MODIS DATA STUDY TEAM PRESENTATION

September 15, 1989

AGENDA

1. Recommended MODIS Data Packet Structure and Formats
2. MODIS Ocean Color Data Products Overview
3. Determination of Attenuation at 490 nm (K490)
4. Determination of Water-Leaving Radiances (CZCS)

RECOMMENDED MODIS DATA PACKET STRUCTURE AND FORMATS

PRELIMINARY

PREPARED BY

THE MODIS DATA STUDY TEAM

SEPTEMBER 15, 1989

TABLE OF CONTENTS

Section		Page
1.	BACKGROUND	1
2.	POSSIBLE SCENARIO FOR USE	1
3.	APPLICABLE STANDARDS	2
4.	IMPLICATIONS OF CCSDS RECOMMENDATIONS	3
5.	MODIS SCIENCE REQUIREMENTS	6
6.	MODIS INSTRUMENT DESIGN IMPLICATIONS	7
7.	SUGGESTED MODIS DATA PACKET STRUCTURES	8
8.	SPECIFIC MODIS-T DATA PACKET FORMATS	10
	Appendix - Table of MODIS-T Parameters	18

1. BACKGROUND

Recently, Tom Magner (Code 717.3) has stated that, in the current MODIS-T design, sensor and engineering data will be inserted into data packets on a "first-come, first-served" basis as data is read from the CCDs. However, the MODIS data team has advocated the creation of specialized packets and has identified several desirable types of MODIS data packets. These include an engineering data packet for health-and-safety monitoring of the MODIS instrument at the ICC, possibly a separate MODIS ancillary data packet to support data processing, and a unique data packet for each spectral band of MODIS-N and MODIS-T (though not for each detector). All data packets will be time tagged at generation.

Tom Magner also indicated that, although there will be memory available to form the packets (on the order of 70% of the MODIS-T data in each scan must be buffered to provide a uniform output rate), the simplest (and cheapest) possible instrument is being designed. He stated that, since his group has no requirement to design specialized data packets, they weren't.

There are specific applications for which specialized data packets offer decided advantages: instrument monitoring in the ICC/IST, near-real-time data transmission and processing, and possibly real-time direct broadcast. In each case, the formation of a unique data packet for each spectral band would permit the isolation of data for specific required channels over specified time intervals.

Here, we state the advantages in creating specialized data packets within the MODIS instrument, provide one possible scenario for use, and outline the suggested data packet structures.

2. POSSIBLE SCENARIO FOR USE

One situation where specialized types of data packets are needed is field experiments. In this section, we will present a possible scenario for the use of the one-band-per-packet capability to support either the priority processing (in near-real-time) or the direct broadcast (in real time) of field experiment data.

The Path Code in the data packet's secondary header (to be explained later) can indicate the destination and processing priority for the data contained in the packet. A specific code setting could indicate to the platform data system that the data packet should be routed to the direct broadcast system, and copied to the platform tape recorder. Alternatively, the code could indicate that the data within the packet should receive priority processing in the ground data system. Provided that individual packets contain information from a single MODIS band, the user could customize his real-time or priority data request by orbital

segment and spectral coverage. Depending on available bandwidth, single or multiple spectral bands could be selected.

Since the orbit for the polar platform is easily predicted 16 (one repeat cycle) or more days in advance, the following scenario is possible:

The team member supplies the team leader with a near-real-time request, establishing the required bands and temporal coverage (UT start and stop times). This information is combined with other team member requests and forwarded to the ICC/EMOC. Appropriate commands are uplinked to the platform and the MODIS instrument. During the specified intervals, the Path Code of the affected data packets is revised to reflect a near-real-time or direct-broadcast requirement and the platform data system routes the data packets accordingly. Ground processing at CDOS and EosDIS would also be directed by the Path Codes.

3. APPLICABLE STANDARDS

The Consultative Committee for Space Data Systems (CCSDS) has published several standards that are applicable for MODIS data transmission and processing. The primary documents governing telemetry include:

> "Telemetry Concept and Rationale", CCSDS 100.0-G-1, Issue 1, Green Book, Consultative Committee for Space Data Systems, December 1987
>
> "Packet Telemetry", Recommendation CCSDS 102.0-B-2, Issue 2, Blue Book, Consultative Committee for Space Data Systems, January 1987.

Two newer documents also contain provisions affecting telemetry:

> "Advanced Orbiting Systems, Networks and Data Links, Concept, Rationale and Performance", CCSDS 700.00-G-1, Issue 1, Green Book, Consultative Committee for Space Data Systems, June 1989
>
> "Advanced Orbiting Systems, Networks and Data Links, Architectural Specification", CCSDS 701.00-R-3, Issue 3, Red Book, Consultative Committee for Space Data Systems, June 1989

The second document is still under review and is issued as a "Red Book". Once the review is complete and all provisions of the recommendation have been accepted, the document will be revised and reissued as a standard "Blue Book" recommendation.

The following CCSDS documents also contain provisions affecting the formatting and handling of MODIS data:

> "Telemetry Channel Coding", CCSDS 101.0-B-2, Issue 2, Blue

Book, Consultative Committee for Space Data Systems, January 1987

"Time Code Formats", CCSDS 301.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987

"Radio Metric and Orbit Data", CCSDS 501.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, January 1987

"Space Data Systems Operations with Standard Formatted Data Units, System and Implementation Aspects", CCSDS 610.0-G-5, Issue 5, Green Book, Consultative Committee for Space Data Systems, February 1987

"Standard Formatted Data Units - Structure and Construction Rules", CCSDS 620.0-B-1, Issue 1, Blue Book, Consultative Committee for Space Data Systems, February 1988

4. IMPLICATIONS OF CCSDS RECOMMENDATIONS

The recently introduced "Advanced Orbiting Systems" standards provide a number of new types of data transmission but maintain upward compatibility with the original Version 1 telemetry packet embodied in earlier CCSDS standards. It appears that MODIS telemetry needs are well served by the original Version 1 packet, so that the implications of the new standard for MODIS are minimal.

As defined in the CCSDS standards, the basic structure of data flow from the MODIS instrument to the ground data system is as shown in Figure 1. The various sources of telemetry data (sensor outputs) contained within the instrument packages (MODIS-N and MODIS-T) are the application 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 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.

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 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

