# ABSTRACT

## The Direct Broadcast Service

## on

## Office of Earth Science Spacecraft

by

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The Direct Access System for the Earth Observing System (EOS) spacecraft provides a means of transmitting some, or all, of the EOS science data directly via X-band to ground. The Direct Access System, or some portions thereof, will fly on the EOS-AM, EOS-PM, and some subsequent Office of Earth Science spacecraft. Included in this Direct Access System is a Direct Broadcast Service which will transmit real-time data from the satellite to anyone within line-of-sight during most of the orbit.

The Direct Broadcast service will be particularly useful to people who need science data quickly (sooner than the normal 24-hour availability through the EOS Data and Information System, EOSDIS) or who are unable to obtain the data easily from the EOSDIS. It will require, however, a sophisticated ground station to receive and process those data.

This paper describes the Direct Broadcast Service as it has evolved thorough the construction of the EOS-AM spacecraft and the design of the EOS-PM spacecraft. It will also discuss requirements placed upon users of the system and caveats of which these users must be aware.

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## Table of Contents

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## INTRODUCTION

The Direct Broadcast Service for the National Aeronautics and Space Administration's (NASA's) Earth Observing System (EOS) spacecraft provides a means of transmitting some, or all, of the science data from Office of Earth Science (OES) spacecraft directly to ground stations. This service will be in place on the EOS-AM and EOS-PM spacecraft as well as on selected, appropriate subsequent spacecraft.

Historically, this service follows the Automatic Picture Transmission (APT) service initially offered in December, 1963 (on TIROS-VIII) and presently used by thousands. APT operated in the UHF band (near 137 MHz with a 2.4 KHz AM data signal) and can be received by anyone with a personal computer and a modest receiver (e.g., a card in the PC). APT produces images with 2 channels and 4 km resolution. APT was followed by High Resolution Picture Transmission (HRPT) in October, 1978. HRPT operated in L-band (around 1.7 GHz) at a higher data rate of 665.4 kilobits/second and produced images with 5 channels and 1.1 km resolution. The equipment required initially cost around $100,000, but the price dropped to $10-20,000. Over 200 people worldwide use HRPT today.

It is the HRPT users that were considered to be a model for Direct Broadcast users. The HRPT users receive and process meteorological data from National Oceanic and Atmospheric Administration's (NOAA) polar orbiting satellites. Their stations have reasonably sophisticated ground processing capabilities and are used for both research and operational use. It is expected that some HRPT users will move up to X-band to accommodate the higher data rates from advanced instruments. It is also expected that the NOAA weather satellites and the EOS PM-series will converge in the future.

The Direct Broadcast service (DB) will provide an almost continuous broadcast of real time science data from an OES spacecraft to any user with a suitable ground station. The Direct Broadcast data are primarily for local consumption and normally are not forwarded to the EOS Data and Information System (EOSDIS). Since all instrument data are also stored onboard the spacecraft for subsequent transmission to the ground, it will later reside in the EOS Data and Information System (EOSDIS). The Direct Broadcast service should prove useful to people who have a need for immediate EOS data, since the data in EOSDIS is usually at least 24 hours old. Direct Broadcast service should also prove useful to those who do not have easy or timely access to the EOSDIS, such as researchers desiring real time support and data for planning or carrying out field experiments.

Direct Broadcast users need have no connection with NASA other than to obtain information relative to constructing and operating their ground stations. The typical Direct Broadcast ground station, if constructed using today's technology, should cost in the range of $250,000 - $400,000, including the data processing and display equipment. This cost is considerably (orders of magnitude) higher than that of an APT weather station, and significantly higher than the original cost of an HRPT station.

CAVEAT: Another capability of the on-board X-band system is the Direct Playback (DP) service. This playback service is more important from an overall mission sense. It enables sending the data stored onboard directly to a few specially equipped NASA-supported ground stations. Unfortunately, this service cannot be used simultaneously with the Direct Broadcast service. Fortunately, the Direct Playback service is used only once or twice an orbit when it sends data to one of two very high-latitude ground stations (located near Fairbanks, AK [about 65N, 148W] and Longyearbyen, Svalbard [about 78N, 15E]). The coverage areas of those two polar ground stations is shown in Figure 1 below.

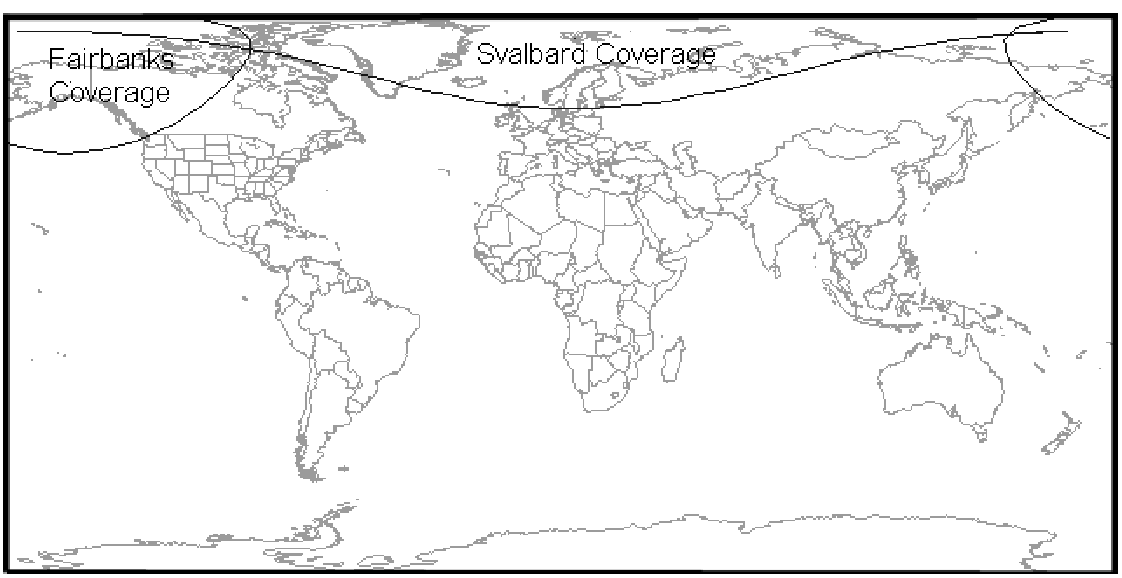


Figure 1: Areas within Line-of-Sight of Fairbanks, Alaska and Longyearbyen, Svalbard.

Within those two areas covering the northern polar cap, Direct Broadcast service will be strongly affected. However, efforts will be made to minimize the impact of these Direct Playback operations on Direct Broadcast users. Once downloaded to the ground via Direct Playback, the stored data will forwarded to the EOSDIS for processing and distribution..

## OFFICE OF EARTH SCIENCE LONG RANGE PLAN

The first spacecraft to be launched with Direct Broadcast service is the EOS-AM (mid 1999), named for its 10:30 a.m. local time southbound equatorial crossing. The thrust of the EOS-AM is the characterization of the terrestrial surface, clouds, aerosols, and radiation balance. Its morning crossing time was chosen to minimize cloud cover. The EOS-AM spacecraft will begin operations using the Tracking and Data Relay Satellite System (TDRSS) to playback its science data, but is expected to phase over to using X-band direct-to-ground downlinks later.

