MODIS DATA SYSTEM STUDY

TEAM PRESENTATION

February 3, 1989

AGENDA

1. Sample Data Requirements Document Entries
2. Methods of Monitoring the MODIS Instrument in the MIDACS
3. On-Board MODIS Processing and Packetization
4. Complexity and Scope of MODIS Metadata

DHC-DATA-REQUEST

1. DESCRIPTION:

Definition: Request to redesignate packet handling and processing priorities.

Purpose: To route image data for selected spectral channels to the ICC as needed to support instrument monitoring and to designate selected data for special handling as required to support field experiments.

Generation Process: ICC requests will be generated at the ICC in response to operator requests to display selected spectral channels. Required field experiment support will be designated by the experimenter.

2. PATH:

Source: ICC

Recipient: DHC

Medium: Low-rate data link

3. REQUIREMENTS:

Input Data: Operator decision on which spectral channels to display; experimenter decision on usefulness of MODIS satellite data.

Quality: Accuracy of ICC request not critical, accuracy may be much more important to field experimenter since operational decisions may depend on MODIS information.

Timeliness: Response to ICC requests should be nearly instantaneous, field experiments are normally planned months in advance. Redesign of the experiment or correction of previous errors may be time-critical for a field experimenter.

Completeness: An ICC operator can easily redesignate data to be selected if his previous selection was not what was needed or wanted. An experimenter will need to be certain that he requests all data that is potentially useful to him.

Other:

4. ATTRIBUTES:

Resolution and Coverage: Any MODIS data packet with a distinct APPLICATION PROCESS ID can be selected for revised routing. Also, if needed, rerouting can be made effective for only a specific period of time, as when the satellite is over a target of particular interest.

Volume: The APPLICATION PROCESS ID contains 11 bits. If a begin time and end time are also designated with the request, each time designation will require approximately 56 additional bits.

Storage and Availability: Real-time and near-real-time requests will be stored at the DHC. Requests generated well in advance by an experimenter will be stored at the ICC.

Units, Scales, and Conversion Factors: Time will be stored in the designated CCSDS standard for time code formats.

Frequency of Update and Processing: Requests are updated at operator or experimenter initiative.

5. IMPACTS: Support from the DHC is an essential element of a responsive MIDACS.

DQA-REPORTS

1. DESCRIPTION:

Definition: Results of routine data quality assessment associated with data receipt and data product operations

Purpose: To provide Team Members with the results of automated CDHF quality checks run on MODIS instrument data

Generation Process: Generated at the CDHF using software supplied by the Team Members

2. PATH:

Source: CDHF

Recipient: TMCF

Medium: High-capacity data line

3. REQUIREMENTS:

Input Data: Level-0-Data, Near-Real-Time-Data, and Ancillary-Data from the DHC

Quality: Although quality of the data throughput is not critical, good data transmission quality is reasonable to expect and should be reasonably attainable.

Timeliness: Time constraints affecting transmission of this data are not critical except when a Team Member may be experimenting with or implementing a new quality algorithm. Prompt feedback in this situation would speed up the overall check-out process.

Completeness: During normal operations completeness is not a critical issue for this data link. As before, it is reasonable to expect that complete data sets will be transmitted.

Other:

4. ATTRIBUTES:

Resolution and Coverage: The resolution and coverage of this data product will be defined by the Team Members. Potentially applicable routines range all the way from broad routines that would provide a synopsis of large volumes of data to routines that would examine and report on minutia of received data.

Volume: The volume of this type of data can vary drastically depending on the philosophy of the implementing Team Member.

Storage and Availability: Selected elements of this data may be permanently stored with data products in the DADS. Data will not be routinely retained at the CDHF. It may be retained by a Team Member so long as he may find it useful to do so.

Units, Scales, and Conversion Factors: Some quality measures may use percentages of data meeting specified quality criteria. Perhaps other measures can be devised.

Frequency of Update and Processing: Routine checks will be applied to all incoming data. Other checks may be applied only to selected subsets of data.

5. IMPACTS: Product quality is, of course, an important criterion affecting the usefulness and validity of the whole MODIS effort.

PRODUCTION REPORT

1. DESCRIPTION:

Definition: Production-Schedule + Production-Status

Purpose: To provide users with the ability to track the production of expected MODIS-Data-Products

Generation Process: Generated by coordination between the ICC, which handles Data Acquisition Requests, and the CDHF, which is responsible for generating the data product.

2. PATH:

Source: CDHF

Recipient: IMC

Medium: Low-rate data lines

3. REQUIREMENTS:

Input Data: Mission-Planning-Information from the ICC, CDHF scheduling information.

Quality: Quality of this data item is not critical.

Timeliness: Timeliness of this data is also not critical. Reasonable timeliness should be achieved.

Completeness: Data should be sufficiently complete to allow a user to track the expected availability of a desired product.

Other:

4. ATTRIBUTES:

Resolution and Coverage: Information should cover all potential situations in which a user might need product availability information for planning purposes.

Volume: Reports may be updated twice daily. Reports may consist of a few pages of text describing processing presently underway and anticipated schedules for the generation of products during the next few days.

Storage and Availability: Reports will be retained by the IMC so long as they are current.

Units, Scales, and Conversion Factors: Textual information relating to schedules.

Frequency of Update and Processing: Updated perhaps twice daily.

5. IMPACTS: Supports the user.

AUTHORIZED-SCHEDULE-DATA

1. DESCRIPTION:

Definition: A schedule containing instrument resources and timeliness, that have been approved by the EMOC through iteration with the ICC.

Purpose: Final schedule-data approved for conversion into command loads by the ICC for uplink to MODIS.

Generation Process: Iteration by the ICC with the EMOC

2. PATH:

Source: EMOC

Recipient: ICC

Medium: Electronic

3. REQUIREMENTS:

Input Data: Schedule-Data from the MODIS and other instrument ICC to the EMOC for conflict resolution

Quality: N/A

Timeliness: N/A

Completeness: N/A

Other: N/A

4. ATTRIBUTES:

Resolution and Coverage: N/A

Volume: 1.68 MB/month

Storage and Availability

Units, Scales, and Conversion Factors: Time and Mnemonic

Frequency of Update and Processing: Weekly

5. IMPACTS: Without Authorized-Schedule-Data, command loads will not be generated.

AUTOMATED-COMMAND-SEQUENCES

1. DESCRIPTION:

Definition: A human readable sequence of commands generated by the planning and scheduling process and used for the generation of command loads.

Purpose: Used to generate the command loads

Generation Process: Output of the ICC planning and scheduling function.

2. PATH:

Source: Internal to the ICC

Recipient: Internal to the ICC

Medium: Electronic

3. REQUIREMENTS:

Input Data: Authorized-Schedule-Data

Quality: N/A

Timeliness: N/A

Completeness: N/A

Other: N/A

4. ATTRIBUTES:

Resolution and Coverage: N/A

Volume: 80 B per page, several pages possible

Storage and Availability: N/A

Units, Scales, and Conversion Factors: N/A

Frequency of Update and Processing: 1/week

5. IMPACTS: Necessary for the generation of command loads.

CANDIDATE-OBSERVATION-SEQUENCE

1. DESCRIPTION:

Definition: A human readable form of the instrument resources and timeliness necessary to perform the observation request. These data are sent to the EMOC for approval.

Purpose: To verify validity of commands with respect to platform resources.

Generation Process: Output of the ICC planning and scheduling process

2. PATH:

Source: ICC

Recipient: EMOC

Medium: Electronic

3. REQUIREMENTS:

Input Data: Data Acquisition Request (Observation Request) from the science team via the IST

Quality: N/A

Timeliness: N/A

Completeness: N/A

Other: N/A

4. ATTRIBUTES:

Resolution and Coverage: N/A

Volume: 1.68 MB per month

Storage and Availability: N/A

Units, Scales, and Conversion Factors: N/A

Frequency of Update and Processing: Once per week

5. IMPACTS: Necessary for planning data acquisition request made by the science team.

REFERENCE-MONITORING-PROFILE

1. DESCRIPTION:

Definition: Expected MODIS instrument engineering parameter levels annotated with limits at which alarm status should be declared.

Purpose: Used by the monitoring process in the ICC to ensure correct health and safety monitoring for implemented commands.

Generation Process: Output of the Planning and Scheduling process.

2. PATH:

Source: ICC

Recipient: ICC internal, CDHF, IST

Medium: Electronic

3. REQUIREMENTS:

Input Data: Automated-Schedule-Data and Observation-Resource-Requirements.

Quality: N/A

Timeliness: Possibly one day before command upload

Completeness: N/A

Other: N/A

4. ATTRIBUTES:

Resolution and Coverage: N/A

Volume: N/A

Storage and Availability: N/A

Units, Scales, and Conversion Factors: N/A

Frequency of Update and Processing: Before command uplinked

5. IMPACTS: Necessary for the correct monitoring process, and to identify the type of science data being collected.

RESOURCE-ENVELOPE

1. DESCRIPTION:

Definition: Maximum allowable resource consumption levels for the MODIS instrument.

