N92-12429 578864

THE MODERATE RESOLUTION IMAGING SPECTROMETER: AN EOS FACILITY INSTRUMENT CANDIDATE FOR APPLICATION OF DATA COMPRESSION METHODS

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Abstract. The Moderate Resolution Imaging Spectrometer (MODIS) observing facility will operate on the Earth Observing System (EOS) in the late 1990's. It estimated that this observing facility will produce over 200 gigabytes of data per day requiring a storage capability of just over 300 gigabytes per day. Archiving, browsing, and distributing the data associated with MODIS represents a rich opportunity for testing and applying both lossless and lossy data compression methods.

1. Introduction

MODIS is a multispectral imaging system to be flown on the EOS in the late 1990's. The capability of the MODIS instrument derives from and expands upon some instruments that have been successfully flown on spacecraft or aircraft and used for many years to observe properties of the earth-atmosphere system and to develop data bases for studies of global change. These instruments are the Advanced Very High Resolution Radiometer (AVHRR) and the High Resolution Infrared Sounder (HIRS) being currently flown on the NOAA operational meteorological satellites, the Coastal Zone Color Scanner (CZCS) flown on the Nimbus-7, the Landsat Thematic Mapper, and various aircraft scanners.

The MODIS system will be composed of two cross-track scanning instruments. One instrument is called MODIS-N (nadir), indicating a multispectral scanner that will not be tilted and provide a continuous cross-track scan. The other instrument is called MODIS-T (tilt), indicating a scanner that will allow the cross-track scan to be tilted 50° fore and aft. The MODIS-N will have 36 spectral bands covering spectral bands in the visible, near-infrared (0.7-1 microns), the short-wave infrared (1-3 microns), and the thermal infrared (3-15 microns). Tables 1 and 2 summarize MODIS-N and Table 3 summarizes MODIS-T. The purposes of the bands in Table 2 are only indicative and not complete. Further details concerning MODIS-T and MODIS-N instrumentation are given in Salomonson [2] and Magner and Salomonson [1].

Data volume coming from the MODIS observing facility will be on the order of a terabit of data per day depending upon the total time the instruments are on and the amount of ancillary information acquired concerning spacecraft attitude, etc. It is quite appropriate, therefore, to consider the MODIS as a case study for data compression methods that would reduce the volume of data involved for archiving, distribution, and analysis. This paper will describe in more quantitative detail the volumes and rates of data associated with the MODIS. The objective of this discussion is to provide those interested in applying data compression methods to MODIS, as a relevant and challenging example, with particulars that should help in assessing the magnitude and complexities of the task.

2. MODIS Data Volumes and Rates

In the broadest sense, it is envisioned that data compression methods might be most appropriately applied to MODIS data for the purposes of data storage, data distribution, providing a browsing capability, or facilitating the direct broadcast of MODIS data to terminals on the ground where only a subset or specific parameter of the data is needed or where reduced data volume or rate is needed in order to be compatible with limited receiving or processing capabilities. It is assumed in this paper that all information for MODIS must be retained in processing, at least through level 1, if not to level 2. The reason for being resolute with regard to the level 1 data processing is that from these data are derived all level 2 products. The level 2 products, of which there will be as many as 100, must utilize all the radiometric and calibration fidelity in level 1. Even in the storage of MODIS data, particularly in the case of level 1, all information must be retained. This, therefore, indicates that only lossless data compression methods should be applied to data storage for level 1, and perhaps level 2 and above. Lossy data compression methods are deemed, at this point in the author's understanding, appropriate for producing browse data or for very specific applications wherein the loss of information can be tolerated.

