Clouds and the Earth's Radiant Energy System (CERES)

Data Management System

Software Requirements Document

Determine Cloud Properties
(Subsystems 4.1 - 4.4)

Release 1
Version 1

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Preface

The Clouds and the Earth's Radiant Energy System (CERES) Data Management System supports the data processing needs of the CERES Science Team research to increase understanding of the Earth's climate and radiant environment. The CERES Data Management Team works with the CERES Science Team to develop the software necessary to support the science algorithms. This software, being developed to operate at the Langley Distributed Active Archive Center, produces an extensive set of science data products.

The Data Management System consists of 12 subsystems; each subsystem represents a stand-alone executable program. Each subsystem executes when all of its required input data sets are available and produces one or more archival science products.

The documentation for each subsystem describes the software design at various significant milestones and includes items such as Software Requirements Documents, Data Products Catalogs, Software Design Documents, Software Test Plans, and User's Guides.

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

Section Page

TABLE OF CONTENTS (cont'd)

Section | Page

TABLE OF CONTENTS (cont'd)

Section Page

TABLE OF CONTENTS (cont'd)

List of Figures

TABLE OF CONTENTS (cont'd)

List of Tables

1.0 Introduction

The Clouds and the Earth's Radiant Energy System (CERES) is a key component of the Earth Observing System (EOS). The CERES instruments are improved models of the Earth Radiation Budget Experiment (ERBE) scanner instruments, which operated from 1984 through 1990 on the National Aeronautics and Space Administration's (NASA) Earth Radiation Budget Satellite (ERBS) and on the National Oceanic and Atmospheric Administration's (NOAA) operational weather satellites NOAA-9 and NOAA-10. The strategy of flying instruments on Sun-synchronous, polar orbiting satellites, such as NOAA-9 and NOAA-10, simultaneously with instruments on satellites that have precessing orbits in lower inclinations, such as ERBS, was successfully developed in ERBE to reduce time sampling errors. CERES will continue that strategy by flying instruments on the polar orbiting EOS platforms simultaneously with an instrument on the Tropical Rainfall Measuring Mission (TRMM) spacecraft, which has an orbital inclination of 35 degrees. In addition, to reduce the uncertainty in data interpretation and to improve the consistency between the cloud parameters and the radiation fields, CERES will include cloud imager data and other atmospheric parameters. The first CERES instrument is scheduled to be launched on the TRMM spacecraft in 1997. Additional CERES instruments will fly on the EOS-AM platforms, the first of which is scheduled for launch in 1998, and on the EOS-PM platforms, the first of which is scheduled for launch in 2000.

1.1 Purpose and Objective of Document

The CERES "Determine Cloud Properties, TOA and Surface Fluxes" Subsystem (Subsystem 4.0) has been divided into two separate subsystems. They are the "Determine Cloud Properties" Subsystem and the "Determine TOA and Surface Fluxes" Subsystem. Each subsystem will develop and publish separate requirements documents and design documents, and will develop separate sets of executable code. The purpose of this document is to provide a basis for the design of the Determine Cloud Properties Subsystem. The intended audience for this document is the CERES cloud subsystem teams, subsystem testers, neighboring subsystem teams, and CERES science reviewers.

The objective of this document is to provide a complete set of Release 1 requirements to guide the development of the subsystem. The Release 1 requirements document will specify requirements from the Science Team's Algorithm Theoretical Basis Documents (ATBDs) 4.1, 4.2, 4.3, and 4.4. The requirements document is being developed by the Data Management Cloud Subsystem Team. This document currently contains the following information:

- 1.0 an introduction
- 1.1 the purpose and objective of the document
- 1.2 a brief overview of the entire subsystem
- 2.0 a description of key concepts used throughout the document
- 3.0 a description of the requirements approach and any trade-offs made

- 4.0 a description of each external interface
- 5.0 the requirements specification section
- 5.1 the subsystem operational modes
- 5.2 the detailed functional requirements for ATBDs 4.1-4.4
- 5.3 a description of design goals and constraints
- 5.4 subsystem resource requirements
- references
- abbreviations, acronyms, and symbols

1.2 System Overview

The Determine Cloud Properties Subsystem's (ATBDs 4.1-4.4) major objective is to use high spectral and spatial resolution cloud imager data to determine cloud microphysical and optical properties within the larger CERES footprint. This will provide a set of cloud properties optimally designed for studies of the role of clouds in the Earth's radiation budget. The cloud properties archived on the Single Satellite CERES Footprint TOA and Surface Fluxes, Clouds (SSF) archival product are described in the CERES Data Management System Data Products Catalog (Reference 1). The cloud properties will enable the cloud physical properties to be tied to the cloud broadband radiative properties in a consistent manner. This initial estimate of cloud properties will be modified in Subsystem 5 to obtain consistency in cloud properties and TOA broadband radiative fluxes (Reference 2).

The Determine TOA and Surface Fluxes Subsystem (ATBDs 4.5 and 4.6) will complete Subsystem 4.0 and the SSF archival product by producing fluxes at the top-of-the-atmosphere (TOA) and fluxes at the surface.

The Determine Cloud Properties Subsystem is divided into four major steps which correspond to each of the cloud ATBDs 4.1 - 4.4. The input and output data products required are shown in the Context Diagram in Figure 4-1. The four major steps (which are all decomposed further into steps) are illustrated in the data flow diagram shown in Figure 5-1 and include:

1. Prepare Data Chunk and Determine Clear/Cloudy Pixels. This major step includes the following functions:
   a) Initialize the cloud process, check all input file header records, and attach various ancillary input surface condition and clear-sky history information to each imager pixel (ATBD 4.1, Reference 3).
   b) Classify each pixel as clear, cloudy, or uncertain. The pixel classification process uses various tests on radiometric data from the imager and determines a cloud mask (ATBD 4.1, Reference 3).

2. Determine cloud macrophysical properties (cloud layer for up to two layers and cloud top pressure for each layer) for cloudy pixels (ATBD 4.2, Reference 4).

3. Determine cloud microphysical and optical properties (base and effective radiating center temperature and pressure, phase, particle size, optical depth at 0.65 micron, water/ice path, emittance at 10.8 micron) for cloudy pixels (ATBD 4.3, Reference 5).

4. Map imager pixel cloud properties onto the CERES footprint and calculate cloud statistics over the footprint (ATBD 4.4, Reference 6). Output the data products, quality control products, and metadata (ATBD 4.0, Reference 2).

The primary input data sets for the Cloud Subsystem are listed below.