Purpose: Used by the ICC to plan and schedule observation. Instrument thermal, power, etc. must remain within the prescribed limits imposed by the EMOC.

Generation Process: N/A

2. PATH:

Source: EMOC

Recipient: ICC

Medium: Electronic

3. REQUIREMENTS:

Input Data: N/A

Quality: N/A

Timeliness: Weeks in advance for planning timeliness

Completeness: N/A

Other: N/A

4. ATTRIBUTES:

Resolution and Coverage: Applicable to all thermal, power, etc sources in the MODIS instrument that can be commanded.

Volume: 1 kB per month

Storage and Availability: N/A

Units, Scales, and Conversion Factors: N/A

Frequency of Update and Processing: N/A

5. IMPACTS: Necessary for modeling of the instrument by the ICC for scheduling the appropriate observation need increased resource requirements (power, thermal,...), for successful observations.

LEVEL-1B DATA

1. DESCRIPTION:

Definition: Level-1A data to which the radiometric calibration algorithms have been applied, perhaps irreversibly, to produce radiances or irradiances, and to which the Earth location and zenith angle algorithms have been applied at the grid points.

Purpose:

Generation Process:

2. PATH:

Source: Level-1B processor (CDHF)

Recipient: Level-2, -3 processors, DADS

Medium: Electronic

3. REQUIREMENTS:

Input Data: Level-1A data

Quality:

Timeliness: Produced within 48 hours of observations

Completeness:

Other:

4. ATTRIBUTES:

Resolution and Coverage: 250 m, 500 m, 1 km resolution depending on channel; daytime and nighttime coverage for thermal channels of MODIS-N, daytime coverage for all other MODIS-N and -T channels.

Volume: 1 Tb/day

Storage and Availability: Archived at DADS for 2 years

Units, Scales, and Conversion Factors: °K

Frequency of Update and Processing: TBD

5. IMPACTS:

LEVEL-2 DATA

1. DESCRIPTION:

Definition: Geophysical parameter data derived from the Level-1B data by application of geophysical parameter algorithms.

Purpose:

Generation Process:

2. PATH:

Source: Level-2 processor (CDHF)

Recipient: Level-3 processor and DADS

Medium: Electronic

3. REQUIREMENTS:

Input Data: Level-1B data, archived data products

Quality: TBD for each Level-2 product

Timeliness: Produced within 72 hours of observation

Completeness: TBD

Other:

4. ATTRIBUTES:

Resolution and Coverage: To specified for each Level-2 product

Volume: 2 x Level-1B volume = 1.9 Tb/d

Storage and Availability: Stored at DADS

Units, Scales, and Conversion Factors: To be specified for each Level-2 product.

Frequency of Update and Processing: 2 reprocessings

5. IMPACTS:

LEVEL-3 DATA

1. DESCRIPTION:

Definition: Earth-gridded geophysical parameter data (including Level-1 radiances), which have been averaged or composited in time and space.

Purpose:

Generation Process:

2. PATH:

Source: Level-3 processor (CDHF)

Recipient: DADS

Medium: Electronic

3. REQUIREMENTS:

Input Data: Levels-1 and -2 data, archived data products

Quality: TBD for each Level-3 product

Timeliness: Produced within 72 hours of observation

Completeness: TBD

Other:

4. ATTRIBUTES:

Resolution and Coverage: To be specified for each Level-3 product

Volume: 15% Level-2 volume = 0.29 Tb/day

Storage and Availability: Stored at DADS for 2 years

Units, Scales, and Conversion Factors: Specified for each product

Frequency of Update and Processing: 2 reprocessings

5. IMPACTS:

METHODS OF MONITORING THE MODIS INSTRUMENT IN THE MIDACS

The original issue in this regard was the desire to take monitoring science data into the MIDACS direct from the MODIS instruments (i.e., in real-time, during a TDRS contact). This requirement has since been relaxed to that of accepting monitoring science data from tape recorder playback. Since this data is used for detailed monitoring of the state-of-health of the MODIS instruments, and for support of field experiments, it is still desireable to acquire the science data in the MIDACS in near real-time (i.e., within a hour or less from observation). One consideration during the following study was to ensure that the eventual MIDACS architecture would accommodate tape recorder playback (TRPB) and direct instrument readout.

The evaluation of this issue thus far has taken the form of an architectural trade study, namely that of determining the size of the MIDACS ingest and image display processors used for selected science monitoring and for near real-time support of field experiments.

Heretofore, it has been assumed that this capability would exist in the MODIS ICC. However, the better solution may be to allow this conclusion to result from the various MIDACS requirements analyses and architectural trade studies.

There are several assumptions that have been made in order to arrive at the tradeoff table which follows. The following is a list of these assumptions:

a. The MIDACS will receive instrument packets containing only MODIS data.

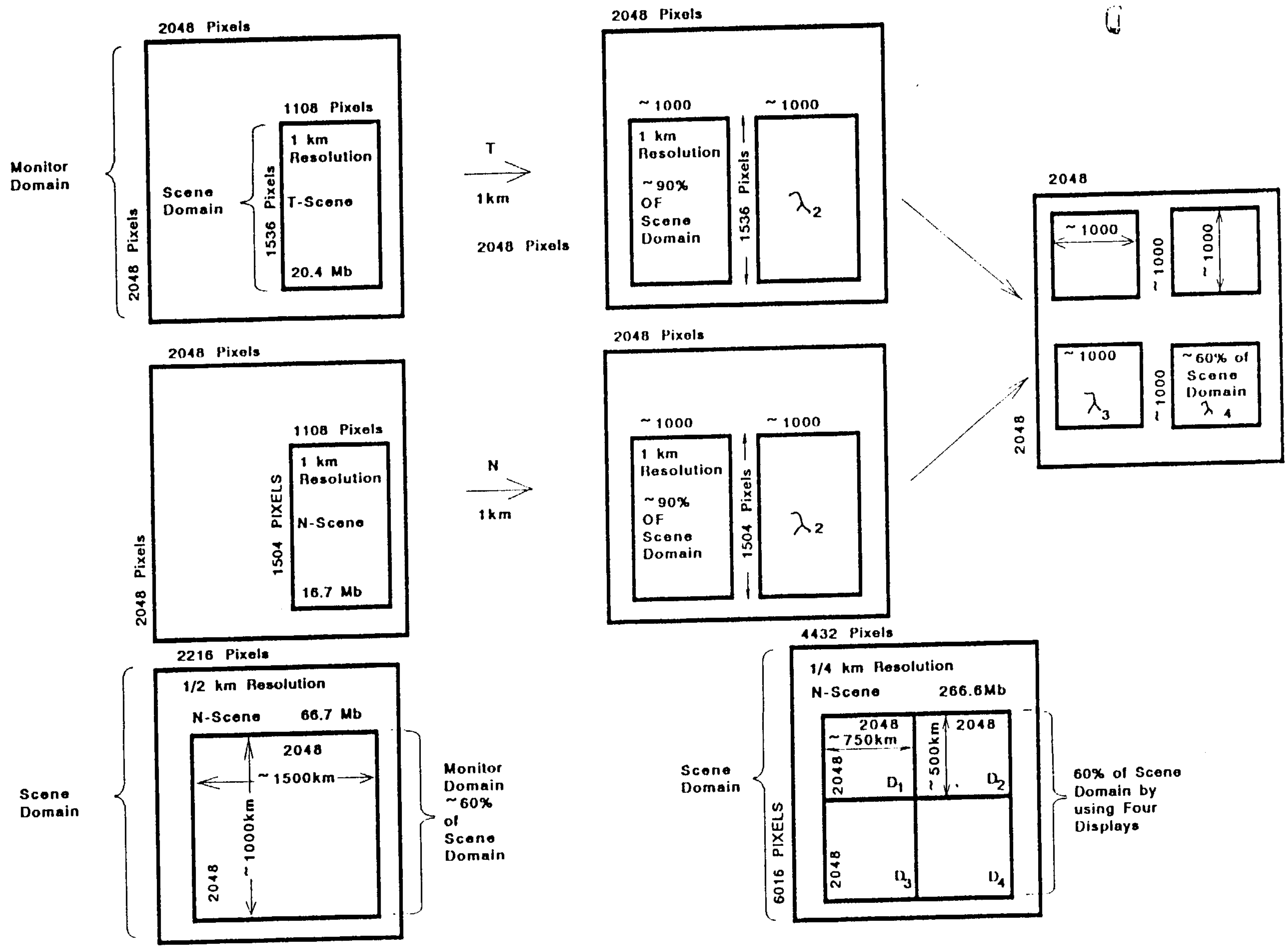
b. The MIDACS will be required to support only a limited number (i.e., <=3) of contiguous scenes at a time. A MODIS scene is approximately 1500 X 1500 km.

c. The DHC will be instructed, in advance, as to which MODIS scene(s) are of interest to the MIDACS.

d. The DHC will forward all MODIS packets within the scenes identified, to the MIDACS. These packets will be forwarded as soon as received (i.e., at the same data rate) or after a short delay to accommodate buffering to a slower data rate.

e. The MIDACS will have four image display monitors, each with 2048 X 2048 pixels.

f. The MIDACS image display processor is capable of dividing each monitor domain into four sectors, each sector accommodating only about 60% of the available 1-km resolution scene domain (see Figure 1).