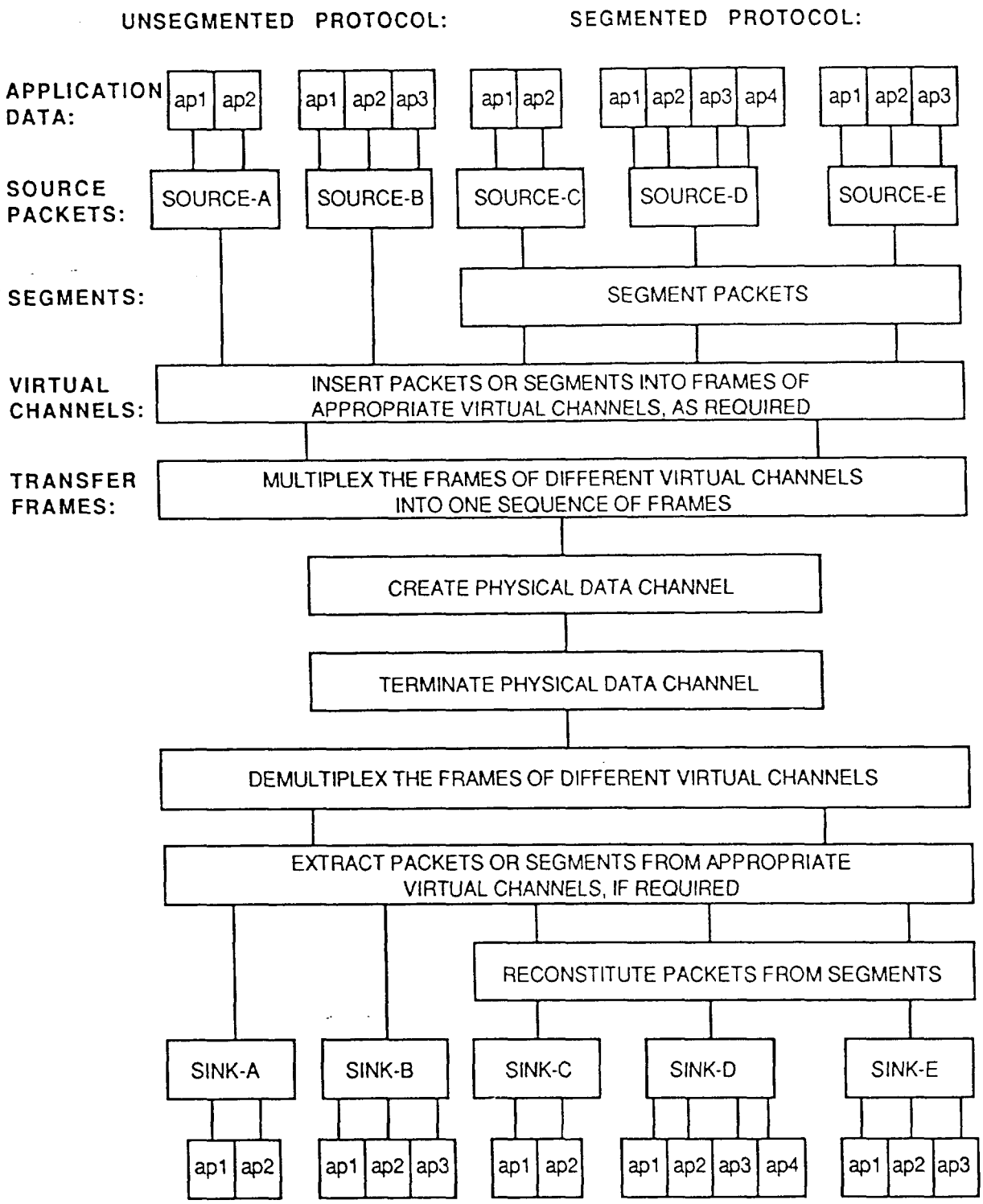

Figure 1: Telemetry Data Flow

Reproduced from "Packet Telemetry", Recommendation CCSDS 102.0-B-2, Issue 2, Blue Book, Consultative Committee for Space Data Systems, January 1987

Major Field	Length (Bits)
Primary Header	48
Secondary Header	Variable (optional)
Source Data	Variable
Packet Error Control	Variable (optional)

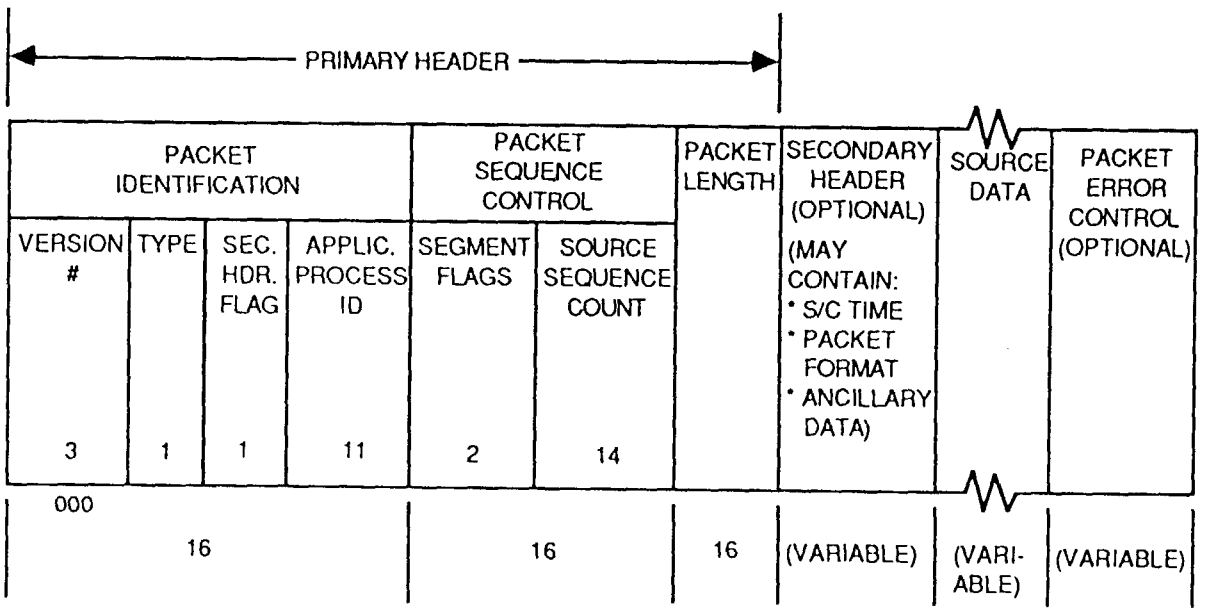

Figure 2: Version 1 "Source Packet" Format

Reproduced from "Packet Telemetry", Recommendation CCSDS 102.0-B-2, Issue 2, Blue Book, Consultative Committee for Space Data Systems, January 1987

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 8 kilobits. If the size of the desired instrument data packet is less than this limit, no problem exists. If the desired length exceeds 8 kilobits, however, the packet may be segmented to acceptable lengths within the "source" field. The packet format contains "segment flags" and a "source sequence count" to support this process.

The above standard provides machinery for the segmentation of long data packets into shorter (approximately 8 kilobit) packet segments that are more suitable for transmission over the spacecraft-to-ground data link. The secondary header may be used as needed to provide platform ancillary and instrument engineering data.

5. MODIS SCIENCE REQUIREMENTS

From the perspective of MODIS data processing and monitoring, the potential advantages of band-unique data packets 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 EosDIS, and a modest on-board processing capability within the MODIS instrument 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 EosDIS.

5.1 For routine processing of MODIS data at the CDHF, there are no major advantages to any particular packetization strategy.

5.2 To efficiently select data for real-time TDRSS transmission, instrument monitoring, and perhaps priority (near-real-time) processing, it is desirable to select MODIS data packets by spectral band.

5.3 Packetization by spectral band permits the user to efficiently access the MODIS sensor data of interest without the need to access and decommutate 100% of the MODIS data stream.

5.4 Band-by-band packetization offers the ability to selectively handle specified bands for specified orbital segments on the platform, across the downlink, and within the ground processing. Selective handling is important for instrument monitoring, for near-real-time support of field experiments,

and, if implemented, for direct data broadcast.

5.5 The trade-off between increased instrument design and fabrication costs for band-by-band packetization and more efficient and responsive data system capabilities must be carefully weighed.

6. MODIS INSTRUMENT DESIGN IMPLICATIONS

It would appear that the packet format that would make the smallest demand 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 to a continuous data rate at the interface, the processor memory would contain many finished data packets awaiting delivery and a single incomplete data packet that is receiving the latest data.

Because of the need to construct sample images to monitor instrument functions (at the ICC) or support field experiments, the optimal data packets for use would contain only data for a single spectral channel. 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 a different detector, so that data from a given detector 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 instrument interface, the 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.

6.1 For the MODIS-T instrument, two types of engineering data will be generated.

6.2 One type is generated in synchronization with each detector frame readout and contains instrument tilt angle, the current scan mirror angle, a time tag, a set of instrument attitude angles, a set of instrument attitude change rates, and a block of reserved bits for future implementation.

6.3 The second type of engineering data may be generated twice for each instrument scan, and contains electronic reference values, thermistor readouts, platform position, a time tag, and instrument status bits.

6.4 The bit allocations for each item, as provided by Tom Magner, are shown as a table in the Appendix.

6.5 Because the MODIS instrument will build "virtual" data packets, which will only be assembled in the ground segment (i.e., at the DHC), minimal on-board data storage will be required.

6.6 The on-board storage requirement will be for 35 packet segments, each 8,800 bits (1,100 bytes) in length. The total storage requirement is just under 40 K bytes. Of course, the actual storage required may possibly be twice this due to the need to fill packet segments while emptying out the completed segments.

7. SUGGESTED MODIS DATA PACKET STRUCTURES

The ground processing of the MODIS sensor data is the central concern of the MODIS data study team. Details of band data packet design that could facilitate data processing operations have become apparent and will be discussed in this section. Also, the format and attributes of other types of MODIS data packets (ancillary data from instrument and platform) have been defined and will be discussed.