The second to be launched (2000) is the EOS-PM, named for its 1:30 p.m. local time northbound equatorial crossing. Its scientific emphasis is on clouds, precipitation, and radiative balance, terrestrial snow and sea ice; sea surface temperature and ocean productivity. Its afternoon crossing time was chosen for its usefulness for meteorological forecasting. It, and subsequent spacecraft, are expected to use direct-to-ground communications for playing back science data

It was originally planned to replace the EOS-AM and EOS-PM spacecraft in orbit to gain a baseline of 15 years of contiguous, consistent data. Those plans have changed. The OES, driven to faster, better, and cheaper missions, will not replicate the EOS-AM and EOS-PM spacecraft, but will instead fly more numerous smaller satellites which will carry the instruments necessary to continue the measurements.

The EOS-PM was expected to be the prototype for the next generation of low Earth orbiting weather satellite (e.g., the NOAA series). Since the inception of the EOS Program, the low Earth orbiting weather satellite programs of the United States have changed. The National Oceanic and Atmospheric Administration (NOAA), NASA, and the United States Department of Defense (DoD) low Earth-orbiting (LEO) weather satellite efforts have been merged into the National Polar-orbiting Operational Environmental Satellite System (NPOESS) managed out of an Integrate Program Office (IPO). NASA will supply new technology and instruments of scientific value to its programs, the DoD will procure the new satellites and their operational instruments, and NOAA will operate the satellites in orbit (including the DMSP satellites). It is anticipated that these NPOESS satellites, when they come into operation in the 2008-2010 time frame, will continue the Direct Broadcast Service, will carry instrumentation comparable to that carried by EOS-PM, and will produce equivalent, consistent data.

The EOS-AM and EOS-PM instruments being supported by the Direct Broadcast service are listed on Table 2 and are described further in Appendix B. Equivalent or better instruments are expected to be flown on subsequent satellites (including the NPOESS satellites). The operating scenario for these instruments is fairly simple - they are either left on or cycle in a day-night sequence. The downlinked data rate will be 15 Megabits-per-second (Mbps) or less. Note that each spacecraft also includes a 16 Kbps engineering data stream with the downlinked data. However, most instruments include all the ancillary data needed to use their data within their downlinked telemetry stream (packets).

| Spacecraft | Instruments | Data Rate (Mb/s) Average | Data Rate (Mb/s) Peak |
|---|---|---|---|
| EOS-AM | MODIS | 6.200 | 11.000 |
| | | Total*: 6.216 | Total*: 11.016 |
| EOS-PM | AIRS | 1.440 | 2.000 |
| | AMSU-A | 0.003 | 0.003 |
| | CERES | 0.020 | 0.020 |
| | HSB | ? 0.004 | ? 0.004 |
| | AMSR-E | ? 0.130 | ? 0.130 |
| | MODIS | 6.200 | 11.000 |
| | | Total*: 7.797 | Total*: 13.157 |

Table 2. EOS Direct Broadcast Instruments and Data Rates

* Totals include engineering/housekeeping data stream of 16 kb/s.

## EOS DATA PRODUCTS AND SOFTWARE

Numerous standard data products will be routinely generated by, and available from the EOSDIS. The individual Direct Broadcast user is not expected to have the resources to produce all of these standard products, and in fact will neither need nor want to. The more difficult processing may require data from sources not easily accessible to the Direct Broadcast user, or may require complex and very expensive computer systems. Nonetheless, the Direct Broadcast users should be able to produce the subsets of the standard data products which they need.

NASA will provide the algorithms (mathematical formulae and the steps in which they are used) to convert the raw instrument data into rudimentary, scientifically useful data. Some, if not all, of these algorithms may be coded as software and provided, via the public domain, to the EOS Direct Broadcast community. Such software would prove useful only if the hardware used is compatible with the software. NASA will define the hardware and software standards which should insure such compatibility, and will share them with the EOS community.

NASA cannot accept the responsibility of installing such software at user sites, nor the responsibility for solving any installation-specific problems. NASA will endeavor to provide quality, bug-free code, but the user must accept the responsibility for its use in the field.

NASA will notify the Direct Broadcast User Group of any updates to the code and of any bug-fixes. Such updates and/or fixes will be available through the same channels as those used to obtain the software originally.

## GROUND SYSTEM REQUIREMENTS

The generic requirements for a Direct Broadcast ground station are given below; the ground stations needed to support Direct Playback are much more complex and expensive.

CAVEAT: Direct Broadcast users are warned that the frequency band being used, 8025-8400 MHz, is shared with other services such as point-to-point ground communications (in the U.S., this band is used by the Federal Aviation Administration) and fixed-satellite service [ground-to-space] (in the U.S., this band is used by the Department of Defense). Those services legitimately operate in this band and both they and the direct broadcast community are afforded legal protection. Hence, the OES Direct Broadcast Service must co-exist with them. One way to co-exist when interference is possible is to coordinate between the services. Such coordination is most easily accomplished by placing Direct Broadcast receiving stations in interference-free geographic areas. To do this coordination, and gain protection, Direct Broadcast Service users must register their proposed ground stations with the proper frequency management authorities in their countries before beginning construction. These authorities are responsible for fostering such coordination and are knowledgeable about other band users. In the United States of America, that frequency management authority is the Federal Communications Commission; other countries have counterpart agencies. Note that transmitters (active devices) are licensed, and that receivers (passive devices) are registered. The rationale for registering receivers is that it puts them formally on record and alerts future band users (especially those using transmitters) of their presence. As a matter of course, most if not all radio astronomy observatories are formally registered with the International Telecommunications Union as well as with their local authorities, and for the same reason.

The Direct Broadcast service is aimed at a broad, fairly sophisticated user community. Members of this community may have NASA funding, but generally will not, and they will have to provide their own equipment. However, there is no charge or licensing fee for receiving and using these data. The users are expected to have, buy, or build, the following capabilities to receive and utilize the normal Direct Broadcast services:

R.F. equipment requirements:

a. A tracking antenna about 3 meters in diameter.

b. An 8 GHz receiver with low noise front end (noise temperature < 270 degrees)

c. A system G/T of at least 23 dB/K (clear sky, 5 degrees elevation).

d. Ability to deconvolve 2:1 convolutionally encoded data (to receive EOS-AM data).

e. Ability to handle Reed-Solomon encoded data.

Data Processing requirements include the ability to:

a. Process Channel Access Data Units (CADU's) per CCSDS standards.

b. Decode Viterbi soft decision logic

c. Process Virtual Channel Data Units (VCDU's) and packets.

d. Store and/or process incoming data at rates up to 15 Mbps.

The above system requirements are believed to be met by current technology. The total cost for a ground station with the above equipment and capabilities is estimated to be in the $250,000 - $400,000 range, assuming no usable equipment is in place, and using current technology. NASA will do its best to inform the users about the needed technology, and to assure that such technology, both hardware and software, is available.