Display Configurations for 2048 x 2048 Image Device

g. The MIDACS will display only 1 1/2-km spectral channel per monitor and the assumed device will accommodate only 60% of the available scene domain.

h. The MIDACS will display only 1/4 of a 1/4-km spectral channel scene per monitor and four of the assumed devices together will accommodate only 60% of the available scene domain.

i. The MIDACS science monitoring image nearest in time to the observation is a level-1B product, i.e. there is no near real-time level-2 requirement. Although, since the path length (PL) for a level-1B to level-2 process is the same (Table 6.3-5, EosDIS Baseline Report) as for level-0 to level-1B, the same processor will accommodate level-2 at the level-1B performance criteria. For example, if a level-1B product is available in 10 minutes, a level-2 product will be available in an additional 10 minutes.

j. The level-1B PL = 20 instructions per bit in the MIPS calculations. It is recognized that this is a very conservative estimate. Section 8 of the MIDACS system specification gives a number closer to 7 instructions per bit and this includes: unpacking, reordering, linear calibration with temperature correction, and 1% earth location.

k. The MIPS calculation exercises the formula:

   MIPS = ((Mbps/ch) * N(ch) * X(%scene) * PL) / 0.7;

   where, typically, X = 1 (100%) or 0.6 (60%), PL = 20, and N = sum total channels displayed.

l. The MIDACS science monitoring ingest processor is a decommutator (i.e., a hardware implementation) whose order of magnitude, in MIPS, is estimated at 100 for TRPB data rates and at 10 for MODIS instrument data rates.

It is clear from the table that the ingest processor is the hardware driver, which results from the DHC priority playback (PPB) data rate output. If the DHC would buffer the PPB subset of data to be sent to the MIDACS, and read the data out to the MIDACS at a rate more nearly like that of the instruments themselves, then one architecture would accommodate both PPB and direct readout MODIS data.

MIDACS SCIENCE MONITORING PROCESSOR TRADEOFF SUMMARY

DHC Buffering	MIDACS Input Data Rate (Mbps)	MIDACS Ingest Processor (MIPS)	Scene Type	Required MIPS (min/max)* (L0 to L1B) 5-Minute Delay	10-Minute Delay	Cost
Without/ With	150/ 20	100/ 10	Day	8/19	4/10	----
			Night	7/15	4/8	----

*Min/Max: Min = 1 per display; max = 4 per display.

ON-BOARD MODIS PROCESSING AND PACKETIZATION

1. INTRODUCTION

One of the issues and uncertainties identified in the MODIS Data System Study relates to the nature and extent of processing support that will be available on board the POLAR platform for MODIS use and the effect of such processing on the data system interfaces that the ground portion of the MODIS data system must accommodate. This document is a first attempt to identify design trade-offs that occur as required processing capabilities are moved between an on-board processor and appropriate sections of the MODIS ground data system.

Section 2 reviews general limitations that affect any satellite-borne processor and describes the general nature of improvements that could be provided by on-board processing, as seen from the perspective of the ground system designer. Section 3 addresses the minimum on-board processing capability required to provide basic MODIS service, and Section 4 considers several potential expansions of on-board processing capability above minimum requirements and the design trade-offs associated with each. Since the goals of the data team relate primarily to the design of the MODIS ground data system and not to the design of hardware components for on-board processing, this review is necessarily biased toward the needs of the ground data system. The material presented here should be considered along with complementary design and trade-off information developed by MODIS flight hardware engineers.

2. CCSDS-DEFINED DATA PACKETIZATION ALTERNATIVES

As defined in CCSDS standard 102.0-B-2 [Packet Telemetry], the basic structure of the data flow from the MODIS instrument data system to the MODIS ground data system is as shown in Figure 1. The various sources of telemetry data (sensor and engineering outputs) contained within the instrument packages (MODIS-N and MODIS-T) are the applications processes shown as the top row of boxes in the figure (ap1, ap2, etc.). The corresponding destinations of data shown at the bottom of the figure are various software modules within the MODIS ground data system where data from the instrument is needed. The data sources and sinks shown as the next layer in the model are the various on-board instruments (SOURCES) and their associated instrument-unique data systems (SINKS), i.e. SOURCE-C might be the MODIS-N instrument, SOURCE-D might be the MODIS-T instrument, and SINK-C might be those portions of the overall ground data system that are dedicated to serving MODIS needs (the MIDACS).

Data output from the individual "SOURCES" must be in CCSDS packet format as shown in Figure 2. As indicated, the packets must be appended with a primary header. Besides the instrument data, the packets may also contain a secondary header (optional) and an

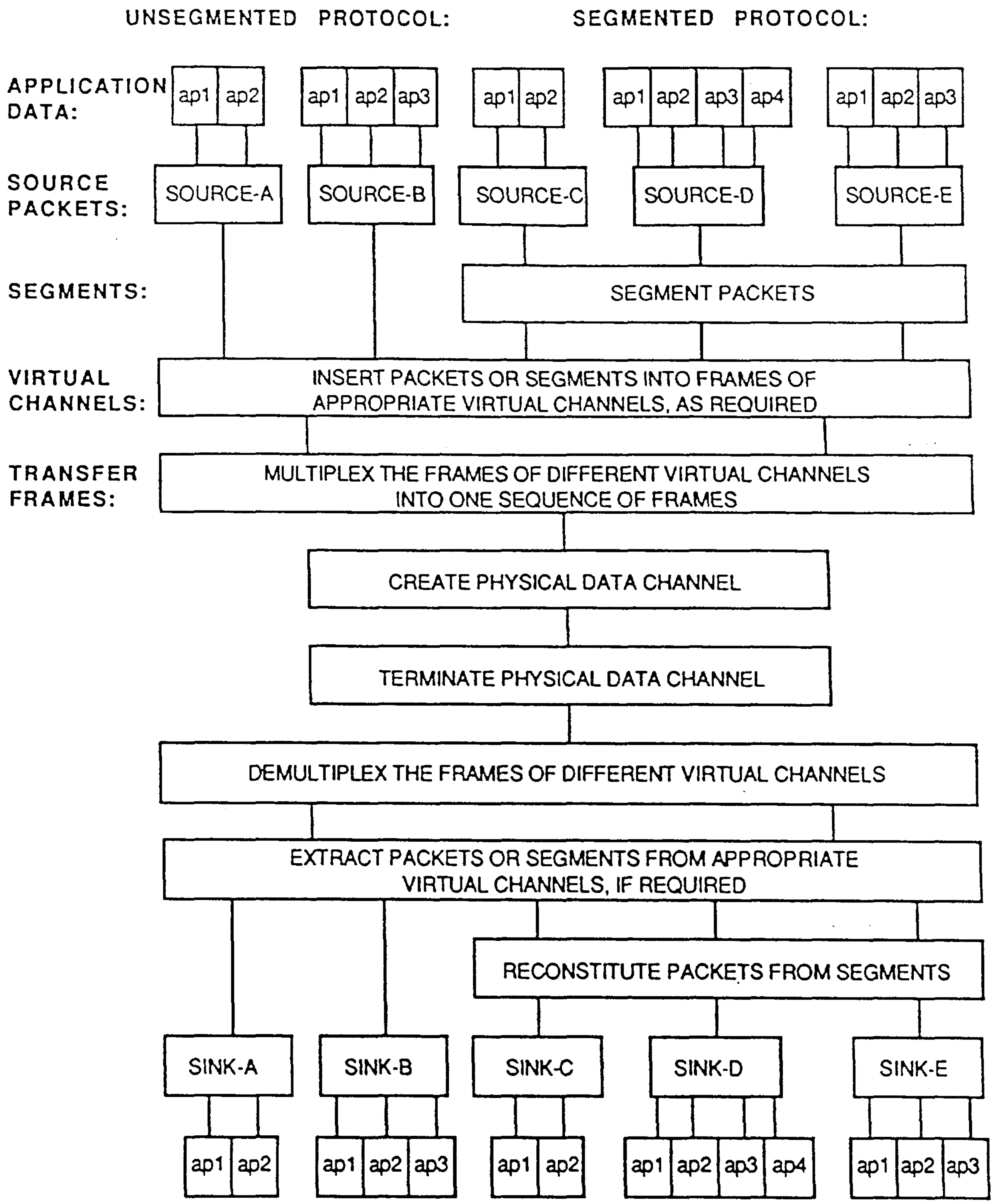

UNSEGMENTED PROTOCOL:
SEGMENTED PROTOCOL:
APPLICATION DATA:
SOURCE PACKETS:
SEGMENTS:
VIRTUAL CHANNELS:
TRANSFER FRAMES:
ap1 ap2
ap1 ap2 ap3
ap1 ap2
ap1 ap2 ap3 ap4
ap1 ap2 ap3
SOURCE-A
SOURCE-B
SOURCE-C
SOURCE-D
SOURCE-E
SEGMENT PACKETS
INSERT PACKETS OR SEGMENTS INTO FRAMES OF APPROPRIATE VIRTUAL CHANNELS, AS REQUIRED
MULTIPLEX THE FRAMES OF DIFFERENT VIRTUAL CHANNELS INTO ONE SEQUENCE OF FRAMES
CREATE PHYSICAL DATA CHANNEL
TERMINATE PHYSICAL DATA CHANNEL
DEMULTIPLEX THE FRAMES OF DIFFERENT VIRTUAL CHANNELS
EXTRACT PACKETS OR SEGMENTS FROM APPROPRIATE VIRTUAL CHANNELS, IF REQUIRED
RECONSTITUTE PACKETS FROM SEGMENTS
SINK-A
SINK-B
SINK-C
SINK-D
SINK-E
ap1 ap2
ap1 ap2 ap3
ap1 ap2
ap1 ap2 ap3 ap4
ap1 ap2 ap3