7.1 The MODIS sensor data for a complete scan and for a single spectral band will be contained in one very long source data packet.

7.2 Each spectral band will generate its own unique data packet.

7.3 CCSDS Version 1 Source Packet Format will be utilized.

7.4 Source-Internal Segmentation, i.e. segmentation within the MODIS instrument, will be applied.

7.5 In this format, the Packet Length field directly indicates the length of the data in the packet segment, and the Source Sequence Count increments once for each segment to indicate the segment number of the data packet within the original very long source packet.

7.6 Segmentation Flags will be used to indicate a first (01), continuation (00), or last (10) segment.

7.7 An Instrument Identification Code, Scan Number, Time Code, and

Path Code will be placed into the data field as part of the secondary header of each segment.

7.8 In each packet segment, the secondary header flag will be set to one, indicating that a secondary header exists. For the DHC or any other facility to perform level-0 processing on the MODIS data, it will be necessary to extract time and scan number from the secondary header.

7.9 Consider the following possible scenario for MODIS-T:

34 bands (32 spectral bands plus 2 additional "dark" bands used for monitoring detector noise and stability) each are given their own data packet.

A 35th data packet could contain both detector-frame-readout and scan referenced instrument engineering data as described in Section 6.

The data volumes of each data packet would be similar (388,960 bits for packet types 1 to 34, and 395,264 (+ TBD) bits per scan for packet type 35)[1].

Each of the 35 data packets generated by the MODIS-T instrument per scan would be segmented into 45 or 47 segments.

This process would be repeated every scan.

7.10 It is possible that an abbreviated form of data packet type 35 (type 36) could be generated simultaneously for continuous real-time transmission to the ICC in support of basic health and safety monitoring.

7.11 The Application Process ID cannot be used to indicate complete path information for MODIS data. If we have 36 distinct types of MODIS-T packets and perhaps 40 distinct types of MODIS-N packets with four types (priorities) of data paths (Routine, Near-Real-Time, Real-Time TDRSS, and Direct Broadcast) and two data destinations (ICC and CDHF), we obtain 608 possible combinations.[2] The 11 bits of the ID in the header allow 2,048 possibilities, and it is unlikely that MODIS will be allowed to use 30% of all the available values.

7.12 If the capability to generate higher-level products within the

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[1]The total amount of overhead developed from the Appendix is approximately 17%.

[2]The Blue and Red CCSDS books regarding telemetry standards disagree as to whether the application process ID describes only the source, or the path including the destination as well.

MODIS instrument is provided, then the data packets generated for these products (presumably for direct broadcast) would require unique data identifiers as well.

7.13 Unique data identification can be achieved using the CCSDS Version 1 Secondary Header. Besides the Time Code (an obvious identifier of data), complete data identification and routing requires an instrument identification code (in case more than one platform carries MODIS instruments that operate concurrently, so that the Time Code does not uniquely identify the instrument), a Scan Number (needed to assure that all data packets generated at the instrument have been received at the ground when the scan is irregular, such as at the beginning or end of a service interruption, say a change in instrument tilt angle), and a Path ID to uniquely indicate the path and priority that is to apply to the transmission of the data in question.

8. SPECIFIC MODIS-T DATA PACKET FORMATS

The primary science data blocks proposed for MODIS use contain all the detector output data for a single scan of the instrument in one spectral channel. Since the MODIS-T instrument has 34 individual spectral channels, 34 of these data blocks will exist for each instrument scan as shown in Figure 3. These packets contain only detector output values and do not contain instrument engineering values (which would be repeated for each spectral channel).

The interpretation of detector output data will require supporting platform ancillary data and instrument engineering parameters. This information is contained in the MODIS Ancillary Scan Data Packet shown at the bottom of the figure. This packet contains platform ancillary and instrument engineering data that applies to all spectral channels.

Some of the data to be included in this packet is instrument engineering data that is sampled once as each detector frame is read out. These data are inserted into the central portion of the data packet shown. There are also scan related engineering parameters and platform ancillary data items that can be read out once (or twice) for each instrument scan. The proposal is that these values be read out once at the beginning of each earth scan and once at the completion of each earth scan (1.154 sec. later) and inserted in proper time order (at the beginning and end) as shown in the figure.

The data blocks discussed thus far are logical data units that are rather long and not suitable for transmission over the spacecraft-to-ground data link, which requires blocks approximately 8 kilobits (maximum) in length. The Version 1 CCSDS data packet format provides packet segmentation machinery that can be used to break up the logical data packets into blocks suitable for transmission.

Suitable packet segments can be constructed at the instrument without the need for complete unsegmented packets to ever exist at the spacecraft end of the link. Since creating segmented data packets requires much less on-board memory than would be required to store unsegmented packets, important hardware simplifications are achieved if data are inserted into segmented packets and transmitted as they are completed. The unsegmented packets shown in Figure 3 never need to exist at the spacecraft end of the data link and may be described as "virtual" data packets for spacecraft purposes.

The unsegmented packets containing complete data for an instrument scan (in a specific spectral channel) will first exist after they are "reconstructed" using DHC software designed to reassemble segmented packets after they are received at the ground terminal. The fact that the unsegmented data packets existed only as "virtual" packets at the instrument will in no way detract from the ability of this software to create the desired scan data packets from the received data.

Figure 4 shows the breakout of a Single-Channel Scan Data Packet into constituent segmented data packets. Forty-five segments are required to contain the data. Figure 4 also shows the breakout of the ancillary data packet. The addition of scan based data at the beginning and end of the packet results in 47 segments.

Figure 5 shows the basic structure of the segmented Single-Channel Scan Data Packets. All Primary Header items except the Application Process ID are defined in CCSDS Blue Book 102.0-B-2, "Packet Telemetry". The proposed Application Process ID would define the spectral channel, i.e. 34 ID values would be required, each in one-to-one correspondence with a unique instrument spectral channel. Amplification would be provided in a secondary header containing a unique instrument identification code for each version of the MODIS instruments, a scan number indicating the number of instrument scans (rotations) completed since midnight (UT) of the present day, a Time Code, and a Path Code. To achieve required time resolution accuracy, it is thought that the proper number of bits (according to CCSDS-defined formats) is 72 rather than the 64 shown some earlier tabulations. Seventy-two bits will provide a time accuracy of 1/10,000 sec. The Path Code is an amplification of the Application Process ID and will be used to indicate processing priorities to the DHC as well as the ultimate intended destination of the data. As shown in the figure, data from 24 frames will fit in each segment.

Figure 6 shows the corresponding breakout for MODIS ancillary data segments. As before, the time tag has been revised to 72 bits. To achieve a total of 360 bits of engineering data for each frame (since the observation data contains 360 bits), the number of spare bits in the sample field has been reduced from 200 to 182. Also, the total number of frames associated with each scan has been

