EOSDIS Support for the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER)

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ABSTRACT

The end-to-end ground data system supporting the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) consists of elements provided by both Japan ASTER Ground Data System and the highly distributed Earth Observing System Data and Information S ystem (EOSDIS). These two systems must interoperate to provide complex mission operations support and process high-rate (approximately 8 Megabits/sec) data into standard I .evel 1, I .evel 2 and higher data products. The EOS Data and operations System (El)0S) will provide ground data capture, rate buffering, and Level O data processing. The EOS operations Center will provide the operational interface between the Japanese Instrument Control Center and the spacecraft and will monitor the instrument health and safety. The 1 and Processes Distributed Active Archive Center (DAAC) at the EROS Data center wilt produce higher-level products based on software provided by the ASTER Science Team and systems provided by the EOSDIS Core System. Highc.r-level data product quality assurance, as well as U.S. Science Team support for instrument scheduling, will be pei formed at a Science Computing Facilit y located at the Jet Propulsion I aboratory. All of these elements are bring developed together to assure that this international mission produces data which will serve the needs of the science community.

1. INTRODUCTION

In 1998, the first of the Earth Observing System (EOS) spacecraft, EOS AM-1, will be launched into a 705 km sun-synchronous orbit, and carry with it the Advanced Spaceborne 'J 'hermal E nission and Reflection Radiometer (ASTER). Development of the EOS spacecraft is being managed by NASA's Goddard Space Flight Center. ASTER development is being **managed** by the Japan Resources Observation Systems (JAROS) organization within the Japanese Ministry of International Trade and Industry (Ml'J'J). ASTER will provide high resolution(15m-90n0 images with a 60 km swath width, in 15 spectral bands. Because of its along-track stereo and multi-spectral thermal capabilities it will represent a unique civil spaceborne capability (Yamaguchi, et rd., 1994; Fujisada, 1994).

The success of ASTER depends not only on flight segment performance, but also on the smooth, reliable operation of the ground data system. The ground system processing elements must meet performance and storage challenges because of the high data volume and complex Level 1 data processing requirements. ASTER will have a duty cycle limited by numerous instrument and spacecraft constraints and a cross-track pointing ability, both of which will result in very complex scheduling operations in order to obtain maximum scientific utility. The ground system supporting ASTER will be developed in both Japan and the U.S., presenting significant intcropcrations and management challenges.

The primary science objective of the ASTER mission is to improve understanding of the local- and regional-scale processes occurring on or near the Earth's surface and lower atmosphere, including surface-atmosphere interactions. ASTER is the only high-spatiat-resolution imaging system planned for EOS AM-1, and it will be used to obtain detailed maps of surface temperature, spectral emissivity, and spectral reflectivity, as well as digital elevation models. Such information can then be used in studies of surface radiation balance, evaporation and evapotranspiration, vegetation, soils, the hydrologic cycle, and volcanic processes.

An objective of both the EOS Program and the ASTER Science Team is to produce a series of calibrated, geophysical data products from the ASTER instrument measurements and to make these data products available to the Earth Science community, especially the EOS Global Change research community. Japan is responsible for the production of Level 1 data products. These Level 1 products will be used to generate to Level 2 products (geophysical quantities and browse images) using algorithms supplied by the Science Team. Standard Level 2 data products will be routinely produced in the U.S. and Japan using the same algorithms.

The term ASTER Integrated Ground System is used to refer to the overall integrated U.S. and Japanese ground system elements which affect the acquisition and processing of ASTER data. The purpose of this paper is to focus on the U.S. portions of the ASTER Integrated Ground System. Companion papers presented at this symposium describe the Japanese elements of the ASTER Integrated Ground System and the ASTER data acquisition scenario. It should be kept in mind that this system is still in its critical design and early implementation phase, so it is possible that significant changes could be made before actual operations.

2.0 ASTER INTEGRATED GROUND SYSTEM

The ASTER Integrated Ground System is the end-to-end ground data system that is being developed to accomplish ASTER instrument operations and the distribution, processing, archive, and dissemination of the returned data. The Japanese data system elements will be provided by MITI's Earth Resources Data Analysis Center (ERSDAC) and are referred to as the ASTER Ground Data System (GDS). instrument engineering support will be provided by JAROS. The data system elements being developed, procured, and placed into operation by NASA's Goddard Space night Center, in support of the ASTER Integrated Ground System, area part of the EOSDIS. These NASA elements are multi-mission in that they support the entire NASA Mission to Planet Earth, and are in only a very few minor cases, dedicated to ASTER. The EOSDIS will provide interfaces with external data systems such as the Nationat oceanic and Atmospheric Administration (NOM) data centers. The Integrated Ground S ystem will provide a variety of services including; 1) data capture and telemetry processing; 2) instrument scheduling, commanding and monitoring; 3) data production, archive, distribution and information management; 4) user support; 5) communications; and 6) ground data system management. The overall end-to-end architecture of the ASTER mission, and the fundamental relationship between Japan and the U.S. is illustrated in Figure 1.