1. The Cloud Imager Data (CID) data product contains time code, pixel location, viewing geometry, and radiance data. For the TRMM mission, the Cloud Subsystem will use the Visible Infrared Scanner (VIRS) cloud imager data. For the EOS AM and PM missions, the Cloud Subsystem will use selected channels from the Moderate Resolution Imaging Spectrometer (MODIS) imager data. Advanced Very High Resolution Radiometer (AVHRR) and High Resolution Infrared Radiation Sounder (HIRS) instrument data from NOAA-9 and NOAA-10 spacecraft provide the test data for Release 1.

2. The CERES Instrument Earth Scans (IES) data product contains time of observation, geolocation data, and filtered radiances for each footprint (ATBD 4.4, Reference 6). The CERES footprint effective diameter is 10 km for Tropical Rainfall Measuring Mission (TRMM) spacecraft and 20 km for EOS AM and PM spacecraft. The ERBE Processed Archival Tape (PAT or S-8) data product will be the test data set for Release 1 until an IES product is available.

3. The Meteorological, Ozone, and Aerosol (MOA) (formerly named ASTR) data product contains meteorological data (surface temperature and pressure; TBD (38 - 50) atmospheric levels of temperature, humidity, pressure, and height; precipitable water, 26 levels of ozone, column ozone, and aerosols) on a 1.25-degree equal-area grid.

4. The Microwave Water Path (MWP) data product contains total column integrated microwave water path values that are used to detect cloud overlap conditions. The Release 1 test data set is TBD.

5. The SURFace MAP (SURFMAP) data product is a composite of maps for elevation, water, coastline, ice, snow, vegetation/ecosystem, surface type, and emissivity. For Release 1, the data are available on a 10-minute equal-angle grid system. The Release 1 test data sets are:

    a) elevation (Navy 10-minute equal-angle map)
    b) water (Navy 10-minute equal-angle map)
    c) coastline (1-minute coastline data)
    d) snow/ice (ERBE 2.5-degree equal-angle snow map)

e) vegetation/ecosystem (EPA 10-minute equal-angle map)

f) surface type/characteristic (Navy 10-minute equal-angle map)

g) emissivity (SARB Working Group)

Detailed descriptions for these input data sets are in the CERES Data Management System Data Products Catalog (DPC) (Reference 1).

The input data set, the Radiative Transfer Model (RTM) look-up table, is developed by the Cloud Science Team members. An additional input data set is the Cloud Processing Parameters, CLDPARAM.

The output data sets for the Cloud Subsystem are listed below.

1. Cloud Validation Data (CLDVAL) includes the Cloud Mask and other validation data (TBD). The Cloud Mask has information about which cloud mask tests are applied, whether each test does or does not indicate cloud, and a final decision of whether each pixel is either cloudy or clear.

2. Cloud Quality control reports (CLDQC) contains processing information, informative messages, and statistics.

3. Cloud Metadata (CLDMETA) contains the metadata collected from the cloud processes and describes each of the data products, CRH (CRH_META) and SSF (SSF_META). The Metadata will conform to EOS Data Information System (EOSDIS) requirements.

The input and output data sets are listed below.

1. SSF is an interim version of the SSF product, which is an hourly CERES archival product that contains footprint geometry, radiance information, and the statistics for full footprint, clear footprint, cloudy footprint, and overlap footprint areas. Subsystem 4.4 uses SSF for input if the Cloud System is in a rerun operational scenario.

2. Clear Reflectance, Temperature History (CRH) (a CERES archival data product) contains clear-sky radiance values. The Release 1 data product contains clear-sky radiance values averaged over a 10-minute equal-angle grid system for all five AVHRR channels. On input, the CRH values will be used to set thresholds for cloud detection. During processing, if a pixel is determined to be clear, the measurements from all five AVHRR channels, or VIRS channels, or five comparable MODIS channels are averaged into a 10-minute equal-angle grid system and are used to update the CRH data product. The time and spatial resolution of the at-launch CRH product is TBD.

Detailed descriptions of CRH and SSF are in the Data Products Catalog (DPC) (Reference 1).

CERES algorithms will be developed in four releases:

- Release 1 will be operational by the end of 1995 and is designed to process global data from the existing ERBE/AVHRR/High Resolution Infrared Radiation Sounder (HIRS) data from the NOAA-9 and 10 spacecraft. This release will be used to test algorithm concepts on global data and to compare multiple algorithms for cloud parameters. Previously, most of the algorithms have only been used for specific regional studies. This step will expose much of the exception handling required to run a global analysis.

- Release 2 will be ready by early 1997, in time for the TRMM launch of the first CERES instrument planned for August 1997 and will also be used for the EOS-AM1 launch in June 1998. Until the new CERES Angle Distribution Models (CADMs) are developed, the CERES analysis will use the ERBE ADMs.

- Release 3 will use the new CERES TRMM CADMs, which are expected to be developed during the first 18 months after the TRMM launch.

- Release 4 will use the new CERES EOS CADMs, which are expected to be developed during the first 18 months after the EOS-AM1 launch.

2.0 Key Concepts

The following key concepts are embodied in the Determine Cloud Properties Subsystem.

Spatial Scales. The Determine Cloud Properties Subsystem has several discrete spatial scales. They are

- Imager pixel
- Pixel array alias tile
- Filtered pixel
- Homogeneous area
- 10-minute (1/6th-degree) equal-angle grid system
- CERES footprint
- Data chunk

Imager pixel refers to a single cloud imager field-of-view, which ranges from 0.25 - 1 km for MODIS pixels, 2 km for VIRS pixels, and 4 km for AVHRR-GAC (Global Area Coverage) pixels. Some of the cloud mask algorithms process one pixel at a time.

Pixel array or Tile means n x m cloud imager pixels. ATBD 4.1 specifies cloud mask tests that process either one pixel, or a tile from Cloud Imager Data (CID). Some of the algorithms require 2 x 2, 16 x 16, 64 x 64, or 256 x 256 tiles.

Filtered pixel is a pixel that passes various tests required by the cloud mask tests. For example, nonpolar daytime water pixels will be tested for Sun glint. If a daytime water pixel is affected by Sun glint; that pixel is treated as if it were a nighttime pixel, and it will be sent to the nighttime instead of daytime cloud mask test algorithms.

Homogeneous Area is an area in which all of the pixels have a similar surface ecosystem, such as all water or all grassland. Some of the algorithms that use tiles require all of the pixels in the tile to be homogeneous.

