiple spatial resolutions, provide consistent spatial and temporal comparisons of vegetation canopy greenness, a composite property of leaf area, chlorophyll and canopy structure. Two vegetation index products are derived from atmospherically-corrected red, near-infrared, and blue wavebands; the MODIS normalized difference vegetation index (NDVI) that provides continuity with NOAA's AVHRR NDVI time series record for historical and climate applications, and the enhanced vegetation index (EVI) that minimizes canopy-soil variations and improves sensitivity over dense vegetation conditions. The two products more effectively characterize the global range of vegetation states and processes.

MODIS Fire and Thermal Anomalies (MOD 14)

MODIS thermal Anomalies/Fire products are primarily derived from MODIS 4 and 11 μm radiances. The fire detection strategy is based on absolute detection of a fire (when the fire strength is sufficient to detect), and on detection relative to its background (to account for variability of the surface temperature and reflection by sunlight). The product includes a fire-mask, detection confidence, fire radiative power, and numerous other layers describing fire pixel attributes. MODIS data on Terra (and Aqua) are acquired twice daily at mid-latitudes allowing for up to four daily MODIS fire observations. These observations serve operational fire management needs and advance global monitoring of the fire process and its effects on ecosystems, the atmosphere, and climate.

MODIS Leaf Area Index (LAI)/Fraction of Photosynthetically Active Radiation (FPAR) (MOD 15)

LAI is defined as the one-sided green leaf area per unit ground area in broadleaf canopies and as half the total needle surface area per unit ground area in coniferous canopies. FPAR is the fraction of photosynthetically active radiation (400-700 nm) absorbed by green vegetation. Both variables are used for calculating surface photosynthesis, evapotranspiration, and net primary production, which in turn are used to calculate terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. Algorithm refinements have improved quality of retrievals and consistency with field measurements over all biomes, with a focus on woody vegetation.

MODIS Evapotranspiration (MOD 16)

Terrestrial evapotranspiration (ET) is the summation of plant transpiration and soil evaporation. The MOD16 ET algorithm is based on the Penman-Monteith equation. Net solar radiation is partitioned into components of vegetation and soil by vegetation cover fraction using the fPAR (MOD15) and the MODIS Albedo (MCD43) products. Air vapor pressure deficit (VPD) and minimum air temperature are used to constraint leaf conductance, which is up-scaled to canopy conductance with MOD15 Leaf Area Index (LAI). Potential soil evaporation is reduced by air humidity and VPD to estimate soil evaporation. MOD16 ET estimates at AmeriFlux towers agree well with measured ET seasonally and inter-annually.

MODIS Gross Primary Productivity (GPP)/Net Primary Productivity (NPP) (MOD 17)

The Gross Primary Productivity (GPP) product is a cumulative composite of GPP values based on the radiation use efficiency concept that may be used as input to data models for calculating terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. Modifications of parameters in Biome Property Look-Up Table (BPLUT) have been made to agree with GPP derived from measurements at eddy flux towers and synthesized NPP. Further, they include a spatially non-linear interpolation of coarse-resolution meteorological data at 1 km MODIS pixel level, instead of nearest neighbor sampling, to increase the accuracy of meteorological data input at pixel level.

MODIS Multi-Angle Implementation of Atmospheric Correction (MAIAC) Product (MOD 19)

MAIAC is a new advanced algorithm that uses time series analysis and a combination of pixel- and image-based processing to improve accuracy of cloud detection, aerosol retrievals and atmospheric correction. MAIAC provides suites of 1km atmospheric and surface gridded products that include cloud mask, column water vapor and aerosol optical depth, type (background, biomass burning or dust), and Ångström parameter, and surface spectral BRF, albedo and Ross-Thick Li-Sparse (RTLS) BRDF model parameters in 7 land and 5 unsaturated ocean bands. The 500m gridded land BRF and albedo are also produced for MODIS bands 1-7. The BRDF is reported every 8 days.