The primary means of downlink for the AM-1 spacecraft will be via the Tracking and Data Relay Satellite System (TDRSS). The EOSDIS will negotiate TDRSS schedules, capture data from AM-1 and process them to remove telemetry errors, eliminate artifacts, and create Level O data products. The EOSDIS will maintain an emergency archive of Level O products. It will provide services for processing and distribution of real-time and near-real time housekeeping data, normal production data, and expedited data. The data system element performing most of these services is the EOS Data and operations System (EDOS). The ASTER GDS is currently negotiating to establish an X-band ground receiving station that will be capable of receiving rcat-time direct downlink data

The EOSDIS will perform spacecraft planning, scheduling, command and control. These functions include coordination of multi-instrument observations, ensuring that the commands generated are valid and within resource constraints, monitoring and maintenance of the health and safety of spacecraft and instruments, engineering analysis of spacecraft data, and maintaining history of spacecraft and instrument operations. EOSDIS will aJso provide appropriate interfaces to ensure command and control of the ASTER instrument. The EOSDIS data system element performing most of these services is the EOS operations Center (EOC).

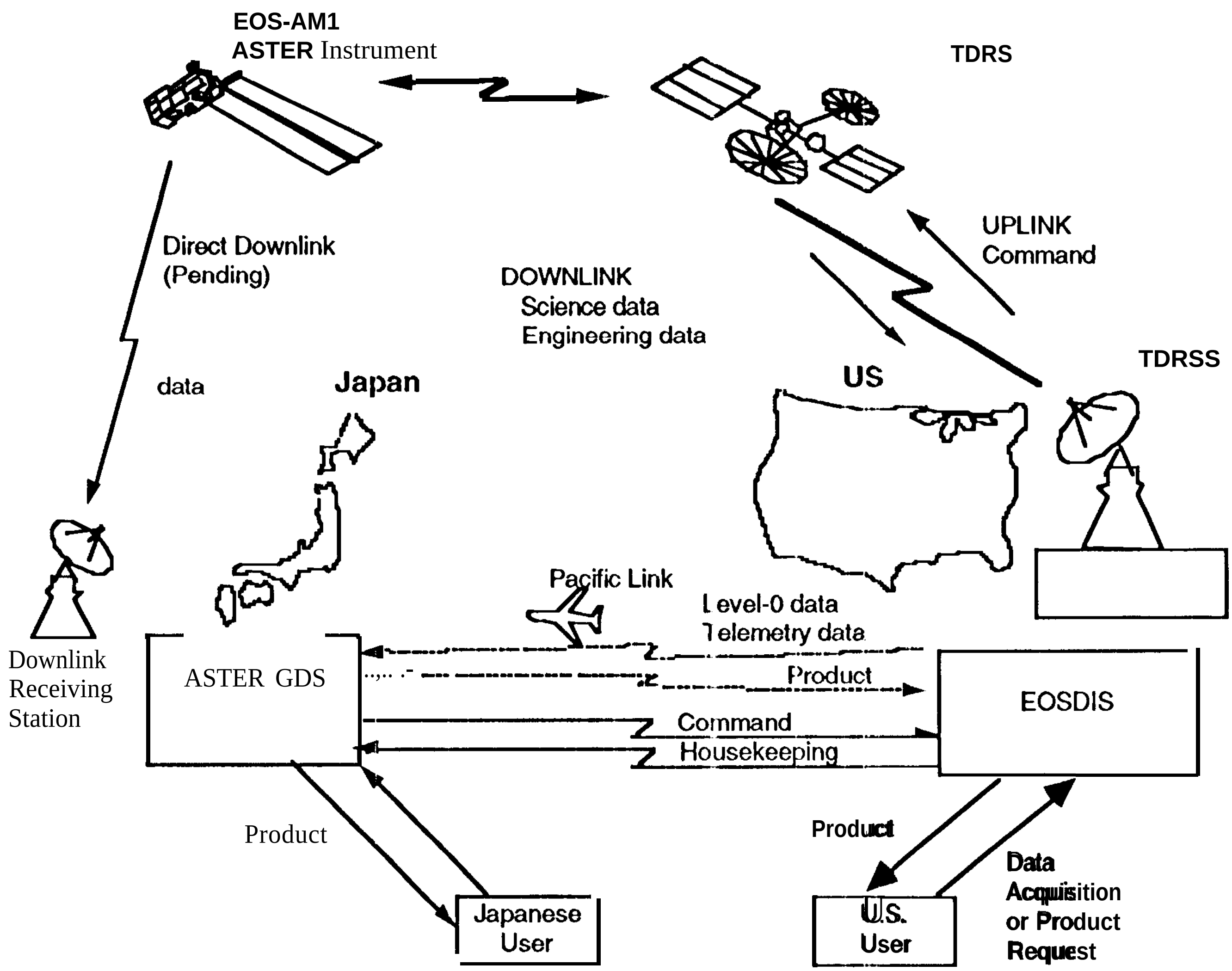


Figure 1, ASTER end-to-end data system architecture

The ASTER GDS will have responsibility for ASTER instrument operations. Because ASTER is limited in its duty cycle (-8%), and because its pointing capability is life-limited and can cause spacecraft disturbances, the scheduling of the instrument is quite complex. Based on guidance from the ASTER Science Team, the ASTER GDS will perform long and short term planning, instrument scheduling, user request processing, and detailed instrument engineering analysis. This will be performed in the Instrument Control Center (ICC) of the ASTER GDS. The ASTER Science Team will be represented in the instrument operations efforts by a Science Scheduling Support Group, composed of both Japanese and U.S. representatives, which shares observation request and scheduling information with the ASTER GDS via an Instrument Support Terminal (1ST).