10-minute equal-angle grid is the grid system used for much of the Release 1 test input ancillary data sets, such as the surface map data and the clear-sky data. The at-launch grid system is TBD resolution, but an equal-area grid is being considered.

Footprint refers to a single CERES field-of-view. ATBD 4.4 convolves imager pixels into a CERES footprint and is a footprint-driven process. The size of a footprint varies with the viewing zenith angle of the scanner. At nadir with a Point Spread Function (PSF) half power cutoff, the CERES footprint size ranges from 9 km by 13 km on TRMM to 17 km by 27 km on EOS. At a 70-degree viewing zenith angle with a Point Spread Function (PSF) 95 percent energy cutoff, the CERES footprint size ranges from 38 km by 116 km on TRMM to 71 km by 212 km on EOS.

Data chunk consists of multiple scan lines of CID imager data. The Determine Cloud Properties Subsystem will derive cloud properties from chunks of imager data at a time.

Cloud Mask. A pixel-level mask which includes information about which cloud mask tests were applied, whether each test indicated cloud, and a final decision of whether cloud was present for each pixel. This cloud mask shall be saved into an internal data product for graphical validation.

In order to illustrate the cloud mask process and results used in the data flow diagrams in Section 5 of this document, we use three flags. They are

- Cloud-flag x
- Cloud-flags
- Final-cloud-code

Cloud-flag x represents the results of ten to fifteen different cloud mask tests conducted on every pixel. The result of each test will be a clear, cloudy, uncertain, or tested. One of these values is represented as "cloud-flag x" in the data flow. The x will range from 1 to the number of tests performed on each pixel. The x indicates which test was performed. Each Cloud-flag x will be initialized to "uncertain" and "untested" at the initialization step and will be set later according to the result of the cloud mask tests conducted on a pixel. For example, if the third cloud mask test determines that a pixel is clear, then cloud-flag 3 will be set to clear and tested.

Cloud-flags is a data structure that represents the set of all of the "cloud-flag x" flags together. It is passed between processes in the data flow diagram.

Final-cloud-code is a parameter that represents the final clear or cloudy decision that is imposed on each pixel based on all cloud-flags from all of the tests performed on that pixel. Since multiple cloud mask tests are performed on the same pixel and recorded individually in cloud-flags, an additional process evaluates the results of the individual tests and makes a final clear/cloudy decision for the pixel.

In addition, we use four control flags in the data flow diagrams in Section 5 of this document to manage requesting the data chunk and to manage abnormal termination. They are

- More-data flag
- Error-halt-flag
- End_FOV_Flag
- Read_FOV_Flag

More-data flag is used to indicate which of the possible processing states is needed. The More-data flag can be in an initial state, a normal processing state, and a restart state. The More-data flag is set to the initial state at the beginning of the hour's processing. During the initial state, data from the previous hour are read. The normal state is selected to request more data from the current hour to be read. The restart state is selected when there is a sufficiently large gap in the imager data or enough input imager records are rejected that neighborhood relationships are invalid.

Error-halt-flag is set to gracefully shut down the process if any fatal errors occur and is used as a means to finish processing, close files, output an error report instead of a normal processing report, and send a message to the Planning and Data Processing System (PDPS) to abort.

End_FOV_Flag is set to indicate when the convolution process has reached the last possible imager pixel within the current CERES footprint. It is used to trigger the termination steps for processing of that footprint.

Read_FOV_Flag is set to signal the need to read a new CERES footprint FOV record in the convolution process. It is used to initiate processing at the start of a new hour of IES data and in conjunction with End_FOV_Flag to control the sequential processing of each footprint record in the IES.

Cloud Category is one of four categories arranged vertically within the atmosphere according to effective pressure, p_e. The four cloud categories are defined as:

High	if p_e < = 300 hPa
Upper Middle	if 300 hPa < p_e < = 500 hPa
Lower Middle	if 500 hPa < p_e < = 700 hPa
Low	if p_e > 700 hPa

Cloud overlap conditions are the eleven combinations of 0, 1, or 2 cloud layers that a single pixel could represent and are defined as:

Clear Only (No layers)
High Only (Single layer)
Upper Middle Only (Single layer)
Lower Middle Only (Single layer)
Low Only (Single layer)
High over Upper Middle (Two layers)
High over Lower Middle (Two layers)
High over Low (Two layers)
Upper Middle over Lower Middle (Two layers)
Upper Middle over Low (Two layers)
Lower Middle over Low (Two layers)

Point Spread Function. The PSF is a weighting function with values ranging from 1.000 at the centroid to 0.000 at points far off-axis. It is symmetrical in the cross-scan direction and slightly asymmetrical in the along-scan direction. The PSF will also be used as the primary selection criterion for inclusion of an imager pixel within a given CERES footprint. The PSF value calculated at the pixel location relative to the footprint centroid will be compared to one or more selectable threshold values to determine whether the pixel shall be included in the current footprint. For the initial implementation, the PSF threshold values are expected to be those that define the 95% and 75% integrated energy envelopes for the PSF.

3.0 Requirements Approach and Tradeoffs

The context diagram (Figure 4-1), in Section 4.0, shows the required input data sets and the output data products the Subsystem must produce as defined by the CERES Science Team. The science algorithms specified in the ATBDs 4.0 through 4.4 were examined in order to determine the processes necessary to at least specify a set of high-level functional requirements for each of the cloud processes. Many of the algorithms discussed in the ATBDs are at research stage and applied to local scale, although the algorithms have not been used in an operational and global manner, nor have the algorithms been used together. The many diverse existing algorithms will need to play together to produce a global cloud product. The task of the Cloud Data Management Team is to specify the framework for the many algorithms so that they can be successfully integrated together into a robust, efficient, and correct system that is also compliant with EOSDIS requirements. Some redundant functions may exist; other functions may need to be tailored for the TRMM and EOS data sets. It is especially important to precisely and correctly specify the input, primary requirements, and output for each of the existing algorithms in order to design the framework that will integrate the algorithms, i.e., existing science code, together in a cohesive manner. The requirements specified in this document are not to the level of detail necessary to design and write new code, but rather attempt to specify the interfaces for each algorithm along with a brief functional description of each algorithm.

