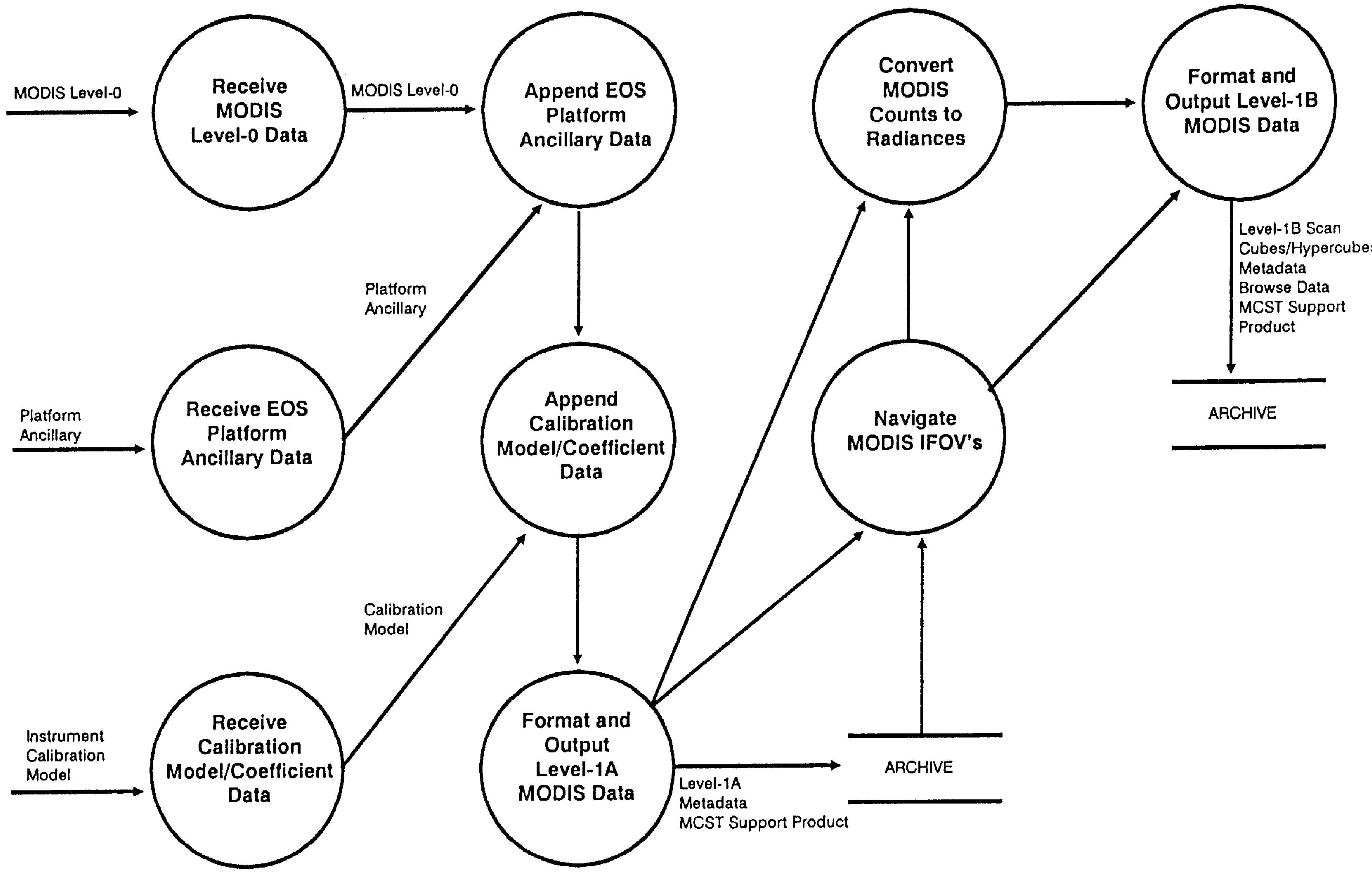
MODIS DATA STUDY
TEAM PRESENTATION

July 13, 1990

AGENDA

1. MODIS Level-1 Data Flows (Ardanuy, McKay)
2. MODIS Level-1 Data Blocking Concepts (Ardanuy)
3. Receive MODIS Level-0 Data (McKay)
4. Assemble Scan Cubes (Schols)
5. Interpolate Platform Data to Anchor Point Times (Blaisdale)
6. Instrument to Platform Coordinate Transformation (Blaisdale)