MODIS TES Land Surface Temperature and Emissivity (MOD 21)

The MODIS TES daily Land surface temperature (LST) and emissivity product consists of day and nighttime 1-km LSTs and thermal infrared (TIR) emissivity for bands 29, 31, and 32 retrieved using the ASTER Temperature Emissivity Separation (TES) algorithm. The TES algorithm uses a radiative transfer model to correct the at-sensor radiance to surface radiance on a pixel-by-pixel basis followed by an emissivity model based on laboratory measurements to separate the surface radiance into temperature and emissivity. The product will include LST, spectral emissivity for bands 29, 31, and 32, uncertainty estimates, quality assessment, observation time, and view angles.

MODIS Bidirectional Reflectance Distribution Function (BRDF)/Albedo Parameter (MCD 43)

The BRDF/Albedo product contains 3-D data sets providing users with BRDF model parameters that users can use to construct the surface BRDF and compute directional reflectances at any solar and viewing geometry. The models support the spatial relationship and parameter characterization best describing the differences in radiation due to the scattering (anisotropy) of each pixel, relying on multi-date, atmospherically corrected, cloud-cleared input data measured over 16-day periods. Both Terra and Aqua data are used in the generation of this product, providing the highest probability for quality input data. The product suite also contains standard spectral albedos for those who do not wish to use the BRDF model parameters and the Nadir-Adjusted BRDF Reflectance (NBAR) at the mean solar zenith angle of the observation period.

MODIS Vegetation Continuous Fields (MOD 44)

Proportional estimates of vegetation cover are developed from global training data derived using high-resolution imagery. The training data and phenological metrics are used with a regression tree to derive percent cover globally. The model is then used to estimate areal proportions of life form, leaf type, and leaf longevity. The current Version 51 collection of the yearly MODIS Vegetation Continuous Fields (VCF) product contains proportional estimates of vegetation cover for woody, herbaceous, and bare ground vegetation types. The data layers in the VCF product are generated on an annual basis from monthly composites of 500 m Surface Reflectance data. Compositing is based on the second darkest albedo to remove clouds and cloud shadow.

MODIS Burned Area Products (MCD 45)

The Burned Area product contains burning and quality information on a per-pixel basis. Produced from both the Terra and Aqua MODIS-derived daily surface reflectance inputs, the algorithm analyzes the daily surface reflectance dynamics to locate rapid changes, and uses that information to detect the approximate date of burning, mapping the spatial extent of recent fires only. It provides varied quality assessment information and a single summary quality assessment score for each pixel. The algorithm improves on previous methods by using a BRDF model-based change detection approach to handle angular variations in the data and uses a statistical measure to identify change probability from a previously observed state.

MODIS Cryosphere Products

*(see also **http://modis-land.gsfc.nasa.gov/**)*

MODIS Snow Cover (MOD 10)

MODIS snow cover data are based on a snow mapping algorithm that employs a Normalized Difference Snow Index (NDSI) and other test criteria. The MODIS snow product suite is composed of products covering a range of spatial and temporal resolutions, from 500 m to 0.05°, and from swath to daily, to 8-day to monthly. All products provide fractional snow cover, and snow albedo is provided in the 500 m resolution products. The overall absolute accuracy of the 500 m resolution products is ~93%, varying by land cover and snow condition. The snow products are used by climatologists, and by modelers both as input to hydrological models, e.g., to develop snow-cover depletion curves, and to compare with GCM output.

MODIS Sea Ice and Ice Surface Temperature (MOD 29)

The MODIS sea ice product contains the sea ice extent and ice surface temperature (IST) measured during daylight and darkness. The sea ice algorithm uses a Normalized Difference Snow Index (NDSI) modified for sea ice to distinguish sea ice from open ocean based on reflective and thermal characteristics. The sea ice product suite is composed of both swath and gridded products at a range of spatial and temporal resolutions, from 1 km to 0.05° (or ~4 km), and temporal resolutions ranging from swath to daily with gridded data in a polar grid (EASE-grid). IST under frozen conditions is accurate to ±1.6 K.

MODIS Ocean products

*(see also **http://oceancolor.gsfc.nasa.gov/**)*

See the above Ocean Color URL for the complete list of community accepted ocean color products and sea surface temperature products. The MODIS ocean color products do not follow the EOSDIS MOD/MYD convention. All MODIS ocean parameters are provided as 1 km (Level 2), 4.6 km equal-area binned, and 4.6 and 9.2-km gridded products (Level 3) over global oceans. The Level 2 product is produced within

hours of observation. It is used to generate the binned and gridded Level 3 temporal composites on daily, 8-day 'weekly', monthly, and yearly timescales, as well as monthly and seasonal climatologies.