The high-level requirements derived from each of the ATBDs are listed here. Additional detail was provided by Science and Data Management Team members. The requirements are decomposed into four major processes:

1. ***Prepare Data Chunk Process and Determine Clear/Cloudy Pixels***

Rationale: ATBD 4.1: Imager Clear-Sky Determination and Cloud Detection

- input a chunk of calibrated imager data from AVHRR and HIRS, or VIRS, or MODIS
- identify the surface conditions for each pixel from the ancillary data
- obtain previous clear-sky information from CRH for each pixel
- calculate the imager solar viewing angles for daytime pixels
- organize the data into pixel arrays (tiles)
- obtain temperature, humidity, pressure profiles from MOA for each tile
- determine if a pixel is clear, cloudy, or undetermined
- output a cloud mask
- update new clear-sky information to CRH.

No single cloud algorithm works well for all cloud types over all backgrounds. The process of both cloud detection and cloud property determination from space can become very complex because cloud fields are highly variable in space and time. This is true especially over variable backgrounds such as mountains, desert, or snow and ice. In Release 1, all of the cloud detection algorithms will be implemented in a convenient order to gain understanding of the timing, sizing, effectiveness, and cost of running each of the suggested algorithms in the global production environment. With Release 1 experience and an extensive cost-benefit analysis, the requirements for Release 2 will specify the preferred global algorithms and a decision tree that guides which algorithms are chosen for which surface conditions.

2. *Determine Cloud Layers and Cloud Heights for Each Layer Process*

Rationale: ATBD 4.2: Imager Cloud Height Determination

The two high-level requirements derived from ATBD 4.2 are to (a) identify whether a cloudy pixel is a member of a single cloud layer or two cloud layers, and (b) determine the cloud top pressure for each layer. A single pixel can have zero (clear), one, or two cloud layers that are represented by combinations of the eleven overlap conditions. Multiple algorithms will be implemented in Release 1 to gain knowledge of their global production behavior and results.

3. *Determine Pixel Level Cloud Optical and Physical Properties Process*

Rationale: ATBD 4.3: Imager Cloud Optical Property Retriveal

ATBD 4.3 specifies many algorithms for determining the cloud properties for each pixel. The cloud properties can be broken into several categories:

- Vertical position information: cloud top pressure, effective cloud pressure, effective cloud temperature, effective cloud altitude, cloud base pressure.
- Spatial information: cloud fraction
- Optical properties: visible optical depth, window emissivity
- Condensed water: liquid water path, ice water path, particle radius
- Aspect ratio: ratio of the vertical extent to horizontal size.

Again, all suggested algorithms will be implemented in Release 1. In addition, the cloud properties to be produced for each pixel are at different stages of understanding by the science community. No single cloud algorithm works well for all cloud types over all backgrounds. Many existing and developing methods will be investigated by the Science Team during the software development phases.

4. *Convolve Imager Cloud Properties with CERES Footprint Process*

Rationale: ATBD 4.4: Convolution of Imager Cloud Properties with CERES Footprint Point Spread Function

The essential requirement addressed by ATBD 4.4 is to identify cloud imager pixels within the CERES instrument footprint, and to use the cloud information from these pixels to characterize the cloud conditions within the footprint. Due to the much higher spatial resolution of the cloud imagers (as compared to the CERES instrument), there will typically be several hundred imager pixels within each CERES footprint. Since the CERES instrument can operate in rotating azimuth plane scan mode, the algorithm must be able to locate pixels within an elongated and skewed footprint. Each imager pixel's contribution to the cloud characterization for the footprint is weighted by the value of the Point Spread Function calculated at the pixel's location within the footprint.

Cloud conditions will be grouped into three major categories: clear, cloudy with one cloud layer, and cloudy with two cloud layers. These general categories are further divided into a total of eleven cloud overlap conditions. Cloud statistics will be kept for each CERES footprint in four separate categories:

- 1) Statistics for the full footprint
- 2) Statistics for the clear footprint area
- 3) Statistics for the cloudy footprint area
- 4) Cloud overlap conditions for each of the 11 cloud overlap conditions.

All cloud statistics are weighted using the PSF value for each pixel as the weighting function.

Also in step 4, the cloud archival product, SSF, and the validation product, CLDVAL, will be produced as specified by the CERES Science Team in ATBD 4.0. The quality control reports will provide statistical analysis and algorithm verification. The metadata is required by EOSDIS.

4.0 External Interface Requirements

This section provides information on the interface requirements which must be satisfied between the system and each of its external input/output entities. These interfaces are depicted graphically in the Context Diagram (Figure 4-1). The subparagraphs following the context diagram provide the detailed requirements for each of the data interfaces represented in the diagram.