MODIS Level-1 Data Flows

DESCRIPTION OF MODIS LEVEL-1 PROCESSING DATA FLOWS

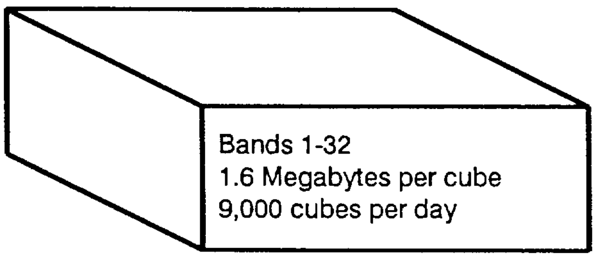
- Receive MODIS Level-0 Data
  - Interpret data transmission quality flags
  - Verify data ID information (if transmission quality poor)
  - Perform initial verification of instrument operation
  - Record data packet receipts
- Receive Platform Ancillary Data
  - Append data descriptors
- Append Platform Ancillary Data
  - Maintain integrity of original Level-0
- Receive MCST Calibration Data

DESCRIPTION OF MODIS LEVEL-1 PROCESSING DATA FLOWS

- Append MCST Calibration Data
- Format and Output Level-1A Data
  - Original Level-0 data with additional needed data appended
- Navigate Anchor Points
  - Select anchor points
  - Interpolate platform data to anchor point times
  - Convert MODIS pointing information
  - Instrument to platform coordinate transformation
  - Determine geodetic Earth coordinates
- Calibrate Observations
  - Equations and procedures supplied by the instrument manufacturer and MCST
- Format and Output Level-1B Data

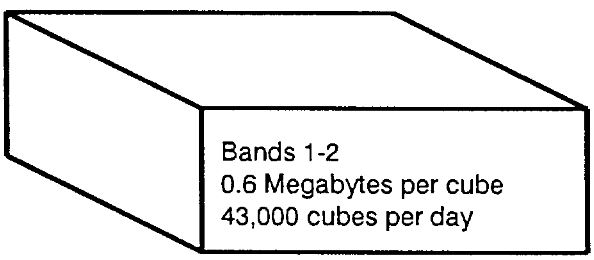
MODIS LEVEL-1 DATA BLOCKING CONCEPTS

MODIS-T: ONE LEVEL-1 DATA CUBE

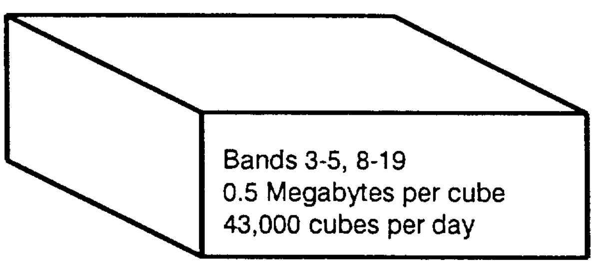


32-1.1 km Spectral Bands

MODIS-N: THREE LEVEL-1 DATA CUBES

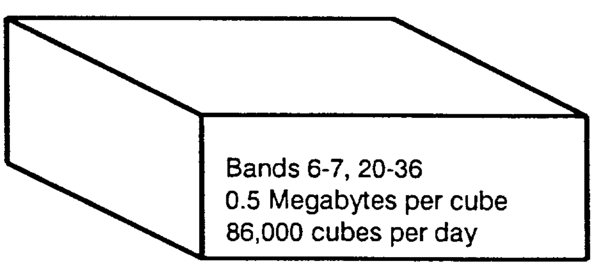


Two 214 m Spectral Bands
(equivalent to 32-856 m bands)



