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MTPE EOS

DATA PRODUCTS HANDBOOK

Volume 1

TRMM & AM-1

NASA - GODDARD SPACE FLIGHT CENTER

MISSION TO PLANET EARTH (MTPE)

EARTH OBSERVING SYSTEM (EOS)

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How to Use This Document

This document is designed to provide you with information about the products available through the EOSDIS system in the TRMM and AM-1 timeframes. If you already know the product name, the name may be found in the summary *List of Products* beginning on page *ix* by either the *Product ID* or the *Data Set Name*. Both the *Product ID* and the *Data Set Name* will direct you to the page number on which you will find the corresponding Product Description and other information.

If you are beginning your research into what products are available through MTPE, you may choose to investigate the twelve science chapters in this document beginning with the Radiance and Imagery products. Data sets are grouped by these classifications, which are derived from the twenty-four EOS critical science measurements. Each category provides a framework for understanding the science objectives as well as providing a thumbnail sketch of what the product is designed to do. Investigators may also cross-reference products by their source instrument and archive. That information, as well as page numbers, is provided in the List of Products.

Investigators and educators should realize that additional information about the products will emerge as the time grows closer to launch of the TRMM and AM-1 missions. An electronic version of the Data Products Handbook will be available online at the EOS Project Science Office Home Page (http://eospso.gsfc.nasa.gov/eospso_homepage.html).

This document also contains information about the EOSDIS Distributed Active Archive Centers (DAACs) and the EOS instrument teams. Access information about the DAACs is contained in Chapter Two. Information about the TRMM and AM-1 instrument teams is contained in Chapter Three.

Abstract

The *MTPE/EOS Data Products Handbook* provides high level descriptions of the science and instrument data sets that will be produced from the Tropical Rainfall Measuring Mission (TRMM) and the first Earth Observing System (EOS) satellite (AM-1). These data sets, which will provide essential information for science and policy research in the areas of global change and Earth system science, will be distributed to the user community through the EOS Data and Information System (EOSDIS). The data set descriptions in the *MTPE/EOS Data Products Handbook* include product descriptions, research and application information, information about precursors to the EOS data, suggested reading, and summary information on product coverage, resolution, and contacts. The *MTPE/EOS Data Products Handbook* is a companion to the *MTPE/EOS Reference Handbook* (Asrar and Greenstone, 1995) and *EOS: Science Strategy for the Earth Observing System* (Asrar and Dozier, 1994).

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Chapter One – Introduction

Introduction

Overview

The MTPE/EOS Data Products Handbook (DPH) provides a brief description of the science data products that will be available from the Earth Observing System Data and Information System (EOSDIS). The objective of the DPH is to promote a broader understanding of how the EOS data products will contribute to science research in the understanding, analysis, and monitoring of global climate change. Table 1 provides a listing of the 24 critical science measurements as identified by the EOS Project Science Office and the instruments that relate to them. This volume describes data products that will be produced from instruments onboard the Tropical Rainfall Measuring Mission (TRMM) satellite and the Earth Observing System (EOS) morning satellite (AM-1).

The information in this document was compiled from many sources: principally, the Algorithm Theoretical Basis Documents (ATBDs), which were written by the science teams; abstracts and information from the product generation engineering effort known as the Ad Hoc Working Group on Production (AHWGP); and preliminary information compiled by the Science Processing Support Office (SPSO) of the Earth Science Data and Information System (ESDIS) Project. The data descriptions in this reference have been reviewed by the science team contacts for accuracy. Readers should be aware that this reference is only the “tip of the iceberg” of information available on the EOS data products.

DPH Volume I Organization

Chapter 1 provides a roadmap through the document itself. Chapter 2 provides additional background on Mission to Planet Earth (MTPE) mission objectives, a table of key characteristics for the TRMM and AM-1 instruments, and information on the EOSDIS and the EOS Distributed Active Archive Centers (DAACs).

Chapter 3 provides an overview (for each instrument) of the process by which the data products are derived from the instrument observations.

Table 1. The 24 Critical EOS Science Measurements

ATMOSPHERE	
Cloud Properties (amount, optical properties, height)	MODIS, GLAS, AMSR, MISR, AIRS, ASTER, EOSP, SAGE III
Radiative Energy Fluxes (top of atmosphere, surface)	CERES, ACRIM, MODIS, AMSR, GLAS, MISR, AIRS, ASTER, SAGE III
Precipitation	AMSR
Tropospheric Chemistry (ozone, precursor gases)	TES, MOPITT, SAGE III, MLS, HIRDLS, LIS
Stratospheric Chemistry (ozone, ClO, BrO, OH, trace gases)	MLS, HIRDLS, SAGE III, ODUS, TES
Aerosol Properties (stratospheric, tropospheric)	SAGE III, HIRDLS, MODIS, MISR, EOSP, GLAS
Atmospheric Temperature	AIRS/AMSU, HIRDLS, TES, MODIS
Atmospheric Humidity	AIRS/MHS, MLS, SAGE III, DFA/MR, MODIS, TES
Lightning (events, area, flash structure)	LIS
SOLAR RADIATION	
Total Solar Irradiance	ACRIM
Ultraviolet Spectral Irradiance	SOLSTICE
LAND	
Land Cover & Land Use Change	ETM+/LATI, MODIS, MISR, ASTER
Vegetation Dynamics	MODIS, MISR, ETM+/LATI, ASTER
Surface Temperature	ASTER, MODIS, AIRS, ETM+
Fire Occurrence (extent, thermal anomalies)	MODIS, ASTER, ETM+
Volcanic Effects (frequency of occurrence, thermal anomalies, impact)	MODIS, ASTER, MISR
Surface Wetness	AMSR
OCEAN	
Surface Temperature	MODIS, AIRS, AMSR
Phytoplankton & Dissolved Organic Matter	MODIS
Surface Wind Fields	SeaWinds, AMSR, DFA/MR
Ocean Surface Topography (height, waves, sea level)	DFA/MR
CRYOSPHERE	
Ice Sheet Topography & Ice Volume Change	GLAS
Sea Ice (extent, concentration, motion, temperature)	AMSR, DFA/MR, MODIS
Snow Cover (extent, water equivalent)	MODIS, AMSR, ASTER, ETM+/LATI

Introduction

Chapters 4 through 14 contain the data set descriptions. Chapter 4 covers imagery, and raw instrument data sets, as well as a few instrument ancillary data sets that are the basis for numerous other data sets with broad application to Earth science research. Chapters 5 through 14 emphasize the 24 science themes that have been identified as critical measurements of the EOS program. Three chapters — upper air temperature, winds, and pressure and heights — include assimilated products which do not map directly to the twenty-four critical science EOS measurements but derive from EOS products which map to these categories.

The purpose of this document's grouping is to provide a first-order indication of the kinds of science research that the data products can be used to support. The science themes are intended both to focus upon the mission objectives during the early EOS time frame and to represent a subset of the overall MTPE science objectives, which encompass a larger number of platforms and hence have a much broader scope.

The data set description chapter titles are as follows:

- Radiance and Imagery Products;
- Precipitation and Atmospheric Humidity;
- Cloud and Aerosol Properties and Radiative Energy Fluxes;
- Lightning;
- Tropospheric Chemistry;
- Upper Air Temperatures;
- Winds;
- Pressure and Heights;
- Surface Temperature of Land and Oceans, Fire Occurrence and Volcanic Effects;
- Vegetation Dynamics, Land Cover, Land Use Change, and Snow Cover;
- Phytoplankton and Dissolved Organic Matter; and
- Snow Cover and Sea Ice.

Readers looking for derived geophysical data (e.g., Sea Surface Temperature) will be most interested in the data described in the topical sections (e.g., Surface Temperature of Land and Oceans), while readers interested in dealing with large-volume data sets such as uncalibrated instrument counts and temperatures, calibrated radiances, and reflectivities can refer to the Imagery and Radiances section.

It is important to understand that the science themes given for the data products are by no means all-inclusive. The applications envisioned today for products will change as new uses are discovered and as the products themselves are improved. These improvements are likely to come after launch through algorithm refinement, or enhancements to input data needed for product development. Many data sets are applicable to more than one theme. Where more than one application is appropriate, a listing of key science applications is provided for the data set within its product summary description.

Data Product Description

The data set descriptions contain the following information (Level 1 and radiance products contain a subset of this information):

- product description;
- research and applications;
- data set evolution;
- suggested reading; and
- product summary information
  - coverage
  - resolution
  - wavelengths (Level 1 products only)
  - key science applications (optional)
  - key (geophysical if applicable) parameters (Level 2, 3, 4 products)
  - processing level and availability
  - product type and production mode
  - science team contact.

The ***Product Description*** contains summary information about what is contained in the data set and a few details about the resolution, derivation, and accuracy of the data. ***Research and Applications*** briefly describes some of the science questions and applications for which the data set will be useful. ***Data Set Evolution*** provides information on precursor data sets and highlights ways in which the data sets improve upon current capabilities. ***Suggested Reading*** provides several references for more information. An effort has been made to include more recent publications which are generally available to the broader science community.

Please note that the terms *data set* and *data product* are used interchangeably throughout this document. The data described in this document will be distributed through the EOSDIS, and the EOSDIS science processing support office has assigned EOS identifiers (EOS-IDs) for each data product. These EOS-IDs are used throughout this document. These product IDs should not be confused with ATBD numbers assigned by the Project Science Office to identify each unique Algorithm Theoretical Basis Document which may contain multiple data products.

Note that CERES products use instrument IDs which do not use a numbering scheme.

Product Summary Information

The product summary information contains an overview of the processing level, coverage, resolution, and contact information for each data set.

Processing Level – Data set processing level is referred to throughout this document. The definitions of processing levels are shown in Table 2. Level 1 data (e.g., Volts, Counts, Brightness Temperatures, etc.) require knowledge, agreed-upon algorithms, and computer processing capability for conversion to Level 2. Level 2 data measure the biogeophysical properties of Planet Earth. When a satellite instrument/algorithm is relatively new, the Level 2 product is heavily used. When the instrument/ algorithm is mature, many users may prefer the Level 3 product.

Level 3 (mapped/gridded) and Level 4 (modeled) products can be used by interdisciplinary scientists to combine data from different areas of knowledge without necessarily having to know the details or undertake all of the processing that would otherwise be necessary (to process Level 1 to Level 3 or 4). The availability of Level 3 and 4 data is a major advantage of EOSDIS in promoting data usage from outside the science field in which the data were generated. Some data sets are being produced and archived in both a Level 2 (unmapped) and Level 3 (mapped and/or temporally sampled) form.

The differences in products allow researchers to choose products available at a particular level, enabling them to work in coarser resolution to model global processes and events or in finely detailed resolution which allows for investigations at targeted regions.

Coverage – The AM-1 satellite is in a Sun-synchronous polar orbit and views the globe, daytime and nighttime, at the same time every day. TRMM, however, is in a precessing, inclined orbit and views the Earth from 38°N latitude to 38°S

Table 2. Data Set Processing Levels (from the EOS Reference Handbook)

Data Level	***Description***
Level 0	Reconstructed unprocessed instrument/payload data at full resolution; any and all communications artifacts (e.g., synchronization frames, communications headers) removed.
Level 1A	Reconstructed unprocessed instrument data at full resolution, time-referenced, and annotated with ancillary information, including radiometric and geometric calibration coefficients and georeferencing parameters (i.e., platform ephemeris) computed and appended, but not applied, to the Level 0 data.
Level 1B	Level 1A data that have been processed to sensor units (not all instruments will have a Level 1B equivalent).
Level 1C	TRMM specific for quality content of Level 1B precipitation radar and ground validation data
Level 2	Derived geophysical variables at the same resolution and location as the Level 1 source data.
Level 3	Variables mapped on uniform space-time grid scales, usually with some completeness and consistency.
Level 4	Model output or results from analyses of lower level data (i.e., variables derived from multiple measurements).

latitude. Many instruments have large swaths and view the entire globe every day. Some of the higher resolution instruments have a small swath width and as such only view the complete Earth's surface over a period of several days or weeks. For each data set described in this reference, a summary of the coverage characteristics (day/night, global/local, etc.) is provided.

Processing Level and Availability – Most of the data sets in this reference are EOS "standard data products." This means the products will be routinely processed for every applicable data acquisition. The goal of EOS is to begin producing and providing products immediately after launch and instrument check-out. The science teams have identified the best available algorithms and methods for producing these data sets given current understanding of physics and instrument performance; these are the "at-launch" data products. Some products, such as seasonal products or products describing variance from seasonal norms, cannot be implemented until some time after launch. In these cases, the data sets are referred to as "post-launch." All Level 1 data sets are standard at-launch products, while some Level 2, 3, and 4 data sets will be phased in after launch.

It is expected that great improvements in the derivation of geophysical products will be made during the first months and years of the satellite operation, and the EOSDIS has been sized to enable reprocessing of standard products periodically as improved methods and instrument characterization are available.

Contacts For Further Information – To learn more about the data sets described in this guide, the ATBDs can be acquired from the EOS Project Science Office (PSO) World Wide Web (WWW) site at http://spso.gsfc.nasa.gov/spso_homepage.html. In addition, a science team contact is listed for each data set described in this volume, and the phone, fax, and e-mail information for these investigators can be found in the *EOS Directory*, available from the PSO Web page, and in Appendix A of this document.

Data Set Reference Evolution

Some of the details of product definition are still being determined. For example, for many mapped Level 3 data sets, the standard grids or map projections have not been finalized, and there are still issues associated with the scope and timing of recompeting the EOSDIS DAACs as this document is being written. These are just a few of the issues being addressed prior to launch. It is anticipated that this reference will be updated or superseded by detailed, online data set guides and catalogues, accessible through the EOSDIS, prior to the launch of the TRMM and AM-1 platforms.

Chapter Two – Background

Background

MTPE

NASA's Mission to Planet Earth (MTPE) program provides measurement systems and research initiatives to further the acquisition and synthesis of environmental data to address scientific issues related to global change and Earth system science. MTPE programs include basic scientific research, field campaigns and experiments such as the Boreal Ecosystem-Atmosphere Study (BOREAS), state-of-the-art data set development through the Pathfinder program, development of Earth- and space-based observing systems including the EOS series of satellites, and data access and distribution systems. Throughout all of these activities, MTPE carries a strong commitment to make high-quality, well-documented, Earth science data easily available to the global community to further environmental and global change research needs. The most pressing issues for global change researchers are described in the *EOS Science Plan, EOS Science Strategy for the Earth Observing System*, and *Our Changing Planet: The FY 1996 U.S. Global Change Research Program*.

EOS

The Earth Observing System (EOS) is a series of Earth-orbiting satellites which will provide global observations of the land surface, atmosphere, and oceans over 15 years or more, with the first satellites being launched in the late 1990s. Complete information and details on the satellites and instruments included in EOS can be found in the *MTPE/EOS Reference Handbook*. This document can be directly accessed at the following Internet address:

http://eospso.gsfc.nasa.gov/eos_reference/TOC.html.

EOS is complemented by missions and instruments from international partners, including Japan, Brazil, the European Space Agency (ESA), and ESA member countries. For example, TRMM is a joint NASA/Japanese mission. Together, these NASA and international programs form the basis for a comprehensive International Earth Observing System (IEOS).

The EOS satellites will carry two classes of instruments: Facility Instruments supplied by NASA in response to general mission requirements, and Principal Investigator (PI) Instruments selected through a competitive process and aimed at the focused research interests of the selected investigators. Two EOS instruments — Clouds and the Earth's Radiant Energy System (CERES) and Lightning Imaging Sensor (LIS) — are being flown on the TRMM satellite, in addition to non-EOS instruments — Precipitation Radar (PR), TRMM Microwave Imager (TMI), and Visible Infrared Scanner (VIRS). However, data from all of the instruments on TRMM are part of the MTPE research and data development program and will be distributed through the EOSDIS archives. Consequently, this data set reference handbook includes descriptions of the data sets from all of the TRMM instruments. Table 3 provides an overview of the instruments which are providing data described in this reference handbook.

The AM-1 platform is in a polar orbit with a descending node equator crossing time of 10:30 a.m. The TRMM satellite is in an inclined, equatorial orbit and only views the Earth from roughly 38°N to 38°S. Most of the AM-1 and TRMM instruments operate in both daylight and darkness, however some of the optical instruments will not collect visible data over areas of darkness.

The instruments have variable scanning and coverage characteristics. Depending on the swath width, some instruments provide global data daily, while some of the higher resolution instruments have smaller swaths and only cover a portion of the day. Within a repeat cycle of a few days, however, most of these instruments also provide global imaging. In the case of TRMM, the orbital processing is 30 days for the geographic and diurnal repeat, and for AM-1, the repeat cycle is roughly 9 days.

Table 3 provides an overview of the coverage characteristics of the instruments on TRMM and AM-1.

Data Sets

Data and data sets define mission success for the EOS. In more than 25 years of Earth observation, scientists have begun only recently to routinely use global data sets of moderate to coarse resolution

Background

Table 3.
Coverage Characteristics of the Instruments on TRMM and AM-1

Satellite	*Instrument*	*Description*
TRMM	PR – Precipitation Radar	An electronically scanning radar operating at 13.8 GHz; 4.3 km instantaneous field-of-view at nadir; 220-km swath. Provided by NASDA (Japan).
TRMM	TMI – TRMM Microwave Imager	A nine-channel conical scanning passive microwave imager making measurements from 10 to 85 GHz, 37 to 4.6 km resolution respectively, covering 760 km swath.
TRMM	VIRS – Visible Infrared Scanner	A five-channel cross-track imaging radiometer (0.63, 1.6, 3.75, 10.7, and 12.0 μm) with nominal 2-km resolution at nadir and 720-km swath.
TRMM & AM-1	CERES – Clouds & the Earth's Radiant Energy System	A three-channel radiometer (0.3 to > 50 μm, 0.3 to 5 μm, 8 to 12 μm). TRMM will have one cross-track scanning radiometer and AM-1 will have two instruments, one operating in cross-track mode and one in rotating azimuth plane mode. The spatial resolution will be *x* from TRMM orbit and *y* from the highest AM-1 orbit.
TRMM	LIS – Lightning Imaging Sensor	Staring telescope/filter imaging system (0.777 μm) with 5-km spatial resolution and 2-msec temporal resolution over an imaging area of 600 × 600 km.
AM-1	ASTER – Advanced Spaceborne Thermal Emission & Reflection Radiometer	A three-radiometer sensor package with three vis/near-IR, six short-wave, and five thermal infrared channels with 15, 30, and 90-m resolution, respectively, and a 60-km swath. Provided by MITI (Japan).
AM-1	MISR – Multi-angle Imaging Spectroradiometer	Thirty-six channel instrument; nine pushbroom cameras with discrete view angles (to ± 70°) in four spectral bands (0.443 to 0.865 μm) with resolution of 275 m to 1.1 km.
AM-1	MODIS – Moderate Resolution Imaging Spectroradiometer	Thirty-six channel imaging radiometer (0.7 μm to 14.3 μm) with 250-m, 500-m, or 1-km resolution and 2,300-km swath width.
AM-1	MOPITT – Measurement of Pollution in the Troposphere	Eight-channel cross track scanning gas correlation radiometer operating at three wavelengths (2.2, 2.3, and 4.7 μm).

(10 -100 km) for global change research. It has taken computational advances, lowering of data cost, relaxation of data access restrictions, and proactive data set generation efforts (such as the Pathfinder programs of NOAA and NASA) to enable the research community to effectively use global, remotely sensed data sets. In the next decade, the EOS data sets and interdisciplinary investigations will advance the state-of-the-art use of global Earth observation data to high to moderate resolution data sets (100 - 1000 m). These data sets present an unprecedented opportunity and challenge for the Earth science community.

The data sets for global change research that are being produced from the TRMM and AM-1 instruments have been selected by NASA through peer review. Investigators developing these data sets may be part of instrument teams or interdisciplinary science investigation teams.

The unprecedented science goals and volumes of these data sets drive several critical issues for the EOSDIS and its ground segment which will produce, archive, and distribute the data. The issues of producing and distributing these data sets fall into two basic categories: science and engineering. In the years prior to the launch of the first EOS instruments, there will be continual refinement, improvement, and even compromise in both these areas. The science issues are being addressed in part through the development of ATBDs and the computation and engineering issues of data set production, archive and distribution are being addressed by the EOSDIS developers.

ATBDs

Efforts defining the data sets' theoretical basis and science algorithms are taking place among the instrument and investigator teams under the coordinating direction of the EOS Senior Project Scientist. Each EOS instrument team for the AM-1 and TRMM (LIS, CERES) platform has presented for peer review an ATBD which provides detailed descriptions of the data set science algorithm. These documents include

- Overview and Technical Background;
- Science Rationale;
- Algorithm Theoretical Description;
  - Physics of the Problem
  - Mathematical Description
  - Uncertainty & Errors
- Practical Considerations;
  - Science Software Considerations
  - Calibration and Validation
  - Quality Control
  - Data Dependencies
  - Product Definition; and
- Implementation Schedule (pre- and post-launch).

Much of the information in this Reference Handbook comes from the ATBDs. In the years prior to launch, these and subsequent documents will describe improvements and refinements to the science algorithms. ATBDs are available over the Internet at the following address:

http://eospso.gsfc.nasa.gov/atbd/pg1.html.

EOSDIS

Critical to the generation and distribution of the EOS data sets is the EOSDIS. The EOSDIS provides traditional flight operations, mission support, and data processing roles for EOS spacecraft and instruments and provides archiving and distribution services for EOS data and a variety of global change and Earth observation data.

The EOSDIS is taking advantage of recent advances in computational hardware, systems engineering, and national and international networking capabilities to implement a system of unprecedented capacity, user service, and openness.

Federated Approach to EOSDIS

The scope and role of EOSDIS and the EOSDIS DAACs is under evaluation at the time of this document's development. A National Research Council (NRC) review recommended a federated, fully competed EOSDIS. The MTPE program has formed a tiger team to prepare NASA's response to the NRC recommendation. The team is led by Dr. Dixon Butler and includes members from NASA Headquarters, Goddard Space Flight Center, other U.S. agencies, and the Earth Science research community. The team is currently finalizing the process for NASA's response.

EOSDIS DAACs

Key elements of EOSDIS are the DAACs, the facilities responsible for producing, archiving and distributing the data sets. The EOSDIS links these archives through high speed networks and an open architecture to integrate and provide data services to the research community. "Open Architecture" means that the user community will be able to access the system directly through their own customized interfaces as well as through standard data access interfaces.

There are currently seven DAACs representing a wide range of Earth science disciplines, with an eighth DAAC acting as a link between the EOS Program and the socioeconomic and educational user community. The geographic distribution of the DAACs is illustrated in Figure 1. Table 4 provides access information for the nine DAACs. These institutions are custodians of EOS mission data, and ensure that data will be easily accessible to users. Acting in concert, DAACs provide reliable, robust services to users whose needs may cross traditional discipline boundaries, while continuing to support the particular needs of their respective discipline communities. DAAC assignments were based primarily on the current distribution of scientific

Background

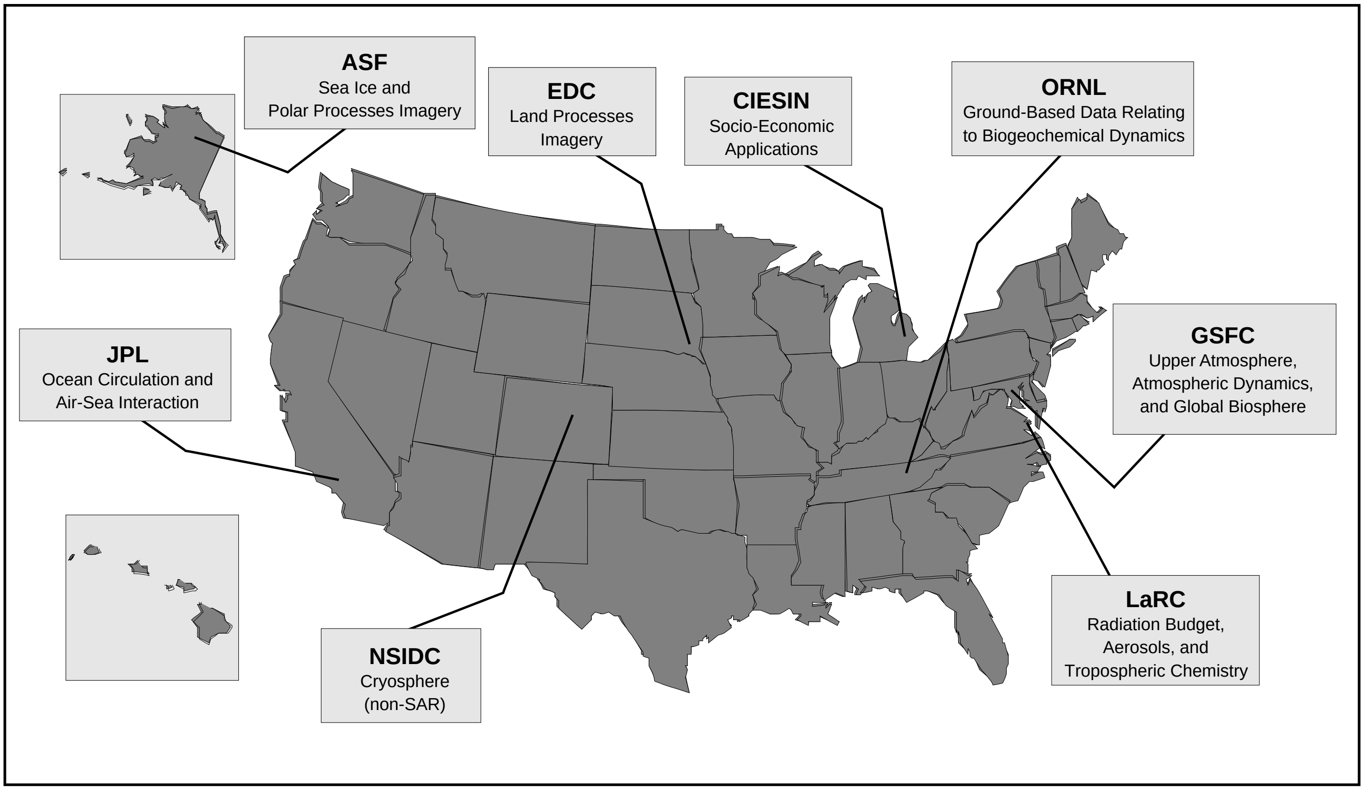

Figure 1. **Geographic Distribution of EOSDIS DAACs.**

expertise, institutional heritage, and capability. Each DAAC has a working group of users to provide recommendations on priorities for scientific data, levels of service and the needed capabilities. The DAACs actively participate in the design, implementation, and operation of EOSDIS.

The EOSDIS online data ordering service provides information and ordering of data and documentation at the DAACs using a menu-driven interface. The service is open to the public with access to restricted data by authorization. The ordering service is graphical and text-based and allows users to identify, browse, and then select data by time and location, geophysical parameter, and processing level. The service is accessible through a guest account via the Internet or dial-in phone line. Access information for online and user support services for each of the DAACs is listed in Table 4.

Data Set Distribution

The EOS data policy is to provide data to the global research community with few restrictions and at no cost or at most no more than the marginal cost of filling an order. Details of the EOS data policy can be found in the *1995 MTPE/EOS Reference Handbook*. EOS data are not copyrighted; however, it is requested that all researchers who publish data or results using EOS data sets include the following acknowledgment:

Data used in this research include data produced through the funding of NASA's Mission to Planet Earth (MTPE) Earth Observing System (EOS) Program.

In addition, for publications using EOSDIS-provided data the following acknowledgment should be used:

Data used in this research include data provided to the authors by the NASA-funded EOS Data and Information System archive at [insert name of archive center providing data].

Table 4. Access Information for the EOSDIS Distributed Active Archive Centers

Alaska SAR Facility (ASF)	**DAAC Mission:** Sea ice and polar processes **Home Page URL:** http://www.asf.alaska.edu **EOSDIS VO IMS:** telnet eosims.asf.alaska.edu 12345 **User Services Address:** P.O. Box 757320, University of Alaska, Fairbanks, AK 99775-7320 **Voice:** (907) 474-6166 **Fax:** (907) 474-5195 **E-mail:** asf@eos.nasa.gov
EROS Data Center (EDC)	**DAAC Mission:** Land processes **Home Page URL:** http://edcwww.cr.usgs.gov/landdaac/landdaac.html **EOSDIS VO IMS:** telnet eosims.cr.usgs.gov 12345 **User Services Address:** EROS Data Center, Sioux Falls, SD 57198 **Voice:** (605) 594-6116 **Fax:** (605) 594-6963 **E-mail:** edc@eos.nasa.gov
Goddard Space Flight Center (GSFC)	**DAAC Mission:** Upper atmosphere, atmospheric dynamics, global biosphere and geophysics **Home Page URL:** http://daac.gsfc.nasa.gov **EOSDIS VO IMS:** telnet eosims.gsfc.nasa.gov 12345 **User Services Address:** NASA/GSFC, Code 902.2, Greenbelt, MD 20771 **Voice:** (301) 286-3209 **Fax:** (301) 286-0268 **E-mail:** gsfc@eos.nasa.gov
Jet Propulsion Laboratory for Physical Oceanography DAAC (PO.DAAC)	**DAAC Mission:** Ocean circulation and air-sea interactions **Home Page URL:** http://podaac-www.jpl.nasa.gov **EOSDIS VO IMS:** telnet eosims.jpl.nasa.gov 12345 **User Services Address:** PO.DAAC JPL, MS 300-320, 4800 Oak Grove Dr., Pasadena, CA 91109 **Voice:** (818) 354-9890 **Fax:** (818) 393-2718 **E-mail:** jpl@eos.nasa.gov
Langley Research Center (LaRC)	**DAAC Mission:** Radiation budget, aerosols, and tropospheric chemistry **Home Page URL:** http://eosdis.larc.nasa.gov **EOSDIS VO IMS:** telnet eosims.larc.nasa.gov 12345 **User Services Address:** LaRC DAAC, MS 157D, NASA/LaRC, Hampton, VA 23681-0001 **Voice:** (804) 864-8656 **Fax:** (804) 864-8807 **E-mail:** larc@eos.nasa.gov
National Snow and Ice Data Center (NSIDC)	**DAAC Mission:** Cryosphere **Home Page URL:** http://www-nsidc.colorado.edu/NASA/GUIDE **EOSDIS VO IMS:** telnet eosims.colorado.edu 123454 **User Services Address:** NSIDC, University of Colorado, Boulder, CO 80309-0449 **Voice:** (303) 492-6199 **Fax:** (303) 492-2468 **E-mail:** nsidc@eos.nasa.gov

Table 4. Access Information for the EOSDIS Distributed Active Archive Centers (Continued)

Oak Ridge National Laboratory (ORNL)	**DAAC Mission:** Biogeochemical processes **Home Page URL:** http://www-eosdis.ornl.gov **EOSDIS VO IMS:** telnet eosims.ornl.gov 12345 **User Services Address:** ORNL DAAC, P.O. Box 20008, MS 6497, Bldg. 1507, ORNL, Oak Ridge, TN 37831-6407 **Voice:** (615) 241-3952 **Fax:** (615) 574-4665 **E-mail:** ornl@eos.nasa.gov
Socioeconomic Data and Applications Center (SEDAC)	**DAAC Mission:** Socio-economic data **Home Page URL:** http://www.ciesin.org **User Services Address:** CIESIN/SEDAC, 2250 Pierce Road, University Center, MI 48710 **Voice:** (517) 797-2727 **Fax:** (517) 797-2622 **E-mail:** sedac@eos.nasa.gov

Reproducibility & Longevity

Since global change studies require access to Earth observation data over decades, one of the key directives of the EOSDIS is that all data archived and distributed will be sufficiently documented such that researchers looking at data 10 or 20 years after the launch of the spacecraft will be able to understand and read the data. Related to this is the principle that all software, documentation, ancillary data, etc. be available to users so that any data set will be reproducible by anyone in the research community. In addition to ensuring easy and open access, this will aid in the scientific peer review and validation process.

References

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Chapter Three

Instrument Data Processing Overview

Instrument Data Processing Overview

The EOS system is designed to foster interdisciplinary use of Earth science data sets in ways that have been previously impossible. The science strategy identified early for MTPE was to group instruments to exploit their capabilities for synergism in surface imaging and in determining related properties of the atmosphere. Cross-calibration of the instruments and validation of their resulting data products will further enhance this synergism. Through EOSDIS, efforts to provide better data utilization include standardization of formats and media, consistency in standards and processing, and a platform of standard analysis tools to support investigation of the data.

Within the full EOS instrument suite, sets of instruments complement one another to produce desired observations. In some instances, certain instrument suites must generate correlative data; therefore, they must make their measurements simultaneously. For example, measurement of ocean circulation requires global altimeter data, precise orbit determination, and water vapor amounts. These observations also contain signals resulting from ocean tide deformation, atmospheric pressure and ocean surface interactions, and sea-level change, including long-term average sea level as well as interannual hemispherical variations. Such sets of observations dictate some minimum payload groupings.

The EOS science program will combine the measurements from the assembled suite of instruments, using some instruments to refine the measurements of others or to provide data products derived from more than one instrument. This strategy permits the extraction of parameters that a single instrument cannot measure reliably. This flow of data, the product of one data set used as input to another, is critical to understanding the complex interrelationships of the Earth's system. Global and regional data assimilation models that function as part of EOSDIS will use the observations from the EOS platforms to provide continuous calculations of the principal fluxes between components.

All EOS instruments have their own primary characteristics, and all fit together to complement each other. For example, compared with Moderate Resolution Imaging Spectroradiometer (MODIS), Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) has higher spatial resolution, but lower average duty cycle (8 percent day, 16 percent night). The Multi-Angle Imaging Spectroradiometer (MISR) is similar to MODIS in the 250-m bands. MODIS data can be used for atmospheric correction for ASTER and cloud screening for Clouds and the Earth's Radiant Energy System (CERES). Similarly, there are synergies between MISR and MODIS in characterizing aerosols over oceans. ASTER with its pointing, stereo mapping, and multi-spectral thermal infrared (IR) radiometer, will provide synergism with MODIS and MISR, and will acquire essential data for the study of volcanoes and surface climate. ASTER will also provide simultaneous multispectral, high-resolution detail to support global mapping of surface vegetation by MODIS and MISR. Simultaneous data from ASTER are essential to understand the subpixel variability of MODIS and MISR data.

The synergy provided by EOS instruments may be used to obtain and apply atmospheric corrections to allow quantitative, rather than qualitative, remote sensing science (such atmospheric attenuation and cloud-screening corrections are applicable to multiple sensors, MODIS cloud cover for CERES and MOPITT, MODIS total-water vapor for ASTER). Also, they may be used to validate data product algorithms and maintain instrument calibrations over a 15-year period, leading to support of a broad range of interdisciplinary investigations describing the Earth's carbon, energy, and water cycles, and our impact on them.

References:

Earth Observing System: Science and Mission Requirements Working Group Report.

Hobish, M.K., *et al.*, 1994.

Acknowledgments

The instrument descriptions for the TRMM instruments were provided by the TRMM science team. All other instrument summaries were adapted from the 1995 MTPE/EOS Reference Guide.

Instrument Data Processing Overview

TRMM

Tropical Rainfall Measuring Mission

TRMM is a small Earth probe designed specifically to monitor rainfall and its associated latent heating in the tropics. The vertical structure of latent heating is particularly important because the atmosphere gets three-fourths of its heat energy from the release of latent heat in the process of precipitation. The location at which this energy is released affects the weather around the world. Despite its fundamental importance to global climate, today the total rainfall in the tropics is not known to within a factor of two and the latent heating can only be estimated imprecisely. Although the sensors on TRMM have utility beyond the primary rainfall parameters, only those products which were critically relevant to monitoring rainfall and its vertical structure have been retained so as not to overwhelm the data system.

Figure 2 shows how the various sensors and algorithms will interact in order to provide the best rain products. The algorithms are coded by the "team" which has the responsibility to develop products. As an example, the passive microwave (TMI) team has responsibility for generating code to produce TMI calibrated brightness temperatures (1B-11), TMI rainfall structure products (2A-12) and TMI monthly surface rainfall maps (3A-11). This type of in-team algorithm development can be seen for each of the three instrument teams.

The in-team processing has a prominent role in the data processing scheme because of its long heritage. The key to TRMM's success, however, is the combined algorithms. These are divided into "Combined" which refers to algorithms applicable to TRMM measurements, and "TRMM & Other Sensors" which refers to algorithms that take the best answer from TRMM and use it to calibrate other available data in order to reduce the sampling bias. The lack of heritage with these products makes these less certain than the in-team algorithms at the onset of the mission.

The TRMM mission recognizes that in the past new sensors have led to significant improvements in interpretation of remotely sensed data and quality of products. To ensure that any improvements in the products are quickly passed on to the research community, TRMM will reprocess data annually if better algorithms become available. To provide the stable long time series of products needed for Earth system research, TRMM will always reprocess data beginning the first day of data availability.

Additionally, the TRMM mission employs a concerted validation effort consisting of 10 ground-based radar sites which will supply high-quality rainfall information throughout the lifetime of the TRMM mission. Because of the importance of these data and their usefulness independent of the satellite, these products are considered part of the TRMM mission and are processed and archived in the same fashion as the satellite data. A flow diagram of these products and how they interact is shown in Figure 3. All ground-based radar products are generated by the TRMM Ground Validation Team using identical methodologies at each of the sites.

To date, the TRMM mission has plans and agreements to generate rainfall products from the following sites: Southern Florida (4 NEXRAD radars), Australia (Darwin), Southeastern Texas (4 NEXRAD sites), Hawaii, Kwajalein Atoll, Taiwan, Thailand (Chiang Mai), Brazil (São Paolo), Guam, and Israel (Jerusalem). TRMM will consider additional radars subject to the approval of the TRMM Project Scientists, the TRMM office (responsible for the implementation of the validation plan) and the TRMM Ground Validation Team (responsible for the scientific integrity of the validation data).

Instrument Data Processing Overview

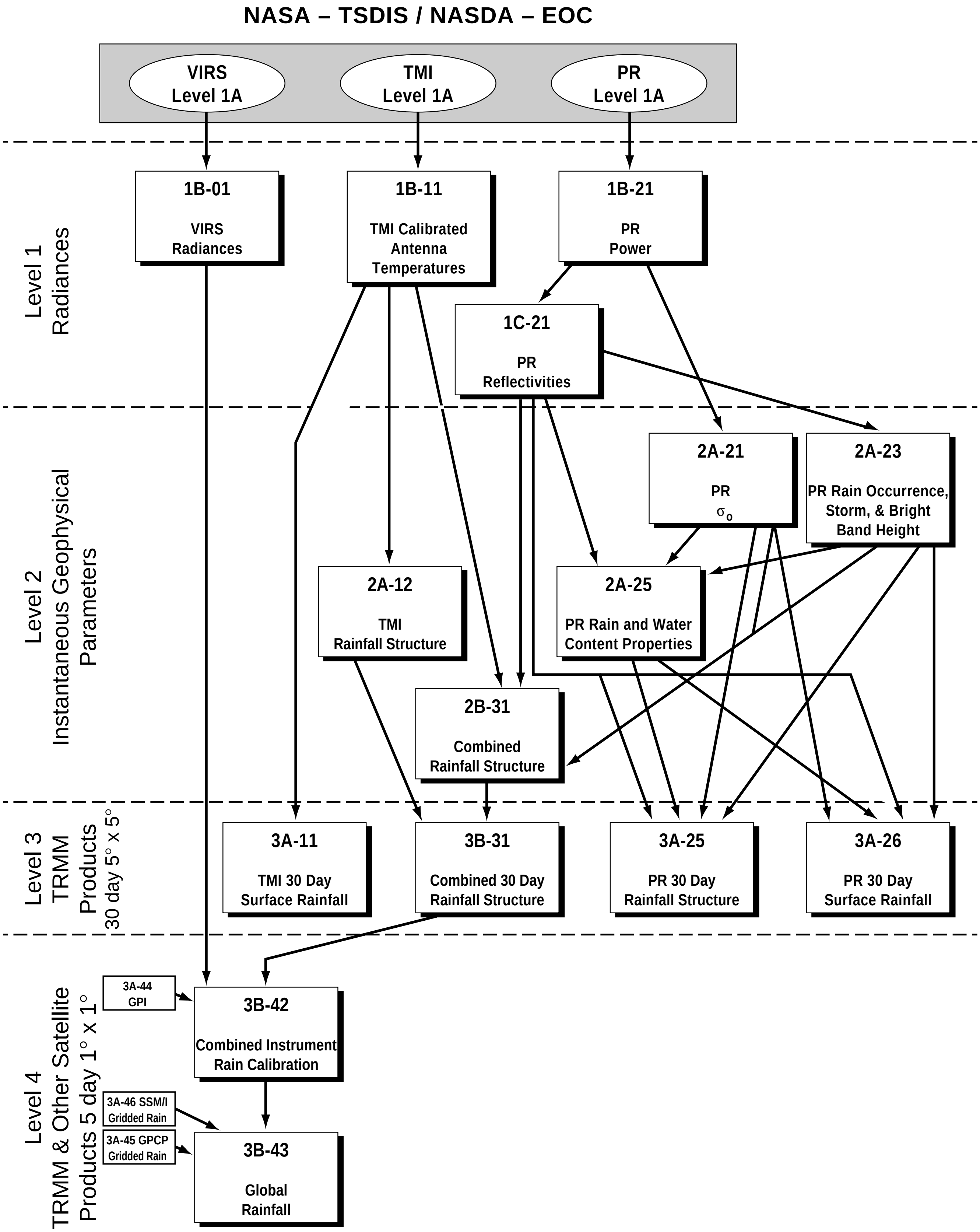


Figure 2. **TRMM Instrument Algorithms and Products.**

Instrument Data Processing Overview

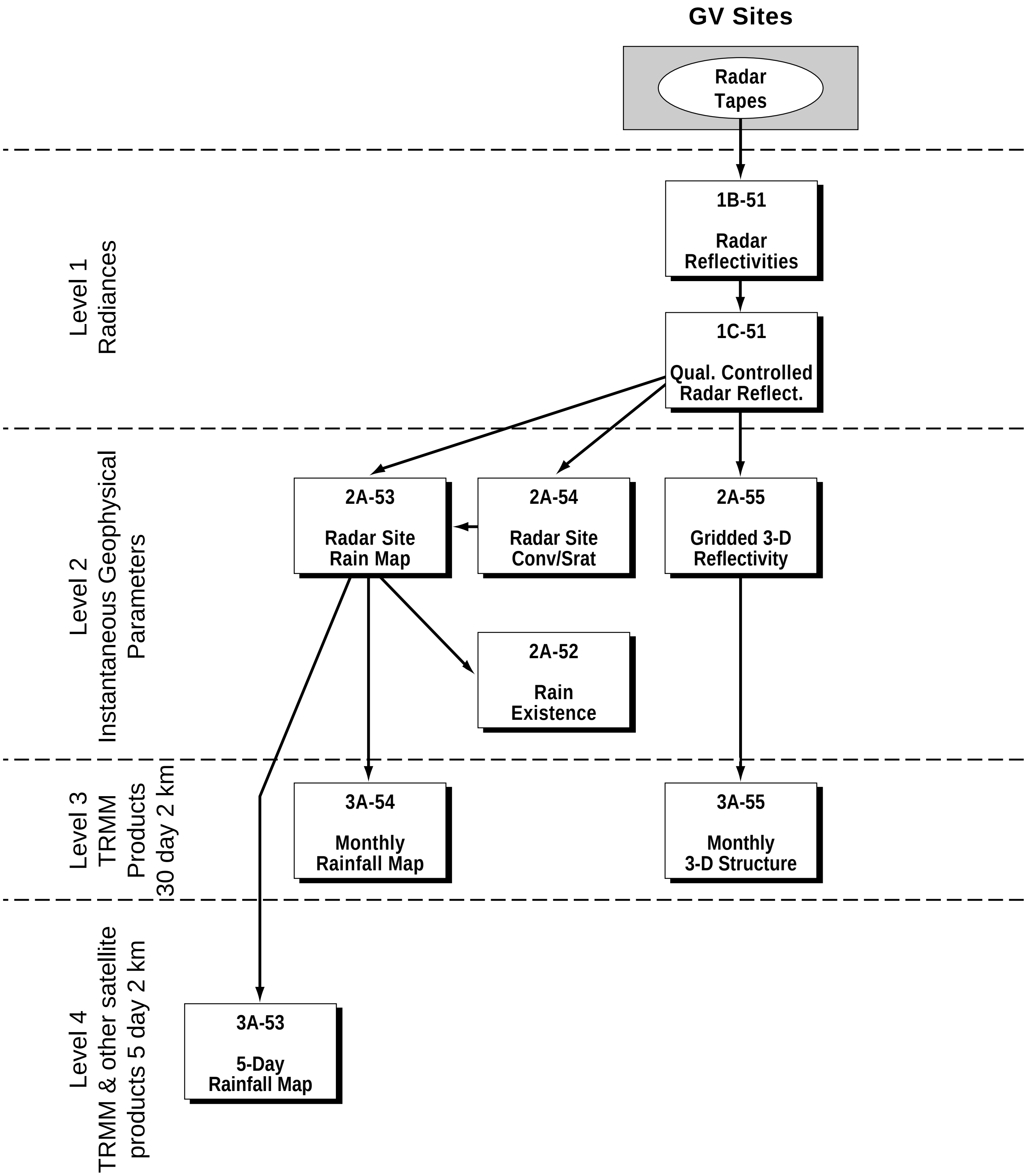


Figure 3. **Flow Diagram Showing Interaction of TRMM Ground-Based Radar Validation Products.**

Instrument Data Processing Overview

LIS

Lightning Imaging Sensor

The calibrated optical LIS will investigate the global incidence of lightning, its correlation with rainfall, and its relationship with the global electric circuit. Conceptually, LIS is a simple device, consisting of a staring imager optimized to locate both intracloud and cloud-to-ground lightning with storm-scale resolution over a large region of the Earth's surface, to mark the time of occurrence, and to measure the radiant energy. It will monitor individual storms within the field-of-view (FOV) for 80 seconds, long enough to estimate the flashing rate of many storms. Location of lightning flashes will be determined to within 5 km over a 600 × 600-km FOV.

The LIS design uses an expanded-optics wide-FOV lens combined with a narrow-band interference filter that focuses the image on a small, high-speed, charge-coupled-device focal plane. The signal is read out from the focal plane into a real-time data processor for event detection and data compression. The particular characteristics of the sensor design result from the requirement to detect weak lightning signals during the day when the background illumination, produced by sunlight reflecting from the tops of clouds, is much brighter than the illumination produced by the lightning.

A combination of four methods is used to take advantage of the significant differences in the temporal, spatial, and spectral characteristics between the lightning signal and the background noise. First, spatial filtering is used to match the instantaneous FOV of each detector element in the LIS focal-plane array to the typical cloud-top area illuminated by a lightning event (about 5 km). Second, spectral filtering is applied, using a narrow-band interference filter centered about the strong singly ionized oxygen emission line (OI [1]) multiplet in the lightning spectrum at 777.4 nm. Third, temporal filtering is applied.

The lightning pulse duration is of the order of 400 µsec, whereas the background illumination tends to be constant on a time scale of seconds. The lightning signal-to-noise ratio improves as the integration time approaches the pulse duration. Accordingly, an integration time of 2 msec is chosen to minimize pulse splitting between successive frames and to maximize lightning detectability. Finally, a modified frame-to-frame background subtraction is used to remove the slowly varying background signal from the raw data coming off the LIS focal plane. If after background removal the signal for a given pixel exceeds a specified threshold, that pixel is considered to contain a lightning event.

LIS investigations will increase further understanding of processes related to, and underlying, lightning phenomena in the Earth/atmosphere system. These processes include the amount, distribution, and structure of deep convection on a global scale, and the coupling between atmospheric dynamics and energetics as related to the global distribution of lightning activity. The investigations will contribute to several important EOS mission objectives, including cloud characterization and hydrologic cycle studies. Lightning activity is closely coupled to storm convection, dynamics, and microphysics, and can be correlated to the global rates, amounts, and distribution of precipitation, to the release and transport of latent heat, and to the chemical cycles of carbon, sulfur, and nitrogen. LIS standard products will be locations, times of occurrence, and intensities of lightning events.

Key LIS Facts

- EOS-funded instrument selected for flight on TRMM-1
- Staring telescope/filter imaging system that detects the rate, location, and radiant energy of lightning flashes
- Investigates the distribution and variability of lightning over the Earth with storm scale spatial resolution
- 90 percent detection efficiency under both day and night conditions using background remover and event processor
- LIS Home Pages:
  http://www.ghcc.msfc.nasa.gov/lightning/
  http://wwwghcc.msfc.nasa.gov/lisotd.html#lis

Instrument Data Processing Overview

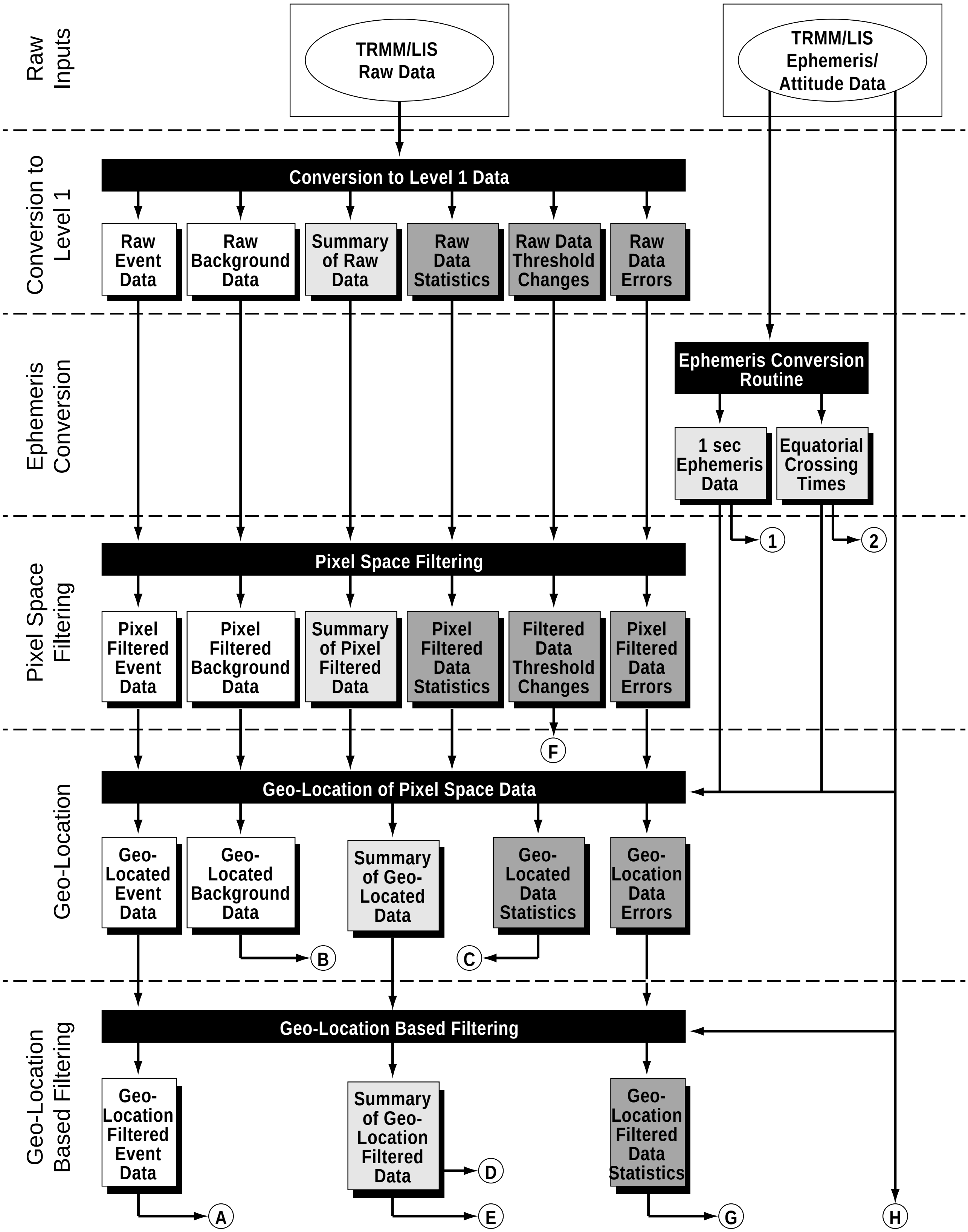


Figure 4. **LIS Data Flow.**

Instrument Data Processing Overview

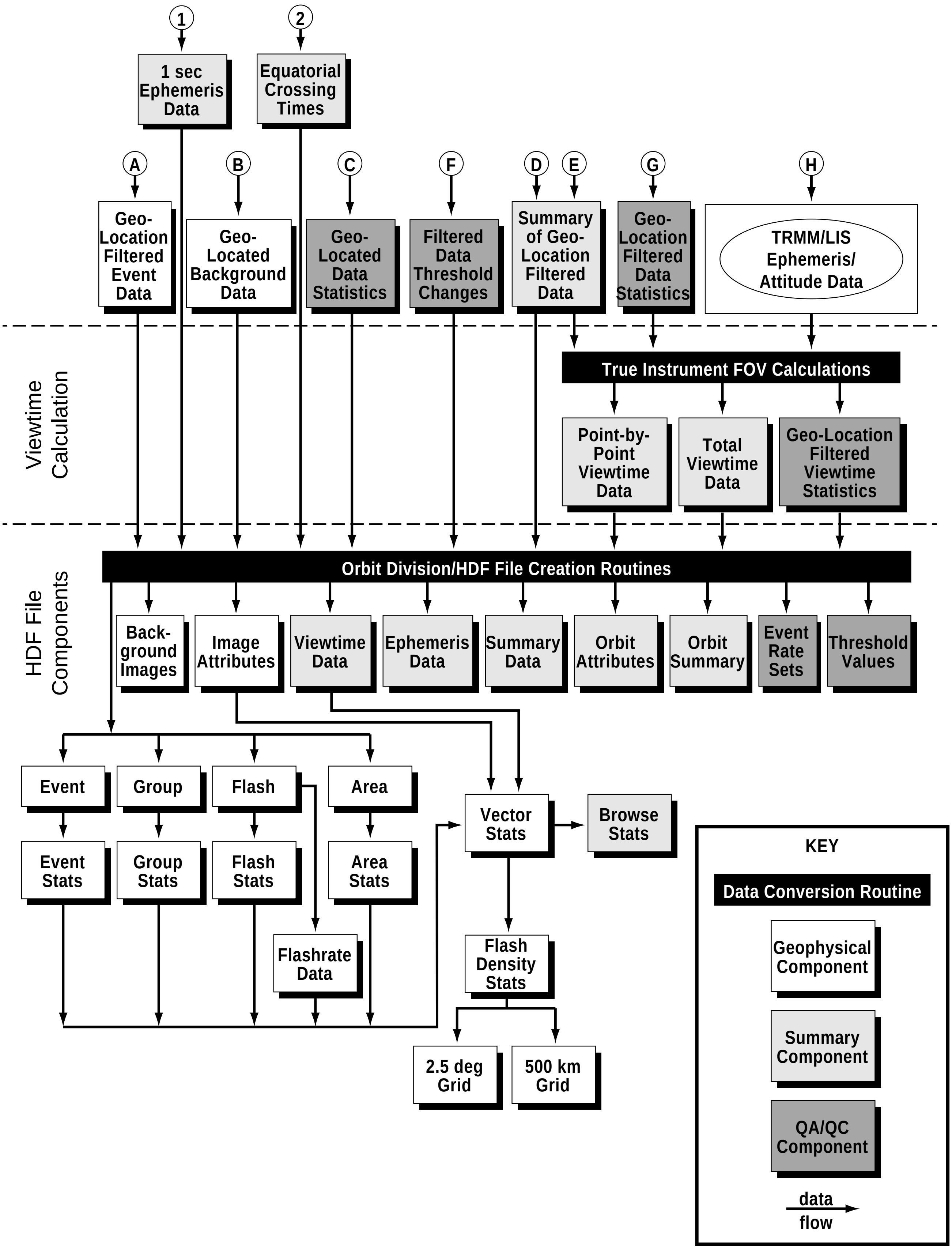


Figure 4. **LIS Data Flow (Continued).**

Instrument Data Processing Overview

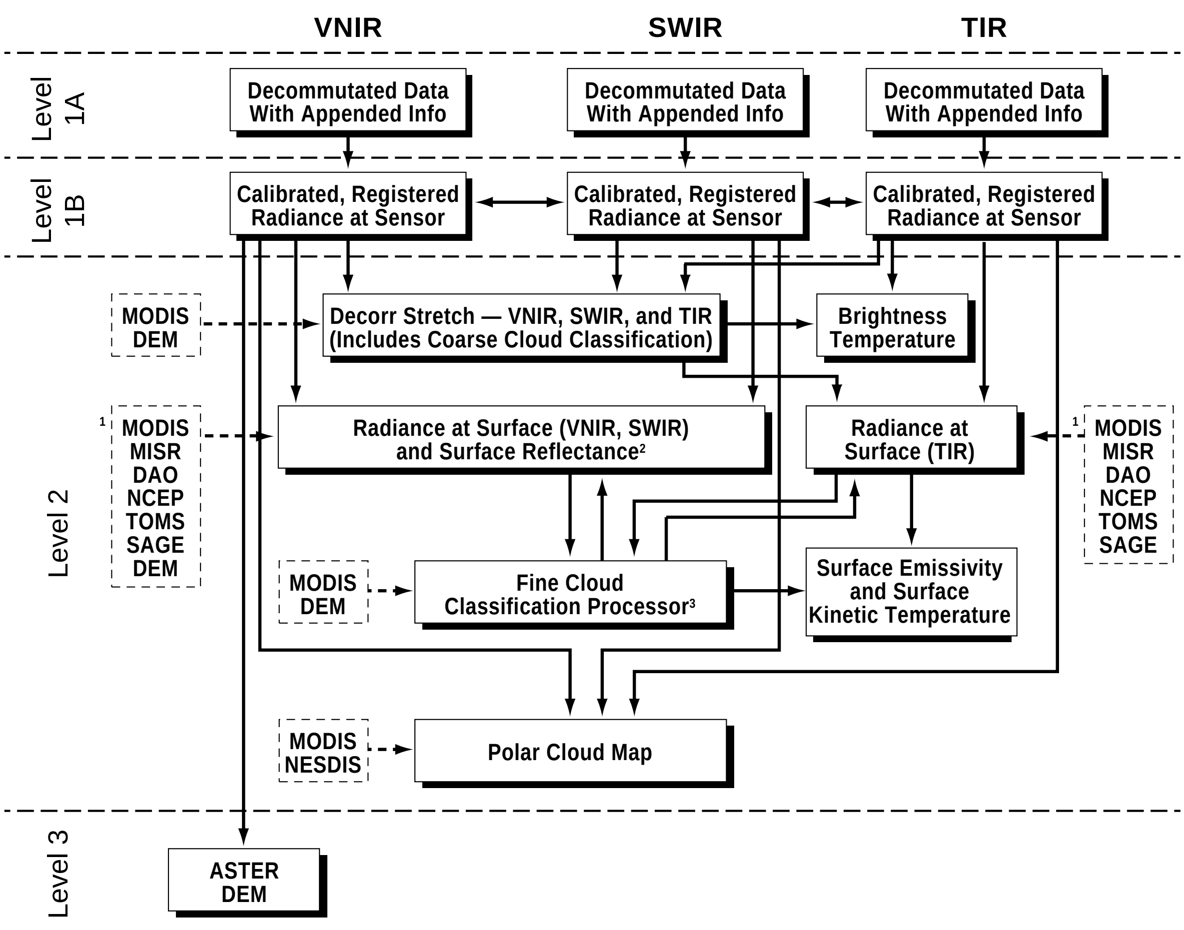
ASTER

Advanced Spaceborne Thermal Emission and Reflection Radiometer

ASTER is a facility instrument provided for the EOS AM-1 platform by the Japanese Ministry of International Trade and Industry (MITI). It will provide high spatial resolution (15-to-90 m) multispectral images of the Earth's surface and clouds in order to better understand the physical processes that affect climate change. ASTER will provide data at a scale that can be directly related to detailed physical processes. These data will bridge the gap between field observations and data acquired by coarse spatial resolution instruments such as MODIS and MISR, and between local-process models and regional models.

Key ASTER Facts

- Selected for flight on EOS AM-1
- Heritage: MESSR and OPS
- Imaging radiometer
- Provides high-resolution images of the land surface, water, ice and clouds
- Earth-orbit stereo capability
- 14 multispectral bands from visible through thermal infrared
- ASTER Home Page: http://asterweb.jpl.nasa.gov



[1]This list contains a variety of alternate input sources, used when the primary input source is not available; [2]Computed simultaneously with Radiance at Surface; [3]Produces a cloud mask that is incorporated into other products.