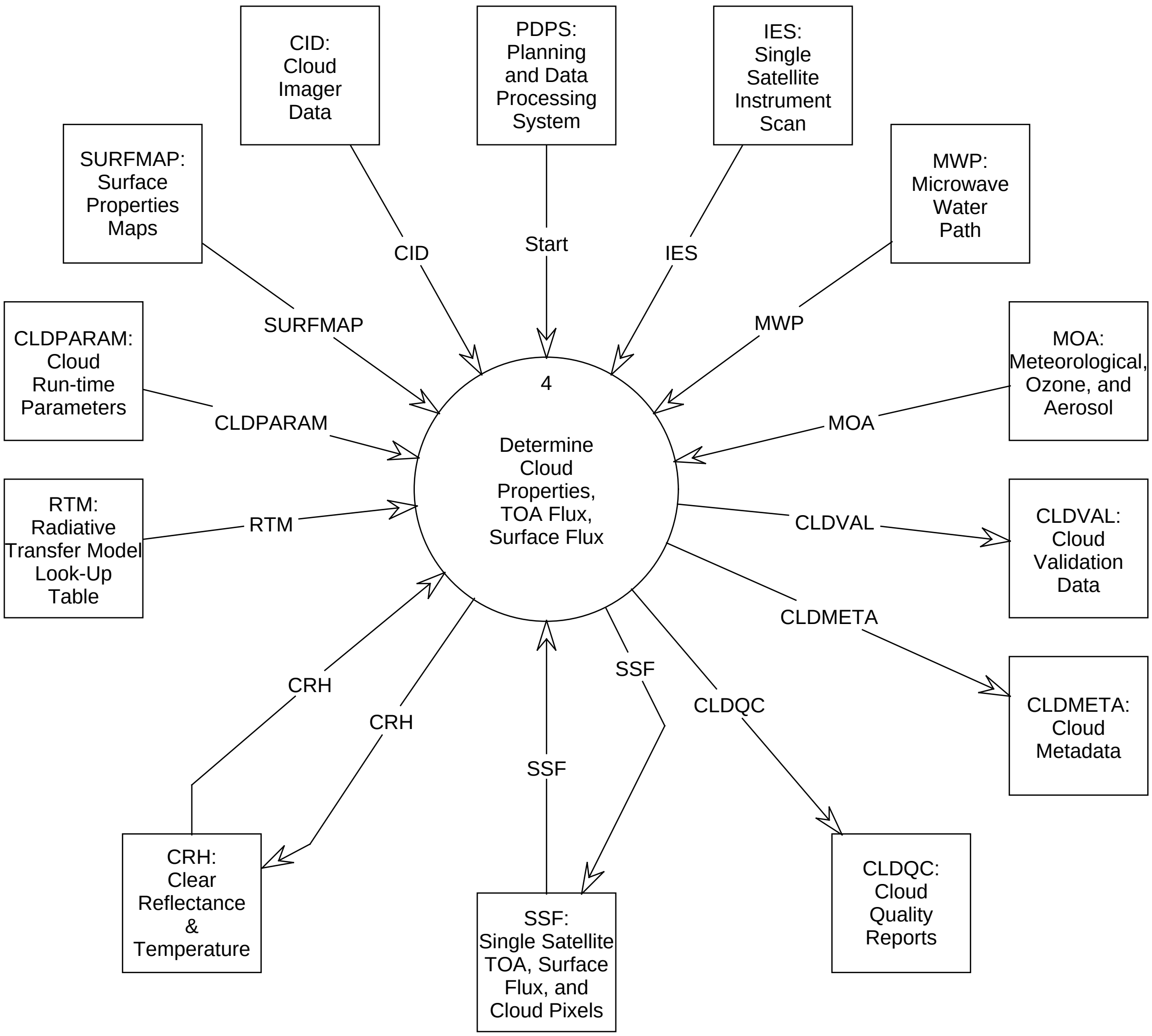

Figure 4-1. Context Diagram

4.1 Input Data Sources

4.1.1 CID

The Cloud Imager Data (CID) vary from the prelaunch AVHRR and HIRS instruments to the launch VIRS and MODIS instruments. The AVHHR Global Area Coverage (GAC) and HIRS data from the NOAA-9 and NOAA-10 spacecraft are the Release 1 CID test data (CID_AVHRR and CID_HIRS). The VIRS Cloud Imager Data (CID_VIRS) are received from the TRMM spacecraft while the MODIS Imager Data (CID_MODIS) are received from the EOS spacecraft. We are requesting Level 1-B data from the five VIRS channels and from eleven MODIS channels. The channels, their micron value, and their resolution are specified in Table 4-1. The data coverage is 1-hour. The product has a header record followed by multiple scan line records. Each pixel in the scan line record has radiance values for each of the channels. It is assumed that the data are organized in scan lines that appear to scan in the same direction for each scan.

CID_AVHRR: Each AVHRR-GAC scan line has (Reference 9):

Scanline number
Time (year, day, hour, minute, second)
Quality indicators
Calibration coefficients
Solar zenith angles
Earth location (latitude, longitude)
Telemetry data
AVHRR pixel data

CID_HIRS: Each HIRS scan line has (Reference 9):

Scanline number
Time (year, day, hour, minute, second)
Quality indicators
Earth location delta (Time adjustment factor)
Calibration coefficients
Satellite height and local zenith angles
Earth location (latitude, longitude)
HIRS/2 data
Minor frame quality

CID_VIRS: Each VIRS scan line has :

Pixel location
Spacecraft position
Solar viewing angles
VIRS pixel data

CID_MODIS: The organizational details of the MODIS Level 1-B product are not finalized yet.

Table 4-1. Cloud Imager Data Channel Matrix

	MODIS			VIRS			AVHRR/HIRS		
Channel Index	Channel Number	Micron	Resolution km	Channel Number	Micron	Resolution km	Channel Number	Micron	Resolution km
1	1	0.645	0.25						
2	1	0.645	0.5						
3	1	0.645	1.0	1	0.63	2	A1	0.63	4
4	6	1.64	0.5						
5	6	1.64	1.0	2	1.60	2	A2	0.91	4
6	7	2.13	0.5						
7	7	2.13	1.0						
8	20	3.75	1.0	3	3.75	2	A3	3.74	4
9	26	1.375	1.0						
10	29	8.55	1.0						
11	31	11.03	1.0	4	10.8	2	A4	10.8	4
12	32	12.02	1.0	5	12.00	2	A5	12.00	4
13	33	13.335	1.0				H7	13.34	17.4
14	34	13.635	1.0				H6	13.66	17.4
15	35	13.935	1.0				H5	13.95	17.4

The CERES Science Team requires averaged data from the 1/4 km resolution channel to 1/2 km and 1 km and the two 1/2 km resolution channels averaged to 1 km resolution. The Cloud Subsystem, thus, requires input data from the 11 channels and the four averaged data sets, for a total of fifteen sets of 'channel' data.

Both CID_VIRS and CID_MODIS products are external to the CERES processing and, they are released after CERES processing is completed. It is assumed that the responsible EOSDIS DAAC will retain a copy of these products, should it be needed by CERES. The LaRC DAAC will retain the CID_AVHRR and CID_HIRS test data sets. A detailed description of this product is in the Data Products Catalog (Reference 1).

4.1.2 CLDPARAM

CLDPARAM contains the information needed to run the Cloud Processing Subsystem and is provided by the PDPS according to CERES Cloud Working Group specifications. The parameters include but are not limited to:

- Data date and time
- Instrument and spacecraft identification of IES
- Instrument and spacecraft identification of CID
- Software version number
- Rerun flag
- Data chunk size
- Maximum allowable consecutive read error
- Maximum allowable total read error
- Processing options
- Threshold values
- Valid range lists

There are four different CID data sources (AVHRR and HIRS, VIRS, and MODIS) whose data structures are different. CLDPARAM shall indicate the data source in order to use the appropriate SDP toolkit calls or open and read statements. If the rerun flag is set to no, the software shall read input from the IES product. If the rerun flag is set to yes, the software shall read input from the SSF product, since the IES parameters are copied to the SSF product and IES is not archived.

As there are many major steps in the cloud process, the software program shall have an option for selecting step(s) that exercise selected portions of the code for validation purposes. The threshold values are those selected values that will be used in various cloud/no cloud determination tests. The valid ranges shall include the minimum and maximum limits for the parameters that require range checking. A parameter might have different ranges for different CID instrument input.