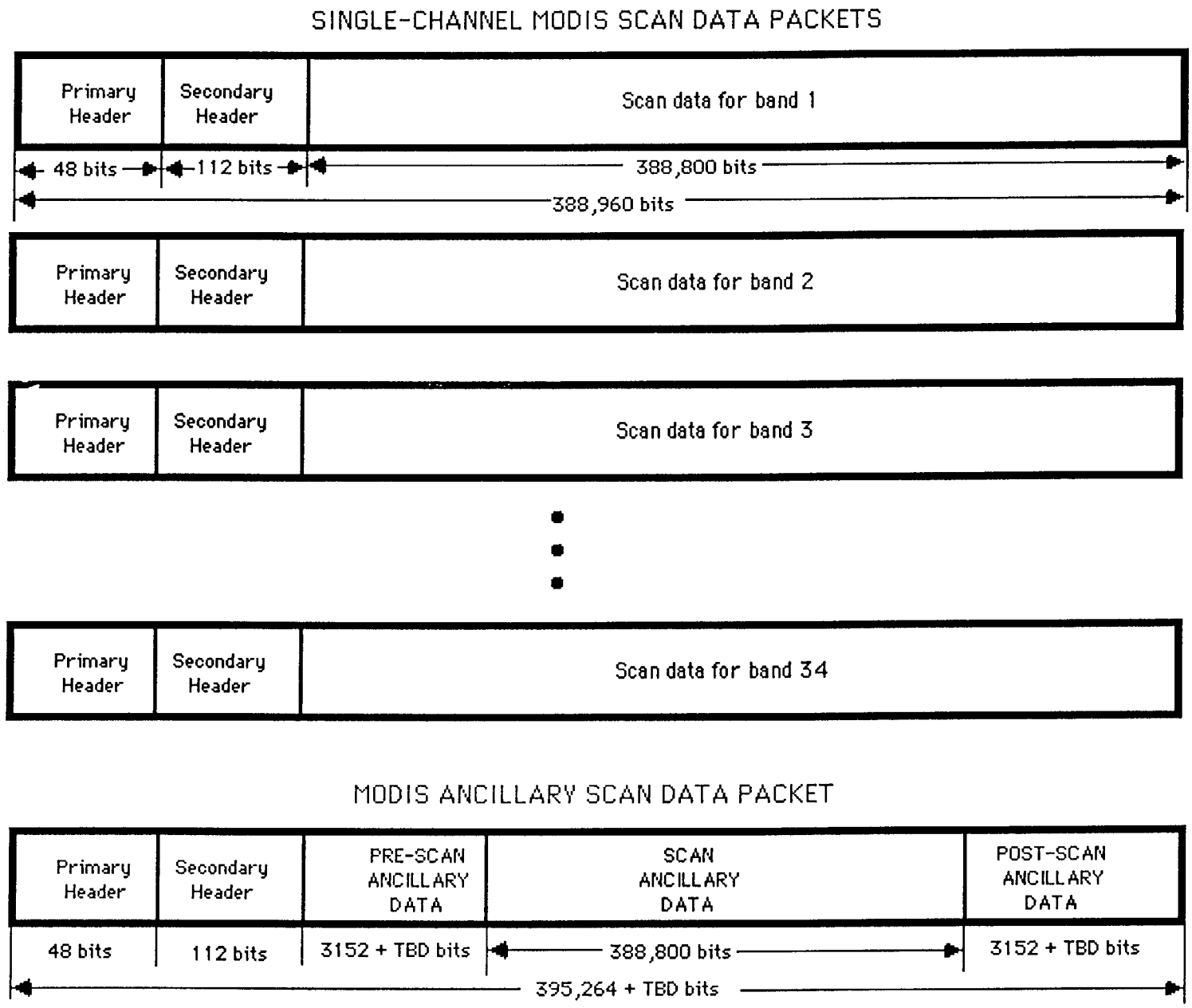


Figure 3. MODIS Source Data Packet Gross Formats

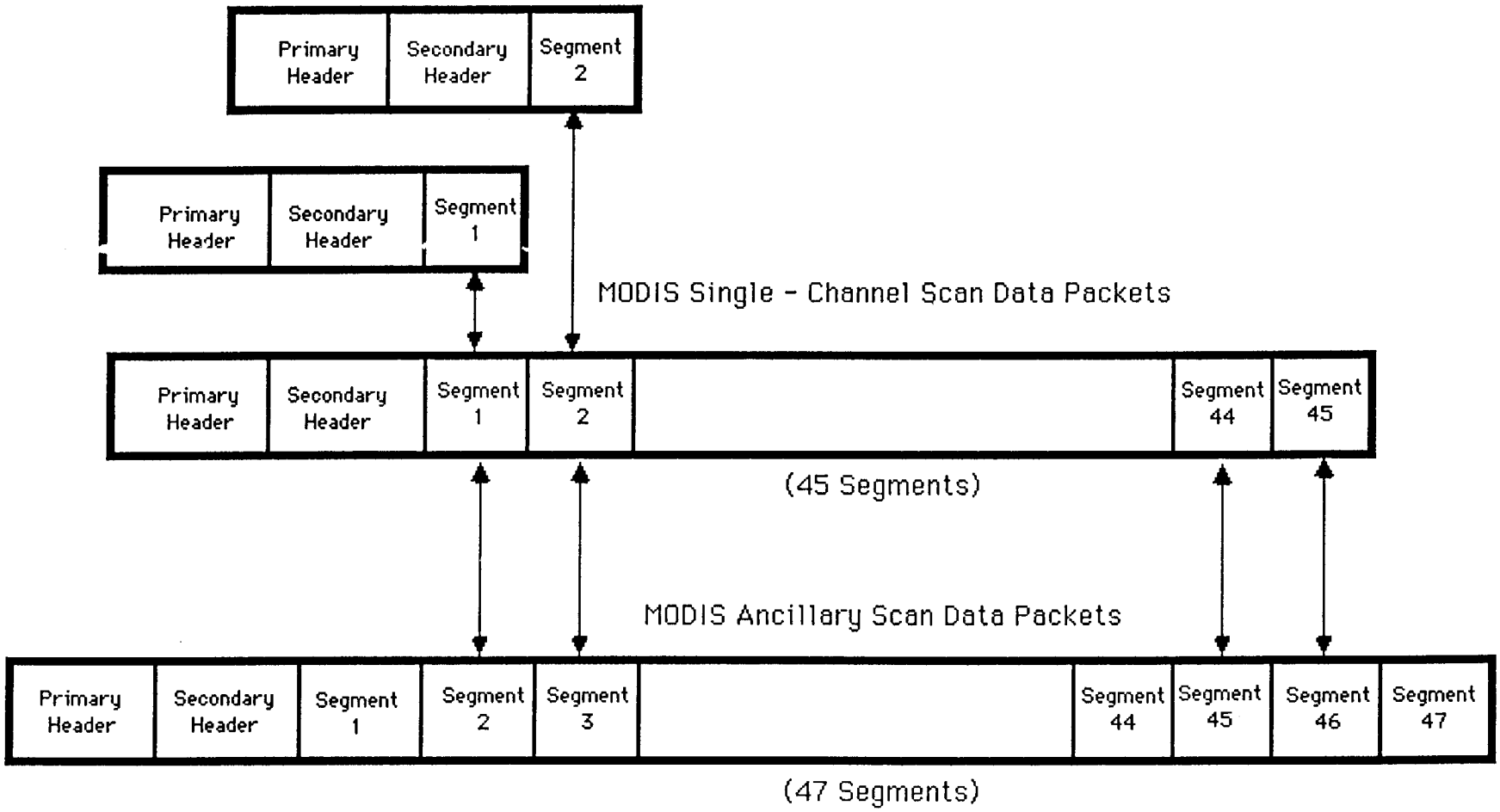


Figure 4. Segmentation Relationships Between MODIS Single-Channel Scan Data Packets and MODIS Ancillary Scan Data Packets