Figure 1

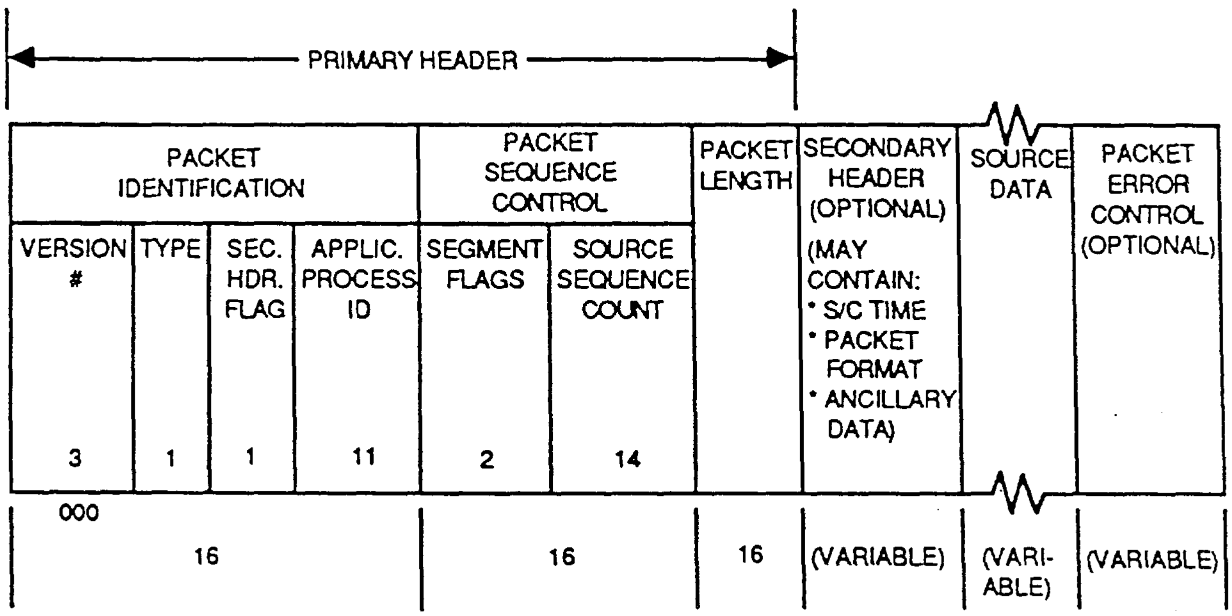

PRIMARY HEADER
PACKET IDENTIFICATION
PACKET SEQUENCE CONTROL
PACKET LENGTH
SECONDARY HEADER (OPTIONAL)
SOURCE DATA
PACKET ERROR CONTROL (OPTIONAL)
VERSION #
TYPE
SEC. HDR. FLAG
APPLIC. PROCESS ID
SEGMENT FLAGS
SOURCE SEQUENCE COUNT
(MAY CONTAIN:
• S/C TIME
• PACKET FORMAT
• ANCILLARY DATA)
3
1
1
11
2
14
000
16
16
16
(VARIABLE)
(VARI-ABLE)
(VARIABLE)

Figure 2

error control check sum (also optional). By CCSDS standards, the original source packets may be of any desired length. However, long data packets increase buffering requirements at the instrument (longer packets must be buffered), they increase buffering requirements for other instruments (facilities are unavailable for longer time periods while the long packets are being serviced), and they complicate error detection and correction (larger blocks of data must be corrected). The CCSDS standard suggests that the upper size limit for useful packet transmission from the spacecraft to the ground is about eight kilobits. If the size of the desired instrument data packet is less than this limit, no problem exists. If the desired length exceeds eight kilobits, however, several alternatives exist. The packet may be segmented to acceptable lengths within the "SOURCE." The packet format shown in Figure 2 contains "SEGMENT FLAGS" and a "SOURCE SEQUENCE COUNT" to support this process. Or the "offending" data packet may be delivered from the source to the platform data system "as is" and the required segmentation may be applied by the on-board data system. The CCSDS standard supplies two methods of doing this. The long packet, complete with original header and (optional) footer, may be segmented and inserted in another packet of identical format (Figure 2) but with segmentation flags and source sequence counts supplied by the on-board system. Or, the on-board system may use a second type of packet as shown in Figure 3. This is a fixed length packet of 2,096, 4,144, or 8,240 bits overall length. Packets exceeding these lengths are broken into shorter lengths as shown in Figure 4. The "SEGMENT LENGTH" field in the Version 2 format (Figure 3) indicates the number of bits from the original packet that remain to be transmitted.

Once packet segments of acceptable length are achieved, segments from all "SOURCES" are pooled and inserted as available into individual transfer frames as shown in Figure 5. The overall length of a transfer frame is fixed at 10,232 bits. Of that length, up to 8,872 bits may be available for the insertion of packets and segments from the various on-board sources. A packet is inserted beginning with first bit in the "TRANSFER FRAME DATA FIELD." If space remains after the packet is inserted and if other packets are waiting to be transmitted, succeeding packets are inserted beginning immediately at the end of the preceding packet until the transfer frame is completely filled. If a packet transfer is in process at the end of the transfer frame, the packet is terminated at the end of the present transfer frame and the remaining portions of the packet are transmitted in the succeeding transfer frame.

While all transfer frames have the format shown in Figure 5, the standard defines up to eight "VIRTUAL CHANNELS" which differ in the address header (VIRTUAL CHANNEL ID, 3 bits) appended to the transfer frame (see Figure 6). VIRTUAL CHANNEL IDs will be used to route transfer frames to their major destinations (JPL, GSFC, etc.). Also, the CCSDS standard provides that a very high data rate instrument may be assigned a virtual channel dedicated to the exclusive service of that instrument. In this case, transfer

SEGMENT HEADER							
SEGMENT IDENTIFICATION				SEGMENT SEQUENCE CONTROL		SEGMENT LENGTH	
VERSION #	TYPE	SEC. HDR. FLAG	APPLIC. PROCESS ID	SEGMENT FLAGS	ORIGINAL PACKET SEQUENCE COUNT	(LENGTH OF THE ORIGINAL SOURCE PACKET WHICH REMAINS YET TO BE TRANSMITTED	SEGMENTED SOURCE PACKET DATA
3	1	1	11	2	14		
100							
16				16		16	2048, 4096, OR 8192