The complete space-to-ground link margin calculation for each spacecraft are discussed in Appendices A. The following discussion, based on EOS-AM, is given as an example of typical, generic ground station requirements and capabilities (see Table 4 for a summary).

| **ELEVATION, Deg.** | 5.00 | 40.00 | 70.00 | 90.00 |
|---|---|---|---|---|
| EOS-AM Signal at Ground, dBWi | -164.24 | -167.14 | -167.34 | -166.74 |
| **USER-GND SYSTEM** | | | | |
| Ant. Gain, dB (3 M antenna) | 45.60 | 45.60 | 45.60 | 45.60 |
| Rec'd Power, dBW | -118.64 | -121.54 | -121.74 | -121.14 |
| Actual G/T, dB/k | 20.89 | 22.88 | 23.22 | 23.53 |
| Rec'd carrier:noise | 85.25 | 84.34 | 84.48 | 85.39 |
| Data Rate, dB-bps | -71.76 | -71.76 | -71.76 | -71.76 |
| Rec'd Eb/No, dB | 13.49 | 12.58 | 12.72 | 13.63 |
| Multipath degradation, dB | -1.00 | -1.00 | -1.00 | -1.00 |
| I-Q power split, dB | -3.00 | -3.00 | -3.00 | -3.00 |

| | | | | |
|---|---|---|---|---|
| Filter Loss | 0.00 | 0.00 | 0.00 | 0.00 |
| Implementation Losses, dB | -3.00 | -3.00 | -3.00 | -3.00 |
| Effective Eb/No, dB | 6.49 | 5.58 | 5.72 | 6.63 |
| Req'd Eb/No, 1:2 conv. | 4.40 | 4.40 | 4.40 | 4.40 |
| **MARGINS** | | | | |
| System Margin, dB | 2.09 | 1.18 | 1.32 | 2.23 |
| Reed-Solomon gain, dB | 0.50 | 0.50 | 0.50 | 0.50 |
| Effective Margin, dB | 2.59 | 1.68 | 1.82 | 2.73 |

Table 4: Generic Receiver-Station Characteristics Based on EOS-AM.

These RF link calculations for EOS-AM Direct Broadcast service during normal, 1:1 power split, DB/DB mode operations under conditions of 4mm/hour of rainfall. A 3-meter diameter ground system antenna was assumed. The calculations were based on a 15 Mb/s data rate and a 14 watt transmitter (Xmtr on EOS-AM). The X-band antenna on the spacecraft, derived from LANDSAT heritage, yields more gain at long ranges (low spacecraft elevations) and less gain when the spacecraft appears directly overhead. To a ground station, the signal from the spacecraft varies only about 3 dB from 5 degrees above the horizon to directly overhead. Note that when the EOS-AM DB/DB mode is operated with a 1:4 power split instead of the normal 1:1 power split, an additional overall +2 dB is added to the net margin in the Q-channel while a loss of -4 dB occurs in the I-channel signal, making the I-channel unusable

## OPERATIONAL CONSIDERATIONS

Since the Direct Broadcast service on the EOS-AM spacecraft is the first of many X-band direct broadcast services and will demonstrate NASA's capabilities to the public at large, reasonable continuity of service must be provided. In fact, a requirement from NASA Headquarters which states that Direct Broadcast service shall be continuous.

Under normal operations, Direct Broadcast service should be available at all times and interrupted only for momentary outages (less than one second, and typically 200 milliseconds) when operating modes are changed. A 200 millisecond outage will result in a gap in the data approximately 1400 meters (the spacecraft travels at about 7 Km/sec) along-track and about 1/7 of a MODIS cross-track swath. The exception is when the on-board data storage is played back to a ground station (Fairbanks or Longyearbyen), in which case there will be a gap of up to 11 minutes in Direct Broadcast Service.

The following ground rules should apply to routine spacecraft operations:

1. Normal usage of the Direct Playback mode will be limited to within line-of-sight of Fairbanks, AK and Longyearbyen, Svalbard (note the caveat in the INTRODUCTION). This

mode usually precludes simultaneous operation of the Direct Broadcast service.

2. The Direct Broadcast service may have to be curtailed (turned off) when in the vicinity of Deep Space Network (DSN) stations, depending upon the observing schedule of those stations. This limitation is due to potential interference with DSN operations and applies to EOS-AM, but should not apply to EOS-PM. Whether this limitation applies to future missions is yet to be determined. The Deep Space Network stations are located near Orroral (Canberra), Australia [near 33.6S, 151.1E]; Madrid, Spain [near 40.4N, 4.3W]; and Goldstone (Mohave), California, U.S.A. [near 35.4N, 116.9W]. See Figure 2.

3. System tests of the Direct Playback mode, contingency modes, and other spacecraft events which might impact Direct Broadcast users should be carefully scheduled, whenever possible, to minimize this impact. That schedule should be posted via Internet or E-mail.

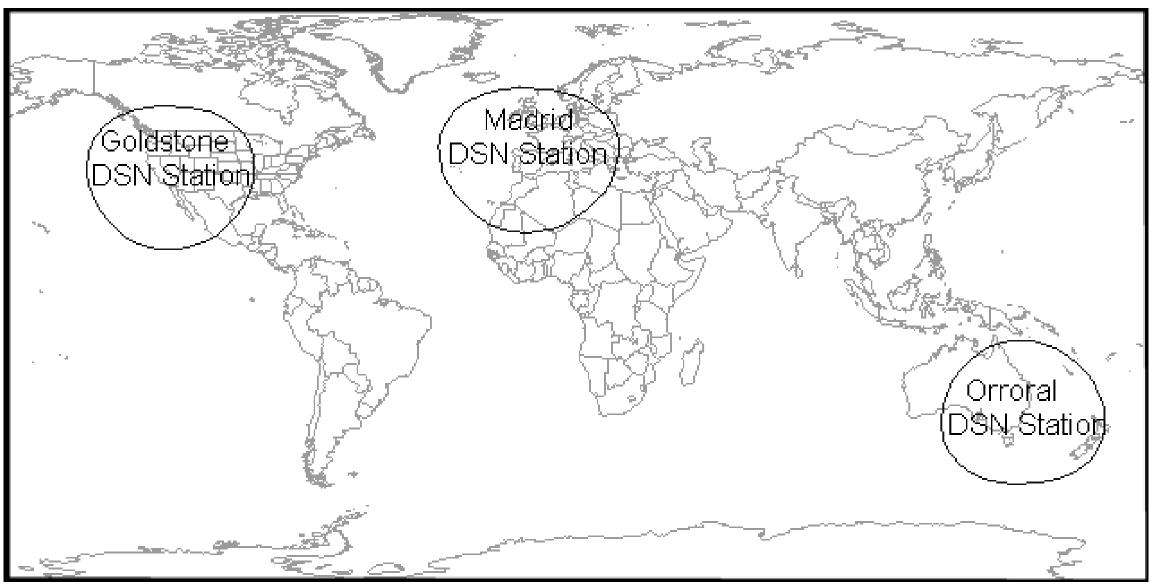


Figure 2: Areas with Possible Deep Space Network - Direct Broadcast Conflicts.