4.1.3 IES

The IES data product contains the equivalent of 1-hour of data from a single CERES scanner. The data records are ordered along the orbital ground track, with each footprint position related to the spacecraft's suborbital point at the start of the hour. The spatial ordering of records within this product will ease the comparison of CERES data with cloud imager data in Subsystem 4. The footprint record is the basic data structure for this data product. This record contains the following kinds of information:

- Time of observation
- Geolocation data (at both the Top-of-Atmosphere and at Earth's surface)
- Filtered radiances (at satellite altitude), with associated quality measures

- Spacecraft orbital data
- Footprint viewing geometric data

The IES data product contains only measurements that view the Earth. For the TRMM mission, this means that approximately 225 Earth-viewing footprints (records) are stored on the IES from each 3.3-second half-scan. Because the Earth scan pattern of the CERES instrument in the biaxial scan mode is irregular, the exact number of footprints in each IES data product varies. This variation is caused by the lack of predictability of the azimuth position at both the start and end of the hour. If the azimuth angle near the start (or end) of an hour is near the crosstrack position, then the number of footprints in the IES product is near the estimated value given below. If the azimuth angle is near the alongtrack position, some of the footprints are instead spatially located within the previous (or next) hour's IES. Thus, we have used an estimate of the number of 3.3-second half-scans per hour (approximately 1091) times the number of Earth-viewing measurements in a half-scan (TRMM estimate is 225, EOS estimate is 195) to arrive at our IES product sizing. For TRMM, this is estimated as 245475 measurements per IES data product and for EOS the estimate is 212745 measurements. The larger of these two measures is used to determine product sizing. A detailed description of this product is in the Data Products Catalog (Reference 1).

4.1.4 MOA

The MOA, a CERES archival product, is produced by the CERES Regrid Humidity and Temperature Subsystem. Each MOA file contains meteorological, ozone, and aerosol data for 1-hour, and is used by several of the CERES subsystems. Data on the MOA are derived from several data sources external to the CERES system, such as the National Meteorological Center (NMC), the Moderate Resolution Imaging Spectrometer (MODIS), the Stratospheric Aerosols and Gases Experiment (SAGE), and various other sources. These data arrive at intervals ranging from four times daily to once a month and are horizontally and vertically organized differently from what the CERES system requires. The Regrid Humidity and Temperature Subsystem interpolates these data temporally, horizontally, and vertically to conform with CERES processing requirements.
Details of this data product are in the Data Products Catalog (Reference 1).

Prior to an EOS-wide review of each Project’s Algorithm Theoretical Basis Documents in May 1994, the MOA was referred to as the Atmospheric Structures (ASTR) file. At the request of the review panel, the name of this file was changed so as to avoid confusion with another EOS Project, the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER).

The MOA contains:

- Surface temperature and pressure
- Vertical profiles of temperature, humidity, and geopotential height as a function of pressure for the internal atmospheric levels requested by the Clouds and SARB Working Groups
- Column precipitable water

- Vertical ozone profiles for internal atmospheric levels requested by the SARB Working Group
- Column ozone
- Total column aerosol
- Stratospheric aerosol

The internal atmospheric levels, in hPa, as requested by the CERES Clouds and SARB Working Groups as of December 1993, are listed in Table 4-2. It should be noted that prior to Release 2, the number of levels most likely will change from 38. Also, the levels themselves may change.

Table 4-2. MOA Internal Atmospheric Levels (in hPa)

Floating Levels	1000 to 875	850 to 725	700 to 450	400 to 225	200 to 70	50 to 1
Surface	1000	850	700	400	200	50
Surface - 10	975	825	650	350	175	30
Surface - 20	950	800	600	300	150	10
	925	775	550	275	125	5
	900	750	500	250	100	1
	875	725	450	225	70	

4.1.5 MWP

The Microwave Liquid Water Path (MWP) Product is a daily, Level 2 product that is currently only available over oceans. The product contains a product header followed by the microwave water path parameter values, which are total atmospheric column integrated. The TRMM Microwave Imager (TMI) data swath on TRMM is approximately 700 km, while the Multifrequency Imaging Microwave Radiometer (MIMR) data swath used for EOS is approximately 1,400 km. The MIMR and TMI field-of-views are approximately 20 km at nadir, so an estimate of the number of MIMR pixels in a scan line is about 75 and the number of scan lines in a day is about 250,000.

The MWP Product is a non-EOS ancillary product, external to the CERES processing system, that the CERES Project plans to keep in the LaRC DAAC for reprocessing. A detailed description of this product is in the Data Products Catalog (Reference 1).

4.1.6 RTM

The Radiative Transfer Model (RTM) is a database developed by the Cloud Working Group, which will be used as a look-up table in the cloud layering process.

4.1.7 SURFMAP

The Surface Map and properties (SURFMAP) product is a composite product of different types of surface condition maps. A 10-minute equal-angle map is used for Release 1. The individual products received from different non-EOS sources are

SURFMAP(DEM)	Digital elevation map
SURFMAP(H2O)	Water map
SURFMAP(ICE)	Ice map
SURFMAP(SNOW)	Snow map
SURFMAP(VEGE)	Vegetation map
SURFMAP(ECO)	World ecosystem map
SURFMAP(COAST)	Coastline map

A "condensed" surface map is derived from the above maps that specifies for each of the grids one of six types: desert, mountains, snow or ice, any other land, ocean, or coastline. The SURFMAP(CONDENSED) is derived in an off-line process.

SURFMAP(CONDENSED)	Condensed surface type map

The remaining surface data are compiled by the CERES Science Team from various clear-sky models into the SURFMAP(STD) product.

SURFMAP(STD)	Science thermophysical data

The STD product consists of:

Surface type indicator
Broadband shortwave surface ADM type
Visible albedo for collimated, overhead Sun illumination
Spectral emissivity from 3.7 micron channel imager data
Spectral emissivity from 11.0 micron channel imager data

The surface type indicator specifies which of the surface conditions best describes the grid cell (land, water, snow, or ice). Snow/ice takes precedence over land/water.

Each of the SURFMAP products contains a product header and parameters for each grid cell. The SURFMAP components are updated at different frequencies, depending on the type of data. For example, the snow and ice map are updated weekly, whereas the elevation map may be used for the life of the mission.

The SURFMAP product will be retained at the LaRC DAAC permanently. EOSDIS may provide the data for some of the required surface conditions, which the CERES software would access through the Science Data Processing Toolkit (Reference 7). A detailed description of each of the component maps is found in the Data Products Catalog (Reference 1).