After ground capture, all ASTER instrument data will be sent to Japan by either electronic means or by air freight. The ASTER GDS will ingest and catalogue the Level O data, process alt data to Level 1A (radiometric and geometric calibration coefficients computed but not applied), perform quality assessment on the data, and convert a subset to Level 1B (coefficients applied). The ASTER GDS will also produce higher level products at the request of Japanese users. The Level 1 image data to be handled by the ASTER GDS, based on the potential of acquiring as many as 777 scenes per day, is greater than 200 GB per day. All Level 1A data will be archived in Japan, and sent to the U.S. as well, Level 1B processing will be carried out on-demand for as many as 310 scenes per day, with resource allocation issues being decided by the Science Team. Requests for observations, archived data products, or requests for new data products will, for Japanese users, be via an Information

Management System (IMS). The ASTER GDS accomplishes these services through it's Science Data Processing Segment (SDPS).

EOSDIS will provide a parallel system in the U.S. for data production, management and access, with the exception that it will support, in the U. S., only Level 2 data product generation. The EOSDIS will provide U.S. user access to all the ASTER standard products, in either the U.S. or Japan, and distribute requested subsets of them to users either electronically (via networks) or on appropriate media. Product generation algorithms, software, documentation, calibration data, engineering, and other ancillary data will be stored and provided to users upon request. In general, these services will be accomplished via the subsystems of the EOSDIS Science Data Processing Segment (SDPS) located at the Distributed Active Archive Centers (DAACs). The DAAC which has been assigned to ASTER is the EROS Data Center, in Sioux Falls, South Dakota, referred to as the I and Processes DAAC (I-PDAAC). All of the EOSDIS DAACS will have user support services to assist users in data acquisition, search, access, and usage. However, most of the interaction with EOSDIS will be through human-computer interfaces. The "look and feel" of the system will be uniform across the multiple points from which the EOSDIS will be accessed.

Both the EOSDIS and the ASTER GDS have a Communications and System Management Segment (CSMS). The CSMS provides the communications, networking and overall data system manage.mcnt functions needed by the ASTER GDS and EOSDIS. Existing and evolving scientific network capabilities in the U.S. and Japan will be used to satisfy end-user connectivity needs. The EOSDIS operational elements will be connected through the EOSDIS consolidated Backbone network (EBnet) to assure security, timeliness, and predictable response. EBnet will provide secure, reliable communications to send uplink commands to the TDRSS ground station and to move Level O instrument data to the DAACs. The EBnet will communicate low-rate ASTER data to a west coast gateway, located at the Jet Propulsion Laboratory, for pick-up by the ASTER GDS. The ASTER Data Network (ADN) provides secure, internal (LAN) communications for the ASTER GDS as well as gateways to external networks that must interface with the GDS.

3.0 EOSDIS ELEMENTS

The main elements of the EOSDIS that effect the functional capabilities associated with ASTER are the EDOS, and the SD]%. The two major functions of the SDPS which arc described here are user access and data product generation. The architecture of the EOSDIS as it is configured to support ASTER is shown in Figure 2.

The SIX'S consists of 7 major subsystems. As shown in Figure 3, these subsystems are: 1) Planning; 2) Data Processing; 3) Data Ingest; 4) Data Server; 5) Data Management; 6) Interoperability; and 7) Client. The central subsystem in this architecture is the Data Server. It translates requests for data from the Earth science domain to the computer science domain. It also provides a consistent interface to a data storage architecture that will include different media and access methods. The Client will reside on the user's workstation and provide user access and data search services, primarily through the Data Management subsystem. The Interoperability subsystem will allow users to insert non-standard data sets into the EOSDIS so that they may be accessed just like any other EOSDIS data set. The Ingest subsystem is responsible for bringing data into the system from external sources, such as EDOS or the ASTER GDS. After data are ingested, they are processed in the Data Processing subsystem. The scheduling for the data processing and management of the processing resources is accomplished by the Planning subsystem. The use of these subsystems for user access and product generation will be described in Sections 3.2 and 3.3.

3.1 EOS Data and Operations System (EDOS)

EDOS, located in White Sands, New Mexico, provides services that support data delivery operations for the AM-1 spacecraft. Data delivery is provided by the Space Network (SN) and EBnet. The SN provides space/ground data communications. EBnet provides ground/ground data communications support for electronic exchanges between EDOS and the ASTER GDS. The EDOS forward link processing services receive forward link data from the EOS Operations Center (EOC) and delivers the data to the SN for uplink to the AM-1 spacecraft. The EDOS return link processing service receives and captures AM-1 spacecraft return link data for a TDRSS Service Session ('1SS) from the SN and performs processing for CCSDS communication services protocols. There are four types of data services provided by EDOS: 1) mat-time data indicating return link performance; 2) rate-buffered housekeeping (H/K) playback telemetry data; 3) Production Data Sets (PDS) containing actual instrument observation&@ and 4) Expedited Data Sets (EDSs) which contain a limited amount of the production data sets, but are made available within a shorter timeframe. A summary of the EDOS data services and interfaces with the ASTER GDS are shown in Figure 4.