**USER PROSPECTS**

The user of the OES Direct Broadcast Service should experience a consistent level of Direct Broadcast service from a variety of spacecraft.

Both EOS-AM and EOS-PM will operate in a 705 Km altitude, 98.2 degree sun-synchronous, retrograde orbit with a 16-day (233 orbit) repeat cycle. these spacecraft can adjust their orbit to remain on station, although periodic orbit adjustments will be necessary. Thus, once a 16-day pattern of station contacts is established for each spacecraft, that pattern should remain fairly constant over the life of the spacecraft. Orbit adjustments, Direct Playback system checks, and other non-normal operations will be announced to the user community in advance, whenever practical, via the Internet. The history of flight operations will be available through the EOSDIS.

The contact time per day at a station will vary, primarily depending upon the latitude of the ground station. An estimate of the contact time per day, averaged over the 16-day repeat cycle, for spacecraft in EOS-AM and EOS-PM orbits, is given on Figure 3 below. Mid-latitude stations will typically have three contacts in the morning (1 short, one long, 1 short) followed by two contacts in the evening (each fairly long), evolving to two in the morning and three in the evening, and back-and-forth.

Known interruptions or limitations to direct broadcast service are the following:

1. Direct Broadcast service at high Northern latitudes will be interrupted often, since most of the satellites are expected to download their onboard stored data to one or the other of two high-latitude ground stations. See Figure 1 above.

2. Direct Broadcast service within line-of-sight of Deep Space Network ground stations may be interrupted when the Direct Broadcast signal could interfere with DSN operations (a problem with EOS-AM, but not expected to affect EOS-PM. The impacts on other satellites are TBD). See Figure 2 above.

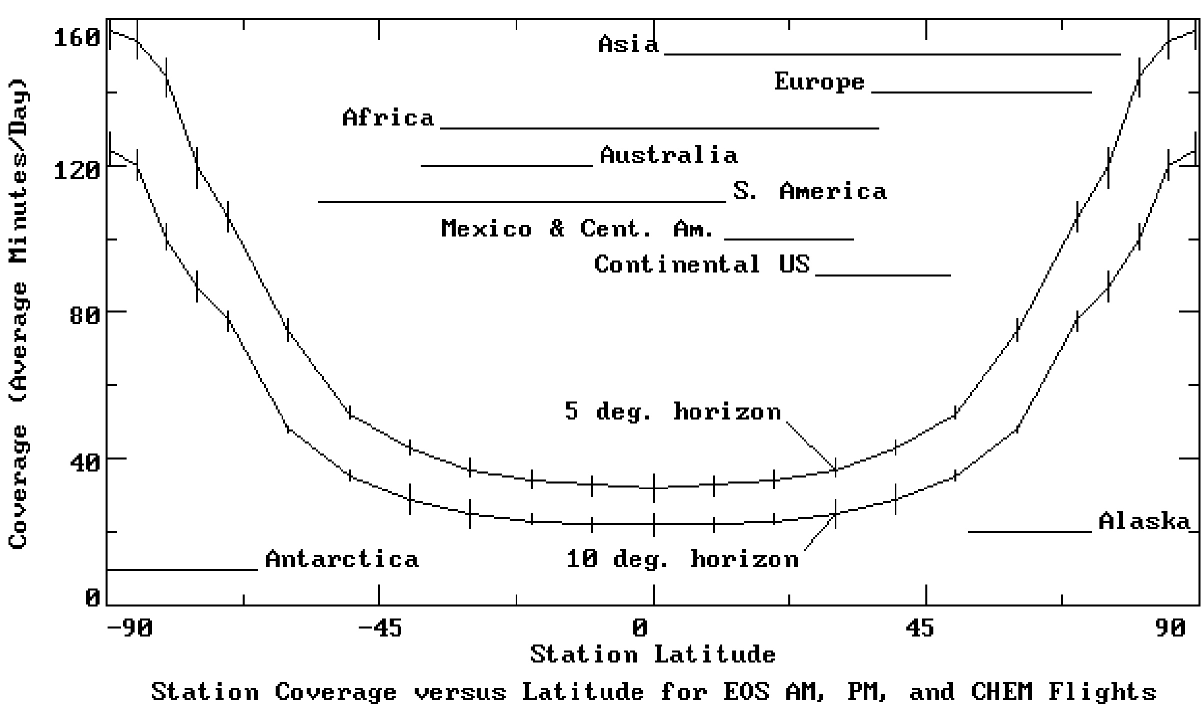


Figure 3. Average Daily Contact Time for the EOS AM, PM, and CHEM Orbits.

3. Direct Broadcast receiving stations may be subject to interference from other legitimate users of the frequency (the means to minimize this interference is discussed under GROUND SYSTEM REQUIRMENTS).

4. The radio frequency signal from the satellite is subject to absorption by water in the atmosphere and may be lost during periods of heavy rainfall.

NASA's Office of Earth Science does not expect to communicate individually with each of the Direct Broadcast user stations. Rather, an ad hoc Direct Broadcast User Group is being formed, and it is anticipated that an electronic bulletin board on the Internet will provide any needed timely information. User group meetings will be scheduled at reasonable intervals (perhaps every 2 years) to enable the direct exchange of information between the NASA, its project offices, and the users, as well as between users themselves.

## APPENDIX A-1:

## EOS-AM SPACECRAFT DESIGN

The EOS-AM Direct Access System (Direct Broadcast, Direct Playback, and Direct Downlink services) communications subsystem consists of two redundant, independent chains of frequency source/modulators feeding up converters which in turn drive RF power amplifiers. These components are not cross-strapped; the only switch is between the two RF power amplifiers and the one filter leading to a single, fixed X-band antenna. This antenna is pointed to the spacecraft nadir and has a shaped beam to compensate for the longer path length when the ground station is not directly underneath the spacecraft. The characteristics of the communications subsystem design are in Table A-1-1.

| Parameter | Requirement |
|---|---|
| Center Frequency | 8212.5 MHz |
| ERP | 14 watts |
| Bandwidth (1st null-to-1st null) | 26 MHz |
| Data Modulation | OQPSK |
| Data Format | |
| I/Q power ration (nominal) | 1:1 |
| Operational Duty cycle | 100% |
| Antenna coverage from nadir | +/- 64 deg. |
| Antenna polarization | RHCP |
| Data Rate | 13 Mb/s |

Table A-1-1. EOS AM X-band System Parameters

The data system on-board the EOS AM-1 formats the data to Consultative Committee for Space Data Systems (CCSDS) standards. The characteristics of the data are:

1. Channel Access Data Unit (CADU) length: 8192 bits
2. Reed-Solomon interleave depth: 4
3. Convolutional encoding prior to transmission: 2:1

The EOS AM-1 Direct Access System will support 4 modes of operation (see Table A-1-2). Direct Access System service will be momentarily interrupted whenever changing modes (e.g., changing from DB/DB to DB/DDL and then, about 11 minutes later, back to DB/DB when a Direct Downlink pass is scheduled). This interruption is expected to be on the order of 200 milliseconds. When the change is from DB/DB to DP/DP and back, there will be about an 11-minute interruption in the Direct Broadcast Service.