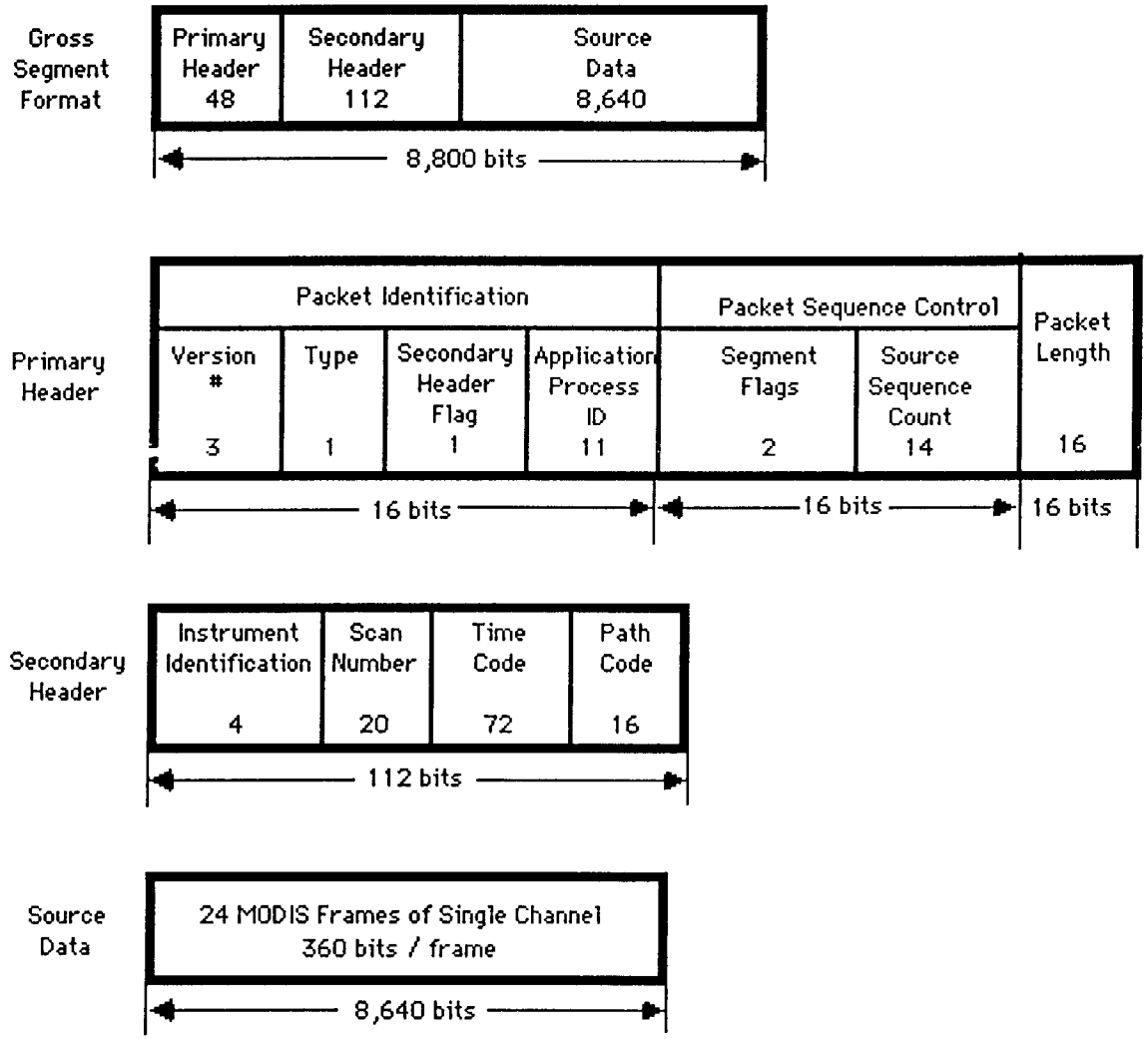


Figure 5. MODIS Single-Channel Scan Data Packet Segment Formats

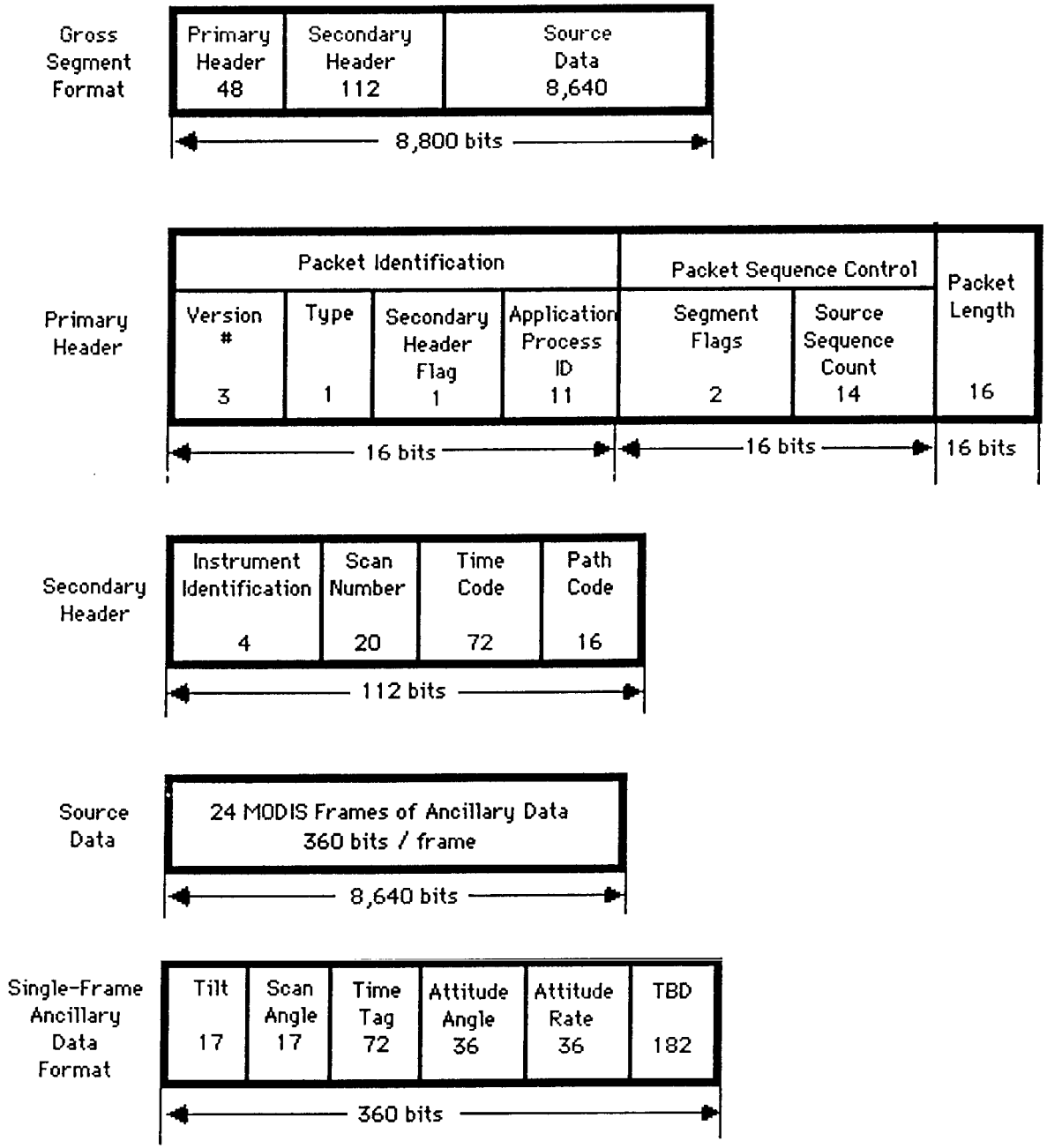


Figure 6. MODIS Ancillary Scan Data Packet Segment Formats

revised from 1,077 to 1,080. This results in ancillary data segments of length identical to observation data segments.

Formats for the pre-scan and post-scan data are shown in Figure 7. These segments have a different length than the other segments and will ultimately depend on the definition of platform ancillary data for their complete specification. For example, the "96 bits" for the POP position will probably include both S/C position and velocity (six components of the state vector), possibly at 32 bits each (192 bits total).