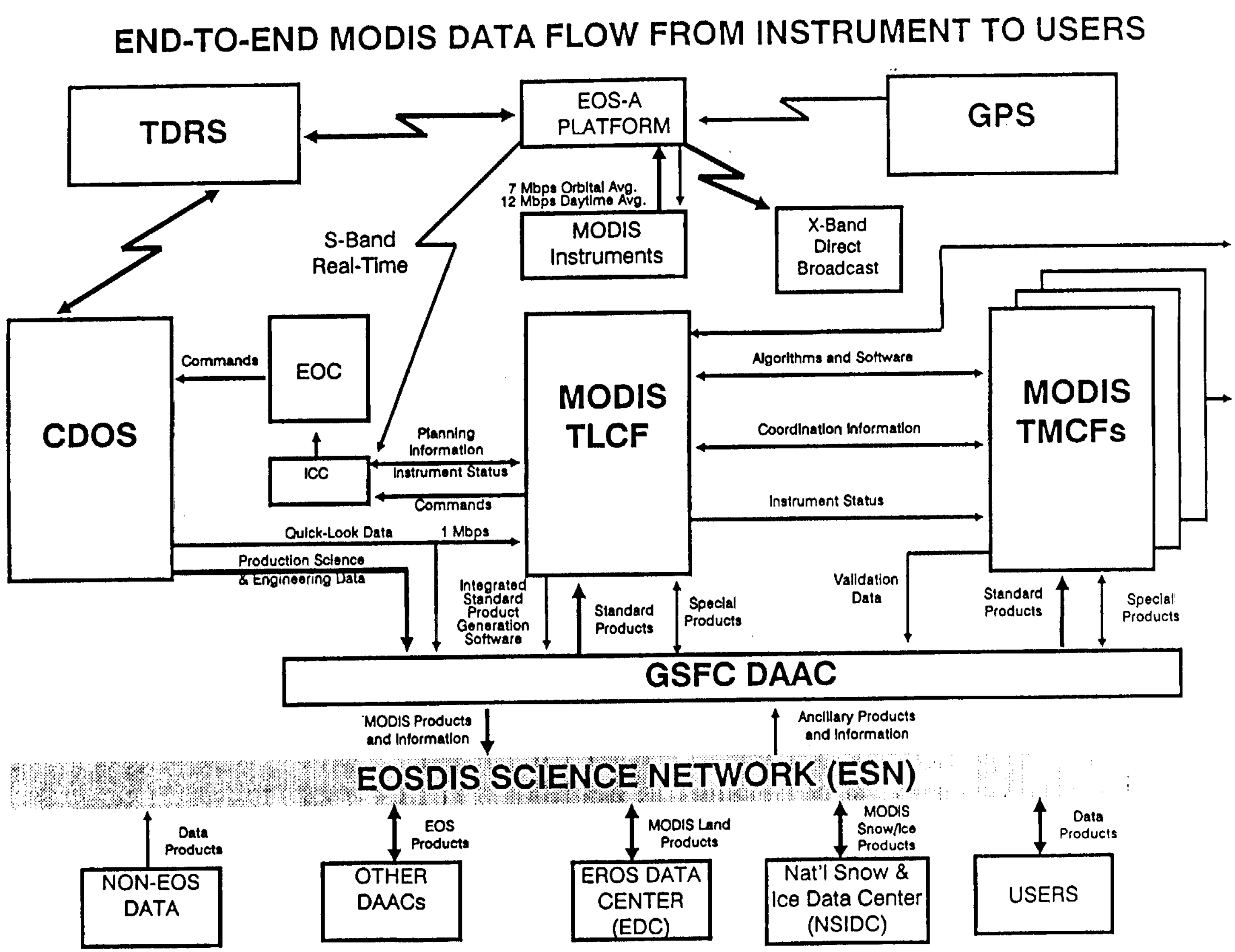
Figure 1 depicts the overall data flow for the MODIS. This figure shows that MODIS data will flow from the EOS platform through the Tracking and Data Relay Satellite (TDRS) to the Customer and Data Operations Systems (CDOS) and into the Goddard Space Flight Center (GSFC) Distributed Active Archive Center (DAAC). In the DAAC, data will be processed after algorithms have been developed and checked for accuracy and quality by the MODIS Science Team Members using the several and distributed Team Member Computing Facilities (TMCF's) and the MODIS Team Leader Computing Facility (TLCF). When products are produced in the appropriate DAAC, they will be archived and distributed to the scientific community and any part of the public at large that desires to use MODIS data. The distribution of the data will occur through the EOS Data and Information System (EOSDIS) electronic network that exists when MODIS becomes operational.

As further detail, Table 4 shows specifics concerning calculated data rates and volumes associated with MODIS-N and -T. In this table, it is worth noting that the 13th bit for MODIS-T data is only included to flag the gain used in sending MODIS-T data to the ground (see [1]). In going from level 1A (calibration and navigation information provided in the header, but not applied) to level 1B (calibration information data applied and pixel location available), the increased volume is due principally to converting the 12-bit information to 16 bits and adding navigation, calibration, and browse information.