15 Daytime Spectral Bands
- Three 428 m bands
- Twelve 856 m bands

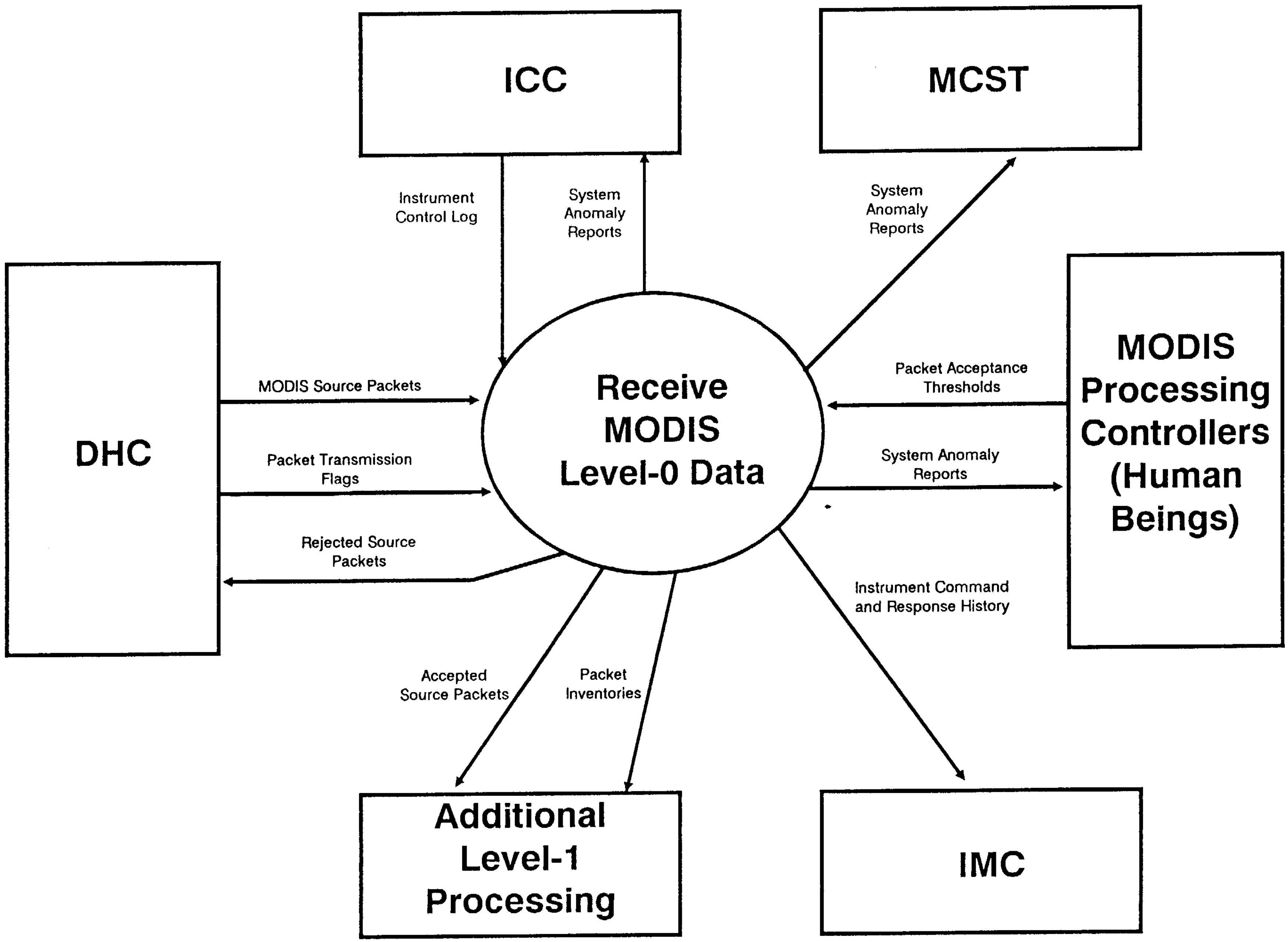
(equivalent to 24-856 m bands)