Figure 5. **ASTER Data Product Architecture.**

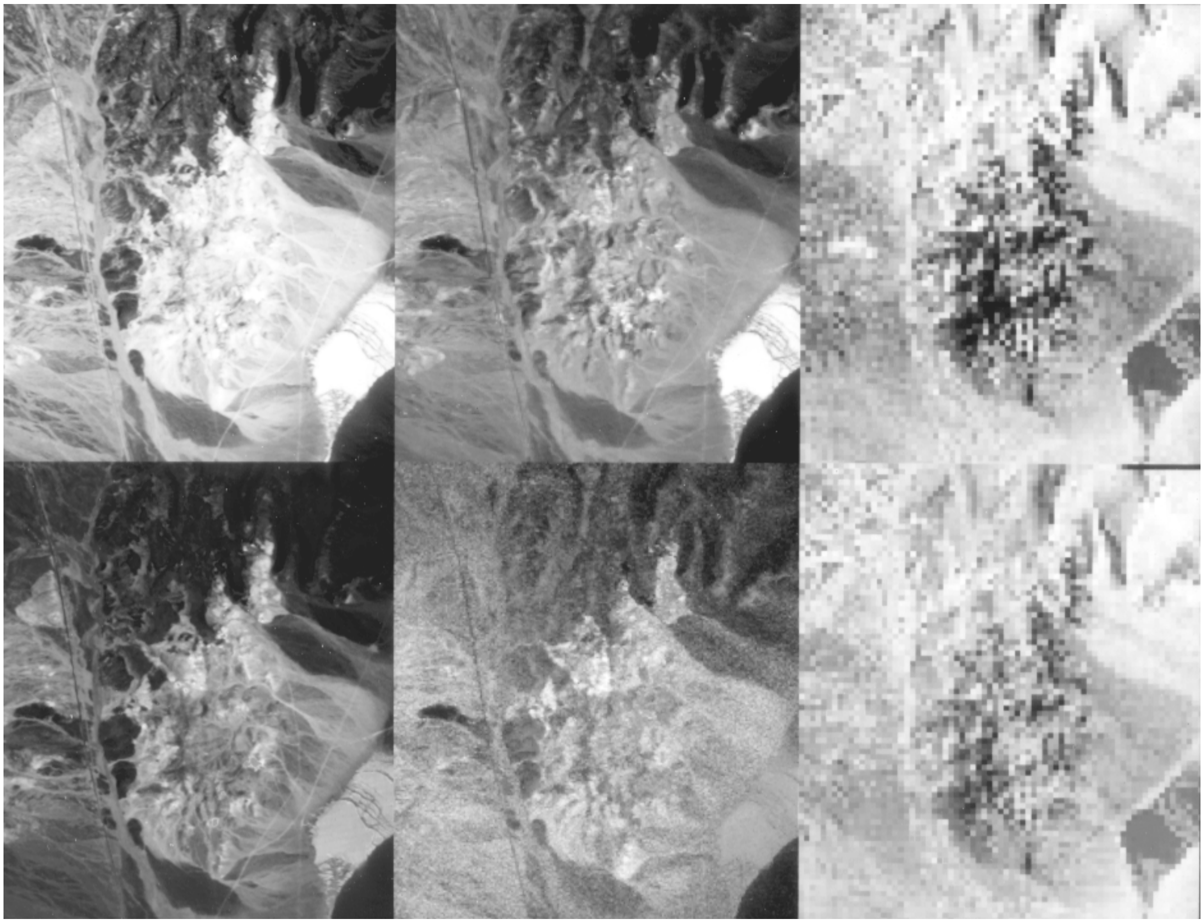


Figure 6. **Simulated ASTER images of Cuprite, Nevada.** Linearly (2%) stretched (top row) and decorrelation stretched (bottom row) color composites of image data. The left images, with 15 m pixel size, display VNIR bands 3, 2, and 1 in red, green and blue, respectively; the center images, with 30 m pixel size, display SWIR bands 4, 6, and 9 in RGB; and the right images, with 90 m pixel size, display TIR bands 13, 12, and 10 in RGB. The simulated data set was created by coregistering airborne AVIRIS and TIMS data, then combining channels to produce the ASTER band passes. The 3x5 km area (full ASTER scenes will be approximately 60x60 km) exposes a range of unaltered and hydrothermall altered volcanic rocks, alluvial fans derived from these rocks, and a dry lake bed. The VIR data highlight the presence and oxidation state of iron-bearing minerals; the SWIR data separate cla-bearing and hydrous minerals; and the TIR data show differences due to silica content. By combining information from the three wavelength regions, ASTER data allow a detailed and accurate geologic and alteration map to pe produced.

Clouds are one of the most important variables in the global climate system. With its high spatial-resolution, broad spectral coverage, and stereo capability, ASTER will provide essential measurements of cloud amount, type, spatial distribution, morphology, and radiative properties. climate and/or forecast models. ASTER data will also be used for long-term monitoring of local and regional changes on the Earth’s surface, which either lead to or are in response to global climate change (e.g., land use, deforestation, desertification, lake and playa water level changes) and other changes in vegetation communities, glacial movement, and volcanic processes.

ASTER will provide radiative (brightness) temperature, and the multispectral thermal infrared (TIR) data can be used to derive surface kinetic temperature and spectral emissivity. Radiative temperature is an element in the surface heat balance. Surface kinetic temperature can be used to determine elements of surface process models, sensible heat flux, latent heat flux, and ground heat conduction. Surface temperatures are also related to thermophysical properties (such as thermal inertia), vegetation health, soil moisture, temporal land classification (e.g., wet vs. dry, vegetated vs. bare soil) and evapotranspiration.

ASTER will operate in three visible and near-infrared (VNIR) channels between 0.52 and 0.86 µm, with 15-m resolution; six shortwave infrared (SWIR) channels between 1.60 and 2.43 µm, with 30-m resolution; and five TIR channels between 8.13 and 11.65 µm, with 90-m resolution. The instrument will acquire data over a 60-km swath whose center is pointable (cross-track ± 8.55° in the SWIR and TIR, with the VNIR pointable out to ± 24°). An additional VNIR telescope (aft pointing) covers the wavelength range of Channel 3. By combining these data with those for Channel 3, stereo views can be created, with a base-to-height ratio of 0.6. ASTER's pointing capabilities will be such that any point on the globe will be accessible at least once every 16 days in all 14 bands and once every 5 days in the three VNIR channels.

ASTER data products will exploit combinations of VNIR, SWIR, and TIR for cloud studies, surface mapping, soil and geologic studies, volcano monitoring, and for surface temperature, emissivity, and reflectivity determination. VNIR and SWIR bands will be used for investigation of land use patterns and vegetation, VNIR and TIR combinations for the study of coral reefs and glaciers, and VNIR for digital elevation models (DEMs). TIR channels will be used for study of evapotranspiration, and land and ocean temperature. The stereoscopic capability will yield local topography, cloud structure, volcanic plumes, and glacial changes.

Instrument Data Processing Overview

CERES

Clouds and the Earth's Radiant Energy System

The U.S. Global Change Research Program classifies the role of clouds and radiation as its highest scientific priority (CEES, 1994). There are many excellent summaries of the scientific issues (IPCC, 1992; Hansen, *et al.*, 1993; Ramanathan, *et al.*, 1989; Randall, *et al.*, 1989, Wielicki, *et al.*, 1995) concerning the role of clouds and radiation in the climate system. These issues naturally lead to a requirement for improved global observations of both radiative fluxes and cloud physical properties. The CERES Science Team, in conjunction with the EOS Investigators Working Group representing a wide range of scientific disciplines from oceans, to land processes, to atmosphere, has examined these issues and proposed an observational system with the following objectives:

1. For climate change analysis, provide a continuation of the ERBE record of radiative fluxes at the top of the atmosphere (TOA), analyzed using the same algorithms that produced the existing ERBE data.
2. Double the accuracy of estimates of radiative fluxes at TOA and the Earth's surface.
3. Provide the first long-term global estimates of the radiative fluxes within the Earth's atmosphere.
4. Provide cloud property estimates which are consistent with the radiative fluxes from surface to top of the atmosphere.

To accomplish these goals, the CERES data products are divided into three major categories as shown in Figure 7:

ERBE-Like Products	Top Row
CERES TOA/Surface Products	Middle Row
CERES TOA/Surface/Atmosphere	Bottom Row

The ERBE-Like products address the first objective of long-term continuity of the ERBE TOA fluxes. The TOA/Surface Products address the second objective and attempt to provide the most direct tie between surface radiative flux estimates and TOA flux measurements. The TOA/Surface/Atmosphere products focus on the last two objectives and attempt to derive an internally consistent set of atmosphere, cloud, and surface to TOA radiative fluxes, all within the context of a state of the art radiative transfer model. In this last case, the observed TOA fluxes are used as a direct constraint on the model calculations

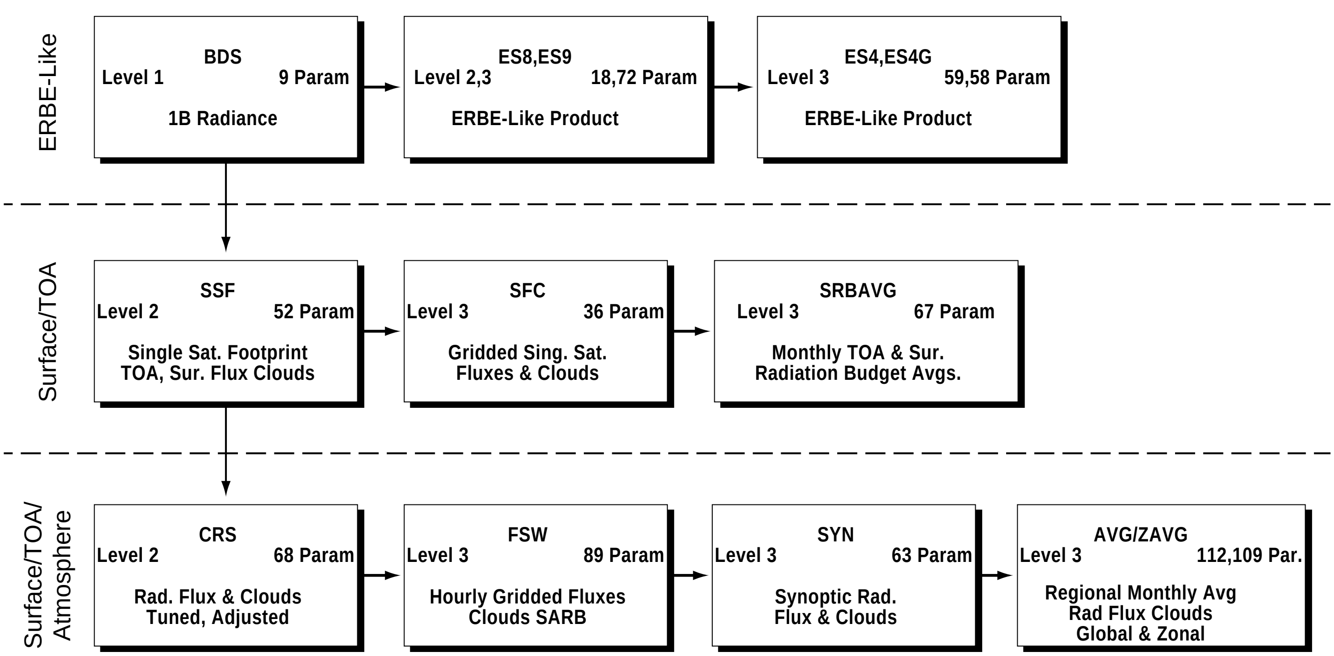


Figure 7. **CERES Data Flow.**

in order to implicitly account for non-plane parallel and other poorly modeled atmospheric radiative effects. As in ERBE, CERES radiative fluxes will be separately determined for both clear and cloudy sky conditions.

One of the major advances of CERES over ERBE is the availability of high spatial and spectral resolution cloud imagers for cloud masking, cloud height, and cloud optical property determination (i.e. VIRS on TRMM, MODIS on EOS AM/PM). A second major advance is the use of one CERES scanner in a crosstrack mode (global spatial coverage) and a second scanner in a rotating azimuth plane mode (complete angular sampling of viewing zenith and azimuth). The rotating azimuth plane scanner will be combined with nearly simultaneous cloud imager data to develop a new set of improved empirical models of the SW and LW anisotropy of radiation as a function of surface and cloud type. While it is estimated to take 2 years of this data to develop new angular models, they are expected to reduce instantaneous TOA flux errors by a factor of 3 from the ERBE levels.

Detailed listing of the CERES data products and their individual parameters can be found in the CERES Data Products Catalog (http://asd-www.larc.nasa.gov/DPC/DPC.html). Documentation of the Release 1 CERES analysis algorithms can be found in the CERES Algorithm Theoretical Basis Documents (ATBDs) Volumes 0 through 12, where each volume covers one of the CERES Data Products and its associated technical algorithms (http://eospso.gsfc.nasa.gov/atbd/cerestables.html). A summary of the CERES experiment can be found in Wielicki, *et al.*, Bulletin of the American Meteorological Society, May, 1996.

Suggested Reading:

Barkstrom, 1984.

Hansen, *et al.*, 1993.

IPPC, 1992.

Ramanathan, *et al.*, 1989.

Wielicki, *et al.*, 1995.

Key CERES Facts

- Selected for flight on TRMM, EOS AM, and EOS PM series
- Heritage: ERBE
- Two broadband, scanning radiometers: One cross-track mode, one rotating plane (bi-axial scanning)
- Measures Earth's radiation budget and atmospheric radiation from the top of the atmosphere to the surface
- First instrument (cross-track scanning) will essentially continue the ERBE mission; the second (biaxially scanning) will provide angular radiance information that will improve the accuracy of angular models used to derive the Earth's radiative balance
- Single scanner on TRMM mission (1997)
- Dual scanners on EOS AM-1 (1998), PM-1 (2000), and single thereafter
- CERES Home Page: http://asd-www.larc.nasa.gov/ceres/docs.html

Instrument Data Processing Overview

MISR

Multi-Angle Imaging Spectroradiometer

MISR will routinely provide multiple angle continuous sunlight coverage of the Earth with high spatial resolution. The instrument will obtain multi-directional observations of each scene within a time scale of minutes, essentially under virtually the same atmospheric conditions. MISR uses nine individual charge-coupled device (CCD)-based pushbroom cameras to observe the Earth at nine discrete view angles: one at nadir, plus eight other symmetrical views at 26.1, 45.6, 60.0 and 70.5° forward and aftward of nadir. Images at each angle will be obtained in four spectral bands centered at 443, 555, 670, and 865 nm. Each of the 36 instrument data channels (four spectral bands × nine cameras) is individually commandable to provide ground sampling of 275 m, 550 m, or 1.1 km.

The swath width of the MISR imaging data is 360 km, providing global multi-angle coverage of the entire Earth in nine days at the equator, and two days at the poles.

The instrument design and calibration strategies have the goal of maintaining absolute radiometric uncertainty to less than ± 3 percent over bright surfaces and ± 6 percent over dark surfaces, with smaller uncertainties in relative band-to-band and angle-to-angle radiances. These objectives will be met through the use of state-of-the-art detector-based calibration, using an on-board calibrator on a monthly basis; the calibrator consists of deployable solar diffuser panels and an array of radiation-resistant and high-quantum-efficiency diodes. Semiannual field calibration exercises are planned to provide a ground-truth verification of the diode performance.

MISR images will be acquired in two observing modes: global and local. Global mode provides continuous planet-wide observations, with most channels operating at moderate resolution and selected channels operating at the highest resolution for cloud screening and classification, image navigation, and stereo-photogrammetry. Local mode provides data at the highest resolution in all spectral bands and all cameras for selected 360 km × 300 km regions. In addition to data products providing radiometrically calibrated and geo-rectified images, global mode data will be used to generate two standard Level 2 science products during ground data processing: the Top-of-Atmosphere (TOA)/Cloud Product and the Aerosol/Surface Product.

Key MISR Facts

- Selected for flight on EOS AM series
- Heritage: Galileo, Wide-Field/Planetary Camera
- Provides top-of-atmosphere, cloud, and surface angular reflectance functions
- Provides global maps of planetary and surface albedo and of aerosol and vegetation properties
- MISR Home Page: http://www-misr.jpl.nasa.gov/

The purpose of the TOA/Cloud Product is to enable study, on a global basis, of the effects of different types of cloud fields (classified by their heterogeneity and altitude) on the solar radiance and irradiance reflected to space, and to determine their effects on Earth's climate. Additionally, this product provides a cloud screen for MISR aerosol and surface retrievals.

The aerosol parameters contained with the Aerosol/Surface Product will enable study, on a global basis, of the magnitude and natural variability in space and time of sunlight absorption and scattering by aerosols in the Earth's atmosphere, particularly in the troposphere. In addition, these parameters will help to determine the aerosols' effects on climate; to improve our knowledge of the sources, sinks, and global budgets of natural and anthropogenic aerosols; and to provide atmospheric correction inputs for surface imaging data acquired by MISR and other instruments (e.g., MODIS and ASTER) that are simultaneously viewing the same position of the Earth. The surface parameters within the Aerosol/Surface Product are designed to enable improved measure of land surface radiative characteristics, particularly bidirectional and hemispherical reflectances, on a global basis; to provide, in conjunction with MODIS, improved measures of land surface classification, dynamics, canopy photosynthesis, transpiration rates over vegetated terrain; and to supplement MODIS studies of the biogeochemical cycle in the tropics by providing atmospherically-corrected ocean color data.

The DPH describes three ancillary products (MIS 10, MIS 11, and MIS 12) that are produced at the MISR Science Computing Facility (SCF) and used in the generation of other MISR products. These products are available from the DAAC as aids in interpreting MISR data.

Instrument Data Processing Overview

MODIS

Moderate Resolution Imaging Spectroradiometer

MODIS is an EOS facility instrument designed to measure biological and physical processes on a global basis every 1 to 2 days. Slated for both the EOS AM and PM satellite series, the instrument will provide long-term observations from which to derive an enhanced knowledge of global dynamics and processes occurring on the surface of the Earth and in the lower atmosphere. This multidisciplinary instrument will yield simultaneous, congruent observations of high-priority atmospheric (cloud cover and associated properties), oceanic (sea surface temperature and chlorophyll), and land surface features (land cover changes, land surface temperature, and vegetation properties). The instrument is expected to make major contributions to understanding of the global Earth system, including interactions between land, ocean, and atmospheric processes.

The MODIS instrument employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror and collecting optics, and a set of linear detector arrays with spectral interference filters located in four focal planes. The optical arrangement will provide imagery in 36 discrete bands from 0.4 to 14.5 µm selected for diagnostic significance in Earth science. The spectral bands will have spatial resolutions of 250 m, 500 m, or 1 km at nadir; signal-to-noise ratios of greater than 500 at 1-km resolution (at a solar zenith angle of 70°); and absolute irradiance accuracies of ± 5 percent from 0.4 to 3 µm (2 percent relative to the Sun) and 1 percent or better in the thermal infrared (3 to 14.5 µm). MODIS instruments will provide daylight reflection and day/night emission spectral imaging of any point on the Earth at least every two days, operating continuously.

MODIS will provide specific global data products, which include the following:

- Surface temperature with 1-km resolution, day and night, with absolute accuracy of 0.2 K for oceans and 1K for land;
- Ocean color, defined as ocean-leaving spectral radiance within 5 percent from 415 to 653 nm, enabled by atmospheric correction from near-infrared sensor channels;
- Chlorophyll fluorescence within 50 percent at surface water concentrations of 0.5 mgm^{-3};
- Concentrations of chlorophyll *a* within 35%;
- Vegetation/land surface cover, conditions, and productivity
  - Net primary productivity, leaf area index, and intercepted photosynthetically active radiation
  - Land cover type, with change detection and identification
  - Vegetation indices corrected for atmosphere, soil, and directional effects;
- Snow cover and sea ice cover;
- Land surface reflectance (atmospherically corrected) with bidirectional reflectance and albedo;
- Cloud cover with 250-m resolution by day and 1,000-m resolution at night;
- Cloud properties characterized by cloud droplet phase, optical thickness, droplet size, cloud-top pressure, and emissivity;
- Aerosol properties defined as optical thickness, particle size, and mass transport;
- Fire occurrence, size, and temperature;
- Global distribution of precipitable water; and
- Cirrus cloud cover.

Key MODIS Facts

- Selected for flight on EOS AM and PM series
- Heritage: AVHRR, HIRS, Landsat TM and NIMBUS-7, and CZCS
- Medium-resolution, multi-spectral, cross-track scanning radiometer
- Measures biological and physical processes
- MODIS Home Page: http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html

Instrument Data Processing Overview

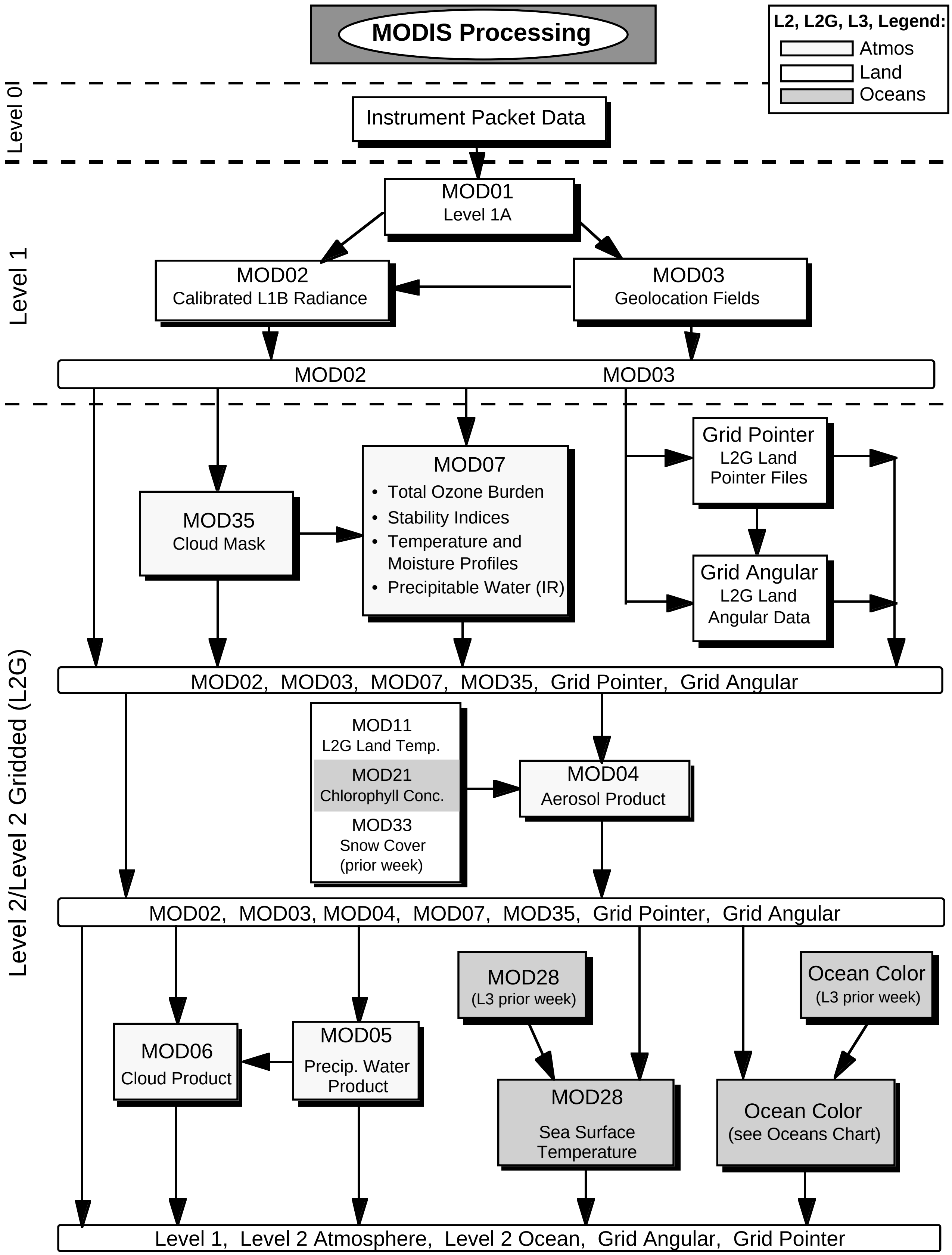


Figure 8. **Flow Diagram Showing Interrelationship of MODIS Atmosphere, Land, and Ocean Products.**

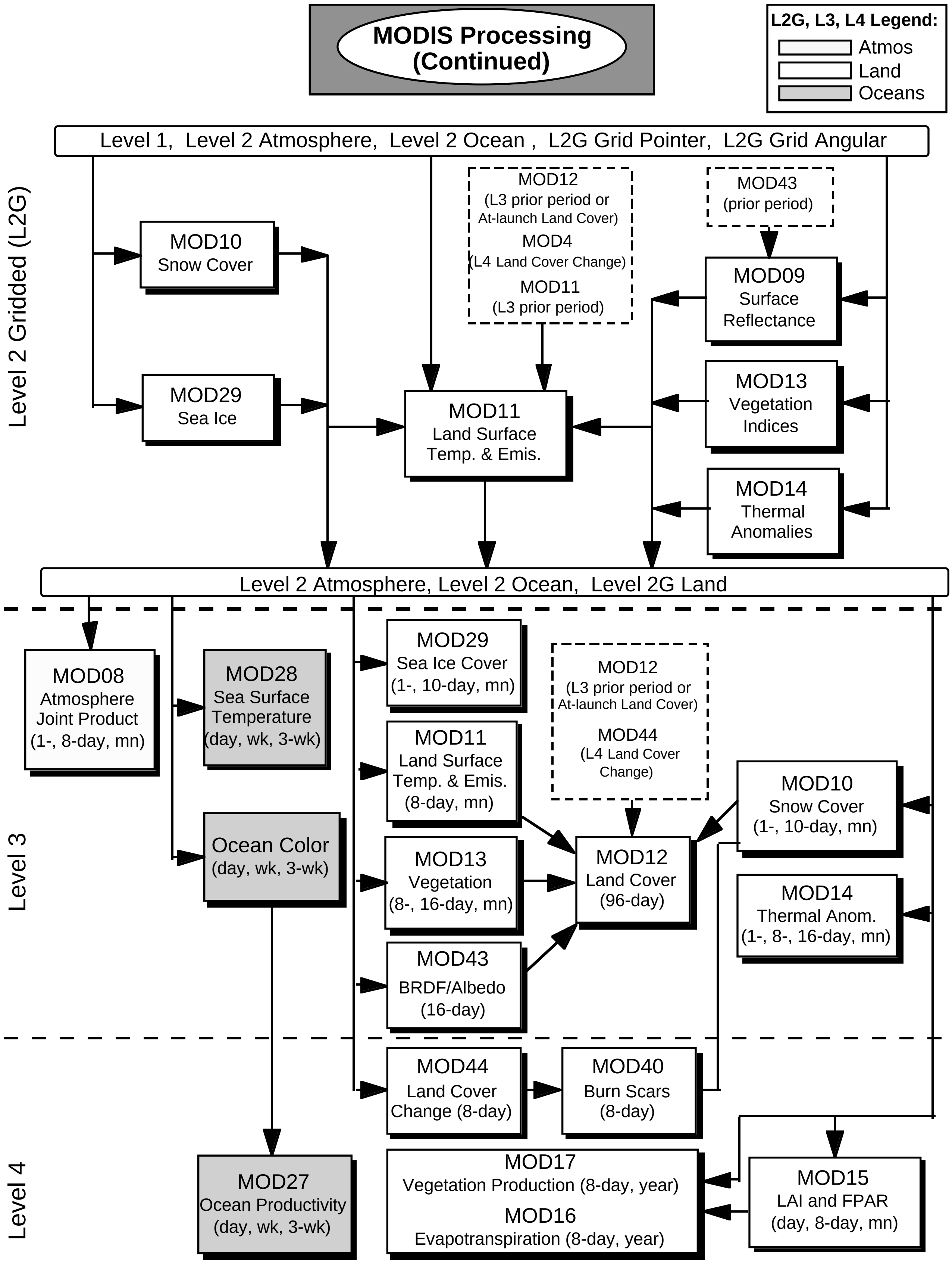


Figure 8. **Flow Diagram Showing Interrelationship of MODIS Atmosphere, Land, and Ocean Products (Continued).**

Instrument Data Processing Overview

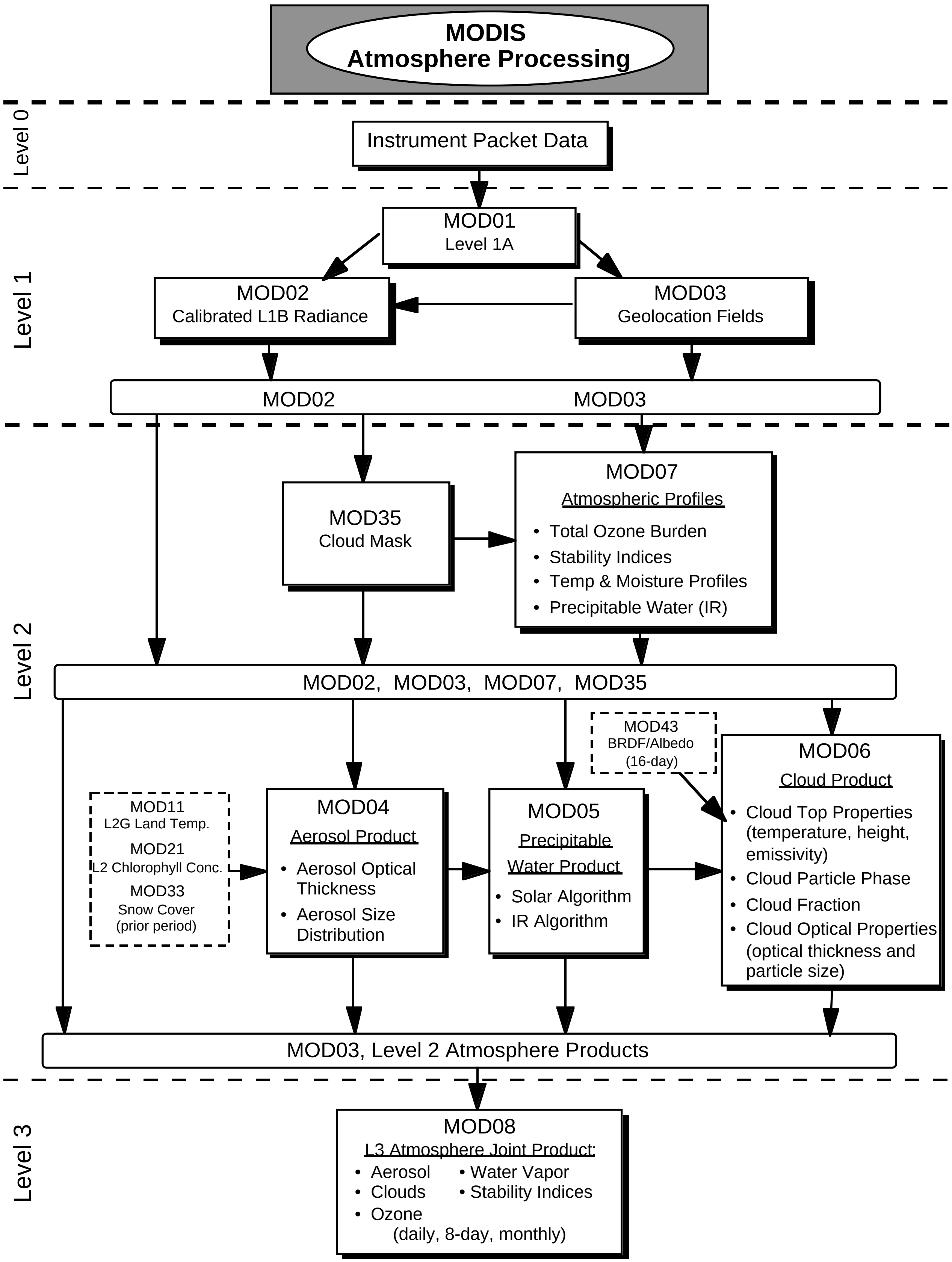


Figure 9. **Flow Diagram Showing Interrelationship of MODIS Atmosphere Products.**

Instrument Data Processing Overview

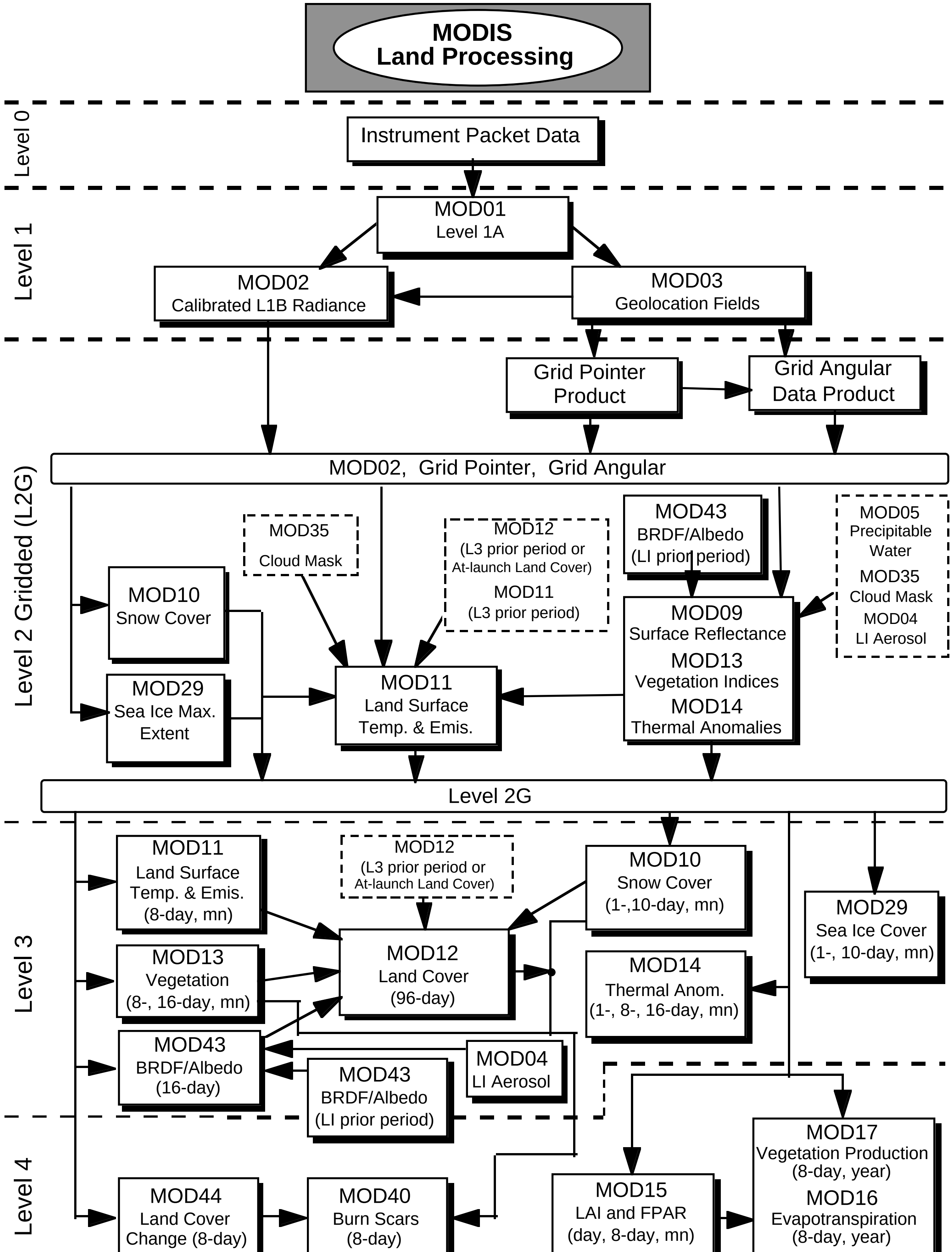


Figure 10. **Flow Diagram Showing Interrelationship of MODIS Land Products.**

Instrument Data Processing Overview

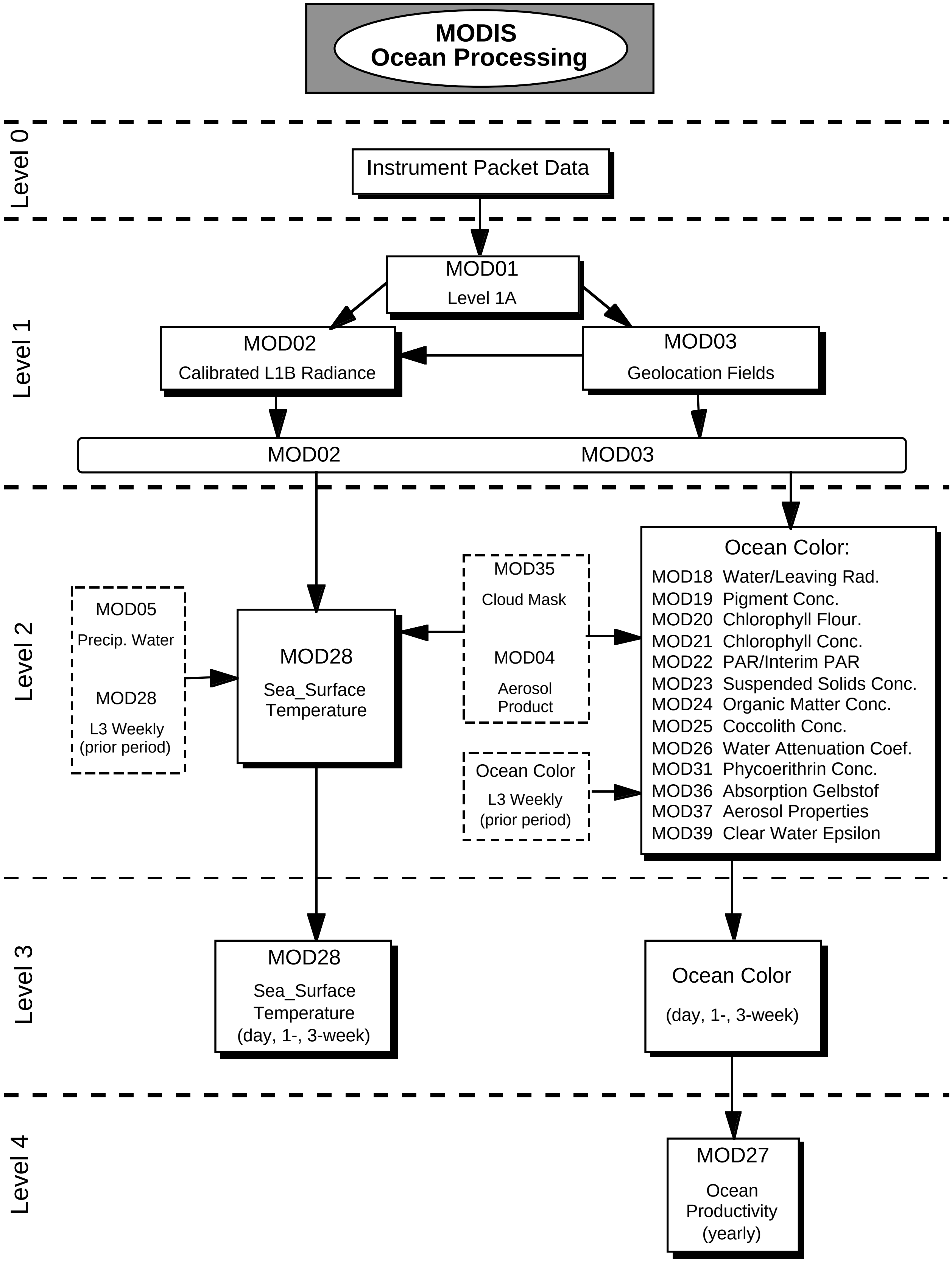


Figure 11. **Flow Diagram Showing Interrelationship of MODIS Ocean Products.**

Instrument Data Processing Overview

MOPITT

Measurements of Pollution in the Troposphere

The MOPITT experiment is provided under a Memorandum of Understanding with the Canadian Space Agency (CSA). MOPITT will measure thermal emission in the 4.6-µm band of carbon monoxide (CO) and reflected solar radiation in the 2.3-µm band of CO and 2.2-µm band of methane (CH_4). Tropospheric CO profile and total columns CO and CH_4, will be derived from those measurements in the retrieval process.

Key MOPITT Facts

- Selected for flight on EOS AM-1
- Heritage: Pressure-modulated cell elements used in the PMR, SAMS, and ISAMS instruments, using similar correlation spectroscopy techniques
- Eight-channel correlation radiometer with cross-track scanning
- Canadian Space Agency to provide the instrument
- MOPITT Home Page: http://eos.acd.ucar.edu/mopitt/home.html

CO is one of the most important trace species in tropospheric chemistry. The full range of the effects of the increased/decreased concentration of CO is not fully understood at the present time, but it is known that CO is photochemically active and plays a major part in the concentration of hydroxyl (OH) radicals in the troposphere. Increased CO may deplete tropospheric OH radicals, thereby reducing the yearly removal of many natural and anthropogenic trace species. In particular, this effect may add to the increase of CH_4, which in turn could further reduce OH concentration. Increased CO may also indirectly intensify global warming and perturb the stratospheric ozone layer by increasing the lifetime of trace gases such as CH_4, methyl chloride (CH_3Cl), and chlorofluorocarbons (CFCs). CH_4 is also a very effective greenhouse gas, and the change of its concentration due to human activities will impact global climate change. Measurements of CO and CH_4 will enhance our knowledge of the chemistry of the troposphere, and particularly how it interacts with the surface/ocean/biomass systems, atmospheric transports, and the carbon cycle.

MOPITT operates on the principle of correlation spectroscopy, a non-dispersive spectroscopy technique. It uses the target gas itself contained in a gas cell as the filter to achieve high spectral resolution as well as high signal to noise. Both pressure modulation cells (PMC) and length modulation cells (LMC) are used in MOPITT. By cycling the amount of gas in the absorption cell between two states (low and high pressure in the case of the PMC, and long and short path in the case of the LMC), the detector will be alternately looking through two different filters that exactly correlate with the target gas spectra. The difference of the two signals will be identical to the output of a system in which the gas cell and its modulator are replaced by an optical filter with non-zero transmission only at the spectral line positions of the target gas (CO and CH_4 for MOPITT). Therefore, the difference signal is most sensitive to the contributions by the target gas and is not sensitive to the contributions of other gases. The average of the two signals can also be obtained. It has the property that its transmittance is near unity away from the lines in the cell, but it reduces the signals at the centers of the lines. Thus, it is sensitive to other gases, and especially to the surface contribution to the upwelling radiation in the spectral regions of interest.

MOPITT is a cross-track scanning instrument which collects data with a scan line of four adjacent 22-km square pixels at nadir and at 14 “stare” positions on either side of nadir. The pixels are arranged in the along-track direction. The stare positions are interleaved so as to produce nearly contiguous coverage in the cross-track and along-track directions. For each orbit, a swath ~ 640 km wide is sampled. With the orbit planned for the for the AM-1 platform, this allows complete sampling of the Earth’s surface about every three days.

MOPITT Level 2 products include: (1) tropospheric CO profiles with a resolution of 22 km horizontally, 4 km vertically and with an accuracy of 10 percent throughout the troposphere; (2) total column of CO with a 10 percent accuracy and 22-km horizontal resolution; and (3) total column of CH_4 with a precision of 1 percent and horizontal resolution of 22 km. The column amounts of CO and CH_4 will only be available on the sunlit side of the orbit. Level 3 products to be developed postlaunch will include gridded three-dimensional global maps of CO, and global maps of CH_4 total column.

Instrument Data Processing Overview

The Data Assimilation Office

DAS Processing Overview

The Data Assimilation Office (DAO) develops research-quality 4-dimensional atmosphere-ocean-land data assimilation products for EOS. The data assimilation combines all available data into a dynamically consistent depiction of the Earth-atmosphere system, and has the unique ability to produce estimates of unobserved quantities.

Data assimilation approaches are used throughout science and engineering. Most simply, data assimilation is the use of a mathematical-physical model to analyze observations, while at the same time quantifying the shortcomings of the model formulation.

In Earth science, a data assimilation system is effectively an Earth-system model constrained by Earth-system observations. The data assimilation system (1) organizes the observations from many diverse instrument sources and measurement times into a single useful data product; (2) complements the observations by propagation of information from observed into unobserved regions and times; (3) provides estimates of expected values of the observations with which to assess data and instrument quality; (4) provides superior products for environmental assessment studies; and (5) supplements the observations by providing estimates of quantities that are difficult or impossible to observe.

Support for EOS Science Goals

The goals of the DAO during the EOS timeframe are to produce assimilation analyses to ensure that the maximum information is gained from the EOS and other observations, and to set the foundation for future Earth system models. Continual research into numerical and theoretical techniques and associated Earth science process studies will ensure that the developed system meets the needs of EOS. Analyzing historical and new data sets available in the pre-launch phase of EOS will serve as the basis to confront Earth system problems, and the successes and failures of these diagnostic and interpretive studies will define the evolution of the data assimilation system. The assimilated data produced in the pre-launch period will be made available to the broad science community to assure infusion of relevant diverse applications into the development process. A commitment is made to continued reanalysis of these data sets to minimize the impact of algorithm changes on interannual signals.

Current Activities

The investigation performs research into all aspects of 4-dimensional data assimilation, including satellite retrievals, data quality control, error propagation, objective analysis, and all component models of the Earth system. Data from satellites such as the Upper Atmosphere Research Satellite (UARS), TRMM, and Advanced Earth Observing System (ADEOS) will be used to assess the utility of new data types, such as wind and constituent data. Initial studies concentrate on meteorology, with an emphasis on the hydrological cycle and seasonal and interannual variability. Near-term development will emphasize land-surface and ocean-surface processes. A strong emphasis will also be placed on global transport processes and atmospheric chemistry.

For TRMM and AM-1 the Goddard EOS Data Assimilation System (GEOS DAS) will provide Level 4 products of land-surface and atmospheric quantities. The process works as follows:

Cycling. The GEOS DAS operates on a 6-hour cycle; it gathers observations in 6-hour blocks and uses them to correct the General Circulation Model's (GCM's) estimates for that same time period. Figure 5 shows a typical cycle.

First Guess. Each 6-hour cycle begins with a restart file from the previous cycle. Using this for its initial conditions, and boundary conditions from other sources (e.g., sea surface temperature, terrain elevation, etc.), the GCM integrates 3 hours into the future to produce the *first guess* (FG). (Note: The restart file is not permanently archived.)

Objective Analysis. *Observations* (EOS and non-EOS) are gathered for 6-hour intervals surrounding the valid time of the FG. For example, if the FG valid time is 06 Universal Time, Coordinated (UTC), then observations from 03 to 09 UTC are used. An objective analysis system compares these observations with the first guess and produces a set

Instrument Data Processing Overview

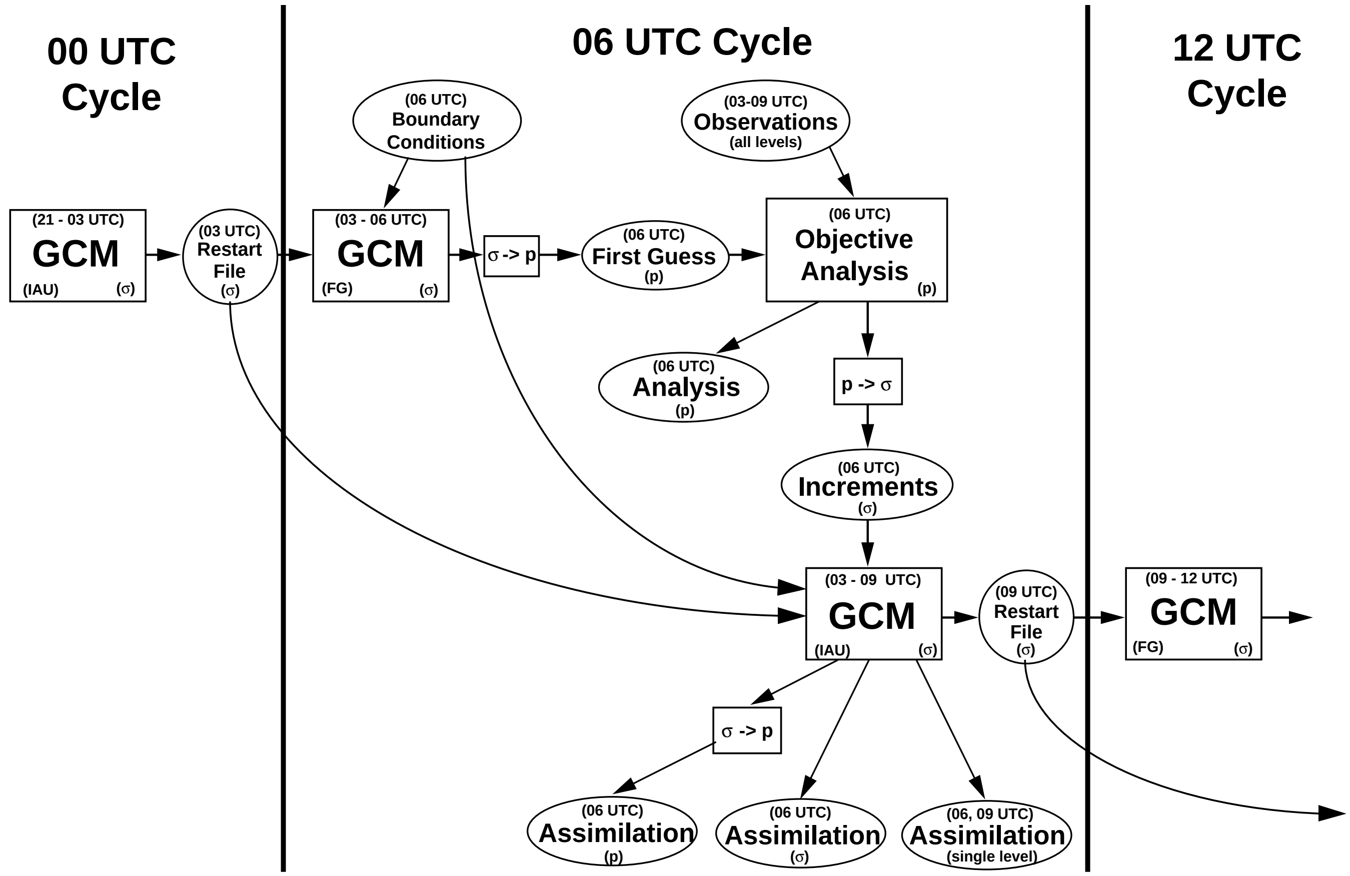


Figure 12. **Typical 6-hour cycle of the GEOS DAS.** Processes are rectangles and data files ovals. Times (UTC) are shown at the top of each process or data file. The vertical coordinate (pressure (p) or sigma (σ)) is shown at the bottom or lower right corner. In the lower left corner, the GCM integrations are identified as either an incremental analysis update (IAU) or first guess (FG). Vertical interpolation steps between sigma and pressure levels are shown in the small rectangles.

of gridded corrections. These corrections are called analysis *increments*. One assimilation technique is to apply these increments all at once to the FG producing the *analysis* in Figure 12.

IAU. The GEOS DAS uses another method called the incremental analysis update (IAU). Rather than putting the increments in all at once at 06 UTC, IAU goes back and reruns the GCM from 03 to 09 UTC, gradually inserting the analysis increments at each model time step. This has several benefits including the ability to produce *assimilations* at much higher temporal resolution. Thus, even though data are gathered in 6-hour blocks, each single-level product is provided every 3 hours through the IAU process. Multi-level (pressure and sigma) assimilations are still archived every 6 hours, but are based on the same IAU process. Furthermore, a first-look analysis (not shown in Figure 12) uses IAU to provide selected fields at very high temporal resolution (every few minutes) along the satellite subtrack for use by TRMM and AM-1 instrument retrievals. The same boundary conditions that went into the first guess are also used for the IAU.

Mandatory Pressure vs. Sigma Levels. The World Meteorological Organization (WMO) has established the following mandatory pressure levels:

1000 mb	250 mb	20 mb	
925 mb	200 mb	10 mb	.7 mb
850 mb	150 mb	7 mb	.5 mb
700 mb	100 mb	5 mb	.4 mb
500 mb	70 mb	3 mb	
400 mb	50 mb	2 mb	
300 mb	30 mb	1 mb	

The objective analysis is done at these mandatory pressure levels while the GCM operates on model sigma levels. The GCM sigma levels are based on the following formula

$$\sigma = (p - p_t) / (p_s - p_t),$$

where p is pressure of the sigma level, p_t is pressure at the top of the GCM, and p_S is surface pressure.

The GEOS DAS GCM uses approximately 70 sigma levels from the surface to .1 mb. Interpolation steps between sigma and pressure levels are indicated in Figure 12.

Continuing the Cycle. The next 6-hour segment begins by creating a new restart file at 09 UTC and then extending the GCM integration 3 more hours to 12 UTC. The FG integration is done without analysis increments.

DAS Products. The table of contents at the beginning of this document lists the GEOS DAS products for TRMM and AM-1. Since all of these fields are inherent to the GEOS DAS, the marginal cost of providing a given field is essentially limited to its storage cost. In fact, many other fields within the GEOS DAS are not archived.

Selecting a Product: The GEOS DAS provides the user with many product options. The *assimilations* on pressure surfaces are compatible with a wide variety of other data sets since they are on the WMO mandatory pressure levels. However, for the user who demands higher vertical resolution or wants to avoid the final sigma-to-pressure interpolation, the *assimilations* on sigma surfaces are the best choice. The *boundary conditions*, *observations*, and *increments* are available for users who want to delve deeper into the sources of the assimilated products. Finally, the *first guess* and *analysis* products are more for internal monitoring the GEOS DAS performance and are not recommended for detailed climatic studies.

Chapter Four

Radiance and Imagery Products

Radiance and Imagery Products

Relationship to Global Change

The instruments on TRMM and EOS AM-1 detect electromagnetic radiation in the visible, infrared, and microwave wavelengths. Each wavelength provides different information about the Earth-atmosphere system. Because there are dozens of geophysical parameters such as atmospheric composition, surface properties, and biological attributes, many independent wavelength measurements are required to monitor the Earth system. Radiances may be thought of as the intensity or brightness of the radiation. Accurate radiances are a fundamental and essential requirement for deriving correct values for all the higher level geophysical parameters that MTPE is monitoring. To ensure correct geophysical measurements are made, it is crucial to have well calibrated radiances within spectral bands of individual instruments, across instruments, and across platforms, all for time intervals from days to decades.

In addition to the radiances, there are a number of ancillary data products such as cloud cover, surface reflectivity and topography, aerosols, and scene type that are important input data sets in the derivation of other geophysical quantities. These ancillary data sets are used for data processing within a single instrument or are transferred from one instrument to another as part of their input data streams. For our purposes we can call these ancillary geophysical data sets “imagery products.” In addition, many of the land and ocean radiance products are grouped here. In this section, we review some of the radiance and imagery data products from nine satellite sensors on two satellite platforms and explain how the products support the overall global change program.

Product Overview

RADIANCES: Electromagnetic energy detected by satellites arises in the Earth-atmosphere system by one of four processes: 1) reflection of solar radiation off the land and oceans or from the atmosphere, 2) thermal infrared to microwave radiation by surface and atmosphere, 3) non-thermal emission of radiation, most prominently by lightning discharges, and 4) return of radiation emitted by the sensor (such as a radar). Detecting each of these processes requires a completely different instrument design. The first three techniques involve passive sensors which take advantage of electromagnetic radiation already present. The last technique uses active sensors that generate their own radiation and monitor the return signals from echoes off the surface and atmosphere. TRMM uses all four techniques. The EOS AM-1 platform concentrates on the first two methods with high spectral and spatial resolutions.

On the EOS AM-1 platform, radiances are derived using the MODIS, ASTER, MOPITT, CERES, and MISR sensors. The reflected solar and thermal spectrum is very sensitive to changes in water vapor, ozone, and aerosol concentrations, to surface reflectivity, emissivity, and temperature, and to cloud properties such as droplet size.

TRMM has five sensors: 1) the Precipitation Radar, 2) the Microwave Imager, 3) the Visible Infrared Scanner, 4) the CERES, and the LIS. Information on tropical precipitation, the radiation budget, and the Earth’s lightning climatology is an important goal for this satellite.

Imagery Data: In the List of Products, there are a number of geophysical parameters that can be classified as imagery products which are used as input in the derivation of higher level geophysical data products. These imagery products include masking type data such as cloud cover and scene type. They include intermediate type products such as water leaving radiances used in the derivation of oceanic biological activity and photosynthetically active radiation (PAR) used in biological studies. And they include geolocation data allowing comparisons between instruments of the same location or across time.

Input Data to Other Instruments: Radiance and imagery data from one instrument are often used as input for processing data on another instrument. For example, the ASTER calibration uses atmospheric absorbing and scattering properties derived from simultaneous MISR and MODIS observations made on the AM-1 platform. In part then, the calibration of the ASTER radiances may have a dependence on the MISR and MODIS radiances.

Radiance and Imagery Products

Product Interdependency and Continuity with Heritage Data

The radiance values are the first physical quantity derived from the raw instrument counts. The accuracy and self-consistency of the higher level geophysical products are dependent on the accuracy of the radiances and hence upon the calibration of the sensors. Image products from one instrument often influence the data processing paths used by other instruments. For example, CERES data processing uses MODIS scene classification input. The ASTER calibration may have a dependency upon the MODIS calibration. Topographic information such as MISR's digital elevation model (MIS 10) is used in the interpretation of satellite radiances. In addition, a rough topography will have a different reflectivity in different directions (referred to as the bi-directional reflectance distribution function or BRDF) than will a smooth topography. The topographic information is a required input for the interpretation of MISR and many other types of satellite observations.

The detection of changes in the Earth's environment requires accurate and self-consistent observations of physical phenomena over many years. The EOS and TRMM programs have placed much emphasis on making well-calibrated measurements. Calibrating the measurements over many years is complicated because many satellites are involved which may or may not have overlapping observations, the instruments themselves are changing (because of degradation, for example) and there are numerous wavelength bands from the visible to the microwave requiring different calibration methods.

Radiation flux and budget observations were started by the Earth Radiation Budget (ERB) and Earth Radiation Budget Experiment (ERBE) and will continue with the CERES instruments on TRMM and AM-1. Calibrated radiances from all these instruments are fundamentally important for the documentation of subtle changes in the Earth's radiation budget. ASTER advances the technology of imagers such as Landsat and France's Systeme pour l'Observation de la Terre (SPOT). MODIS provides improved spectral resolution compared to the Advanced Very High Resolution Radiometer (AVHRR), the Coastal Zone Color Scanner (CZCS), and earlier scanning spectroradiometers. MOPITT, MISR, and the TRMM instruments represent significant advances over their predecessors as well. A significant portion of these improvements can be directly attributed to the increased emphasis on calibration of all the sensors coming online in the EOS era.

Suggested Reading

Brest, C.L., and S.N. Goward, 1987.

Christian, H.J., *et al.*, 1989.

Gillaspie, A.R., *et al.*, 1986.

Goodman, A.H. and A. Henderson-Sellers, 1988.

Gordon, H.R., 1978.

Price, J.C., 1984.

Slater, P.N., *et al.*, 1987.

VIRS Calibrated Radiances

Product Description

This Level 1B data set contains calibrated radiances in mW/(cm^2 • µm • sr) from the 5 channels of the VIRS instrument. Geolocation, data quality, and solar and scan geometry information are appended to the 5 channels. Data are collected in day and night modes over land and ocean. While the Earth is in darkness, the instrument operates in night mode collecting data only from channels 3-5 (3.75, 10.80, and 12.00 µm). Radiometric calibration is performed using ground testing and in-flight data. In-flight calibration of channels 1 and 2 is via an onboard solar diffuser and occasional views of the moon. Channels 3-5 use an onboard blackbody and a space view to update calibration parameters before each scan line. Processing to compensate for undesirable sensor effects is performed, but the data is not geometrically corrected or resampled.

The VIRS instrument is similar to the AVHRR instrument and as such the radiance data may be used for a variety of atmospheric, terrestrial, and oceanographic research. This product is an input to TRMM 3B-42 which generates surface rainfall derived from geostationary satellites and calibrated by the data from the TRMM sensors.

VIRS 1B-01
PRODUCT SUMMARY

Coverage:
16 orbits of 720 km each precessing through diurnal cycle

Resolution:
2.11 km

Wavelengths:
0.63, 1.61, 3.75, 10.80, 12.00 µm

Product Type:
standard, at-launch

Science Team Contact:
W. Barnes

TMI Calibrated Brightness Temperatures

Product Description

This Level 1B data set contains calibrated brightness temperatures, in degrees Kelvin, from the high- and low-resolution TMI channels. Pixel geolocation, calibration and instrument pointing and location information are also included.

The TMI is similar to the SSM/I instrument flown on the DMSP satellites with two key differences: (1) the addition of vertically and horizontally polarized 10-GHz channels; and (2) the scan geometry is the same for every scan instead of alternating between an A scan and a B scan. The TMI Level 1B data format is similar to the SSM/I Wentz Antenna Temperature data, however some changes were made due to instrument characteristics and feedback from the investigator community.

Aside from the rainfall parameters derived as part of the TRMM mission, TMI data may also be used to derive sea surface wind speed, atmospheric water vapor content and cloud liquid water content over the ocean. Over land, passive microwave frequencies found on TMI can be useful for monitoring soil moisture and vegetation.

TMI 1B-11
PRODUCT SUMMARY

Coverage:
16 orbits of 760 km each precessing through diurnal cycle

Resolution:
4.6 - 37 km

Wavelengths:
10.65 (V, H), 19.35 (V, H), 21.3 (H), 37.0 (V, H), 85.5 (V, H) GHz

Product Type:
standard, at-launch

Science Team Contact:
J. Shiue

PR – Radar Total Power, Noise, and Reflectivity

Product Description

The Level 1B Precipitation Radar (1B-21) data set contains returned power and noise information, along with satellite information such as navigation (spacecraft position and velocity) and radar calibration information. The Level 1C PR data (1C-21) are radar reflectivity derived from the Level 1B data where data are excluded if no significant echoes are found (i.e., little or no rain activity) and noisy data are suppressed and set to predefined values.