Figure 3

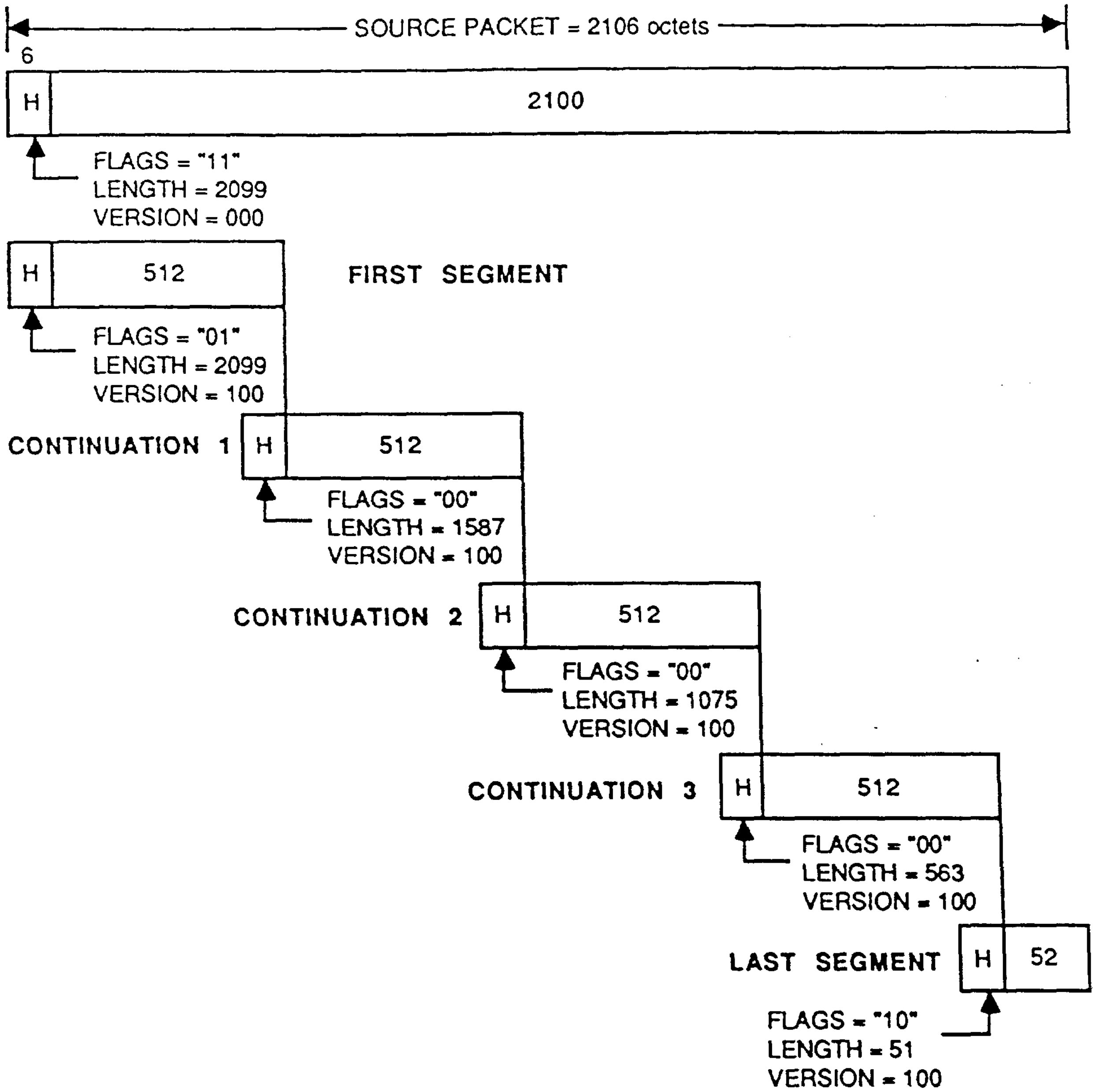

SOURCE PACKET = 2106 octets
6
H
2100
FLAGS = "11"
LENGTH = 2099
VERSION = 000
H
512
FIRST SEGMENT
FLAGS = "01"
LENGTH = 2099
VERSION = 100
CONTINUATION 1
H
512
FLAGS = "00"
LENGTH = 1587
VERSION = 100
CONTINUATION 2
H
512
FLAGS = "00"
LENGTH = 1075
VERSION = 100
CONTINUATION 3
H
512
FLAGS = "00"
LENGTH = 563
VERSION = 100
LAST SEGMENT
H
52
FLAGS = "10"
LENGTH = 51
VERSION = 100

Figure 4

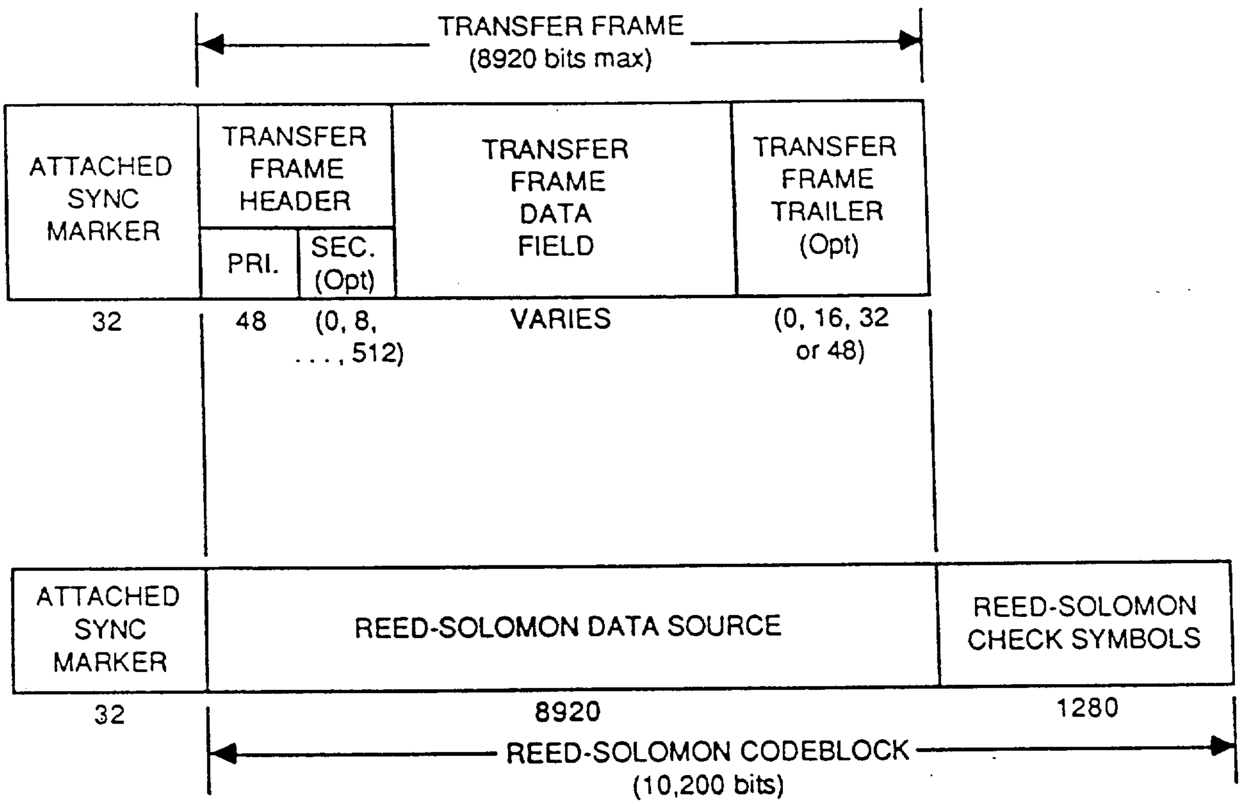

TRANSFER FRAME
(8920 bits max)
ATTACHED SYNC MARKER
TRANSFER FRAME HEADER
PRI.
SEC. (Opt)
TRANSFER FRAME DATA FIELD
TRANSFER FRAME TRAILER (Opt)
32
48
(0, 8, . . . , 512)
VARIES
(0, 16, 32 or 48)
ATTACHED SYNC MARKER
REED-SOLOMON DATA SOURCE
REED-SOLOMON CHECK SYMBOLS
32
8920
1280
REED-SOLOMON CODEBLOCK
(10,200 bits)