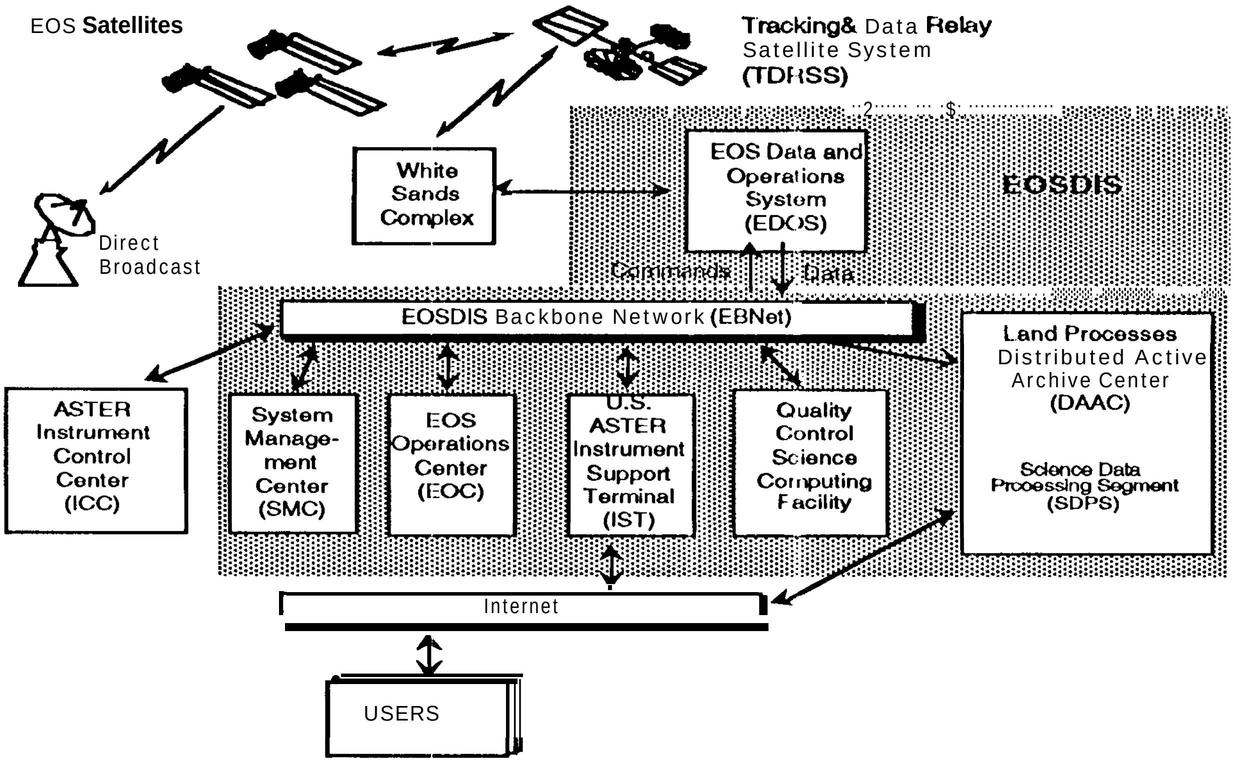


Figure 2 EOSDIS ASTER-specific architecture

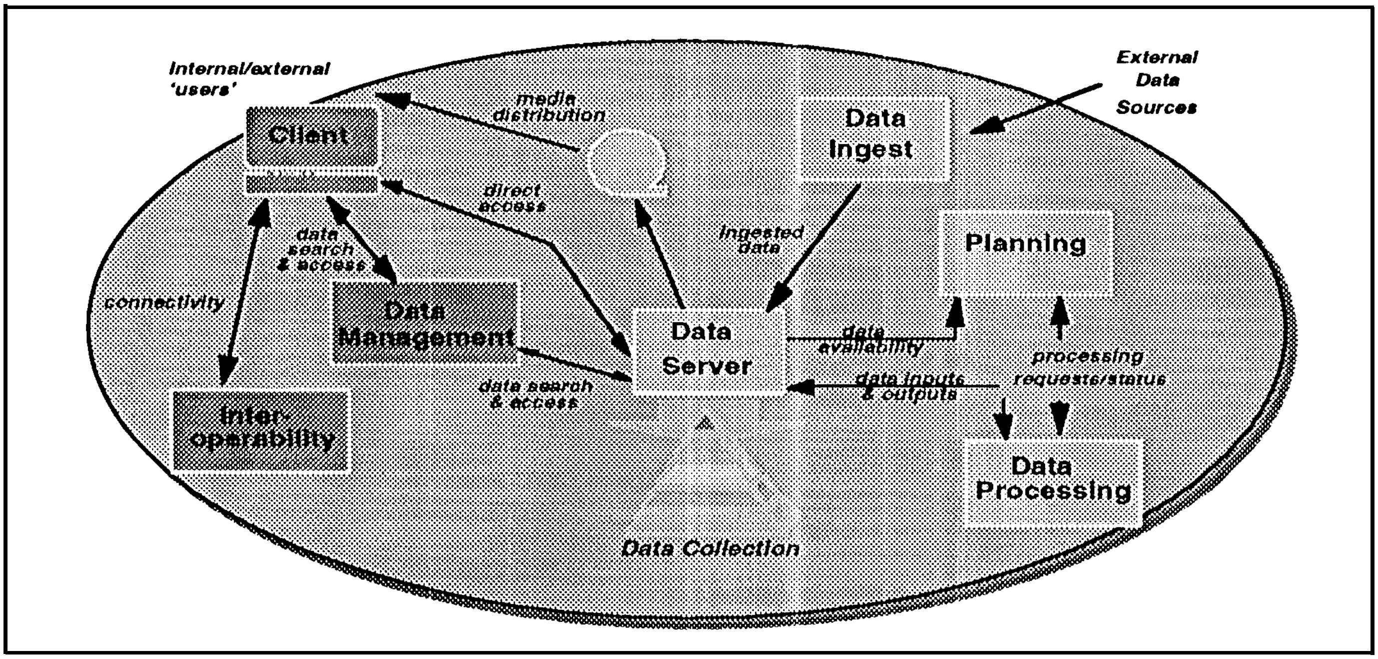
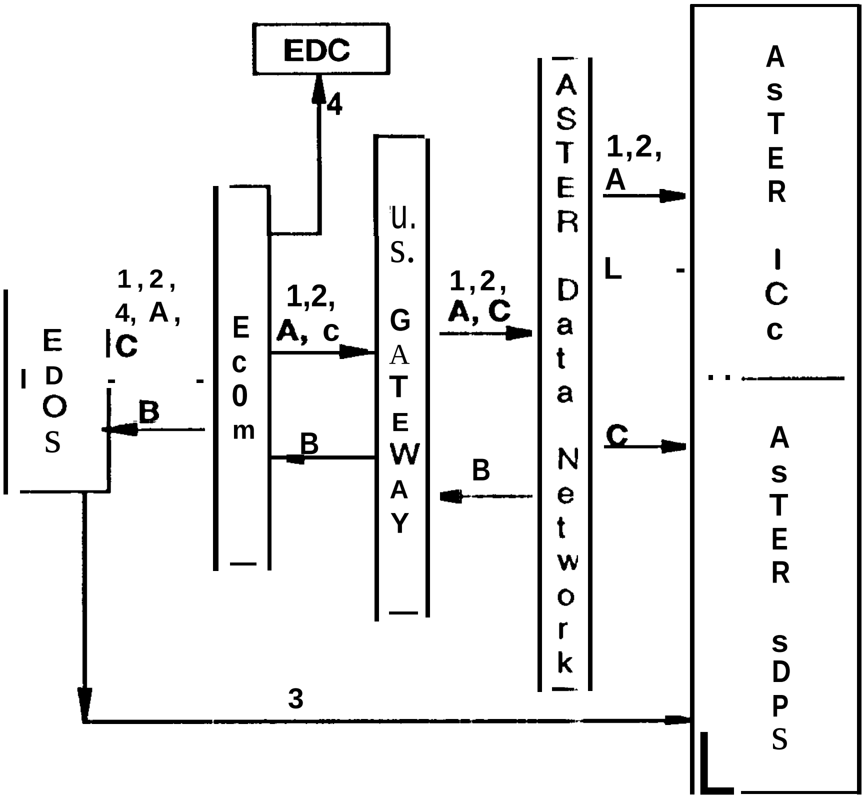