PR 1B-21, 1C-21
PRODUCT SUMMARY

Coverage:
36°N - 36°S; 16 orbits at 220 km each precessing through diurnal cycle

Resolution:
4.4 km (horiz.) 250 m (vertical)

Wavelengths:
13.8 GHz

Product Type:
standard, at-launch

Science Team Contact:
K. Okamoto

LIS Pulse/Background

Product Description

This Level 1A product consists of 8 parameters, including pulse/background, Calibration Matrix, Navigation Data, Continuity Data, Error List, QA Data, and Correction Data. It is the raw data stream from the LIS instrument including all instrument housekeeping information along with the lightning pulses and background images. The purpose of this product is to provide a "snapshot" of the LIS field of view when the lightning data volume is low. The data from the background images are transmitted as part of the data stream when there is space available. The pulse and background data from the instrument will be processed from a set of products with many components or categories.

LIS 01
PRODUCT SUMMARY

Coverage:
global, 35°N - 35°S

Resolution:
3.5 km × 3.5 km, daily (2 ms)

Key Measurements:
Pulse/background, calibration matrix, navigation data, continuity data, error list, QA data, and correction data

Processing Level:
1A

Product Type:
standard, at-launch

Science Team Contact:
H. Christian, S. Goodman

MODIS Level-1A Radiance Counts

Product Description

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. This product includes all MODIS data in digitized (counts) form for all bands, all spatial resolutions, all time tags (converted), all detector views (Earth, solar diffuser, SRCA, black body, and space view), and all engineering and ancillary data.

MOD 01
PRODUCT SUMMARY

Coverage:
global, daily (daytime and nighttime)

Resolution:
0.25, 0.5, and 1 km

Wavelengths:
20 channels 0.4-3.0 µm, 16 channels 3-15 µm

Product Type:
standard, at-launch

Science Team Contact:
V. Salomonson

MODIS Level-1B Calibrated, Geolocated Radiances

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 radiance units are in $W\,m^{-2}\,\mu m^{-1}\,sr^{-1}$). In addition, Earth BRDF may be determined for the solar reflective 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.

Visible, SWIR, and NIR measurements are made during daytime only, while radiances for TIR are measured continuously. Only Channels 1 and 2 have 250-m resolution, Channels 3-7 have 500-m resolution, and the rest have 1-km resolution.

MOD 02
PRODUCT SUMMARY

Coverage:
global, daily (daytime and nighttime)

Resolution:
0.25, 0.5, and 1 km

Wavelengths:
20 channels 0.4-3.0 µm, 16 channels 3-15 µm

Product Type:
standard, at-launch

Science Team Contact:
H. Montgomery

MODIS Geolocation Data Set

Product Description

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, the instrument telemetry, and a digital elevation model.

MOD 03
PRODUCT SUMMARY

Coverage:
global, daily (daytime and nighttime)

Resolution:
1 km

Wavelengths:
n/a

Product Type:
standard, at-launch

Science Team Contact:
V. Salomonson

MODIS Surface Reflectance; Atmospheric Correction Algorithm Products (also called Spectral Reflectance)

Product Description

The MODIS surface reflectance product, MOD 09 (#2015), is a seven-band product computed from the MODIS Level 1B land bands 1, 2, 3, 4, 5, 6, and 7 (centered at 648 nm, 858 nm, 470 nm, 555 nm, 1240 nm, 1640 nm, and 2130 nm, respectively). The product is an estimate of the surface spectral reflectance for each band as it would have been measured at ground level if there were no atmospheric scattering or absorption.

The correction scheme includes corrections for the effect of atmospheric gases, aerosol, and thin cirrus clouds; it is applied to all noncloudy MOD 35 (#3660) Level 1B pixels which pass the Level 1B quality control. The correction uses band 26 to detect cirrus cloud, water vapor from MOD 05 (#1874), aerosol from MOD 04 (#2293), and ozone from MOD 07 (#1333); best available climatology is used if the MODIS water vapor, aerosol, or ozone products are unavailable. Also, the correction uses MOD 43 (#3669), BRDF without topography, from the previous 16-day time period for the atmosphere-BRDF coupling term.

Research & Applications

The surface reflectance product is the input for product generation for several land products: Vegetation Indices (VIs), BRDF, thermal anomaly, snow/ice, and Fraction of Photosynthetically Active Radiation/Leaf Area Index (FPAR/LAI). It is, therefore, an important and essential product. The at-launch version will be fully operational.

Data Set Evolution

Because of the novelty of the at-launch MODIS aerosol product (MOD 04) over land and the cirrus detection, the inclusion of the correction for aerosol and thin cirrus clouds will be implemented following at launch thorough evaluation of these products.

Suggested Reading

Vermote, E.F., *et al.*, 1996.

MOD 09
PRODUCT SUMMARY

Coverage:
global land surface (Level 2)

Spatial/Temporal Characteristics:
bands 1 and 2: 250 m
bands 3 - 7: 500 m
daylight data only

Key Science Applications:
global climate modeling, regional climate modeling, surface energy balance modeling, land cover characterization

Key Geophysical Parameters:
surface reflectance

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
E. Vermote

MODIS Surface Reflectance; Atmospheric Correction Algorithm Products (also called Spectral Reflectance)

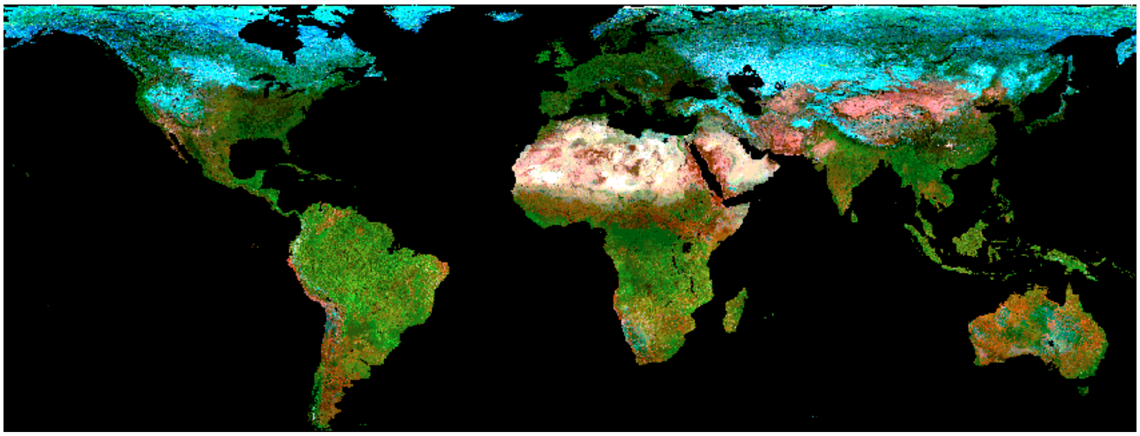


Figure 13. **RGB composite (Red=3.75µm , Green=0.87 µm, Blue=0.67 µm) January 89**

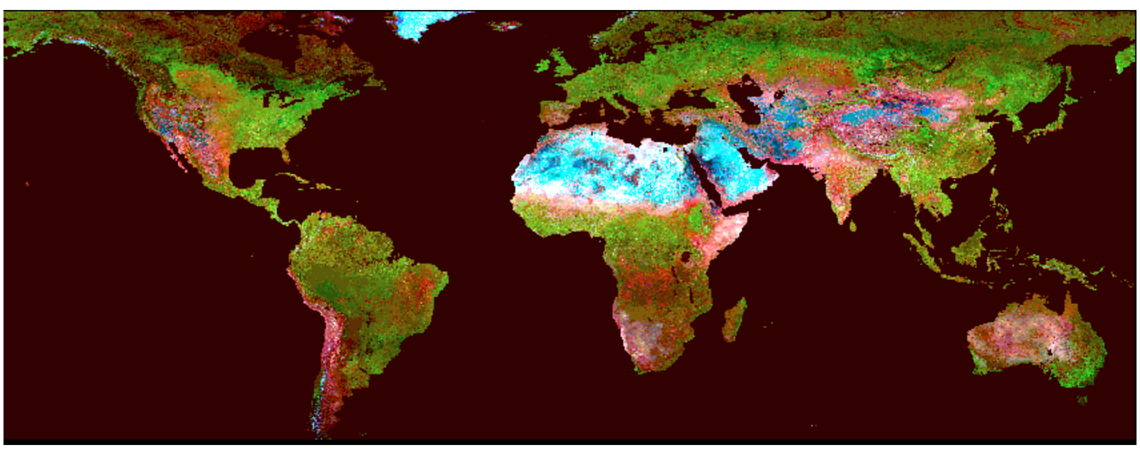


Figure 14. **RGB composite (Red=3.75µm , Green=0.87 µm, Blue=0.67 µm) July 89.** These images were generated from AVHRR reflectances in channels 1 (0.67 µm), 2 (0.87 µm) and 3 (3.75 µm); channels 1 and 2 were corrected for atmospheric effects from rayleigh scattering, ozone (using TOMS gridded ozone product) and water vapor (using DAO total precipitable water). They reflect the state of land cover for January and July 89 : the green color produced by low values in AVHRR channels 1 and 3 and high values in channel 2 represents vegetated areas. Blue color in the January composite is produced for snow and residual clouds. The blue color over the desert in the July composite is due to the saturation of AVHRR channel 3 which leads to erroneous values of reflectance at 3.75 µm

MODIS Surface Reflectance; BRDF/Albedo Parameter

Product Description

The BRDF/Albedo Parameter provides (1) coefficients for mathematical functions that describe the BRDF of each pixel in the seven MODIS “Land” bands (1-7); and (2) albedo measures derived simultaneously from the BRDF for bands 1-7 as well as three broad bands (0.4-0.7; 0.7-3.0, 0.4-3.0 μm). Because deriving BRDF and albedo requires merging multiple looks at each pixel, the BRDF/Albedo parameter is provided every 16 days. Its spatial resolution is 1 km, gridded to Level 3. A thirty-day summary albedo product at one-quarter degree spatial resolution is also provided.

Research & Applications

The BRDF functions provided by the BRDF/Albedo parameter (1) allow normalization of MODIS data to standard viewing and illumination angles, thus removing geometric effects from multidate images; (2) quantify the directional information in the remotely-sensed signal, which is related to ground cover type; and (3) provide a surface radiation-scattering model for boundary layer parameterization in regional and global climate modeling. The BRDF is also used in extraction of surface reflectances at Level 2. Two albedo measures are provided: “black-sky” albedo (directional-hemispherical reflectance), and “white-sky” albedo (bi-hemispherical reflectance). These are intrinsic surface properties, independent of atmospheric state. They describe the upward scattering of the solar beam and of uniform diffuse irradiance, respectively, and may be used as input to global and regional climate models.

Data Set Evolution

The BRDF/Albedo algorithm combines gridded, multidate, multiband surface reflectance data from EOS MODIS and MISR instruments to produce BRDF functions and derived albedo measures. For each grid cell, all cloud-free observations in a 16-day period are assembled and fit to a suite of semi-empirical models that describe the BRDF as a linear function of basic BRDF shapes. The shapes are derived by simplifying physical models that describe volume scattering and surface scattering of land surface covers. In addition, a single empirical model (modified Walthall) is also fitted. The algorithm outputs (1) the model and parameters that best fit the observations, (2) modified Walthall parameters, (3) black-sky and white-sky spectral and broadband albedos, (4) an extensive series of quality flags, and (5) information on model fits and surface structure inference.

Suggested Reading

Barnsley, M.J. and J.-P. Muller, 1991.

Brest, C.L., and S.N. Goward, 1987.

Wanner, W., *et al.*, 1995.

Wanner, W., *et al.*, 1995.

MOD 43
PRODUCT SUMMARY

Coverage:
global land surface

Spatial/Temporal Characteristics:
1 km, 16-day; 1/4° 30-day

Key Science Applications:
biogeochemical cycle modeling, net primary productivity estimation, global climate models

Key Geophysical Parameters:
bidirectional reflectance, spectral albedo

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
A. Strahler, J.-P. Muller

MODIS Normalized Water-Leaving Radiance

Product Description

This Level 2 and Level 3 product contains ocean water-leaving radiances for 7 of the 36 wavelengths/ spectral bands (Band 8 through 14, 412 through 681 nm) of MODIS. These are the "ocean" bands; the water leaving radiances in these bands are used to derive nearly all of the MODIS ocean products. In addition, another key parameter generated by the algorithm is provided as Product MOD 37: Aerosol Optical Depth (Param. 2344). The Level 2 product is provided daily at 1-km resolution for cloud-free pixels. The product constraints are that only cloud-free pixels are used (with Sun glitter below a threshold), and all valid pixels are outside a distance threshold from land. The product availability is at-launch.

Research & Applications

Normalized Water-Leaving Radiance is the radiance that would exit the ocean in the absence of the atmosphere if the Sun were at the zenith. It is used in the bio-optical algorithms to estimate chlorophyll *a* concentration and ocean primary productivity on a global scale. The algorithm evolved from experience from the CZCS experiment which proved the feasibility of measuring ocean color from space. Extensive testing of the algorithm will be conducted using SeaWiFS imagery. This is the fundamental product for recovering most of the MODIS ocean products.

Data Set Evolution

Inputs to the algorithm are the Level 1 radiances in Bands 8-14, screened for clouds and land, and estimates of the surface wind speed, atmospheric pressure, and ozone concentration derived from National Centers for Environmental Prediction (NCEP, formerly the NMC). The success of the algorithm depends on the accurate characterization of the atmospheric effect which for water typically constitutes 90 percent of the at-satellite radiance. The algorithm includes single scattering, multiple scattering effects, and whitecap removal, and uses six types of ancillary data. There are three major sources of uncertainty in the product: (1) The N candidate aerosol models chosen to describe the aerosol may be unrepresentative of the natural aerosol, (2) there is uncertainty in the estimate of the whitecap reflectance/radiance, and (3) there is uncertainty in the sensor's radiometric calibration. The product will be validated by comparing simultaneous surface-based measurements (including drifting buoy radiometers) and MODIS-derived values at a set of locations.

Suggested Reading

Deschamps, P.Y., *et al.*, 1983.

Evans, R.H. and H.R. Gordon, 1994.

Gordon, H.R. and D.K. Clark, 1981.

Gordon, H.R., and A.Y. Morel, 1983.

Gordon, H.R. and M. Wang, 1994.

MOD 18, MOD 37
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
ocean chlorophyll, ocean productivity

Key Geophysical Parameters:
water-leaving radiances in the ocean bands, aerosol optical depth

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
H.R. Gordon

MODIS PAR (Photosynthetically Active Radiation)

Product Description

This Level 2 and 3 product consists of four related parameters which describe the irradiance at the ocean surface. The first is Downwelling Solar Irradiance (Param. 5354) which is the incident irradiance just above the sea surface in each of the visible MODIS ocean bands (8, 9, 10, 11, 12, 13, 14). The second is Instantaneous Photosynthetically Active Radiation, Param. 2266 (IPAR), which 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 to 700 nm. The third is PAR (Param. 2330) which is the irradiance averaged over an entire day. Since measurements are only available at the time MODIS views the pixel, this parameter is estimated from IPAR by the algorithm. The product is produced at 1 km daily for Level 2 and gridded at Level 3 daily and weekly at 1 km. The fourth is ARP (absorbed radiation by phytoplankton) averaged over the first optical depth. This parameter is critical for calculation of fluorescence efficiency, a product useful for conditioning phytosynthesis models (MOD 23).

Research & Applications

This product is critical for determining photosynthetic rate of growth of phytoplankton and primary ocean production. Downwelling irradiance is needed as an input to the chlorophyll *a* algorithm (MOD 21) and it is used to convert the normalized water-leaving radiance values (MOD 18) into remote-sensing reflectance values. A series of irradiance models specific for terrigenous aerosols have been available; however, the aerosol characteristics of these models differ greatly in size and optical characteristics from marine aerosols. The irradiance model of Gregg and Carder (1990) uses a mixture of marine and terrigenous aerosols and forms the basis for the algorithm for MODIS PAR product.

Data Set Evolution

Product generation begins with solar irradiance data at 1 nm resolution which is taken from the revised Neckel and Labs data and corrected for Earth-Sun distance for the current day. Atmospheric correction is made for the effects of scattering, absorption by ozone, absorption by gas, and water vapor. This spectrum is then binned and weighted appropriately to give the irradiance in each of the MODIS ocean bands. Next, the below-surface values are computed and summed to give IPAR. Inputs to the algorithm are Water Leaving Radiance (MOD 18), PAR (MOD 22) and Absorption Coefficient (MOD 36).

Suggested Reading

Gordon, H.R. and M. Wang, 1994.

Gregg, W.W. and K.L. Carder, 1990.

Iqbal, M., 1983.

Paltridge, G.W., and C.M.R. Platt, 1976.

MOD 22
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
ocean chlorophyll, productivity

Key Geophysical Parameters:
photosynthetically available irradiance

Processing Level:
2, 3

Product Type:
Validation, at-launch

Science Team Contact:
K. Carder, D. Tanré,
W. Esaias, M. Abbott

MODIS Processing Framework and Match-up Database

Product Description

This Level 2 product consists of the calibration dataset (Param. 3303) to be used in the generation of all the MODIS Oceans products. It consists of a database which contains *in situ* observations of ocean parameters matched with satellite measurement data. This matchup database will initially be populated with existing ocean surface data matched temporally and spatially with CZCS and AVHRR data and with SeaWiFS data as it is obtained and then MODIS data post-launch. The product includes the definition of the processing framework in which all the MODIS ocean product algorithms will operate. It is produced daily, weekly and monthly and supports ocean products at 1 km but the product itself does not have a spatial resolution.

Research & Applications

This is a calibration product for MODIS ocean processing. It is used through a vicarious calibration scheme to update MODIS radiometric calibration coefficients which directly relate MODIS Level 1A raw counts to Level 2 calibrated water-leaving radiances and to monitor long-term performance of the MODIS instrument. MOD 32 as a matchup database is also used to validate derived ocean geophysical parameters such as SST and for quality control of the ocean team retrievals.

Data Set Evolution

Heritage programs provide the basis for MODIS algorithms. A program developed for the Pathfinder ocean SST product forms the framework for analyzing AVHRR derived SST, algorithm development and validation, and application of the matchup database. Development for ocean color algorithms is based on experience gained in transition from CZCS to SeaWiFS algorithms. Development of the SeaWiFS program involves integration of algorithms generated by H. Gordon (atmospheric correction) and K. Carder (chlorophyll). In addition, daily validity tests are being developed through collaboration of the SeaWiFS CAL/VAL team and our group. The *in situ* records are first temporally matched against the AVHRR extractions. AVHRR data for the match-up database were extracted for 3 × 3 pixel boxes centered at each *in situ* sea surface temperature measurement location. Sea surface observations are from two main types of platforms: moored buoys and drifting buoys. After the SeaWiFS and Pathfinder programs are validated using actual sensor data, they will be converted from a scalar to a parallel implementation and coded using the FORTRAN 90 language and EOS coding standards. Code for the MODIS algorithms initially will be based on SeaWiFS and Pathfinder programs. These implementations will evolve to support product production for the MODIS ocean investigators and will be coded using a combination the C and FORTRAN 90 programming languages and EOS coding standards.

Suggested Reading

Evans, R.H. and H.R. Gordon, 1994.

Gordon, H.R., 1987.

Gordon, H.R., and A.Y. Morel, 1983.

Slater, P.N., *et al.*, 1987.

Smith, R.C. and W.H. Wilson, 1981.

MOD 32
PRODUCT SUMMARY

Coverage:
global ocean surface

Spatial/Temporal Characteristics:
1 km/daily, weekly, monthly

Key Science Applications:
ocean chlorophyll, ocean productivity, all ocean products

Key Geophysical Parameters:
matchup databases, water leaving radiances, *in situ* measurements

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
R. Evans, H.R. Gordon

MODIS Clear-Water Epsilon

Product Description

This product provides a single parameter (3707). The parameter is the ratio of clear water-leaving radiance at 531 nm to that at 667 nm and is called the clear-water epsilon [ε(531,667)]. This quantity relates directly to the iron content of aerosols over clear waters mostly in the ± 35^{o} latitude range. The Level 2 product is produced daily and the Level 3 product is produced daily and weekly, all at 1 km spatial resolution.

Research & Applications

The primary purpose of this algorithm is to estimate aerosol iron content over ocean waters. The aerosol iron influences the validity of other MODIS products. The secondary objective is to flag instances when normalized water-leaving radiance retrievals may need adjustment due to aerosol absorption at blue and green wavelengths. Such errors will affect chlorophyll *a* calculations. The third objective is to provide a check on the Angstrom exponent derived at red and infrared wavelengths. The algorithm is valid for pigment concentrations up to 2 mg/m^3. When pigment concentrations are larger than this the algorithm can no longer be applied. A research algorithm is planned post-launch that will use a coupled ocean-atmosphere radiance model to interactively address aerosols in high-pigment water.

Data Set Evolution

The algorithm is based on methods developed for obtaining clear-water epsilon values from CZCS data (Gordon, 1981). Modifications for the MODIS algorithm include extension of the clear-water concept to include waters with higher pigment concentrations and modification of the values of the normalized water-leaving radiance at 520, 550 and 670 nm for CZCS to the slightly different MODIS bands by means of the water absorption curve. Product validation will use SeaWiFS data in the pre-launch and MODIS data post-launch. Scattering and optical thickness data plus ship data of water-leaving radiances data will be acquired to test the clear-water radiance assumptions. This is an interim validation product which may not be archived.

Suggested Reading

Carder, K.L., *et al.*, 1991.

Gordon, H.R., 1978.

Gordon, H.R. and D.K. Clark, 1981.

Gordon, H.R., and A.Y. Morel, 1983.

Gordon, H.R. and M. Wang, 1994.

MOD 39
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
aerosol iron estimation, water-leaving radiance correction

Key Geophysical Parameters:
clear-water epsilon, aerosol iron content

Processing Level:
2, 3

Product Type:
validation, at-launch

Science Team Contact:
K. Carder

MODIS Reformatted Annotated Product

Product Description

The Level 1A Reformatted Annotated Product contains raw MISR data which are decommutated, reformatted (12-bit L0 data shifted to byte boundaries, reversal of square-root encoding applied, and converted to 16-bits) and annotated (e.g., with time information, etc.). The MISR Level 1A data set is the primary archive of MISR instrument Charge-Coupled Device (CCD) science data, instrument engineering data (e.g., instrument temperatures, electrical status, command verification, etc.), calibration data, motor data, and navigation data (raw spacecraft position and attitude). These data are used by the Level 1B1 processing algorithm to generate calibrated radiances. The science data output preserves the spatial sampling rate of the Level 0 raw MISR CCD Science data.

CCD data are collected during routine science observations of the sunlit portion of the Earth. Each product represents one ‘granule’ of data. A ‘granule’ is defined to be the smallest unit of data required for MISR processing. Also included in the Level 1A product will be pointers to calibration coefficient files provided for Level 1B processing.

MIS 01
PRODUCT SUMMARY

Coverage:

daytime, 378-km swath width (nadir), 413 km swath width (off nadir), providing global coverage in 9 days.

Resolution:

The spatial sampling of the nadir viewing camera is 250 m (cross-track) × 275 m (along-track), while for the 8 off-nadir cameras the sampling is 275 m in both directions. On-board averaging up to 1.1 km is selectable by ground command.

Wavelengths:

443, 555, 670, 865 nm

Product Type:

standard, at-launch

Science Team Contact:

C. Bruegge

MISR Radiometric Product

Product Description

The MISR Radiometric Product (MIS 02) is produced during Level 1B1 processing. It contains spectral radiances for all MISR channels (four spectral bands and nine cameras), given in units of $W/(m^2 \cdot \mu m \cdot sr)$. Each radiance value represents the incident radiance averaged over the sensor's total band response. Processing includes both radiance scaling and conditioning steps. Radiance scaling converts the Level 1A data from digital counts to radiances, using coefficients derived in combination with the On-Board Calibrator (OBC) and vicarious calibrations. The OBC contains Spectralon calibration panels which are deployed monthly and reflect sunlight into the cameras. The OBC detector standards then measure this reflected light to provide the calibration. Vicarious field campaigns are conducted less frequently but provide an independent methodology useful for reducing systemic errors.

Radiance conditioning removes undesirable instrument effects. Image enhancement is provided by deconvolving the scene with the sensor's point-spread-function. Additionally, in-band scaling adjusts the reported radiances to correspond to a nominal band response profile. This frees the Level 2 software from the need to correct for detector element non-uniformities. No out-of-band correction is done for this product, nor are the data geometrically corrected or resampled.

MIS 02
PRODUCT SUMMARY

Coverage:
daytime, 378-km swath width (nadir), 413-km swath width (off nadir), providing global coverage in 9 days.

Resolution:
The spatial sampling of the nadir viewing camera is 250 m (cross-track) × 275 m (along-track), while for the 8 off-nadir cameras the sampling is 275 m in both directions. On-board averaging up to 1.1 km is selectable by ground command.

Wavelengths:
443, 555, 670, 865 nm

Product Type:
standard, at-launch

Science Team Contact:
C. Bruegge

MISR Geo-rectified Radiance Product

Product Description

The Geo-rectified Radiance Product (GRP) consists of parameters that have had geometric corrections applied and have been projected to a Space-Oblique Mercator (SOM) map grid. Included in this product is the surface-projected TOA radiance which is the calibrated radiance from the Level 1B1 data (MIS 02) that has had a geometric correction applied to remove spacecraft position and pointing knowledge errors as well as effects due to topography. The radiance is then orthorectified on a reference ellipsoid at the surface. Also part of the GRP is the ellipsoid-projected TOA radiance which uses supplied spacecraft position and pointing and is not corrected for topography, but is resampled at surface reference ellipsoid. In addition, geometric parameters such as solar and view zenith and azimuth angles are included.

Resampling of MISR data at Level 1B2 is critical because the pushbroom images from the nine cameras are obtained at widely separated locations along the subspacecraft track. However, derivation of geophysical products requires that the multiangle, multispectral radiances for any single ground target be coregistered.

MIS 03
PRODUCT SUMMARY

Coverage:
daytime, 378-km swath width (nadir), 413-km swath width (off nadir), providing global coverage in 9 days.

Resolution:
The resampled data are provided on a 275 m × 275 m Space Oblique Mercator grid in certain channels, and a 1.1 km × 1.1 km grid in the remaining channels, as established by the instrument observing configuration.

Wavelengths:
443, 555, 670, 865 nm

Product Type:
standard, at-launch

Science Team Contact:
D. Diner

MISR Ancillary Geographic Product

Product Description

The MISR Ancillary Geographic Product (AGP) contains terrain data (generated from a high resolution DEM), referenced to the WGS84 reference ellipsoid and mapped onto a SOM grid. It is an archival product generated once preflight at the MISR SCF, but which can be distributed to the scientific community through the DAAC as an aid in interpreting MISR retrievals. The AGP is used as input to Level 1B2 and Level 2 processing. Its contents include latitude, longitude, scene elevation (average and standard deviation), topographic shadow and obscuration mask, surface-normal zenith angle (average and standard deviation), surface-normal azimuth angle, and a land/ocean/inland water/ephemeral water/coastline mask. All parameters are given on 1.1-km centers.

MIS 10
PRODUCT SUMMARY

Coverage:
global, one-time only.

Resolution:
1.1 km

Wavelengths:
n/a. Parameters include latitude, longitude, elevation, obstruction mask, and land & water classification.

Product Type:
internal, on-request

Science Team Contact:
D. Diner

MISR Ancillary Radiometric Product

Product Description

The MISR Ancillary Radiometric Product (ARP) contains coefficients and data variables which are used in the Level 1B1 processing. Updated ARP parameters include the sensor radiometric calibration coefficients, uncertainties in calibration, signal-to-noise ratios, pixel data quality indicators, and quality assessment threshold parameters. Static ARP parameters include spectral response parameters, point-spread-functions (PSF), fields-of-view, passband-weighted solar irradiance values, and PAR integration weights. The ARP is regenerated periodically at the MISR SCF to update the instrument performance report. The ARP is used as input to Level 1B1 as well as Level 2 processing.

MIS 11
PRODUCT SUMMARY

Coverage:
n/a, generated periodically.

Resolution:
per pixel

Parameters:
radiometric calibration coefficients, uncertainties, signal-to-noise ratios, spectral response parameters, PSF, fields-of-view, band averaged solar irradiance and PAR weights

Product Type:
internal

Science Team Contact:
C. Bruegge

ASTER Reconstructed, Unprocessed Instrument Data

Product Description

The ASTER Level 1A raw data (AST 01) are reconstructed, unprocessed instrument digital counts with ground resolution of 15 m, 30 m, and 90 m for 3 VNIR (0.52-0.86 µm), 6 SWIR (1.60-2.43 µm), and 5 TIR (8.13-11.65 µm) channels. This product contains depacketized, demultiplexed, and realigned instrument image data with geometric correction coefficients and radiometric calibration coefficients appended but not applied. This includes correcting for SWIR parallax as well registration within and between telescopes. The spacecraft ancillary and instrument engineering data are also included. This product is the responsibility of Japan.

The radiometric calibration coefficients consisting of offset and sensitivity information is generated from a database for all detectors. The geometric correction is the coordinate transformation for band-to-band coregistration.

AST 01
PRODUCT SUMMARY

Coverage:
regional up to 780 60x60 km scenes per day (daytime for all channels, daytime and nighttime TIR channels, nighttime SWIR and TIR channels for volcano observation)

Resolution:
15, 30, 90 m (VNIR, SWIR, TIR, respectively)

Wavelengths:
VNIR - 0.52 - 0.86 µm (3 channels + 1 stereo channel), SWIR - 1.60 - 2.43 µm (6 channels), TIR - 8.13 - 11.65 µm (5 channels)

Product Type:
standard, at-launch

Science Team Contact:
H. Fujisada

ASTER Registered Radiance at Sensor

Product Description

This Level 1B product (AST 03) contains radiometrically calibrated and geometrically coregistered data for all ASTER channels. This product is created by applying the radiometric and geometric coefficients to the Level 1A data. The bands have been coregistered both between and within telescopes, and the data have been resampled to apply the geometric corrections. As for the Level 1A product, these Level 1B radiances are generated at 15-m, 30-m, and 90-m resolutions corresponding to the VNIR, SWIR, and TIR channels. Calibrated, at-sensor radiances are given in W/(m^2 • μm • sr). This product serves as input to derived geophysical products.

AST 03
PRODUCT SUMMARY

Coverage:
regional up to 310 60 km × 60 km scenes per day (daytime and nighttime)

Resolution:
15, 30, 90 m (VNIR, SWIR, TIR, respectively)

Wavelengths:
VNIR - 0.52 - 0.86 μm (3 channels + 1 stereo channel), SWIR - 1.60 - 2.43 μm (6 channels), TIR - 8.13 - 11.65 μm (5 channels)

Product Type:
standard, at-launch

Science Team Contact:
H. Fujisada

ASTER Brightness Temperature at Sensor

Product Description

This Level 2 product includes brightness temperature in degrees Celsius (C) at 90-m resolution for ASTER's 5 thermal-infrared channels (8-12 µm). This is an on-request product and will be generated only when requested. Brightness temperature is the apparent temperature of the surface assuming a surface emissivity of 1.0. Setting the emissivity to one is equivalent to assuming the target is a black body, so the brightness temperature is defined as the temperature a blackbody would be in order to produce the radiance perceived by the sensor.

Brightness temperature has been used to observe volcanic ash clouds, detect ice leads in the Arctic, and to identify anthropogenic and natural fires, to name a few examples. The ASTER brightness temperature will be used as an alternate to radiance in the temperature/emissivity separation algorithm to report relative cloud top temperature because there will be no routinely available applicable atmospheric correction to enable a calculation of exact cloud-top temperature.

ASTER brightness temperatures can be acquired during the day or night and over all surface types (land, water, cloud, etc.).

AST 04
PRODUCT SUMMARY

Coverage:
regional up to 70 64 × 60 km scenes per day (AM and PM overpass)

Resolution:
90 m

Wavelengths:
brightness temperatures (°C) derived for each thermal infrared channel

Processing Level
2

Product Type:
standard, at-launch

Science Team Contact:
R. Alley

ASTER Browse Data - Decorrelation Stretch Product

Product Description

This Level 2 browse product contains decorrelation stretch images of ASTER VNIR, SWIR, and TIR radiance data. These images are produced at pixel resolutions of 15 m for VNIR, 30 m for SWIR, and 90 m for TIR. Decorrelation stretched images provide an overview that enhances reflectance and emissivity variations and subdues variations due to topography and temperature.

Research & Applications

The decorrelation stretch is a process that is used to enhance the spectral differences found in a multispectral image dataset. These images are used as a visual aid in browsing the ASTER scene data and making the selection of suitable scenes for further analysis and research. In particular, a decorrelation stretched image would show the potential user which scenes have spectral variations large enough to be useful for subsequent spectral analysis.

Data Set Evolution

The algorithm used removes the interchannel correlation found in the input pixels. The decorrelation-stretched images are color coded producing a color composite containing the maximum contrast for the features in the original set of bands. The user may request as an on-demand product a decorrelation stretched image generated from any three ASTER channels that share a single telescope (VNIR, SWIR, or TIR).

Suggested Reading

Gillaspie, A.R., *et al.*, 1986.

Loeve, M., 1955.

Rothery, D.A., 1987.

Taylor, M.M., 1973.

AST 06
PRODUCT SUMMARY

Coverage:
regional, three images available per scene

Resolution:
15 m (VNIR), 30 m (SWIR), 90 m(TIR)

Wavelengths:
any 3 ASTER channels within a single telescope for on-demand products

Processing Level
2

Product Type:
standard, at-launch

Science Team Contact:
R. Alley

ASTER Surface Reflectance and Surface Radiance

Product Description

The Level 2 surface reflectance data set (AST 07) contains surface reflectance for VNIR and SWIR channels at 15-m and 30-m resolutions, respectively, derived by applying an atmospheric correction to observed satellite radiances. The data product is recorded as percent reflectance. The method uses a look-up table approach based upon a radiative transfer model capable of estimating the magnitude of scattering and absorption given atmospheric turbidity parameters. The needed section of the look-up table is selected using a set of atmospheric parameters (e.g., scattering optical depths, columnar ozone, and water vapor) known at the time and location of the satellite measurements. The retrieved surface reflectance is only of known accuracy for cloud-free pixels because inputs are known for clear-sky pixels only.

The Level 2 surface radiance data set (AST 09) contains surface radiance, in W/(m^2 • µm • sr), for VNIR, SWIR, and TIR channels at 15-m, 30-m, and 90-m resolutions, respectively. The product is derived by applying an atmospheric correction to satellite radiances. The atmospheric correction used to derive AST 09 for the VNIR and SWIR bands is similar to that used to drive AST 07. The approach for atmospheric correction in the thermal infrared uses a radiative transfer model capable of estimating the magnitude of atmospheric emission, absorption, and scattering using a set of atmospheric parameters (e.g., temperature, water vapor, ozone, profiles, and scattering optical depths) known at the time and location of the satellite measurements. The retrieved surface radiance is only of known accuracy for cloud-free pixels because inputs are known for clear-sky pixels only.

Both AST 07 and AST 09 are generated only upon request. The products based on VNIR data are available only for daytime satellite overpasses. Those from SWIR data are available for daytime overpasses, and, in cases of high temperature sources (e.g., volcanoes or fires), available for nighttime overpasses. Surface radiance from TIR data are available for both daytime and nighttime overpasses.

Research and Applications

The objective of these ASTER products is to provide estimates of the surface radiance and reflectance. The thermal infrared radiance includes both surface emitted and surface reflected components. After accurate atmospheric correction, seasonal and annual surface changes can be studied and surface kinetic temperature and emissivity can be extracted. Surface radiances and reflectances can also be used for surface classification, desertification studies, and surface energy balance work.

Data Set Evolution

This product, as well as similar products for other AM-1 instruments, mark the first implementations of operational atmospheric corrections in environmental satellites. Past work to retrieve surface reflectance from satellite imagery has focused on small sets of satellite data for highly studied ground targets. The primary reason for this is that atmospheric correction is a computationally intensive process. Methods for

AST 07, AST 09
PRODUCT SUMMARY

Coverage:
regional; 16 days required for global coverage; 70 scenes per day

Resolution:
15, 30, 90 m (VNIR, SWIR, TIR, respectively)

Wavelengths:
VNIR - 0.52 - 0.86 µm (4 channels),
SWIR - 1.6 - 2.43 µm (6 channels),
TIR - 8.125 - 11.65 µm (5 channels)

Product Type:
standard, on-request

Science Team Contact:
K. Thome (VNIR, SWIR),
F. Palluconi (TIR)

ASTER Surface Reflectance and Surface Radiance

reducing the computational requirements include using look-up tables and making assumptions about the horizontal homogeneity of the atmosphere.

Research into developing future versions of code to produce AST 07 and AST 09 will focus on attempting pixel-by-pixel corrections using pixel-by-pixel atmospheric input parameters rather than assuming horizontal homogeneity. Because of ASTER's small ground instantaneous field of view, future versions of the atmospheric correction will include corrections for multiple scatter effects from adjacent pixels of differing reflectance, also known as the adjacency effect. Look-up tables will also expanded to include other parameters such as surface bidirectional reflectance characteristics.

Suggested Reading

Deschamps, P. and T. Phulpin, 1980.

Hilland, J.E., *et al.*, 1985.

McMillin, L.M., 1975.

Prabhakara, C., *et al.*, 1975.

Price, J.C., 1984.

ASTER Digital Elevation Models (DEMs)

Product Description

This data set contains topographic information derived from the along-track, 15-m ASTER optical stereo data acquired in the near-infrared. 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 degrees over horizontal distances of more than 100 m. ASTER DEM's should meet 1:50,000 to 1:250,000 map accuracy standards.

This is an on-request product which will be generated by the Land DAAC at EROS Data Center only when requested, and at a rate to be determined. Based on simulations of instrument operations, mission planning, cloud cover and illumination, the ASTER digital stereo data with a base/height ration of 0.6 should be acquired for all of the Earth's land surface below 85 degrees latitude by the end of the 5-year mission. These data are appropriate for users interested in generating DEMs themselves.

Research and Applications

Topographic data as well as derived slope and slope aspect are basic to all aspects of land surface research including; cartography, climate modeling, biogeochemistry, biogeography, geophysics, geology, geomorphology and soil science. Digital elevation data are also required for atmospheric and radiometric correction of most satellite-acquired observations of the land surface. Digital elevation data are also used for practical engineering applications such as studies of drainage and runoff, site suitability studies for buildings, or waste containment sites.

Data Set Evolution

Generation of elevation models from stereo photographic data, now a routine adjunct to standard surveying methods, has been developed over the past 60 years based on the principles of photogrammetry. Extensions of these principles to the generation of DEMs from optical stereo satellite data had been implemented over the past two decades. Examples of these satellite stereo systems include SPOT, JERS-1 OPS, and MOMS. Currently, there are large areas of the globe for which no consistent, high-resolution, widely available elevation models exist. ASTER DEMs will help provide much needed coverage over many of these remote areas.

Suggested Reading

American Society of Photogrammetry, 1952.

Bohme, R., 1993.

O'Neill, M.A. and I.J. Dowman, 1993.

Welch, R. and H. Lang, 1994.

AST 14
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
15 m

Key Geophysical Parameters:
digital topography

Key Science Applications:
cartography, land sciences, correction of remotely sensed data.

Processing Level:
4

Product Type:
on request, at-launch

Science Team Contact:
H. Lang

DAS Assimilated Land/Water/Ice Flags

Product Description

This product contains geolocated Level 1B radiances for the eight spectral channels of the MOPITT instrument. Radiances are obtained at three different wavelengths using two different methods of gas correlation radiometry. Reflected solar radiation is measured at 2.2 and 2.3 µm using length modulator cells to determine the total atmospheric columns of methane and carbon monoxide respectively. Thermal radiation at 4.6 µm is measured in four channels using a combination of length modular and pressure modulator cells to provide information on the vertical profile of carbon monoxide. Engineering data describing the state of the gas cells and calibration are also provided to support transformation of the radiances into Level 2 products.

Radiances are acquired by cross track scanning about the nadir resulting in an interlaced swath of pixels approximately 640 km wide. All channels are simultaneously measured on four separate pixels each with a resolution of 22 × 22 km. Each channel measures radiance in two states of its correlation cell. An average and a difference radiance are derived from these two.

Suggested Reading

MOPITT Algorithm Theoretical Basis Document: Conversion of MOPITT Digital Counts into Calibrated Radiances in Carbon Monoxide and Methane Absorption Bands (Level 0 to Level 1),

MOPITT Algorithm Theoretical Basis Document: Retrieval of Carbon Monoxide Profiles and Column Amounts of Carbon Monoxide and Methane from MOPITT Radiances (Level 1 to Level 2).

MOP 01
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
650 km swath centered at nadir.
interlaced crosstrack scan of 4 pixels each 22 × 22 km at nadir

Wavelengths:

wavelength	width
2.258 µm center	± 0.355
2.334 µm center	± 0.011
4.627 µm center	± 0.055

Processing Level:
1B

Product Type:
standard, at-launch

Science Team Contact:
J. Drummond

Bi-Directional Scan Product (BDS)

Product Description

The Level 1 radiance product (BDS) contains filtered radiances in the three CERES spectral bands: shortwave (< 5 μm), longwave-window (8-12 μm), and total (0.3-100 μm). The label "filtered" is used since the radiances upwelling from the top of the atmosphere are filtered through the optics of the CERES instrument and by the spectral response of the detector for each band. All the calibrated radiances from one day's global observations at the full resolution footprint (20-km nadir) for CERES are produced and archived as one product. The platform ephemeris data are appended as housekeeping data in engineering units and the Level 0 instrument inputs, allowing this product to be a used for reprocessing in the case of changes in the calibration coefficients or other improvements in Level 1 processing.

Research & Applications

These radiance data products are the primary inputs to all the CERES product algorithms. The spacecraft ephemeris and sensor telemetry are inputs to this subsystem which uses instrument calibration coefficients to convert the spacecraft telemetry inputs into geolocated filtered radiances and housekeeping data into engineering units.

Data Set Evolution

The Radiance product algorithm operates on the Level 0 reformatted raw sensor counts and produces calibrated radiances in the three channels. The steps in the processing are: (1) Convert the raw housekeeping telemetry into engineering units [temperatures, voltages, etc.]; (2) calculate the geographical location of the CERES footprints; (3) merge the raw spacecraft ephemeris and detector point knowledge telemetry converted housekeeping data and the raw radiometric detector telemetry; (4) revise the radiometric detector count conversion coefficients when required; (5) convert the detector radiometric signals into filtered radiances; and (6) archive the BDS standard products.

Suggested Reading

Hoffman, L.H., *et al.*, 1987.

Jarecke, P.J., *et al.*, 1991.

Lee III, R.B., *et al.*, 1996.

Smith, G.L., *et al.*, 1986.

BDS
PRODUCT SUMMARY

Coverage:
global for AM-1; 40°N - 40°S for TRMM

Spatial/Temporal Characteristics:
20 km - not averaged or binned/ 1 per day

Key Geophysical Parameters:
TOA SW, LW, and window radiances, geolocation data, surface temperature and albedo

Processing Level:
0, 1

Product Type:
standard, at-launch

Science Team Contact:
B. Lee

DAS Assimilated Land/Water/Ice Flags

Product Description

This Level 4 product provides boundary conditions for the Goddard EOS data assimilation system (GEOS DAS). It is an estimate of land elevation, land & water coverage, and permanent and sea ice at each grid point of the GEOS DAS. This field is based on the Navy 10 minute × 10 minute topography dataset and satellite derived estimates of permanent and sea ice.

Research & Application

This product is for reference by researchers using GEOS DAS products. It provides elevation references and insight into the boundary conditions in the GEOS DAS general circulation model.

Data Set Evolution

Most of this field remains fixed in time. The only exception is the amount of sea ice.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 01
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2 × 2.5 deg lat-lon grid, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
land water ice flags

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs

Chapter Five

Precipitation and Atmospheric Humidity

Precipitation and Atmospheric Humidity

Relationship to Global Change Issues

The hydrological cycle is one of three key Earth system processes that are components of global climate; the carbon and energy cycles are the others. Monitoring precipitation and atmospheric humidity is critical to obtaining hydrological-cycle parameters needed for developing global climate models and detecting climate change. The processes that generate rainfall are central to the dynamical, biological, and chemical processes in the atmosphere, in the oceans, and on the land surfaces. It is clear that space-based measurement is the only means to a more accurate global documentation of tropical rainfall. The TRMM instruments are designed to provide greatly-improved measurements of rain rates over both land and ocean compared to current methods. TRMM is often referred to as a “flying rain gauge,” with a high potential contribution to the World Climate Research Program’s (WCRP’s) rain climatology initiative. This section describes the TRMM and EOS products that support the monitoring of rainfall and atmospheric humidity, including the TRMM ground truth validation data acquisition.

Precipitation: The majority of global precipitation occurs in the tropics, between latitudes of 30° N and 30° S. Tropical rain is one of the key parameters that affects the global climate change, the global heat balance, and the global water cycle. To understand and predict large variations in weather and climate, it is critical to understand the coupling between the atmosphere and the surface below, which is ocean over 75 percent of the globe. Atmospheric circulation transports both energy and water, moving heat from the tropics to polar regions. Water, evaporated from the oceans and the land surface, falls as rain or snow often in places far removed from its point of origin. There is evidence that tropical rainfall variability, apparently coupled with changes in the underlying surface (particularly sea surface temperature), is associated with significant alterations in wind patterns and rainfall. Fluctuations in rainfall amount impact climate on both short-term and long-term timescales.

Unlike the small-scale general features that appear on daily weather maps, the long-term, time-averaged circulation and precipitation fields show large-scale features associated with the annual evolution of the monsoons, trade wind systems, and oceanic convergence zones. Large-scale features are also evident on a monthly and seasonal scale. Interannual variability is dominated by tropical Pacific ocean-atmosphere interactions. These interactions are associated with the ENSO cycle, whose major swings, which occur at irregular intervals of 2-7 years, are associated with pronounced year-to-year precipitation variations over large areas of the tropics. The large-scale spatial coherence and systematic evolution of both intraseasonal and interannual tropical precipitation anomalies is of great significance to climate prediction. They are also important to the development of optimum sampling strategies for estimating accumulated precipitation over periods of a few weeks to a few months.

The characterization of rainfall in tropical regimes is fundamental to improving techniques of radar-rainfall measurements as well. Not only are there regional and seasonal differences, but significant differences also occur within tropical rain systems. These differences can be broadly classified as 1) *morphological*, referring to sizes, lifetimes, and spatial structures of rain producing systems; and 2) *microphysical*, referring to raindrop formation processes, and the raindrop size distribution. Rainfall rates display a highly variable structure in both time and space, meaning radar surveillance systems must take frequent measurements to accurately assess rainfall totals. Three-dimensional volume scans (like the WSR-88D radar scans on the nightly weather reports) every five minutes are desirable, although scans at 15-minute intervals provide useful data. The hydrological and severe weather monitoring requirements of most operational radar systems satisfy these criteria, providing invaluable ground-based validation data with nominal additional expenditure.

Humidity: Atmospheric circulation redistributes moisture and heat. Water vapor evaporates from the ocean and land surfaces, then is transported to other parts of the atmosphere where condensation occurs, clouds form, and precipitation ensues. There is a net outflow of atmospheric moisture from the tropics, where sea-surface temperatures are high and the warm atmosphere can hold large amounts of water

Precipitation and Atmospheric Humidity

vapor, to higher latitudes, where condensation and precipitation remove the moisture. Current numerical weather prediction models give inconsistent results about the future distribution of precipitation.

Humidity is the amount of water vapor in the atmosphere. Water vapor concentration depends on temperature, which determines the total amount of water that the atmosphere can hold without saturation. Hence, water vapor amounts decrease from equator to pole and with increasing altitude. Generally, water amounts are less over the continents than over the oceans, and the upper atmosphere is drier than the near-surface atmosphere. Superimposed on this general behavior are smaller variations of water vapor amounts that determine the formation and properties of clouds and rainfall. Simultaneous imaging of clouds and water vapor by TRMM and EOS AM-1 can provide the data necessary to understand better the interactions among cloud processes and the large-scale flow and distribution of water vapor.

Product Overview

The products included in this section are primarily produced by the TRMM instruments, with MODIS from the EOS AM-1 platform providing two products giving humidity data. The DAS products included in this section are primarily based on TRMM data.

The TRMM mission is designed to use the measurements of multiple instruments flying on its platform to quantify the distribution of the two-thirds of global precipitation estimated to fall in the tropics and subtropics. The PR will measure the 3-D rainfall distribution over both land and ocean. More specifically, this instrument will provide information about the vertical structure of precipitation, the key to determining the latent heat input to the atmosphere. A unique feature is that it will permit the measurement of rain over land where passive microwave precipitation estimation techniques have difficulty.

The fundamental data set to be obtained from the TRMM program is a 3-year sequence of instantaneous rainfall rates as well as monthly, tropical, rainfall accumulations averaged over geographical grid squares 500 km on a side. These gridded monthly averages can be used to validate climate forecasting models. The TRMM data product sequence begins with the TMI and the precipitation radar data, which form the basis of the improved rainfall estimation promised by the mission. Rainfall estimates from the TMI and the PR are combined in TRMM product 3B-31, and then combined with Sun-synchronous low-orbit satellite microwave data (SSM/I), geostationary satellite IR data (e.g., GOES) and rain gauge data to produce the final rainfall product (3B-43).

The MODIS products provide water vapor measurements (MOD 05) needed for atmospheric correction algorithms for all surface parameter retrieval tasks. They are also input to research to improve understanding of the hydrological cycle, energy budget, and climate. The atmospheric stability parameter in MOD 07 gives information on convection and instability which, along with temperature and moisture profiles, also contained in product MOD 07, is needed by the atmospheric correction algorithms.

A set of TRMM ground validation products from approximately 10 independent sites is included. These products provide the rainfall data used to validate the data obtained from the PR on TRMM. Included are the instantaneous surface rainfall maps (2A-53), the radar site Convective/Stratiform Map (2A-54), and the radar site gridded reflectivities (2A-55) used to validate the vertical hydrometeor and latent heating retrievals of the TMI and the PR. Five-day and 30-day rainfall data at the radar sites (3A-53, 54) and monthly 3-D radar reflectivity distributions (3A-55) complete the set of products that are needed to validate and improve all the TRMM rainfall products.

Product Interdependency and Continuity with Heritage Data

The TRMM mission will carry the first quantitative precipitation radar to be flown in space. Previous measurements from space of rain rate have used passive microwave measurements from instruments on Nimbus and the Defense Meteorological Satellites, which are in polar orbits and cannot capture the diurnal variability of rainfall in the tropics. TRMM includes a microwave radiometer (TMI) that provides continuity with these earlier data and which will be used in conjunction with the TRMM PR and the heritage instrument data to provide greatly-improved accuracy in rainfall mapping. The radiometers on TRMM will give good measurements of rainfall rates over the oceans, but such measurements will continue to be less reliable over land where the surface emissivity inhomogeneities make interpretation more difficult. VIRS, which is derived from AVHRR heritage technology, is also included in the TRMM instrument complement so that the rainfall measurements from the radar and passive microwave instruments can be used to better interpret VIS/IR measurements from past and future operational satellites.

The MODIS humidity products will be used by atmospheric characterization and climate modeling researchers in conjunction with the rainfall data even though there is not a direct product dependence between MODIS and TRMM.

The assimilated data products in this section come from the GEOS DAS. This system combines a global general circulation model with standard meteorological observations, along with TRMM and AM-1 observations, to produce dynamically consistent estimates of the fields described.

Suggested Reading

Chiu, L.S., 1988.

Fujita, M., *et al.*, 1985.

Inoue, T. 1987.

Rasmusson, E.M., 1985.

Simpson, J., Ed., 1988.

Simpson, J., *et al.*, 1996.

Theon, J.S., Ed., 1988.

Theon, J.S., *et al.*, Eds., 1992.

Wu, R., J.A. Weinman, and R.T. Chin, 1985.

PR Surface Cross-Section as Function of Scan Angle

Product Description

This Level 2 product provides an estimate of the path attenuation and its reliability by using the surface as a reference target. Path attenuation is estimated by comparing the apparent surface cross section measured in the presence of rain, with the averaged surface cross section measured in the absence of rain. A reliability parameter is also provided based on the variability of the surface cross section in the absence of rain. The product includes the spatial and temporal statistics of the surface scattering cross section, and classification of the cross sections into land/ocean, rain/no rain categories. Output parameters consist of attenuation, reliability, surface cross section (sigma zero).

Research & Applications

One of the ways by which attenuating-wavelength radars such as TRMM can correct for attenuation is by means of the surface reference method. In this method, the path integrated attenuation caused by rain is estimated by a ratio of the apparent surface cross section, σ_o, in the raining region to a temporally or spatially averaged value of this quantity in rain-free regions.

As the surface cross sections are closely related to the vegetation and soil moisture conditions over land, and the wind speed and directions over oceans, a number of TRMM-related studies can be undertaken with these data sets.

Data Set Evolution

There have been limited σ° measurements made from aircraft radars, but systematic global maps have not previously been compiled.

Relation to Other TRMM Products

This product is used as input for the PR rain profiling algorithm (2A-25). For areas far away from rainfall, σ° is a unique product of TRMM.

Suggested Reading

Meneghini. R., and T. Kozu, 1990.

PR 2A-21
PRODUCT SUMMARY

Coverage:
36°N - 36°S; 16 orbits at 220 km each precessing through diurnal cycle

Spatial/Temporal Characteristics:
radar swath, ± 17° incidence,
4 km at nadir

Key Geophysical Parameters:
path attenuation, surface cross section

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
K. Okamoto

PR Rain Occurrence and Rain Type & Bright Band Height

Product Description

The Level 2 product 2A-23 indicates the presence of a "bright band," which in turn indicates the presence of stratiform rain. If the bright band is detected, its height is determined. This information is used to classify the rain type (stratiform type, convective type or warm rain). TSDIS will supply information as to the background type: land, ocean, or indeterminate. The height of the bright band is useful to the TMI algorithms to identify the height of the freezing level.

Research & Applications

PR will provide information on the distribution and characterization of rainfall and latent heating over the global tropics and subtropics. This information will be used to advance the Earth system science objective to understand global energy and water cycles. In addition, it will provide understanding of the mechanism through which tropical rainfall and its variability influence global atmospheric circulation by improving the modeling of rainfall and atmospheric circulation interactions. This will enable the improved prediction of monthly and longer global circulation and rainfall variability. Finally, it will improve modeling of convectively-driven precipitating systems in the tropics, including their organization on the mesocale and their interactions with the ocean and the atmosphere.

Data Set Evolution

There have been a number of airborne radars that have flown on field campaigns over the last few years. Most notably, ARMAR is a 13.8 GHz radar flying on the NASA DC8 which was built specifically to simulate TRMM observations.

Relationship to Other TRMM Products

Product 2A-23 is a qualitative description not previously available. It will be useful to passive microwave as well as input to the PR rain algorithm.

Suggested Reading

Furuhama, Y., *et al.*, 1982.

Iguchi, T. and R. Meneghini, 1994.

Theon, J.S., *et al.*, Eds., 1992.

PR 2A-23
PRODUCT SUMMARY

Coverage:
16 orbits of 760 km each precessing through diurnal cycle

Spatial/Temporal Characteristics:
radar swath, ± 17° incidence,
4 km at nadir

Key Geophysical Parameters:
storm and bright-band height, rain type

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
K. Okamoto

PR Range Profiles of Rain and Water Content

Product Description

Level 2 product 2A-25 retrieves rain parameters over each PR resolution cell (4 km × 4 km × 250 m). Products 1C-21, 2A-21, and 2A-23 are input to this product. In the presence of rain, these parameters include rainfall structure, estimated path attenuation, and its reliability.

Research & Applications

PR will provide information on the distribution and characterization of rainfall and latent heating over the global tropics and subtropics. This information will be used to advance the Earth system science objective to understand global energy and water cycles. In addition, it will provide understanding of the mechanism through which tropical rainfall and its variability influence global atmospheric circulation by improving the modeling of rainfall and atmospheric circulation iterations. This will enable the improved prediction of monthly and longer global circulation and rainfall variability. Finally, it will improve modeling of convectively-driven precipitating systems in the tropics, including their organization on the mesocale and their interactions with the ocean and the atmosphere.

Data Set Evolution

There have been a number of airborne radars that have flown on field campaigns over the last few years. Most notably, ARMAR is a 13.8 GHz radar flying on the NASA DC8 which was built specifically to simulate TRMM observations.

Relationship to Other TRMM Products

Product 2A-25 provides the best single instrument rain profile information. Over the narrow swath of the radar it will be used to improve the passive microwave algorithm (2A-12), thereby extending the usefulness of the PR to the wide swath of the TMI.

Suggested Reading

Iguchi, T. and R. Meneghini, 1994.

Kozu, T., *et al.*, 1991.

Theon, J.S., *et al.*, Eds., 1992.

PR 2A-25

PRODUCT SUMMARY

Coverage:
day and night, 38°N - 38°S

Spatial/Temporal Characteristics:
swath PR resolution cell: 4 km × 4 km, 250 m vertical at nadir

Key Geophysical Parameters:
rain rate profile

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
K. Okamoto

TMI Surface Rainfall and Vertical Structure

Product Description

This product contains vertical hydrometeor profiles from the TMI obtained by blending the radiometric data with dynamical cloud model data. The results consist of the surface rainfall rate and a confidence parameter, as well as 3-D results, with five hydrometeor classes and the associated latent heating derived at ~ 14 vertical layers. The layer information must be viewed as approximate since it is inferred through the cloud model rather than from direct measurements. This is a Level 2 product which has not been resampled; scan time, latitude, longitude, and scan line/pixel number are included for each pixel in this product.

Research & Applications

The research objectives of this product include

- improve the ability to obtain rainfall and latent heat release over the global tropics;
- validate and improve models that promote the understanding of the formation and organization of convection and their interactions with the ocean and ambient atmosphere and the climate system; and
- advance understanding of the Earth's global energy and water cycles by determining how tropical rainfall and its variability influence global circulation.

Relationship to other TRMM products

This product generates output similar to 2A-25 and 2B-31. Product 2A-25, the PR rainfall vertical structure has better vertical resolution (250 m), but is limited to a relatively narrow swath of 220 km as compared to the 760 km swath of the TMI. Sensitivity to the integrated ice content is also greater from the TMI product that the PR product.

Product 2B-31 combines information from both the radar and radiometer over the narrow swath of the radar. In this region, 2B-31 should ultimately provide the best surface rainfall and structure products. Problems related to co-registration of the sensors, as well as the lack of PR heritage, make this product (2B-31) less reliable at the onset of the mission.

Data Set Evolution & Applications

The TMI is similar to several spaceborne microwave instruments which have flown over the past decade, including the SSM/I on-board the DMSP satellites and the SMMR on-board Nimbus-7. The major changes are the addition of 10 GHz dual-polarized-channels and increased spatial resolution, which will reduce the footprint filling uncertainty that affects passive microwave algorithms.

Suggested Reading

Kummerow, C., and L. Giglio, 1994.

Mugnai, A., *et al.*, 1993.

Smith, E.A., *et al.*, 1994.

Smith, E.A., *et al.*, 1994.

TMI 2A-12
PRODUCT SUMMARY

Coverage:
16 orbits of 760 km each precessing through diurnal cycle

Spatial/Temporal Characteristics:
swath, 10 km resolution

Key Geophysical Parameters:
rainfall, hydrometeors, and latent heating profile

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
C. Kummerow

TRMM Combined Surface Rainfall Rate and Vertical Structure

Product Description

This is a Level 2 product which combines information from more than one sensor. This product contains vertical hydrometeor profiles obtained by blending reflectivities obtained by the PR with brightness temperatures from the TMI instrument. The results consist of the surface rainfall rate and a confidence parameter. Also included are the 3-D results, with five hydrometeor classes and the associated latent heating derived at the vertical resolution of the PR (250 m).

This product is designed to improve our ability to obtain rainfall and latent heat release over the global tropics. Additionally, it will be used to validate and improve models that promote the understanding of the formation and organization of convection and their interactions with the ocean and ambient atmosphere and the climate system. Finally, it advances our understanding of the Earth's global energy and water cycles by determining how tropical rainfall and its variability influence global circulation.

Research & Applications

The vertical distribution of hydrometeors is an important part of any surface rainfall rate retrieval algorithm, because the distribution strongly affects the microwave radiances. Once problems associated with different viewing geometries and sensor resolutions are overcome, this product should constitute the best product available from the TRMM mission.

Relationship to Other TRMM Products

This product generates output similar to 2A-12 and 2A-25. Product 2A-12 (the TMI rainfall vertical structure) has wider coverage (760 km vs. 220 km). The PR algorithm serves primarily to ensure a robust solution until problems related to co-registration of the sensors and different spatial resolutions are properly solved.

Data Set Evolution & Applications

The simultaneous use of active and passive microwave sensors can yield dramatic improvements over either sensor alone. Some limited aircraft studies have demonstrated this point. The opportunity to merge radiances from active and passive sensors, as well as visible and infrared radiances on a global dataset, is a capability which is unique to the TRMM satellite. As the algorithm matures, this product will form the cornerstone of TRMM retrievals and will serve as the transfer standard to calibrate previous satellites' measurements.

Suggested Reading

Schols, J.L. and J.A. Weinman, 1994.

Smith, E.A., *et al.*, 1994.