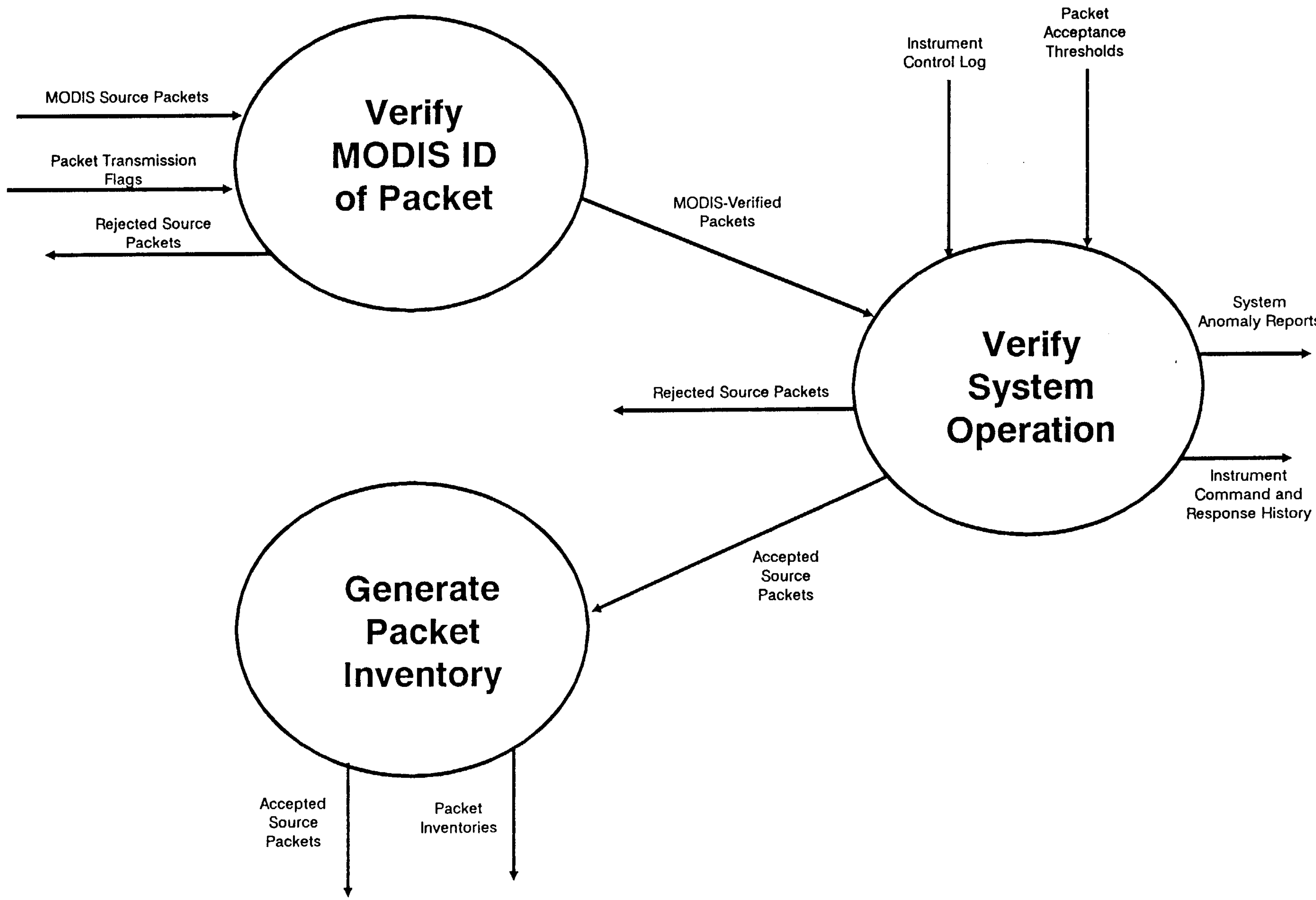


19 Day/Night Spectral Bands
- Two 428 m bands
- 17-256 m bands

(equivalent to 25-856 m bands)

NOTE: Above is valid for Level-1A; at Level-1B, packing might be by scene (a group of scans), yielding a four-dimensional hypercube.