The mixed modes (DB/DDL and DB/DP) should not be operated in the unbalanced power split, which produces an unusable signal to most DB ground stations.

When EOS-AM is operating in the pure Direct Broadcast mode (DB/DB) operation, the Direct Broadcast data are transmitted in both the I- and Q-channels. During EOS-AM Direct Broadcast/Direct Downlink (DB/DDL) or Direct Broadcast/Direct Playback (DB/DP) operation (mixed modes), the Direct Broadcast data are still being broadcast in the "I" channel. The typical Direct Broadcast ground station should be able to receive all of these signals, although there may be signal degradation near the horizon or during rain storms. There are two power splits between the I- and Q-channels available in most modes. Normally, the power will be balanced at 7 watts in both the I- and Q-channels. An unbalanced power split provides 11.2 watts (+2 dB) in the Q-channel, while reducing the I-channel to 2.8 watts (-4 dB). In an unbalanced mode, ground stations (assumed capable of receiving the Q-channel as well as the I-channel) should be able to receive the Direct Broadcast service under more difficult conditions. When EOS-AM is operating in the pure Direct Playback (DP/DP) mode - generally within line-of-sight of either Fairbanks, AK or Longyearbyen, Svalbard - no direct broadcast data will be available.

It is expected that the DB/DB mode will be used routinely with only occasional, brief (11 minutes or less) changes to the DB/DDL mode or the DB/DP mode. A momentary (less than 1 second) interruption may occur during mode changes. The unbalanced power split will be used only if necessary to support ground stations under particularly trying conditions.

| \ Service<br>Mode \<br>Channel | Broadcast | | Playback | | Downlink | |
|---|---|---|---|---|---|---|
| | I | Q | I | Q | I | Q |
| DB/DB | MODIS<br>15 Mb/s<br>7 w<br>2.8 w | MODIS<br>15 Mb/s<br>7 w<br>11.2 w | ---- | ---- | ---- | ---- |
| DB/DDL | MODIS<br>15 Mb/s<br>7 w | ---- | ---- | ---- | ---- | ASTER<br>105 Mb/s<br>7 w |
| DB/DP | MODIS<br>15 Mb/s<br>7 w | ---- | ---- | ALL<br>105 Mb/s<br>7 w | ---- | ---- |
| DP/DP | ---- | ---- | HALF<br>75 Mb/s<br>7 w | HALF<br>75 Mb/s<br>7 w | ---- | ---- |

Table A-1-2: EOS AM-1 Direct Access System Modes, Instruments, Data Rates, and Power

The EOS AM-1 Direct Broadcast service provides MODIS data and operates both in combination with the Direct Downlink and Direct Playback services, and in a single, stand-alone mode:

> DB/DB: This is a pure Direct Broadcast-only mode. The same Direct Broadcast data stream (12.5 - 15 Mbps/s) is placed in both I and Q channels. This mode will be used most of the time.

Direct Playback service is provided in two modes, both scheduled, and used as needed:

> DB/DP: This is a mixed Direct Broadcast and Direct Playback mode. The Direct Broadcast data stream (12.5 - 15 Mb/s) is placed in the I channel, while the Direct Playback data stream (105 Mb/s) is placed in the Q channel.
>
> DP/DP: No broadcast service is provided in this "pure" Direct Playback mode. Two 75 Mb/s , bit-interleaved data streams are sent down the I and Q channels, for a combined downlink rate of 150 Mb/s. This is the only mode providing no Direct Broadcast service.

The Direct Downlink service provides intermittent, scheduled real time ASTER data in a single, mixed mode.

> DB/DDL: This is a mixed Direct Broadcast and Direct Downlink mode. The Direct Broadcast data stream (12.5 - 15 Mb/s) is placed in the I channel, while the Direct Downlink (ASTER) data stream (105 Mb/s) is placed in the Q channel.

The following overall space-ground system signal margins have been estimated based on data from the EOS-AM contractor. The RF link calculations for Direct Broadcast service during normal, 1:1 power split, DB/DB mode operations are given on Table 4. Note that when the DB/DB mode is operated with a 1:4 power split instead of the normal 1:1 power split, an additional overall +2 dB is added to the net margin in the Q-channel while a loss of -4 dB occurs in the I-channel signal, making the I-channel unusable.

A 3-meter diameter ground system antenna is assumed. The calculations are based on a 15 Mb/s data rate and a 14 watt transmitter (Xmtr). The X-band antenna on the spacecraft, derived from LANDSAT heritage, yields more gain at long ranges (low spacecraft elevations) and less gain when the spacecraft appears directly overhead. To a ground station, the signal from the spacecraft varies only about 3 dB from 5 degrees above the horizon to directly overhead.

| ELEVATION, Deg. | 5.00 | 40.00 | 70.00 | 90.00 |
|---|---|---|---|---|
| | | | | |
| **S/C LINK** | | | | |
| Xmtr Pwr, dBW | 11.46 | 11.46 | 11.46 | 11.46 |
| Pass.Loss,dB | -1.20 | -1.20 | -1.20 | -1.20 |
| Ant.Gain,dB | 7.00 | -5.80 | -9.00 | -9.00 |
| EIRP (dBW) | 17.26 | 4.46 | 1.26 | 1.26 |
| | | | | |
| **XMISSION MEDIUM** | | | | |
| Range, km | 2574.60 | 1029.00 | 744.00 | 705.00 |
| Free Space Loss, dB | -178.90 | -171.00 | -168.20 | -167.70 |
| Atmos.Atten.,dB | -0.80 | -0.10 | -0.10 | -0.10 |
| Rain Atten., dB (4 mm/hr) | -1.70 | -0.40 | -0.20 | -0.10 |
| User Pointing loss, dB | 0.00 | 0.00 | 0.00 | 0.00 |
| User Polariz.Loss, dB | -0.10 | -0.10 | -0.10 | -0.10 |
| Total Path Loss, dB | -181.50 | -171.60 | -168.60 | -168.00 |
| Signal at Ground, dBW | -164.24 | -167.14 | -167.34 | -166.74 |
| | | | | |
| **USER-GND SYSTEM** | | | | |
| Ant. Gain, dB | 45.60 | 45.60 | 45.60 | 45.60 |
| Rec'd Power, dBW | -118.64 | -121.54 | -121.74 | -121.14 |
| System G/T, dB/K | 23.00 | 23.70 | 23.70 | 23.70 |
| System temp, K | 180.00 | 155.00 | 155.00 | 155.00 |
| Rain Temp, K | 116.00 | 32.00 | 18.00 | 6.00 |
| Actual temp., K | 296.00 | 187.00 | 173.00 | 161.00 |
| Actual G/T, dB/k | 20.89 | 22.88 | 23.22 | 23.53 |
| | | | | |
| Rec'd carrier:noise | 85.25 | 84.34 | 84.48 | 85.39 |
| Data Rate, dB-bps | -71.76 | -71.76 | -71.76 | -71.76 |
| Rec'd Eb/No, dB | 13.49 | 12.58 | 12.72 | 13.63 |
| Multipath degradation, dB | -1.00 | -1.00 | -1.00 | -1.00 |
| I-Q power split, dB | -3.00 | -3.00 | -3.00 | -3.00 |
| Filter Loss | 0.00 | 0.00 | 0.00 | 0.00 |
| Implementation Losses, dB | -3.00 | -3.00 | -3.00 | -3.00 |
| Effective Eb/No, dB | 6.49 | 5.58 | 5.72 | 6.63 |
| Req'd Eb/No, 1:2 conv. | 4.40 | 4.40 | 4.40 | 4.40 |
| | | | | |
| **MARGINS** | | | | |
| System Margin, dB | 2.09 | 1.18 | 1.32 | 2.23 |
| Reed-Solomon gain, dB | 0.50 | 0.50 | 0.50 | 0.50 |
| Effective Margin, dB | 2.59 | 1.68 | 1.82 | 2.73 |

Table A-3: RF Link Calculations for EOS AM-1 Operating in DB/DB mode (1:1 power split).