TMI 2B-31
PRODUCT SUMMARY

Coverage:
36°N - 36°S; 16 orbits at 220 km each precessing through diurnal cycle

Spatial/Temporal Characteristics:
swath 4 km at nadir

Key Geophysical Parameters:
rainfall profile

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
E. Smith

TMI Surface Rainfall

Product Description

This product consists of mean monthly rainfalls over 5° × 5° cells. Retrievals are only possible over oceanic areas, where data are needed most for climate model verification. The frequency of occurrence of rain intensities in different rate categories over a specified area can be plotted as a histogram or as a smoothed curve which fits the histogram. This curve is called the probability density function (pdf) of the rain rates. In the case of tropical rainfall, the pdf's are always highly skewed such that a large fraction of the total rainfall is concentrated into a relatively small number of storms of high intensity or in a small fraction of the time or of the area in which it is raining. This product is obtained by considering histograms of 19-GHz, 21-GHz and 19-21-GHz combinations. Monthly rainfall indices are computed by statistically matching the histograms with the model calculated pdfs. The main purpose of this product is to provide a robust baseline of surface rainfall rates.

Research & Applications

This product is designed to advance understanding of the Earth's global energy and water cycles by determining how tropical rainfall and its variability influence global circulation. A reliable measurement of rainfall, particularly over the oceans, will provide for the first time space-time variability of vertically integrated latent heating. This, coupled with information on the nature of synoptic disturbances in different regions of the tropics, can help determine the vertical structure of the diabatic heating.

Data Set Evolution

The TMI is similar to several spaceborne microwave instruments which have flown over the past decade including the SSM/I on-board the DMSP satellites and the SMMR onboard Nimbus-7. The major changes are the addition of 10 GHz polarized channels and increased spatial resolution, which will reduce the footprint filling uncertainty that affects passive microwave algorithms. The surface rainfall algorithm is very similar to the one developed and applied as part of the GPCP program for the past 8 years.

Relationship to Other TRMM Products

This product generates monthly surface rainfall with sampling corresponding to the wide swath of the TMI. This parameter may also be obtained from the TRMM combined sensor algorithm but is included as a standard product to serve as a very robust baseline.

Suggested Reading

Wilheit, T.T., *et al.*, 1991.

TMI 3A-11
PRODUCT SUMMARY

Coverage:
day and night, 40°N - 40°S
over oceans only

Spatial/Temporal Characteristics:
5° × 5°, monthly

Key Geophysical Parameters:
rainfall amount and statistics

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
A. Chang

PR Accumulated Rainfall and Vertical Structure, Accumulated Surface Rainfall

Product Description

Statistics of rain data are provided in this Level 3 product, including probability distributions of rain rates, to help identify and characterize sampling errors, and to determine patterns in precipitation movement and latent heat transfer. The statistical nature of the rainfall is characterized by the outputs from the Level 2 radar algorithms. Four categories of output products will be computed over $5° \times 5° \times 1$ month domains. The four categories are: mean and variance of the rain rate at five heights above the surface; fractional rain areas (stratiform, convective, both); histograms of the rain rates, reflectivity factors, heights of the bright-band and storm top, and path attenuation; and correlation coefficients between rain rates at the various heights.

Research & Applications

This product is designed to provide the temporal continuity and spatial coverage necessary for routine evaluation of time-space mean precipitation. Applications include quantitative estimates of large scale, time-averaged precipitation over the global tropics, analyses of the seasonal, interannual and diurnal variability of precipitation, and the establishment of multiyear time series data for global climate change.

Relationship to Other TRMM Products

Inputs to algorithm 3A-25 will be the output products from the Level 2 PR algorithms. A few of the output products from 3A-25 and 3A-26 will provide estimates of the same quantity (e.g., the monthly mean rain rate at the $5° \times 5°$ boxes over the TRMM domain). The approach used in 3A-25 is that of a straightforward sample mean of the individual measurements obtained during the month whereas 3A-26 uses a somewhat more involved statistical approach. Comparisons of these products over the TRMM ground-validation sites are obviously important. As the TMI 3A-11 algorithm will output monthly means over the same $5° \times 5°$ cells as will 3A-25 and 3A-26, comparisons of the output products should be made. To reduce the effects of sampling errors on 3A-25 and 3A-26, comparisons of these outputs with those of 3A-11 should also be made over longer time periods (3 months, 6 months, and yearly).

Data Set Evolution

Approaches for measuring statistically averaged rain rates for TRMM have their heritage in the GARP Atlantic Tropical Experiment (GATE) measured rain rates experiments, as well as the Florida Area Cumulus Experiment (FACE). The GATE and FACE radar rain distributions were the heritage data sets used to describe some of the key statistics characteristics of the precipitation which TRMM is intended to measure. Additionally, by identifying the ranges of rain rates measured in these experiments, they served to enable instrument designers to better specify the parameters of and performance of the observing system.

Suggested Reading

Atlas, D., *et al.*, 1990.

Meneghini, R. and J.A. Jones, 1993.

Wilheit, T.T., *et al.*, 1991.

TRMM 3A-25, 3A-26
PRODUCT SUMMARY

Coverage:
40°N - 40°S

Spatial/Temporal Characteristics:
$5° \times 5°$, monthly

Key Geophysical Parameters:
rain rate statistics, storm top height, path attenuation

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
K. Okamoto

Combined Accumulated Rainfall and Vertical Structure

Product Description

This Level 3 product consists of rainfall accumulations over $5° \times 5°$ areas and monthly time scales of surface rainfall, as well as the 3-D hydrometeor structure and measurements of latent heating. Retrievals are made over both land and ocean using the sampling characteristics of the TMI instrument. The product is a calibration of the TMI profiling algorithm (2A-12), where the calibration is obtained by comparing the coincident geophysical products from the TMI 2A-12 with those of the combined sensors approach (2B-31). The calibration coefficients are then applied to the entire 2A-12 dataset and monthly accumulations are computed.

The simultaneous use of active and passive microwave sensors can yield dramatic improvements over either sensor alone, as demonstrated by earlier aircraft studies. The opportunity to merge radiances from active and passive sensors as well as visible and infrared radiances on a global dataset is a capability which is unique to the TRMM satellite. As the algorithm matures, this product will form the cornerstone of TRMM retrievals and will serve as the transfer standard to calibrate previous satellites measurements.

Research & Applications

At present there are no reliable data sets for either monthly or seasonal mean rainfall or for their interannual variability to validate the global atmospheric models. Latent heat derived from precipitation is the major source of energy within the atmosphere, and its vertical distribution affects the stability of the atmosphere and hence the propagation pattern of Rossby waves, which influence the climate in regions that are located far from the tropical storms where the latent energy is released. This product will allow the measurement of latent heating to be calculated from condensation. The direct observation of precipitation, and the cloud systems which produce it in varying amounts, will permit researchers to know exactly where the latent heat is being released. This information can be used as input to climate models to determine higher latitude effects and possible interannual changes.

Relationship to Other TRMM Products

This product generates monthly surface rainfall and latent heating with sampling corresponding to the wide swath of the TMI. Product 3A-25 generates similar products but only uses the narrower swath of the PR.

Data Set Evolution

Precipitation distributions have already been retrieved from spaceborne microwave radiometers, and TMI builds on that earlier work. The primary instrument currently used to retrieve volumetric rainfall from space is the SSM/I passive radiometer system on the DMSP. The TRMM Combined Monthly Rainfall product overcomes the limitation of radiometric measurements, which include difficulty in measuring light rain and snowfall over land. Combing radar and radiometric measurements in a common precipitation retrieval algorithm takes advantage of the strengths of both types of measurements.

Suggested Reading

Smith, E.A., *et al.*, 1994.

Schols, J.L. and J.A. Weinman, 1994.

TRMM 3B-31
PRODUCT SUMMARY

Coverage:
day and night, 40°N - 40°S

Spatial/Temporal Characteristics:
$5° \times 5°$, monthly

Key Geophysical Parameters:
rainfall, hydrometeors, land heating distribution

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
E. Smith

TRMM Combined Instrument Rain Calibration and Combined Instrument Global 1-Degree Rainfall

Product Description

This pair of products implements the "flying rain gauge" aspect of TRMM by calibrating other precipitation estimates with the "best" TRMM estimate of precipitation to provide improved rainfall estimates on finer scales than TRMM can provide by itself. The TRMM Combined Instrument Rain Calibration (3B-42) uses TRMM estimates of surface rain and hydrometeor structure to calibrate and adjust rain estimates made from geosynchronous infrared observations. The "Rainfall" (3B-43) combines 3B-42 with rain gauge analyses (where available) and SSM/I estimates — a passive radiometer system on the Defense Meteorological Satellite Program (DMSP) satellite, similar to the TMI — to objectively determine the best estimate of rainfall on the space and time scales indicated. This includes adjustments for bias between the satellite and gauge fields, where feasible, and objective combination based on the relative errors estimated for each field. Each product has an associated field of estimated error that reflects the local sampling of the various input fields and the reliability of each data source.

TRMM 3B-42, 3B-43
PRODUCT SUMMARY

Coverage:
day and night, 40°N - 40°S

Spatial/Temporal Characteristics:
1° × 1° × 5 day

Key Geophysical Parameters:
rainfall

Processing Level:
4

Product Type:
standard, at-launch

Science Team Contact:
R. Adler

Research & Applications

Surface rainfall in many parts of the world is very poorly documented on the time and space scales that these products provide. These products will provide considerably more detail for validation of numerical weather and climate predictions, accumulations into seasonal-scale climatologies, and input to surface hydrology models. As well, these products will provide systematic insight into the accuracy of the independent input fields, both regionally and seasonally, which will motivate fresh research to improve the precipitation estimation and process.

Relationship to Other TRMM Products

The Surface Rainfall and Vertical Structure (2B-31), and consequently all of the products antecedent to 3B-31, is key to making 3B-42 (and hence 3B-43) as

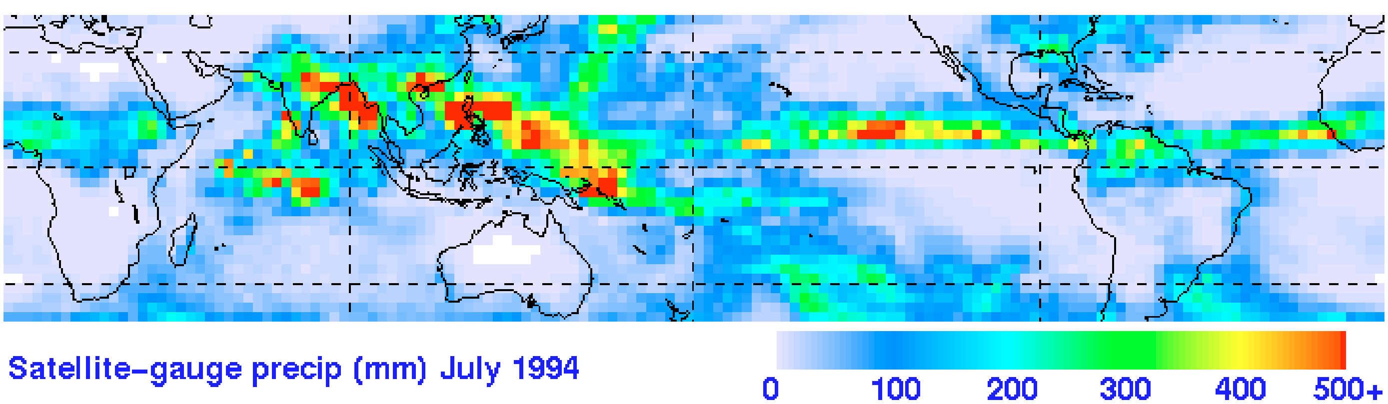


Figure 15. **Satellite-Gauge Estimate of Precipitation for July 1994 (in mm/mo).** This technique for combining low-orbit microwave, geosynchronous-orbit infrared, and rain gauge data is a prototype of TSDIS Algorithm 3B-43.

TRMM Combined Instrument Rain Calibration and Combined Instrument Global 1-Degree Rainfall

accurate as possible. The TRMM VIRS 11 µm temperatures (1B-01) provide key data in the calibration step of 3B-42. The TRMM Global Rainfall products provide finer space and time scales than pure TRMM products, but at the expenses of depending on data sources outside TRMM.

Data Set Evolution

The analysis procedures for 3B-42 and 3B-43 were developed for rainfall estimates from the SSM/I, which has flown on selected DMSP polar-orbiting platforms since mid-1987. The TRMM versions of both procedures are third-generation code; further development is expected as researchers gain experience with the new data sources.

Suggested Reading

Adler, R.F., *et al.*, 1994.

Huffman, G.J., *et al.*, 1995.

Radar Site Rain Map

Product Description

The Level 2A Ground Validation Radar Site Rain Map (2A-53) product contains instantaneous (highest temporal, 2-km horizontal resolution) rainmaps produced from the 1C-51 reflectivity fields. These require application of an appropriate reflectivity (Z) to rain (R) transformation, determined separately for each site on the basis of rain gauge, radar, and raindrop size information.

Research and Applications

This product is used to determine the intensity, duration, and spatial extent of rain producing systems at each ground validation site.

Relationship to Other TRMM Products

This product is necessary to validate instantaneous rainfall retrievals derived from measurements by instruments on the TRMM satellite (2A-12, 2A-25; 2B-31).

Data Set Evolution

Rainfall estimation from surface-based radar observations have been used operationally for several decades in short-term forecasting and for hydrological purposes. Recent upgrades to the operational systems and rainfall algorithms are used in the TRMM Ground Validation Program.

Suggested Reading

Krajewski, W.F., 1987.

Rosenfeld, D., *et al.*, 1994.

Steiner, M., and R.A. Houze, Jr., 1993.

TRMM GV2A-53
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation radar, continuous

Resolution:
2 km (minimum)

Key Geophysical parameters:
rainfall

Processing Level:
2

Product Type:
validation, at-launch

Science Team Contact:
R. Houze

GV Radar Site Convective/Stratiform Map

Product Description

The Level 2A Ground Validation Radar Site Convective/Stratiform Map identifies rainfall from TRMM 2A-53 as occurring from either convective or stratiform type clouds and generated from the reflectivity product 1C-51.

Research and Applications

Characterization of precipitation types as stratiform or convective is essential for determining the vertical profile of heating associated with these two major classifications. Classification methods include information on the vertical and horizontal structure of reflectivity fields.

Relationship to Other TRMM Products

Product 2A-54 will be used to validate the convective/stratiform separation derived by the PR algorithm 2A-23. The convective stratiform classification map will be used as input to 3A-55 to be used in evaluation of the vertical heating profile, which is of interest to large scale models for initialization and validation studies.

Data Set Evolution

Convective/stratiform classification methods have been developed for use in studies of the structure, dynamics, and evolution of tropical mesoscale convective systems.

Suggested Reading

Churchill, D.D. and R.A. Houze, Jr., 1984.

Houze, R.A. Jr., 1989.

Rosenfeld, D., *et al.*, 1995.

Steiner, M., *et al.*, 1995.

TRMM GV2A-54
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation site, continuous

Resolution:
2 km (minimum)

Key Geophysical parameters:
rain type

Processing Level:
2

Product Type:
validation, at-launch

Science Team Contact:
R. Houze

GV Radar Site Reflectivities

Product Description

The Level 2A Ground Validation Radar Site Reflectivity (2A-55) product contains instantaneous (highest temporal, 2-km horizontal resolution) 3-D Cartesian gridded reflectivities, interpolated from volume scan reflectivities (1C-51). The origin and outer boundaries of the 3-D Cartesian grid will be determined by the TRMM Ground Validation Team. In addition to the 3-D gridded reflectivity data, this product will include vertical profiles of the mean reflectivity and the frequency distribution at each height. The frequency distribution will be provided in the form of contoured frequency by altitude diagrams (CFADs). Vertical profiles and CFADs will be provided for the following categories: total, total-land, total-ocean, total-convective, total stratiform, total-anvil, land-convective, land-stratiform, land-anvil, ocean-convective, ocean-stratiform, and ocean-anvil.

Research and Applications

The three-dimensional structure of radar reflectivity is determined by hydrometeor distributions within cloud systems and is indicative of both microphysical and dynamical processes within such systems. The reflectivity structure can be used to simulate satellite observations of precipitating cloud systems, given assumptions about the hydrometeor distributions.

Relationship to Other TRMM Products

This product will be used to validate the vertical hydrometeor and latent heating retrievals of the TMI (2A-12), PR (2A-25), and combined product (2B-31) vertical hydrometeor and latent heating retrievals.

Data Set Evolution

Pre-operational tests within TSDIS began in August 1995 and will continue until the launch of TRMM.

Suggested Reading

Yuter, S.E., and R.A. Houze, Jr. 1995.

TRMM GV2A-55
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation site, continuous

Resolution:
2 km horizontal (minimum); 1.5 km vertical (minimum)

Key Geophysical parameters:
3-D reflectivity

Processing Level:
2

Product Type*:*
validation, at-launch

Science Team Contact:
R. Houze

GV 5 Day Site Rain Map

Product Description

5-day, 2 km × 2 km surface rainfall at site.

Research and Applications

Significant variations in tropical rainfall patterns have been found to occur at periods longer than 5 days. These patterns frequently have large-scale structure and persistence that could be useful for weather prediction and validation of general circulation models.

Relationship to Other TRMM Products

Although TRMM sampling by itself is not sufficient to accurately represent 5-day rainfall totals, supplementary observations of proxy rainfall data observed continuously by other satellites can be calibrated regionally by the validation product to globally map and monitor variations in rainfall patterns occurring at periods in the range of weeks to a month or two. Directly, this product will validate the estimates for the TRMM and other satellite algorithms (3B-42 and 3B-43).

Data Set Evolution

Pre-operational tests within TSDIS began in August 1995 and will continue until the launch of TRMM.

Suggested Reading

Huffman, G.J., *et al.*, 1995.

Rosenfeld, D., *et al.*, 1994.

Steiner, M., and R.A. Houze, Jr., 1993.

TRMM GV3A-53
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation radar, continuous

Spatial/Temporal Characteristics:
5-day accumulations, 2 × 2 km

Key Geophysical Parameters:
surface rainfall

Processing Level:
3

Product Type:
validation, at-launch

Science Team Contact:
R. Houze

GV 30 Day Site Rain Map

Product Description

30-day, 2 km × 2 km surface rainfall at site.

Research and Applications

This product will be used to validate the satellite algorithms and to provide independent validation to climate and forecast models.

Relationship to Other TRMM Products

This product is the principal means of validating all the TRMM monthly 5° × 5° rainfall estimates.

Data Set Evolution

Rainfall estimation from surface-based radar observations have been used operationally for several decades in short term forecasting and for hydrological purposes. Recent upgrades to the operational systems and rainfall algorithms are used in the TRMM Ground Validation Program.

Suggested Reading

Huffman, G.J., *et al.*, 1995.

Rosenfeld, D., *et al.*, 1994.

Steiner, M., and R.A. Houze, Jr., 1993.

TRMM GV3A-54
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation radar, continuous

Spatial/Temporal Characteristics:
30-day accumulations, 2 × 2 km

Key Geophysical Parameters:
rain vertical structure and latent heating

Processing Level:
3

Product Type:
validation, at-launch

Science Team Contact:
R. Houze

GV Monthly 3-D Structure

Product Description

This product contains vertical profiles of the mean reflectivity and the frequency distribution at each height. The frequency distribution will be provided in the form of CFADs. Vertical profiles and CFADs will be provided for the following categories: total, total-land, total-ocean, total-convective, total-stratiform, total-anvil, land-convective, land-stratiform, land-anvil, ocean-convective, ocean-stratiform, and ocean-anvil.

Research and Applications

The 3-D structure of radar reflectivity is determined by hydrometeor distributions within cloud systems and is indicative of both microphysical and dynamical processes within such systems. The reflectivity structure can be used to simulate satellite observations of precipitating cloud systems, given assumptions about the hydrometeor distributions.

Relationship to Other TRMM Products

This product is necessary to cross-check the vertical structure retrieved by TRMM satellite instruments (3A-25, 3A-26; 3B-31).

Data Set Evolution

Pre-operational tests within TSDIS began in August 1995 and will continue until the launch of TRMM.

Suggested Reading

Keenan, T.D., *et al.*, 1988.

Yuter, S.E., and R.A. Houze, Jr. 1995.

TRMM GV3A-55
PRODUCT SUMMARY

Coverage:
150 km radius of ground validation radar, continuous

Spatial/Temporal Characteristics:
30-day accumulations, 2 × 2 km

Key Geophysical Parameters:
3-D reflectivity

Processing Level:
3

Product Type:
validation, at-launch

Science Team Contact:
R. Houze

MODIS Total Precipitable Water

Product Description

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.

Both daily Level 2 (MOD 05) and daily, 8-day, and monthly Level 3 (MOD 08) gridded averages are included. 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 5×5 1-km pixel resolution both day and night using the infrared algorithm when at least 9 FOVs are cloud free. The infrared-derived precipitable water vapor is generated as one component of product MOD 07, and simply added to product MOD 05 for convenience. Level 3 data are computed on 0.5° latitude and longitude, equal area and equal angle grids.

The solar retrieval algorithm relies on observations of water vapor attenuation of reflected solar radiation in the near-infrared MODIS channels so that the product is produced only over areas where there is a reflective surface in the near IR.

Research & Applications

The near-infrared total column precipitable water is very sensitive to boundary layer water vapor since it is derived from attenuation of reflected solar light from the surface. This data product is essential to understand the hydrological cycle, aerosol properties, aerosol-cloud interactions, energy budget, and climate. Of particular interest is the collection of water vapor data above cirrus cloudiness, which has important applications to climate studies. MODIS will also provide finer horizontal scale atmospheric water vapor gradient estimates than are currently available from the POES.

Data Set Evolution

The solar column water vapor parameter is derived from the attenuation by water vapor of near IR solar radiation. Techniques employing ratios of water vapor absorbing channels 17, 18, and 19 with the atmospheric window channels 2 and 5 are used. The ratios remove partially the effects of variation of surface reflectance with wavelength and result in the atmospheric water vapor transmittances. The column water vapor amounts are derived from the transmittances based on theoretical radiative transfer calculations and using look-up table procedures. MODIS is the first space instrument to use near IR bands together with the traditional IR bands to retrieve total precipitable water. Experience in this

MOD 05, MOD 08
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
varies with retrieval technique;
1 km near-infrared daylight only, and
5 km infrared day and night (Level 2),
0.5° (Level 3)/daily, 8-day, and monthly

Key Science Applications:
hydrological cycle climatology, effect on aerosol and clouds, atmospheric correction, characterization of the atmosphere

Key Geophysical Parameters:
atmospheric total column water vapor

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
B. C. Gao, Y. Kaufman, D. Tanré,
P. Menzel

MODIS Total Precipitable Water

retrieval is based on an AVIRIS instrument aboard an ER-2 aircraft. Atmospheric water vapor should be determined with an accuracy of 5-10%.

The thermal column water vapor parameter is derived by integrating the moisture profile through the atmospheric column. Other split window methods also exist. This class of techniques uses the difference in water-vapor absorption that exists between channel 31 (11 µm) and channel 32 (12 µm).

Data validation will be conducted by comparing these data with water vapor measurements from the NWS radiosonde network, from ground-based upward-looking microwave radiometers, and from a ground-based sunphotometer network. Quality control will be performed in two dimensions. The first will be comparisons of specific validation sites across as many different climatic and geographic regions as possible. The second will be a statistical analysis of the entire data set.

Suggested Reading

Gao, B.-C. and A.F.H. Goetz, 1990.

Gao, B.-C., *et al.*, 1993.

Green, R.O. and J.E. Conel, 1995.

Jedlovec, G.J., 1987.

Kaufman, Y.J. and B.-C. Gao, 1992.

King, M.D., *et al.*, 1992.

Kleepsies, T.J. and L.M. McMillan, 1984.

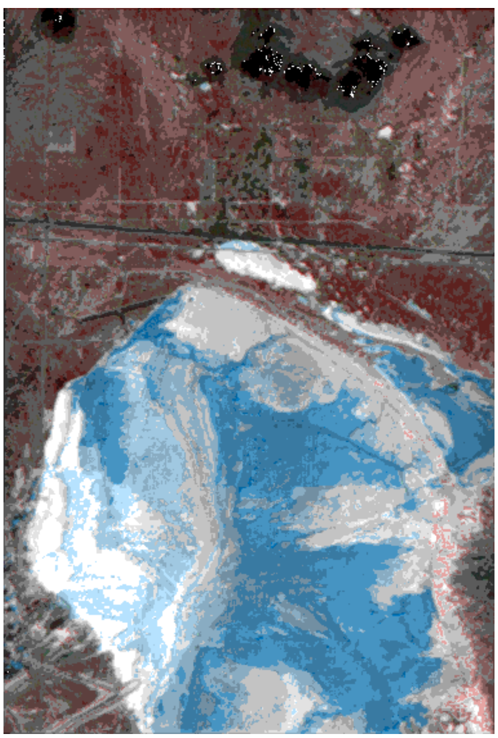


Figure 16. **Total Precipitable Water** (Green and Conel, 1995). The figure on the left represents an AVIRIS false color image of Rogers Dry Lake, California, while the figure on the right corresponds to derived column water vapor. In the water vapor image, black represents precipitable water of 1.2 cm and white precipitable water of 1.5 cm. The spatial variability of water vapor values is up to 20% over this topographically uniform terrain, but is easily detectable from measurements of solar radiation reflected by the surface in the near-infrared spectral region.

DAS Assimilated Soil Moisture

Product Description

This Level 4 product consists of 3-hourly estimates of soil moisture at 3 levels; shallow, root, and deep. It is produced by the land-surface model of the GEOS DAS. This model estimates the net balance of water into and out of the soil considering precipitation, snowmelt, evaporation, and runoff.

Research & Application

Soil moisture is a crucial part of the Earth's hydrologic system. Vegetation depends on soil moisture. In addition, there is constant moisture feedback between the solid Earth and atmosphere. Like the atmosphere, the soil is a vast reservoir of moisture. An accurate depiction of the Earth's hydrologic state must include estimates of soil moisture.

Data Set Evolution

Soil moisture derived directly from satellites is sporadic and often inaccurate. Data assimilation provides an alternative for estimating global soil moisture. Numerical weather prediction centers like the European Centre for Medium Range Weather Forecasts (ECMWF) and NCEP include soil moisture parameterizations in their forecast models. The GEOS DAS will extend these techniques beyond the current state-of-the-art by including new EOS observations to improve precipitation estimates and incorporating improved land-surface models.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 02
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
soil moisture at 3 levels: shallow, root, and deep

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Surface Moisture

Product Description

This Level 4 product consists of 3-hourly estimates of the surface saturation specific humidity produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS.

Research & Application

An estimate of the surface saturation specific humidity is needed to determine evaporation rates over land. Evaporation is a critical element in the moisture feedback between Earth and atmosphere. An accurate depiction of the Earth's hydrologic state must include estimates of soil moisture.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products will greatly improve the accuracy and coverage of the data used to produce this field. In addition, data assimilation provides dynamically consistent estimates of surface moisture through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 03
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface saturation specific humidity

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Surface Evaporation

Product Description

This Level 4 product consists of 3-hourly estimates of the surface evaporation produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, moisture, and wind observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. The calculation of evaporation within the GEOS DAS is based on the vertical gradient of moisture, the potential evapotranspiration fraction for the given surface type (1 over oceans), and the turbulent eddy exchange coefficient for heat and moisture at the surface.

Research & Application

Evaporation is a critical element in the moisture feedback between Earth and atmosphere. An accurate depiction of the Earth's hydrologic state must include surface evaporation.

Data Set Evolution

There are a wide variety of pressure, temperature, moisture, and wind data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products will greatly improve the accuracy and coverage of the data used to produce this field. In addition, data assimilation provides dynamically consistent estimates of evaporation through its general circulation model that takes into account global circulation systems, precipitation, and radiation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 04
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface evaporation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Moisture Profile

Product Description

This Level 4 product consists of 6-hourly estimates of atmospheric moisture produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Specific humidity at 2 and 10 m above the surface are contained in Q2M and Q10M. Mixing ratios are available at mandatory pressure levels in MIXR. Estimates of the error in the assimilated mixing ratios are given in MIXRE. Relative humidity at mandatory pressure levels are in RH. Vertical profiles of specific humidity at both mandatory pressure and model sigma levels are given in SPHU.

Research & Application

Water vapor is a key greenhouse gas and thus crucial to global climate change. It is also a critical element in the Earth's hydrologic cycle. Determining the global distribution of water vapor is essential to global change research.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of water vapor through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 05
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, 24 mandatory pressure or 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
moisture profiles (mixing ratio, relative humidity, and specific humidity)

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Hou, D. Ledvina

DAS Assimilated Moisture Changes

Product Description

This Level 4 product consists of 6-hourly estimates of atmospheric moisture changes at a given level of the atmosphere estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. TURBQ is an estimate of the moisture change taking place at a given level as a result of turbulent mixing. MOISTQ is an estimate of the moisture change taking place at a given level as a result of convection. Both fields are available at mandatory pressure and model sigma levels.

Research & Application

Water vapor is a key greenhouse gas and thus crucial to global climate change. It is also a critical element in the Earth's hydrologic cycle. These fields provide important insight into the vertical exchange of moisture taking place at both large scales and sub-grid scales.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of water vapor changes through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 06
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 24 mandatory pressure and 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
moisture changes from turbulence and convection

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Moisture Flux

Product Description

This Level 4 product consists of 3-hourly estimates of vertically integrated atmospheric moisture flux estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. The field is separated into two components, VINTUQ (zonal u-wind) and VINTVQ (meridional v-wind).

Research & Application

Water vapor is a key greenhouse gas and thus crucial to global climate change. It is also a critical element in the Earth's hydrologic cycle. Changes in moisture flux can lead to extreme conditions like droughts or floods.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of moisture flux through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 07
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
vertically integrated atmospheric moisture flux

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Precipitable Water

Product Description

This Level 4 product consists of 3-hourly estimates of precipitable water produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS.

Research & Application

Water vapor is a key greenhouse gas and thus crucial to global climate change. It is also a critical element in the Earth's hydrologic cycle. Precipitable water provides a quick estimate of the horizontal distribution of water vapor.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of precipitable water through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 08
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
precipitable water

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Hou, D. Ledvina

DAS Assimilated Precipitation

Product Description

This Level 4 product consists of 3-hourly estimates of precipitation rates (mm/day) produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Two fields are provided, total precipitation rate (PREACC) and convective precipitation rate (PRECON).

Research & Application

Precipitation is a critical element in the Earth's hydrologic cycle.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of precipitation through its general circulation model that takes into account global circulation systems and local convective processes.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 09
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
precipitation rates (total and convective)

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Chapter Six

Cloud and Aerosol Properties and Radiative Energy Fluxes

Cloud and Aerosol Properties, and Radiative Energy Fluxes

Relationship to Global Change

The flow of energy to and from the Earth is modulated by clouds and aerosols. As such, measuring and understanding these elements is key to predicting climate change and to testing global climate models. The technology for accurately measuring radiative fluxes, cloud properties, and aerosol properties from space has advanced to the point that these observations can be used to greatly advance our ability to address critical global change issues. For example: if the global climate changes, do clouds act as a positive or negative feedback? Do aerosols offset some of the expected warming from increasing greenhouse gases? The products described below provide key global observations needed to explore these questions.

CLOUDS: A key step in measuring cloud properties from space is to determine where clouds exist, how they are distributed through the atmosphere, and what their dimensions are. Once clouds are identified and mapped, cloud properties such as effective particle size, thermodynamic phase (water, ice), cloud top properties, and optical thickness (which all help determine how much radiation passes through them) may be measured. The MODIS, MISR, and ASTER instruments on the EOS AM-1 platform and the VIRS instrument on TRMM will provide these key cloud measurements. The daily observations provided by these instruments also will provide the sampling needed to drive and verify climate models.

AEROSOLS: The measurement of aerosols, suspended particles in the atmosphere (e.g., dust, sulfate, smoke, etc.), is an important element in describing energy transmission through the atmosphere. Aerosols are a significant source of uncertainty in climate modeling because they affect cloud microphysics by acting as condensation nuclei, thereby affecting cloud radiative properties. They also interact directly with solar radiation, thus affecting the radiative balance. The location of anthropogenic aerosols is also an important consideration in their impact on climate. While TRMM data will not directly address aerosol concentrations or properties, aerosol products described here, derived from MODIS and MISR on AM-1, will provide new information on aerosol formation, distribution, and sinks over both the land and ocean.

RADIATION: The flow of radiation from the Sun to the Earth, its absorption, reflection, and emission, determines the energy balance of the Earth, and hence the nature of the life of its inhabitants. The information from products describing optical and physical properties of clouds and aerosols is combined with broadband radiation measurements from CERES to provide estimates of solar and infrared radiative fluxes, which in turn determine the heating and cooling of the Earth and the atmosphere. The radiation estimates needed to do this are both shortwave and longwave fluxes at the surface and at the top of the atmosphere, both downwelling and upwelling, so that the net flow can be determined. Also, fluxes must be distinguished between cloudy and clear-sky regions, and the fluxes over a series of elevation intervals are needed to test atmospheric models.

Product Overview

The physical quantities that must be measured for the cloud, aerosol, and radiation categories are discussed in the previous section. In this section we relate the data products to these measurement needs and explain how the product groups support the overall global change program. An evolutionary approach to product generation for the CERES cloud and radiation products will be used to implement a progression from ERBE to CERES algorithms. The ERBE program has produced a ten-year record of cloud and radiation budget information and CERES will continue these measurements.

Starting 6 months after launch (following instrument and analysis validation) CERES will begin production of ERBE-Like data products. These TOA fluxes will use the ERBE analysis algorithms to allow consistent comparisons to historical ERBE data. The first 24 months after launch will be used to develop a new set of CERES angular distribution models (ADMs). These ADMs are used to convert broadband CERES radiances (i.e., radiative energy at a single viewing direction) into estimates of broadband hemispheric fluxes. The CERES rotating

Cloud and Aerosol Properties, and Radiative Energy Fluxes

azimuth plane scan mode will be used along with the cloud properties derived using VIRS and MODIS data to derive a new and much more accurate set of ADMs. Beginning 24 months after launch, these more accurate CERES estimated TOA fluxes will be produced in addition to the ERBE-Like data. Finally, starting 30 months after launch, CERES will routinely provide estimates of radiative fluxes at the surface and at a selected number of levels within the atmosphere. The number of atmospheric levels will depend on the accuracies determined during post-launch validation.

All the CERES products except the ERBE-like products are classed as "post-launch" for the reasons discussed above. The MODIS, MISR, and ASTER products are "at-launch" except for the gridded MISR products (MIS 07, MIS 08) and AST 13. The following section discusses how these products satisfy the measurement needs in the three categories.

The **cloud products** provide the parameters needed to determine how much solar radiation reaches the Earth and how much escapes back to space. The parameters also supply information on factors that influence cloud formation and forces driving circulation and global climate. The cloud products fall into two classes: (1) *cloud detection and delineation*, and (2) *cloud property retrieval*. *Cloud detection and delineation* produces masks indicating where clouds exist and information on layering and overlap to give a geometric picture of global cloud coverage. *Cloud property retrieval* quantifies the physics of the cloud by means of parameters such as optical thickness, temperature, liquid water content, ice water content, particle radius, cloud top altitude, and phase, which all relate to the radiative transmission, reflection, and emission of the cloud.

The CERES cloud detection process uses TRMM VIRS and AM-1 MODIS observations to produce a global binary mask indicating the presence or absence of a cloud in each pixel. The MISR cloud products provide along-track directional reflectance measurements of clouds that will enable development of bidirectional models for different cloud types, especially for horizontally inhomogeneous cloud fields. Stereo matching of MISR multi-angle imagery enables cloud top elevations to be obtained. These parameters are provided in products MIS 04 and MIS 07. The ASTER cloud product (AST 13) also provides stereo views of cloud cover, which will complement the MISR data and will permit cloud top elevation estimation. The major advantage of the ASTER cloud product is the high spatial resolution that allows the study of individual cloud cells. The disadvantage is very limited spatial and time coverage. The ASTER products are also tuned to the difficult polar cloud detection task, which will include the detection of water clouds and ice clouds. The MODIS cloud mask (MOD 35) is a global product that provides a probability that a view of the Earth is obstructed by cloud and whether cloud shadow is detected. It also provides information on the processing path taken by the algorithm (land/sea, day/night, etc.), along with individual spectral test results used in the determination of the final cloud mask product.

Cloud physical properties are obtained using a set of algorithms operating on multispectral imagery data from multiple sources including MODIS and VIRS. CERES cloud properties include cloud layer mapping, cloud-top and cloud base pressure, infrared emissivity, liquid water path, particle radius, and cloud overlap, all derived from MODIS or VIRS data and remapped onto the broadband CERES fields of view for studies of the Earth's atmosphere energy distribution. The MODIS cloud property parameters include particle size and phase, optical thickness, cloud top height, emissivity and temperature, and cloud fraction in a region, all of which support specific MODIS science tasks that complement the radiation studies and products from other instruments.

Aerosol Properties are provided by MODIS (MOD 04) and MISR (MIS 05). Aerosols must be accounted for during the retrieval of surface and atmospheric parameters. The MODIS aerosol products will document one of the most elusive and least understood radiatively active components of the atmosphere by providing information on aerosol optical thickness, aerosol size distribution, and aerosol sources and sinks. MISR provides unprecedented constraints on aerosol optical depth over ocean and many land surfaces along with information about particle size, sphericity, and

Cloud and Aerosol Properties, and Radiative Energy Fluxes

comsitional type. Both MODIS and MISR will aid in understanding how sunlight is absorbed by aerosols, determining global aerosol budgets, and improving correction for aerosol effects in the retrieval of surface parameters.

The **Radiant Energy Flux Products** provide estimates of the radiative flux downward and upward at the top-of-atmosphere, at the Earth's surface, and at selected intermediate altitudes, as well as the net flux, which is used to determine the radiation budget. This budget determines the overall heating and cooling of the atmosphere and Earth's surface and subsequent changes in climate. These parameters are generated from CERES data and from the final averaged flux and radiation budget products AVG, ZAVG and CRH. The radiation algorithms use the cloud and aerosol products in the process of determining how much solar radiation is transmitted, reflected, and absorbed in the cloud/atmosphere/Earth surface system, and are thus critical to the success of the global climate monitoring task.

Product Interdependency and Continuity with Heritage Data

The products from these instruments, especially the cloud products from MODIS, CERES, MISR, and ASTER, are interrelated on a number of levels. First, many algorithms require output products from other instruments as ancillary input data. For example, CERES cloud parameters (SSF) require MODIS and TRMM ancillary data products such as the cloud products (MOD 06) and microwave water path (MWP). MISR aerosol optical depth products will benefit from MODIS water vapor measurements, and MISR cloud albedo retrievals will use MODIS cloud phase. The MODIS cloud mask may be used in the viewing decisions of high resolution instruments like ASTER. In many cases, output data from one instrument become input ancillary data for another. This permits the formatting necessary to permit the generation of higher level products, and does not represent a duplication of data products.

Second, surface-viewing instruments will use ancillary data in atmospheric correction algorithms to reduce contamination of surface retrievals. Similar products from different instruments may use different algorithms and are useful for mutual comparison and validation. Finally, a degree of redundancy for principal (especially cloud) products used as ancillary input is necessary to permit alternative sources of ancillary data in the event of instrument failure or degradation.

The CERES instruments on TRMM and AM-1 are a continuation of the ERBE project, extending a heritage of radiation budget products dating back more than a decade. Several CERES data products will use ERBE algorithms to ensure continuity. As with other EOS-era missions, the data sets produced by continuing past missions will provide valuable information on long-term trends. Analysis of the trends will provide valuable input to long-term predictive models, and will enable scientists to interpret better the possible causes or consequences of changes to clouds, aerosols, and radiation budget on global climate change.

Suggested Reading

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Di Girolamo, L. and R. Davis, 1994.

Diner, D.J., *et al.*, 1991.

Holben, B.N., *et al.*, 1992.

Kaufman, Y.J. and C. Sendra, 1988.

Kaufman, Y.J., *et al.*, 1996.

King, M.D., *et al.*, 1992.

King, M.D., 1987.

Ramanathan, V., 1986.

Ramanathan, V., 1987.

Sohn, B.-J. and F.R. Robertson, 1993.

Tanré, D., *et al.*, 1996.

Wang, M. and H.R. Gordon, 1994.

Wielicki, B.A., *et al.*, 1995.

MODIS Aerosol Product

Product Description

The MODIS Aerosol Product (MOD 04) monitors the ambient aerosol optical thickness and size distribution globally over the oceans and the moist parts of the continents. The size distribution is derived only over the oceans; the aerosol type is derived over the continents. Daily Level 2 and daily, 8-day, and monthly Level 3 gridded averages are provided. The Level 2 (MOD 04) data are produced at the spatial resolution of a 10 × 10 1-km (at nadir) pixel array. The Level 3 (MOD 08) spatial resolution is 0.5° latitude and longitude, equal area and equal angle for both ocean and land, and includes not only aerosol but also cloud and water vapor properties.

Research & Applications

Aerosols are one of the greatest sources of uncertainty in climate modeling. Aerosols modify cloud microphysics by acting as CCN, and as a result impact cloud radiative properties and climate. Aerosol scatters back to space and absorbs solar radiation. The MODIS aerosol product will be used to study aerosol climatology, sources and sinks of specific aerosol types (e.g., sulfates and biomass burning aerosol), interaction of aerosols with clouds, and atmospheric corrections of remotely sensed surface reflectance over the land.

Data Set Evolution

Present satellite measurements are limited to reflectance measurements in one (GOES, METEOSAT) or two (AVHRR) channels. There has been no real attempt to retrieve aerosol content over land on a global scale. Algorithms have been developed for use only over dark vegetation. The blue channel on MODIS, not present on AVHRR, offers the possibility to extend the derivation of optical thickness over land to additional surfaces. The algorithms will use MODIS bands 1 through 7 and 22, and require prior cloud screening using MODIS data. Over the land, the dynamic aerosol models will be derived from ground-based sky measurements and used in the net retrieval process.

Over the ocean, 3 parameters that describe the aerosol loading and size distribution will be retrieved. Pre-assumptions on the general structure of the size distribution are required in the inversion of MODIS data and the volume size distribution will be described with two log-normal modes: a single mode to describe the accumulation mode particles (radius < 0.5 μm) and a single coarse mode to describe dust and/or salt particles (radius > 1.0 μm). The aerosol parameters we therefore expect to retrieve are: the ratio between the two modes, the spectral optical thickness, and the mean particle size of the each mode.

The quality control of these products will be based on comparison with ground stations and climatology.

MOD 04, MOD 08
PRODUCT SUMMARY

Coverage:
global over oceans, nearly global over land

Spatial/Temporal Characteristics:
10 km for Level 2; 0.5° latitude and longitude, equal area and equal angle (Level 3)/daily, 8-day, and monthly

Key Science Applications:
aerosol climatology, biomass burning aerosols, atmospheric corrections, cloud radiative properties, climate modeling

Key Geophysical Parameters:
atmospheric aerosol optical depth (global) and aerosol size distribution (oceans)

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
Y. Kaufman, D. Tanré

MODIS Aerosol Product

Suggested Reading

Holben, B.N., *et al.*, 1992.

Kaufman, Y.J. and L.A. Remer, 1994.

Kaufman, Y.J. and B.N. Holben, 1996.

Kaufman, Y.J. *et al*., 1996.

Kaufman, Y.J. and C. Sendra, 1988.

King, M.D., *et al.*, 1992.

Rao, C.R.N., *et al.*, 1989.

Remer, L.A. *et al.*, 1996.

Tanré, D. et al., 1996.

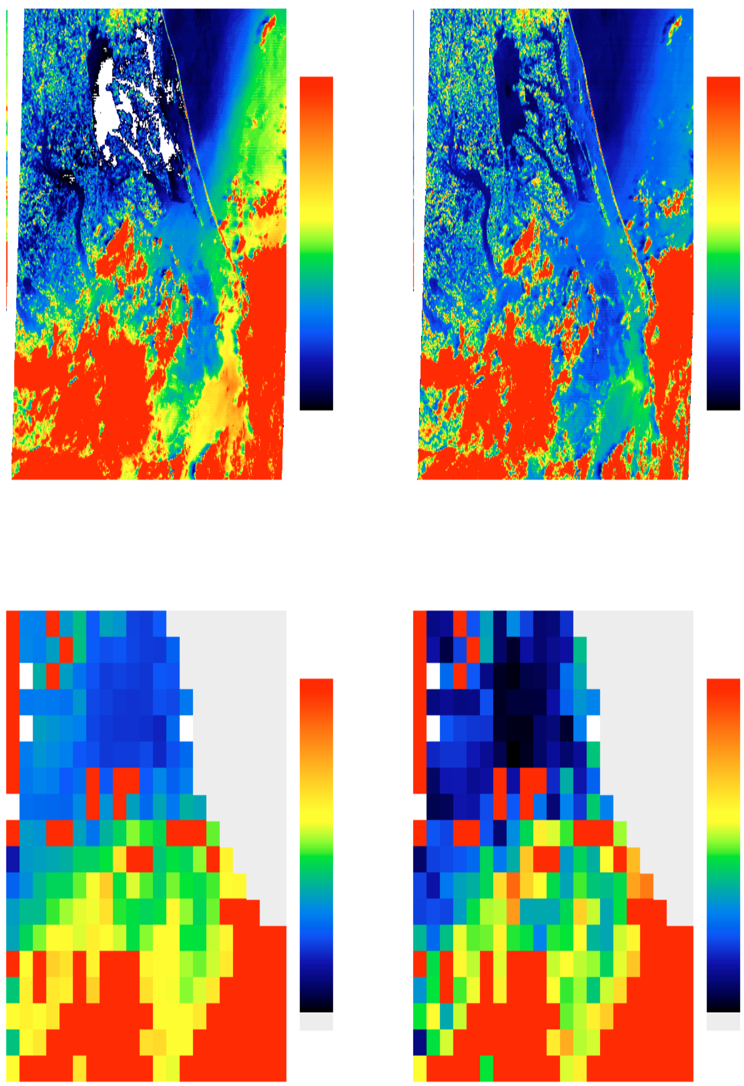

Figure 17. **Aerosol Optical Thickness.** False color Landsat TM image over the North Carolina -Virginia region (12 July 1993). The apparent reflectance of TM 0.47 µm (left) and 0.66 µm channels (right) are shown in the upper panels. The bottom panels are the corresponding aerosol optical thickness retrieved by the MODIS aerosol algorithm for the reduced resolution Landsat image.

MODIS Cloud Product

Product Description

The MODIS Cloud Product (MOD 06) combines infrared and visible techniques to determine both physical and radiative cloud properties. Daily global Level 2 (MOD06) and daily, 8-day and monthly Level 3 products (MOD08) are provided. Cloud particle phase (ice vs. water, clouds vs. snow), effective cloud particle radius, and cloud optical thickness are derived using the MODIS visible and near-infrared channel radiances. An indication of cloud shadows affecting the scene is also provided. Cloud top temperature, height, effective emissivity, phase (ice vs. water, opaque vs. non-opaque), and cloud fraction are produced by the infrared retrieval methods both day and night at 5×5 1-km pixel resolution.

Research & Applications

A thorough description of global cloudiness and its associated properties is essential to the MODIS mission for two reasons. First, clouds play a critical role in the radiative balance of the Earth, and must be accurately described in order to accurately assess climate and potential climate change. In addition, the presence or absence of cloudiness must be accurately determined in order to properly retrieve many atmospheric and surface parameters. For many of these retrievals, cloud cover, even thin cirrus, represents contamination. Key radiative properties of clouds such as phase, optical depth, and temperature may be retrieved using MODIS instruments with unprecedented resolution.

Data Set Evolution

The determination of cloud top properties will require the use of MODIS bands 29 and 31-36, along with the cloud mask product (MOD 35), to screen for clouds. In addition, NCEP or DAO global model analyses of surface temperature and pressure, profiles of temperature and moisture, and blended SST analyses will be required in the calculation of cloud forcing as a function of atmospheric pressure and emissivity. The Menzel cloud phase algorithm will require MODIS bands 29, 31, and 32 and analyses of surface emissivity.

The validation of cloud top heights will be conducted through comparisons with stereo determinations of cloud heights from GOES and lidar estimates and aircraft observations of cirrus heights. Cloud emissivity will be compared to lidar determined values. These interim products will be used in concert with field campaigns with the MAS instrument. The Menzel cloud phase parameter will be validated using HIRS/AVHRR data and by comparison to the King cloud phase parameter.

The King cloud phase algorithm requires product MOD 02, calibrated multispectral radiances. Cloud particle size and optical depth require these radiances plus the cloud top parameters within MOD 06 and

MOD 06, MOD 08
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
varies with parameter; once or twice per day, at resolutions of 1 km or 5 km (Level 2) and 0.5° latitude and longitude, equal area and equal angle (Level 3)/ daily, 8-day, and monthly

Key Science Applications:
cloud parameterization, climate modeling, climate monitoring, increasing accuracy of other MODIS retrievals

Key Geophysical Parameters:
cloud particle phase (two algorithms), cloud particle size and optical depth, and cloud top temperature, emissivity and height

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
P. Menzel, M. King

the Menzel cloud phase parameter. In addition, these parameters require MODIS product MOD 09 (surface reflectance) and the NCEP analyses and profiles described above. The validation and quality control of these products will be performed primarily through the use of *in situ* measurements obtained during field campaigns and with the use of the MAS instrument.

Suggested Reading

King, M.D., *et al.*, 1992.

King, M.D., *et al* ., 1996.

Nakajima, T.Y. and T. Nakajima, 1994.

Platnick, S., *et al* ., 1996.

Strabala, K.I., *et al.*, 1994.

Wylie, D.P., *et al.*, 1994.

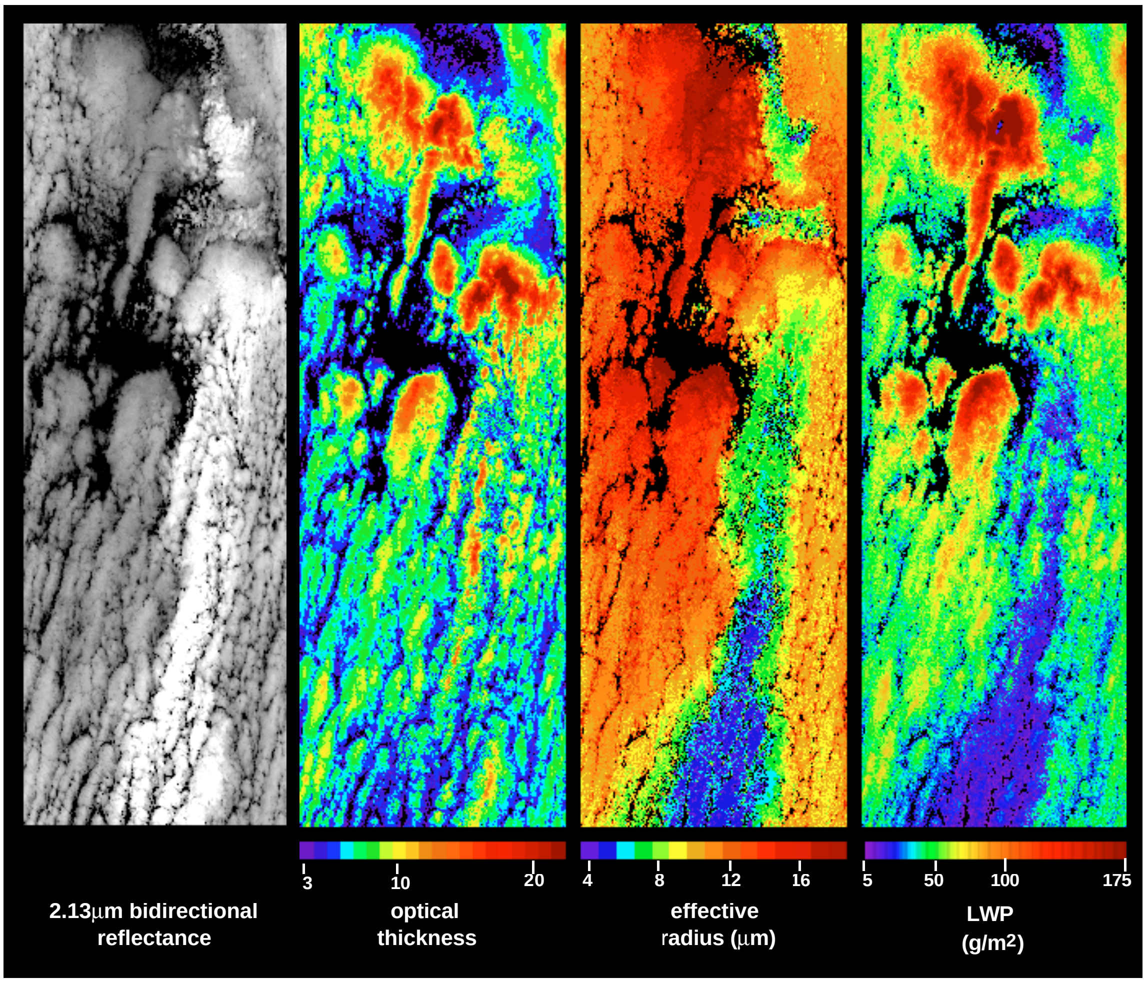

Figure 18. **Cloud Optical Thickness and Effective Radius**. MODIS Airborne Simulator 2.13 µm bidirectional reflectance along with retrieved cloud optical thickness, effective radius, and liquid water path (using MAS visible and 2.13 µm channels) for the southern portion of a ship track imaged off the coast of California on 29 June 1994. The ship is easily seen as the bright region in the reflectance panel and as the lower droplet size in the effective radius panel; the track is not obvious in the optical thickness panel. The last panel is liquid water path which is approximated as being proportional to the product of optical thickness and effective radius.

MODIS Cloud Product

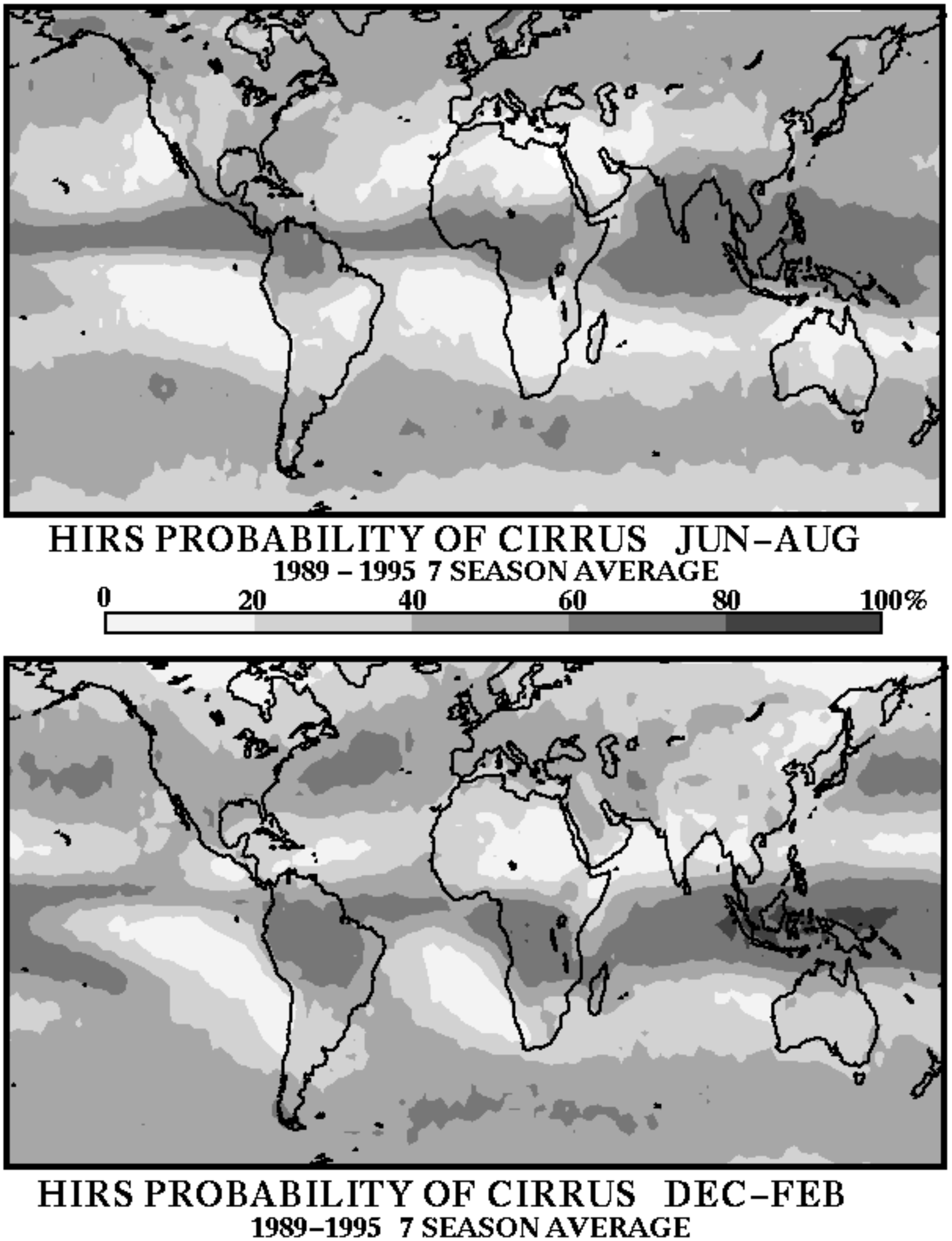

Figure 19. **HIRS Probability of cirrus**. Level 3 MODIS cloud product using a combination of the effective emissivity and cloud top pressure product to determine a geographical distribution of cirrus cloud. HIRS observations were used to generate this example. Top figure is for June-August, and the bottom figure December-February. Both panels represent 7 year averages.

MODIS Cloud Mask

Product Description

The MODIS Cloud Mask (MOD 35) is a daily, global Level 2 product generated at the 1-km and 250-m (at nadir) spatial resolution. The algorithm employs a series of visible and infrared threshold and consistency tests to specify confidence levels that an unobstructed view of the Earth's surface is observed. An indication of shadows affecting the scene is also provided. The 250-m cloud mask flags are based on the visible channel data only. Radiometrically accurate radiances are required, so holes in the Cloud Mask will appear wherever the input radiances are incomplete or of poor quality.

Research & Applications

A determination of the presence of global cloudiness is essential to the MODIS mission for two reasons. First, clouds play a critical role in the radiative balance of the Earth, and must be accurately described to assess climate and potential climate change. Second, the presence of cloudiness must be accurately determined to properly retrieve many atmospheric and surface parameters. For many of these retrieval algorithms even thin cirrus represents contamination.

Data Set Evolution

The MODIS cloud mask algorithm employs a battery of spectral tests, which use methodology applied for APOLLO, International Satellite Cloud Climatology Project (ISCCP), CLAVR, and SERCAA to identify cloudy FOVs. From these a clear-sky confidence level (> 99 percent, > 95 percent, > 66 percent, or < 1 percent) is assigned to each FOV. For inconclusive results, spatial and temporal variability tests are applied. The spectral tests rely on radiance (temperature) thresholds in the infrared and reflectance thresholds in the visible and near-infrared. Thresholds vary with surface type, atmospheric conditions (moisture, aerosol, etc.), and viewing geometry. Along with MOD 02 calibrated radiances, a 1-km land/water mask, DEM, ecosystem analysis, snow/ice cover map, NCEP analysis of surface temperature and wind speed, and an estimate of precipitable water will be required as inputs.

Cloud mask validation will be conducted using MAS data from several field campaigns, all-sky cameras, and comparison with NOAA operational instruments and other EOS AM-1 instruments such as ASTER.

Suggested Reading

Gao, B.-C., *et al.*, 1993.

Gustafson, G.B., *et al.* , 1994.

King, M.D., *et al.*, 1992.

Rossow, W.B. and L.C. Garder, 1993.

Saunders, R.W. and K.T. Kriebel, 1988.

Stowe, L.L., *et al.*, 1991.