MODIS Sea Surface Temperature (MOD 28)

Sea surface temperatures (SST) are generated from the mid-range infrared channels of MODIS for both the daytime and nighttime global oceans. A second estimate of sea surface temperatures (SST4) is generated from the shortwave infrared channels for the nighttime portion of the orbit only. In addition, a quality assessment parameter is included for each pixel, as well as a standard deviation and bias estimate, for both the SST and SST4 products.

MODIS Remote Sensing Reflectance

The principal measurement in ocean color is the spectral distribution of normalized water-leaving radiance, $NLw(\lambda)$, which is defined as the upwelling radiances just above the ocean surface, normalized to represent the case of no atmosphere with the Sun directly overhead. For application in biooptical algorithms, this quantity is converted to remote sensing reflectance, Rrs, which is simply nLw divided by mean extraterrestrial solar irradiance. From these reflectances, information on a host of ocean optical properties (dissolved substance and particle absorption and scattering coefficients) and constituent concentrations (e.g., chlorophyll-*a*) are derived. Rrs products are generated for each of the nine MODIS visible wavelengths (400-700 nm).

MODIS Sub-surface Chlorophyll-*a* Concentration

Chlorophyll-*a* is the main plant pigment involved in photosynthesis and is a good indicator of phytoplankton biomass. It is required for estimation of primary production and ocean biological sequestration of carbon. It is a core MODIS data product. Records of chlorophyll-*a* started in September 1997 with SeaWiFS and chlorophyll-*a* concentrations are now also derived from the MODIS sensors on Terra and Aqua. Chlorophyll*a* algorithms have reached maturity and are very reliable over ~90% of the World Ocean. The chlorophyll-*a* data are available to the community through the NASA Ocean Biology Processing Group Ocean Color Web server.

MODIS Diffuse Attenuation at 490 nm

Diffuse attenuation is related to the exponential decrease in light intensity with water depth, i.e., it is the wavelength-dependent coefficient of depth in the exponent. Therefore, it is an indicator of water clarity and is used to estimate light penetration and absorption, both of which are important for calculations of primary production and mixed layer heating. The diffuse attenuation at 490 nm (Kd490) is a core product for SeaWiFS and MODIS/Aqua and Terra, so the global time series starts with the SeaWiFS data in 1997.

MODIS Aerosol Optical Thickness (for ocean color atmospheric correction)

Aerosol optical thickness at band 869 nm, $\tau_a(869)$, over ocean is derived from the ocean color data processing for every pixel with a clear atmosphere using the MODIS near-infrared (NIR) measurements at 748 and 869 nm. Aerosol NIR spectral reflectance is used to retrieve aerosol models and derive $\tau_a(869)$ value. For productive waters, the NIR ocean contributions are estimated using the biooptical models. The $\tau_a(869)$ is defined as the integrated extinction coefficient at 869 nm over a vertical column of unit cross section. The $\tau_a(869)$ value is proportional to the aerosol particle concentration and can be related to atmosphere turbidity (visibility).

MODIS Aerosol Ångström exponent

Aerosol Ångström exponent $\alpha(443)$ (dimensionless) over ocean is the estimated slope at 443 nm of the curve plotting the log of the optical depth versus the log of the wavelength. It is derived from the MODIS bands at 531 nm, 748 nm, and 869 nm for every pixel with a clear atmosphere. The $\alpha(443)$ is a measure of the spectral variation of the aerosol optical thickness and is a function of the aerosol particle size (the larger the exponent, the smaller the particle size).

MODIS Particulate Organic Carbon

Particulate Organic Carbon (POC) is the carbon stored in organic particles (soft tissues) suspended in the water column. Because passive radiometers like MODIS only sense the light that is scattered out of the

water column very near the surface, the MODIS POC is essentially the surface concentration in gC/m^3. POC is an important component of the ocean carbon cycle.