Table 5 shows the archiving requirements in gigabytes per day for MODIS-N and -T. These are rough estimates based on preliminary estimates using existing or planned algorithms for the principal products to be derived from the MODIS. In many cases these estimates are based upon experience from the heritage instruments indicated in the Introduction. From a similar perspective, the expected lines of code estimates shown in Table 6 have been derived. In general, the bulk of the effort for producing lines of code and storing the results falls in producing at-satellite radiances (levels 1A and 1B) and in producing water leaving and land leaving radiances.

Table 7 shows the estimated load on the data distribution system in providing MODIS data to other DAAC's in the EOSDIS. The other main DAAC, besides the GSFC DAAC, is at the EROS Data Center (EDC) in Sioux Falls, South Dakota. At the EDC, all level 2 products produced over land areas will be archived and all level 3 land products will be produced and distributed from the EDC. Other key DAAC's are at the Langley Research Center in Virginia and the National Snow and Ice Data Center in Boulder, Colorado. The assumptions as to the fraction of MODIS data that will go to these DAAC's is provided in the third column of Table 7.

With regard to direct broadcast of MODIS data and the volume of MODIS browse data, the following statements are provided. For direct broadcast it has been assumed that 100 percent of the raw data would be involved, but, in this instance, on-board data compression techniques could be examined. If such an approach is to be used, however, that must be decided soon (i.e., in a year or 2) in order for it to be implemented with the instrument or on the EOS spacecraft. The situations surrounding direct broadcast from the EOS are relatively undefined, but one may assume that a 15 megabit direct broadcast link will be available to be shared among the instruments. MODIS, of course, has the potential for occupying a large share of this capability unless data compression is applied appropriately. In the case of browse data, by assuming that browse data will be comprised of 5 percent of levels 1B, 2, and 3,



TDRS
EOS-A PLATFORM
GPS
7 Mbps Orbital Avg.
12 Mbps Daytime Avg.
MODIS Instruments
X-Band Direct Broadcast
S-Band Real-Time
CDOS
Commands
EOC
ICC
Planning Information
Instrument Status
Commands
Quick-Look Data
1 Mbps
Production Science & Engineering Data
MODIS TLCF
Algorithms and Software
Coordination Information
Instrument Status
MODIS TMCFs
Integrated Standard Product Generation Software
Standard Products
Special Products
Validation Data
Standard Products
Special Products
GSFC DAAC
MODIS Products and Information
Ancillary Products and Information
EOSDIS SCIENCE NETWORK (ESN)
Data Products
NON-EOS DATA
EOS Products
OTHER DAACs
MODIS Land Products
EROS DATA CENTER (EDC)
MODIS Snow/Ice Products
Nat'l Snow & Ice Data Center (NSIDC)
Data Products
USERS

FIGURE 1

resulting in an estimate of about 12 gigabytes of data per day. Browse data is a prime candidate for applying lossy compression methods.

In the case of archiving MODIS data, it has already been indicated that no information should be lost in archiving the data. However, lossless compression methods could, and perhaps should, be applied that allow the progressive extraction of archived data at various levels of accuracy depending upon the amount of information actually needed. This means that if the data are compressed appropriately, one could access the archive and extract first-order information. If this initial extraction indicates further information is needed, another pass through the compressed archive could result in higher-order information. Ultimately it appears that data compression methods are available for archived data wherein the complete information available in the original data stream ultimately could be retrieved.

3. Summary and Conclusions

The MODIS provides a rich opportunity for applying data compression methods for archiving, browsing, and distribution. Lossless methods should be developed for archiving that allow eventual extraction of all the information contained in the MODIS. Lossy methods can very appropriately be applied in order to browse MODIS data and distribute it for quick-look analyses. The challenges include costs of developing and applying data compression methods including associated hardware costs, the availability of off-the-shelf versus special purpose hardware and software, demonstrating reliability and low risk of losing information for lossless methods plus, in many cases, making the application of data compression transparent to the average user.

Acknowledgments

The author wishes to acknowledge the assistance of Dr. A. Fleig, Dr. D. Han, and members of the Research and Data Systems Corporation (RDC) staff for developing the tables and figure in this paper. Kelly Pecnick prepared the final drafts of the paper. Her help and expertise are very much appreciated.

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[2] Salomonson, V. V., 1991: Execution Phase (C/D) Spectral Band Characteristics of the EOS Moderate Resolution Imaging Spectrometer-Nadir (MODIS-N) Facility Instrument. *Advances in Space Research*, Vol. 3, pp. 231-236.