During Release 1, the SURFMAP(ECO) will be used in combination with other maps. SURFMAP(ECO) contains 73 ecosystems from World Ecosystem, which are listed below, although only 59 are used:

0 :	Waters, including Ocean and Inland Waters	
1 :	CCX	City complexes--being added for MM4 type cat.1
2 :	SSG	Short or Sparse Grass/Shrub of semiarid climates
3-5:	Not used	
6 :	TBE	Temperature/Tropical-montane Broadleaf Evergreen covers warm temperature or montane broadleaf evergreen forest [Africa only]
7 :	Not used	
8 :	DMB	Desert, mostly bare stone, clay or sand
9-15:	Not used	
16 :	(BES)	Broadleaf Evergreen Shrub, commonly with #46 and #47
17 :	ICE	Antarctic ice cap
18-19:	Not used	
20 :	SRC	Snowy, rainy coastal conifer
21 :	MBC	Main Boreal conifer forest, closed or open
22 :	SNB	Snowly non-Boreal conifer forest
23 :	CDF	Conifer/deciduous, snow persisting in winter
24 :	TBC	Temperature Broadleaf/Conifer forest: with deciduous and/or evergreen hardwood trees
25 :	SDF	Snowy Deciduous Forest, e.g., summergreen (=cold-deciduous) types
26 :	TBF	Temperature broad-leaf forest: deciduous, semideciduous, and some temperature-subtropical broadleaf evergreen types that are least active in winter
27 :	NSC	Non-snowy conifer forest category
28 :	TMC	Tropical montane complexes, typically evergreen, including dwarfed ("elfin") forest, opening to grass, or tall or short forbs (puna, paramo)
29 :	TBS	Tropical Broadleaf Seasonal, with dry or cool season
30 :	CFS	Cool Farmland & Settlements, more or less snowy
31 :	MFS	Mild/hot farmland & settlements
32 :	RGD	Rain-green (drought-deciduous) or very seasonal dry evergreen forests to open woodlands, very frequently burned
33 :	TRF	Tropical RainForest
34-35:	Not used	
36 :	PRA	Paddy rice and associated land mosaics
37 :	WCI	Warm/hot cropland, Irrigated extensively

38 :	CCI	Cool cropland and pasture, irrigated locally
39 :	CCP	Cold cropland and pasture, irrigated locally
40 :	CGS	Cool grass/shrub, showy in most years
41 :	MGS	Mild/warm/hot grass/shrub
42 :	CSM	Cold steppe/meadow +/- larch woods (in Siberia), scrub (Bering Sea) or tundra (Tibetan highland)
43 :	SGW	Savanna/Grass, seasonal woods: Trees or shrubs above grass groundcover may be interspersed on many scales in savana belts of varying drought duration and high fire frequency
44 :	MBF	Mires include peaty Bogs and Fens (mostly in high latitudes)
45 :	MOS	Marsh or other swampy wetlands include various transitions to or mixtures with trees
46 :	MES	Mediterranean-type Evergreen (mostly) broadleaved scrub and forest relics
47 :	DHS	Dry or highland scrub, or open woodland mostly in interior Australia and South America
48 :	DEW	Dry Evergreen Woodland or low forest, mapped mostly in interior Australia and South America
49 :	HVI	Hot-mid volcanic "islands" (Galapogos), with local denser forest on some older lava flows but wide areas of sparse cover on recent lavas
50 :	SDB	Sand Desert, partly Blowing dunes
51 :	SDS	SemiDesert/Desert Scrub/succulent/sparse grass
52 :	CSS	Cool/cold shrub semidesert/steppe
53 :	TUN	Tundra (polar, alpine)
54 :	TER	Temperate Evergreen Rainforest (e.g., in Chile)
55 :	SFW	Snowy Field/Woods complex
56 :	FFR	Forest/Field complex with Regrowth after disturbances, mixed with crops and/or other non-wooded lands
57 :	SFF	Snowy Forest/Field, commonly openings are pasture and/or mires
58 :	FWG	Field/Woods with Grass and/or Cropland
59 :	STW	Succulent and thorn Woods or shrub is widespread
60 :	SDT	Southern Dry Taiga or similar aspen/birch with northern and mountain conifers
61 :	LT	Larch Taiga with deciduous conifer
62 :	NMT	Northern or maritime taiga typifies a wide latitude belt or a narrow altitude belt above denser forest or woodland
63 :	WTM	Wooded tundra margin or mountain shrub/meadow
64 :	HMW	Heath and Moorland, Wild or artificially managed, as by burning and/or grazing. Can include wetland (#44-45) interspersed with drier heath, with dwarfed or taller, commonly dense shrub on peat or sand
65 :	CNW	Coastal : Northwest quadrant near most land
66 :	CNE	Coastal : NorthEast quadrant near most land
67 :	CSE	Coastal : SouthEast quadrant near most land
68 :	CSW	Coastal : SouthEast quadrant near most land
69 :	PDS	Polar desert with rock Lichens, locally abundant or productive

		(even between mineral grains) but provide little food. Animals import residues for localized humus
70 :	GLA	Glaciers in polar or alpine complex, with rock fringes
71 :	SSF	Salt/soda flats desert playas, occasionally with intermittent lakes
72 :	MSM	Mangrove and non-saline swamps and tidal Mudflats [Africa only]
73 :	TSL	Islands and shore waters in oceans and/or lakes [Elba Island]

4.1.8 Start

The Start command is generated by the Planning and Data Processing System (PDPS). This command is sent when all of the required input data files for the Subsystem are available for a scheduled Cloud Subsystem processing run.

4.2 Output Data Sources

4.2.1 CLDMETA

CLDMETA is the metadata collected from the cloud retrieval process, which describes the CRH and SSF products. The metadata shall conform with EOSDIS requirements and standards.

4.2.2 CLDQC

CLDQC represents the quality control reports produced by the Cloud Retrieval Subsystem. Specific information provided in these reports includes but is not limited to:

- Spacecraft and instrument identification
- Data date and time
- Processing date and time
- Software version number
- Number of input and output pixels processed
- Number of CERES footprints processed
- Diagnostic messages indicating any unexpected or unusual conditions
- Imager data statistics:

    Number of clear-sky pixels
    Number of cloudy pixels
    Number of pixels in the full footprint area
    Number of pixels in the clear footprint area
    Number of pixels in cloudy footprint area
    Number of pixels for each cloud overlap condition

4.2.3 CLDVAL

CLDVAL contains several internal products to be used for validation purposes. The first product is the Cloud Mask, which records the results (clear, cloudy, uncertain, or untested) from each cloud mask test and an additional result for the final clear or cloudy decision for each pixel. The Cloud Mask product currently consists of cloud mask data for each pixel, and navigation data. The navigation data are needed to display the cloud mask results as a map.