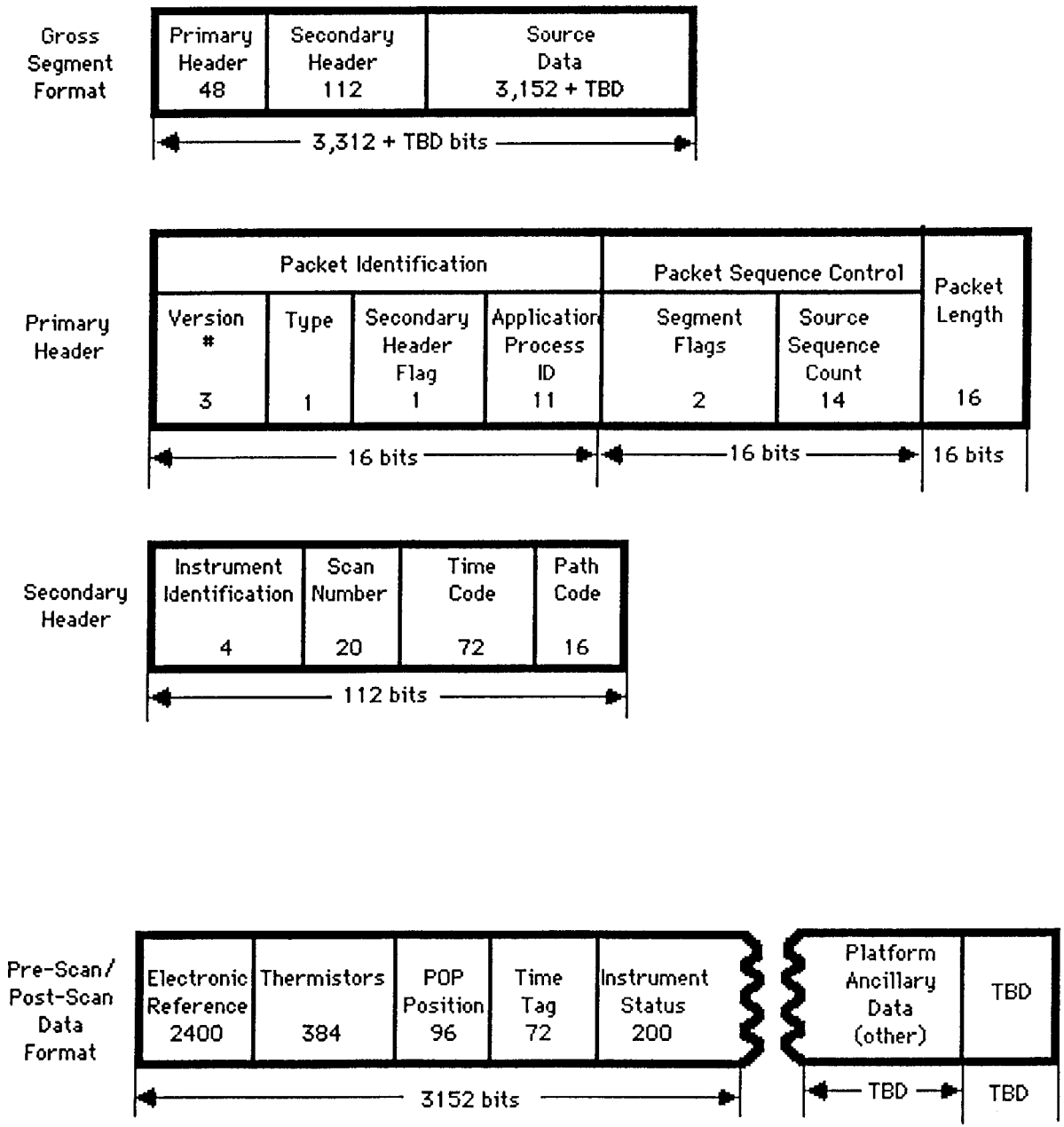


Figure 7. MODIS Ancillary Scan Data Packet Segment Formats Continued

APPENDIX

Table of MODIS-T Parameters

Revised on	28-Aug-89
	1.1 km along track IFOV
	1.1 km cross track IFOV
	single scan speed
	F3.1
ground frames	1,007
dark frames	50
calibration frames	20
total frames	1,077
detector	30 pix by 34 pix
slit FOV	1.1 km by 33 km
slit FOV	1.560 mrad by 46.809 mrad
slit FOV	5' 22" by 2° 40' 48"
detector pitch	161.7 µm by 220.5 µm
detector A reg size	4851 µm by 7497 µm
#bits/frame	
frame (12 bit A/D)	12,240
tilt	17
scan	17
time tag	64
Attitude angle	36
attitude rate	36
TBD	200
total bits/frame	12,610
#bits/swath	
frames	13,580,970
electronic reference	2,400
thermistors	384
POP Position	96
Time tag	64
Instrument status	200
Total #bits/swath	13,584,114
total scan time (sec)	4.615
scan mirror speed (rev/min)	6.501
transmitted data rate (bits/sec)	2,943,569
earth scan time (sec)	1.154
frame time (msec)	1.146
data generated during earth scan (bits)	12,698,270
earth scan data rate (bits/sec)	11,006,457
earth scan data rate (pixels/sec)	917,205

1.1 km. Pixels, Single Scan Speed, 30 Along Track Pixels

MODIS Ocean Data Products Overview

We present here for the first time an overview of the ocean core data products proposed for MODIS. Although the overview may be considered a candidate processing scenario, its primary purpose is to show the interrelations between the products. The overview is intended to be compatible with elements of the MODIS data processing scenario presented by the MODIS Data Study Team on August 25, 1989, but is more detailed with respect to the ocean products. Figure 1 is a graphic representation of the overview, which is discussed in more detail in the following. Note that in Figure 1, only core products are enclosed, methods and processes to generate those products are left open.

Derivation of MODIS ocean data products begins with Level 1B calibrated radiances. A cloud filter is applied, which diverts the data stream from ocean products to cloud products (if pixels are cloudy they will not be processed for ocean products). However, these cloud products will be used to make determinations of surface incident photosynthetically available radiation (PAR), for use later in the ocean processing scheme.

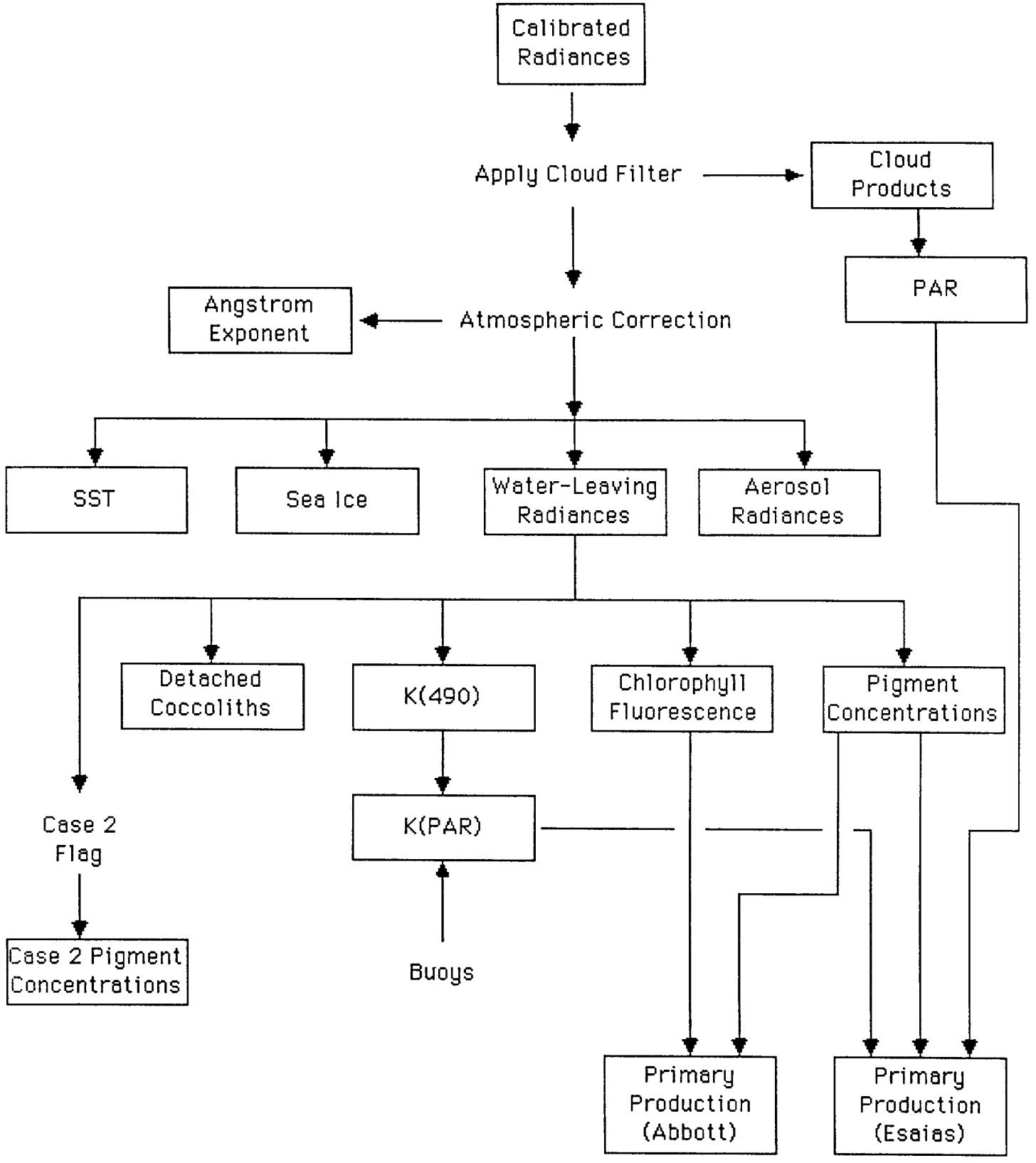
If pixels pass the cloud test (if they are sufficiently clear), they will be atmospherically corrected; i.e., the Rayleigh scattering and aerosol absorption and scattering contributions to the total radiances will be removed. Angstrom coefficients (an indicator of the wavelength dependence of aerosol attenuation) comes out directly in this process.