MOD 35
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
250 m and 1 km, daily

Key Science Applications:
cloud determination and screening, climate modeling, climate monitoring, increasing accuracy of other MODIS retrievals

Key Geophysical Parameters:
presence of cloud or shadow

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
P. Menzel

MODIS Cloud Mask

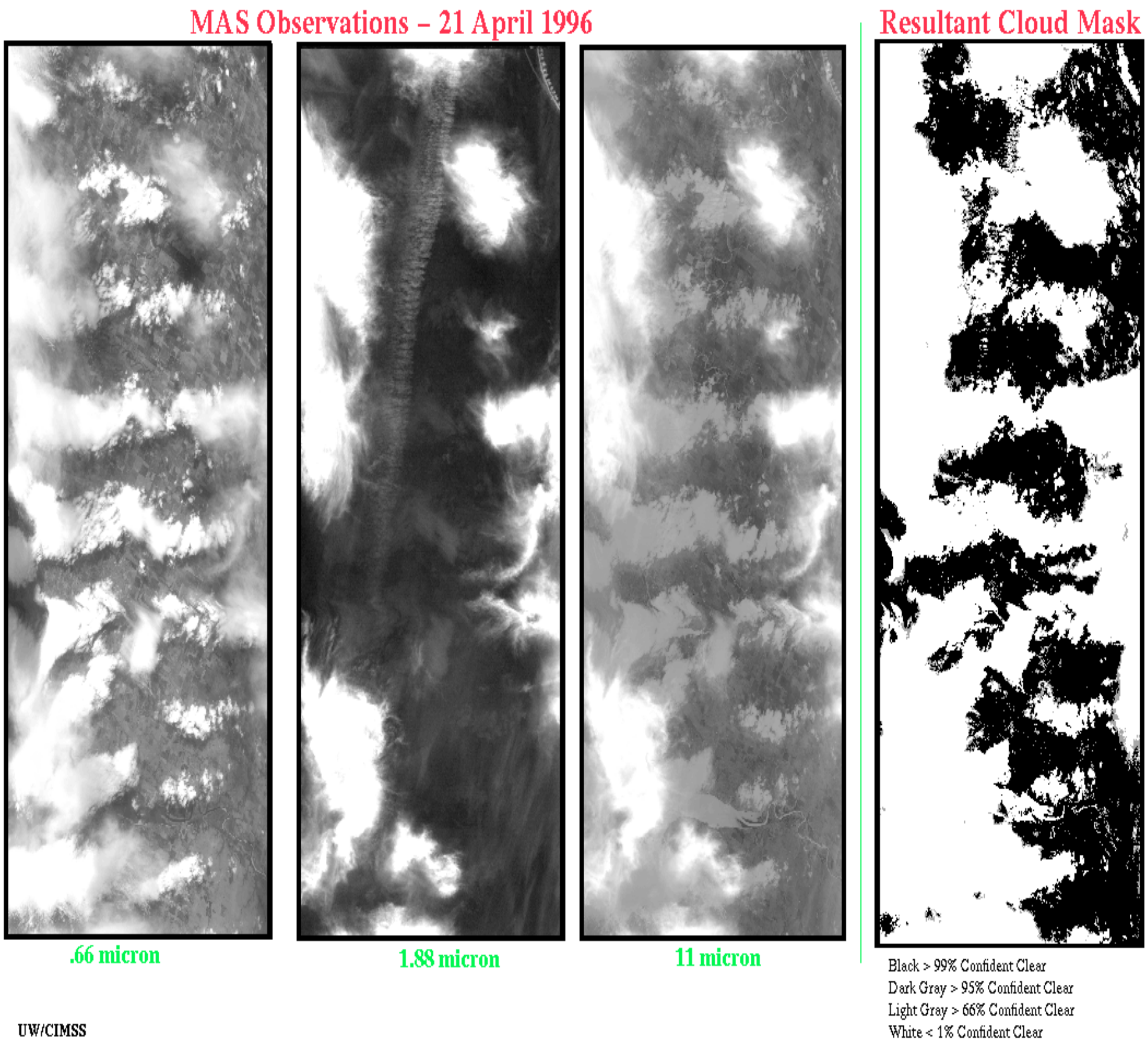

Figure 20. **Cloud Mask.** The three panels on the left represent MODIS Airborne Simulator (MAS) images acquired as part of NASA's Subsonic Assessment Program (SASS) over Oklahoma on 21 April 1996 at 0.66, 1.88, and 11.02 µm. The 1.88 µm channel is sensitive to water vapor absorption and is therefore similar in principle to the 1.38 µm channel that will be used by MODIS to detect the presence of high thin clouds. Each of these channels has difficulty in detecting a certain cloud type. For example, the 1.88 µm channel is least sensitive to the occurrence of low level cloud, while thin cirrus is difficult to detect using the 0.66 µm channel. The final panel is the resultant cloud mask image. Most of the scene is classified as either high confident clear (black) or high confident cloudy (white).

MISR TOA and Cloud Data

Product Description

The Level 2 Top-of-Atmosphere (TOA)/Cloud Product (MIS 04) consists of TOA radiation and cloud information including: finely-sampled (2.2 km) TOA albedo, coarsely-sampled TOA albedos projected to 30-km altitude (35.2 km), TOA bi-directional reflectance factor (BRF) at 2.2 km, and Reflecting Level Reference Altitude (RLRA) for 2.2-km regions, texture indices at 2.2 km, altitude-binned (high, middle, and low) and total cloud fractions at 17.6 km. The coarse TOA albedos provided will include a restrictive albedo, derived from the nine multiangle observations of a single region, and an expansive albedo which is calculated including contributions from surrounding regions, at the appropriate angles. Nadir cloud masks on 1.1-km centers for thick and high clouds will also be included. Data from MIS 04 will be mapped to produce Level 3 globally gridded products (MIS 06, MIS 07) postlaunch.

Research & Applications

The main purpose of the MISR TOA/cloud product is to produce accurate measures of spectral albedo classified by scene type. These will be used to study the global effects of different types of cloud fields, including spatial and temporal dependencies, and to determine their effects on Earth's climate. Bi-directional reflectances of clear and cloudy regions obtained by MISR will be used to develop anisotropic reflectance models classified by cloud type, determine the spatial and temporal variability of cloud albedo, and validate coarse spatial resolution angular reflectance models generated by other instruments. Automated stereo matching of multiangle imagery will be used to estimate cloud-top elevations. In addition, MISR will help to obtain a better understanding of the nonlinear scaling between sub-grid and grid scale processes in GCMs and provide improved parameterization in these models.

Data Set Evolution

Earlier satellites, notably Nimbus-7 (ERB) and NOAA-9 Earth Radiation Budget Experiment (ERBE), pioneered the beginnings of techniques to directly integrate radiances from the same scene, measured more or less coincidentally at several different angles, to yield the hemispherical flux. The Nimbus-7 scanner reduced its FOV to keep the viewed area about the same size, but had to look at different scenes across track and build up directional models. In its along track mode, the NOAA-9 scanner obtained a very limited data set looking at fixed regions, but since its scanner had a fixed FOV the size of the target area changed systematically with angle. The presently available models have been painstakingly constructed from Nimbus-7 data, but cannot accommodate different cloud types, and define only a few categories of cloud cover amounts.

Suggested Reading

Di Girolamo, L. and R. Davies, 1994.

Goodman, A.H. and A. Henderson-Sellers, 1988.

Rossow, W.B. and L.C. Garder, 1993.

Wielicki, B.A. and L. Parker, 1992.

MIS 04, MIS 06, MIS 07
PRODUCT SUMMARY

Coverage:
daytime, 9-day for global repeat coverage

Spatial/Temporal Characteristics:
9-day for global coverage with 1.1 km, 2.2 km, 17.6 km and 35.2 km sampling (various parameters) at Level 2; 16-day, monthly, and seasonal globally gridded products at Level 3

Key Geophysical Parameters:
TOA albedo, TOA bi-directional reflectance factor, reflecting level reference altitude, cloud screens, altitude-binned cloud fraction

Processing Level:
2, 3

Product Type:
standard, at-launch (MIS 04) post-launch gridded products (MIS 06, MIS 07)

Science Team Contact:
R. Davies

MISR Aerosol and Surface Data

Product Description

The Level 2 Aerosol/Surface Product (MIS 05) contains a variety of information on the Earth's atmosphere and surface. The aerosol data include tropospheric aerosol optical depth on 17.6-km centers, archived with a compositional model identifier and retrieval residuals, ancillary data including relative humidity (RH), ozone optical depth, stratospheric aerosol optical depth, and retrieval flags. The land surface data include hemispherical directional reflectance factor, bihemispherical reflectance (i.e., albedo), bidirectional reflectance factor, directional hemispherical reflectance, BRF model parameters, FPAR, and terrain-referenced view and illumination angles. Ocean data include water-leaving equivalent reflectance and phytoplankton pigment concentration. In addition to MIS 05 geophysical products, the mapped, global, seasonal gridded aerosol products (MIS 08) and surface products (MIS 09) also will include tropospheric aerosol absorbed shortwave energy and mass loading, surface shortwave albedo, and selected surface biophysical parameters. The Level 3 globally gridded products (MIS 08 and MIS 09) will be developed post-launch.

Research & Applications

MIS 05, MIS 08, and MIS 09 products will be used to study absorption and scattering in the lower atmosphere and at the surface for use in climate and biosphere-atmosphere interaction studies. The MISR aerosol data sets will enable: (1) the study of the global magnitude and variability of sunlight absorption and scattering by aerosols in the Earth's atmosphere (particularly tropospheric aerosols) and their effect on climate; (2) improved understanding of the sources, sinks, and global budgets of aerosols; and (3) improved atmospheric correction for surface imaging data acquired by MISR and other instruments (e.g., MODIS and ASTER).

The MISR surface data sets will enable: (1) the study of the global magnitude and variability of sunlight absorption and scattering by the Earth's surface, particularly through determination of the surface hemispherical reflectance (albedo); (2) improved measures of land surface classification and dynamics; and (3) improved observations of ocean color in the tropics by providing data in equatorial regions to supplement MODIS observations.

MIS 05, MIS 08, MIS 09
PRODUCT SUMMARY

Coverage:
daytime

Spatial/Temporal Characteristics:
9-day for global coverage with 1.1 km and 17.6 km sampling (various parameters) at Level 2; 16-day, monthly, and seasonal globally gridded products at Level 3

Key Geophysical Parameters:
column aerosol optical depth, aerosol compositional model identifier, directional hemispherical reflectance factors, hemispherical reflectances, BRF model parameters, FPAR, terrain-referenced view and illumination angles, tropical ocean water-leaving equivalent reflectance, tropical ocean phytoplankton pigment concentration

Processing Level:
2, 3

Product Type:
standard, at-launch (MIS 05); post-launch (MIS 08, MIS 09)

Science Team Contact:
J. Martonchik

Data Set Evolution

MISR builds on earlier work with satellite and aircraft optical sensors such as the AVHRR and ASAS. Surface hemispherical reflectance (spectral albedo) is retrievable with much higher accuracy from MISR multi-angle observations than it can be inferred from solely nadir spectral reflectance factors. In addition, current aerosol retrievals (e.g., from AVHRR) are unable to distinguish different particle

MISR Aerosol and Surface Data

types, since they are based on measurements at a single wavelength and angle of view, and the algorithm to convert observed radiance to aerosol optical depth assumes particles of a fixed composition and size. MISR retrievals will be based on more extensive coverage in both wavelength and view angle, providing greater ability to distinguish different particle types based on their physical and optical properties.

Suggested Reading

Dickinson, R.E., *et al.*, 1990.

Irons, J.R., *et al.*, 1991.

Martonchik, J.V. and D.J. Diner, 1992.

Wang, M. and H.R. Gordon, 1994.

MISR Aerosol Climatology Product

Product Description

The Aerosol Climatology Product (ACP) is generated once, at the MISR SCF, with possible infrequent updates. It is used for interpretation of the aerosol data contained in MIS 05. The ACP contains the physical and optical properties that define common atmospheric aerosol types. The parameters reported in the ACP include an aerosol model identifier (name, number, and composition); a water activity identifier (hygroscopic or not, and if so, how hydrophilic); a particle shape identifier (spherical, polyhedral, or irregular); a grid of relative humidity values for which all optical properties have been calculated; particle size distribution parameters; particle density (volume-weighted for mixtures); complex index of refraction; scattering and extinction cross-section; single scattering albedo; scattering anisotropy parameter; and phase function. It also includes the definitions of the aerosol mixtures to be used during generation of MIS 05, along with climatological likelihood parameters for these mixtures.

MIS 12
PRODUCT SUMMARY

Coverage:
n/a, one-time only, with possible infrequent updates

Resolution:
n/a

Wavelengths:
443, 555, 670, and 865 nm plus selected MODIS wavelengths; parameters include aerosol optical properties

Product Type:
internal

Science Team Contact:
R. Kahn

ERBE-Like Product Unfiltered Radiances, TOA Fluxes (ES-8)

Product Description

This Level 2 ERBE-like data set (ES-8) contains a 24-hour collection of scanner fluxes from a single satellite. ERBE (flown on NOAA-9, 10, and ERBS) is the heritage instrument for CERES and this product is tailored to match the characteristics of the similar ERBE product which was labeled S-8. ES-8 product is expected to be available 6 months after launch. Fluxes at TOA are produced from unfiltered radiances by ERBE inversion algorithms and ERBE angular distribution models (ADMs) to correct for anisotropies over an observed scene. The ES-8 also includes the shortwave (SW), longwave (LW), and window (WN) channel radiometric data; SW, LW, and WN unfiltered radiance values; and the ERBE scene identification (clear, partly cloudy, mostly cloudy, or overcast data over ocean, coasts, land, snow, and desert). These data are organized according to the CERES 3.3-sec scan into 6.6-sec records. These records contain only Earth-viewing measurements, approximately 450 for TRMM and 390 for EOS. As long as there is one valid scanner measurement within a record, the ES-8 record will be generated. A complete listing of parameters for this data product can be found in the CERES Data Products Catalog (http://asd-www.larc.nasa.gov/DPC/DPC.html).

Research & Applications

This product is a CERES-produced equivalent to the instantaneous fluxes derived from the ERBE scanner on ERBS, NOAA-9, and NOAA-10. ES-8 flux data are directly comparable to ERBE fluxes, and thus effectively extend the time series of ERBE flux measurements, allowing global change experiments to continue using ERBE algorithms without the errors associated with comparing fluxes estimated by two different algorithms. Improved TOA flux estimation algorithms for CERES (using improved ADMs and VIRS/MODIS cloud identification) are available in product Single Satellite Footprint (SSF). Producing the two versions of TOA fluxes will allow continuity with the previous ERBE data along with improved accuracy of CERES TOA Flux data (see Product SSF).

Data Set Evolution

The ERBE-like Inversion Subsystem consists of algorithms which convert filtered radiometric measurements to instantaneous flux estimates at the TOA. The basis for this procedure is the ERBE Data Management System which produced TOA fluxes from the ERBE scanning radiometers. The system consists of algorithms for *Spectral Correction*, *Observed Scene Type*, *Radiance-to-Flux Conversion using Angular Distribution Models*, and finally the *Regional Averaging* algorithm which produces regional fluxes. A linear estimation scheme is used to relate the filtered and unfiltered radiances. Ancillary parameter files are required for processing, namely ERBE-Like ADMs and ERBE Spectral Correction Coefficients for converting filtered radiances to unfiltered radiances. Documentation on the ES-8 algorithms can be found in CERES ATBD Subsystem 2.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

ES-8
PRODUCT SUMMARY

Coverage:
global (for AM-1); 40°N - 40°S for TRMM

Spatial/Temporal Characteristics:
20 km - not averaged or binned/1 per day

Key Geophysical Parameters:
TOA SW, LW fluxes and radiances, scene type

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
R. Green

ERBE-Like Product
Unfiltered Radiances, TOA Fluxes (ES-8)

Suggested Reading

Avis, L.M., *et al.*, 1984.

Barkstrom, B.R. and G.L. Smith, 1986.

Green, R.N. and J.R. Robbins, 1995.

Lee,R.N., *et al.*, 1995.

Smith, G.L., *et al.*, 1986.

ERBE-Like Products Gridded Monthly, Regional, Zonal Earth Radiation & Atmospheric Data (ES-9, ES-4, ES-4G)

Product Description

This Level 3 product (ES-9) provides radiative flux estimates in the ERBE format for 2.5° regions daily and flux averages over a month. This product is the ERBE equivalent of CERES product AVG/ZAVG and provides continuity with the ERBE mission and experiments. For each region, data are collected by the local solar hour for each hour of each day in the month. Recorded data includes the mean estimates of shortwave and longwave radiant flux at the TOA, the standard deviations of these estimates, the maximum and minimum estimate, and scene information or cloud condition. Similar parameters are determined for those scanner measurements identified as viewing clear-sky areas. The daily, monthly hourly, and monthly averages are also stored and for all observations summary statistics are provided including mean, minimum and maximum values, standard deviation, and number of days with at least one sample.

The ES-4 data product consists of regional, zonal, and global averages of scanner TOA fluxes arranged temporally by local time, day, and month. Data are averaged spatially to regions, latitude zones, and the globe. The seven sets of records correspond to regional and zonal (2.5°), nested regional and zonal (5.0° and 10°), and global averages. The ES-4G data product contains the same time and space averages as the ES-4 science data product, with the difference being the arrangement of the data. The ES-4G file presents a gridded data product with all regions for a given data parameter grouped together, while ES-4 presents all parameters for each region.

ES-9, ES-4, ES-4G
PRODUCT SUMMARY

Coverage:
global (for AM-1) 40°N - 40°S for TRMM

Spatial/Temporal Characteristics:
2.5°, 5.0°, 10.0°, global/monthly (by day and hour)

Key Geophysical Parameters:
TOA shortwave and longwave radiant flux, scene type, albedo, solar incidence, cloud condition

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
P. Minnis

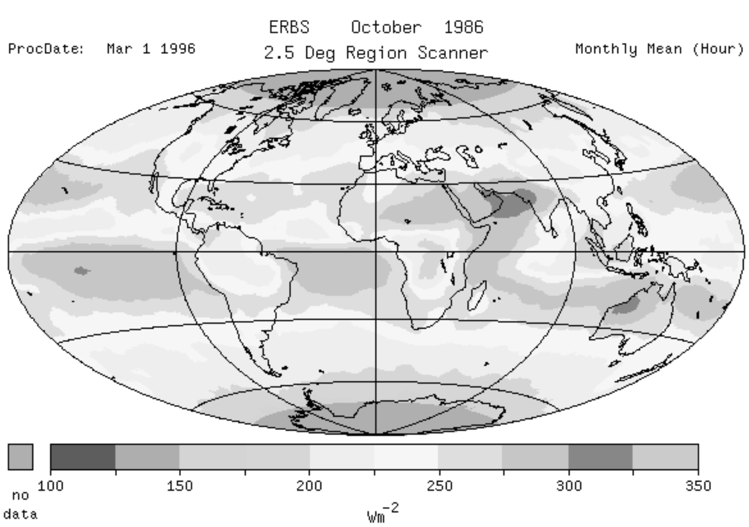

Figure 21. **Longwave Radiation From CERES ERBE-Like Processing (plotted from an ES-4 produced at the Langley DAAC from a full month of ERBE data as a simulation for CERES).**

Research & Applications

This product provides an equivalent of the ERBE-based radiation balance component of inputs to global climate models which were developed as part of or over the same period as the ERBE program and will allow continuation of this research while new algorithms are developed for CERES data. The collection of products ES-9, ES-4, and

ERBE-Like Products Gridded Monthly, Regional, Zonal Earth Radiation & Atmospheric Data (ES-9, ES-4, ES-4G)

ES-4G are equivalent to their ERBE analogs (S-9, S-4, S-4G), and effectively extend the time series of ERBE flux measurements through the EOS era. Various spatial scales are provided to simplify intercomparisons with earlier NIMBUS-7 and ERBE non-scanner time series.

Data Set Evolution

These datasets are generated using heritage ERBE algorithms operating on inputs from CERES calibrated Level 1 data and ancillary data. Data processing uses CERES Subsystem 3.0 which temporally interpolates CERES measurements using linear interpolation over oceans and half-sine curve fit over land and desert regions. Monthly and monthly-hourly means are then computed using the combination of observed and interpolated values. Documentation on the algorithms used to create the data products can be found in CERES ATBD Subsystem 3.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Brooks, D.R., *et al.*, 1986.

Harrison, E.F., *et al.*, 1990.

Harrison, E.F., *et al.*, 1995a.

Ramanathan V., *et al.*, 1989b.

Single Satellite Footprint TOA and Surface Flux and Clouds (SSF)

Product Description

This Level 2 product is the Single Satellite Flux and Cloud Swath data set that contains single satellite footprint (SSF) geometry and viewing angles; radiance and radiative flux (TOA and Surface); cloud and clear-sky statistics, scene type, and imager viewing angles; footprint statistics for each of four cloud height categories; visible optical depth; infrared emissivity; liquid water path; ice water path; cloud top pressure; cloud effective pressure, temperature, and height; cloud bottom pressure; water and ice particle radius; particle phase; vertical aspect ratio; visible optical depth/IR emissivity (13 percentiles); and cloud overlap conditions (11 conditions). Means and standard deviations are provided for most parameters. Each SSF covers a single-hour swath from a single CERES instrument mounted on one satellite. The SSF is an archival product that will be run daily in validation mode starting with the TRMM launch until sufficient data have been collected and analyzed to produce a production quality set of CERES broadband angular models. It is estimated that at TRMM launch plus 24 months, the SSF product will be produced on a routine basis and will be archived within EOSDIS for distribution to the science community.

SSF
PRODUCT SUMMARY

Coverage:
global (AM-1); 40°N - 40°S (TRMM)

Spatial/Temporal Characteristics:
hourly, footprints at full resolution (20 km at nadir)

Key Geophysical Parameters:
radiance and flux (TOA and Surface); cloud and clear-sky statistics, optical depth, infrared emissivity, liquid water path, ice water path, cloud top pressure, cloud effective pressure, cloud temperature and cloud height, cloud bottom pressure, water and ice particle radius

Processing Level:
2

Product Type:
standard, post-launch

Science Team Contact:
B. Baum

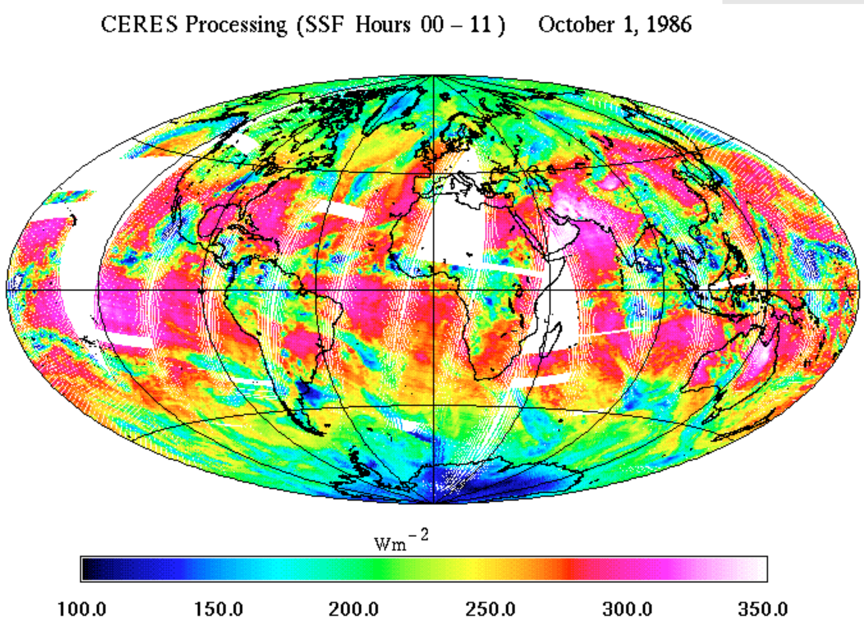

Figure 22. **CERES TOA LW Flux (plotted from an SSF produced at the Langley DAAC using ERBE data as a simulation for CERES and AVHRR data as a simulation for VIRS/MODIS).**

Research & Applications

This product generates the basic data on radiation and cloud characteristics needed by all the hourly, monthly, gridding, averaging, and radiation budget algorithms producing all the CERES output products.

Data Set Evolution

This product is the first step in the sequence of processes from the 1B radiances to global radiation budget estimates.

The SSF analysis uses coarse spatial resolution broadband radiance data

Single Satellite Footprint TOA and Surface Flux and Clouds (SSF)

from CERES, matched with simultaneous high spatial resolution narrowband radiance data from VIRS (TRMM) and MODIS (EOS-AM, PM). Analysis proceeds in six basic steps:

1. Cloud masking and clear-sky map update.
2. Cloud height and layering determination.
3. Cloud optical property determination.
4. Convolution of imager pixel level cloud/surface properties with the CERES point spread function for each CERES field of view.
5. Use of convolved cloud/surface properties to select a broadband anisotropic model for conversion of CERES radiance to TOA flux.
6. Estimation of radiative fluxes at the surface using theoretical/statistical relationships to TOA fluxes.

The final SSF data product contains the matched cloud and radiative flux data which will also be used for later determination of radiative fluxes within the atmosphere (CRS data product). The algorithms are described in the CERES ATBD 4.0-4.6 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Baum, B.A., *et al.,* 1995a.

Baum, B.A., *et al.,* 1995b.

Green, R.N. and B.A. Wielicki, 1995.

Green, R.N., *et al.,* 1995.

Minnis, P., *et al.,* 1995.

Wielicki, B.A.., *et al.,* 1995.

Single Satellite CERES Footprint Radiative Fluxes and Clouds (CRS)

Product Description

This Level 2 post-launch product contains corrected and adjusted longwave and shortwave radiative fluxes for surface, multiple atmosphere levels (between 2 and 18 levels 2.5 years after launch, depending on validation results) and TOA for both clear-sky and total-sky for each CERES footprint for one hour or a single satellite swath (8-12 percent of the Earth) from one satellite. Fluxes within the atmosphere are calculated with a plane parallel radiative transfer code; atmospheric properties (such as clouds) are adjusted to produce agreement with satellite-observed fluxes at the top of the atmosphere. This product is the second stage of refinement in a sequence starting with SSF and ending with AVG/ZAVG (See CERES Data Flow diagram in Chapter Three, Instrument Overviews). This data set contains time and location data, algorithm flags, cloud category properties for up to four cloud layers (lower, lower middle, upper middle, and high), and cloud overlap data for eleven overlap conditions (clear, low (L), lower middle (LM), upper middle (UM) high (H), H/UM, H/LM, H/L, UM/LM, UM/L, LM/L). The flux adjustments for both clear-sky and total sky are also included. Cloud properties include pressure, optical depth, water and ice path, and particle radius and optical depth/IR emissivity frequency distribution. PAR at the surface is also provided. A complete listing of parameters for this data product can be found in the CERES Data Products Catalog (http://asd-www.larc.nasa.gov/DPC/DPC.html).

Research & Applications

The surface and atmospheric radiation budget (SARB) is the primary driver of the hydrological cycle and the general circulation of the atmosphere. Anthropogenically induced changes in the radiatively active trace gases and aerosols will affect the SARB and will therefore force a climate response. The 68 radiance and radiant flux and cloud parameters provided by this product are inputs to higher level algorithms which produce gridded, averaged flux and cloud property products. This product contains a further enhancement of the basic data on radiation and cloud characteristics from SSF needed for determination of the amount of energy passing from space through the atmosphere to the Earth and flowing from the Earth back to space which is provided by products SRBAVG, AVG, and ZAVG. It is a global product and is used as the input to the hourly gridded computation of surface, multiple atmosphere levels and TOA radiative fluxes. The analysis algorithms are described in the CERES ATBD Subsystem 5.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html). An example of the radiative flux profile, expressed in terms of the radiative diabatic heat rate, is given in Figure 9. The local scale CERES/ARM/GEWEX Experiment (CAGEX) provides a prelaunch window to this component of CERES with on-line access to input data, calculated fluxes, and validating measurements (http://snowdog.larc.nasa.gov:8081/cagex.html).

CRS
PRODUCT SUMMARY

Coverage:
global for AM-1; 40°N-40°S for TRMM

Spatial/Temporal Characteristics:
hourly, footprints at full resolution (20 km)

Key Geophysical Parameters:
shortwave and longwave radiant flux at the surface, multiple atmosphere levels, and TOA, scene identification, cloud parameters

Processing Level:
2

Product Type:
standard, post-launch

Science Team Contact:
T. Charlock

Data Set Evolution

The inputs to this product come from the SSF product and the cloud parameters are further

Single Satellite CERES Footprint Radiative Fluxes and Clouds (CRS)

corrected and adjusted. The TOA and surface values are corrected for satellite and cloud effects to produce observed TOA and tuned surface estimates. This data set is tailored to provide the needed inputs to the hourly gridded flux and surface radiation budget Level 3 product, FSW.

Suggested Reading

Charlock, T.P., and T.L. Alberta, 1996

Charlock, T.P., *et al.*, 1993.

Charlock, T.P., *et al.*, 1995.

Fu, Q., and K. Liou, 1993.

Liou, K.-N., 1992.

Whitlock, C.H., *et al.*, 1995.

Wu, M., and L.-P. Chang, 1992.

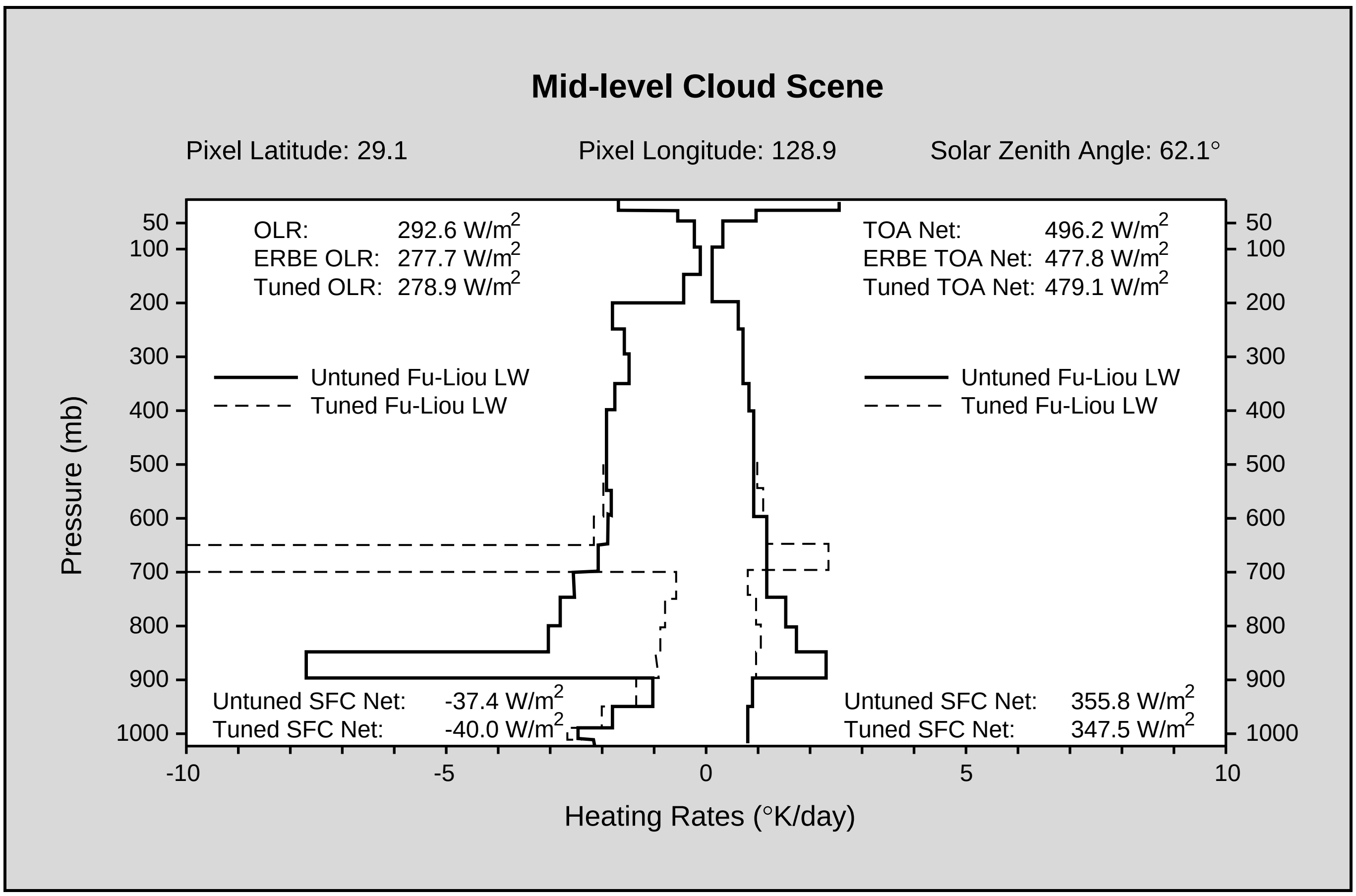

***Figure 23.* Longwage and Shortwave Heating Rates.** For LW and SW, fluxes at the TOA (as untuned FL, ERBE observations, and tuned FL), fluxes at the surface (as untuned FL and tuned FL), and heating rates (untuned are solid and tuned are dashed). One ERBE footprint containing low clouds.

Hourly Gridded Single-Satellite Fluxes and Clouds (FSW)

Product Description

The Hourly Gridded Single Satellite Fluxes and Clouds (FSW) Level 3 data product contains hourly single satellite flux and cloud parameters derived from the single satellite cloud radiative swath (CRS) data set averaged over 1° equal angle regions. Each FSW covers a single-hour swath from a single CERES instrument mounted on one satellite. The single satellite case is indicated since the heritage instrument, ERBE, had up to three satellites operating and these data were integrated by the final flux and radiation budget algorithms. The same integration is part of the CERES system which will process data from TRMM, EOS-AM, and EOS-PM satellites. Data presented for each region include radiative fluxes at TOA, surface, and atmospheric levels for both clear-sky and total-sky, cloud overlap conditions, cloud properties for up to four cloud layers (lower, lower middle, upper middle, and high), column-averaged cloud properties, angular model scene classes and adjustment parameters. Summary statistics (mean, standard deviation, number of observations) are included for most parameters for data quality verification.

Research & Applications

This product is an interim step in the generation of regional and global radiation products from CERES footprint data. It contains the gridded data on radiation and cloud characteristics needed by the synoptic flux and clouds algorithm SYN. The contribution of this product is the averaging and gridding operations applied to both the radiative flux and cloud property data.

Data Set Evolution

The algorithm is based on ERBE algorithms and carries out aggregation of the high resolution 20 km (nadir) data products to 1° (110 km) data cells using weighted averaging and linear interpolation to produce the flux and cloud data in this grid cell format chosen for final products. This is an equal angle grid consisting of regions that are 1° in latitude by 1° in longitude. The parameter list is essentially the same as for CRS. The analysis algorithms are described in the CERES ATBD Subsystem 6.0 (http://spso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Smith, G.L., and T.D. Bess, 1983.

Stowe, *et al.,* 1993.

FSW
PRODUCT SUMMARY

Coverage:
global (AM-1); 40°N - 40°S (TRMM)

Spatial/Temporal Characteristics:
1° grid/hourly

Key Geophysical Parameters:
gridded surface, atmosphere layer and TOA fluxes, clear-sky and total-sky, cloud parameters in CRS, (e.g., cloud overlap, cloud pressure, cloud altitude, cloud temperature, ice water properties, ice particle properties, liquid water properties)

Processing Level:
3

Product Type:
standard, post-launch

Science Team Contact:
L. Smith

Synoptic Radiative Fluxes and Clouds (SYN)

Product Description

This Level 3 product contains regional LW, SW, and WN radiative fluxes for surface, selected atmospheric levels as in CRS, and TOA for 3-hour intervals on a 1° equal angle grid at synoptic times (0, 3, 6, ... 21 UTC), and includes data from up to three CERES instruments (the product generation system has the capability of combining data from CERES instruments on TRMM, EOS-AM, and EOS-PM). This includes the region data, observed CERES TOA data for clear-sky and total-sky, cloud properties for up to four cloud layers (lower, lower middle, upper middle, and high), cloud top pressure, cloud area fraction, column averaged cloud properties for five weighting schemes (TOA SW, TOA LW, LW, LWC [liquid water] and IWC [ice water]), angular model scene classes for 12 ERBE scenes types, and atmospheric flux profile, as well as flux adjustment for surface and TOA for both clear-sky and total-sky, adjustment parameters for clear-sky and cloud layers.

Research & Applications

The synoptic format of this product provides data which is global and simultaneous in time. This is preferred by climate modelers since the synoptic times ensure consistency with ground truth meteorological observations from weather stations and radiosondes as well as with geostationary satellites which provide images at synoptic hours. The production of a CERES synoptic data product is important because synoptic views provide a basis for studying the life cycle of cloud systems and for validating the CERES data processing, and it provides a regular data structure which simplifies the design of algorithms and operation of the data processing system. Synoptic fields of radiation and clouds are potentially valuable in developing and understanding the role of clouds in the generation and dissipation of available potential energy, since the calculation of this quantity requires integration over approximately horizontal layers within the atmosphere.

Data Set Evolution

The CERES time-space averaging and time interpolation algorithm is based on techniques used in previous Earth radiation budget systems such as ERBE. The chief input to the time interpolation process is the gridded SW and LW TOA clear-sky and total-sky fluxes and cloud information provided by the FSW product. Data from the three possible systems which could be simultaneously in orbit (TRMM, EOS-AM, and EOS-PM) provide up to six samples per day. This significantly reduces temporal sampling errors. Estimates of the cloud properties at synoptic times are also provided. The cloud mask output defines clear-sky conditions for the 1° cells for the radiative fluxes which are averaged over 3 hour periods. Interpolation to the synoptic times uses geostationary data to assist in modeling meteorological variations between times of observations. The analysis algorithms are described in CERES ATBD Subsystem 7.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

SYN
PRODUCT SUMMARY

Coverage:
global (AM-1); 40°N - 40°S (TRMM)

Spatial/Temporal Characteristics:
1°, 3-hour intervals

Key Geophysical Parameters:
synoptic time interval clear-sky, total-sky fluxes at surface, atmosphere levels and TOA, cloud parameters including cloud overlap, cloud pressure, cloud altitude, cloud temperature, optical depth, ice water properties, ice particle properties, liquid water properties, photosynthetically active radiation

Processing Level:
3

Product Type:
standard, post-launch

Science Team Contact:
T. Wong

Synoptic Radiative Fluxes and Clouds (SYN)

Suggested Reading

Breigleb and Ramanathan, 1982.

Brooks, D.R., *et al.*, 1986.

Harrison, E.F., *et al.*, 1988.

Minnis, P. and E.F. Harrison, 1984.

Smith, G.L., *et al.*, 1995.

Young, D.F., *et al.*, 1995a.

Regional Average Data Product & Zonal and Global Monthly Average Data Product

Product Description

The regional monthly radiative flux and cloud averages (AVG) product contains monthly and monthly-hourly averages of the TOA and surface LW and SW radiative fluxes, together with LW and SW fluxes at standard pressure levels in between. This final product also contains observed cloud and clear-sky properties at the standard 1° horizontal resolution. Included in this data set are radiative fluxes for both clear-sky and total-sky at TOA, cloud categories for four cloud layers (lower, lower middle, upper middle, and high), column-averaged cloud properties for five weighting schemes (TOA SW, TOA LW, surface LW, liquid water, and ice), overlap data for eleven cloud conditions, angular model scene classes, atmospheric flux profile, flux adjustment for surface and TOA for both clear-sky and total-sky, and adjustment parameters for clear-sky and cloud layers. Mean, standard deviation, and number of days or number of observations are given with most parameters. A complete listing of parameters for this data product can be found in the CERES Data Products Catalog. The zonal monthly radiative fluxes and clouds averages (ZAVG) product is similar to the regional monthly average data set, however it contains a summary of the zonal (1° latitudinal zones) and global averages of the radiative fluxes and cloud properties. This data set, which is equivalent to the zonal averages and global averages in the ERBE S-4 product, may be used as a browse product for the CERES data.

Research & Applications

This product will be used by meteorological researchers to study climate and improve global climate models. Zonal quantities are needed for studying energy transport since averaging on large spatial scales minimizes the effects of regional-scale anomalies in studying climate change and global dynamics. Global averages can be compared with other historical data sets derived from different regional scales to detect climate temperature trends and evaluate large-scale climate anomalies such as the effects of major volcanic eruptions.

Data Set Evolution

The product algorithm first calculates the means on a regional (1° equal-angle grid) basis from one month of synoptic maps from the SYN 3-hourly product. Regional means are then combined to obtain zonal and global averages. The main steps of the monthly averaging process are: (1) regionally sort the synoptically-ordered data, (2) linearly average all flux data to produce monthly and monthly-hourly means, (3) average the cloud properties using the proper weighting schemes, and (4) combine and average the regional means into zonal and global means. Once regional means are computed for all parameters and all regions, these means are combined into zonal and global means. Area weighting factors are used to correct for the variation of grid box size with latitude. The analysis algorithms are described in CERES ATBD Subsystem 8.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Harrison, E.F., *et al.*, 1990.

Li, Z. and H. Leighton, 1993.

Young, D.F., *et al.*, 1995b.

AVG, ZAVG
PRODUCT SUMMARY

Coverage:
global (for AM-1 and AM-1/TRMM combined)

Spatial/Temporal Characteristics:
monthly 1° (AVG) and 1° latitudinal zones (ZAVG)

Key Geophysical Parameters:
averaged clear-sky, total-sky surface, TOA and standard CERES pressure level fluxes, cloud parameters include: cloud overlap, pressure, temperature, optical depth, ice particle properties, liquid water properties, PAR

Processing Level:
3

Product Type:
standard, post-launch

Science Team Contact:
T. Wong

Gridded Single Satellite Fluxes and Clouds (SFC)

Product Description

This is a Level 3 product which takes the cloud and atmosphere-processed CERES radiance data from the high resolution (21-km at nadir) footprint format to a 1° (110-km in latitude) equal-angle grid which is common to all the CERES output products. The data for each region contain spatially averaged values from a single hour swath from a single CERES instrument mounted on one satellite. The major categories of data output on the SFC are total-sky radiative fluxes at TOA and surface, clear-sky radiative fluxes at TOA and surface, column-averaged cloud properties, angular model scene classes, PAR, and direct/diffuse ratio. Data are presented for each region with summary statistics (mean, standard deviation, number of observations).

This product differs from FSW in the following ways. First, SW and LW radiative fluxes are provided only at the TOA and Surface. Second, cloud properties are only provided as column averages. These first two changes substantially reduce the data volume. Third, the surface fluxes are estimated differently than in FSW. Here, the surface flux estimates rely heavily on parameterized relationships of fluxes at the surface to those measured at the TOA. The intent is to use radiative transfer models only to derive the form of the parameterized relationship, while simultaneous TOA and Surface observations are used to confirm the relationship and if necessary to modify it. The FSW product focuses on deriving an internally consistent set of atmosphere, cloud, and radiative fluxes from surface to top of the atmosphere given the constraint of a state-of-the-art radiative transfer model.

Research and Applications

This product is a necessary step in the transformation of raw CERES data to the radiation budget outputs from product SRBAVG. The averaging and gridding operations performed on the footprint data serve to reduce variability by averaging to a 1-hour period and present the data in a uniform grid which is required for temporal comparison of flux and cloud parameters.

Data Set Evolution

The parameters generated by this product are derived from the SSF product which creates all the flux and cloud parameters. Each of the parameters from SSF are averaged to the 1° grid using equal weighting which results in approximately 50 footprints being averaged for each geographic cell. These parameters are all inputs to the SRBAVG final radiation budget product. The analysis algorithms are described in CERES ATBD Subsystem 4.6 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Barkstrom, B.R., *et al.*, 1995.

Cess, R., *et al.*, 1991.

Gupta, S.K., *et al.*, 1992.

Gupta, S.K., *et al.*, 1995.

Inamdar, A.K. and V. Ramanathan, 1994.

Inamdar, A.K. and V. Ramanathan, 1995.

Kratz, D.P. and Z. Li, 1995.

Li, Z., *et al.*, 1993.

SFC
PRODUCT SUMMARY

Coverage:
global (AM-1); 40°N - 40°S (TRMM)

Spatial/Temporal Characteristics:
1°, hourly (1-hour period summary)

Key Geophysical Parameters:
total-sky, clear-sky and angular model scene radiative fluxes (TOA and surface), cloud parameters, including cloud pressure, cloud altitude, cloud temperature, optical depth, photosynthetically active radiation, direct/diffuse ratio

Processing Level:
3

Product Type:
standard, post-launch

Science Team Contact:
D. Kratz, T. Charlock

Monthly TOA and Surface Radiation Budget Averages (SRBAVG)

Product Description

The Monthly Level 3 TOA and Surface Radiation Budget Averages (SRBAVG) final product (CER 06) contains monthly and monthly-hourly regional, zonal, and global averages of the TOA and surface LW and SW fluxes (clear-sky and total-sky), column-averaged cloud properties, and angular model scene types for each 1° equal-angle region. This product differs from the AVG/ZAVG product in three ways. First, the surface fluxes have been calculated from the TOA fluxes using statistical parameterizations. Second, no flux fields are calculated at levels between TOA and the surface. Third, the regional fluxes are calculated using two methods: with and without geostationary data. The monthly TOA/SRB average data set is produced for each spacecraft and for each combination of spacecraft. At the TRMM launch, this product will be produced in a validation mode for the first 30 months. During these 30 months, the CERES Science Team will derive a production quality set of angular distribution models which are needed to produce the LW and SW instantaneous fluxes.

Research and Applications

The cloud properties as a function of LW and SW radiative fluxes at TOA and surface are critical to cloud forcing issues and cloud properties as a function of liquid water and ice water volume are critical to cloud dynamics modeling.

Data Set Evolution

This product is obtained from the chain of processes which start with the 1B radiances and flow through products BDS, IES, SSF, SFC ultimately producing the final averaged radiative flux and surface radiation budget (SRB) product. The regional fluxes are calculated using two different methods which will help produce very stable, accurate long-term data sets and averages for use in detailed regional studies of radiation and clouds and interdisciplinary studies. This is a post-launch product. Currently, there is no adopted method available for producing total-sky surface LW flux from TOA flux. Data required for parameterization must be obtained from either MOA atmospheric data set or from CERES and ISCCP cloud properties. In addition, data used in this product are limited to days in which there is at least one observation. The cloud parameters are also averaged monthly and monthly-daily. The surface radiation budget is the net radiative flux at the surface and is computed using the hourly gridded TOA and surface fluxes from SFC, parameterized models, atmospheric profiles, cloud parameters, surface temperature and emissivity to produce the downward and net shortwave and longwave fluxes at the surface. The LW algorithm is based on parameterized equations developed expressly for computing surface LW fluxes in terms of meteorological parameters obtained from satellite and/or other operational sources. The analysis algorithms are described in CERES ATBD Subsystem 10.0 (http://eospso.gsfc.nasa.gov/atbd/cerestables.html).

Suggested Reading

Cess, R., *et al.*, 1991.
Gupta, S.K., *et al.*, 1992.
Harrison, E.F., *et al.*, 1995b.
Li, Z., *et al.*, 1993.
Suttles, J.T., and G. Ohring, 1986.

SRBAVG
PRODUCT SUMMARY

Coverage:
global (AM-1, TRMM and AM-1 combined); 40°N - 40°S (TRMM)

Spatial/Temporal Characteristics:
1°, one per month

Key Geophysical Parameters:
averaged total-sky radiative fluxes (TOA and surface), net surface radiative fluxes (surface radiation budget), averaged cloud parameters

Processing Level:
3

Product Type:
standard, post-launch

Science Team Contact:
T. Charlock, T. Wong

Polar Surface and Cloud Classification

Product Description

This Level 2 product is a polar classification map, consisting of the following classes: water, wet/slush ice, snow/ice, land, shadow, water cloud, and ice cloud. Each pixel is classified using a bit map for each of the above classes. Therefore, for complex scenes such as cirrus over broken sea ice, the water, ice, and ice cloud bits would be set. This product is produced at 30-m spatial resolution and uses a combination of visible, near-infrared, and infrared channels. The polar regions are defined as all land and water regions lying poleward to 60°N or 60°S. Both daytime and nighttime classifications will be available, with the daytime algorithm applied for solar zenith angles less then 85°, and the nighttime algorithm applied in all cases. This is an on-request product.

Research & Applications

Since greenhouse forcings are expected to be amplified in the polar regions, these regions may act as early warning indicators of global climate shifts. Cloud cover can be expected to be altered by greenhouse forcings, and cloud changes are expected to have a significant effect on sea ice conditions and regional ice-albedo feedbacks, especially to the polar heat balance which directly affects surface melting. ASTER polar data will be used to monitor changes in surface conditions, notably temperature, albedo, and sea ice breakup.

Data Set Evolution

This data set builds on work over the past decade with data from Landsat TM, AVIRIS, TIMS, and MAS. The improved spectral coverage, resolution, and radiometric accuracy will enable ASTER to provide remotely sensed polar data of unprecedented accuracy.

The ASTER polar data set will also be used to validate the global-scale polar data and cloud property retrievals from MODIS. In particular, this data set will be used to validate the MODIS cloud optical thickness and effective particle sizes which directly impact the Earth's radiative budget. Only ASTER has the spatial resolution necessary to fully analyze the cloud 3-D effects.

Suggested Reading

Ebert, E., 1987.

Tovinkere, V.R., *et al.*, 1993.

Welch, R.M., *et al.*, 1990.

Welch, R.M., *et al.*, 1990.

AST 13
PRODUCT SUMMARY

Coverage:
regional (poleward from 60° N or S)

Spatial/Temporal Characteristics:
30 m over 60 km × 60 km scenes

Key Science Applications:
climate modeling, polar heat balance,

Key Geophysical Parameters:
polar clouds, thick cloud, thin cloud, shadow, ice, wet ice

Processing Level:
3

Product Type:
standard, on-request

Science Team Contact:
R. Welch

DAS Assimilated Cloud Fraction

Product Description

This Level 4 product consists of 3- and 6-hourly estimates of cloud fraction produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Two fields are provided, two-dimensional cloud fraction (CLDFRC) and three-dimensional cloud fraction (CLROLW).

Research & Application

Clouds play a crucial role in the Earth's radiative balance. Accurate estimates of global cloud coverage are needed to quantify global climate change.

Data Set Evolution

Satellite observations of clouds have been available for many years. TRMM and AM-1 will provide much needed improvements to these observations. Cloud estimates from the GEOS DAS will be consistent with the dynamics of the assimilation general circulation model. However, for the near future assimilated clouds are unlikely to be as accurate as satellite imagery and thus should be used cautiously.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 11
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, 1 level for 2-D, 70 model sigma levels for 3-D, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
cloud fraction (2-dimensional 8 times/day, 3-dimensional 4 times/day)

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Cloud Mass Flux

Product Description

This Level 4 product consists of 6-hourly estimates of cloud mass flux per unit time from all convective clouds as estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. These fields are generated by the convective parameterization within the GEOS DAS GCM. Two fields are provided, cumulative cloud mass flux from all convective clouds (CLDMAS) and mass flux at the top of each convective cloud (DTRAIN).

Research & Application

Convective clouds play a crucial role in the Earth's radiation balance. Accurate estimates of cloud mass flux from convective clouds will help determine the life cycle of convective cloud systems and thus their impact on global climate change.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through convective parameterization schemes within global GCMs. The GEOS DAS convective parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 12
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
cloud mass flux

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Heating Rates

Product Description

This Level 4 product consists of 6-hourly estimates of heating rates from longwave and shortwave radiation under clear skies as estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. These fields are generated by the radiation parameterization within the GEOS DAS GCM. Two fields are provided, clear-sky heating rate due to shortwave radiation (SWCLR) and clear-sky heating rate due to longwave radiation (LWCLR).

Research & Application

Radiative heating of the atmosphere is a significant component to the global heat balance. Heating rates are needed to determine atmospheric stability which drives local convection and to determine horizontal temperature gradients which modify the atmosphere's general circulation.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through radiation parameterization schemes within global GCMs. The GEOS DAS radiation parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 13
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
clear-sky heating rates from longwave and shortwave radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

DAS Assimilated Surface Sensible Heat Flux

Product Description

This Level 4 product consists of 3-hourly estimates of surface sensible heat flux estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. This field is generated by the turbulence parameterization within the GEOS DAS GCM.

Research & Application

Surface sensible heat flux is a significant component to the global heat balance. Heating rates near the Earth's surface are needed to determine atmospheric stability (which drives local convection) and to determine horizontal temperature gradients (which modify the atmosphere's general circulation).

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through turbulence parameterization schemes within global GCMs. The GEOS DAS turbulence parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 14
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface sensible heat flux

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Outgoing Longwave Radiation

Product Description

This Level 4 product consists of 3-hourly estimates of outgoing longwave radiation produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. These fields are generated by the radiation parameterization within the GEOS DAS GCM. Two fields are provided, net outgoing longwave radiation (OLR) and net clear-sky outgoing longwave radiation (OLRCLR).

Research & Application

Outgoing longwave radiation plays a significant role in to the global heat balance. It is also indicative of the presence of clouds and snow cover.

Data Set Evolution

Outgoing longwave radiation measurements are already available from satellite instruments such as ERBE and will be available from CERES on TRMM and AM-1. Although the GEOS DAS will not directly assimilate ERBE and CERES measurements, the assimilated estimates of outgoing radiation will be dynamically consistent with other assimilation products such as precipitation and atmospheric circulation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 15
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
outgoing longwave radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Outgoing Shortwave Radiation

Product Description

This Level 4 product consists of 3-hourly estimates of outgoing shortwave radiation produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. These fields are generated by the radiation parameterization within the GEOS DAS GCM. Two fields are provided, net outgoing shortwave radiation (OSR) and net clear-sky outgoing shortwave radiation (OSRCLR).

Research & Application

Outgoing shortwave radiation plays a significant role in to the global heat balance. It is also indicative of the presence of clouds and snow cover.

Data Set Evolution

Outgoing shortwave radiation measurements are already available from satellite instruments such as ERBE and will be available from CERES on TRMM and AM-1. Although the GEOS DAS will not directly assimilate ERBE and CERES measurements, the assimilated estimates of outgoing radiation will be dynamically consistent with other assimilation products such as precipitation and atmospheric circulation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 16
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
outgoing shortwave radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Incident Shortwave Radiation

Product Description

This Level 4 product consists of 3-hourly estimates of incident shortwave radiation at the top of the atmosphere produced by the GEOS DAS. It is based on the solar constant, Earth-Sun distance, and Sun zenith angle.

Research & Application

Incident shortwave radiation plays a significant role in to the global heat balance.

Data Set Evolution

This field does not require special observations. It is simply calculated from the Earth's orbit about the Sun.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 17
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
incident shortwave radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Surface Radiation

Product Description

This Level 4 product consists of 3-hourly estimates of surface radiation produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. These fields are generated by the radiation parameterization within the GEOS DAS GCM. Six fields are provided, net downward clear-sky shortwave radiation at the surface (SWGCLR), net downward shortwave radiation at the surface (RADSWG), net downward visible radiation at the surface (VISDNG), net upward clear-sky longwave radiation at the surface (LWGCLR), net upward longwave radiation at the surface (RADLWG), and net downward longwave radiation at the surface (LWDNG).

Research & Application

Surface radiative heat flux is a significant component to the global heat balance. Heating rates near the Earth's surface are needed to determine atmospheric stability which drives local convection and to determine horizontal temperature gradients which modify the atmosphere's general circulation.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through radiation parameterization schemes within global GCMs. The GEOS DAS radiation parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 18
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Surface Albedo

Product Description

This Level 4 product consists of 3-hourly estimates of surface albedo. It is produced by the land surface model of the GEOS DAS. This model uses as input calculations of land surface type, greenness, and leaf area index based on MODIS measurements. The model converts these characteristics to albedo using surface radiation contained within the radiation parameterization of the GEOS DAS. Four types of albedo are provided, near-IR diffuse (ANIRDF), near-IR direct (ANIRDR), visible diffuse (AVISDF), and visible direct (AVISDR).

Research & Application

Surface albedo is a significant component to the global heat balance. It determines the heating rate at the Earth's surface. Heating rates near the Earth's surface are needed to determine atmospheric stability which drives local convection and to determine horizontal temperature gradients which modify the atmosphere's general circulation.

Data Set Evolution

MODIS will provide improved estimates of surface the characteristics used as input to the GEOS DAS albedo calculations. Previously, the GEOS DAS calculated surface albedo based on monthly mean values.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 19
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface albedo

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Chapter Seven

Lightning

Lightning

Relationship to Global Change Issues

Understanding lightning is a way to understand the interplay of some key components of atmospheric dynamics. Lighting is closely coupled to storm convection dynamics and can be correlated to the global rates, amounts, and distribution of convective precipitation. It points to where strong convection is occurring, when large quantities of water are growing in the mixed phase regions of storms, and suggests how latent heat is being released during the storm's life cycle. Since the microscales on which particles interact to generate electricity are coupled through storm scale processes to synoptic scale systems, lighting activity should provide information on the development of the atmosphere over many scale sizes, especially in the tropics.

The Lightning Imaging Sensor (LIS) on the TRMM Observatory is designed to detect, locate, and measure the intensity of lightning for scientific investigation of the distribution and variability of total lightning over the Earth and to increase our understanding of the Earth's atmosphere system. LIS will provide a global lightning and thunderstorm climatology from which changes (even subtle temperature variations) might be easily detected. These data will be used in a variety of global change studies, including cloud characterization, hydrologic cycle studies, storm convection, microphysics and dynamics, and the seasonal and interannual variability of thunderstorms.

LIS represents a significant advance over any previous satellite-borne lightning detectors. Those instruments could provide only a relative global distribution of lightning of a strictly statistical nature. Additionally, they required collecting data for long periods of time before they could be meaningfully interpreted in terms of global distributions. It was not possible to determine the lightning frequency of a particular storm with the earlier estimates. Lightning observations from the LIS can be readily associated with the thunderstorms that produce them, and the detection of even a single discharge is significant and provides important information (e.g., storm location, precipitation estimates, storm height, the presence of ice, lightning frequency, electrical output, etc.).

LIS has been designed to study the distribution and variability of total lightning on a global basis. Its staring imager is optimized to locate and detect lightning with storm scale resolution of 5 - 10 km over a large region (600 $\times$ 600 km) of the Earth's surface. The field of view (FOV) is sufficient to observe a point on the Earth or a cloud for 80 seconds, adequate to estimate the flashing rate of many storms. This makes it possible to estimate lightning frequency even for storms with flash rates as low as 1 - 2 discharges per minute.

Product Interdependency and Continuity with Heritage Data

During the 1980s, the extensive optical and electrical observations of lightning were made from high altitude NASA U-2 aircraft with the primary objective of defining a baseline design criteria for a space sensor capable of mapping lightning discharges from geostationary orbit during day and night, with high spatial resolution and high detection efficiency. The results, combined with parametric trade-off studies and other research, have clearly established the feasibility of making this kind of lightning measurement from space with present state-of-the-art technology.

Global lightning signatures from the Defense Meteorological Satellite Program (DMSP) Optical Linescan System (OLS) have been analyzed from the filmstrip imagery and digital DMSP tapes archived at the NOAA National Geophysical Data Center (NGDC) National Snow and Ice Data Center in Boulder, Colorado. This global lightning database will be an important reference dataset for LIS.

In the TRMM pre-mission period, space-based lightning observations are being provided by the Optical Transient Detector (OTD), launched in 1995 as a secondary payload on a Pegasus launch vehicle.

In a near-polar orbit, OTD (Figure 10) is able to detect all types of lightning events, including cloud-to-ground, cloud-to-cloud, and intra-cloud. Considered to be a LIS prototype, OTD data will populate a database of global lightning activity to which LIS data will be added.

Lightning

Suggested Reading

Christian, H.J., *et al.*, 1989.

Christian, H.J., *et al.*, 1992.

Guo, C. and E.P. Krider, 1982.

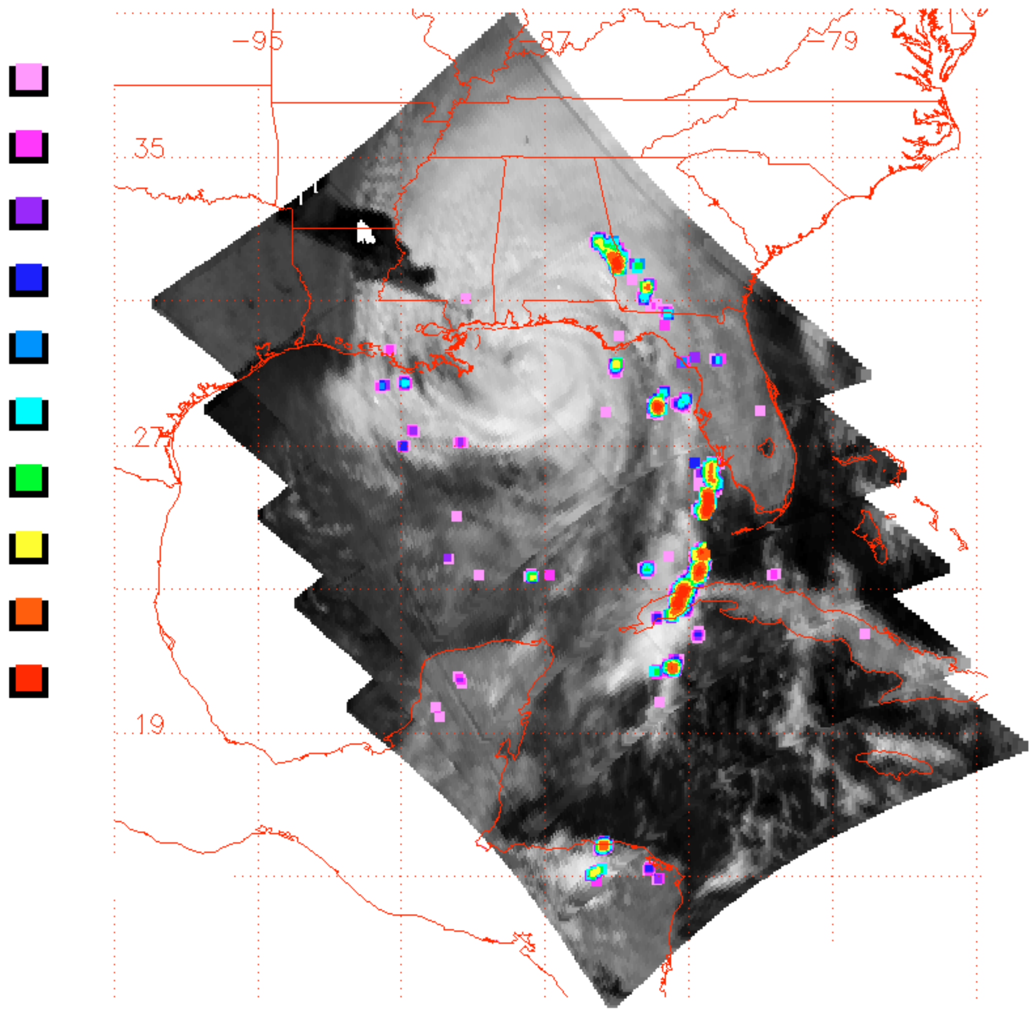

Figure 24. **Hurricane Opal.** Data from the OTD sensor shows lightning flashes occurring during Hurricane Opal, October 4, 1995. The OTD is based on the LIS instrument and can be viewed as a LIS prototype.