# APPENDIX A-2:

## EOS-PM SPACECRAFT DESIGN

The following information was lifted from the EOS-PM1 X-BAND DIRECT BROADCAST INTERFACE DESCRIPTION DOCUMENT (CDRL 2208), DATED 10 December, 1997, produced by the TRW, Inc. Space and Electronics Group for the EOS-PM1 Project Office at the NASA Goddard Space Flight Center.

In the Broadcast mode the spacecraft continuously transmits all real-time instrument science data, real-time spacecraft engineering (housekeeping) data, and instrument engineering (housekeeping) data as it travels in a sun-synchronous near circular orbit at a nominal altitude of 705 km. The data rate is 15 Mbps at a nominal downlink frequency of 8160 MHz. In normal operations the Broadcast mode will be used during most of the orbit. The only time it is not used is during the approximate 8 to 22 minutes of every 99 minute orbit when the Playback or Downlink modes are active in playing back stored or real time data to the two Earth Observing System Polar Ground Stations (EPGS).

| Parameter | Requirement |
|---|---|
| Center Frequency | 8160 MHz |
| ERP | 27.2 watts |
| Bandwidth (1st null-to-1st null) | 15 MHz |
| Data Modulation | SQPSK |
| Data Format | NRZ-L |
| I/Q power ratio | 1:1 |
| Operational Duty cycle | 100% |
| Antenna coverage from nadir | +/- 64 deg. |
| Antenna polarization | RHCP |
| Data Rate | 15 Mb/s |

Table A-2--1: EOS PM X-band System Parameters

The EOS PM X-band communication system consists of two modulators, a hybrid coupler, two traveling wave tube amplifiers (TWTAs), two isolators, a waveguide switch, a bandpass filter, a lowpass filter, and an X-band earth coverage antenna. Each of the identical modulators receive broadcast or playback I and Q channel data from the Formatter Multiplexer Unit (FMU) in the Command and Data Handling (C&DH) subsystem. A clock signal is output from the active modulator to the FMU, setting the modulator input data rate. For the EOS-PM mission, the data rate is 15 Mbps using the Direct Broadcast link. The I& Q channels are balanced so that

alternating bits of the data stream are placed on each channel (viz 7.5 Mbps). The incoming data is then directly Staggered Quadriphase Shift Key (SQPSK) modulated onto an 8160 MHz carrier. The resulting RF signal is then sent to the active TWTA via the 3 dB hybrid coupler. The coupler provides cross strapping between the redundant modulators
and redundant TWTAs. Each X-band TWTA consists of a traveling wave tube and power converter. The power converter generates the required traveling wave tube voltages from the spacecraft DC power bus. To prevent TWTA damage and/or performance degradation due to potential voltage reflection, an isolator is used at the TWTA output. The active TWTA amplifies the modulated input signal to a nominal saturated output power of 25 Watts (23 Watts EOL minimum). The resulting RF signal from the isolator is routed through a waveguide switch to the filters. This switch provides a two-for-one redundancy of the RF signal path.

Before transmission through the earth coverage antenna, the TWTA output signal is filtered by two X-band Filters. The purpose of the filters is twofold. First, the bandpass filter reduces the portion of the spectrum falling within the Deep Space Research band (8400 MHz to 8450 MHz) to meet the CCIR recommended power spectral density requirement at the ground. Second, the lowpass filter suppresses harmonic components to comply with on-board instrument noninterference requirements. After filtering, the signal is radiated with Right Hand Circular Polarization (RHCP) through the X-band earth coverage antenna. The antenna is mounted at the end of a boom that is deployed after launch to obtain a full earth field-of-view. Across a 63.8 degree half angle cone the reflector is shaped to provide approximately constant power density to a fixed earth station as the spacecraft passes overhead. Since a 5 degree ground station elevation angle corresponds to 63.8 degrees from antenna Nadir, the cone represents the nominal operating beamwidth of the antenna.

The link margin follows:

| ELEVATION, Deg. | 5.00 | 71.00 | 90.00 |
|---|---|---|---|
| | | | |
| **S/C LINK** | | | |
| Xmtr Pwr, dBW | 13.6 | 13.6 | 13.6 |
| Pass.Loss,dB | -3.9 | -3.9 | -3.9 |
| Ant.Gain,dB | 5.6 | -8.00 | -4.00 |
| EIRP (dBWi) | 15.4 | 1.8 | 5.8 |
| | | | |
| **XMISSION MEDIUM** | | | |
| Range, km | 2574.6 | 744.0 | 705.0 |
| Free Space Loss, dB | -178.9 | -168.2 | -167.7 |
| Atmos.Atten.,dB | -0.5 | -0.0 | -0.0 |
| Rain Atten., dB (4 mm/hr) | (-1.7) | (-0.2) | (-0.1) |
| User Pointing loss, dB | 0.0 | 0.0 | 0.0 |
| User Polariz.Loss, dB | -0.4 | -0.4 | -0.4 |
| Total Path Loss, dB | -179.8 | -168.5 | -168.1 |
| Signal at Ground, dBWi | -164.4 | -166.7 | -162.3 |
| | | | |
| **USER-GND SYSTEM** | | | |
| Ant. Gain, dB | 45.6 | 45.6 | 45.6 |
| Rec'd Power, dBW | -118.8 | -121.1 | -116.7 |
| System G/T, dB/K | --.- | --.- | --.- |
| System temp, K | ---.- | ---.- | ---.- |
| Rain Temp, K | 116. | 18.0 | 6.0 |
| Actual temp., K | --.- | --.- | --.- |
| Actual G/T, dB/k | 21.0 | 22.7 | 23.4 |
| | | | |
| Rec'd carrier:noise | 85.3 | 84.6 | 89.8 |
| Data Rate, dB-bps | -71.8 | -71.8 | -71.8 |
| Rec'd Eb/No, dB | 13.5 | 12.8 | 18.0 |
| Multipath degradation, dB | (-1.0) | (-1.0) | (-1.0) |
| I-Q power split, dB | (-3.0) | (-3.0) | (-3.0) |
| Filter Loss | 0.0 | 0.0 | 0.0 |
| Implementation Losses,dB | -4.0 | -4.0 | -4.0 |
| Effective Eb/No, dB | 9.5 | 8.8 | 14.0 |
| Req'd Eb/No, 1:2 conv. | 6.8 | 6.8 | 6.8 |
| | | | |
| **MARGINS** | | | |
| System Margin, dB | 2.7 | 2.0 | 7.2 |
| Reed-Solomon gain, dB | 0.5 | 0.5 | 0.5 |
| Effective Margin, dB | 3.2 | 2.5 | 7.7 |

Table A-2-2: Link Margin Calculations for EOS-PM.