Atmospheric correction generates four ocean core products: sea surface temperature (SST) and sea ice from the infrared channels, and water-leaving radiances and aerosol radiances from the visible channels. At this point, six of the 14 ocean core data products have been produced. Water-leaving radiances form the basis for seven of the eight remaining products. The 8th product, in-situ validation observations, are determined by other means.

Water-leaving radiances will be used to directly obtain detached coccolith (from coccolithophores) concentrations, K(490), chlorophyll fluorescence, and chlorophyll a pigment concentrations for Case 1 and Case 2 waters. In the generation of Case 2 pigment concentrations, a flag differentiating Case 1 from Case 2 areas will be used to determine whether to employ the Case 2 algorithm. From K(490) and the in-situ optical buoys of Dennis Clark, K_{PAR} will be determined.

For the final ocean core data product, primary production, two algorithms have been proposed, neither of which has been fully defined at this time. Mark Abbott proposes to use MODIS-generated chlorophyll fluorescence in conjunction with pigment concentrations to develop a semi-analytical algorithm for production, involving also sea surface temperature, scatterometer winds, and physiologically-based models of phytoplankton growth. Wayne Esaias proposes an empirical approach, whereby MODIS-generated pigment concentrations, surface incident PAR, and the diffuse attenuation coefficient for PAR (K_{PAR}) will be related to measured in-situ primary production. Thus he will combine three MODIS products to generate a fourth.

Figure 1. MODIS Ocean Core Data Overview



Determination of Attenuation at 490 nm, K(490)

This algorithm is to determine the diffuse attenuation coefficient at 490 nm, denoted K(490). The algorithm is of simple power-law form, and requires as input either water-leaving radiances or pigment (both Level 2 products). Thus the algorithm is applicable only where these products are available (i.e., for cloud-free pixels).

The algorithm follows the form

$$K(490) = A(R)^B + K_w, \tag{1}$$

where R is the ratio of water-leaving radiances at 443 nm to 550 nm (in the CZCS algorithm), K_w is the attenuation by pure seawater (known a priori), and A and B are empirical constants, also determined a priori. The algorithm may also be computed from pigment concentration in the same form as Eqn. 1 with R replaced by C (pigment concentration), however, with different constants A and B.

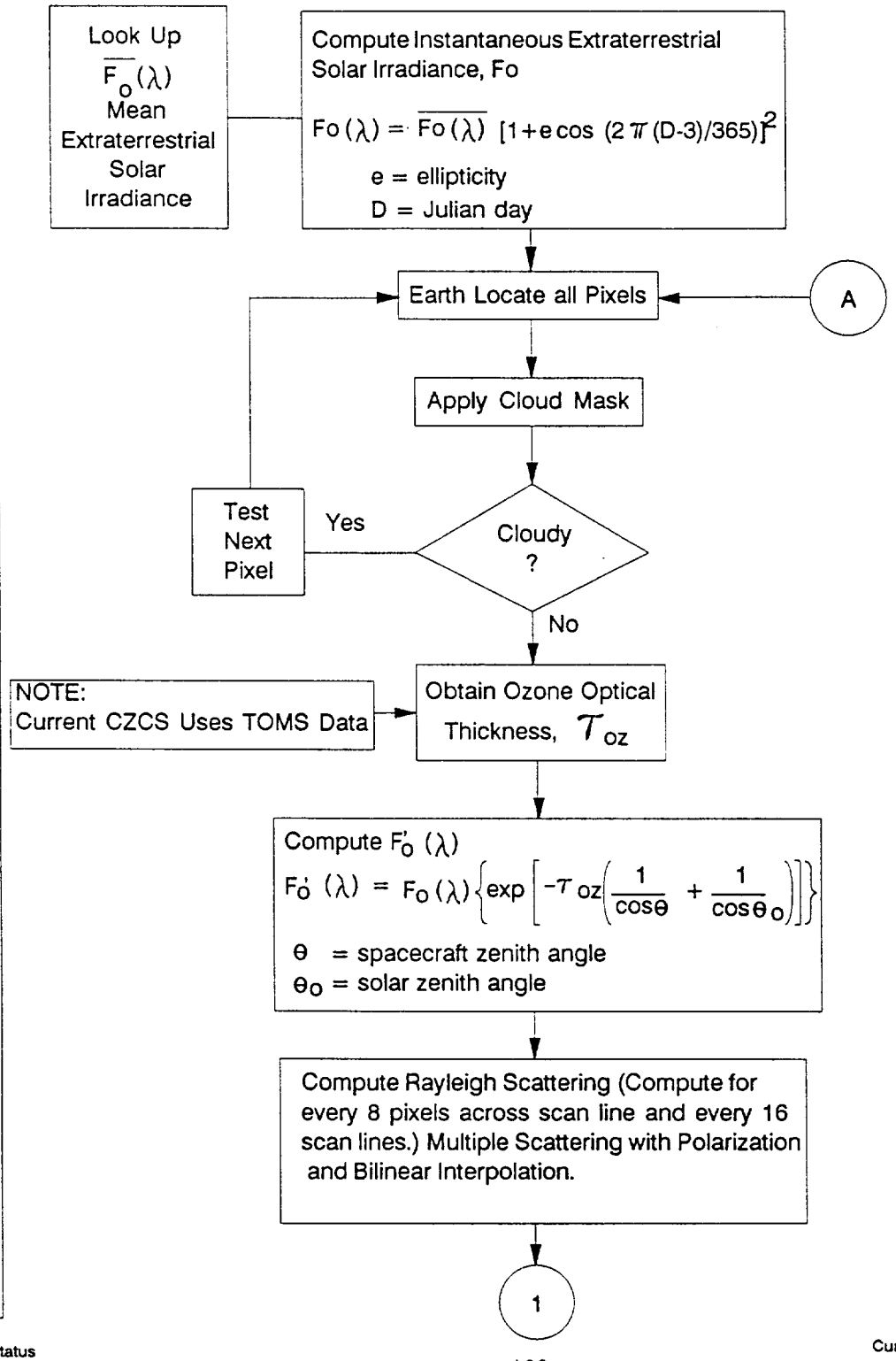
There are several variants of the constants A and B, depending upon whether or not Case 2 waters are excluded. For routine processing one will probably assume Case 1 waters. Finally, it should be noted that these empirical constants were determined before refinement of the current CZCS atmospheric correction algorithms, and are subject to change after the launch of SeaWIFS. However, the form of the K(490) algorithm can be expected to remain the same.

Reference: Gordon, H.R. and A.Y. Morel, 1983. Remote assessment of ocean color for interpretation of satellite visible imagery. A review. Lecture Notes on Coastal and Estuarine Studies. Springer-Verlag. New York. 114 pp.

Coastal Zone Color Scanner Algorithm for Deriving Water Leaving Radiance.
Phytoplankton Pigment Concentrations in the Middle Atlantic Bight: Comparison of Ships Determinations and CZCS Estimates. Gordon, H.R., D.K. Clark, J.W. Brown, O.B. Brown, R.E. Evans, and W.W. Broenkow
Applied Optics, Vol. 22, No. 1, January 1983

Algorithm requires that there is an area of clear water in the scene, i.e., clear water radiance.