TABLE 1

MODIS-Nadir (N) Summary

PARAMETERS	DESIGN SPECIFICATIONS OR EXPECTED PERFORMANCE
PLATFORM ALTITUDE	705 KM
IFOV (no. of bands @ IFOV)	29 @ 1000 M 5 @ 500 M 2 @ 250 M
SWATH	110 DEG/2330 KM
SPECTRAL BANDS	36 BANDS TOTAL (19/0.4-3.0 μm; 17/3-15 μm)
RADIOMETRIC ACCURACY	5% ABSOLUTE, < 3 μm 1% ABSOLUTE, > 3 μm (possibly < 0.3%) 2% REFLECTANCE
QUANTIZATION	12 BIT
POLARIZATION SENSITIVITY	2% MAX, < 2.2 μm
MODULATION TRANSFER FUNCTION	0.3 AT NYQUIST
S/N PERFORMANCE (70 DEGREE SOLAR ZENITH/OCEANS)	830:1 (443 nm) 745:1 (520 nm) 503:1 (865 nm)
NEDT PERFORMANCE (THERMAL BANDS) @ 300 DEG K/WINDOW BANDS	LESS THAN 0.05
SCAN EFFICIENCY	(TO BE DETERMINED)
INTEGRATION TIME	(TO BE DETERMINED)
SIZE (APPROX)	1 X 1.6 X 1 M
WEIGHT	APPROX 200 kg
POWER	250 w
PEAK DATA RATE	11 MBS (daytime)
DUTY CYCLE	100%

TABLE 2

MODIS-N Bands

BAND	CENTER *	IFOV (m)	WIDTH	PURPOSE
	LAND AND CLOUD BOUNDARIES BANDS			
1	659	250	50	VEG CHLOROPHYLL ABS
				LAND COVER TRANS.
2	865	250	40	CLOUD AND VEGETATION
				LAND COVER TRANSF.
	LAND AND CLOUD PROPERTIES BANDS			
3	470	500	20	SOIL, VEG DIFFRNCS
4	555	500	20	GREEN VEGETATION
5	1240	500	20	LEAF/CANOPY PROPRTIES
6	1640	500	20	SNOW/CLOUD DIFFRNCES
7	2130	500	50	LAND & CLOUD PROPRTIES
	OCEAN COLOR BANDS			
8	415	1000	15	CHLOROPHYLL
9	443	1000	10	CHLOROPHYLL
10	490	1000	10	CHLOROPHYLL
11	531	1000	10	CHLOROPHYLL
12	565	1000	10	SEDIMENTS
13	653	1000	15	SEDIMENTS, ATMOSPHERE
14	681	1000	10	CHLOR. FLUORESCENCE
15	750	1000	10	AEROSOL PROPERTIES
16	865	1000	15	AEROSOL/ATM PRPRTS
	ATMOSPHERE/CLOUD BANDS			
17	905	1000	30	CLOUD/ATM PROPERTIES
18	936	1000	10	CLOUD/ATM PROPERTIES
19	940	1000	50	CLOUD/ATM PROPERTIES
	THERMAL BANDS			
20	3.75	1000	0.18	SEA SURFACE TEMP
21	3.75	1000	0.05	FOREST FIRES/VOLCANOES
22	3.96	1000	0.05	CLOUD/SFC TEMPERATURE
23	4.05	1000	0.05	CLOUD/SFC TEMPERATURE
24	4.47	1000	0.05	TROP TEMP/CLD FRACTION
25	4.52	1000	0.05	TROP TEMP/CLD FRACTION
26	4.57	1000	0.05	TROP TEMP/CLD FRACTION
27	6.72	1000	0.36	MID-TROP HUMIDITY
28	7.33	1000	0.30	UPPER-TROP HUMIDITY
29	8.55	1000	0.30	SFC TEMPERATURE
30	9.73	1000	0.30	TOTAL OZONE
31	11.03	1000	0.50	CLOUD/SFC TEMPERATURE
32	12.02	1000	0.50	CLOUD/SFC TEMPERATURE
33	13.34	1000	0.30	CLD HEIGHT & FRACTION
34	13.64	1000	0.30	CLD HEIGHT & FRACTION
35	13.94	1000	0.30	CLD HEIGHT & FRACTION
36	14.24	1000	0.30	CLD HEIGHT & FRACTION