ICC
MCST
Instrument Control Log
System Anomaly Reports
System Anomaly Reports
DHC
MODIS Source Packets
Packet Transmission Flags
Rejected Source Packets
Receive MODIS Level-0 Data
Packet Acceptance Thresholds
System Anomaly Reports
MODIS Processing Controllers (Human Beings)
Instrument Command and Response History
Accepted Source Packets
Packet Inventories
Additional Level-1 Processing
IMC


MODIS Source Packets
Packet Transmission Flags
Rejected Source Packets
Verify MODIS ID of Packet
MODIS-Verified Packets
Instrument Control Log
Packet Acceptance Thresholds
Verify System Operation
System Anomaly Reports
Rejected Source Packets
Instrument Command and Response History
Accepted Source Packets
Generate Packet Inventory
Accepted Source Packets
Packet Inventories

ASSUMPTIONS:

1. CDOS processing will provide reconstructed MODIS "Source Packets" as MODIS Level-0 data.

2. The DHC will deliver source packets for MODIS processing as soon as all required "transfer frames" have been received and packet reconstruction processing is complete.

3. Source packets will be spectral band interleaved.

4. Instrument Engineering Data could be contained in a separate source packet.

5. Packets still incomplete 24 hours after data acquisition will be delivered "as is" with missing data segments annotated.

6. Data transmission quality indicator flags will be provided with the source packets. Segments that are Reed-Solomon uncorrectable may be delivered for MODIS processing.

DATA VERIFICATION TESTS:

1. The MODIS identification test (designed to help assure that mislabeled source packets for other EOS instruments are rejected) may consist simply of a segment length test to determine if the length of the segment corresponds to an allowed MODIS length.

2. The system verification test may consist of a comparison of the candidate source packet with a template of expected instrument status bit values derived from the instrument command log. Correspondence between expected and received status bit values would test the following system functions:

a. Command upload generation

b. Command uplink

c. Command routing on the platform

d. Instrument decoding and execution of commands

e. Instrument status sensing

f. Sensor data downlink, including data transmission errors

g. Data packet identification (MODIS or other EOS instrument?)

ASSEMBLE SCAN CUBES

As one of the first steps of level-1 processing, the MODIS data will be reformatted into a data cube. The three dimensions are along-track position, across-track position, and wavelength, as indicated in the figure.

A data cube contains the science (radiometric) data from the MODIS instrument and a header. The cube dimensions and contents will be somewhat be different for each instrument (i.e., MODIS-N and MODIS-T). The header information contains ancillary platform data (which comes as a separate data stream from the Level-0 instrument data stream), instrument ancillary data, and some space reserved for data quality flags. The header information is appended to the sensors' radiometric data.

The header at Level-1 is assumed to be in a form of a template containing locations to be filled in at the various levels of standard data processing. The fully completed header will contain all relevant information pertaining to all levels of standard products to which it is attached.

Header allocations might include the following topics :

- Science Team reserved - TBD requirements.
- Geolocation reference transformations - orbit and attitude reference origins and matrix elements; science instrument "boresight" reference origin and pointing characteristics.
- Geolocation ancillary parameters - data embedded orbit, attitude, and instrument pointing parameters (e.g., scan number).
- User information - description of the data format and how to read the data.
- Metadata - e.g., orbital revolution number, standard scenes covered (or coverage), spatial/temporal resolutions - by product, appropriate standard map/projections, percent relevant geophysical parameter(s).
- Error codes - error codes imposed by the ground receiving station, transmission errors to/from the LZP, processing errors detected by the LZP, processing errors detected by the EOSDIS, calibration/validation/ product-certifications by the Science Team
- Calibration references - calibration equations, algorithms, coefficients, constants, version number and when last changed.
- Calibration parameters - mapping of the data value locations to which the calibration is to be applied.