MODIS Particulate Inorganic Carbon

Particulate Inorganic Carbon (PIC) is a form of particulate calcium carbonate and constitutes the skeletons of microscopic marine plankton (plants and animals). Coccolithophores are a well-known source of calcite particles because they shed calcite platelets during a phase of their lifecycle. The Cliffs of Dover are composed of calcite from such plankton species. Like POC, PIC is another important component of the marine carbon cycle and carbon is in concentrations of gC/m^3.

MODIS Fluorescence Line Height (FLH)

FLH (mW/cm^2-μm-sr) is a measure of the chlorophyll fluorescence that peaks at around 685 nm. The MODIS fluorescence band at 678 nm is offset from the peak to avoid an atmospheric oxygen absorption band (O_2 B-band). MODIS FLH is derived by subtracting a baseline radiance computed from the 667 and 748 nm bands that lie outside the fluorescence band. Recent research on FLH has shown that it can be used to study phytoplankton physiology, or health (see the next product, the Instantaneous PAR). The maturity of the FLH product is provisional.

MODIS Instantaneous Photosynthetically Available Radiation

Instantaneous Photosynthetically Available Radiation (iPAR) is the total downwelling flux of photons just below the sea surface at the instant MODIS views the pixel, integrated over the wavelength range of 400-700 nm. It is derived for all cloud free pixels using the retrieved atmospheric properties to attenuate the extraterrestrial solar irradiance at each MODIS visible wavelength, and then integrating over wavelength space. The iPAR can be used in combination with the FLH to estimate chlorophyll fluorescence quantum yield. Variations in fluorescence quantum yield have been interpreted as indicators of phytoplankton physiology (e.g., iron stress).

MODIS Daily Mean Photosynthetically Available Radiation

Like iPAR, Daily Mean Photosynthetically Available Radiation (PAR) is the total downwelling photon flux integrated over the wavelength range of 400-700 nm. However, PAR is derived for all ocean pixels (both clear and cloudy), and it uses a model of 24-hour solar illumination to integrate over a full daily cycle. Thus, PAR represents the average energy available for photosynthesis over each day, at each MODIS pixel. PAR is a critical input to models of net primary productivity, and SeaWiFS PAR has been in widespread use for over a decade. PAR has previously been produced only from SeaWiFS data, as the MODIS ocean channels saturate over cloudy pixels. It is now being produced with MODIS data using the land channels at 469, 555, and 645 nm.

MODIS Product not part of the "core product"

MODIS Polar Winds

The polar wind product provides tropospheric wind speed, direction, and height over the Arctic and Antarctic, poleward of approximately 70° latitude. It has been generated in real-time since 2002 using MODIS data from the Terra and Aqua satellites, and is now a NOAA/NESDIS operational product. The polar wind data are used by 12 numerical weather prediction centers in eight countries.

MOPITT

MOPITT observations yield Level 1, Level 2, and Level 3 products. Products are available for the periods March 3, 2000 - May 6, 2001, Aug. 25, 2001 - July 27, 2009, and Sept. 30, 2009 - present. Products may be accessed through the Langley Atmospheric Science Data Center data pool (eosweb.larc.nasa.gov/HPDOCS/datapool/) or the NASA Reverb/ECHO system (reverb.echo.nasa.gov).

MOPITT Level 1 Product

The MOPITT Level 1 product is a single-instrument product, containing calibrated radiances and associated uncertainties for 12 CO-sensitive channels and 4 methane sensitive channels in "swath" format, along with geolocation information. The Version 5 Level 1 product was released in 2011. The Version 6 Level 1 product included corrected geolocation data and was released in 2013. The primary user of the

Level 1 product is the MOPITT Science Investigator-led Processing System (SIPS), which exploits it for MOPITT Level 2 processing.

MOPITT Level 2 Products

MOPITT Level 2 TIR Product

The MOPITT Level 2 TIR (thermal-infrared only) product contains retrieved profiles of CO concentration on a ten-level grid and CO total column based on observations in the 4.7 micron band. Product also includes (1) retrieval uncertainties, (2) geolocation information, (3) diagnostics including "averaging kernels" for each retrieval, and (4) retrieval byproducts including surface temperature and emissivity. All datasets are in "swath" format. MODIS cloud mask data are also used to produce this product. The Level 2 TIR-only product has a longer heritage than the NIR-only or TIR/NIR products and is considered more mature. The Version 5 and Version 6 Level 2 TIR-only products were respectively released in 2011 and 2013, and are both validated. The Version 6 product features several minor improvements such as corrected geolocation data, updated a priori and MERRA meteorological fields instead of NCEP.