Lightning Imaging Sensor Product

Product Description

The TRMM LIS generates a single lightning product with multiple components which describe lightning strikes spatially and temporally. The Level 1 components provide lightning pulse and background data with navigation and browse data to provide a "snapshot" of the LIS field of view. *Events* are defined as a pixel value exceeding a threshold for 2 ms and is the basic unit of lightning data. The pixel location, amplitude, and time of the event are included. Both lightning pulses which fill more than one pixel and groups of pulses are placed in a Level 2 group component, which includes size and number of events in the group. The *flash* component corresponds to a classically-defined lightning flash and includes time, location, duration in the LIS field of view, and number of groups in the flash. The *area* component corresponds to a classically defined thunderstorm or thunderstorm complex along with the descriptive parameters. Level 3 summary information about the data obtained during one orbit is provided in the *vector and browse* components, which includes location, average observation time, counts of events, groups, flashes, and areas at 2.5° grid points. The Level 3 flash density data product holds all data associated with the flash density parameter recorded during the orbit. It will be used to produce the equal angle and equal area maps of monthly lightning activity.

Research and Applications

LIS will view a total area exceeding 600 km × 600 km at the cloud top using a 128 × 128 photodiode array. Individual storms and storm systems are monitored for 80 seconds, a period long enough to obtain a measure of the lightning flash rate while the storm is in the field of view of the sensor. This makes it possible to estimate lightning frequency even for storms with flash rates as low as 1-2 discharges per minute. LIS represents a significant advance over any previous satelliteborne lightning detector. Lightning observations from the LIS can be readily associated with the thunderstorms that produce them, and the detection of even a single discharge is significant and provides important information (e.g., storm location, precipitation estimates, storm height, the presence of ice, lightning frequency, electrical output, etc.). The earlier satelliteborne lightning instruments provided only a relative global distribution of lightning of a strictly statistical nature; this required collecting data for long periods of time before it could be meaningfully interpreted in terms of global distributions. It was not possible to determine the lightning frequency of a particular storm with the earlier estimates.

Data Set Evolution

NASA U-2 aircraft lightning detection data were collected in order to provide a baseline for future satellite-based lightning instruments. Based on a combination of the results of U-2 data and advanced in technology, the OTD (Figure 11) has been able to begin establishing a database of lightning observations from a near-polar orbit at a 70° inclination, at an altitude of 740 km, and with a FOV of 1300 × 1300 km. LIS data sets will further build upon OTD with a FOV of 600 × 600 km and a storm scale resolution of 5-10 km.

LIS 02, 03, 04, 05, 06, 07, 08, 09, 10, 11, 12, 13, 14, 15, 16, 17, 18
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
5 km × 5 km pixel at nadir and
2.5° × 2.5° browse grid/daily

Key Science Applications:
thunderstorm distribution and variability, rainfall mapping and thunderstorm analysis

Key Geophysical Parameters:
lightning events, groups, flashes, areas

Processing Level:
1, 2, 3, 4

Product Type:
standard, at-launch

Science Team Contact:
H. Christian, S. Goodman, R. Blakeslee

Lightning Imaging Sensor Product

Suggested Reading

Christian, H.J., *et al.*, 1989.

Guo, C. and E.P. Krider, 1982.

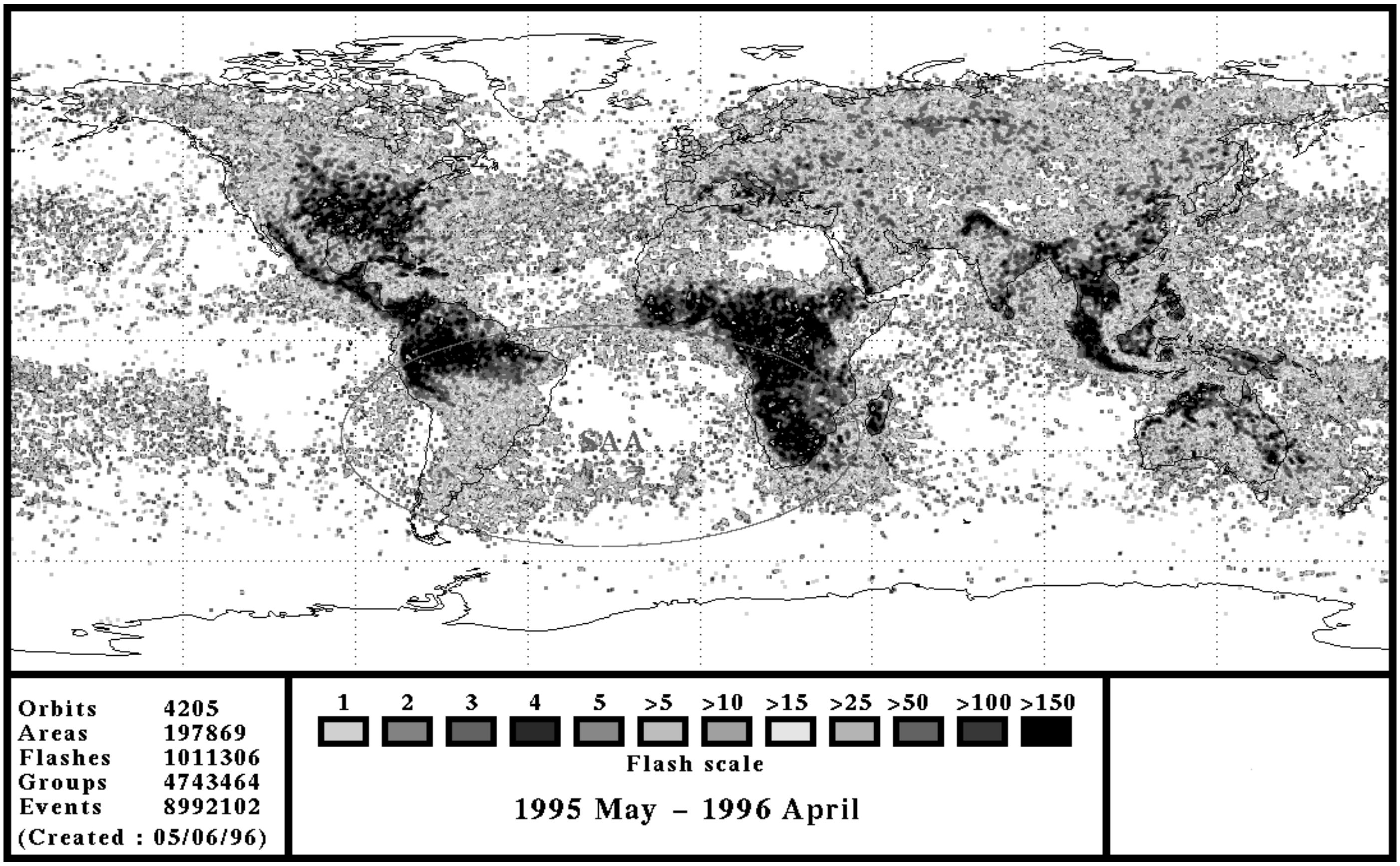

Figure 25. **Annual Summary.** Flash summary map for May 1995 - April 1996 shows lightning flashes detected within the field of view of the OTD. Lightning is closely coupled to storm convection dynamics and can be rrelated to the global rates, amounts and distribution of convective precipitation.

Chapter Eight

Tropospheric Chemistry

Tropospheric Chemistry

Relationship to Global Change Issues

In recent years, increasing concern has focused on the natural and anthropogenic alteration of the Earth's environment and how these activities impact global change. Human activities are changing the concentrations of trace constituents in the troposphere; these in turn affect the radiative balance, dynamics, and chemistry of the atmosphere. One of the most pressing global change issues facing researchers and policymakers today involves the greenhouse effect and potential global warming. Carbon dioxide, nitrous oxide, methane, and CFCs are the principal anthropogenic greenhouse gases that are responsible for this effect. Of these, carbon dioxide has the highest concentration and plays the most significant role. However, the other gases are more efficient (on a per molecule basis) at trapping infrared radiation, and their combined effects are almost as large as that of carbon dioxide, even though their concentrations are much smaller. Ozone also proves significant, because the catalytic chemical process involved in its breakdown in the stratosphere and its increasing tropospheric concentrations have a multifaceted influence on the Earth's radiative balance.

Within the EOS AM-1 timeframe, the primary objective of studies in tropospheric chemistry is understanding the interaction with the surface/ocean/biomass systems, atmospheric transports and the carbon cycle. The particular focus is the time evolution of the distributions of CO and CH_4 in the troposphere. The scientific questions become convoluted when considering the sources, chemistry and ultimate sinks of minor atmospheric constituents and their interrelationships. The planet's inorganic and organic matter are the sources of many of these gases, increasing the importance of land-surface studies to determine emission rates and locations. Yet, the large-scale and seasonal distribution of these sources remains poorly understood. Space-based remote sensing provides the ideal platform for global monitoring of trace gas sources.

Scope

Whether the changes are anthropogenic or naturally occurring, understanding these changes in the trace chemical makeup of the troposphere is a critical component in anticipating global climate change. On EOS AM-1, the MOPITT instrument will investigate the evolution of tropospheric trace and greenhouse gases and their interaction with the climate and biosphere. Along with trace gas measurements, studies of greenhouse gases also require information from additional disciplines (e.g., ocean color, biomass burning, and land vegetation). Data products associated with those discipline areas are described in other sections of this document. Finally, knowledge is required of the regional increases in tropospheric ozone as well as studies of the decrease in stratospheric ozone.

Interdisciplinary studies will also advance knowledge about the chemistry of the troposphere and the lower stratosphere. The GEOS DAS will produce the 4-D data assimilation system wind data (Winds, p. 205) to provide standard global wind data based on meteorological and constituent inputs. The model will estimate transport and mixing rates for atmospheric constituents for use in atmospheric chemistry models. The effects of trace constituents on temperature profiles and dynamics differ greatly between the troposphere and stratosphere. Other 4-D GEOS DAS models will address the vertical exchange of constituents in the tropopause region. They will elucidate mechanisms for transport between the troposphere and stratosphere through process studies that use aircraft and balloons to carry out *in situ* measurements in the atmosphere.

Product Overview

Key to our understanding of the horizontal and vertical measurements of the troposphere is the measurement of CO and CH_4.

Carbon monoxide possesses a lifetime (on the order of 3 to 7 months), such that the CO is moved around on a regional scale, and thus performs the function of a chemical tracer. In addition to horizontal transport, studies have shown that there is considerable vertical transport of CO, pointing to the use of 3-D measurements which could be used to study chemical transport processes in the troposphere. MOPITT CO data, along with data from other instruments, will be used in modeling efforts by several researchers to advance our understanding of global tropospheric chemistry and its relationship to sources, sinks, and atmospheric transports.

The full range of the effects of the increased concentration of CO are not fully understood at the present time, but it is believed that CO is photochemically active and plays a major role in the concentration of OH radicals in the troposphere. The OH radical acts as a “detergent” in the troposphere, oxidizing many compounds. Satellite observations may clarify whether CO is increasing or decreasing. Increases in CO are likely to be the result of a rise in human activities. Increases in CO may deplete tropospheric radicals, thereby reducing the yearly removal of many natural and anthropogenic trace species. In particular, this effect may add to the increase of CH_4, which in turn could further reduce OH concentration. Increased CO may also indirectly intensify global warming and perturb stratospheric ozone by increasing the lifetime of other trace greenhouse gases. Greenhouse gases are those chemicals that permit the influx of solar radiation to the surface below, but inhibit to some degree longwave radiation leaving the Earth, producing a net warming effect.

The MOPITT data set also addresses the measurement of CH_4. Methane is the most abundant hydrocarbon in the atmosphere and possesses several infrared absorption bands, including one at approximately 7.7 µm, which lies in an atmospheric window with no significant absorption by other gases. This wavelength is also close to the peak radiating temperature of terrestrial thermal radiation (about 250 K), making the gas a strong contributor to the so-called “greenhouse effect.” Moreover, CH_4 currently appears to be increasing at a rate of 1 percent per year, but the source of this increase is not certain and there is evidence that it began

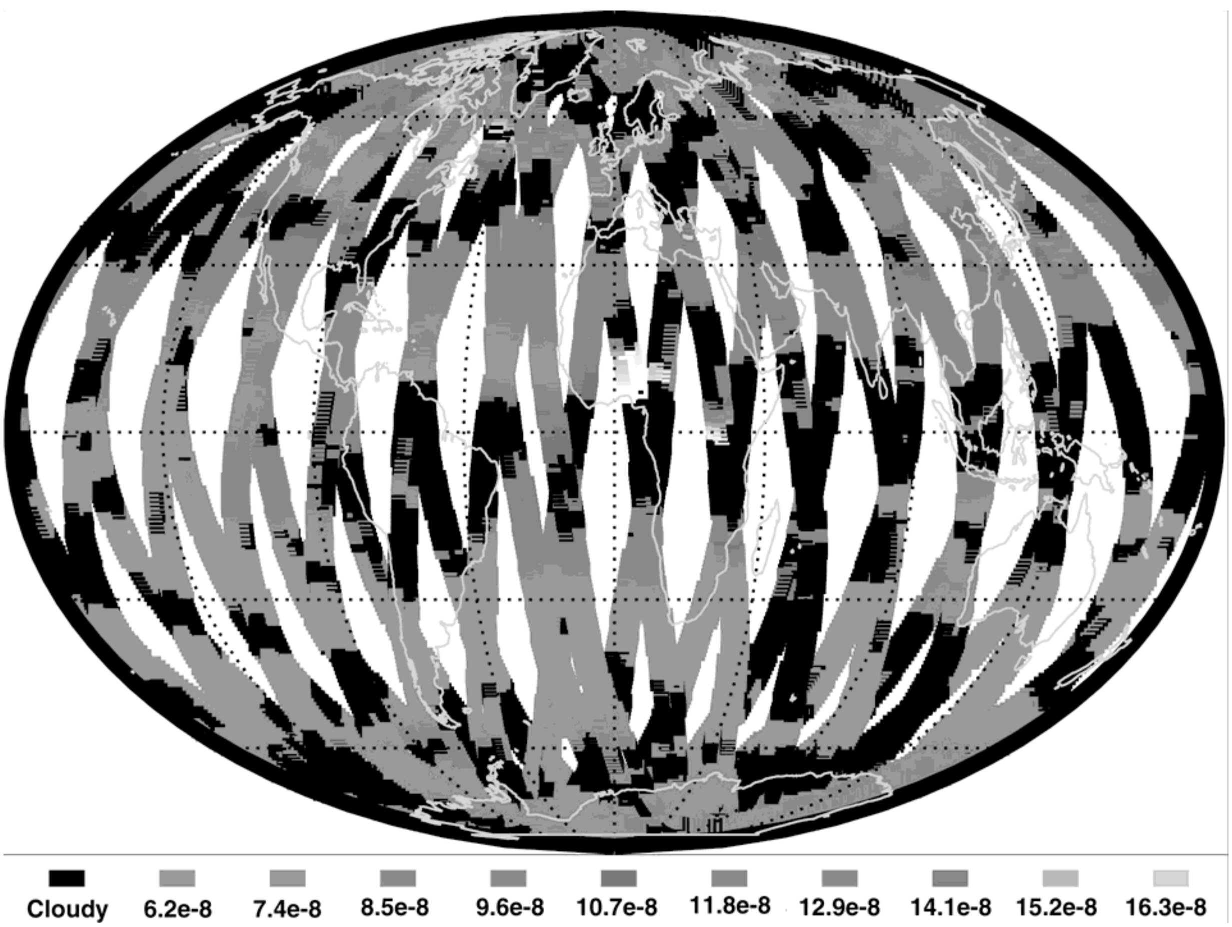

Figure 26. **Simulation of MOPITT Level-2 carbon monoxide data product for one day of observations for January climatological conditions.**

Tropospheric Chemistry

decelerating during the 1980s. Improved knowledge of the source strengths and distributions will help to resolve this uncertainty. Knowledge of the global column distribution of CH_4 taken with dynamical data may lead to a better quantitative understanding of its biogeochemical cycles. The Level 2 CH_4 data set may be used to produce Level 3 global grids which in turn may be used to develop regional and seasonal averages and other special products.

Measurement of CH_4 from the EOS AM-1 platform is expected to be extremely useful in observing the distribution and variation of the sources of CH_4. While ground-based observations tend to generate a specified accuracy over time, they cannot observe the spatial and temporal variations of the sources that are of most interest at present. Studies conducted in conjunction with other measurements of meteorological conditions (such as local wind speed and direction) may determine the source magnitude from the atmospheric perturbations to the background amount. The combination of space-based and *in situ* measurements can be synthesized with other databases of gaseous concentrations and emissions into global climate models for a better understanding of the overall problem.

In addition to the MOPITT product, Total Ozone Burden (a parameter in MOD 07) will measure total column ozone to monitor the potential environmental hazard of anthropogenic ozone depletion, and to help develop and use atmospheric correction models.

Product Interdependency and Continuity with Heritage Data

The MOPITT instrument heritage includes the Nimbus-7 Stratospheric and Mesospheric Sounder (SAMS) instrument and the Improved Stratospheric and Mesospheric Sounder (ISAMS) instrument on UARS, which employed correlation spectroscopy systems similar to that employed by MOPITT. Currently operating stratospheric instruments such as TOMS and others onboard UARS are helping scientists learn about the exchange of trace gases between the stratosphere and troposphere. Prior to the launch of EOS AM-1, surface fluxes of some land- and ocean-derived trace gases will be estimated using AVHRR and SeaWiFS observations and 4-D data assimilation. The Japanese Interferometric Monitor for Greenhouse Gases (IMG) instrument onboard ADEOS will also supply global measurements of long-lived trace gases in the pre-EOS era.

Suggested Reading

Brasseur, G.P. and R.G. Prinn, 1992.

Brenninkmeijer, C.A.M., *et al.*, 1992.

Chicano, R.J. and R.S. Oremland, 1988.

Crutzen, P.J., 1991.

Dlugokencky, E.J., *et al.*, 1994.

Dickerson, R.R., *et al.*, 1987.

Drummond, J.R., 1992.

Novelli, P.C., *et al.*, 1994.

Pan., L.D., *et al.*, 1995.

Reichle, Jr., H.G., *et al.*, 1989.

Reichle, Jr., H.G., *et al.*, 1990.

Steele, L.P., *et al.*, 1992.

Wofsy, S.C., *et al.*, 1972.

CO Profile, CO Column and CH_4 Column Data

Product Description

The carbon monoxide (CO) vertical profile and CO column data, along with methane (CH_4) total column, make up the three parameters of the MOPITT Level-2 product. The parameters are retrieved daily over the globe with column measurements available only in the sunlit portion. Horizontal resolution is variable from 22 km to ~ 100 km, depending on cloud clearing and pixel averaging, to maintain high signal to noise. The profile vertical resolution is about 4 km in the troposphere. CO profile and total column precision are expected to be 10 percent. Methane column precision is expected to be 1 percent.

Research & Applications

Global CO measurements are very important because of the role of the gas in the extremely complicated chemical balance of the troposphere. Most of the chemistry in this region of the atmosphere is induced by the chemical activity of the hydroxyl and similar radicals. These agents react rapidly with many trace gases of both natural and anthropogenic origin preventing their buildup in the troposphere through the creation of chemical products that are rained out or lost from the atmosphere by dry deposition. However, the concentrations of these radicals are extremely difficult to measure due to their short lifetimes and low concentrations. The major agents regulating the concentrations of the radicals are carbon monoxide, ozone, and nitrogen oxide. Global CO measurements used in conjunction with atmospheric chemical models therefore provide an important measure of assessing the ability of the atmosphere to “cleanse” itself.

The Level-2 carbon monoxide parameters will also be used in the future to produce Level-3 global grids which in turn may be used to develop regional and seasonal averages and other special products. These data products will provide a time evolution of the distribution of CO in the troposphere. From these a better knowledge of the chemical interactions, transports, sources and links will be obtained. Understanding their biogeochemical cycles and the intimate interrelation with other gases and with the climate will lead to better predictions of possible efrfects of anthropogenic activities.

Measurements from the EOS AM-1 platform are expected to be extremely useful in resolving the temporal and spatial variations in CH_4 not observable by ground-based networks. Knowledge of the global column distribution of methane taken with dynamical data may lead to a better quantitative understanding of its biogeochemical cycles. The Level-2 methane data set may be used in the future to produce Level-3 global grids which in turn may be used to develop regional and seasonal averages and other special products.

The global distribution of these profiles and column amounts will be used in descriptive studies of these gases on a global basis, providing the first detailed information on their horizontal, vertical, and

MOP02
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
CO profiles retrieved daily, day and night; column amounts retrieved daily in sunlit portion of orbits; resolution 22 km with some degradation depending on cloud clearing and pixel averaging

Key Geophysical Parameters:
atmospheric total column carbon monoxide; tropospheric vertical profile of carbon monoxide; atmospheric total column methane

Key Science Applications:
biogeochemical modeling
tropospheric chemical modeling
greenhouse gas modeling

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
J.R. Drummond

temporal variations, and their relationships to other activities such as biomass burning, industrial activity, thunderstorm venting of the boundary layer, etc. There are also a wide variety of temporal and spatial scales involved. By observing the sources, their magnitudes and their variation we could learn a considerable amount about the interaction of the surface and the troposphere. By monitoring the magnitude of the sinks, in conjunction with atmospheric chemical models, we learn about the chemistry of the troposphere.

Data Set Evolution

The products are derived from measurements of both thermal upwelling radiation and the attenuation of solar radiation by atmospheric carbon monoxide and methane. Absorption due to CO or CH_4 is discriminated from other gases by means of length modulator cells containing known amounts of the gases. A fast forward radiance model is used by the data processing algorithm to compute average and difference signals for known states of the atmosphere. The algorithm adjusts the CO and CH_4 amounts to bring the computed radiances into agreement with the observed. Ancillary data from the NCEP (formerly the NMC) are used to specify the atmospheric temperature and water vapor content in the calculations.

The particular instrument and algorithm configuration described here has not been previously applied. However, the maximum likelihood retrieval scheme has been successfully utilized in several space missions remotely measuring atmospheric chemical species. The use of correlation radiometry to determine concentrations of CO in the mid-troposphere has been successfully demonstrated by the Measurement of Air Pollution from Satellites (MAPS) instrument which has been flown aboard the

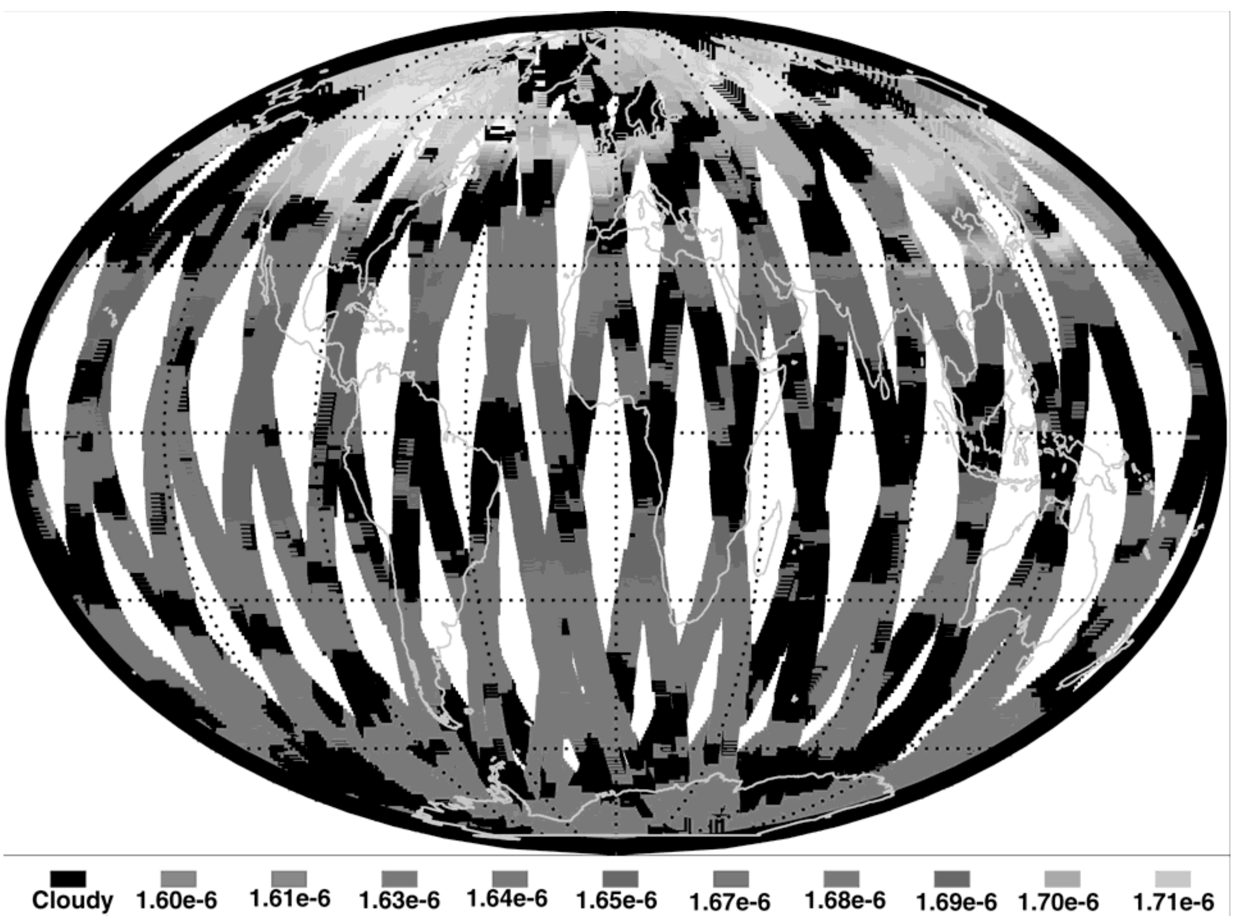

Figure 27. **Simulation of MOPITT Level-2 methane data product for one day of observations for January climatological conditions.**

CO Profile, CO Column and CH_4 Column Data

Space Shuttle several times. The approach of using reflected solar radiation to determine the total column amounts of an atmospheric gas has been successfully used many times. Perhaps the most notable application has been with NASA's TOMS, first deployed on the Nimbus-7 satellite.

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MOPITT Algorithm Theoretical Basis Document: Retrieval of Carbon Monoxide Profiles and Column Amounts of Carbon Monoxide and Methane from MOPITT Radiances (Level 1 to Level 2).

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Chapter Nine

Atmospheric Temperatures

Atmospheric Temperatures

Relationship to Global Change Issues

The atmosphere is not physically uniform but has significant variations in temperature and pressure with altitude. The regions where temperature is either increasing or decreasing with height define the different layers of the atmosphere. The lowest 10 to 15 km of the atmosphere is called the troposphere, and the region from about 15 to 50 km is known as the stratosphere. The transitional region between the troposphere and stratosphere is known as the tropopause.

Upper air temperature is an important parameter influencing the hydrological cycle and is a key input to global climate models. Tropospheric and stratospheric temperatures are central to the problem of greenhouse warming because Global Circulation Models (GCMs) predict that temperature changes with enhanced concentrations of greenhouse gases will have a characteristic profile in these layers, with warming in the mid-troposphere and cooling in much of the stratosphere. Cooler stratospheric temperatures is an expected consequence of the increased trapping of terrestrial radiation in the troposphere. Most ozone depletion occurs in the lower part of the stratosphere (15 to 25 km). Accurate knowledge of the fluctuations in stratospheric temperature on a global scale is therefore highly desired to understanding global warming.

The most valuable data for understanding atmospheric dynamics and initializing forecast models are 3-D horizontal wind and temperature data. These variables are followed in priority by the 3-D moisture distribution, surface wind, surface pressure, and sea-surface temperature. Problems with the establishment of 3-D global temperature data are the notable gaps of data over the oceans. Also, although sharp temperature inversions exist in the atmosphere, they are difficult to infer from satellite.

However, in the absence of satellite coverage of direct wind observations, the data assimilation system can provide a dynamically consistent, temporally frequent, globally covered, and statistically optimal global dataset.

The data assimilation system organises the observations from many diverse instrument sources and measurement times into a single useful data product, complements the observations by propagation of information from observed into unobserved regions and times, and supplements the observations by providing estimates of quantities that are difficult or impossible to observe.

The GEOS DAS models with sufficient vertical resolution are expected to provide consistent inversion data, improving short-range forecasts. These forecast improvements will occur when the data input to the models reaches a vertical resolution of 2 km, which are the parameters association with the TRMM/EOS GEOS DAS temperature profiles. Present infrared sounders have an accuracy of about 2.5° and a vertical resolution of 5 km to 6 km.

Product Overview

MODIS Atmospheric Profiles (MOD 07, 08) provides atmospheric temperature, as well as total ozone burden, atmospheric stability, moisture profiles and atmospheric water vapor. Four assimilated products will be available in the TRMM /EOS AM timeframe. Temperature Profiles (DAS 20) provides 3- and 6-hourly estimates of atmospheric temperatures and includes temperatures at the surface and 2 and 10 meters above the surface. Temperatures and mandatory pressure and model sigma levels are also provided. Temperature changes (DAS 21) provides 6-hourly estimates of atmospheric temperature changes at a given level of the atmosphere. Parameters include estimates of temperature changes from turbulent mixing, convection, and long and shortwave radiation. Temperature Flux (DAS 22) consists of 3-hourly estimates of integrated atmospheric temperature flux. Both zonal u-winds and meridional v-winds are included. All the assimilated temperature products are classified as level 4 within EOS.

Product Interdependency and Continuity with Heritage Data

Data assimilation using a numerical weather forecast model is critical to the success of EOS objectives. The GOES-1 DAS ingests the global conventional observations and the temperature retrievals to the forecasting models to produce assimilated data products. The present series of atmospheric sounders (TOVS) aboard NOAA polar satellites are limited by their vertical resolution in the atmosphere.

NOAA's operational satellites and the Defense Meteorological Satellite Program (DMSP) instruments have been providing the temperature and humidity profiles and surface products for ingesting in assimilation models and climate studies. Three NOAA instruments are: AVHRR since 1981; the TOVS since 1979; the Geostationary Operational Environmental (GOES) satellite VISSR and its VISSR atmospheric sounder version since 1978. Considerable progress has also been made with the high-resolution interferometer sounder (HIS/2) deployed on geostationary satellites. Also, the four channel MSU replaced with 20 channel on Advanced Microwave Sounding Unit (AMSU), is presently flown on NOAA-K providing high resolution weather atmospheric temperature profile.

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Takacs, L.L., *et al.*, 1994.

Assimilated Temperature Profiles

Product Description

This Level 4 product consists of 3- and 6-hourly estimates of atmospheric temperature produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Surface air temperature is contained in TS. Temperatures at 2 and 10 m above the surface are contained in T2M and T10M. Temperatures at mandatory pressure and model sigma levels are in TMPU.

Research & Application

Variation in atmospheric temperature drives the Earth's general circulation. Convective precipitation is generated by vertical variations in atmospheric temperature. Specification of atmospheric temperature is critical to understanding global climate change.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 20
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 24 mandatory pressure or 70 model sigma levels, daily at 00, 06, 12, and 18 UTC. Surface 2-m and 10-m data, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
temperature profiles

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Assimilated Temperature Changes

Product Description

This Level 4 product consists of 6-hourly estimates of atmospheric temperature changes at a given level of the atmosphere estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. TURBT is an estimate of the temperature change taking place at a given level as a result of turbulent mixing. MOISTT is an estimate of the temperature change taking place at a given level as a result of convection. RADLW and RADSW are estimates of the temperature changes taking place at given levels as a result of longwave and shortwave radiation. All four fields are available at mandatory pressure and model sigma levels.

Research & Application

Variation in atmospheric temperature drives the Earth's general circulation. Convective precipitation is generated by vertical variations in atmospheric temperature. Specification of atmospheric temperature is critical to understanding global climate change. This product gives important insight into the mechanism responsible for local temperature changes in the atmosphere.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature changes through its general circulation model that takes into account global circulation systems, precipitation, radiation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 21
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, 24 mandatory pressure and 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
temperature changes from turbulence, convection, and radiation

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Assimilated Temperature Flux

Product Description

This Level 4 product consists of 3-hourly estimates of vertically integrated atmospheric temperature flux estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. The field is separated into two components, VINTUT (zonal u-wind) and VINTVT (meridional v-wind).

Research & Application

Variation in atmospheric temperature drives the Earth's general circulation. Specification of atmospheric temperature flux is critical to understanding global climate change.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature flux through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 22
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
vertically integrated atmospheric temperature flux

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Tropopause Temperature and Pressure

Product Description

This Level 4 product consists of 3-hourly estimates of the tropopause pressure and temperature produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Tropopause pressures are in TROPP and temperatures in TROPT.

Research & Application

CERES requires tropopause information for its retrieval algorithms.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 23
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
tropopause

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

MODIS Atmospheric Profiles

Product Description

The MODIS Atmospheric Properties (MOD 07 at Level 2 and MOD 08 at Level 3) consists of several parameters; they are Total Ozone Burden, Atmospheric Stability, Temperature and Moisture Profiles, and Atmospheric Water Vapor. All of these parameters are produced day and night for Level 2 at 5 x 5 1-km pixel resolution when at least 9 FOVs are cloud free; for Level 3, data are generated on a 0.5° latitude/longitude resolution grid daily, monthly, and seasonally.

The MODIS Total Ozone Burden is an estimate of the total column tropospheric and stratospheric ozone content. The MODIS Atmospheric Stability consists of three daily Level 2 and monthly Level 3 atmospheric stability indices. The Total Totals (TT), the Lifted Index (LI), and the K index (K) are each computed using the infrared temperature and moisture profile data also derived as part of MOD 07. The MODIS Temperature and Moisture Profiles are produced at 20 vertical levels for temperature and 15 levels for moisture. A simultaneous direct physical solution to the infrared radiative transfer equation in a cloudless sky is used. The MODIS Atmospheric Water Vapor product is an estimate of the total tropospheric column water vapor made from integrated MODIS infrared retrievals of atmospheric moisture profiles in clear scenes.

Research & Applications

Total column ozone estimates at MODIS resolution are required by MODIS investigators developing atmospheric correction algorithms. This information is crucial for accurate land and ocean surface parameter retrievals. Furthermore, strong correlations have been found to exist between the meridional gradient of total ozone and the wind velocity at tropopause levels, providing the potential to predict the position and intensity of jet streams. Total column ozone monitoring is also important due to the potential harm to the environment caused by anthropogenic ozone depletion.

Atmospheric instability measurements are predictors of convective cloud formation and precipitation. The MODIS instrument offers an opportunity to characterize gradients of atmospheric stability at high resolution and greater coverage. Radiosonde-derived stability indices are limited by the coarse spacing of the point source data too large to pinpoint local regions of probable convection.

MOD 07, MOD 08
PRODUCT SUMMARY

Coverage:
global, clear-sky only

Spatial/Temporal Characteristics:
5 km (Level 2), 0.5° (Level 3)/daily, monthly

Key Science Applications:
for ozone: atmospheric correction, prediction of cyclogenesis, anthropogenic ozone depletion

for atmospheric stability: atmospheric correction, prediction of convective cloudiness and precipitation, characterization of the atmosphere

for soundings: atmospheric correction algorithm development and use, characterization of the atmosphere

for total column water vapor: atmospheric correction algorithm development and use, characterization of the atmosphere

Key Geophysical Parameters:
total column ozone, atmospheric stability (Total Totals, Lifted Index, and K index), atmospheric profiles of temperature and moisture, atmospheric total column water vapor

Processing Level:
2, 3

Product Type:
standard, routine

Science Team Contact:
P. Menzel

MODIS Atmospheric Profiles

Atmospheric temperature and moisture sounding data at high spatial resolution from MODIS and high spectral resolution sounding data from AIRS will provide a wealth of new information on atmospheric structure in clear skies. The profiles will be used to correct for atmospheric effects for some of the MODIS products (e.g., sea surface and land surface temperatures, ocean aerosol properties, water leaving radiances, and PAR) as well as to characterize the atmosphere for global greenhouse studies.

Total column precipitable water estimates at MODIS resolution are required by MODIS investigators developing atmospheric correction algorithms. This information is crucial for accurate land and ocean surface parameter retrievals. MODIS will also provide finer horizontal scale atmospheric water vapor gradient estimates than are currently available from the POES.

Data Set Evolution

One of two ozone retrieval methods developed using the HIRS will be chosen as best suited for application with MODIS data. Both use a first guess perturbation method and radiances from MODIS channel 30 (9.6 µm) to solve the radiative transfer equation. The perturbations are with respect to some *a priori* conditions that may be estimated from climatology, regression, or more commonly from an analysis or forecast provided by a numerical model. The MODIS cloud mask product (MOD 35) will also be used to screen for clouds.

Atmospheric stability estimates will be derived from the MODIS temperature and moisture retrievals contained in product MOD 07. Layer temperature and moisture values may be used to estimate the temperature lapse rate of the lower troposphere and the low-level moisture concentration.

Temperature and moisture profile retrieval algorithms are adapted from the International TOVS Processing Package (ITPP), taking into account MODIS' lack of stratospheric channels and far higher horizontal resolution. The profile retrieval algorithm requires calibrated, navigated, and coregistered 1-km FOV radiances from MODIS channels 20, 22-25, 27-29, and 30-36. The MODIS cloud mask (MOD 35) is used for cloud screening. The algorithm also requires NCEP model analyses of temperature and moisture profiles as a first guess and an NCEP analysis of surface temperature and pressure.

Several algorithms for determining atmospheric water vapor, or precipitable water, exist. It is most directly achieved by integrating the moisture profile through the atmospheric column. Other split window methods also exist. This class of techniques uses the difference in water-vapor absorption that exists between channel 31 (11 µm) and channel 32 (12 µm).

Data validation will be conducted by comparing results to *in situ* radiosonde measurements, NOAA HIRS operational retrievals, GOES sounder operational retrievals, NCEP analyses, and retrievals from the AIRS instrument on the PM platform. A field campaign using a profiler network in the central U.S. and the MAS-equipped aircraft will be initiated in the first year after launch. Quality control will consist of manual and automatic inspections, with regional and global mean temperatures at 300, 500, and 700 hPa monitored weekly, along with 700 hPa dew point temperatures. For total ozone, data validation will consist of comparing the TOMS as well as operational NOAA ozone estimates from HIRS to the MODIS retrievals.

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Jedlovec, G.J., 1987.

Kleepsies, T.J. and L.M. McMillan, 1984.

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Prabhakara, C., *et al.*, 1970.

Shapiro, M.A., *et al.*, 1982.

Smith, W.L. and F.X. Zhou, 1982.

Smith, W.L., *et al.*, 1985.

Sullivan, J. *et al.*, 1993.

MODIS Atmospheric Profiles

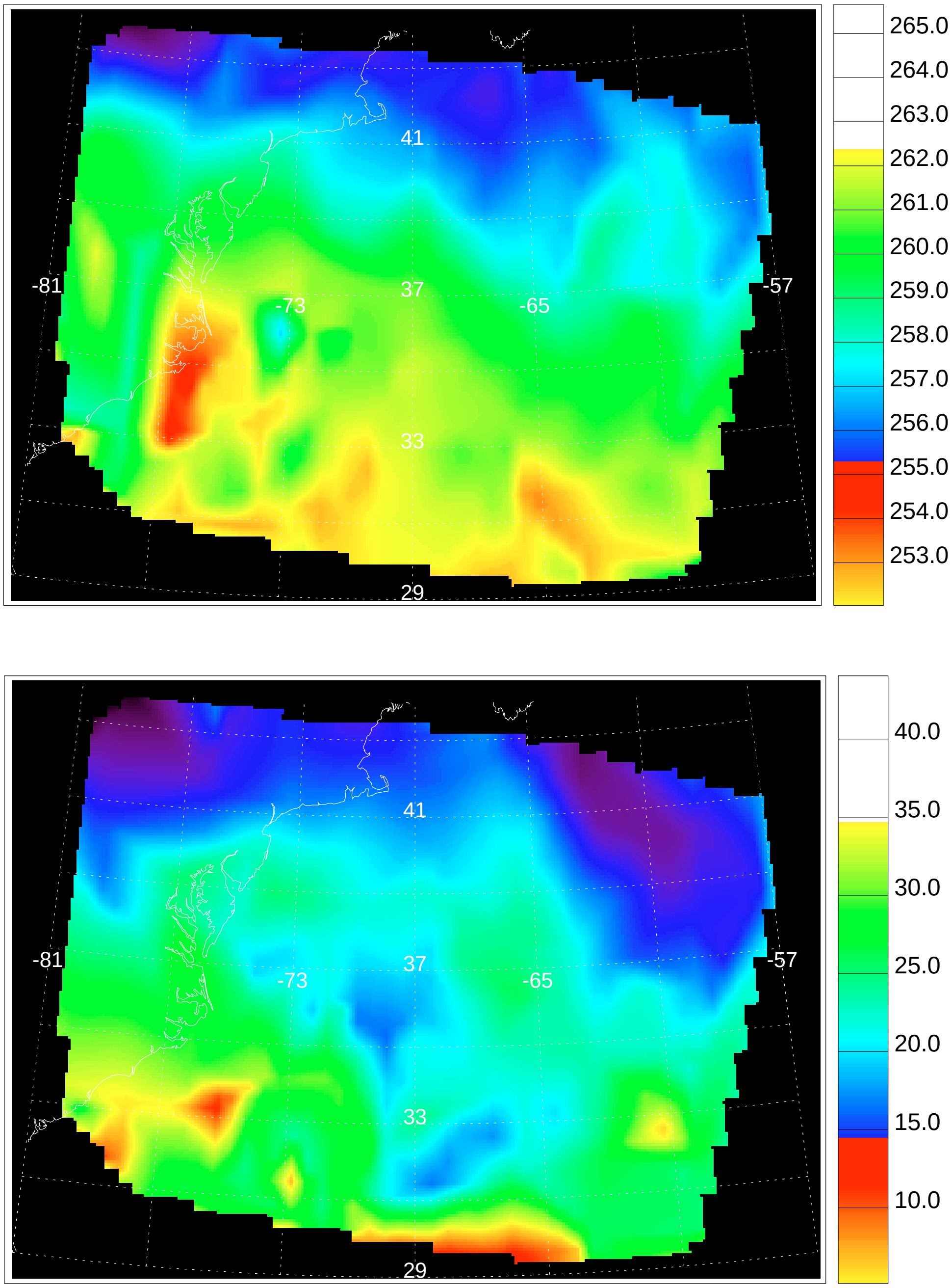

Figure 28. **MODIS Atmospheric Profiles**. *Level 2 MODIS atmospheric properties generated by the International TOVS Processing Package (ITPP) using NOAA-12 HIRS data acquired on 15 May 1995 at 12:12 UTC. The upper panel represents temperature at 500 hPa (K), whereas the lower panel represents total precipitable water (mm).*

Chapter Ten

Winds

Winds

Relationship to Global Change Issues

Atmospheric winds provide information essential to understanding atmospheric circulation and dynamics in addition to global climate change. Global wind estimates, for example, provide information about the sources, sinks and transport mechanisms of stratospheric trace gases important to resolving global warming issues. Winds are also a vehicle for addressing various multidisciplinary questions involving the global biogeochemical and hydrologic cycles. The 1991-1992 El Niño was the first El Niño to be predicted in advance and was based on winds as the driving force of a global circulation model.

Because wind fields have been primarily measured by land-based rawinsondes, measurements have been too irregularly distributed to provide adequate data for global climate studies. Missing data includes oceanic areas (covering roughly three quarters of the Earth's surface) and some less-developed Southern hemisphere land areas have been poorly observed. These measurements historically have been inferred from satellite cloud tracking imagery or computed from pressure gradients. Tracking of clouds by satellites provides estimates of low- and high-level winds over portions of the Earth, but uncertainties in heights introduce errors and there are many gaps in the data. The desired accuracy is ± 10 percent, which corresponds to about 1 m/s in the lower troposphere and 5 m/s in the upper troposphere. Even with these data, however, there are significant gaps in global coverage.

However, in the absence of satellite coverage of direct wind observations, the Goddard EOS Data Assimilation System (GEOS DAS) can provide dynamically consistent, temporally frequent, globally covered, and statistically optimal global datasets. And assimilated wind products in the TRMM/AM-1 timeframe provide significant improvements over prior measurements available today.

Within the EOS AM-1 timeframe, new products from the TRMM and AM-1 instruments will greatly improve the accuracy and coverage of the data. Improvements will come as EOS and TRMM instrument data fill spatial and temporal gaps in the observational data used in the GEOS DAS with well calibrated and high quality atmospheric fields. The TMI and MODIS instruments will also provide improved boundary conditions for the forecast model. The GEOS DAS assimilated products are classified as Level 4 products in EOS.

Data assimilation is the process of ingesting observations into a model of the Earth system. The current product uses meteorological observations and an atmospheric model. The result is a comprehensive and dynamically consistent dataset which represents the best estimate of the state of the atmosphere at that time. The assimilation process fills data voids with model predictions and provides a suite of data-constrained estimates of unobserved quantities such as vertical motion, radiative fluxes, and precipitation. The GEOS DAS process not only combines all the data globally but accounts for instruments errors and bridges the gap between observations.

Product Overview

The assimilated wind products are a synthesis of measurements and short-term model forecasts. In the GEOS-I system, this is accomplished using an analysis scheme in which observations of the following variables are used: geopotential thickness, zonal (u) and meridional (v) winds, water vapor mixing ratio, sea level pressure and surface winds over the ocean. The assimilation process is carried out at a horizontal resolution of 1° latitude by 1° longitude at 50 model sigma /21 mandatory upper-air pressure levels and at sea level. The analysis increments (observation minus background forecast) are computed every 6 hours using observations from a ± 3-hour data window centered on the analysis times (00, 06, 12, and 18 UTC). The increments are then inserted gradually into the global circulation model (GCM) by rerunning the forecast and adding a fraction of the increment at each model time step. Over the 6-hour period centered at the analysis time the full effect of incrementing is realized. In this way, the assimilation consists of a continuous GCM forecast with additional heat, momentum, moisture and mass source terms updated every 6 hours from observations. It is the output of this assimilation procedure that makes up the datasets provided here.

Winds

GEOS DAS classifies the parameters as prognostic or diagnostic. Prognostic parameters are atmospheric state variables which the model forecasts (e.g., temperature and humidity profiles). During the assimilation these are the parameters most directly influenced by the observations. Prognostic fields are sampled 4 times daily at 00, 06, 12, 18 UTC.

The assimilated products, surface wind speed (DAS 24), surface stress (DAS 29), surface roughness (DAS 30), surface drag coefficient (DAS 31), and planetary boundary layer depth (DAS 32) are classified as diagnostic parameters. These parameters are generally not measured, but are calculated by the model's physical parameterizations in a manner consistent with the observations. Diagnostic surface or other single level fields are given 8 times daily as time averages over the three hours-preceding the time stamp (i.e., at 00 for 21 (previous day) to 00, at 03 for 00 to 03, at 06 for 03 to 06 UTC). Diagnostic upper air fields are given 4 times daily as time averages over 6 hours centered on the times 00, 06, 12, 18 UTC.

The GEOS DAS assimilated wind products include the following datasets.

- **Surface winds** (DAS 24) drive ocean currents and exchange momentum with the oceans and land. Sea level winds are used to infer wind stresses affecting ocean circulation. **Surface Wind Stress** (DAS 29) plays an important role in regulating the Earth's general circulation. It is also an important forcing function for ocean circulation. **Surface Roughness** (DAS 30) provides estimates to approximate the drag imposed on low-level winds. This field is needed to specify iterations in the planetary boundary layer (PBL). **Surface Drag Coefficients** (DAS 31) provides drag coefficients for temperature, moisture, winds which are used in calculating surface sensible heat and moisture flux and in calculating surface wind stress.
- **Wind profiles** (DAS 25) define the Earth's general circulation. Specification of the atmosphere's general circulation is critical to understanding global climate change. **Vertical Velocity** (DAS 26) determines atmospheric cloud formation and precipitation. Upward motion produces clouds and precipitation while downward motion produces clear skies. **Vertically Integrated Winds** (DAS 27) provides angular momentum studies of the Earth's atmosphere.
- **Turbulence** plays an important role in the atmosphere's general circulation; its parameterization consists of elements that handle vertical diffusion of surface fluxes of heat, moisture, and momentum. **Turbulence Profiles** (DAS 28) provides data on how turbulence influences the general circulation model within the GEOS DAS.

Boundary layer processes control the exchange of momentum, energy and mass across the lower boundary of the atmosphere. It is critical for developing efficient coupled ocean-atmosphere models. Measuring boundary level wind profiles is also a significant step forward in understanding regional climate change following alteration of land surface by overgrazing and deforestation. The **Planetary Boundary Layer Depth** (DAS 32) is generated by the turbulence parameterization with the GEOS DAS General Circulation model (GCM). It is defined as the depth at which turbulent kinetic energy reduces to ten percent of its surface value.

Product Interdependency and Continuity with Heritage Data

The GEOS DAS assimilated wind products are the results of ongoing research to track, model, and validate assimilated fields. The GEOS DAS incorporates observations from instruments on satellites JERS-1, ERS-1, SSM/I, TOVS, GOES, and METEOSATS for improving the assimilation procedures. The DOA also provides assimilated wind data sets in support of the Tropical Ocean Global Atmosphere (TOGA) subproject of the Global Ocean-Atmosphere Response Experiment (COARE) and from UARS, which has temperature, wind and constituent measurements. In many ways UARS provides a prototype for the EOS effort, making UARS a very important mission to study prior to the launch of the EOS satellites.

Future wind scatterometers (NSCAT launched in 1996 on board ADEOS, ERS-2, and the NSCAT follow-on SeaWinds on ADEOS II) and Radarsat will provide measurements of the basic wind-forcing fields and wind stress maintaining the continuity of the ocean vector wind dataset allowing improved estimates of critical air-sea fluxes of heat, momentum. and chemical species.

Suggested Reading

Daley, R., 1991.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D. and R.B. Rood, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

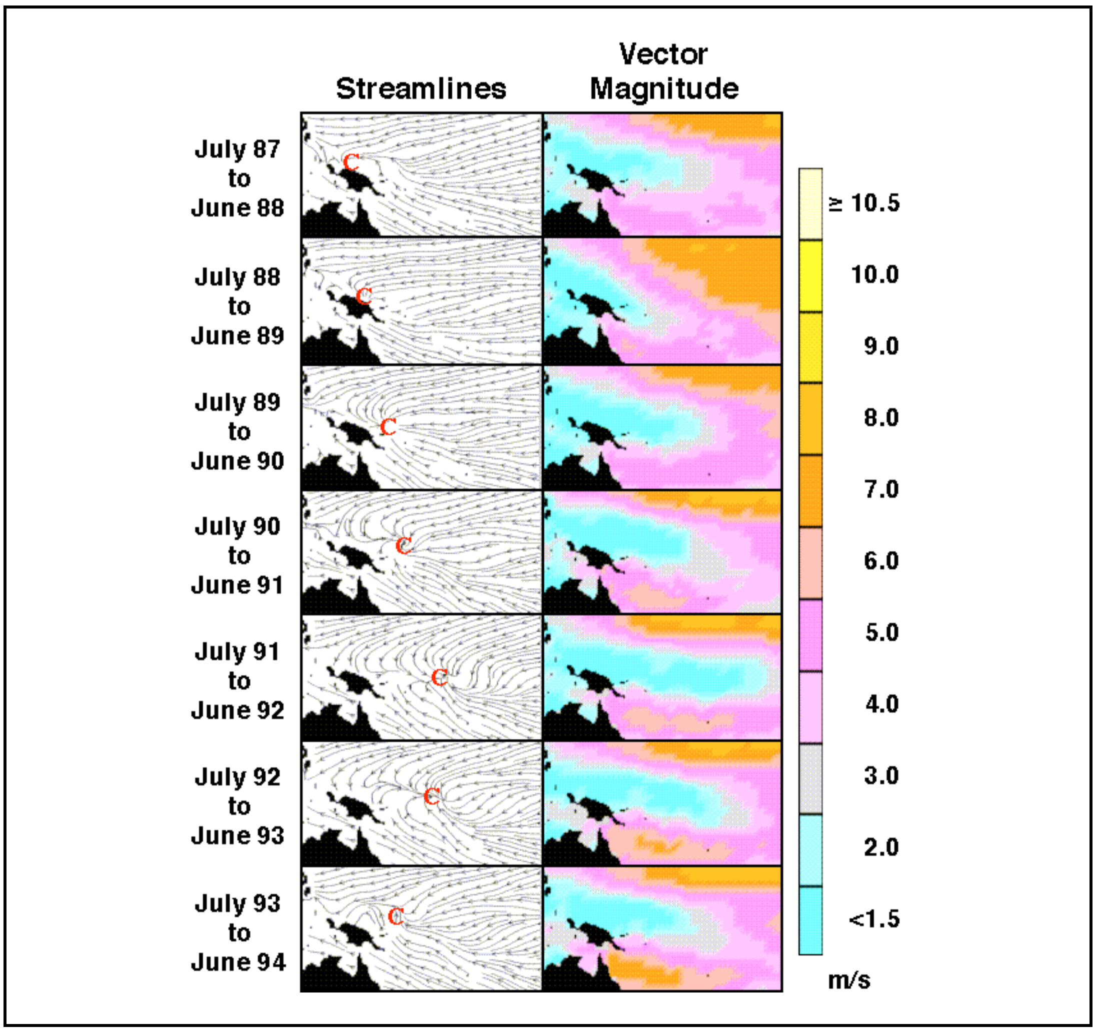

Figure 29. **Annual Average Surface Streamline and Vector Magnitude Patterns for the Western Tropical Pacific.** Interannual variability can be discerned from the SSM/I surface wind velocity data set. Each of the seven years of data shown is assumed to begin with July 1 and to end with June 30 of the following year (http://nimbus.gsfc.nasa.gov:8080/DIG/SpaceBasedSW/SSMI/SurfWindVel/InterAnnualVar/InterAnnualVar.html).

Assimilated Surface Winds

Product Description

This Level 4 product consists of 3-hourly estimates of the sea level winds and surface wind speed produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Three fields are provided: u-component sea level winds (SLU), v-component sea level winds (SLV), and surface wind speed (WINDS) which includes sea level winds over the oceans and winds over land.

Research & Application

Accurate sea level wind estimates are needed for MODIS retrievals over the oceans. Sea level winds are also needed to infer wind stresses affecting ocean circulation.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products will greatly improve the accuracy and coverage of the data used to produce this field. In addition, data assimilation provides dynamically consistent estimates of surface winds through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 24
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18 and 21 UTC

Key Geophysical Parameters:
surface winds

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Assimilated Wind Profiles

Product Description

This Level 4 product consists of 3 and 6-hourly estimates of atmospheric winds produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. UWIND and VWIND contain the u- and v-components of wind at mandatory pressure and model sigma levels. U2M, V2M, U10M, and V10M contain the u and v-components at 2 m and 10 m above the Earth's surface. UWINDE and VWINDE contain the estimated wind errors at the mandatory pressure levels.

Research & Application

Atmospheric winds define the Earth's general circulation. Specification of the atmosphere's general circulation is critical to understanding global climate change.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 25
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 24 mandatory pressure or 70 model sigma levels, daily at 00, 06, 12, and 18 UTC plus 2 m and 10 m data daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
wind profiles

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Assimilated Vertical Velocity

Product Description

This Level 4 product consists of 6-hourly estimates of atmospheric vertical velocity produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Vertical velocity is not measured directly but derived from the continuity equation within the GEOS DAS general circulation model.

Research & Application

Atmospheric vertical velocity determines atmospheric cloud formation and precipitation. Upward motion produces clouds and precipitation while downward motion produces clear skies.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 26
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 21 mandatory pressure or 50 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
vertical velocity

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Assimilated Vertically Integrated Winds

Product Description

This Level 4 product consists of 3-hourly estimates of vertically integrated winds estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. The field is separated into two components, UBAR (zonal u-wind) and VBAR (meridional v-wind).

Research & Application

Vertically integrated wind estimates are angular momentum studies of the Earth's atmosphere.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature flux through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 27
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
vertically integrated barotropic winds

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Turbulence Profiles

Product Description

This Level 4 product consists of 6-hourly estimates of atmospheric turbulence produced by the turbulence parameterization of the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. QQ is the turbulent kinetic energy. TURBU and TURBV are the u- and v-component momentum changes due to turbulence.

Research & Application

Turbulence plays an important role in the atmosphere's general circulation. This product provides information on how turbulence influences the general circulation within the GEOS DAS.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of temperature through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 28
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, 24 mandatory pressure or 70 model sigma levels, daily at 00, 06, 12, and 18 UTC

Key Geophysical Parameters:
turbulence profiles

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Surface Wind Stress

Product Description

This Level 4 product consists of 3-hourly estimates of surface wind stress estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. This field is generated by the turbulence parameterization within the GEOS DAS general circulation model (GCM). UFLUX is the turbulent flux of zonal (u-component) momentum from the surface while VFLUX is the turbulent flux of meridional (v-component) momentum from the surface. USTAR is the surface-stress velocity, or friction velocity. USTAR is used to calculate surface roughness length, Z0, over the ocean.

Research & Application

Surface wind stress plays an important role in regulating the Earth's general circulation. It is also an important forcing function for ocean circulation.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through turbulence parameterization schemes within global GCMs. The GEOS DAS turbulence parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 29
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface wind stress

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Surface Roughness

Product Description

This Level 4 product consists of 3-hourly estimates of surface roughness produced by the GEOS DAS. Over land, it is based on monthly mean data from Dorman and Sellers (1989). Over oceans it is based on surface stress velocity estimated by the GEOS DAS GCM. Surface stress velocity is based on the assimilation of pressure, temperature, wind, and moisture observations from conventional meteorological sources, both *in situ* and remotely sensed, along with other TRMM and AM-1 data such as TMI and MODIS.

Research & Application

Surface roughness estimates are needed to approximate the drag imposed on low-level winds. This field is needed to specify interactions in the PBL.

Data Set Evolution

Surface roughness estimates over land will not improve much as a result of TRMM or AM-1. Surface roughness over the ocean, however, will improve based on better wind estimates using TMI and MODIS.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Dorman, J. L., and P.J. Sellers, 1989.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 30
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface roughness

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Surface Drag Coefficients

Product Description

This Level 4 product consists of 3-hourly estimates of surface drag coefficients estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. This field is generated by the turbulence parameterization within the GEOS DAS GCM. CT is the surface drag coefficient for temperature and moisture. CU is the drag coefficient for winds. CT is used in calculating surface sensible heat and moisture flux while CU is use in calculating surface wind stress.

Research & Application

Surface heat and moisture flux along with surface wind stress play an important role in determining the Earth's general circulation.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through turbulence parameterization schemes within global GCMs. The GEOS DAS turbulence parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 31
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
surface drag coefficients

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Assimilated Planetary Boundary Layer Depth

Product Description

This Level 4 product consists of 3-hourly estimates of PBL depth estimated by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. This field is generated by the turbulence parameterization within the GEOS DAS GCM. It is defined as the depth at which turbulent kinetic energy reduces to 10 percent of its surface value.

Research & Application

The depth of the PBL plays an important role in the vertical mixing that takes place in the atmosphere. A shallow PBL may trap harmful pollutants near the Earth's surface.

Data Set Evolution

This very specialized data set is not generally available globally from conventional observations. It is usually estimated through turbulence parameterization schemes within global GCMs. The GEOS DAS turbulence parameterization scheme will have the advantage of additional observational input from TRMM and AM-1 instruments.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 32
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
planetary boundary layer depth

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod

Chapter Eleven

Pressure and Heights

Presssure and Heights

Relationship to Global Change Issues

Monitoring surface pressure and geopotential heights is important to the understanding of atmospheric dynamics on regional and global scales. These measurements are critical to obtaining hydrological cycle parameters (wind) needed for locating the position of storm systems and for developing atmospheric global climate models (GCMs) whereas geopotential heights have been crucial in the understanding of large-scale circulation changes.

Although pressure is one of the fundamental atmospheric variables, there are no current remote sensing techniques for measurement of this pressure field. Limited maps have been produced either by *in situ* measurements or by indirect methods. However, dynamically consistent global atmospheric fields are provided from assimilation of available surface-based observations and satellite retrievals to the AGCM, constrained by some surface boundary conditions. The practical aspects of this approach are enormous. The data assimilation system complements the observations by propagation of information from observed into unobserved regions and times.

Data assimilation is the process of ingesting observations into a model of the Earth system. The current product uses meteorological observations and an atmospheric model. The result is a comprehensive and dynamically consistent dataset which represents the best estimate of the state of the atmosphere at that time. The assimilation process fills data voids with model predictions and provides a suite of data-constrained estimates of unobserved quantities such as vertical motion, radiative fluxes, and precipitation. The GEOS DAS process not only combines all the data globally but accounts for instruments errors and bridges the gap between observations.

The geopotential height is used for all aerological reports because of its convenience. It represents the height of a surface where parcels of air have the same potential energy (effectively it is gravity weighted height relative to sea level). Because of poleward increase of gravity along a constant geometric-height surface, a given geopotential surface has a smaller geometric height over the poles than over the equator. Geopotential height is used to compute geopotential thickness (differences in the geopotential heights of two constant pressure surfaces in the atmosphere) for input to the assimilating model.

Assimilated values of surface pressure (especially over oceans) have been shown to improve the forecasts during the Global Energy and Water Cycle Experiment (GEWEX) in 1979, especially in the southern hemisphere. These assimilated data provide reliable surface reference levels for satellite measurements and are also used to estimate surface winds in regions where other measurements are not available.