In putting together a data cube, we try to develop one single cube concept, which can be used throughout the whole Level-1 processing scenario.

As a concept of a Level-1 data cube (scene/hypercube), the total science data content should not occupy more than 100 MB for the 1 km * 1 km (the 856 m or 1.1 km) pixels. The cubes are stored in memory as 3-D (4-D) arrays A_{ijkl}, where the first index is the wavelength. This organization provides fast retrieval of the data when they are going to be calibrated within Level-1. The calibration can be carried out through parallel processing by layers (i.e., per wavelength). For the higher-resolution MODIS-N pixels we add more layers to the cubes, viz. four for the 428 m pixels and 16 for the 214 m pixels.

The following gives an explanation of one derives the described cube/hypercube concept:

To construct this cube, one has to consider the following questions:

- How much data do we want to store in one cube/hypercube?
- How do we organize the data content of the cube into a 3-D/4-D array (i.e., which index goes first, second, etc.)?
- How might the data in a cube be processed (i.e., scalar/vector/ parallel)?

These questions are discussed in detail in the following.

Question 1:

The amount of data that goes into a cube will be primarily determined by

- The processing scenarios, described in the Science Team Members' (STMs) proposals;
- The memory capacity of the computer system. There will also be a trade-off between storage and CPU.

For cloud detection one may wish to process scenes (multiple scans) of data. A scene, which covers an area with a horizontal extent of a few thousand kilometers on each side, contains several scan cubes (or a hypercube).

A scan cube is defined as all data from a single instrument scan, for all wavelengths. For MODIS-N (MODIS-T) this is 8 * 1582 = 12,656 (32 * 1007 = 32,224) 1.1 km * 1.1 km pixels of two bytes each, at 36 (32) wavelengths, which corresponds to 0.9 MB (2 MB) of data. A MODIS-N (MODIS-T) scan covers an area of roughly 8 km * 1,800 km (32 km * 1,500 km for no tilt).

A scene/hypercube contains between ten or 20 (MODIS-T) and a few hundred (MODIS-N) scans (cubes) of data, which is between 50 and 150 MB. For the higher-resolution pixels of 428 m and 214 m the data content in a scene amounts to 600 and 2,400 MB.

Question 2:

A data cube is stored in memory as a multi-dimensional array A_{ijk} (A_{ijkl}). It is assumed that the data in memory is going to be sequentially accessed. The order of the indices of the array determines the speed at which the data in a cube can be accessed and processed.

For calibration purposes one wants to process the data in the cube per wavelength (i.e., per image). It is then conceivable that the wavelength goes as the first index of the array. The calibration has to be performed for each science datum in each image.

One wants to geolocate only the anchor points (i.e., approximately 1% of the pixels in a cube). This information goes in a header, which is to be appended to the stack of images on top of the data cube. For this reason, one would again prefer to let the wavelength be the first index.