Figure 3 Architecture of the EOSDIS Science Data Processing Segment



Data Products

1. Real-time Path Service **EDUs**
2. Rate Buffered **Data**
3. **PDSs,** and **archived PDSs, on removable physical storage media**
4. **EDSS (for ASTER)**

Operations Management Data

A. **Reports**
B. **Verifications**
C. **Records**

Figure 4 EDOS interfaces with the ASTER GDS

For the real-time service, return link data from a TSS are demultiplexed by separating individual Virtual Channel Data Units (VCDUs) based upon identifying information in the Service Data Unit (SDU) header. This identifying information is provided by the VCDU Identifier (VCDU-ID), consisting of the Spacecraft ID and Virtual Channel ID found in the VCDU header. Subsequent processing is determined by the VCDU-ID fields, together with EDOS management information. CCSDS packets are demultiplexed from the VCDUs designated to contain multiplexed packets. The resulting packet is the SDU that is used to form the EDOS Data Unit (EDU). Quality and accounting data are concatenated with the SDU to form the Path Service EDU. Path Service EDUs are transferred in the same order as the corresponding SDUs are received.

EDOS provides a Rate Buffered service for the Spacecraft's House Keeping (H/K) Telemetry Playback data. The Rate Buffered Data file contains all Path Service EDUS for a single TSS. Data transfer of rate-buffered data is initiated within 5 minutes of completion of a TSS. EDOS electronically transmits the file to the ICC, via the File Transfer Protocol.

EDOS builds a PDS from the CCSDS packets, in accordance with the PDS processing parameters specified by prior agreement or by an ASTER GDS service request. EDOS records the PDS on a removable physical media unit, electronically forwards a delivery notification message, and sends the data to the ASTER GDS via airfreight. Upon arrival in Japan, ASTER GDS personnel then verify receipt of the media unit and data set(s). EDOS PDSs are processed to Level O within 24 hours. The EDOS data archive service provides an archive of production processed data. Archived Production Data Sets, copies of existing PDSs, are sent to the ASTER SDPS, on request, via removable physical storage media.

ASTER instrument commands identify whether the instrument generates data for expedited data processing. If the CCSDS packets received by EDOS have the Quick-Look ftag set, or a Service Request (initiated by the ASTER GDS) has been received requesting EDS processing for the next TSS, EDOS builds the EDS and electronically transmits the EDS to a server at the LPDAAC. Transfer of Expedited Data Sets (EDSs) is initiated within 3 hours of the "1SS. The ASTER SDPS picks up the data from the LPDAAC server.

EDOS provides the capability to monitor and control data delivery operations. Data quality and accounting information and processing status information are provided with the products to the ASTER GDS. Daring the TSS, EDOS forwards Customer Operations Data Accounting (CODA) Reports to the ICC. These reports summarize EDOS activities, and provide 1SS accounting and quality information since the previous CODA Report.

37 User Access

The SDPS provides information about&@ both in EOS and in the ASTER GDS archive, on a 24-hour basis. It accepts user orders for EOS data and provides information about future data acquisition and processing schedules. It also accepts and forwards data acquisition and product requests. It maintains information on system status, management, and coordination. Users accessing the SIX% through any DMC will see the same comprehensive Earth science view of the overall EOSDIS database (spanning all of the DAACs). The SDPS will also perform the functions required for constructing U.S. user Data Acquisition Requests (DARs) for ASTER observations and forwarding thcm to Japan. The U.S. SIX'S will obtain DAR schedule information from Japan's IMS, and will provide information to users on DAR status.