The anomalies of the northern hemisphere map of assimilated geopotential heights of the 500 mb have been successfully used in the understanding (Kalnay, *et al.*, 1983) of the stratospheric sudden warming events observed during the FGGE period, winter of 1979 and in the understanding of atmospheric “blocking” (persistence of large-scale meridonal flow in the middle troposphere for at least 10 days, and manifesting as quasi-stationary high amplitude planetary waves in the midtropospheric geopotential height fields) observed at middle and high latitudes over the oceanic regions of the northern hemisphere.

Within the DAS the input observational database are mostly acquired from NCAR, NCEP, and NOAA/NESDIS. For global sea level pressure and near surface wind analysis over the oceans, data from surface land synoptic reports (sea level pressure only), ships and buoys are used. The upper-air analysis of temperature, height/geopotential thickness, wind and moisture incorporate the data from rawinsondes, dropwindsondes, rocketsondes, aircraft winds, cloud tracked winds, and the TOVS soundings. The other input for the model is a series of boundary conditions (land surface type, sea surface temperature, albedo, sea ice, snow cover) based on climatology provided either through NCEP or NCAR. The assimilating forecasting model generates an improved global gridded dataset of surface pressure and geopotential heights in addition to other atmospheric and surface parameters vital to

Pressure and Heights

future forecasting and other land and atmosphere studies.

Use of better observations from TRMM and EOS AM-1 such as TMI and MODIS will improve the assimilation products and hence global modeling efforts, numerical weather predictions, investigation of atmosphere-surface interactions, and monitoring of climate variations and trends.

Product Overview

The products in this category include assimilated surface pressure (DAS 33) and assimilated surface and upper air geopotential heights (DAS 34). These are EOS Level 4 products.

The product DAS 33 includes surface pressure, sea level pressure, sea level pressure error, pressure of the top of the model relative to observed surface pressure and 3-hour average of surface pressure and surface pressure tendency. The product DAS 34 consists of 6 hourly estimates of assimilated upper air geopotential heights and associated analyzed errors at 24 mandatory pressure levels, and upper air perturbation geopotential heights at 70 model sigma levels. Surface geopotential heights included in DAS 34 and all surface parameters of DAS 33 are reported at 3-hour intervals.

Product Interdependency and Continuity with Heritage Data

Prior to the launch of the EOS sensors, new high-resolution data from the sensors of present satellite missions (GOES, DMSP, ERS, UARS, TOPEX/POSEIDON, SeaWiFS, and ADEOS) along with other sources such as the Pathfinder and COADS data sets, will be used to carry out the validation studies towards the improvement and enhancement of assimilation algorithms and prediction models.

Once EOS satellite missions are launched, new data from advanced sensors aboard NOAA, DMSP, GOES, ERS, TRMM, EOS AM, ADEOS II, EOS PM, and CHEM platforms, will be used to improve the quality of assimilated products that include 4-dimensional gridded fields of atmospheric parameters (e.g., wind, temperature, moisture, geopotential, turbulence, radiative heating/flux, clouds, precipitation, sensible and latent heat flux, and planetary boundary layer depth) and surface land and ocean parameters (e.g., albedo, temperature, pressure, evaporation, roughness, snow depth, soil moisture, vegetative moisture, and sea level height).

In particular, EOS sensors TRMM, MODIS, and CERES will provide high vertical resolution temperature, moisture profiles (MOD 07) and cloud height information (MOD 06 & CER 07), and better surface temperature (MOD 11) and land cover type (MOD 12) values to be used in EOS-DAS assimilation system as input and boundary conditions.

Suggested Reading

Daley, R., 1991.

Kalnay, E., *et al.*, 1983.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

Assimilated Surface Pressure

Product Description

This Level 4 product consists of 3-hourly estimates of the surface pressure humidity produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. This product includes surface pressure (PSFC), sea level pressure (SLP), sea level pressure error (PRSE), surface pressure minus pressure at the top of the GEOS DAS general circulation model (PSPTOP), three-hour average of surface pressure (PAVE), and surface pressure tendency (DPDT).

Research & Application

An estimate of the surface pressure is needed by many of the TRMM and AM-1 instrument retrieval algorithms. Surface pressure patterns also indicate the position of storm systems and the general circulation of the atmosphere.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products will greatly improve the accuracy and coverage of the data used to produce this field. In addition, data assimilation provides dynamically consistent estimates of surface pressure through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 33
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18 and 21 UTC

Key Geophysical Parameters:
surface pressure

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Assimilated Geopotential Heights

Product Description

This Level 4 product consists of 3- and 6-hourly estimates of atmospheric geopotential heights produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations. These include conventional meteorological observations, both *in situ* and remotely sensed, as well as TRMM and AM-1 data such as TMI and MODIS. Surface air temperature is contained in TS. Surface geopotential heights are in PHIS. Geopotential heights of mandatory pressure levels are in HGHT and their errors in HGHTE. Perturbation geopotential heights at model sigma levels are in PHGHT.

Research & Application

Variation in atmospheric geopotential drives the Earth's general circulation.

Data Set Evolution

There are a wide variety of pressure, temperature, wind, and moisture data available from conventional meteorological sources. These include surface observing sites, rawinsondes, satellite soundings, etc. Yet even with all these data, there are significant gaps in global coverage. The accuracy of individual measurements also varies widely. The best way to combine all these data globally is through data assimilation which takes into account instrument errors and bridges the gaps between observations. New AM-1 and TRMM products such as MODIS and TMI will greatly improve the accuracy and coverage of the data used to produce these fields. In addition, data assimilation provides dynamically consistent estimates of geopotential heights through its general circulation model that takes into account global circulation systems, precipitation, and evaporation.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 34
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, 24 mandatory pressure or 70 model sigma levels, daily at 00, 06, 12, and 18 UTC (mandatory and sigma level data) and daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC (surface data only)

Key Geophysical Parameters:
geopotential heights

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, L. Takacs, D. Lamich

Chapter Twelve

Surface Temperatures of Land and Oceans, Fire Occurrence, and Volcanic Effects

Surface Temperatures of Land and Oceans, Fire Occurrence and Volcanic Effects

Relationship to Global Change Issues

The surface temperature of the land and ocean is a parameter which determines the vigor of biogeochemical activity and the rate of heat flow and water transport between the surface and the atmosphere. These in turn influence global environmental processes. On land, soil and canopy temperature are among the main determinants of the rate of growth of vegetation and they govern seasonal starting and termination of growth. Hydrologic processes such as evapotranspiration and snow and ice melt are highly sensitive to surface temperature fluctuation. In addition, surface temperature has been shown to be an important discriminating factor in classification of land surface types which supports the global land cover type product. For the oceans, the surface temperature influences the rate of growth of phytoplankton, the rate of absorption of carbon dioxide and other gases by sea water, and the rate of flow of heat to and from the atmosphere. Thus, temperature products are key inputs to many of the EOS product algorithms as well as providing data for global temperature mapping and change observation.

In the ocean, phytoplankton carries out the fixation of carbon through photosynthesis, which takes in dissolved carbon dioxide in sea water and produces oxygen enabling phytoplankton growth. This process captures about an equal amount of carbon as does photosynthesis by land vegetation. Changes in the amount of phytoplankton indicate the change in productivity of the oceans and provide a key ocean link for global climate change monitoring. Ocean and land biological productivity, heat exchange, and water exchange processes are tightly coupled; global change models take all interactions into account in global climate change prediction. In addition, these annual productivity products can be used for global and regional scale studies of ocean productivity, for comparisons with annual summations of daily analytic algorithms, and for comparison of global biogeochemical models to continually improve the technology for global change analysis.

The need also exists for information on the occurrence of fires on the land surface, since fire changes the surface cover type and releases gases and particulate matter into the atmosphere, affecting ecosystems and atmospheric chemistry on a rapid and intense scale. The burning of oil slicks on water is also a significant but infrequent intense input into the land and atmosphere systems which will be monitored by the fire product.

Testing of volcanoes is important because of the disastrous geophysical consequences they have on the Earth's atmosphere, including increased precipitation, ozone destruction, and the lowering of the global temperature. Moreover, cooling of the middle and upper stratosphere—from the increase in reflecting caused by aerosols and the reduced absorption of ultraviolet light because of reduced ozone from volcanoes and other sources—plays a significant role in climate change.

What Must be Measured?

Surface temperature algorithms require calibrated radiances as a basic input. Since the radiances observed have passed through the atmosphere, corrections must be made for atmospheric attenuation and scattering, hence meteorological data on temperature and water vapor profiles, as well as chemical constituents, are needed. Also, the radiance emitted by the surface is determined by surface emissivity as well as temperature. The land surface pixel can contain a mixture of materials having different emissivity, geometric, and topographic characteristics which must be known before temperature can be computed. Land material emissivity also can have significant variability as a function of wavelength, and for the mid-wave IR bands significant reflectance can exist such that solar reflected energy must be predicted and removed from the observed radiance. The emissivity of the sea surface is assumed to be unity and the sea-surface-temperature algorithm in this case produces what is called the brightness temperature. The ancillary information needed is supplied by external sources and precomputed databases keyed on surface material provided by the land cover type product and the global ocean masks.

Fire detection and measurement must be implemented with sensor bands which do not saturate at fire temperatures. This requirement is met with

Surface Temperatures of Land and Oceans, Fire Occurrence, and Volcanic Effects

MODIS by a special fire channel that saturates at 500K, which provides sufficient range to segment fire intensity. ASTER temperature data are used in combination with the MODIS global fire data for high resolution mapping of fires and in the monitoring and analysis of volcanic processes.

Product Overview

The EOS land and ocean surface temperature and fire products are provided by MODIS and ASTER instruments. The MODIS land surface temperature product (MOD 11) provides the needed composite temperature of each pixel and the estimated emissivity from database information plus adjustments made possible by the multiwindow algorithm. The accuracy is better than 1K for materials with known emissivities. The ASTER surface temperature product (AST 05, AST 08) has high spatial resolution and will be used for comparison and validation of the MODIS temperature products and for the monitoring and analysis of volcanic processes. The sea surface temperature (MOD 28) derived from radiance measurements is an estimate of the skin temperature (top millimeter) of the 1 km pixel viewed by MODIS. The algorithm is similar to the land surface temperature algorithm in that it uses multiple atmospheric window techniques to estimate the atmospheric parameters which are required to compensate for absorption and scattering. The bulk temperature of the near-surface ocean is the temperature of the upper 10-20 cm to meter as measured by conventional thermometers on buoys and ships. Extensive analysis has been done of satellite and *in situ* data to enable the algorithm to estimate bulk temperature as well as skin temperature.

Assimilated ground temperature from the GEOS DAS (DAS 35) will provide 3-hour estimates combining MODIS ground temperature information with pressure, temperature, wind, and moisture observations. The thermal anomaly product (MOD 14, MOD 40) contains information unique to understanding the characteristics of fires, including energy emitted, size, temperature, and the ratio of smoldering to flaming area and is available for both day and night periods. The composites produced include a monthly day and night fire occurrence aggregation and a summary of the number of fires in classes related to the strength of the fire. The ASTER land surface temperature product will provide high resolution mapping of fires as a complement to MODIS global fire data.

Product Interdependency and Continuity with Heritage Data

The land surface temperature product requires MODIS calibrated radiances and the cloud mask product as inputs. Also, atmospheric temperature and water vapor profiles are needed along with a database of emissivities, the use of which is driven by the land cover classification products which enable surface material to be specified for each pixel. The land surface temperature product from ASTER is needed for comparison and spatial variation analysis of the MODIS land-surface temperature product over test sites. The land-surface temperature product is an input to other land products including vegetation indices, evapotranspiration, and net primary production and as a background temperature estimate for the fire product.

Similarly, the sea-surface temperature product uses MODIS calibrated radiances and the cloud mask product, but does not require the complex emissivity estimation databases and algorithms that the land-surface temperature product needs. Sun glint is a significant source of error in the mid-wave IR bands which used so the mask product is critical to identifying glint pixels as is sea surface wind ancillary data which is used to estimate the magnitude of the glint area radiance

In addition to the calibrated MODIS radiances and cloud mask, the fire product uses a number of products including vegetation indices, land surface temperature, and cover type.

Existing meteorological stations on land and ship and buoy-based instruments at sea measure surface temperatures at large numbers of worldwide locations; however, these measurements are not adequate in terms of the radiative phenomenon or spatial coverage. Land- and sea-surface temperature data taken by TRMM and EOS AM-1 will add to the valuable input already provided by AVHRR, HIRS, Landsat, and CZCS, providing a large, long-term global land and sea surface temperature data set in order that we may more fully understand the effects of the various Earth system cycles on temperature.

Suggested Reading

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Becker, F., 1987.

Chaine, M.T., 1980.

Kaufman, Y.J., *et al.*, 1991.

Price, J.C., 1983.

Robinson, J.M., 1991.

Running, S.W., *et al.*, 1994.

Walton, C.C., *et al.*, 1990.

MODIS Land Surface Temperature (LST) & Emissivity

Product Description

This Level 2 and 3 product contains land surface temperature and emissivity retrieved at spatial resolutions of 1 km and 5 km over global land surface. Both daytime and nighttime land surface temperatures are included in its daily product. Daily, 8-day, and monthly Level 3 products will be also generated at equal-angle grids of half degree latitude and longitude. For land covers (including dense evergreen canopies, lake surface, snow, ice, and most soils) with high and stable emissivities in the split-window range, a view-angle dependent generalized split-window LST algorithm will be used to retrieve the surface temperature. For these land covers, the accuracy of the generalized split-window LST algorithm is better than 1K in most cases. This LST algorithm is optimized by separating the ranges of atmospheric column water vapor, lower boundary temperature, and the surface temperature into tractable subranges. For other land covers with variable emissivities, a physics-based day/night LST algorithm will be used to simultaneously retrieve surface band emissivities and temperatures from a pair of daytime and nighttime observations in seven MODIS TIR bands through a statistical regression approach and/or a least-square fit approach. Input data for the MODIS LST algorithms include the following MODIS products: Level 1A geolocation and 1B TIR radiance; Level 2 cloud mask, atmospheric temperature and water vapor profiles, snow, sea ice, and NDVI; and the previous quarter's Level 3 land-cover product.

Research & Applications

Land surface temperature is a good indicator of both the energy balance at the Earth's surface and the greenhouse effect because it is one of the key parameters in the physics of the land-surface processes. It is required for a wide variety of climate, hydrological, ecological, and biogeochemical studies. This product will be used in generating other MODIS land products and in a variety of EOS interdisciplinary studies.

Data Set Evolution

During the past decade significant progress has been made in estimating land-surface emissivity and temperature from airborne thermal IR data, including multichannel, thermal log residual, and alpha residual methods. Three types of methods have been developed to retrieve LST from space: the single IR channel method, the split-window method which is also used in various multichannel sea-surface temperature algorithms, and a new day/night MODIS LST method which is designed to take advantage of the unique capability of the MODIS instrument. The strategy for development of the MODIS LST algorithms incorporates experience from the SST algorithms, surface emissivity knowledge base from laboratory and field measurements, accurate radiate transfer simulations, and efficient look-up table anderpolation scheme for operational production.

MOD 11
PRODUCT SUMMARY

Coverage:
global land surface

Spatial/Temporal Characteristics:
1 km, daily Level-2 LST
1 km and 5 km, daily Level-3 LST
1-degree latitude and longitude, daily, 8-day, and monthly Level-3 LST

Key Science Applications:
inputs to climate, hydrological, ecological modeling

Key Geophysical Parameters:
land-surface temperature (MODIS parameter 2484); land-surface emissivity (MODIS parameter 3323)

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
Z. Wan

MODIS Land Surface Temperature (LST) & Emissivity

Suggested Reading

Running, S.W., *et al.*, 1994.

Salisbury, J.W. and D.M. D'Aria, 1992.

Snyder, W. and Z. Wan, 1996.

Wan, Z. and J. Dozier, 1989.

Wan, Z. and J. Dozier, 1996.

Thermal Anomalies – Fires & Biomass Burning

Product Description

The product includes fire occurrence (day/night), fire location the logical criteria used for the fire selection and an energy calculation for each fire. The product also includes composite 16 day and night fire occurrence (full resolution), composite monthly day and night fire occurrence (full resolution), gridded 10-km summary per fire class (daily/ten day/monthly), gridded 0.5° summary of fire counts per class (daily/ten-day/monthly). The Level 2 product includes various fire-related parameters including the occurrence of day and nighttime thermal anomalies which will be flagged and grouped into different temperature classes with emitted energy from the fire. These parameters are retrieved daily at 1-km resolution. The fire product uses the special fire channel at 3.9 µm that saturates at 500K and the high-saturation level of the 11-µm channel. During the night, the fire product will also use the 1.65- and 2.15-µm channels. In the early post-launch period the product will include the smoldering/flaming ratio per fire class and an estimate of the area burned.

Research & Applications

Fire is an important process within a significant number of terrestrial biomes, and the release of gases and particulate matter during biomass burning is an important contributor to the chemical reactions and physical processes taking place in the atmosphere. Fire is a significant and continuous factor in the ecology of savannas, boreal forests, and tundra, and plays a central role in deforestation. Fire information will be used to drive regional emissions models, trace gas transport models, and mesoscale models of atmospheric chemistry. Important impacts of fires include

- changes of physical state of vegetation and release of greenhouse gases;
- release of chemically-reactive gases during biomass burning;
- release of soot and other particulate matter during fires;
- changes in the exchange of energy and water between land surfaces and the atmosphere; and
- changes in plant community development and soil nutrient, temperature, and moisture.
- cloud development and reflectivity

Data Set Evolution

The MODIS fire products build and improve upon the experience of fire assessment primarily using the NOAA AVHRR and GOES systems. Currently, no one sensing system provides the instrument characteristics needed for an effective global fire monitoring program. The MODIS sensor has been designed to include characteristics specifically for fire detection and will provide a unique capability over existing sensors in terms of fire monitoring. The location accuracy and improved instrument characterization and calibration will enable unprecedented fire monitoring data sets. Attention should be given to the overpass time (10:30 a.m. for the AM-1 platform) for fire detection with respect to the diurnal cycle of fire activity. MODIS will also offer unique spatial and radiometric capabilities for burn scar detection; automatic procedures for burn

MOD 14, MOD 40
PRODUCT SUMMARY

Coverage:
global, daytime/nighttime

Spatial/Temporal Characteristics:
1 km, 10 km, 0.5°

Key Geophysical Parameters:
fire occurrence and class, fire selection criteria, fire location, smoldering and flaming ratio, burned area

Processing Level:
2, 3

Product Type:
standard, at-launch and post-launch

Science Team Contact:
Y. Kaufman, C. Justice

Thermal Anomalies – Fires & Biomass Burning

scar detection are under development as a post-launch product.

Suggested Reading

Andreae, M.O., *et al.*, 1994.

Global Biomass Burning. J.S. Levine, Ed., 1991.

Justice C.O., *et al.*, 1993.

Kaufman, Y.J., *et al.*, 1990b.

Penner, J.E., *et al.*, 1992.

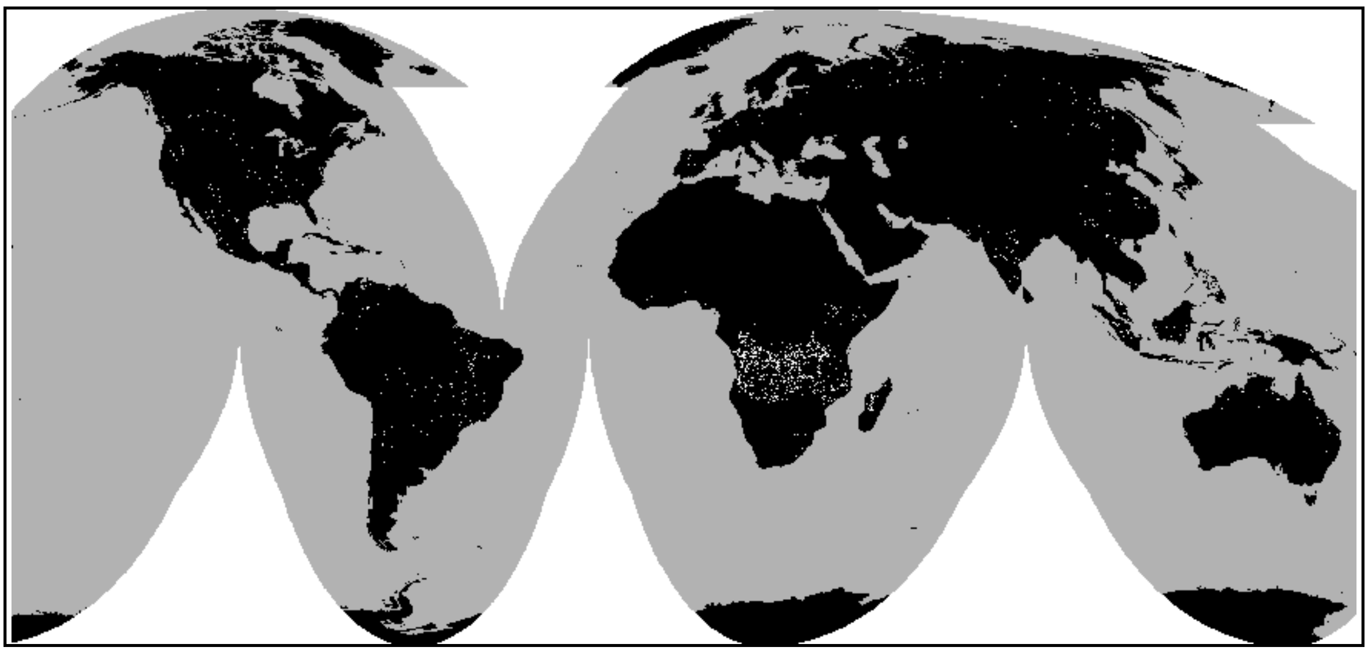

Figure 30. **NOAA/AVHRR Detected High Temperature Sources: June 25, 1992.** Derived from the IGBP-DIS Global 1-km set provided by USGS Eros Data Center.

Sea Surface Temperature (SST)

Product Description

This Level 2 and 3 product provides sea surface temperature at 1-km resolution over the global oceans. In addition, a quality assessment parameter is included for each pixel. The Level 2 product is produced daily and consists of global day and night coverage every 24 hours. It is used to generate the gridded Level 3 products daily and weekly for day and night conditions. A quality parameter is provided for each dataset.

Research & Applications

The global distribution and variability of sea-surface temperature are key inputs to Earth energy and hydrological balance studies and long-term climate change studies. In addition, sea-surface temperature is required by a number of MODIS algorithms including generation of perceptible water, lifted index, water-leaving radiance, productivity, oceanic aerosol properties, and temperature and water vapor profiles. MODIS sea-surface temperature retrievals will be incorporated into a match-up database with radiance and buoy sea-surface temperature observations (see MOD 32).

Data Set Evolution

Sea-surface temperature determination is based on MODIS calibrated mid- and far-IR radiances, (Bands 20, 22, 23, 31 and 32 from MOD 02) using an algorithm which exploits the differences in atmospheric transmissivity in the different IR bands to enable highly accurate estimation of the atmospheric effects which enables accurate SST generation. The cloud screening product (MOD 04) is an ancillary input to the algorithm along with a land mask which is used to mark non-water pixels while an ice-extent mask limits polar sea coverage. A sequence of spatial and temporal homogeneity tests are applied to validate the quality of the cloud-free observations. The AIRS SST estimate (Parameter 2523) will be used as a near-real time quality assessment of skin temperature. Visible and near-IR radiances (Bands 3, 4, 5, 6) will be used as a secondary cloud flag in the event that the cloud screening product is not available.

Suggested Reading

Abbott, M.R. and D.B. Chelton, 1991.

Barton, I.J., *et al.*, 1989.

Brown, O.B. and R.E. Chaney, 1983.

Edwards, T., *et al.*, 1990.

Llewellyn-Jones, D.T., *et al.*, 1984.

McClain, E.P., *et al.*, 1985.

Minnett, P.J., 1991.

Minnett, P.J., 1995.

Schluessel, P., *et al.*, 1990.

Smith, A.H., *et al.*, 1994.

Smith, W.L., *et al.*, 1996.

Strong, A.E. and E.P. McClain, 1984.

MOD 28
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly/day and night

Key Science Applications:
energy and hydrological balance, climate change models

Key Geophysical Parameters:
sea-surface temperature (MODIS parameter 2527) and quality assessment (MODIS parameter 5359)

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
O. Brown

Sea Surface Temperature (SST)

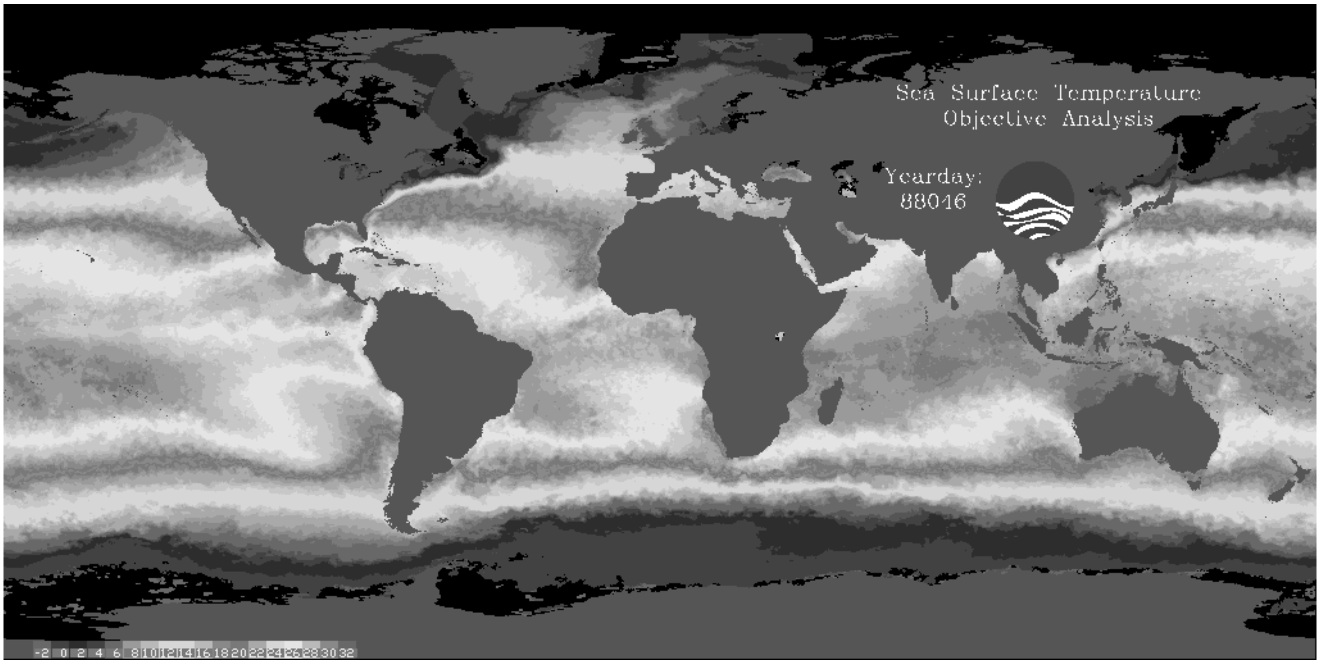

Figure 31. **Global Infrared Sea Surface Temperature.** This daily pre-MODIS Sea Surface Temperature (SST) image for February 15, 1988, was produced using objective analysis techniques applied to NOAA AVHRR data. MODIS is expected to reduce the uncertainties in IR SST by a factor of 2 because of improvements in sensor calibration and algorithms. *O. Brown, R. Evans, RSMAS*

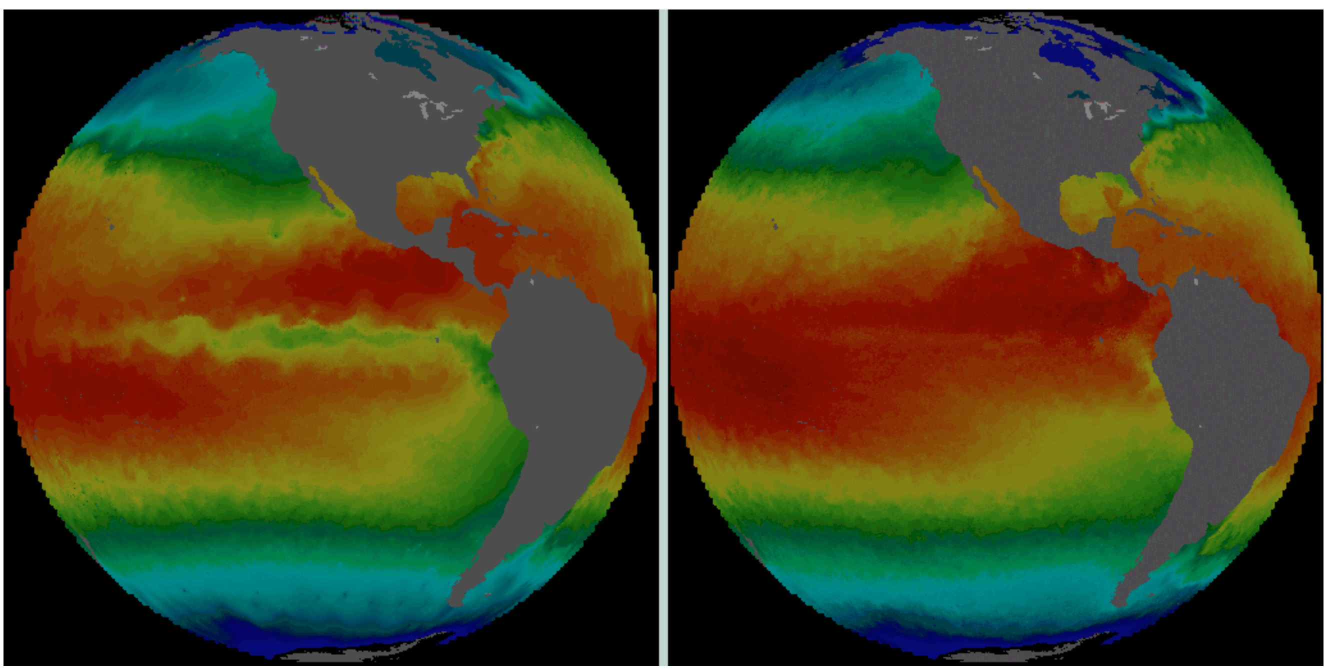

Figure 32. **Changes in Pacific SST Due to El Niño.** Sea Surface Temperature (SST) from the NOAA AVHRR, showing patterns before (left) and during (right) the major 1992 El Niño. The improved accuracy of IR SST products expected from MODIS will enable scientists to investigate the relatively small changes in SST hypothesized to be responsible for triggering El Niño cycles in the Pacific and their ramifications globally. (Note: temperatures range from 20-30°C.) *O. Brown and G. Feldman, "Reports to the Nation: El Niño and Climate Prediction," Spring 1994, No. 3, University Corporation for Atmospheric Research., Boulder, CO.*

ASTER Surface Emissivity & Surface Kinetic Temperature

Product Description

This Level-2 product (AST 05) contains surface emissivity at 90-m resolution generated only over the land from ASTER's five thermal-IR channels. Surface emissivity is required to derive land-surface temperature (AST 08) data, also at a resolution of 90-m. Land surface temperatures are determined from Planck's Law, using the emissivities to scale the measured radiances after correction for atmospheric effects. Pixels classified as "cloud" will have no atmospheric correction due to a lack of knowledge of cloud height, and the cloud temperature will be given as the brightness temperature at sensor.

Research & Applications

The emissivity product is critical for deriving 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.

The derived land surface temperature has applications in studies of surface energy and water balance. Temperature data will be used in the monitoring and analysis of volcanic processes, day and night temperature data will be used to estimate thermal inertia, and thermal data will be used for high-resolution mapping of fires as a complement to MODIS global fire data.

Data Set Evolution

Current sensors provided only limited information useful for deriving surface emissivity, and researchers currently are required to use emissivity surrogates such as land-cover type or vegetation index in making rough estimates of emissivity and hence land surface temperatures. The five thermal-IR channels of the ASTER instrument enable direct surface emissivity estimates.

Mapping of thermal features from optical sensors such as Landsat and AVHRR has been used for many developmental studies. These instruments, however, lack the spectral coverage, resolution, and radiometric accuracy that will be provided by the ASTER instrument.

Suggested Reading

Dozier, J., and Z. Wan, 1994.

Hook, S.J., *et al.*, 1992.

Kahle, A.B., 1986.

AST 05, AST 08
PRODUCT SUMMARY

Coverage:
regional, land surface

Spatial/Temporal Characteristics:
90 m

Key Science Applications:
local heat balance, volcanology, biomass burning, thermal inertia

Key Geophysical Parameters:
surface emissivity, surface temperature

Processing Level:
2

Product Type:
standard, on request

Science Team Contact:
A. Gillespie

Assimilated Ground Temperature

Product Description

This Level 4 product consists of 3-hourly estimates of ground temperature produced by the GEOS DAS. It is based on the assimilation of MODIS-observed ground temperatures along with pressure, temperature, wind, and moisture observations from conventional meteorological sources, both *in situ* and remotely sensed, along with other TRMM and AM-1 data. Over the oceans, this product is the sea surface temperature extracted from sources outside the GEOS DAS. Three fields are provided, ground temperature (GTMP), 3-hour average ground temperature (GTAVE), and ground virtual temperature (TVSFC).

Research & Application

Ground temperature determines how the lower atmosphere is heated and cooled. Heating rates near the Earth's surface are needed to determine atmospheric stability which drives local convection, and to determine horizontal temperature gradients which modify the atmosphere's general circulation. Ground temperature also regulates the rate of surface evaporation.

Data Set Evolution

Most assimilation systems derive ground temperatures strictly from air temperature measurements near the ground. The new GEOS DAS will also use ground temperature measurement from MODIS and thus should provide much more accurate estimates of this important field.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

Takacs, L.L., *et al.*, 1994.

DAS 35
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
2° × 2.5° lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
ground temperature

Processing Level:
4

Product Type:
standard, post-launch

Science Team Contact:
R. Rood, A. Molod, J. Joiner

Chapter Thirteen

Vegetation Dynamics, Land Cover, and Land Cover Change

Vegetation Dynamics, Land Cover, and Land Cover Change

Relationship to Global Change Issues

About 30 percent of the Earth's surface is covered by land and much of this is vegetated, making land surface processes important components of the terrestrial climate system. Vegetation, land cover and land use change provide the basis for understanding land and water resource management as well as a range of research and global monitoring objectives, including global carbon modeling, greenhouse gas emission inventories, regional environment and development assessments, and forest resource management. Ecologists and climatologists have developed models which describe the matter and energy exchanges, but lack of long term global data limits their use in Earth system models. Additionally, we lack good global data on surface albedoes over land, on the distribution of soils and important properties of vegetation morphology and physiology, and on water storage in soils and snow cover and their relationship to runoff. Incorporation of this information in the land-surface component of climate models will improve estimates of exchanges of water and energy with the atmosphere and lead to more realistic climate simulations

Product Description

VEGETATION

The Land Vegetation products provide information on terrestrial systems which have important links to climate and atmospheric composition that are needed for development and application of models of the Earth's system. These links involve exchanges of energy and moisture, radiatively active trace gases, e.g., carbon dioxide and methane, and photochemically active species such as methane, nitric oxide, and non-methane hydrocarbons that soils, plants, and biomass burning release.

The EOS-AM Vegetation products provide the basic measurements of the photosynthetic engines which drive carbon transport on land. For land areas, vegetation density and vegetation canopy factors are produced which are used to generate the land primary productivity, the amount of carbon fixed by vegetation growth per day or longer unit of times such as per year. The MODIS vegetation measurements are provided by the Vegetation Index (MOD 13), Leaf Area Index and Fraction of Photosynthetically Active Radiation (FPAR) (MOD 15), and Vegetation Cover Conversion (MOD 44) products. Vegetation indices are radiometric measures of the amount of vegetation present on the ground in a particular pixel. The indices are obtained from measurements of reflected visible and near infrared energy from vegetation and are called normalized difference vegetation indices (NDVI). These indices have values between -1 and 1 and increase with increasing amounts of vegetation. Several new indices have been developed which compensate for soil and atmospheric effects and these are combined into the modified vegetation index (MVI), also be to produced by MODIS. The indices will be produced at different resolutions and time averaging intervals to provide measures of vegetation density and productivity which are required by global change models.

The Leaf Area Index product provides information on the structural property of a plant canopy such as the number of equivalent layers of leaves the vegetation displays relative to a unit ground area. It is derived from the vegetation index. This parameter is an input to the Photosynthesis and Net Primary Production algorithms which produce the global model inputs for land. The FPAR product provides another key input to the production algorithm. It measures the proportion of available radiation in the specific photosynthetically active wavelengths of the spectrum that a canopy absorbs. It is also derived from the vegetation index. These two products provide the vegetation measurement inputs which are combined with surface temperature and radiation input information in the vegetation production algorithm.

LAND COVER AND LAND COVER CHANGE

Land cover (MOD 12) maps global terrestrial land cover at a 1-km resolution. The land cover change product will detect areas of change and identify types of change processes as they occur. Land cover as well as both human and natural alteration of land cover plays a major role in global-scale patterns of climate and biogeochemistry.

Vegetation Dynamics, Land Cover, and Land Cover Change

The land cover product will recognize 18 basic classes of land cover types, independent of climate. Vegetation classes will separate needleleaf, broadleaf, and graminoid leaf structures; annually deciduous and evergreen canopy habits; and sparse to dense cover fractions following the International Geosphere-Biosphere Program (IGBP) scheme. Also, major classes of agricultural activities will be recognized as well as several categories of land surfaces with little or no plant cover—such as bare sand, soil, or rock.

The land cover product will detect and categorize changes in terrestrial features and processes on a global scale. Independent of the land cover product, the land-cover change algorithm will compare, pixel-by-pixel, the temporal development curve of a set of biophysical and spatial indicators derived from MODIS data.

MISR LAND SURFACE DATA

The MISR instrument provides a variety of information on the Earth's surface. Product descriptions for MISR Aerosol and Surface Data (MIS 05, MIS 09) are available on page 115 of this document.

Product Interdependency and Continuity with Heritage Data

The land products flow in a chain from the Level 2 reflectance and land cover type parameters to the biophysical and biochemical derived products which are inputs to the Earth system models.

Specific product dependencies for the land vegetation indices are MODIS radiance and imagery products, including Level 1-B calibrated radiance, surface leaving radiance and aerosol optical depth. The vegetation index is the key input to Leaf Area Index and FPAR products with are the key inputs along with land cover type into the biomass product algorithm.

Each instrument product set has its own science requirements and objectives and support the generation and validation of other instrument products. Vegetation Index products have been produced for many years from AVHRR and other instrument data and MODIS will produce a "continuity" NDVI to maintain the NDVI time series using an algorithm which closely approximates the heritage index. A worldwide database has been created with the data and EOS will continue this series.

References

Asrar, G. and J. Dozier, 1994.

Li, X., *et al.,* 1995.

Moody, A. and C. E. Woodcock, 1995.

Running., S., *et al.,* 1994.

Vorosmarty, C., *et al., 1993*.

Land Cover/Land Cover Change

Product Description

This Level 3 product contains land cover type (Param. 2669) and land cover change (2761) parameters which will be produced at 1-km resolution on a quarterly basis beginning 18 months following launch of the AM-1 platform. The land cover parameter identifies 17 categories of land cover following the IGBP global vegetation database, which defines nine classes of natural vegetation, three classes of developed lands, two classes of mosaic lands and three classes of nonvegetated lands (snow/ice, bare soil/rocks, water.) The land cover change parameter quantifies subtle and progressive land-surface transformations as well as major rapid changes. As such, it is not a conventional change product that only compares changes in land cover type at two times but combines analyses of change in multispectral-multitemporal data vectors with models of vegetation change mechanisms to recognize both the type of change and its intensity. In addition to the basic 1-km product, summary products containing proportions of land covers and change characteristics will be available at one-quarter, one-half, and 1° resolutions.

Research & Applications

This product is used for biophysical and biogeochemical parameterization of land cover for input to global and regional scale models of climate, hydrologic processes, and biogeochemical cycling. Examples of biogeophysical parameters keyed to land cover include leaf area index, vegetation density, and FPAR. Other parameters are biomass permanence and energy transfer characteristics of the land surface.

Data Set Evolution

Recent attempts to produce regional scale land cover datasets use coarse spatial resolution, high temporal frequency data from the AVHRR instrument aboard the NOAA series of meteorological satellites. Most of these efforts have used the Normalized Difference Vegetation Index (NDVI) parameter derived from this data. The NDVI generally quantifies the biophysical activity of the land surface and as such does not provide land cover directly. The MODIS land cover algorithm draws from information domains well beyond those used in these efforts including directional surface reflectance, texture, vegetation index, acquisition geometry, land surface temperature, and snow/ice cover. The algorithm will rely on a neural network approach to classification as this method has been shown to outperform conventional supervised classifiers such as maximum likelihood. Product validation will be based on a network of test sites chosen to represent major global biomes and cover types. High resolution imagery (e.g., Landsat) will be used to establish truth for the sites which will be used post-launch to train the land cover classifier and validate the products. The validation procedure will characterize the accuracy of the product as well as provide information that can be used in spatial aggregation to provide land cover and land cover change data at coarser resolutions.

MOD 12
PRODUCT SUMMARY

Coverage:
global, land only

Spatial/Temporal Characteristics:
1 km, 1/4°, seasonal

Key Science Applications:
biogeochemical cycles, land cover change

Key Geophysical Parameters:
land cover type, land cover change

Processing Level:
3

Product Type:
standard, at launch

Science Team Contact:
A. Strahler, A. Huete,
S.W. Running, C. Justice

Land Cover/Land Cover Change

Suggested Reading

Lambin, E.F. and A.H. Strahler, 1994.

Lambin, E.F. and A.H. Strahler, 1994.

Moody, A., *et al.*, 1994.

Nemani, R.R. and S.W. Running, 1995.

Running, S.W., *et al.*, 1994.

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Strahler, A., *et al.*, 1995.

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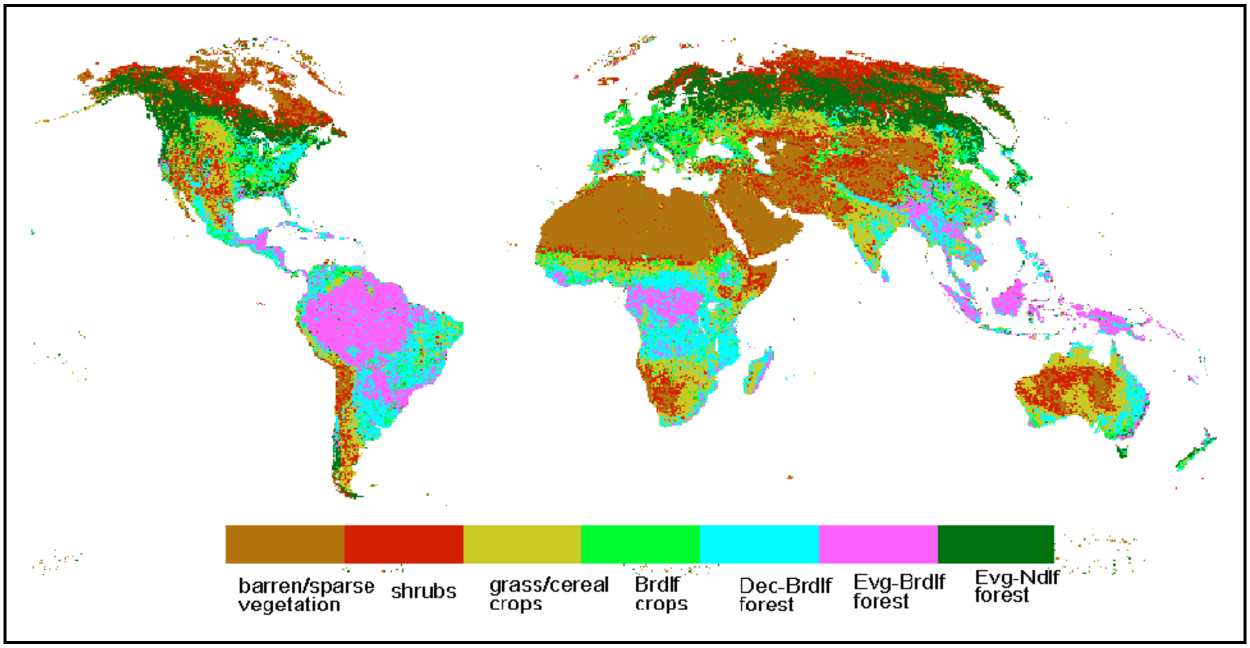

Figure 33. **Global Distribution of the Six Canopy Structure Based Vegetation Classes Required for Carbon, Water and Climate Modeling, Derived from AVHRR Pathfinder Data.**

MODIS Vegetation Indices: The Normalized Difference Vegetation Index (NDVI) and an Enhanced, Modified Vegetation Index (MVI)

Product Description

The MODIS vegetation indices (VIs) will provide consistent spatial and temporal comparisons of global vegetation conditions which will be used to monitor the Earth's photosynthetic vegetation activity for phenologic, change detection, and biophysical interpretations. The VIs are determined daily and globally for land from MODIS blue, red and near-infrared reflectances (centered at 470 nm, 648 nm, and 858 nm, respectively). Two indices are planned; the NDVI will be a continuity index with the existing NOAA-AVHRR derived NDVI. A modified vegetation index (MVI) uses the blue band to remove residual atmospheric contamination due to smoke and sub-pixel/thin clouds, and uses a feedback adjustment to minimize canopy background variations and enhance vegetation sensitivity from sparse to dense vegetation conditions. The VIs use atmospherically-corrected (at ~ 50 km resolution) bi-directional surface reflectances masked for water, cloud, and cloud shadow. The NDVI and MVI products are archived at a 250-m pixel resolution, along with the Sun and view angles of each grid cell.

Research & Applications

Vegetation Indices are used for global monitoring of vegetation conditions. The VIs are used as input in the land cover and land cover change products. They also play an important role in the derivation of the FPAR, LAI, and thermal products. The at-launch version will be fully operational.

Data Set Evolution & Applications

Although a global validation scheme has been implemented for the VIs, a thorough evaluation and calibration of these indices will be made at launch.

Suggested Reading

Huete, A., *et al.*, 1994a.

Huete, A., *et al.*, 1994b.

Liu, H.Q. and A.R. Huete, 1995.

MOD 13
PRODUCT SUMMARY

Coverage:
global land surface (Level 2)

Spatial/Temporal Characteristics:
(Level 2) daily at 250 m

Key Science Applications:
global vegetation monitoring, global biogeochemical and hydrologic modeling, global and regional climate modeling, land cover characterization

Key Geophysical Parameters:
vegetation index

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
A. Huete

Leaf Area Index (LAI) & Fraction of Photosynthetically Active Radiation (FPAR) – Moderate Resolution

Product Description

This Level 4 product includes two parameters, Leaf Area Index (LAI, Parameter 2680) and Fraction Photosynthetically Active Radiation (FPAR, Parameter 5367) which will be retrieved at 500 m spatial resolution and composited to 1 km on the 8-day compositing period. LAI defines an important structural property of a plant canopy which is the number of equivalent layers of leaves relative to a unit ground area. FPAR measures the proportion of available radiation in the photosynthetically active wavelengths (0.4 to 0.7 µm) that a canopy absorbs. The LAI product will be an LAI value between zero and 12 of the global gridded database at the corresponding MVI compositing interval. The FPAR product will be an FPAR value between 0.0 and 1.0 assigned to each 1-km cell of the global gridded database at the corresponding MVI compositing interval.

Research & Applications

LAI and FPAR are biophysical variables which describe canopy structure and are related to functional process rates of energy and mass exchange. Both have been related directly to the NDVI from AVHRR by theoretical canopy modeling and field studies. Both LAI and FPAR have been used extensively as satellite derived parameters for calculation of surface photosynthesis, evapotranspiration, and NPP. These products are essential in calculating terrestrial energy, carbon, water cycle processes, and biogeochemistry of vegetation. The LAI product is an input to Biome-BGC (Biogeochemical) models to produce conversion efficiency coefficients which are combined with the FPAR product to produce daily terrestrial PSN (photosynthesis) and annual NPP.

Data Set Evolution

This product is derived directly from the modified vegetation index (MVI) and ancillary information on surface characteristics such as land cover type and background. The algorithm combines these parameters using a 3-D radiative transfer model to produce LAI and FPAR values which are stored in a look-up table. This approach places the computationally intensive load in a preprocessing phase and minimizes the routine load on the PGS.

Suggested Reading

Asrar, G., *et al.*, 1992.

Nemani, R.R., *et al.*, 1993a.

Running, S.W., *et al.*, 1994.

Sellers, P.J., 1987.

MOD 15
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
1-km/8-day composite

Key Science Applications:
biogeochemical cycle modeling, NPP estimation

Key Geophysical Parameters:
leaf area index, fraction photosynthetically absorbed radiation

Processing Level:
4

Product Type:
standard, at-launch

Science Team Contact:
S.W. Running

Leaf Area Index (LAI) and Fraction of Photosynthetically Active Radiation (FPAR) – Moderate Resolution

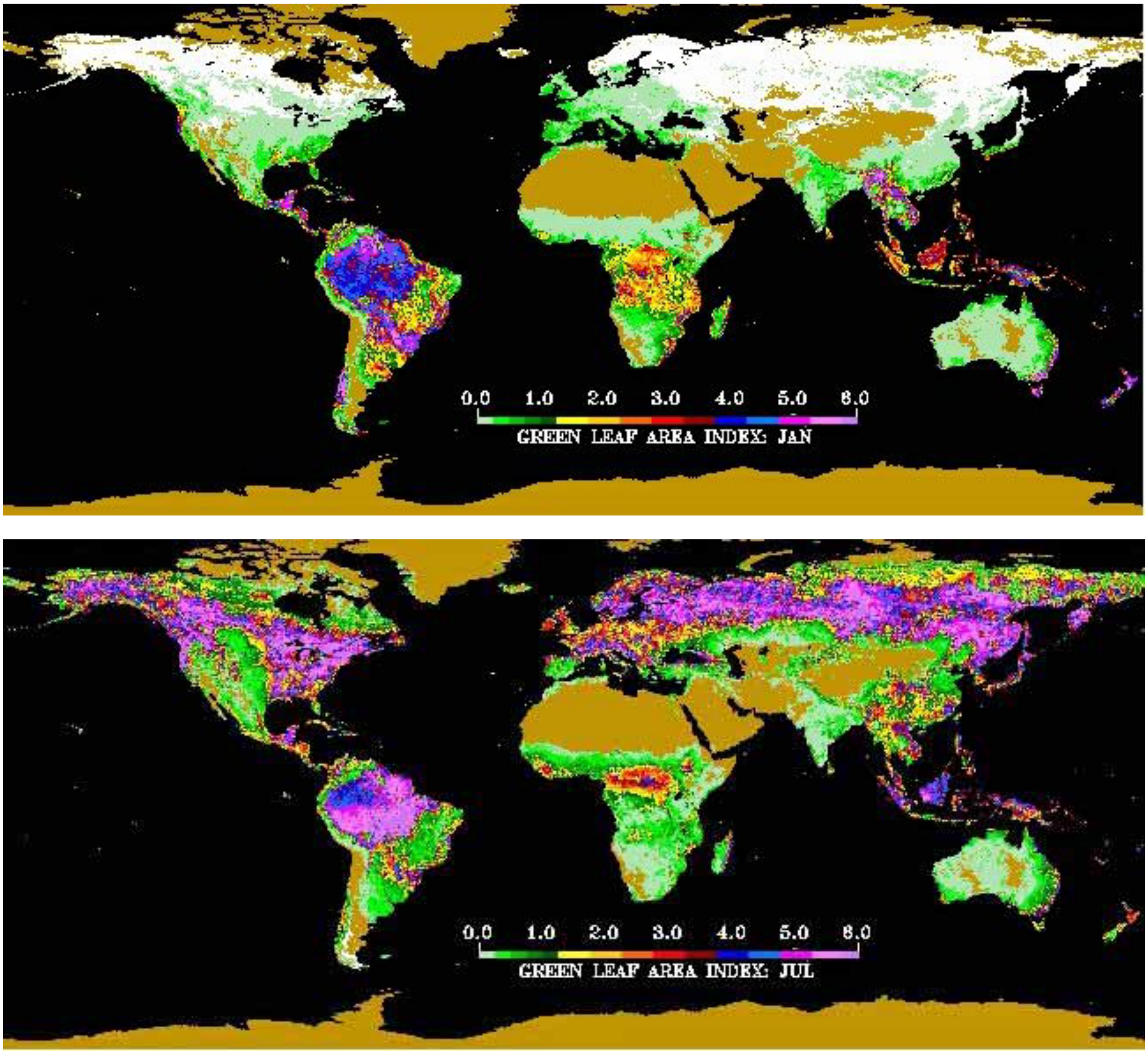

Figure 34. **Global Leaf Area Index Estimated with the NDVI-LAI Relationships Derived from the Radiative Transfer Model and Applied to the Advanced Very High Resolution Radiometer (AVHRR) Pathfinder NDVI Data Set.** Biome-specific relations were applied to the 10-day composite NDVI data and the resulting LAI values were averaged to obtain monthly LAI. The top image is the color-coded LAI in January obtained by further averaging over the 9-year period of record. Similarly, the bottom image shows the global LAI distribution during the month of July. Areas colored white denote either missing data (terminator effect) or where the algorithm failed.

Evapotranspiration & Surface Resistance

Product Description

This Level 3 product consists of Evapotranspiration (ET, Param. 3722) and Surface Resistance(Param. 4335) parameters and have temporal resolution of 8 days at a spatial resolution of 1 km over the land surface only. The Land Surface Resistance is a post-launch product to calculate a remotely-sensed epsilon for NPP and PSN. The spatial resolution of these products is 1 km.

Research & Applications

These two parameters are essential to global modeling of climate, water balance and gas traces. In addition, they are required in estimating photosynthesis, respiration, and net primary production. The surface resistance product is a PM-1 (post-launch) research data product intended for real-time implementations. Practical applications of this product are for wildfire danger monitoring and crop/range drought monitoring.

Data Set Evolution

The ET product is derived from the product of surface resistance, vegetation index (MVI), photosynthetic active radiation (PAR) and the latent heat of vaporization.

Suggested Reading

Dickinson, R.E., 1987.

Goward, S.N. and A.S. Hope., 1989.

Nemani, R. and S. W. Running, 1989.

Nemani, *et al.*, 1993b.

Running, S., *et al.*, 1994.

Running, S.W., *et al.*, 1989.

MOD 16
PRODUCT SUMMARY

Coverage:
Global

Spatial/Temporal Characteristics:
1 km/8 days

Key Science Applications:
global water balance, net primary production

Key Geophysical Parameters:
surface resistance, evapotranspiration

Processing Level:
4

Product Type:
PM-1, post-launch

Science Team Contact:
S. Running

Vegetation Production & Net Primary Productivity

Product Description

MOD 17 is a Level 4 product consisting of 8-day Net Photosynthesis (PSN, Parameter 3716) and Net Primary Production (NPP, Parameter 2703). Annual NPP is the time integral of the PSN product over a year.

Research & Applications

This product provides an accurate measure of terrestrial vegetation growth and production activity. The theoretical use is to define the seasonally dynamic flux of terrestrial surface carbon dioxide for climate modeling. Fluxes will be computed specific to each vegetation type. The practical utility is to measure crop yield and forest production and any other socially significant products of vegetation growth. As this global NPP product becomes regularly available, a wide variety of derived products are expected to be developed making regionally specific estimates of crop production. The value of an unbiased, regular source of crop and forest production estimates for global political and economic decision making is immense.

Data Set Evolution

The NPP parameter is the yearly integral of the PSN which is obtained from the product of PAR (Photosynthetically Active Radiation), FPAR (Fraction Photosynthetically Active Radiation) and conversion efficiency coefficients obtained from other MODIS products and other sensors and ancillary data. The algorithms for these products are based on the original logic of Monteith (1972) which relates PSN and NPP to the amount of Absorbed Photosynthetically Active Radiation (APAR). The vegetation indices (MVI) along with climate and the land cover product are used to estimate APAR.

Suggested Reading

Field, C.B., *et al.*, 1995.

Monteith, J.L., 1972.

Prince, S.D. and S.N. Goward, 1995.

Ruimy, A., *et al.*, 1994.

Running, S.W., 1990.

Running, S.W., *et al.*, 1994.

MOD 17
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
0.5, 1,10 km/every 8 days and yearly

Key Science Applications:
interannual variability of vegetation

Key Geophysical Parameters:
NPP, photosynthesis, respiration

Processing Level:
4

Product Type:
standard, at-launch

Science Team Contact:
S.W. Running

Vegetation Production & Net Primary Productivity

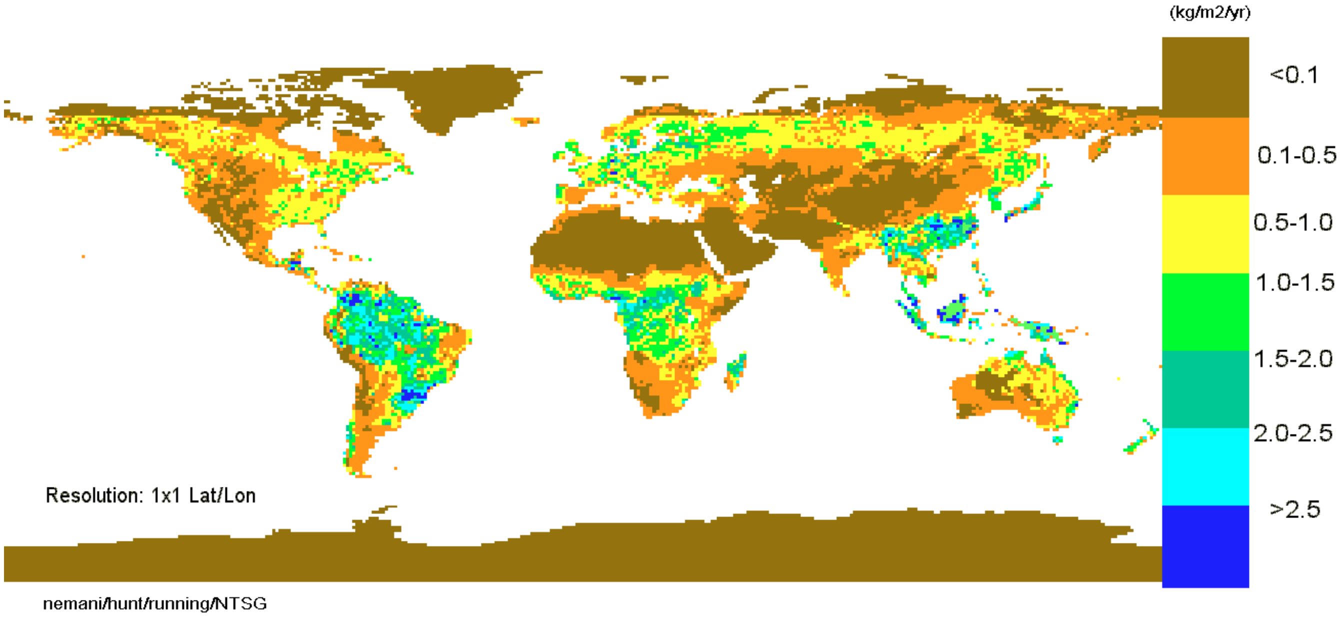

Figure 35. **Global Net Primary Production During 1987.** This dataset is produced using 1 × 1 degree gridded climate data from 7000 weather stations distributed globally, Mathews land cover classes collapsed into our six classes, biome specific NDVI-LAI relations used to estimate LAI from NOAA/NASA Pathfinder data and ecosystem simulation model, BIOME-BGC.

MODIS Gridded Vegetation Indices: The Maximum Value Composited NDVI (#2749a) and the BRDF-Adjusted MVI (#4334a)

Product Description

The MODIS gridded VIs will provide consistent spatial and temporal comparisons of global vegetation conditions which will be used to monitor the Earth's photosynthetic vegetation activity for phenologic, change detection, and biophysical interpretations. The gridded VIs are 10- and 30-day temporal and spatial, re-sampled products designed to provide cloud-free vegetation maps at nominal resolutions from 250 m to 0.5°. The NDVI composites consist of cloud-free and atmospherically corrected pixels at 250 m resolution and 10 day intervals and are based on the maximum value of NDVI. The MVI composites are calculated from cloud-free and atmospherically corrected gridded surface reflectances standardized to nadir views with the help of BRDF models. The VIs are also composited to monthly (30-day) intervals. The 10-day NDVI composites contain 16 bytes for each grid cell, which include maximum NDVI value, red and NIR surface reflectances, solar and sensor zenith angles, relative azimuth, and quality control parameters. The 10-day MVI composites contain 12 bytes per pixel and include nadir-adjusted MVI value, nadir-adjusted red, NIR, and blue surface reflectances, median solar zenith and azimuth angles, and quality control parameters.

Research & Applications

VIs are used for global monitoring of vegetation conditions. The VIs are used as input in the land cover and land cover change products. They also play an important role in the derivation of the FPAR, LAI, and thermal products. The at-launch version will be fully operational.

Data Set Evolution & Applications

Although a global validation scheme has been implemented for the VIs, a thorough evaluation and calibration of these indices will be made at launch.

Suggested Reading

Huete, A., *et al.*, 1994a.

Huete, A., *et al.*, 1994b.

Los, S.O., *et al.*, 1994.