Figure 5

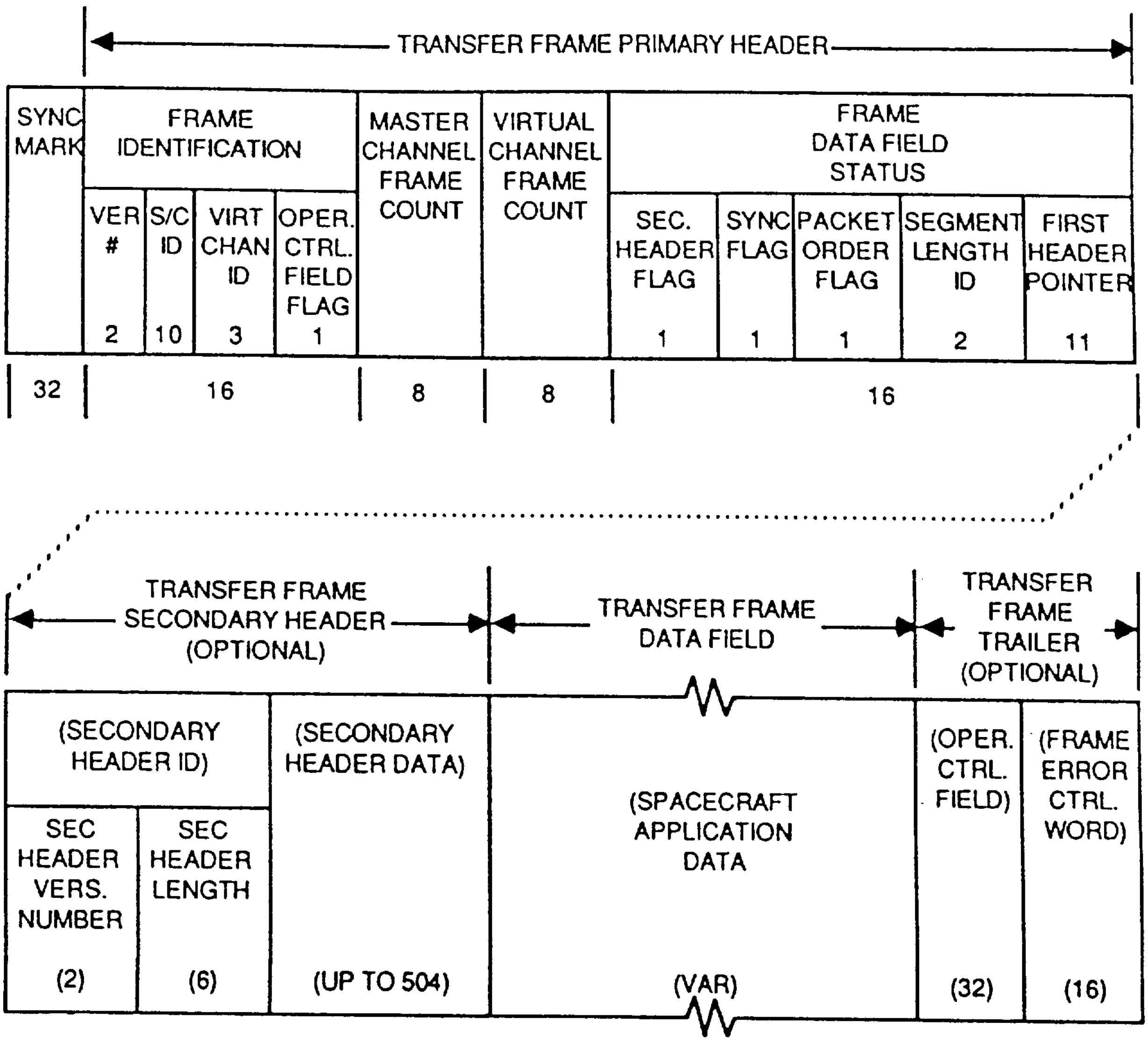

TRANSFER FRAME PRIMARY HEADER
SYNC MARK
FRAME IDENTIFICATION
VER # 2
S/C ID 10
VIRT CHAN ID 3
OPER. CTRL. FIELD FLAG 1
MASTER CHANNEL FRAME COUNT
VIRTUAL CHANNEL FRAME COUNT
FRAME DATA FIELD STATUS
SEC. HEADER FLAG 1
SYNC FLAG 1
PACKET ORDER FLAG 1
SEGMENT LENGTH ID 2
FIRST HEADER POINTER 11
32
16
8
8
16
TRANSFER FRAME SECONDARY HEADER (OPTIONAL)
TRANSFER FRAME DATA FIELD
TRANSFER FRAME TRAILER (OPTIONAL)
(SECONDARY HEADER ID)
SEC HEADER VERS. NUMBER (2)
SEC HEADER LENGTH (6)
(SECONDARY HEADER DATA) (UP TO 504)
(SPACECRAFT APPLICATION DATA) (VAR)
(OPER. CTRL. FIELD) (32)
(FRAME ERROR CTRL. WORD) (16)

Figure 6

frames contain only data for that single high-rate instrument. In the presently discussed data system design, high-rate instruments are themselves responsible for generating the transfer frames required to transmit their high-rate data. MODIS is being considered for designation as a high-rate instrument with a dedicated virtual channel.

3. PROPOSED MODIS DATA PACKET STRUCTURES

The processing of instrument sensor data and derived geophysical data is the central concern of the MODIS data system. Details of image packet design that could facilitate sensor data processing operations have become apparent and will be discussed in this section. Also, preliminary attributes of other types of MODIS data packets have been defined and will be discussed here. The MODIS ground data system will accept a variety of MODIS and platform science and ancillary data packets. These packets will be designed specifically to support the scheduling, monitoring, and data processing functions of the MODIS data system.

3.1 MODIS-N and MODIS-T Command Storage Data Packets

The MODIS-N and MODIS-T instruments will construct and release to the platform LAN data packets listing the entire command stream (commands and times of execution) as stored by each instrument. The packets will be generated at least once per day, or more frequently if requested by the MODIS ICC.

3.2 MODIS-N and MODIS-T Ancillary Data Packets

The MODIS-N and MODIS-T instruments will construct and release to the platform LAN data packets containing all ancillary MODIS data required by the ground data system for processing the MODIS data. The ancillary data packets will be common to all sensor data. The format of the packets will be not vary greatly with time. The packets will contain:

- GMT time
- Temperature monitor outputs
- Voltage monitors
- Mirror and scan encoder values
- Instrument status words and bits

3.3 MODIS-N and MODIS-T Monitor Data Packets

The MODIS-N and MODIS-T instruments will construct and release to the platform LAN data packets containing specific ancillary or low-rate-subset sensor data requested by the ICC for monitoring purposes. The contents of these packets may replicate the contents of the MODIS Ancillary Data packets, though perhaps at a lower sampling rate than that required at the CDHF. In addition, subsampled sensor data may be included in these packets. The format of these packets will be under the control of the monitoring personnel who will, from time to time, vary the format of the packets to their specifications.

3.4 Platform Ancillary Data Packets

The platform data system will construct and release to the platform LAN data packets of ancillary data containing information required by all instrument data systems for routine and other processing. The format of the packets will be not vary greatly with time. The packets will contain:

GMT time
Platform position vector (resolved in time to .0001 second)
Platform velocity vector
Platform attitude vector
On/off/other status information for all platform instruments
Other relevant platform ancillary information

3.5 MODIS-N and MODIS-T Alarm Packets

Upon the detection by the MODIS-N or MODIS-T instruments of anomalous operating conditions, the MODIS instrument may generate a specific alarm data packet, to be transmitted at real time or priority playback to the MODIS ICC. This alarm packet will provide an assortment of predesignated ancillary and sensor data to aid in the identification and diagnosis of the instrument's status and health on the ground.

3.6 MODIS-N and MODIS-T Sensor Data Packets

The MODIS-N and MODIS-T instruments will construct and release to the platform LAN data packets containing all the sensor data taken while scanning the Earth, space, or internal calibration sources. Observations from each of the 64 MODIS-T channels and each of the 40 MODIS-N channels will be segregated into unique data packets for each channel. For MODIS-T, with 64 detectors along track, on the order of 1200 observations across track per detector, and 12 bits per sample, on the order of 115 8000-bit packets will be required to deliver the sensor data from a single channel (wavelength) for each scan. This will require buffering on the order of 1% of each scan, which will probably be required for MODIS burst-buffer purposes (the MODIS on-Earth data rate will be higher than its mean data rate and will probably exceed the LAN capacity). The format of the packets will be not vary greatly with time. The packets will contain:

GMT time
Packet sequence within scan
Channel number
Sensor data

As discussed in Section 2.0, the CCSDS standards provide several segmentation alternatives for packets that are longer than the (approximate) eight kilobit limit imposed by the space-to-ground communications link. Segmentation may be done either within the individual instrument data systems before data is received by the on-board LAN or segmentation may be done by the spacecraft data system after the data has been transmitted from the instrument to the on-board LAN and the data is received by the platform data system. In the analysis that follows it will be assumed that data segments are created within the MODIS data system. This will facilitate access to the on-board LAN by other on-board instruments and may potentially reduce the data buffer requirement for the MODIS instrument. It will also facilitate the construction of image data packets particularly suited to the needs of the MODIS instrument monitoring facility at the ICC.

Consider the MODIS observation space defined as shown in Figure 7, where x represents the cross-track coordinate at which an observation is made, y represents the corresponding along-track coordinate, and z is a spectral channel coordinate that represents the spectral wavelength at which an observation is made. Forty spectral channels are defined for the MODIS-N instrument and 64 are defined for MODIS-T. These channels may be represented by the integers 1 through 40 or 1 through 64 on the z axis.

Since (we shall assume) the MODIS-N instrument senses eight contiguous pixels in the along-track direction and scans across track ±55° from nadir, with a nadir resolution of 0.85 km from a 705 km altitude, the observation space representation for a complete MODIS-N scan is as shown in Figure 7, where each cube represents a separate observation made during the scan. The MODIS-N baseline configuration calls for eight channels at twice the fundamental resolution, and two additional channels at four times the fundamental resolution, requiring 752 detectors in a one km cross-track by eight km along-track array. Altogether, the scan contains $1{,}295 \times 752 = 10^6$ observations. A corresponding solid can be drawn for the MODIS-T instrument. It contains 64 pixels in the along-track direction and it also supports 64 spectral wavelengths. It contains about 6.5×10^6 observations.

If the instruments use a rotating mirror of constant angular velocity to generate the scan, then the "natural order" in which data will be generated at the sensors is beginning at one end of the solid and moving to the other as shown in Figure 7. In this representation, a fixed volume of data (say the eight kilobit limit for packet size) corresponds to a fixed volume in the figure.