It will be possible for U.S. users to query the data holdings in the Japan GDS and request products. Japanese users may likewise access the EOSDIS data holdings and request data, The goal of the two systems is to accomplish Level 3 interoperability as defined by the Committee on Earth Observation Systems (CEOS). With Level 3 interoperability, the user is hidden from the specific operation of each catalogue service agent (data providing system). A query placed through a catalogue service agent is routed automatically to one or more catalogue service agents and the results from each returned to the original access point.

A user will access data search and request services through a set of software applications called the Scientist's Workbench, which reside on the user's local system as part of the ECS Client Subsystem. The workbench provides access to various types of data, including Directory level information (high level, summary information), Guide level documents, Inventory (granule-level metadata), data products, and browse. These data can reside at ECS data centers as well as non-ECS data centers such as at NOAA.

The services supported and tools provided by the Workbench include 1) starching for products of interest; 2) ordering a desired produce 3) requesting that the ASTER instrument acquire data meeting certain criteria; 4) supporting a graphical selection of areas of interest using a pointing device and a map background reference; and 5) displaying areas that have selected data associated with them.

Figure 5 shows the major elements involved in fulfilling a user request for data search or ordering. The Client resides on the user's local system (PC, Macintosh, and UNIX-based versions will be available), and communicates with a data server and related software residing at the "home" DAAC of the user. The data server is responsible for archiving, accessing, and distributing all types of data (metadata, browse, products, documents, etc.). It also forwards DARs and other appropriate service requests to the ASTER GDS. In conjunction with related software, the data server at the home DAAC communicates with the other data centers from which services are requested. While only EOS data centers are shown, non-EOS data centers can also provide services, and make service requests, as long as they follow the appropriate protocols.

A typical session would begin with the user selecting the Client's search function, which will probably be represented as an icon on the workbench. After the search function is initiated the user can formulate a metadata query using the forms provided. This query is then submitted to the data server at the home DAAC, which searches its database for records that meet the query's criteria, then returns these to the Client. If the database to be searched resides at a different data center, then the server and related software will submit the query to the appropriate data center on the user's behalf. The results are passed to the Client, which displays them to the user as a list of products, and the user has the option of requesting browse data, ordering the products, or editing or saving the query result. If the user submits an order for a product, this request is forwarded to the data server, which retrieves the product from the archive (or forwards the request to the appropriate data center) and then sends it out electronically or copies it to the requested media format so it can be shipped.