* BAND CENTER AND BANDWIDTH ARE IN NANOMETERS FOR BANDS 1-19 AND MICROMETERS FOR BANDS 20-36

TABLE 3

MODIS-Tilt (T) Summary

PARAMETERS	DESIGN SPECIFICATIONS OR EXPECTED PERFORMANCE
PLATFORM ALTITUDE	705 KM
IFOV	1.4 MRAD (1.1 KM)
SWATH	90 DEG/1500 KM
SPECTRAL BANDS (10-15 nm WIDTH)	32 (400-880 nm.) (AREA ARRAY)
DYNAMIC RANGE	Lmax 95% @ 22.5 deg solar zenith angle
RADIOMETRIC ACCURACY	5% absolute 2% relative to the sun
QUANTIZATION	12 BIT
POLARIZATION SENSITIVITY	<2.3 % (< 20 deg tilt)
MODULATION TRANSFER FUNCTION	0.3 AT NYQUIST
S/N PERFORMANCE (SPEC) (70 DEGREE SOLAR ZENITH)	835:1(440 nm) 685:1(625 nm) 400:1(845 nm)
NEDT PERFORMANCE (THERMAL BANDS)	N/A
SCAN EFFICIENCY	25 %
INTEGRATION TIME MODE)	1.127 MSEC (COMPOSITE
COLLECTING APERTURE (DIA)	34 MM
SIZE (APPROX)	75 X 140 X 100 cm
WEIGHT	~170 kg
POWER	~130 w
PEAK DATA RATE	~3 mbps (day)
DUTY CYCLE	DAYTIME/100%

TABLE 4

MODIS-N and MODIS-T Data Rate and Volume Estimates

Earth Radius (km)	6371
Satellite Altitude (km)	705
Orbital Period (min)	98.9
Modis-N # 1000 m REF channels	12
Modis-N # 500 m REF channels	3
Modis-N # 250 m REF channels	2
Modis-N # 1000 m TIR channels	17
Modis-N # 500 m NIR channels (1.6, 2.1 nm)	2
Modis-T # 1.1 km REF channels	32
MODIS-N # bits/REF channel	12
MODIS-N # bits/TIR channel	12
MODIS-T # bits/REF channel	13
MODIS-N REF Duty Cycle	50%
MODIS-N TIR Duty Cycle	100%
MODIS-T REF Duty Cycle	45%
MODIS-N # Along-track IFOVs	8
MODIS-T # Along-track IFOVs	30
MODIS-N # Detectors	648
MODIS-T # Along-track detectors	30
MODIS-N # Maximum scan angle (deg)	55
MODIS-T # Maximum scan angle (deg)	45
MODIS-N # IFOV FWHM (deg)	8.13E-02
MODIS-T # IFOV FWHM (deg)	8.94E-02
MODIS-N # pixels along-scan/on-Earth	1354
MODIS-T # pixels along-scan/on-Earth	1007
MODIS-N Scan Period (sec)	1.2
MODIS-T Scan Period (sec)	4.6
MODIS-N VIS Data (megabits/scan)	7.3
MODIS-N TIR Data (megabits/scan)	3.2
MODIS-N Daytime Data (megabits/scan)	10.5
MODIS-T Daytime Data (megabits/scan)	12.6
MODIS-N # Scans/Orbit	5000
MODIS-T # Scans/Orbit	579
MODIS-N Daytime Data Rate (mbps)	8.9
MODIS-N Nighttime Data Rate (mbps)	2.7
MODIS-T Daytime Data Rate (mbps)	2.7
MODIS-N Orbital Ave Data Rate (mbps)	5.8
MODIS-T Orbital Ave Data Rate (mbps)	1.2
MODIS-N Daily Data Volume (gigabytes)	62.6
MODIS-T Daily Data Volume (gigabytes)	13.1
Total Daily Data Volume (gigabytes)	75.8
MODIS-N Volume (gigabytes) Level-1A	65.8
MODIS-T Volume (gigabytes) Level-1A	13.8
Total Daily Volume (gigabytes) @1A	79.6
MODIS-N Volume (gigabytes) Level-1B	113.6
MODIS-T Volume (gigabytes) Level-1B	23.1
Total Daily Volume (gigabytes) @1B	136.7
Total Daily Volume (gigabytes) @1A&1B	216.3

TABLE 5

MODIS Long-Term Archive Storage Requirements
(Gigabytes Per Day)