Items in parentheses are not included, but appear in the EOS-AM calculations.

# APPENDIX B:

# DESCRIPTION OF INSTRUMENTS BEING USED FOR DIRECT BROADCAST

This information has been abstracted from the *1995 MTPE EOS Reference Handbook*, *EOS Project Plan (dated September, 1993),* and the EOS Science Processing Support Office web page:

http://spsosun.gsfc.nasa.gov/cgi-bin/eos-ksh/eos_instru.ksh

## AIRS:

AIRS stands for the Atmospheric Infrared Sounder. It is a shared aperture, grating-array spectrometer operating in the infrared. The AIRS science objectives are the detection of the effects of greenhouse gases, improvement of numerical weather prediction, study of global energy and water cycles, investigation of atmosphere-surface interaction, and monitoring of climate variations and trends. Scientific data expected to be derived from AIRS include:

- Outgoing day/night longwave surface flux
- Outgoing day/night ocean surface flux
- Outgoing atmospheric longwave spectral radiation and cloud optical thickness
- Net oceanic shortwave flux.

Derived parameters include atmospheric temperature and humidity profiles, surface temperature, land skin surface temperature, cloud-top heights, cloud type, and ozone retrieval.

AIRS is designed to meet the NOAA requirement of a high-resolution infrared sounder to fly on future operational weather satellites. The AIRS instrument characteristics are:

- Spatial resolution: 13.5 km horizontal at nadir<br>1 km vertical
- Swath: 1650 km (+/- 49.5 degrees cross-track)
- Absolute accuracy: 1 K temperature retrieval<br>0.05 emissivity accuracy.

- Spectral resolution: 2300 spectral channels, lambda/delta-lambda of 1200
- Signal to noise: >500 at 1 km resolution

| Spectral Range micron | Vertical Resolution km | Horizontal Resolution km | Primary Application |
|---|---|---|---|
| 0.4 - 1.0 | 1 | 13.5 | Temperature and moisture profiles |
| 3.74 - 4.61 | 1 | 13.5 | Temperature and moisture profiles |
| 6.20 - 8.22 | 1 | 13.5 | Temperature and moisture profiles |
| 8.80 - 15.5 | 1 | 13.5 | Temperature and moisture profiles |

Table B-1: AIRS Instrument Parameters.

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**AMSU:**

AMSU stands for Advanced Microwave Sounding Unit. It is a passive microwave radiometer that measures atmospheric temperature. AMSU was designed primarily to obtain temperature profiles from the surface to 45 km and to provide atmospheric water vapor/ precipitation estimates, and to provide cloud-filtering capability for tropospheric observations. Scientific data expected to be derived from AMSU include:

- Cloud thermodynamic phase (ice/water)
- cloud water content.
- Sea-ice cover (old/new) and
- ocean surface (scalar) wind speed.

AMSU will first fly on operational NOAA satellites in the mid- 1990's. The instrument characteristics are:

- Swath: 1650 km (+/- 49.5 degrees cross-track)

| Center Frequency GHz | Spatial Resolution km | Primary Application |
|---|---|---|
| 23.8 | 40 horizontal at nadir | Water vapor burden |
| 31.4 | 40 horizontal at nadir | Rain detection |
| 50.3 | 40 horizontal at nadir | Surface temperature |
| 52.8 | 40 horizontal at nadir | Surface temperature |
| 53.33 | 40 horizontal at nadir | Tropospheric temperature |
| 54.40 | 40 horizontal at nadir | Tropospheric temperature |
| 54.94 | 40 horizontal at nadir | Tropospheric temperature |
| 55.50 | 40 horizontal at nadir | Tropospheric temperature |
| 57.29 | 40 horizontal at nadir | Stratospheric temperature |
| 57.29 +/- 0.217 | 40 horizontal at nadir | Stratospheric temperature |
| 57.29 +/- 0.048 | 40 horizontal at nadir | Stratospheric temperature |
| 57.29 +/- 0.022 | 40 horizontal at nadir | Stratospheric temperature |
| 57.29 +/- 0.010 | 40 horizontal at nadir | Stratospheric temperature |
| 57.29 +/- 0.0045 | 40 horizontal at nadir | Stratospheric temperature |
| 89.0 | 40 horizontal at nadir | Cloud top, snow indicator |

Table B-2: AMSU Instrument Parameters.

**AIRS and AMSU Combined:**

AIRS and AMSU form a single facility instrument program, and will produce some data products jointly. Scientific data that may be derived collectively from AIRS and AMSU include:

- Atmospheric temperature profile, humidity profile, total precipitable water, fractional cloud cover, cloud top height, and cloud top temperature
- Land skin surface temperature, day and night land surface temperature differences.
- Ocean skin surface temperature

**AMSR-E:**

AMSR-E stands for Advanced Microwave Scanning Radiometer-E. It is a passive microwave radiometer supplied by the National Space Development Agency of Japan(NASDA).

The AMSR-E science objectives are to measure precipitation rates, cloud water, water vapor, sea-surface temperatures, sea ice and snow cover, sea-surface winds, and soil moisture. Scientific data expected to be derived from AMSR-E include:

- Precipitation

- Soil moisture
- Global ice and snow cover
- Sea surface temperature and wind speed
- Atmospheric cloud water, and
- Atmospheric water vapor content

The instrument characteristics are:

- Swath: 1250 km
- Radiometric stability: 0.2 - 0.7 K
- Absolute accuracy: 1 - 1.5 K

| Center Frequency, GHz (both polarizations) | Spatial Resolution km | Primary Application |
|---|---|---|
| 6.9 | 59 x 35 | Sea Surface Temperature |
| 10.7 | 39 x 23 | Sea wind speed |
| 18.7 | 22 x 13 | Ocean cloud water, Oceanic water vapor |
| 23.8 | 25 x 15 | Ocean cloud water, Oceanic water vapor |
| 36.5 | 12 x 7 | Precipitation |
| 89.0 | 5 x 3 | Precipitation |

Table B-3: AMSU Instrument Parameters.

**CERES:**

CERES stands for Clouds and Earth's Radiant Energy System. CERES uses thermistor bolometers to measure shortwave and longwave infrared radiation. Early flights (AM-1 and PM-1) will fly two CERES instruments, one scanning cross-track, to continue the ERBE measurements, and the other capable of biaxial scanning to provide angular flux information. Later flights (AM-2, AM-3, PM-2, and PM-3) will fly single scanners operating primarily in the cross-track mode.