Suppose that the scan mirror rotates at a constant angular velocity and observes the earth only during part of its scan, so that data appears in bursts as shown in Figure 8. In the hypothetical configuration displayed in the figure, the instrument takes data (Earth data and a limited amount of adjacent space data) during about 61% of each scan. During the remainder of the scan no useful data is acquired by the scanner. While the mean (daytime) data rate is taken at nine megabits per second (mbps), the peak (on-Earth) rate is actually about 15 mbps. With an

Conceptual View of Data Taken During a MODIS-N or MODIS-T Scan

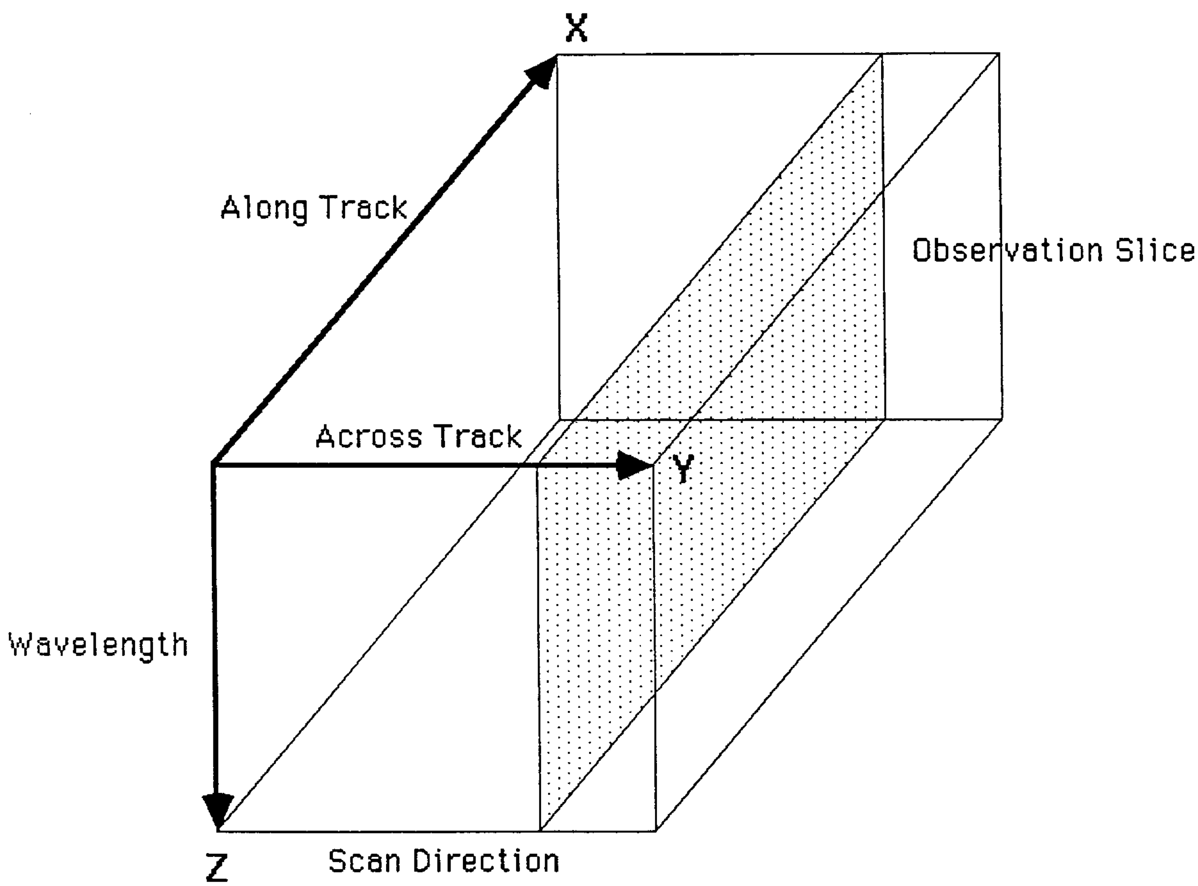


Figure 7

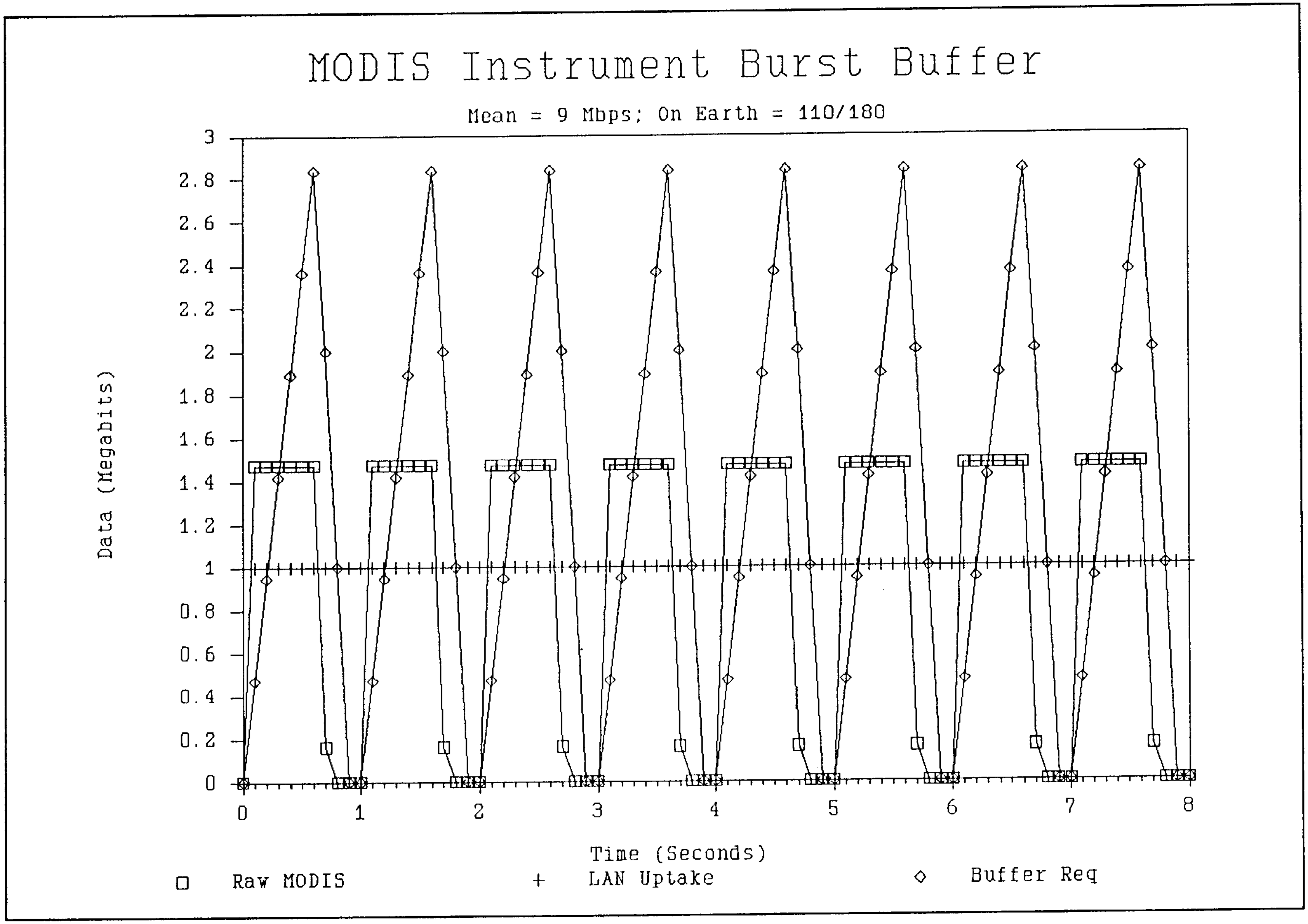

MODIS Instrument Burst Buffer
Mean = 9 Mbps; On Earth = 110/180
Data (Megabits)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0
1
2
3
4
5
6
7
8
Time (Seconds)
Raw MODIS
LAN Uptake
Buffer Req

Figure 8

assumed platform LAN capacity of ten mbps, a burst buffer will be required to accommodate the excess data that will accumulate during each scan. We see that, for this example, about 0.5 megabits will accumulate every 0.1 seconds for this one-second scan period.

4. GENERAL CONSIDERATIONS FOR ON-BOARD PROCESSING

4.1 Positive Factors

From the perspective of the MODIS ground data system designer, the potential advantages of on-board processing include improved data routing in the ground data system and potential improvements in instrument responsiveness. MODIS instrument data is routed to several points within the MIDACS, and a modest on-board processing capability would allow the creation of instrument data packets specifically tailored to the needs of the recipient system, i.e. containing only the specific data that is needed at the destination, in a format that allows easy identification and use of the data. If MODIS data packets are generated taking data in exact order as it is generated by instrument sensing elements, extensive on-the-ground data sorting will be required to create special-purpose blocks of data required at a number of locations within the MIDACS.

A substantial on-board processing capability could potentially support adaptive sensing and improved instrument reliability. Adaptive sensing would alter the instrument sensing routine or detector gains according to the target being observed, i.e. sensing routine or detector gains could be altered for land or ocean observations, cloud cover, etc. Also, extensive on-board processing could provide MODIS Built-in-Test capability, direct on-board monitoring of instrument status, automatically declare alarm status, and automatically initiate instrument safe-store sequences.

4.2 Negative Factors

Several unfavorable aspects of on-board processing from a satellite platform are immediately apparent. One obvious limitation is that physical access to the system is very limited after launch. The potential consequences of this obvious fact include the inability to provide timely repairs in the event of hardware failure and the inability to readily upgrade system software and hardware as new technology becomes available or as new processing needs become apparent. On-board processing uses the limited resources of an orbiting platform and takes place in a generally hostile environment that must be modified using special facilities such as temperature-controlled chambers, etc. Flight hardware must be specially qualified, and construction standards are rigorous and generally burdensome to meet.