MOPITT Level 2 NIR Product

The MOPITT Level 2 NIR (near-infrared only) product contains retrieved profiles of CO concentration on a ten-level grid and CO total column based on observations in the 2.3 micron band. Product also includes (1) retrieval uncertainties, (2) geolocation information, (3) diagnostics including "averaging kernels" for each retrieval, and (4) various retrieval byproducts. All datasets are in "swath" format. MODIS cloud mask data are also used to produce this product. The MOPITT NIR-only product was first released as part of the Version 5 release in 2011. The Version 6 product was released in 2013 and features several minor improvements (such as corrected geolocation data, updated a priori and MERRA meteorological fields instead of NCEP). Both the V5 and V6 NIR-only products are validated.

MOPITT Level 2 Combined TIR/NIR Product

The MOPITT Level 2 combined TIR/NIR product contains retrieved profiles of CO concentration on a ten-level grid and CO total column based on observations in both the 4.7 μm and 2.3 μm bands. Compared to the TIR-only and NIR-only products, this product offers improved sensitivity to CO concentrations in the boundary layer. This product also includes (1) retrieval uncertainties, (2) geolocation information, (3) diagnostics including "averaging kernels" for each retrieval, and (4) retrieval byproducts including surface temperature and emissivity. All datasets are in "swath" format. MODIS cloud mask data are also used to produce this product. This product was first released as part of the Version 5 release in 2011. The Version 6 product was released in 2013 and features several minor improvements such as corrected geolocation data, updated a priori and MERRA meteorological fields instead of NCEP. Both the V5 and V6 TIR/NIR products are validated.

MOPITT Level 3 Products

MOPITT Level 3 TIR Product

The MOPITT Level 3 TIR product includes daily and monthly-mean averages of MOPITT Level 2 TIR product data, averaged on a 1° by 1° latitude/longitude grid. Various diagnostics, such as grid cell-averaged averaging kernels, are also included. MODIS cloud mask data are required to produce the MOPITT Level 2 product, which the Level 3 product requires. Versions 5 and 6 of this product were released in 2011 and 2013 respectively.

MOPITT Level 3 NIR Product

The MOPITT Level 3 NIR product includes daily and monthly-mean averages of MOPITT Level 2 NIR product data, averaged on a 1° by 1° latitude/longitude grid. Various diagnostics, such as grid cell-averaged averaging kernels, are also included. MODIS cloud mask data are required to produce the MOPITT Level 2 product, which this Level 3 product requires. Versions 5 and 6 of this product were released in 2011 and 2013 respectively.

MOPITT Level 3 Combined TIR/NIR Product

The MOPITT Level 3 combined TIR/NIR product includes daily and monthly-mean averages of MOPITT Level 2 data, averaged on a 1° by 1° latitude/ longitude grid. Compared to the TIR-only and NIR-only products, this product offers improved sensitivity to CO concentrations in the boundary layer. Various diagnostics, such as grid cell averaged averaging kernels, are also included. MODIS cloud mask data are required to produce the MOPITT Level 2 product which this Level 3 product requires. Product will be based on both NIR and TIR radiances. Versions 5 and 6 of this product were released in 2011 and 2013 respectively.

MOPITT Product User Contacts (Primary Level 2 Product Users)

Richard Engelen, ECMWF, Project Manager for MACCII (Monitoring Atmospheric Composition and Climate) data assimilation system, richard.engelen@ecmwf.int. Daniel Jacob, Atmospheric Chemistry Modeling Group, Harvard University, djacob@fas.harvard.edu.

Number of Terra Core Data Products:

12 ASTER
13 CERES
12 MISR
37 MODIS (3 L1, 7 Atmos, 13 Land, 2 Cryo, 11 Ocean, 1 other)
7 MOPITT

81 Total