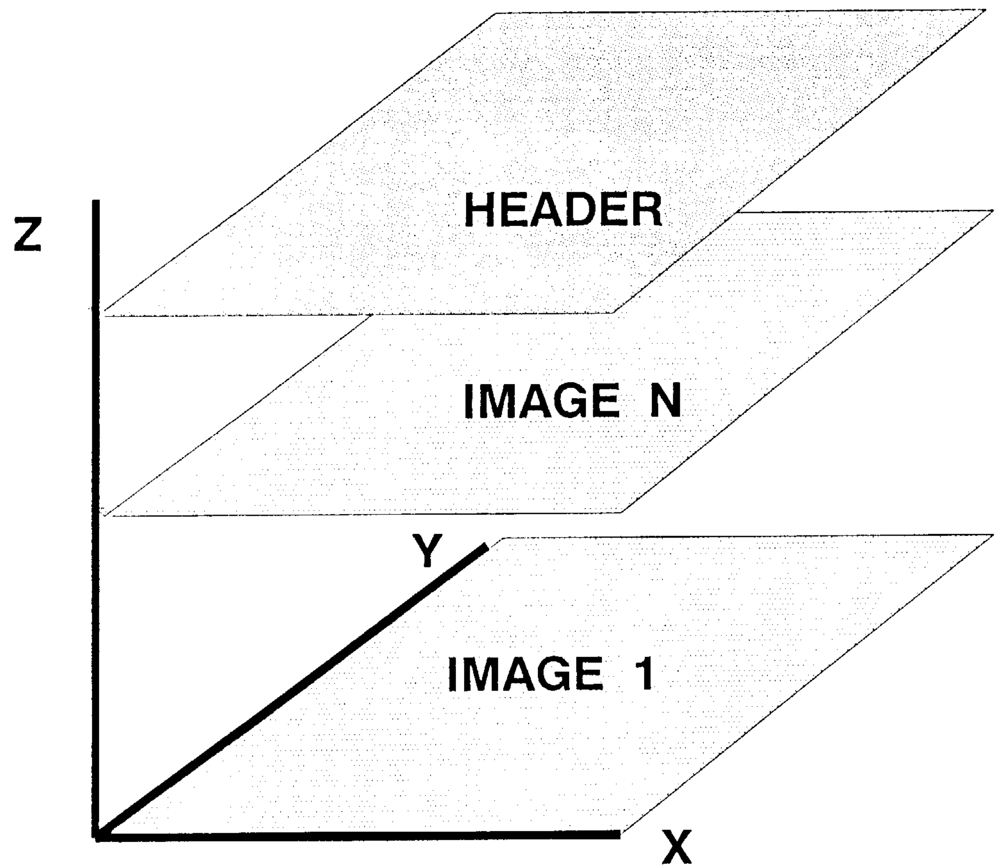
The science team members (and their multiple-band standard data product algorithms) will generally access the data cube on a pixel-by-pixel basis. For that purpose we may prefer to have the cross-track dimension as the first index.

Question 3:

In processing the data cubes there are two extremes. One is to have many processors, each of which has sufficient memeory and processing power for one single cube, while the other is a large segmented memory and one processor with sufficient power to do all the required calculations.

For calibration purposes we want to process the data in a cube all at the same time for each wavelength.

Cube concept.



X = ALONGTRACK
Y = CROSSTRACK
Z = WAVELENGTH

INTERPOLATE PLATFORM DATA TO ANCHOR POINT TIMES

The platform data for position, velocity, and attitude will in general not be available at the same times as the times when the selected anchor points were observed. This will require interpolation. The exact form of interpolation will depend on the frequency of the platform data, with more complicated procedures necessary if the data are available less frequently.

The data which we will require in the Earth location process are the position and attitude of the platform at the instant of each anchor point observation. The attitude uncertainty is expected (at this time) to cause the largest error.[1] The position error affects Earth location in a quasi-linear fashion.[2] Timing errors will be important mainly as they result in erroneous position and attitude data being selected for a particular anchor point.

In general, the attitude data are expected to be available from CDOS with adequate frequency to require only a linear or perhaps four-point interpolation.[3] It is not anticipated that the platform attitude will be allowed to wander irregularly. If unresolved short-period oscillations are in fact present, it may not be possible to isolate them anyway and additional inaccuracies in the Earth location may result.

The position data will require a more complicated interpolation as the spacecraft position must be known accurately. If the frequency of data is high enough, at least once per second, a relatively simple procedure utilizing only the position and velocity will probably achieve the required accuracy. If this data rate proves to provide insufficient accuracy, more complicated polynomial fits, e.g. Chebyshev, may be utilized.