5. MINIMUM REQUIRED ON-BOARD PROCESSING CAPABILITIES

Certain minimum on-board processing capabilities are required to obtain a functioning MODIS instrument. The essentials include on-board storage of command sequences, time-based retrieval of commands as they are needed for execution, the generation of MODIS data packets, and the buffering of observation data as it flows between the detector and the on-board LAN.

5.1 Command Storage and Retrieval

Instrument commands must be stored on the orbiting platform to provide instrument operation during the time periods when direct TDRSS contact is not available. Advance storage of commands also provides increased security in the event of equipment failure or other contingency affecting the command uplink. Time tags associated with each command specify the time when the stored command should be executed. Since failure in the command link could profoundly affect instrument operation, special precautions to assure data integrity may be needed in this portion of the data system.

5.2 On-Board Data Packet Generation

MODIS data packets must be fitted with descriptive header and footer information that describes the contents of the packet, provides error control (optional), and specifies the relative location of the packet in the sequence of all data packets returned by the instrument. While this procedure does not demand extensive hardware or software capability, the formatting of MODIS data packets is a MODIS responsibility and the MODIS instruments must certainly be equipped with at least enough processing capability to generate the required packets. Since individual items of observation data are perhaps not as critical to overall mission success as items of command data, this processing may perhaps be implemented in a separate system that operates independently of the command processing system and does not have the same provisions to insure data system integrity that are required in the command system.

5.3 Data Buffering

If the MODIS instruments use a rotating mirror scanning procedure, data will appear in bursts at the output of the detectors as the scan sweeps across the Earth observation area. Only a few, or perhaps no observations will be made in the "dead" region when the scan is outside the area of observational interest. [Certain calibration measurements may be made while the mirror is in a non-Earth observing position]. Given the "burstiness" of the observation data, the processor must either accommodate the peak rate of the data burst or the data must be stored in a buffer that smooths out data peaks and valleys and allows the processor to proceed at the average rate of data flow through the instrument. Efficient use of resources usually dictates the latter procedure. It will be assumed in this analysis that data buffering will be provided at the interface between the detectors and the MODIS on-board processor.

Similar considerations dictate that buffering must be provided between the output of the MODIS processors and the on-board LAN. The peak overall data storage requirement for the instrument data system occurs at the end of an observational sweep. During the sweep, data has accumulated at a much faster rate than it is absorbed by the LAN. Buffering allows the LAN to receive MODIS data packets at the average data throughput rate rather than the peak rate. Buffering at this interface is also required to accommodate those time periods when the LAN is not available for MODIS use because it is accommodating other Eos or platform instruments.

6. CANDIDATE ON-BOARD MODIS PROCESSING CAPABILITIES AND DISCUSSION OF TRADE-OFFS

6.1 Construction of Data Packets to Exact MODIS Requirements

In this section we will discuss the likely MODIS data packet formats if the formats are chosen to minimize the on-board processing requirement. We will then consider the optimal data packet format for MIDACS on-the-ground use, and we will conclude with a comparison of the hardware resources that are required to implement each of these alternatives.

It would appear that the packet format that would make the least demands on the on-board processor would insert the data into packets directly as the data is generated at the detectors, in the same order as the data becomes available. This would allow the system to work with the construction of a single packet of observation data at a given time; the single packet would contain observation data from many spectral channels. Since data packets must be buffered at the interface with the LAN, the processor memory would contain many finished data packets awaiting receipt by the LAN and a single incomplete data packet that is receiving the latest data.

Because of the need to construct sample images to monitor instrument function at the ICC, the optimal data packets for MIDACS use would contain only data for a single spectral channel. Sample images at the ICC are constructed using data from only a few spectral channels; up to four spectral channels may be selected for each MODIS instrument (maximum of eight). If MODIS data packets contain only data for a specific spectral channel, only those packets containing required data need to be routed to the ICC. Otherwise, required data may be distributed throughout the instrument data stream, and the entire stream of data returned by the instrument may need to be routed to the ICC.

The construction of data packets containing only data for a given spectral channel requires the on-board data system to simultaneously construct many data packets - one for each spectral channel being observed. Data for each spectral channel appears at different detectors, so that data from a given set of detectors can be routed directly to the appropriate packet. It appears that the additional on-board CPU capability required to route the data directly to the appropriate packet rather than to a single data packet that receives all spectral channels would be insignificant. Memory requirements to simultaneously generate many data packets may be somewhat greater than the corresponding requirements if only a single packet is constructed at a given time. However, because of the need to buffer data packets at the interface with the LAN, overall memory requirements are roughly comparable. If it is assumed that the maximum packet buffering requirement occurs at the end of an observation scan, and if it is also assumed that data packet generation is synchronized with the scan period and that all data packets are filled at the end of the scan, then the memory requirements of the two alternatives are exactly equal.

6.2 Real-Time Instrument Control

6.2.1 Adaptive Sensing

[This section can be expanded to include a discussion of possible adaptive sensing routines and the general resources that might be required to implement the alternatives.]

6.3 Lossless and Lossy Data Compression

[It is expected that all compression of basic science data will be lossless. This section can consider the possible application of lossy data compression to monitoring data and the system tradeoffs that would result.]

COMPLEXITY AND SCOPE OF MODIS METADATA

MODIS Metadata issues are in part derived from projected MODIS data usage and data granularity. The metadata's depth and breadth has an effect on the level of processing necessary for the MODIS datasets' production, the amount of storage necessary for these datasets, and the Science user's ability to retrieve these datasets. In order to determine the most effective way to apply and utilize metadata, MODIS metadata issues will be addressed through questions such as:

1. What is the lowest level of MODIS data that could be individually addressable?

2. What effects do alternative levels of MODIS data granularity have on the quantity or quality of metadata?

3. What are the effects of using some MODIS non-science data as metadata, as well as some MODIS science data as metadata?

4. To what degree could MODIS data usage level be an indicator of metadata needs?

5. Do MODIS standing orders have impacts on metadata requirements?

Factors Affecting MODIS Metadata Complexity and Scope

Metadata is comprised of descriptive terms MODIS investigators can use to locate desired science data. Each term can have a range of values, one of which is assigned to a MODIS dataset when it is generated. These values can also serve to locate other MODIS datasets.

For example, an investigator examines browse data and determines that MODIS passed over the Mississippi delta at a given date and time. The investigator can now order specific Level 2 and 3 products as a function of two MODIS metadata values; location, and time coverage. If the investigator also wants to perform independent analyses, the Level 1 data used to generate standard MODIS products can also be ordered as a function of these date and time values.

MODIS metadata complexity and scope were examined in terms of the five areas presented below. The summary of the findings in terms of these areas are as follows:

- The TBD appears to be the lowest useful level of MODIS data granularity.
- MODIS data granularity can TBD.
- MODIS non-science data when used as metadata, TBD, and MODIS science data, when used as metadata, TBD.
- Heavy MODIS data users will be expected to rely less on metadata than other users, with a user's reliance on metadata increasing as monthly MODIS usage rates decrease.
- MODIS standing orders are not expected to significantly affect metadata requirements.

These findings may be preliminary, as they are drawn from issues that may require substantial input and resolution from the yet-to-be-selected MODIS Science Team.

1.0 MODIS Data Granularity

- o Cube
- o Swath
- o Fiber

2.0 MODIS Data Granularity and Metadata Breadth/Depth

- o Increased Metadata Elements and Values
- o Redundancy vis a vis other DADS databases

3.0 Inclusion of MODIS Science and Non-Science data as Metadata

- o Science data
- o Non-Science data

4.0 MODIS data Usage Level and Metadata Requirements

An estimated 700 megabytes/day of Metadata are expected to be generated and made available to MODIS users. These users have been categorized as light, medium, and heavy users, with their respective requested data quantities of 1.25, 12.5, and 125 megabytes/month. MODIS users are also assumed to be equally divided among these categories.

User familiarity with the IMC/DADS MODIS retrieval capability is expected to be a function of usage rate. Heavy users will be continuous users, while the remaining two user categories will have more sporadic usage times and rates. Heavy users will be more familiar with the IMC/DADS MODIS retrieval capability, and will be able to directly locate and retrieve datasets relevant to their Science needs.

Medium and light users (67 percent of the user population) will be expected to be less familiar with this retrieval capability. In addition to relying comparatively more on the menus for query formulation, they will be more dependent on metadata coverage for locating related datasets. Therefore, for interactive users, the rate of metadata usage will be expected to increase as the rate of the user's system usage decreases.

5.0 Standing Orders and MODIS Metadata

Standing orders are periodically scheduled retrievals of MODIS datasets that are executed in the background. They are initiated by the system on a weekly, monthly, or other basis as initially requested by the Science user. Their time period is expected to be a function of the MODIS platform having made one or more passes over the desired geographic coordinates.

Standing orders are executed as a function of the metadata values specified in the retrieval request. When the request's Boolean logic is satisfied, MODIS datasets are retrieved, copied to the designated media, and shipped to the user. Therefore, standing orders are completely dependent on metadata. They are based on a user's request that has most likely been clarified through the IMC/DADS menu processing facility. They do not, however, reflect any increased or decreased metadata coverage. If additional retrieval parameters or logic were required, the user would be initiating and formulating an interactive query.