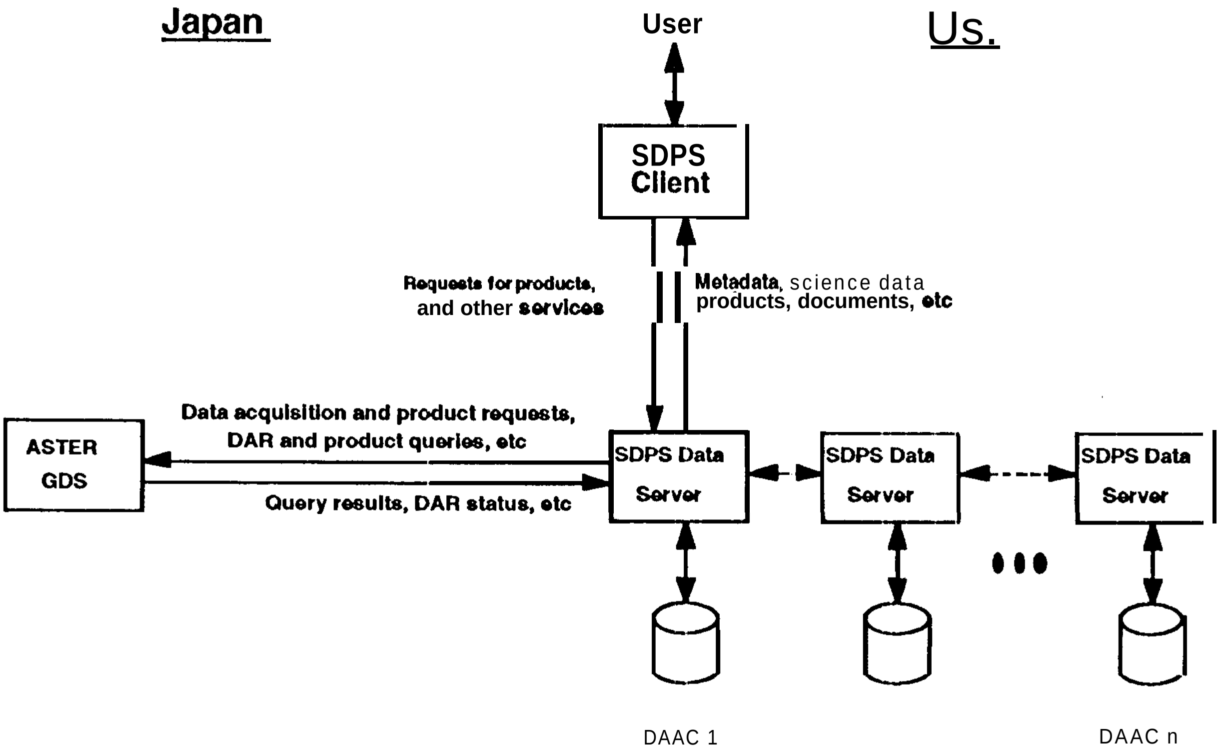


Figure 5 User access using the EOS SDPS

3.3 Data Product Generation

The EOSDIS will perform routine processing for ASTER Level 2 standard data products in support of U.S. users. This will be accomplished by integrating the production science processing software, which implements the scientific algorithms, with the computing environment of the EOSDIS. The interface between these two entities is controlled through the required use of a standard Application Programmer Interface (API) for standard services such as I/0, and ancillary data acquisition. The API is implemented as a part of the science software Toolkit and is distributed to all Science Teams by the EOSDIS. The SDPS provides the operational environment for the product generation software provided by the Science l'earn, The science software consists of several Product Generation Executables (PGEs) that must be executed in a certain sequence in order to produce the desired product. The SDPS hardware and software provides for planning of data product generation taking into account data acquisition plans, interdependencies among PGEs and instruments, and the distribution of computational resources. It provides data sets from NOAA needed for the standard data products and it supports the extraction of appropriate subsets of standard data products to assist in scientific quality control by the ASTER Science Team. The ASTER data products to be produced by the EOSDIS, and their interdependencies, are illustrated in Figure 6.

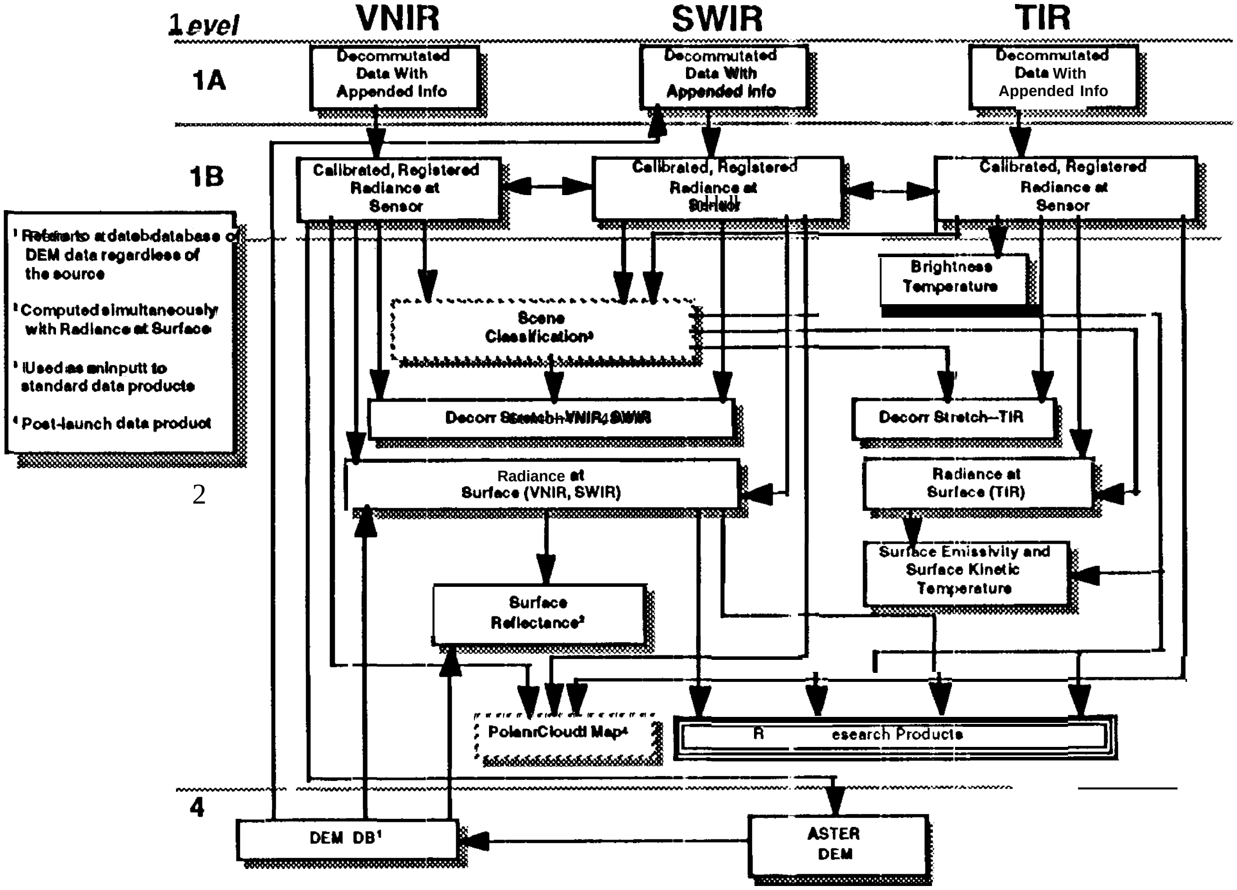


Figure 6 ASTER Data Product Architecture

The production of standard data products, including on-demand ASTER products, is carried out primarily by three subsystems of the SDPS: 1) the Planning Subsystem (PLS); 2) the Data Server Subsystem (DSS); and 3) the Data Processing Subsystem (DPS). The relationship among these subsystems is illustrated in Figure 3. The PLS develops data processing tasks that are carried out by the DPS. The PLS also manages the computers and software resources **utilized by the DPS. The production of standard products** is initiated by either a standing order or by the usc of a "subscription", created from **Production** Requests (PRs) submitted by users. Standing orders for products that are produced on a routine basis are entered into the PLS during the integration and test of the science software package being used to generate a given product. The other method used to initiate product generation is to have users issue PRs to the DSS, which in turn generates a subscription to fulfill the PR. The DSS is the storage **facility** for **all** of the software and data files that are needed in the production process.