It is anticipated that CDOS will issue some recommendations for the use of their attitude and orbit products, as the considerations discussed above for MODIS will apply to many of the EOS instruments. Further review of documentation should precede any detailed algorithm development in the current Level-1 processing design effort.

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[1]For example, an altitude of 705 km, a 1 km error at nadir is produced by an attitude error of 293 arc seconds; an error of 0.125 km (one-half the high resolution pixel) is produced by an attitude error of 37 arc seconds.

[2]To first order, an error of 1 km along the orbit will result in a ground error of about 1 km along-track.

[3]The MODIS Data Study Team has established a 10 Hz sampling requirements for the platform attitude to resolve perturbations resulting from instrument-scan uncompensated momentum.

INSTRUMENT TO PLATFORM COORDINATE TRANSFORMATION

The following coordinate systems are defined in the "General Instrument Interface Specification for the EOS Observatory," dated 5 January 1990.

Orbital Reference Coordinate System. Coordinate system centered at platform center of mass, where X is platform velocity vector, Z is toward center of Earth.

Platform Reference Coordinate System. Body-fixed coordinate system which Guidance, Navigation, and Control Subsystem attempts to keep aligned with orbital reference coordinate system.

Instrument Reference Coordinate System. Instrument-centered coordinate system which is required to be parallel to the platform reference coordinate system. The orientation of the instrument is defined in this system.

Three more coordinate systems are required for a complete discussion and are informally defined here:

Sensor Coordinate System. Coordinate system nominally aligned with the instrument reference coordinate system but allowing for misalignments in the mounting of the instrument. In this system the scan is exactly described by a rotation about the X-axis (the axis nearly aligned with the platform velocity.)

Geocentric Reference Coordinate System. Coordinate system centered on the Earth with the Z-axis through the north pole and the X-axis through the intersection of the equator and the prime meridian.

Geoaligned Coordinate System. Coordinate system parallel to the geocentric reference coordinate system but centered on the platform.

Each coordinate rotation is represented by a series of three angle rotations about the three coordinate axes. Unless otherwise specified, we recommend a 3-2-1 (yaw, pitch, roll) sequence definition as the most convenient for MODIS. The general form of such a coordinate transformation matrix is

```
| cp*cy                  cp*sy                  -sp   |
|                                                     |
| sr*sp*cy - cr*sy       sr*sp*sy + cr*cy       sr*cp |
|                                                     |
| cr*sp*cy + sr*sy       cr*sp*sy - sr*cy       cr*cp |
```

where r, p, y represent the roll, pitch, and yaw angles, and c and s represent cosine and sine, respectively. A sequence of rotations can be represented by the rotation matrix corresponding to the product of the individual rotation matrices.

Level-0 data arrive in the sensor coordinate system as defined above, where the angular position data correspond to along-track and cross-track angles from the sensor Z-axis. For Earth location, the geocentric frame will be the most convenient, and it will be most efficient to form products and partial products of the four rotation matrices which transform the data from sensor to instrument to platform to orbital to geoaligned coordinates. This process will deal only with the rotations from frame to frame, which are convenient to group together. The translations from instrument center to platform center to Earth center are deferred until process 3.1.5.

The four rotations are driven by the following input data:

Sensor to instrument. This is the mounting matrix, as adjusted by biases determined in flight due to mechanical adjustments. These data would be anticipated to be stable and will arrive as necessary from the MCST.

Instrument to platform. This rotation matrix is nominally identity, but must be included to allow for platform flexure. The source for these data are TBD (perhaps from the MCST or CDOS).

Platform to orbital. This rotation matrix is provided by the platform attitude data which are part of the platform ancillary data.

Orbital to geoaligned. This rotation matrix is determined by the platform position with respect to the Earth. These data are derived from/provided as a part of platform ancillary data.

The sensor to instrument to platform matrix product should need to be formed only infrequently as new data will only be available occasionally. The platform to orbital and orbital to geoaligned rotations will probably be formed for every distinct time step. They may usefully be performed as a product as there may be multiple anchor points for a given time frame.