The CERES science objectives are to generate data products that provide cloud-radiative and forcing inputs to the climate system models, and observations baseline of clear-sky radiative fluxes and radiative input to atmospheric and ocean energy models. Scientific data expected to be derived from CERES include:

- Cloud area coverage
- Cloud altitude
- Cloud liquid water content
- Cloud shortwave and longwave optical depths

The CERES instruments build upon ERBE experience and will extend ERBE's long-term record of the Earth's radiation budget. The characteristics of the CERES instruments are:

- Swath: limb to limb (78 degrees cross-track, 360 degrees azimuth)

| Center Wavelength microns | Spatial Resolution km | Primary Application |
|---|---|---|
| 0.3 to > 50 | 21 at nadir | Earth's radiation budget |
| 0.3 - 5 | 21 at nadir | Earth's radiation budget |
| 8 - 12 | 21 at nadir | Earth's radiation budget |

Table B-4: CERES Instrument Parameters.

**HSB:**

HSB stands for the Humidity Sounder from Brazil. It is a passive, multichannel microwave radiometer, and it replaces the Microwave Humidity Sounder. Presumed characteristics are:

- Swath: 1,650 km (+/- 49.5 degrees)

| Center Frequency GHz | Spatial Resolution km | Primary Application |
|---|---|---|
| 89 | 13.5 at nadir | Precipitation |
| 166 | 13.5 at nadir | Temperature moisture profiles |
| 183.3 | 13.5 at nadir | Temperature moisture profiles |
| 183.3 | 13.5 at nadir | Temperature moisture profiles |
| 183.3 | 13.5 at nadir | Temperature moisture profiles |

Table B-5: HSB Instrument Parameters.

**MODIS:**

MODIS stands for the MODerate-Resolution Imaging Spectroradiometer. It employs a conventional imaging radiometer concept, consisting of a cross-track scan mirror, collecting optics, and a set of linear detector arrays with spectral interference filters located in 4 focal planes.

MODIS is designed to measure biological and physical processes on a global basis every 1 to 2 days. Scientific data expected to be derived from MODIS include:

- surface temperatures with 1 km resolution, day and night, with absolute accuracy of 0.2 K for oceans and 0.1 K for land.

- Ocean color, defined as ocean-leaving spectral radiance within 5% from 415 to 653 nm, based on adequate atmospheric correction from near-infrared sensor channels.

- Chlorophyll fluorescence within 50% at surface water concentrations of 0.5 $mg/m^3$.

- Concentration of chlorophyll alpha within 35%.

- Vegetation/land surface cover, condition, 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 reflectance.

- Cloud cover with 250 m resolution by day and 1000 m resolution by 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.

- Fire occurrence, size, and temperature.

- Global distribution of total precipitable water.

MODIS derives from AVHRR, HIRS, Landsat Thematic Mapper, and Nimbus-7 Coastal Zone Color Scanner heritage. The MODIS data products shall be better, or at least equivalent in all respects to, the same or similar products derived from these predecessor instruments. The instrument parameters follow:

- Swath: 2300 km (+/-55 degrees cross-track)

- Signal to noise: >500 at 1 km resolution

- Absolute accuracy: 5% for wavelengths > 3 micrometers<br>1% for wavelengths < 3 micrometers.

| Channel | Spectral Range micron | Spatial Resolution | Primary Application |
|---|---|---|---|
| 1 | 0.620-0.670 | 0.25 km | Land/cloud boundaries |
| 2 | 0.841-0.876 | 0.25 km | Land/cloud boundaries |
| 3 | 0.459-0.479 | 0.5 km | Land/cloud boundaries |
| 4 | 0.545-0.565 | 0.5 km | Land/cloud boundaries |
| 5 | 1.230-1.250 | 0.5 km | Land/cloud boundaries |
| 6 | 1.628-1.652 | 0.5 km | Land/cloud boundaries |
| 7 | 2.105-2.155 | 0.5 km | Land/cloud boundaries |
| 8 | 0.405-0.420 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 9 | 0.438-0.448 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 10 | 0.483-0.493 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 11 | 0.526-0.536 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 12 | 0.546-0.556 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 13 | 0.662-0.672 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 14 | 0.673-0.683 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 15 | 0.743-0.753 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 16 | 0.863-0.877 | 1 km | Ocean Color/Phytoplankton/Biogeochemistry |
| 17 | 0.890-0.920 | 1 km | Atmospheric water vapor |
| 18 | 0.931-0.941 | 1 km | Atmospheric water vapor |
| 19 | 0.915-0.965 | 1 km | Atmospheric water vapor |
| 20 | 3.66-3.84 | 1 km | Surface/cloud temperature |
| 21 | 3.929-3.989 | 1 km | Surface/cloud temperature |
| 22 | 3.929-3.989 | 1 km | Surface/cloud temperature |
| 23 | 4.02-4.08 | 1 km | Surface/cloud temperature |
| 24 | 4.433-4.498 | 1 km | Atmospheric temperature |
| 25 | 4.482-4.549 | 1 km | Atmospheric temperature |
| 26 | 1.36-1.39 | 1 km | Cirrus cloud |
| 27 | 6.535-6.895 | 1 km | Water vapor |
| 28 | 7.175-7.475 | 1 km | Water vapor |
| 29 | 8.400-8.700 | 1 km | Water vapor |
| 30 | 9.580-9.880 | 1 km | Ozone |
| 31 | 10.780-11.280 | 1 km | Surface/cloud temperature |
| 32 | 11.770-12.270 | 1 km | Surface/cloud temperature |
| 33 | 13.185-13.485 | 1 km | Cloud top temperature |
| 34 | 13.485-13.785 | 1 km | Cloud top temperature |
| 35 | 13.785-14.085 | 1 km | Cloud top temperature |
| 36 | 14.085-14.385 | 1 km | Cloud top temperature |

Table B-5: MODIS Instrument Parameters.

## APPENDIX C:

## PROJECTED DIRECT BROADCAST SERVICE USERS

The following institutions and/or countries have expressed a serious interest in receiving OES direct Broadcast data (* are latitudes and longitudes estimated from maps):

| Country | City, State | Institution | Latitude | Longitude |
|---|---|---|---|---|
| Australia | Alice Springs | Australian Met. Office | S 23.5* | E 134* |
| Australia | Hobart, Tasmania | Australian Met. Office | S 43* | E 147* |
| Brazil | Alcantara | INPE | S 2.34 | W 44.40 |
| Brazil | Ciuaba | INPE | S 15.55 | W 56.1 |
| China | TBD #1 | TBD #1 | | |
| China | TBD #2 | TBD #2 | | |
| Europe | TBD #1 | TBD #1 | | |
| Europe | TBD #2 | TBD #2 | | |
| Japan | Hatoyama | NASDA | N 36.00 | E 139.33 |
| Korea | TBD | TBD | | |
| USA | Greenbelt, MD | NASA/GSFC | N 39.1* | W 76.8* |
| USA | Honolulu, HA | U. of Hawaii | N 21.32 | W 157.88 |
| USA | La Jolla, CA | Scripps Inst. of Oceanography | N 32.867 | W 117.258 |
| USA | Lawrence, KS | U. of Kansas | N 39* | W 95* |
| USA | Madison, WI | U. of Wisconsin | N 43* | W 89.4* |

Table C-1: Anticipated Sites of Direct Broadcast Ground Stations.