DATA PRODUCT	PRODUCT LEVEL 1A	1B	2/T	2/N	3	TOTAL
Navigation		18.7				18.7
Calibration		6.8				6.8
Spacecraft Ancillary	4.3					4.3
At-Satellite Radiances	75.3	104.7				180.0
Water-Leaving Radiances			10.1	4.0	6.6	20.7
Single Scattering Aerosol Radiances			8.2	2.6		10.9
Angstrom Exponents			0.3	0.4		0.8
Chlorophyll-A Concentrations (Case 1)			0.3	0.4	0.2	1.0
Chlorophyll-A Concentrations (Case 2)			0.0	0.0	0.2	0.3
Chlorophyll-A Fluorescence			0.3	0.4	0.2	1.0
CZCS Pigment Concentrations			0.3	0.4	0.2	1.0
Sea-Surface Temperature				1.1	0.2	1.3
Sea-Ice Cover				0.1	0.1	0.2
Attenuation at 490 nm			0.3	0.4	0.2	1.0
Detached Coccolith Concentration			0.1	0.1	0.2	0.5
Phycoerythrin Concentrations			0.3		0.2	0.5
Dissolved Organic Matter			0.3	0.4	0.2	1.0
Suspended Solids			0.3	0.4	0.2	1.0
Glint Field			0.3	0.4	0.2	1.0
IPAR			0.1	0.1	0.1	0.2
Ocean Cal Data Sets						0
Primary Production (Oceans)			0.3	0.4	0.2	1.0
Land-Leaving Radiances			2.7	14.4	2.8	20.0
Topographically Corrected Radiance			2.7	14.4	2.8	20.0
Vegetation Index				3.8	1.7	5.5
Polarized Vegetation Index				3.8	1.7	5.5
Land Surface Temperature				0.5	0.2	0.6
Thermal Anomalies				0.5		0.5
Evapotranspiration					0.1	0.1
Primary Production (Land)					0.1	0.1
Snow Cover				0.2	0.0	0.2
Spacial Heterogeneity (not sized here)						0
Land Cover Type					0.0	0.0
Bidirectional Reflectance, BRDF					0.0	0.0
Cloud Mask			0.3	1.6		1.9
Cloud Fraction					0.0	0.0
Cloud Effective Emissivity				0.1	0.0	0.1
Cloud-Top Temperature and Pressure				0.3	0.0	0.3
Cloud Optical Thickness (0.66 fm)				0.1	0.0	0.1
Cloud Particle Effective Radius				0.1	0.0	0.1
Cloud Particle Thermodynamic Phase				0.0	0.0	0.0
Aerosol Optical Depth (0.41 to 2.13fm)					0.0	0.0
Aerosol Size Distribution					0.0	0.0
Aerosol Mass Loading					0.0	0.0
Atmospheric Stability				0.1	0.0	0.1
Total Precipitable Water				1.7	0.0	1.7
Total Ozone				0.1	0.0	0.1
Browse		6.5	1.4	2.7	1.0	5.0
Metadata (Not sized here)						0
Ocean Discipline Subtotal (L-2/3)			21.8	12.1	9.5	43.4
Land Discipline Subtotal (L-2/3)			5.4	37.6	9.5	52.5
Atmosphere Discipline Subtotal (L-2/3)			0.3	4.0	0.0	4.3
Total	79.6	136.7	28.9	56.4	20.0	315.0

TABLE 6

Estimated MODIS Data Processing Requirements
(Lines of Code)

PROCESSING LEVEL	LAUNCH LOC	GROWTH LOC
Level-1A	25,000	25,000
Level-1B	25,000	30,000
Calibration/Monitor	72,000	144,000
Level-2 Ocean	12,000	24,000
Level-2 Land	40,000	80,000
Level-2 Atmosphere	20,000	40,000
Level-2 Shell	30,000	30,000
Level-2 Utility	40,000	80,000
Level-2 IDS Products	36,000	72,000
Level-3	30,000	60,000
Near-Real-Time	17,800	81,500
Subtotal	347,800	666,500
Supporting Software (validation)		552,000
Total		1,218,500

TABLE 7

MODIS Data Distribution
(Gigabytes Per Day)

FROM	TO	DATA DESCRIPTION	DATA VOLUME
CDOS	GSFC	All Level-0 Products	76
GSFC	MODIS Investigators	10% of Level-1A Products 50% of Level-1B Products 100% of Level-2 Products 100% of Level-3 Products	182
GSFC	Other Investigators	5% of Level-1B Products 10% of Level-2 Products 10% of Level-3 Products	17
GSFC	EDC	Level-1B for Land Products	41
GSFC	Langley Research Center	100% of Level-1B Products	137
GSFC	National Snow and Ice Data Center (NSIDC)	Level-1B for Snow and Ice Products	4

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