Before product generation can begin, the science software must successfully be integrated and tested to run within the SDPS processing environment. At that time, details concerning the individual PGEs are **gathered from the software delivery** package. A PGE is defined as the smallest schedulable entity managed by the product generation subsystems. In almost all cases it consists of executable programs and script files that usually produce one or more standard products or interim products which arc used subsequent.1 y for the generation of a product. A PGE profi le is developed that describes the ingredients of a PGE; the executable programs and associated scripts, parameters needed for the running of the executables, input and output data tiles needed and created, predicted computing resources required, and performance statistics of the PGE.

Product generation begins with the PLS generating a number **of "candidate** plans" comprised of processing tasks. A task is defined by the following information 1) the PGEs and associated scripts needed for a product; 2) input data needed and output data generated and the location for both; 3) an estimate of the amount of time the PGE should take to complete; and 4) the priority of the PGE. The time period covered by a plan will vary, with the individual DAACs influencing bow the plans get formulated, but a 30 day plan is likely to be the norm. The plans generated witl be placed on the DSS for viewing by the user community via some type of electronic interface (e.g., a World Wide Web browser). Users will also be able to view the candidate plans by subscribing to a plan availability notification service.

These candidate plans will be modified over time for a variety of reasons, such as the failure of a process to execute or the failure of all necessary input data sets to be available. Revised versions of the 30 day candidate plans will be issued at the periodically to keep the user community informed about changes in the planned processing. The DAAC Manager will be responsible for making the decision on which candidate plan to implement. 'f'he plan selected out of the candidate set will then become the "active plan". The active plan may still be modified depending on how a particular DAAC Manager's implements operations at the DAAC. Once an active plan is finalized, a portion of the plan is submitted to the DPS for the generation of products. The current design calls for the submission of 27 hours of an active 30-day pfan as the amount of scheduled processing to accomplish in onc day at any of the DAACS.

The generation of products involves interaction between the PLS and the DPS. It also requires support from the DSS which primarily acts as a file repository which supplies and stores information to and from the other two subsystems. A COTS scheduling and monitoring tool will be used to control much of the processing that occurs within the DPS. 'Ibis tool helps ensure efficient usc of the DPS resources by automating, as much as possible, the scheduling and managing of the large number of processes required for production. Ptatinum Technology's AutoSys and AutoSys Xpert Tools have been selected for this task. AutoSys is a job scheduling tool used to automate the execution of processes running in a distributed UNIX environment. AutoSys uses a rotational database management system to develop a schedule of processing jobs for a given time period. Custom software will be developed to take a portion of an active plan and break it down into the detailed fields needed by AutoSys to control the actual processing.

Higher level ASTER products will primarily be produced in an on-demand basis, That is, an end user will submit a PR to produce a Level 2 ASTER product, as opposed to a standing order. The current operations concept for handling on-demand products is still being developed. One scenario is to develop candidate plans in a shorter time span than arc generated for routine processing, and to accumulate PRs for ASTER products for a TBD time period, before submitting the candidate plan to the DPS for processing. The other scenario is to have a portion of the SDPS be set up to do ASTER on-demand processing (i.e., a portion of the SDPS will have dedicated hardware for the generation of ASTER Products). The design trade-offs on this issue are now being studied.

The SDPS is being developed to be a "data driven" production environment, (i.e., a processing task is only released to initiate processing on a given set of resources after the PLS "knows" that the required inputs are available from the DSS). The sequence of events to initiate processing involves the PLS acting as an interface between the DSS and the AutoS ys Tool. The usual chain of events areas follows: 1) The DSS subscription service notifies the PLS that a suite of required input data sets for a given set of DPRs are available; 2) the PLS, which is responsible for tracking that a task's input dependencies are satisfied, checks to see which suite of required input data sets satisfies the current day's list of tasks scheduled for activation; and 3) the PLS notifies Autos ys that the task can be initiated. After a given task successfully finishes, the next task scheduled by the AutoSys Tool is prepared for processing. If different data sets arc needed for this next task, AutoSys and PLS work in concert to make sure that these data sets are available and are brought over from the DSS. This procedure along with the three steps listed above, are done repetitively until the scheduled part of the active plan (i.e., the 27 hours of the processing scheduled) is completed.

The AutoSys Xpert Tool is used to monitor and generate report.s about the set of processes (i.e., a job schedule) which has been initialed by the AutoSys Tool. AutoSys Xpert allows the production operator, to view what is going on in the production machines by the usc of a GUI which provides different views (e.g., time-lines, Gantt charts) of how production jobs are progressing on any machine within the production environment, This tool also provides the operator the ability to do "what-if" simulations to assist in determining the effects of modifying a job schedule. Part of the power of the AutoSys and AutoSys Xpert Tool suite is that if an operator sees that processing is being delayed for any reason, the operator can cancel the process. The operator can then use the AutoS ys Tool to initiate the next process of the active plan for which all of the required input data arc available.

4.0 SUMMARX

The Integrated ASTER Ground System constitutes a substantial effort to Ming two major data systems together for a common purpose. The integrated system has to support high data rates, high data processing volumes, a large number of controlled interfaces, modern user access methods, and considerable complexity in scheduling operations. The distributed nature of this system and the physical and language differences between the co-developers provides additional challenges. However, as international cooperative missions in space become more common. it will be important for the major space-faring nations to develop these types of systems quickly and efficiently. The ASTER Integrated Ground System will not only provide users with scientific data during the EOS time-frame, but also provide a set of lessons-learned, and perhaps some of the infrastructure, that will form the basis for the development of future systems.

5.0 ACKNOWLEDGMENTS

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