Sta	LOC	HI	Step



Algorithm Status

O - Operational
D - Development
C - Conceptual

LOC

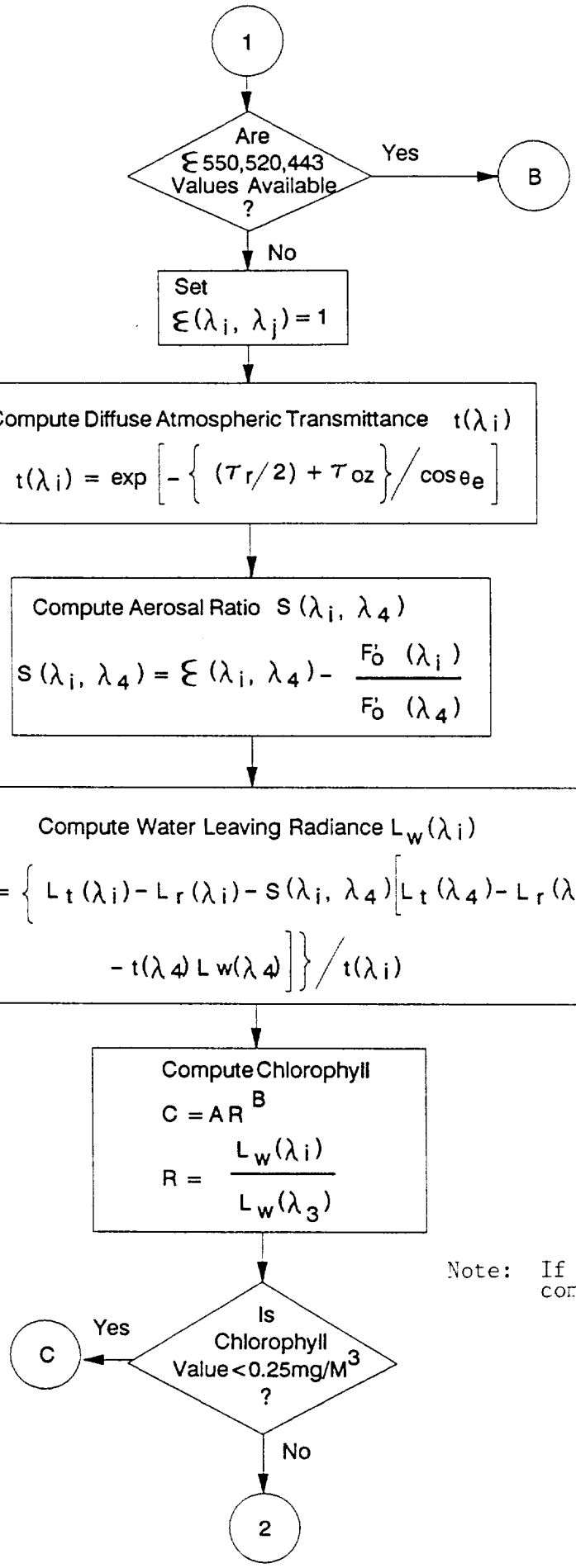
Lines of Code

Current Human Intervention

A - Autonomous
H - Some Human
M - All Manual

Sta	LOC	HI

Step



Note: If scene complete

Sta	LOC	HI

Step

2

C

Compute Diffuse Atmospheric Transmittance $t(\lambda_i)$

$$t(\lambda_i) = \exp\left[-\left\{(\tau_r/2) + \tau_{oz}\right\}\Big/\cos\theta\right.$$

Input $L_w(\lambda)_N$ (Normalized Water Leaving Radiance

For λ = 520, 550, and 670

Compute Water Leaving Radiance at Clear Water Pixel

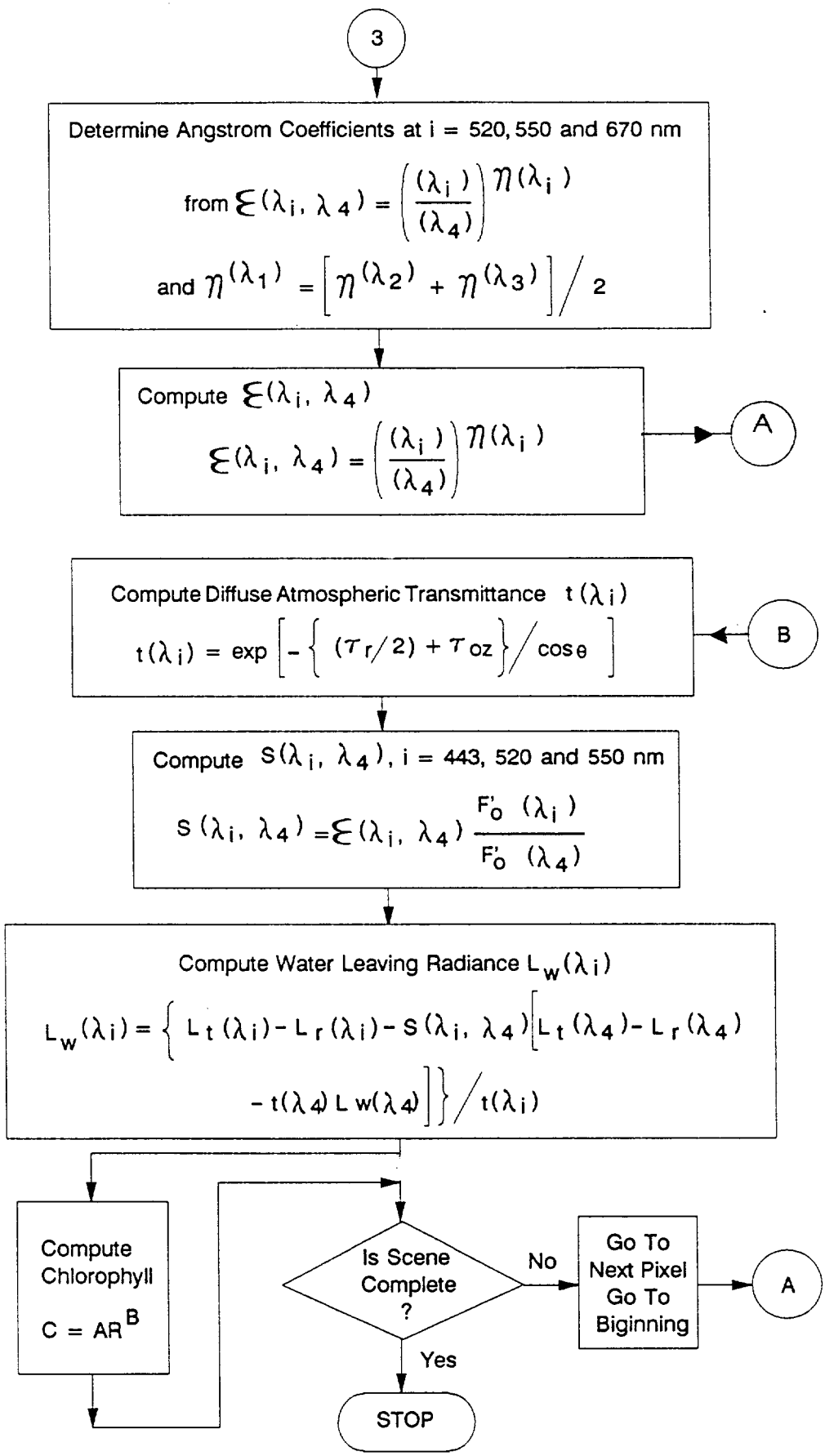
$$L_w(\lambda) = \left[L_w\right]_N t(\lambda) \quad \cos\theta_o$$

Compute Aerosol Ratio, $S(\lambda_i, \lambda_4)$ i = 520 and 550nm

$$S(\lambda_i, \lambda_4) = \frac{L_T(\lambda_i) - L_r(\lambda_i) - t(\lambda_i)L_w(\lambda_i)}{L_T(\lambda_4) - L_r(\lambda_4) - t(\lambda_4)L_w(\lambda_4)}$$

Compute $\varepsilon(\lambda_i, \lambda_4)$, i = 520 and 550 nm

$$\varepsilon(\lambda_i, \lambda_4) = S(\lambda_i, \lambda_4)\frac{F'_o(\lambda_4)}{F'_o(\lambda_i)}$$

3

Sta	LOC	HI	Step