MOD 34
PRODUCT SUMMARY

Coverage:
global land surface (Level 3)

Spatial/Temporal Characteristics:
(Level 3) 10 day and monthly at 250 m

Key Science Applications:
global vegetation monitoring, global biogeochemical and hydrologic modeling, global and regional climate modeling, land cover characterization

Key Geophysical Parameters:
vegetation index

Processing Level:
3

Product Type:
standard, at-launch

Science Team Contact:
A. Huete, C. Justice

MODIS Gridded Vegetation Indices: The Maximum Value Composited NDVI (#2749a) and the BRDF-Adjusted MVI (#4334a)

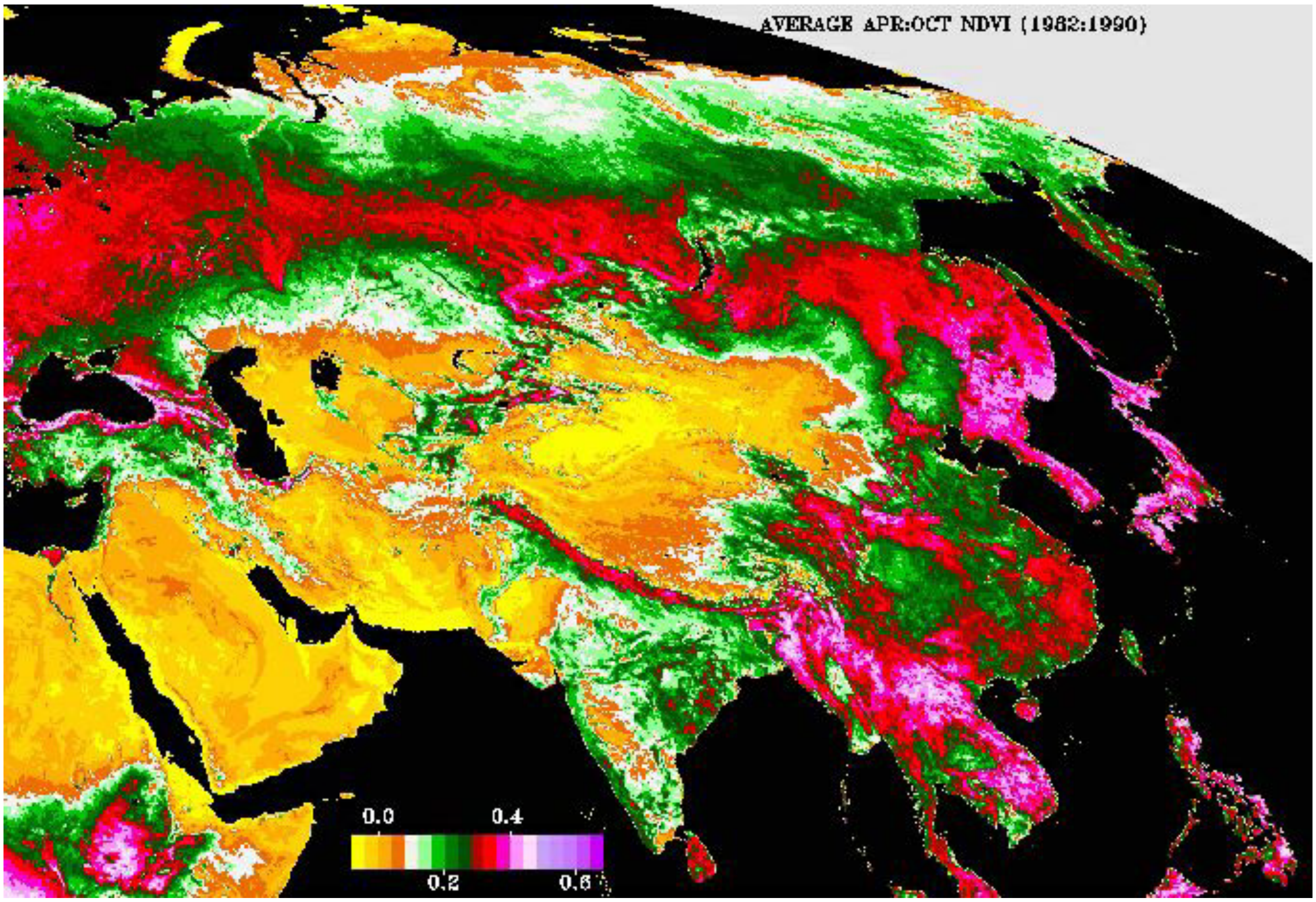

Figure 36. **Growing Season Average NDVI of Asia Derived from the Advanced Very High Resolution (AVHRR) Pathfinder Data Set.** Monthly NDVI was calculated as the average of three 10-day composites. The monthly values were further averaged over the 9-year period of record before Mount Pinotubo eruption (1982-1990) to obtain long-term average monthly NDVI values.

Vegetation Cover Conversion

Product Description

Using MODIS data from the two 250-m bands the product will show the global distribution of the occurrence of vegetation cover change. Where there is sufficient evidence, the type of change will be labeled (e.g. forest conversion to grassland). The distribution of these changes will be represented at a resolution of 250 m and as gridded 10-km summaries. These will be generated at 3 monthly intervals. An interannual product is also being produced which displays the global distribution of change during the previous year.

Research & Applications

Vegetation cover change is an important driver of many important biogeochemical, hydrological and climate processes. It also represents the integrated response to several biophysical and anthropogenic impacts. Among the important influences of vegetation cover change are the following:

- Strongly affects changes in many biophysical factors such as surface roughness and albedo.
- Has a major effect on changes in sensible heat flux, since it affects global albedo and surface roughness which affects atmospheric drag.
- Is of crucial importance for determining the biogeochemical cycling of carbon, nitrogen, and other elements at regional to global scales.
- Has a major impact on the runoff characteristics of catchments through its effects on evapotranspiration and partitioning of precipitation into overland flow, interflow and groundwater accretion.
- Gives a direct insight into ecosystem response related to climate change and anthropogenic influences
- Affects biodiversity through direct impacts on habitat
- Forms an increasingly important set of information for natural resource managers.

This product will be combined with data obtained from finer spatial resolution data from sensors such as Landsat and ASTER to assist the identification of the types of conversion occurring. The product also provides information to assist the acquisition strategy of finer resolution systems since they help flag areas where significant changes are likely.

Data Set Evolution

Previous work has shown that data with a resolution of 1 km and coarser are sufficient for the mapping of the distribution of vegetation cover and for the monitoring of those changes in vegetation cover caused by seasonal to inter-annual climate change. However such relatively coarse resolution data are often inadequate to detect changes caused by anthropogenic factors. Analyses of many types of vegetation cover change indicates that they are relatively small in size largely due to the inherently local nature of anthropogenic vegetation cover conversions. Consequently a very high proportion of changes are only detectable at fine spatial resolutions. For this reason it was decided to use the two 250-m bands for the identification and mapping of this type of conversion.

Suggested Reading

Townshend, J.R.G. and C.O. Justice, 1988.

Townshend, J.R.G., *et al.*, 1991.

MOD 44
PRODUCT SUMMARY

Coverage:
global, daytime

Spatial/Temporal Characteristics:
250m, 10km, three monthly, yearly

Key Geophysical Parameters:
vegetation cover change occurrence and type

Processing Level:
3

Product Type:
at-launch and post-launch

Science Team Contact:
J. Townshend

Chapter Fourteen

Phytoplankton and Dissolved Organic Matter

Phytoplankton and Dissolved Organic Matter

Relationship to Global Change Issues

The ocean stores huge amounts of chemical species, primarily carbon, which influence the climate system. The organic carbon dissolved in the oceans equals the vegetative carbon reservoir on land; the phytoplankton fixes as much carbon through photosynthesis as terrestrial vegetation. However, there are large differences in the turnover rates and reservoirs of carbon and land and in the ocean. Land ecosystems have large amounts of structural plant material with life cycles ranging from one year to centuries. The oceans, on the other hand, are dominated by unicellular plants—phytoplankton that have life cycles of days. Land soil is a large reservoir of carbon and has a turnover time of many years to centuries, whereas dissolved organic material in the ocean is thought to be similar in amount and turnover time to soil carbon; the carbon cycle of marine bottom sediments has a turnover time of millions of years.

Scientists have observed that over the last century, with the dramatic increase of biomass burning and fossil fuel burning, there has been a corresponding increase in carbon dioxide released into the atmosphere. Much of this carbon dioxide eventually enters the oceans and is used by phytoplankton for photosynthesis. The amount of carbon dioxide consumed by the phytoplankton depends heavily on ocean circulation which supplies nutrients to the upper layers of the ocean where sunlight is abundant. Some fraction of carbon produced by the phytoplankton sinks to the ocean floor—a long-term sink for atmospheric carbon dioxide. The fraction is not well known and is a source of a large uncertainty in the global carbon budget. Unraveling this complex system—called the “biological pump”—is difficult. Scientists wish to understand the coupling of physical and biological aspects of the carbon system in the ocean in order to estimate how changes in the oceans will affect the global carbon dioxide system as well as the population of phytoplankton, which is an essential link in the Earth’s marine biosphere. Hopefully, these products will help scientists answer important questions, such as: Is productivity in the ocean changing, and how do changes relate to our understanding of the global carbon cycle? How will the marine biosphere respond to global changes, both natural and anthropogenic?

Product Overview

The ocean phytoplankton products support the estimation of the global ocean primary productivity product as well as provide inputs needed for ocean biophysical studies that will enable improvements in the ocean process algorithms. The primary productive provides the phytoplankton biomass which governs the fixing of carbon and which influences CO_2 in the atmosphere and ultimately global climate.

The Pigment Concentration product (MOD 19) and three associated products, Suspended Solids Concentration (MOD 23), Organic Matter Concentration (MOD 24) and Ocean Water Attenuation (MOD 26), are used by the ocean scientific community to support development and validation of the algorithms for primary productivity. Similarly, the Coccolith Concentration (MOD 25) product provides information on phytoplankton products that deposit carbon on the ocean floor in the form of calcium carbonate, accounting for about 75 percent of the deposition of carbon on the sea floor. In the same way, the Phycoerythrin Concentration product (MOD 31) provides information about a key phytoplankton pigment group to enable study of the global phytoplankton species variability. Extensive experimental evidence has been obtained indicating that water-leaving radiance includes backscattering and absorption effects of phycoerythrin pigments, and that these phenomena need to be measured and studied to enable more accurate estimation of the parameters used in the primary production algorithm.

The primary phytoplankton indicator product used as input to the primary ocean productivity algorithm is Chlorophyll *a* Concentration (MOD 21). This product uses the Water-leaving Radiances and Match-up Databases to calibrate semi-analytical models using the remote-sensing reflectances in the MODIS oceans bands. The second phytoplankton indicator used as input to the productivity algorithm is the Chlorophyll Fluorescence product (MOD 20), which provides another measure of chlorophyll concentration and hence phytoplankton concentration.

The MISR instrument also provides data on phytoplankton pigment concentration. Product information is described in MISR Aerosol and Surface Data (MIS 05, MIS 09) on pages 104-105 of this document.

The ocean production product provides the analogous measure of the growth of photosynthetically active material in the ocean as NPP does for land. In the case of the ocean, dissolved inorganic carbon is fixed into organic matter through phytoplankton photosynthesis. The algorithm estimates phytoplankton production from chlorophyll data by linear regression using databases obtained from ship-based sea water measurements of phytoplankton, chlorophyll, and other constituents from numerous sites and satellite data from the Coastal Zone Color Scanner (CZCS) ocean color sensor. These data, plus water-leaving radiance and sea-surface temperature from MODIS, are used by the chlorophyll and production algorithms. A daily estimate of production for each 1-km square ocean pixel, the amount of carbon generated in a column of sea water in milligrams per square meter per day is generated. An annual total production value is aggregated from the daily values and is given in gigatons of carbon per year for the global ocean. This is a running total which is updated each day, and for the Level 3 product each week.

Product Interdependency and Continuity with Heritage Data

Specific product dependencies for the ocean products include the water-leaving radiance and matchup table products, which provide remote sensing and *in situ* sea surface radiance measurements. Some products require additional parameters such as Chlorophyll *a* Case I for Fluorescence and downwelling sea surface radiance for Chlorophyll *a*. The correlated radiance and directional reflectance products from MISR and ASTER are used in the baseline radiance and image products such as MOD 09 surface reflectance and are not inputs to the product discussed here. The MODIS pigment algorithms were developed from existing CZCS pigment algorithms to provide a direct link to the series of measurements made by CZCS over the past 19 years.

Although there is already a long-term data set from CZCS, it is important that other simultaneous data sets be taken to provide further global context. Extensive testing of the algorithms will be done with SeaWiFS ocean color data, expected to be available in 1996.

Suggested Reading

Asrar, G. and J. Dozier, 1994.

Goyet, C. and P.G. Brewer, 1993.

Running, S.W., *et al.*, 1994.

Vorosmarty, C., *et al.*, 1991.

Yoder, J.A., *et al.*, 1993.

Pigment Concentration

Product Description

This set of products provides particle concentrations in Case 1 sea water. Product MOD 19 is total Pigment Concentration (Parameter 2591); Product MOD 23 is Suspended-Solids (Parameter 3085); Product MOD 24 is Organic Matter Concentration in two parameters, Particulate (2608) and Dissolved (2580); and Product 26 gives Ocean Water Attenuation Coefficient at two wavelengths, 490 nm (Parameter 3199) and 530 nm (Parameter 3206). The products are available at Level 2 daily and at Level 3 daily and weekly. Both levels are produced at 1 km and 20 km.

Research & Applications

This set of ocean substance concentrations is needed for input to the ocean productivity algorithm which is a key element in global biogeochemical models and ultimately global climate models. The pigment parameter is the sum of the chlorophyll *a* and phaeopigment concentration in Case 1 waters. Case 1 waters have optical properties which are dominated by chlorophyll and associated covarying detrital pigments. (Case 2 waters contain substances which affect optical properties which may not covary with chlorophyll such as gelbstoff, suspended sediments, cocolithophores, detritus, and bacteria.) The suspended-solids parameter is a measure of ocean suspended sediments which is used in the analysis of complex bio-optical properties of coastal and estuarine regions/environments and helps to map the extent of terrestrial changes. The organic matter concentration relates to the composite of carbon and nitrogen substances. The ocean water attenuation coefficient is derived using MODIS bands 10 and 11 and describes penetration of sunlight in the sea.

Data Set Evolution

The algorithm is based primarily on methods and algorithms developed for the CZCS program described by Gordon and Clark (1980) and refined and adapted to the MODIS bands. The recasting of the CZCS forms of the phytoplankton pigment algorithms in terms which are more representative for MODIS has resulted in minor changes. Particularly significant is that the multiple band ratios will provide a robustness not possible with the CZCS's limited spectral coverage.

Suggested Reading

Gordon, H.R. and D.K. Clark, 1980.

Gordon, H.R., *et al.*, 1980.

Gordon, H.R., and A.Y. Morel, 1983.

Lorenzen, C.J., and S.W. Jeffrey, 1980.

Smith, R.C. and K.S. Baker, 1977.

MOD 19, MOD 23, MOD 24, MOD 26 PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
ocean productivity, biogeochemical models

Key Geophysical Parameters:
total ocean pigment, suspended solids, organic matter concentration, attenuation coefficient

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
D. Clark

Pigment Concentration

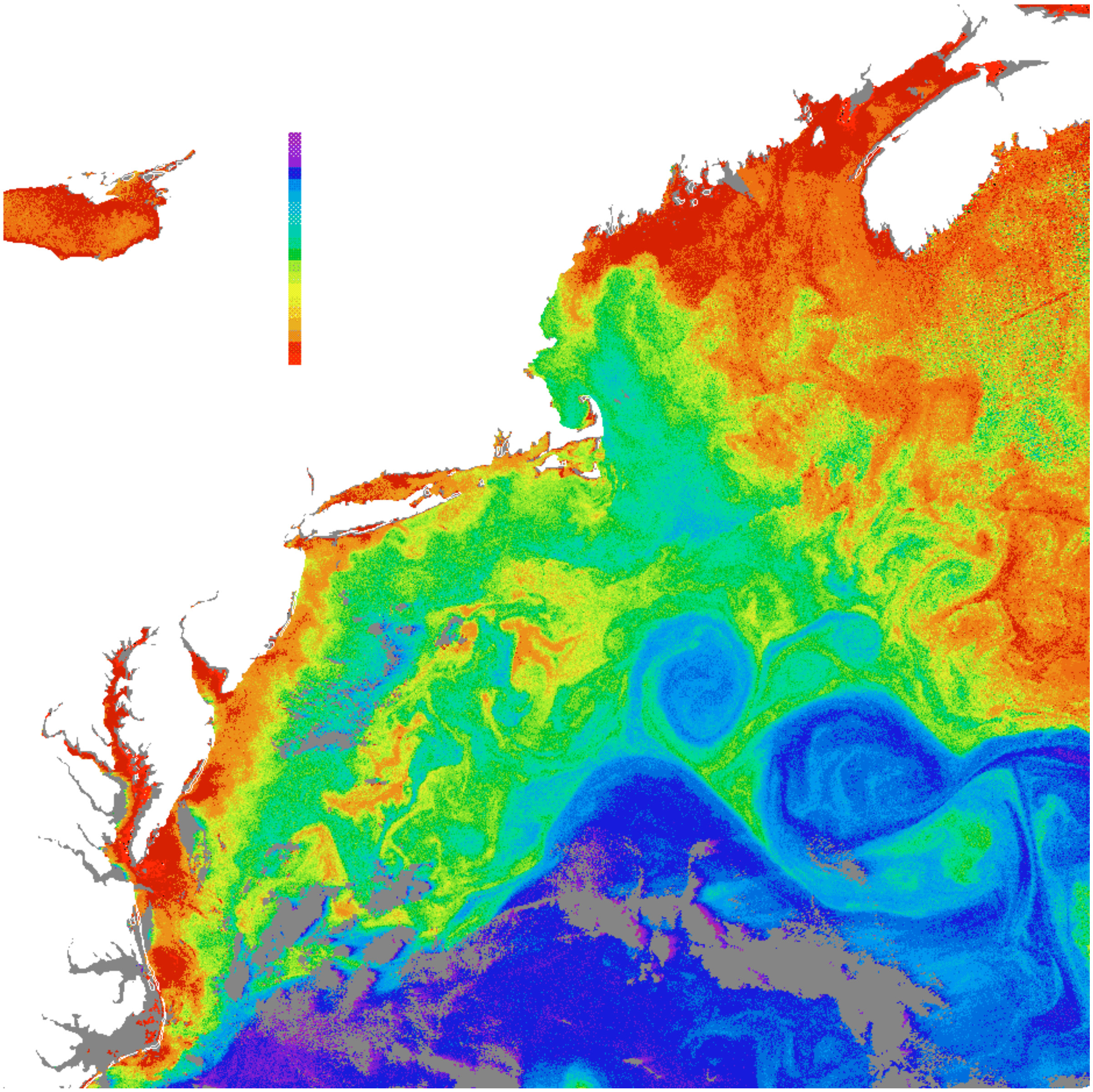

Figure 37. **East Coast Ocean Color Image.** A daily Coastal Zone Color Scanner product for the northeastern coast of the United States reveals the high pigment concentrations along the coast and the influence of the Gulf Stream. Phytoplankton concentrations, and additional ocean carbon system parameters from MODIS, will be much more accurate than was possible with the CZCS because of improvements in spectral bands, calibration, and algorithms. *NASA, GSFC*

Pigment Concentration

Product Description

This Level 2 product contains several parameters describing ocean chlorophyll fluorescence properties. Fluorescence line height (Parameter 2575) is a relative measure of the amount of radiance leaving the sea surface at the fluorescence wavelength of 683 nm. Parameter 3211 is Fluorescence Efficiency which provides a relative measure of the absorption of PAR and its emission as chlorophyll fluorescence. The third is Fluorescence Line Curvature (Parameter 2573). The spatial resolution will be 1 km for chlorophyll levels greater than 1.5 mg/m^3 and 5×5 km for values less than 1.5. The Level 2 product is produced daily and Level 3 is gridded and produced daily and weekly.

Research & Applications

Solar stimulated chlorophyll fluorescence is a measure of the current photophysology of phytoplankton, in contrast to the biomass estimate provided by chlorophyll. The product quantifies the level of photosynthesis by phytoplankton in the ocean. Historically, the coupling between fluorescence and chlorophyll has been studied extensively and recent research has focused on the use of Sun-stimulated fluorescence to estimate primary productivity (Kiefer and Reynolds, 1992). Basic fluorometric measurements are made using an instrument described by Holm-Hansen *et al.* (1965) which uses blue light stimulation and this method has been used unchanged for 30 years. Gower (1990) was among the first to attempt using Sun-stimulated radiance at 683 nm to estimate chlorophyll concentrations from aircraft and satellites.

Data Set Evolution

Inputs to the algorithm are Chlorophyll Concentration (MOD 19), Absorbed Radiation by Phytoplankton (MOD 22), and Water-Leaving Radiance (MOD 18). Water-leaving radiance for MODIS bands 13 (667 nm), 14 (678 nm) and 15 (748 nm) are used in the algorithm. The algorithm is applied to the daily input standard product datasets and is remapped into standard Level 3 grids. The validation approach will be to compare the fluorescence line height result with other MODIS data products (e.g. Chlorophyll *a*, comparison with surface measurements and comparison of MODIS fluorescence products with other satellite-based estimates of the same products). The products are produced only for non-cloud, glint-free ocean pixels during daylight hours.

Suggested Reading

Abbott, M.R., *et al.*, 1982.

Chamberlin, W.S. and J. Marra, 1992.

Gower, F.J.R. and G.A. Borstad, 1990.

Holm-Hansen, O., *et al.*, 1965.

Kiefer, D.A. and R.A. Reynolds, 1992.

Topliss, B.J., and T. Platt, 1986.

MOD 20
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km for chlorophyll levels greater than 2.0 mg/m^3/daily, weekly

Key Science Applications:
ocean chlorophyll, ocean productivity

Key Geophysical Parameters:
chlorophyll fluorescence

Processing Level:
2

Product Type:
standard, at-launch

Science Team Contact:
M. Abbott

Chlorophyll *a* Pigment Concentration

Product Description

This is a Level 2 and 3 product which contains ocean chlorophyll *a* pigment concentration for Case 1 waters (Parameter 2571) and Case 2 waters (Parameter 2569) at 1-km resolution. It is produced daily at Level 2 and 3 and weekly at Level 3. Absorption parameters generated by the chlorophyll algorithm are also provided as interim product MOD 36 Total Absorption (Parameter 3206) which includes absorption due to water, phytoplankton, detritus and gelbstoff, and gelbstoff absorption only (Parameter 5362). Valid data exists only for ocean cloud-free pixels and the weekly composite will be an average of cloud-free acquisitions for each ocean pixel.

MOD 21, MOD 36
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
ocean productivity, bio-optical properties

Key Geophysical Parameters:
Case 1 and 2 chlorophyll *a* concentration, absorption coefficients

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
K. Carder

Research & Applications

Chlorophyll *a* concentration is a key input to the primary ocean production product (MOD 27) and is used to trace oceanographic currents, jets, and plumes. The product provides the concentration of Case 1 chlorophyll in sea water (water that has optical properties which are dominated by chlorophyll and associated covarying detrital pigments) and in Case 2 waters (which are waters that contain substances which affect optical properties but do not covary with chlorophyll, such as gelbstoff (marine chromomorphic dissolved organic matter [CDOM] substance which absorbs at 400 nm), suspended sediments, cocolithophores, detritus and bacteria). The algorithm derives from extensive research using CZCS data in which good performance was obtained for Case 1 waters and has evolved to perform successfully for the Case 2 waters for the MODIS algorithm. The 1-km resolution and nearly daily coverage will allow the observation of mesoscale oceanographic features in coastal and estuarine environments which are of increasing importance in marine science studies.

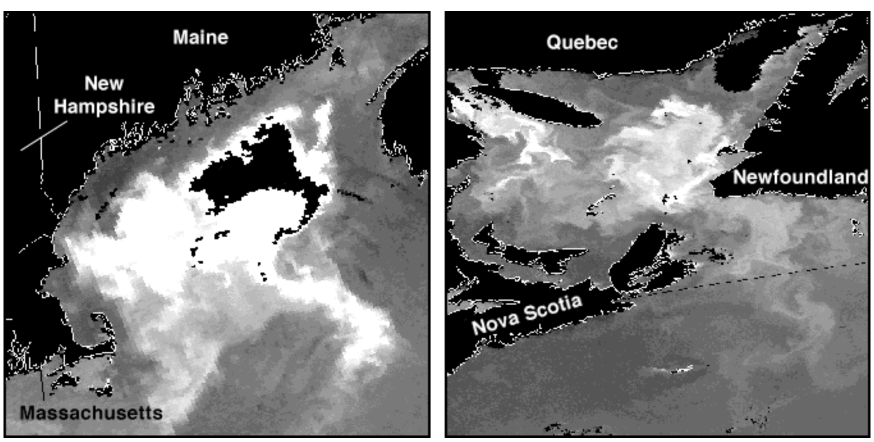

Figure 38. Satellite ocean color imagery, in addition to allowing the concentration of single-celled plants to be remotely measured, permits the detection and identification of certain algal blooms. The above images, taken by the Coastal Zone Color Scanner sensors, are of the Gulf of Maine and Gulf of St. Lawrence. The white to light grey waters in both regions are blooms of a single type of algae (called coccolithophores) which affect regional climate and fisheries.

Chlorophyll *a* Pigment Concentration

Data Set Evolution

The product algorithm is based on a semi-analytical, bio-optical model of remote sensing reflectance which uses Water Leaving Radiance (MOD 18), PAR (MOD 22), and Absorption Coefficient (MOD 36). The model is inverted to obtain the absorption coefficient due to phytoplankton at 675 nm and chlorophyll *a* concentration is derived from this coefficient. The algorithm will be thoroughly tested during the SeaWiFS project and post launch validation will be conducted using data from instrumented collection cruises through ocean test sites including the nine used for algorithm development. Also, hyperspectral data from will be used to simulate the 10 nm bands and produce comparison results.

Suggested Reading

Austin, R.W., 1974.

Carder, K.L., *et al.*, 1986.

Carder, K.L., *et al.*, 1991.

Holm-Hansen, O. and B. Riemann, 1978.

Lee, Z.P., *et al.*, 1995.

Smith, R.C. and K.S. Baker, 1982.

Coccolith Concentration

Product Description

This Level 2 and 3 product provides five parameters describing the concentration of coccoliths in sea water. Parameter 2577 is the detached coccolith concentration in number/m^3 and Parameter 5355 is the estimated calcite concentration due to the coccoliths in mg-$CaCO_3/m^3$. The pigment concentration in the coccolithophore biomass is Parameter 5356; Parameter 5357 is a descriptor for the particular look-up table used, and Parameter 5358 is a quality measure. The product is produced a 1 km and 20-km spatial resolution daily for Level 2 and 3 and weekly at Level 3.

Research & Applications

Coccolithophores are small marine phytoplankton which form external calcium carbonate ($CaCO_3$) scales having diameters of a few µm and a thickness of 250 to 750 nm called coccoliths. Coccolithophores are the largest source of calcium carbonate on Earth. Thus, coccolith production is an important part of the biogenic carbon cycle. The observed characteristics of coccolithophores, including their ubiquitous nature, possible role in climate, and intense scattering property, make a global-scale study of their distribution an important application for MODIS imagery. Specifically, it is important to estimate the rate at which $CaCO_3$ is formed by phytoplankton and to look for long-term changes in that rate.

Data Set Evolution

The algorithm for extracting the detached coccolith concentration from surface waters is based on the semianalytic model of ocean color of Gordon (1988). The model relates the normalized water-leaving radiance to the absorption and scattering properties of the constituents of the water using radiative transfer theory. The absorption and scattering properties are then related to the constituent concentrations through statistical analysis of direct measurements. The model is validated by comparison with a set of water-leaving radiances independent of the measurements used to establish the statistical relationships between constituents and optical properties.

Suggested Reading

Balch, W.M., *et al.*, 1991.

Gordon, H.R., *et al.*, 1988.

Groom, S.B. and P.M. Holligan, 1987.

Holligan, P.M., *et al.*, 1983.

Sarmiento, J.L., *et al.*, 1988.

Sikes, S. and V. Fabry, 1994.

MOD 25
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km, 20 km/daily, weekly

Key Science Applications:
input to global biogeochemical cycle models

Key Geophysical Parameters:
coccolith and calcite concentration, pigment concentration in coccolithophore blooms

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
H.R. Gordon, W. Balch

Phycoerythrin Concentration

Product Description

This product consists of three parameters which give the concentration of one of the major algal pigment groups in ocean water: Phycoerythrobilin Concentration (Parameter 3320), Phycourobilin Concentration (Parameter 5360), and Constituent Inherent Optical Properties (CDOM absorption, chlorophyllous absorption, and particulate backscatter, Parameter 5361). These quantities are provided at Level 2 at 1 km spatial resolution daily and at Level 3 daily and weekly at 1 km. The product is valid only for clear-sky ocean pixels.

Phycoerythrin is one of three major algal pigment groups found in marine phytoplankton and bacteria (Bidigare, 1990). The phycoerythrins are further subdivided into phycourobilin-rich (PUB) and phycoerythrobilin-rich (PEB) phycoerythrins. This algorithm retrieves both PUB and PEB rich cases. Phycoerythrin is a chlorophyll accessory pigment and serves to receive photosynthetically usable light in the 480 - 505 nm and 540 - 560 nm ranges. It is used to infer the global extent of phycoerythrin-bearing phytoplankton such as cyanobacteria which are nitrogen-fixing and thus provide information on the nitrogen cycle. Used in conjunction with phytoplankton chlorophyllous pigment, the apparent species diversity of the oceans can be inferred.

Research & Applications

One of the intended uses of the phycoerythrin data product is to allow scientific investigators to study the global distribution(s) of the phycoerythrin pigment, and in so doing allow definition of the diversity of phycoerythrin-bearing species such as cyanobacteria. When used in conjunction with chlorophyll distribution, phycoerythrin allows global phytoplankton species variability studies.

Data Set Evolution

The phycoerythrin retrieval algorithm requires water-leaving radiances which are generated from the incident solar irradiance, the total backscatter and the total absorption of sea water. The PUB and PEB parameters are retrieved by a sequential-convergent-iteration method (Gordon, 1988) which uses 5 independent bands. MODIS Band 10 (488 nm) and Band 12 (551 nm) correspond to the peaks of the PUB and PEB phycoerythrins. The major assumption for the algorithm is that the pigment specific absorption coefficient spectral model used is applicable for the oceanic province where the satellite image was acquired. The algorithm will be validated by ship and airborne laser-induced and water Raman normalized fluorescence measurements.

Suggested Reading

Bidigare, R.R., *et al.*, 1990.

Culver, M.E. and M.J. Perry, 1994.

Hoge, F.E. and R.N. Swift, 1986.

Hoge, F.E. and R.N. Swift, 1990.

MOD 31
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
global phytoplankton species studies, ocean productivity models

Key Geophysical Parameters:
phycoerythrobilin-rich (PEB) and phycouroblin-rich (PUB) phycoerythrins

Processing Level:
2, 3

Product Type:
research, at-launch

Science Team Contact:
F. Hoge

Ocean Primary Productivity

Product Description

This product provides an estimate of the Ocean Primary Productivity daily (Parameter 2602) and on an annual basis (Parameter 2606). The Level 2 product is produced daily at 1 km for local and regional areas and at 20 km for the annual productivity as a running, annual average. The Level 3 product will be produced daily at 1 km and weekly at 1 km and at 20 km for the global annual productivity.

Research & Applications

The objective of the product is to quantify the magnitude and inter-annual variability (for decadal trends) in the oceanic primary productivity and phytoplankton carbon fixation. Primary productivity is the time rate of change of phytoplankton biomass, and with allowance for excreted soluble carbon compounds, reflects the daily integrated photosynthesis within the water column. The integral of the daily values over the year is the annual primary productivity (Iverson and Esaias, 1994).The annual productivity product will be used for global and regional scale studies of interannual variability of ocean productivity, for comparisons with annual summations of daily analytic algorithms, and for comparison with global biogeochemical models.

Data Set Evolution

Ocean primary productivity algorithms fall into two general classes, termed empirical and analytic algorithms. The empirical approach is based on simple correlation between time averaged *in situ* estimates of productivity and satellite derived estimates of surface chlorophyll concentration. The analytic approach is based on models of the general photosynthetic response of the algal biomass as a function of major environmental variables such as light, temperature, and nutrient concentration. The overall methodologies differ significantly in the way various parameters are estimated and in the way they are assigned spatially and temporally across ocean basins. The approach taken for the MODIS algorithm is to begin implementation of an annual, global, empirical algorithm for at-launch product generation, while pursuing a vigorous research program within the SeaWiFS Science Team, to develop a consensus analytic algorithm for daily global productivity. Cloudiness prevents deriving chlorophyll *a* concentrations over about 60 percent of the ocean on a daily basis excluding that already lost due to high Sun glint. Chlorophyll *a* concentrations derived from other sensors such as EOS Color and MODIS PM will be used to increase sampling frequency since these plankton processes vary rapidly over time and space.

Suggested Reading

Eppley, R.W., *et al.*, 1985.

Fitzwater, S.E., *et al.*, 1982.

Iverson, R.L., and W.E. Esaias, 1994.

Morel, A., and J.M. Andre, 1991.

Platt, T.C., *et al.*, 1991.

MOD 27
PRODUCT SUMMARY

Coverage:
global ocean surface, clear-sky only

Spatial/Temporal Characteristics:
1 km/daily, weekly

Key Science Applications:
ocean productivity, biogeochemical models

Key Geophysical Parameters:
annual and daily ocean productivity

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
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Ocean Primary Productivity

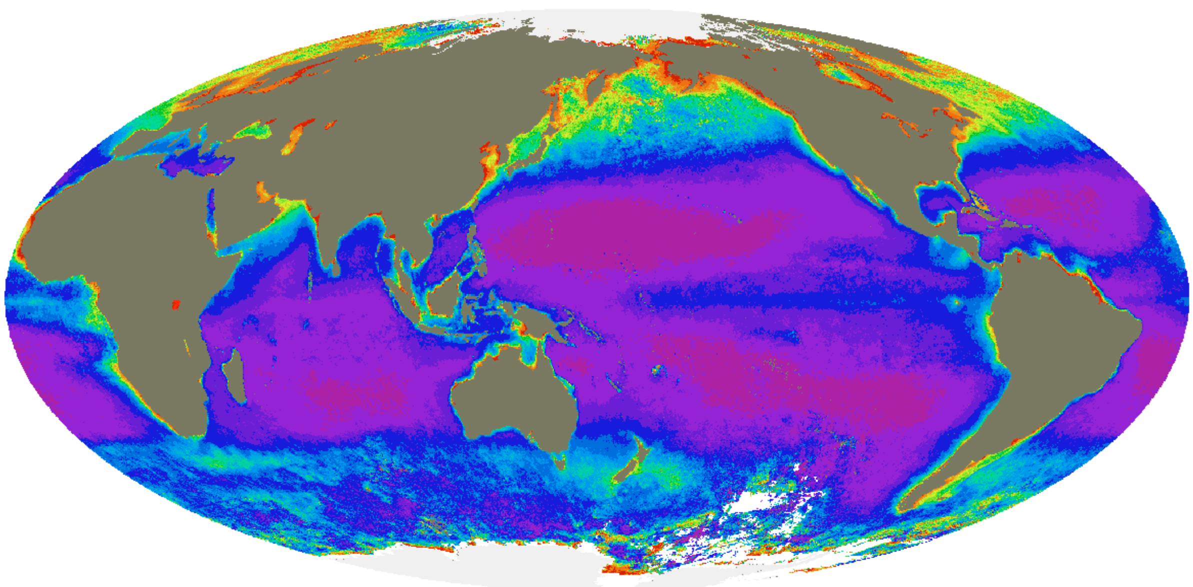

Figure 39. **Global Ocean Phytoplankton Biomass.** A pre-MODIS, global ocean color product from the Coastal Zone Color Scanner shows the algal pigment concentrations within the upper layers of the ocean and indicates the biomass and productivity distribution within the oceans. While this is an annual product, MODIS will provide comparable global coverage on a weekly to monthly basis to enable scientists to study large-scale changes in marine ecosystems over weeks to decades. *NASA, GSFC*

Chapter Fifteen

Snow and Sea Ice Cover

Snow and Sea Ice Cover

Relationship to Global Change Issues

Observing and predicting changes in elements of the cryosphere (glaciers, frozen ground [permafrost], snow cover, and floating ice [sea, lake, and river]) are important to understanding global change because the cryosphere is a sensitive component of the geosphere to global climate warming. Snow and ice cover dramatically influence surface albedo, hydrologic properties, and regulation of ecosystem biological activity.

MODIS data will be used to monitor the dynamics of large-area (greater than 10 square kilometers) snow and ice cover and, on a daily and weekly basis, report the maximum area covered by each. Information about snow and ice cover is important for a number of agricultural, industrial, social, and environmental reasons. For example, snow cover data are needed to predict water supply, to plan for agricultural and industrial developments, to anticipate flooding, to forecast crop yield, and to estimate freeze damage.

The amount and depth of snow cover affect climate on a regional and global scale. When snow is deposited on a land surface, it typically increases the degree to which the surface reflects incoming solar energy. In so doing, snow affects the Earth's radiation balance (the balance between energy entering and leaving the Earth's climate system) and, in turn, its climate. By gaining more accurate information about the properties and effects of snow cover, scientists hope to develop more accurate models to help them understand and predict the role of snow in the Earth's climate.

Product Overview

The Snow Cover products (MOD 10, MOD 33) are based on the SNOMAP algorithm which will identify snow by its unique reflectance, absorption, and emittance properties. SNOMAP will also map ice on large inland lakes. The algorithm consists of a series of criterion tests that identifies snow in each pixel of a MODIS image. Using SNOMAP and ICEMAP, MODLAND will map the spatial and temporal variability in reflected and emitted radiances observed by MODIS over snow- and ice-covered areas. These maps will help us to understand how the spatial and temporal variability in snow cover, lake ice cover, and sea ice cover relate to surface water balance components over continental-scale drainage basins.

The Sea Ice Cover product (MOD 29, MOD 42) maps daily and weekly sea ice cover. The algorithm ICEMAP is similar in structure to SNOMAP for mapping sea ice.

The Assimilated Snow Depth product (DAS 10) is a Level 4 product consisting of 3-hourly estimates of snow depth reported in liquid-hourly equivalent. The GEOS DAS calculates snow depth using its estimates of temperature and precipitation along with melting rates based on land surface temperatures.

Product Interdependency and Continuity with Heritage Data

NASA has had missions that collected ice data for many years, and snow and ice is among the many variables included in NASA's Pathfinder Program, which is providing research-quality data sets on global change from past and current satellite missions.

The Electrically Scanning Microwave Radiometer (ESMR) on the Nimbus-5 satellite provided the first detailed data sets of sea-ice distributions for cloud and cloud-free conditions. The data from ESMR and its successor, the Scanning Multichannel Microwave Radiometer (SMMR), launched on Nimbus 7, have resulted in three major atlases, giving the history of the Arctic and Antarctic sea-ice covers from the years 1973-76 and 1978-87. The Defense Meteorological Satellite Program (DMSP) has flown a Special Sensor Microwave/Imager (SSM/I) since 1987. This instrument is similar to SMMR, and its data are being analyzed to determine snow cover and sea-ice concentrations. Other satellite data used in the study of snow and ice include high-resolution images from the Landsat series of satellites, and radar altimetry data from NASA's Seasat and the Department of Defense Geosat satellites that have been used to determine and map the elevation contours of the southern half of the Greenland ice sheet.

Suggested Reading

Chang, A.T.C., *et al.*, 1987.

Foster, J.L. and A.T.C. Chang, 1993.

Hall, D.K., *et al.*, 1995.

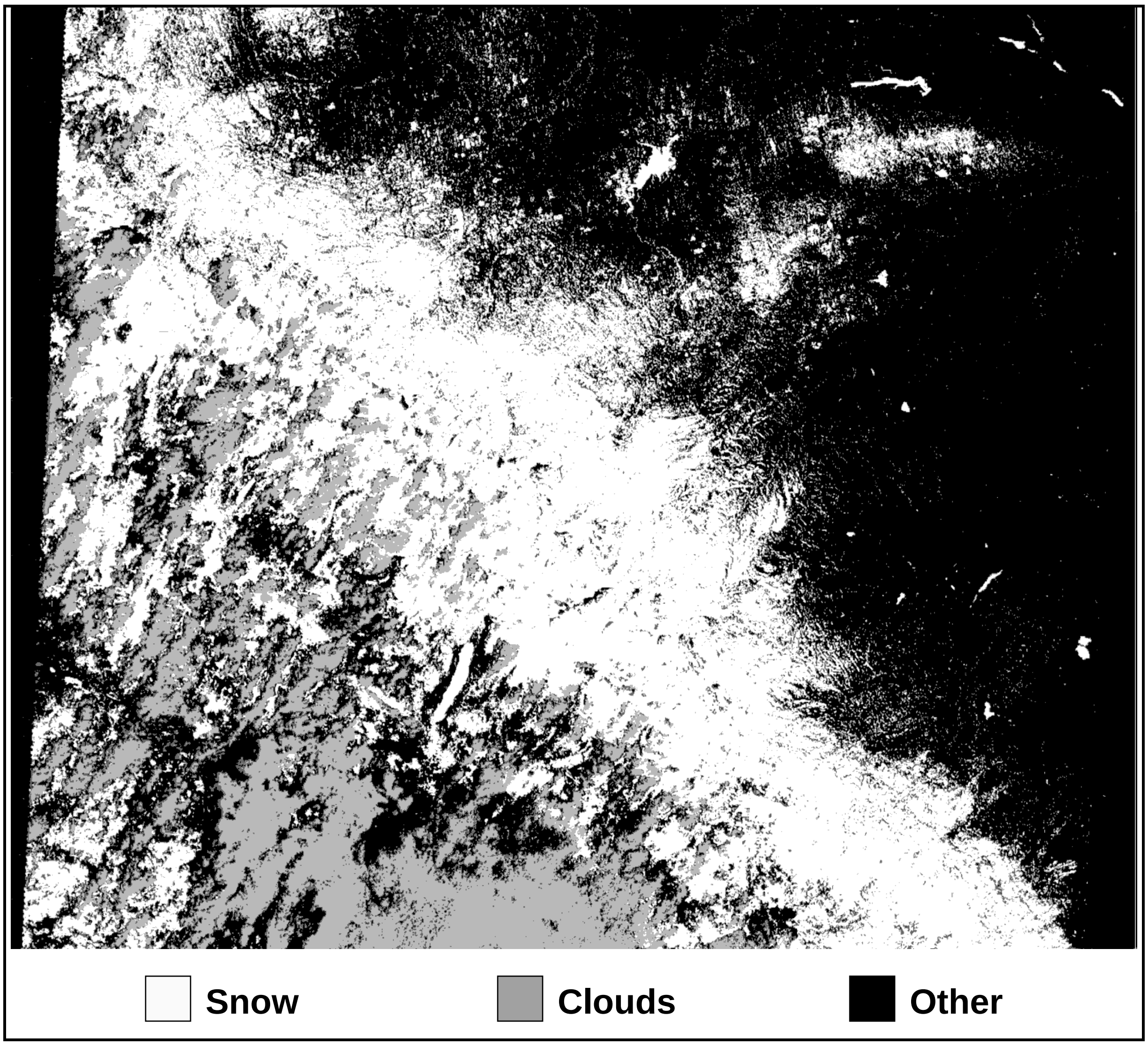

Figure 40. **Result of applying the SNOMAP algorithm (Hall, *et al.*, 1995) to a Landsat TM scene of northern Montana including Glacier National Park.** The TM scene was acquired on March 14, 1991 (scene i.d. #5256917454). (Note: Snow and non-snow features were classified automatically by the SNOMAP algorithm, but cloud features were classified by supervised classification.)

Snow Cover

Product Description

Global snow cover (including ice on large, inland water bodies) will be mapped daily and weekly over the Earth's land surfaces at 500-m resolution using the SNOMAP algorithm (Hall, *et al.*, 1995). A global, daily snow cover map will be an at-launch MODIS product. Snow cover, with its high albedo, is a key parameter of the global energy balance, reflecting much of the incident solar radiation back to space. Snow cover of the Northern Hemisphere is currently mapped by NOAA on a weekly basis, but the accuracy of the maps has been difficult to determine, in part, because a variety of techniques has been used to map snow cover over the almost 30-year period during which the maps have been produced.

Additionally, snow/cloud discrimination is difficult and often impossible using the current NOAA sensors because of the available bands. MODIS bands will allow automatic snow/cloud discrimination, and, in conjunction with the cloud mask to be produced by another MODIS investigator, will allow automated snow mapping. The MODIS weekly snow-cover product is designed to provide snow-cover persistence statistics for each pixel so that users can determine how long the snow has been on the ground during a compositing period selected by the user. This is especially important during the transition seasons.

Research & Applications

Large, inland water bodies such as the Great Lakes, are often ice-covered during the winter months, and navigation during part of the winter is a significant problem. NOAA data are currently used to map ice cover on the Great Lakes, but snow/ice and cloud discrimination is a problem. Additionally, ice cover on lakes can be an important climate indicator, as the dates of freeze-up and break-up are influenced by meteorological conditions. A trend toward earlier break-up, for example, could signify a warming as has been observed in some areas (e.g., Comb, 1990). Thus, it is important to measure ice conditions on large lakes over an extended period of time in order to detect trends as well as for operational uses over the short term.

Data Set Evolution

SNOMAP has a considerable heritage. It is based on the normalized difference of a visible and a shortwave-infrared band. This technique has been used, since at least 1978, to map snow from aircraft (Kyle, *et al.*, 1978). Since the mid-1980s, it has been used to map snow using Landsat data on the drainage-basin scale (Dozier, 1989).

Global snow cover has also been mapped using passive-microwave data at a resolution of about 50 km^2 (Foster and Chang, 1993). While these data allow snow mapping through cloud cover, passive-microwave data do not provide a resolution that is suitable for detailed snow mapping. Basin-scale mapping is required for hydrological modeling, and, in particular for snowmelt-runoff calculations which are essential for hydroelectric-power generation and for water-supply forecasts in the western U.S. and in

MOD 10, MOD 33
PRODUCT SUMMARY

Coverage:
global, daytime

Spatial/Temporal Characteristics:
500 m × 500 m daily (Level 2 MOD 10) and 500 m × 500 m weekly (Level 3 mapped-MOD 33).

Key Geophysical Parameters:
snow cover, lake ice cover

Processing Level:
2, 3

Product Type:
MOD 10 - standard, at-launch
MOD 33 - standard, at launch

Science Team Contact:
D. Hall

Snow Cover

many other parts of the world. The expected use of passive-microwave and MODIS snow-cover data together should yield information on snow extent and snow-water equivalent (Salomonson, *et al.*, 1995). Snow-cover data are also needed for general circulation modeling.

Suggested Reading

Comb, D.G., 1990.

Dozier, J., 1989.

Foster, J.L. and A.T.C. Chang, 1993.

Hall. D.K., *et al.*, 1995.

Kyle, H.L., *et al.*, 1978.

Salomonson, V.V., *et al.*, 1995.

Sea-Ice Cover

Product Description

Global sea-ice cover will be mapped daily and every 10 days at 1-km resolution using an algorithm called ICEMAP. Global sea-ice cover will be an at-launch MODIS product. Sea ice is present over approximately 13 percent of the Earth's ocean surface (Weeks, 1981). Snow-covered sea ice, with its high albedo, is a key parameter of the global energy balance, reflecting much of the incident solar radiation back to space. Additionally, the sea-ice cover is an insulating layer between the ocean and atmosphere; heat loss through open water is up to 100 times greater than heat loss through thick ice. As a consequence, leads and polynyas (linear and nonlinear openings in the sea ice, respectively) are significant to the energy budget of the ice-covered ocean and to local and regional climatology. Such open water areas and areas of reduced ice concentration are also important for shipping in ice-covered seas.

Research & Applications

Sea ice cover is currently mapped by NOAA visible and near-infrared sensors, and by microwave sensors, both passive and active. Using the NOAA sensors, snow/cloud discrimination is a major hindrance in identifying sea ice. The passive-microwave sensors map sea ice through cloud cover, but at a resolution of only about 30 km^2. Active microwave sensors have good spatial resolution, up to about 25 m^2, but currently do not map sea ice cover globally on a daily basis. MODIS will be able to map sea ice globally but with the significant limitation that cloud cover will obscure the view of the surface for much of the time. Together, the MODIS and microwave sensors will provide important information on the presence and concentration of sea ice. MODIS data, when available, will provide the higher resolution view of the sea ice that is not obtainable using passive-microwave data.

Data Set Evolution

ICEMAP has a considerable heritage. It is based on the normalized difference of a visible and a shortwave infrared band. This technique has been used to map snow from aircraft and satellites (Kyle, *et al.*, 1978; Dozier, 1984 and Hall, *et al.*, 1995) and has been shown to be effective for mapping sea ice as well. The 10-day composited sea ice cover product is designed to provide sea ice-cover persistence statistics for each pixel so that users can determine how long sea ice has been present during the previous 10 days in any given location. A cloud mask will be provided by another MODIS investigator.

Suggested Reading

Dozier, J., 1984.

Hall. D.K., *et al.*, 1995.

Kyle, H.L., *et al.*, 1978.

Weeks, W.F., 1981.

MOD 29, MOD 42
PRODUCT SUMMARY

Coverage:
global, daytime over nonequatorial ocean

Spatial/Temporal Characteristics:
1 km × 1 km daily (Level 2 MOD 29) and 1 km × 1 km weekly (Level 3 mapped MOD 42).

Key Geophysical Parameters:
sea ice extent

Processing Level:
2, 3

Product Type:
standard, at-launch

Science Team Contact:
D. Hall

Assimilated Snow Depth

Product Description

This Level 4 product consists of 3-hourly estimates of snow depth (reported in liquid water equivalent) produced by the GEOS DAS. It is based on the assimilation of pressure, temperature, wind, and moisture observations from conventional meteorological sources, both *in situ* and remotely sensed, along with other TRMM and AM-1 data such as TMI and MODIS. The GEOS DAS calculates snow depth using its estimates of temperature and precipitation along with melting rates based on land surface temperature.

Research & Application

Snow melt plays a major role in the Earth's hydrologic cycle. Accurate estimates of the water equivalent snow depth are needed to assess global change. Many regions of the world rely on snow melt as their major source of water.

Data Set Evolution

Satellite instruments such as MODIS can measure snow cover but not snow depth. Assimilated snow depth will provide added information to complement MODIS snow cover estimates.

Suggested Reading

Bloom, S.C., *et al.*, 1995.

Pfaendtner, J., *et al.*, 1995.

Schubert, S.D., *et al.*, 1995.

Schubert, S.D., *et al.*, 1993.

DAS 10
PRODUCT SUMMARY

Coverage:
global

Spatial/Temporal Characteristics:
$2° \times 2.5°$ lat-lon grid, daily at 00, 03, 06, 09, 12, 15, 18, and 21 UTC

Key Geophysical Parameters:
snow depth

Processing Level:
4

Product Type:
standard, post-launch

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Appendix A –

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Appendix B – Acronyms

Acronyms

ACRIM Active Cavity Radiometer Irradiance Monitor

ADADS ASTER Data Archive and Distribution System

ADC Affiliated Data Center

ADEOS Advanced Earth Observing Satellite (Japan)

ADM angular distribution model

AGP Ancillary Geographic Product (MISR)

AHWGP Ad Hoc Working Group on Processing

AIRS Atmospheric Infrared Sounder

ALT altimeter

AM EOS morning crossing mission

AMI Active Microwave Instrument

AMRIR Advanced Medium Resolution Imaging Radiometer

AMSU Advanced Microwave Sounding Unit

APAR Absorbed Photosynthetically Active Radiation

APOPP Aerosol Physical And Optical Properties Product

ARP Ancillary Radiometric Product

ASF Alaskan SAR Facility (DAAC)

ASTER Advanced Spaceborne Thermal Emission and Reflection Radiometer

ATBD Algorithm Theoretical Basis Document

AVHRR Advanced Very High-Resolution Radiometer

AVIRIS Airborne Visible and Infrared Imaging Spectrometer

BCC biogeochemical models

BDRF bi-directional reflectance factor

BDS Bi-Directional Scan Product (CERES)

BOREAS Boreal Ecosystem – Atmosphere Study

BRDF bi-directional reflectance distribution function

BRF bi-directional reflectance factor

CADM CERES Angular Directional Model

CAGEX CERES/ARM/GEWEX Experiment

CAL/VAL calibration/validation

CCD Charge-Coupled Device

CDDIS Crustal Dynamics Data Information System

CDROM chromomorphic dissolved organic matter

CEES Committee on Earth and Environmental Sciences

CEOS Committee on Earth Observation Satellites

CERES Clouds and the Earth's Radiant Energy System

CFC chlorofluorocarbon

CH_3Cl methyl chloride

CH_4 methane

CIESIN Consortium for International Earth Science Information Networks

CNES Centre National d'Etudes Spatiales (France)

CO carbon monoxide

COARE Coupled Ocean-Atmosphere Response Experiment (of TOGA)

Co-I Co-Investigator

CRS cloud radiative swath

CSA Canadian Space Agency

CZCS Coastal Zone Color Scanner

DAAC Distributed Active Archive Center

DAO Goddard EOS Data Assimilation Office

DEM digital elevation model

DLPO DoD Landsat Program Office

DMSP Defense Meteorological Satellite Program

DPH Data Products Handbook

ECMWF European Centre for Medium-Range Weather Forecasts (UK)

ECS EOSDIS Core System

EDC EROS Data Center

ENSO El Niño Southern Oscillation

EOS Earth Observing System

EOSAT Earth Observation Satellite Company

EOSDIS Earth Observing System Data and Information System

EOSDIS Earth Observing System Data and Information System

EPOP European Polar-Orbiting Platform

ERBE Earth Radiation Budget Experiment

ERBS Earth Radiation Budget Satellite

EROS Earth Resources Observation System

ERS-1 European Remote-Sensing Satellite-1

ERTS-1 Earth Resources Technology Satellite-1

ESA European Space Agency

Acronyms

ESDIS Earth Science Data and Information System (GSFC)
ESMR electrically scanning microwave radiometer
ESSC Earth System Sciences Committee
ETM Enhanced Thematic Mapper (Landsat)
EUMETSAT European Organization for the Exploitation of Meteorological Satellites
EUV Extreme ultraviolet
FACE Florida Area Cumulus Experiment
FG first guess
FIFE First ISLSCP Field Experiment
FIRE First ISCCP Regional Experiment
FOV field of view
FPAR Fraction of Photosynthetically Active Radiation
FSW (CERES)
GAC Global Area Coverage
GARP Global Atmospheric Research Program
GATE GARP Atlantic Tropical Experiment
GCDIS Global Change Data and Information System
GCM General Circulation Model
GCMD Global Change Master Directory
GCRP Global Change Research Program
GEDEX Greenhouse Effect Detection Experiment
GEMS Global Environmental Monitoring System
GEWEX Global Energy and Water Cycle Experiment
GHz gigahertz
GIMMS Global Inventory Modeling and Monitoring Study
GLAS Geoscience Laser Altimeter System (formerly GLRS-A)
GLI Global Imager
GMS Geostationary Meteorological Satellite
GMT Greenwich Mean Time
GOES Geostationary Operational Environmental Satellite
GOME Global Ozone Monitoring Experiment
GPCP Global Precipitation Climatology Project
GRD Geo-rectified Radiance Product (MISR)
GSFC Goddard Space Flight Center
GTE Global Tropospheric Experiment
HIRIS High Resolution Imaging Spectrometer
HIRS High Resolution Infrared Radiation Sounder
IAV incremental analysis update
ICWG International Coordination Working Group
IDS Interdisciplinary Science
IEOS International Earth Observing System
IFOV instantaneous field of view
IGBP International Geosphere – Biosphere Programme
IMG Interferometric Monitor for Greenhouse Gases (Japan)
IPAR Instantaneous Photosynthetically Active Radiation
IR infrared
IR-RAD infrared radiometer
IRTS Infrared Temperature Sounder
ISAMS Improved Stratospheric and Mesopheric Sounder
ISCCP International Satellite Cloud Climatology Project
ISLSCP International Satellite Land Surface Climatology Project
ISTP International Solar Terrestrial Physics
ITIR Infrared Thermal Imaging Radiometer (renamed ASTER)
ITTP International TOVS Processing Package
IWC ice water content
JEOS Japanese Earth Observing Satellite
JERS Japanese Earth Remote-sensing Satellite-1
JPL Jet Propulsion Laboratory
LAC Local Area Coverage
LAI Leaf Area Index
Landsat Land Remote Sensing Satellite
LaRC Langley Research Center (DAAC)
LAWS Laser Atmospheric Wind Sounder
LIMS Limb Infrared Monitor of the Stratosphere
LIS Lightning Imaging Sensor
LMC length modulation cell
LST land surface temperature
LW long wave
LWC liquid water content
LWIR Long-Wavelength (Thermal) Infrared
LZP level zero processing

Acronyms

MAPS	Measurement of Atmospheric Pollution from Satellites
MAS	MODIS Airborne Simulator
Mbps	megabits per second
MESSR	Multispectral Electronic Self-Scanning Radiometer
METEOSAT	Geosynchronous Meteorology Satellite (ESA)
MHS	Microwave Humidity Sounder
MHz	megahertz
MISR	Multi-Angle Imaging Spectroradiometer
MITI	Ministry of International Trade and Industry (Japan)
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOPITT	Measurements of Pollution in the Troposphere
MRIR	Medium Resolution Infrared Radiometer (Nimbus)
MSFC	Marshall Space Flight Center
MTPE	Mission to Plant Earth
MVI	Modified Vegetation Index
MWIR	Medium-Wavelength Infrared
MWP	microwave water path
NAS	National Academy of Sciences
NASA	National Aeronautics and Space Administration
NASDA	National Space Development Agency of Japan
NCAR	National Center for Atmospheric Research
NCDC	National Climate Data Center (NOAA)
NCEP	National Centers for Environmental Prediction (formerly the NMC)
NDSC	Network for the Detection of Stratospheric Change
NDVI	Normalized Difference Vegetation Index
NESDIS	National Environmental Satellite, Data, and Information Service
NEXRAD	NEXt generation weather RADar
Nimbus	NASA Meteorological Satellites (1 through 7)
NIR	near infrared
NMC	National Meteorological Center (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NPP	net primary production
NRC	National Research Council
NRL	Naval Research Laboratory
NSCAT	NASA Scatterometer
NSF	National Science Foundation
NSIDC	National Snow and Ice Data Center (DAAC)
NWS	National Weather Service
OBC	On-Board Calibrator
OH	hydroxyl radical
OI (1)	Singly Ionized Oxygen Emission Line
OLS	Optical Linescan System
OPS	Optical Sensor
ORNL	Oak Ridge National Laboratory (DAAC)
OTD	Optical Transient Detector
PAR	photosynthetically available radiation
PAR	photosynthetically active radiation
PBL	planetary boundary layer
PEB	phycoerythrobilin-rich phycoerythrins
PI	Principal investigator
PISP	Polar Ice Sheet Program
PM	EOS afternoon crossing mission (post meridian)
PMC	Pressure-Modulator Cell
PMIR	Pressure Modulator Infrared Radiometer
PoDAG	Polar DAAC Advisory Group
POEM	Polar-Orbiting Earth Mission (ESA)
POES	Polar-Orbiting Environmental Satellite
ppb	parts per billion
ppm	parts per million
PR	Precipitation Radar (TRMM)
PSN	Net Photosynthesis
PSO	Project Science Office
PUB	phycourobilin-rich phycoerythrins
QA	quality assurance
RLRA	reflectivity level reference altitude
SAGE III	Stratospheric Aerosol and Gas Experiment III
SAMS	Stratospheric and Mesospheric Sounder
SBUV	Solar Backscatter Ultraviolet
SCF	Science Computing Facility

Acronyms

SeaWiFS	Sea-viewing Wide Field-of-view Sensors second
SEDAC	Socioeconomic Data and Applications Center
SMMR	Scanning Multichannel Microwave Radiometer
SPOT	Systeme pour l'Observation de la Terre (France)
SPSO	Science Processing Support Office
SRB	Surface Radiation Budget
SSBUV	Shuttle Solar Backscatter Ultraviolet radiometer
SSF	Single Satellite Footprint (CERES)
SSM/I	Special Sensor Microwave/Imager (DMSP)
SST	sea-surface temperature
SWIR	shortwave infrared
TDRSS	Tracking and Data Relay Satellite System
TES	Tropospheric Emission Spectrometer
TIR	Thermal Infrared
TIROS	Television Infrared Observing Satellite
TMI	TRMM Microwave Imager
TMR	TOPEX Microwave Radiometer
TOA	Top of the Atmosphere
TOGA	Tropical Ocean Global Atmosphere
TOGA/ COARE	TOGA/Coupled Ocean-Atmosphere Response Experiment
TOMS	Total Ozone Mapping Spectrometer
TOPEX/ Poseidon	Ocean Topography Experiment (joint US-France)
TRMM	Tropical Rainfall Measuring Mission (U.S.-Japan)
TSDIS	TRMM Science Data and Information System
UARS	Upper Atmosphere Research Satellite
USGCRP	U.S. Global Change Research Program
UTC	Universal Time, Coordinated
UV	Ultraviolet
VI	Vegetation Index
VIR	Visible and Infrared Radiometer
VIRS	Visible Infrared Scanner (TRMM)
VISSR	Visible/Infrared Spin-Scan Radiometer
VNIR	Visible Near Infrared
WMO	World Meteorological Organization
WN	window channel radiometric data
WWW	World Wide Web

Appendix C –
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