Preliminary plans for additional validation products include an on-line browse product of global cloud properties for the most current 3-day period. The global browse product may be synoptic, giving an image of the cloud conditions at a particular time within each day, perhaps every 8 hours. The browse product could be accessed through Mosaic or the World Wide Web network. As a new synoptic map becomes available, the oldest map would be dropped out. Thus, only current information is presented and the product remains a static size.

4.3 Input/Output Data Sources

4.3.1 SSF

The Single Satellite CERES Footprint TOA and Surface Fluxes, Clouds (SSF) is produced from the cloud identification, inversion, and surface processing for CERES. The SSF produced by cloud identification algorithms is an interim product, which is completed by the inversion and surface processes. Each SSF covers a single hour swath from a single CERES scanner (3 channels) mounted on one satellite. The product has a product header and multiple records of approximately 125 parameters or 315 elements for each footprint.

The major categories of data output on the SSF are

- CERES footprint geometry and CERES viewing angles
- CERES footprint radiance and flux (TOA and Surface)
- CERES footprint cloud statistics and imager viewing angles
- CERES footprint clear area statistics
- CERES footprint cloudy area statistics for each of four cloud height categories
    - Visible optical depth (mean and standard deviation)
    - Infrared emissivity (mean and standard deviation)
    - Liquid water path (mean and standard deviation)
    - Ice water path (mean and standard deviation)
    - Cloud top pressure (mean and standard deviation)
    - Cloud effective pressure (mean and standard deviation)
    - Cloud effective temperature (mean and standard deviation)
    - Cloud effective height (mean and standard deviation)
    - Cloud bottom pressure (mean and standard deviation)

Water particle radius (mean and standard deviation)
Ice particle radius (mean and standard deviation)
Particle phase (mean and standard deviation)
Vertical aspect ratio (mean and standard deviation)
Visible optical depth/IR emissivity (13 percentiles)

CERES footprint cloud overlap conditions (11 conditions)

The SSF is an archival product that will be run daily in validation mode starting with the TRMM launch until sufficient data have been collected and analyzed to produce a production quality set of CERES Angular Distribution Models (CADM). It is estimated that at TRMM launch plus 18 months, the SSF product will be produced on a routine basis, and it will be archived within EOSDIS for distribution to the science community. A detailed description of this product is in the Data Products Catalog (Reference 1).

4.3.2 CRH

The Clear Reflectance/Temperature History (CRH) product is an hourly product of clear-sky values averaged on a global 10-minute equal-angle grid for Release 1. The launch requirement may call for a TBD resolution equal-area grid. The data coverage is 1-hour, and is updated by the Cloud Subsystem (ATBD 4.1) with new clear-sky information. The CRH data product consists of a product header followed by fixed-length records organized according to the grid pattern. Each grid has:

- Albedo from 0.63 micron imager channel (mean, standard deviation)
- Albedo from 0.92 micron imager channel (mean, standard deviation)
- Temperature derived from 3.75 micron imager channel (mean, standard deviation)
- Temperature derived from 10.8 micron imager channel (mean, standard deviation)
- Temperature derived from 12.0 micron imager channel (mean, standard deviation)
- Imager solar zenith angle over grid (mean)
- Imager viewing zenith angle over grid (mean)
- Narrowband ADM type
- Number of days since last cell grid update

The CRH product is the same structure for AVHRR, VIRS, and MODIS values. There is a source indicator on the header record that specifies from which instrument the data entries were calculated. Since CERES has requested eleven MODIS channels, clear-sky data from the MODIS channels with the same spectral ranges as those from AVHRR and VIRS will be saved. The CRH is archived so that the CERES investigation will have access to any particular day throughout the life of the mission, when it is needed for reprocessing. A detailed description of this product is in the Data Products Catalog (Reference 1).

For Release 1, the CRH product is initially derived from an ISCCP 2.5-degree equal-area grid product, which consists of a product header followed by fixed-length records organized according to the gridding scheme. For each hour, each ISCCP record contains:

- date
- albedo (~ 0.6 micron channel)
- standard deviation of albedo
- tropopause pressure
- cosine of solar zenith angle
- temperature (~11 micron channel)
- standard deviation of temperature
- snow percentage

Later releases may produce a 3-hour product limited to a daytime/nighttime scale, or simply output a daily value as a method of data volume reduction. The date and time is included in the granule name and in the product header, rather than in each grid cell.

5.0 Requirements Specification

This section provides the specification of requirements which must be satisfied by the system. Included are functional requirements, internal data elements, performance requirements, and implementation constraints. In addition, this section identifies design goals which will be addressed during the design phase and estimates for the processing resources required by the Subsystem. The design goals are distinguished from the requirements by the fact that it is not possible to include formal tests for the design goals in the system Test Plan.

5.1 Operating Modes

The Cloud Subsystem needs hourly input files and produces hourly output products for a single Product Generation Executable (PGE). It is assumed that the PDPS will not start the cloud processing system until all required input files are available. It is also assumed that the PDPS will not start the cloud processing system until the CID file for the requested hour and the CID file for the next hour and the previous hour (unless an overlap file is used) are available.

For platforms with two CERES instruments, there will be two IES products. Both IES input products will be processed in the same PGE and two SSF products produced, one for the Rotating Azimuth Plane Scanner (RAPS) mode and one for the Fixed Azimuth Plane Scanner (FAPS) mode. The rationale is to minimize reading the imager data and determining the cloud properties.

The Cloud Subsystem will be run at launch in a validation mode in order to collect enough SSF products from the CERES instrument operating in a RAPS mode and in the FAPS mode, in order to derive the new CERES ADMs (CADM). This validation period is estimated to be from 18 to 24 months after the TRMM launch.

If the Cloud Subsystem is rerun, the PDPS will stage the appropriate SSF product as an input file. If it is not a rerun, the PDPS will stage the requested IES. SSF is needed for the rerun because IES is not archived, and copies of the IES parameters are on the SSF product.

5.2 Functional Requirements

This section identifies the specific functional requirements for the Subsystem, which are depicted graphically in data flow diagrams. A top-level Subsystem context diagram was previously depicted in Section 4. The first level decomposition of the subsystem is shown in the Data Flow Diagram for Level 0 (Figure 5-1). A discussion of the functionality shown in Figure 5-1 can be found in the System Overview (Section 1.2). The subparagraphs following the Data Flow Diagram for Level 0 provide the detailed requirements (process specifications, or "p-specs") for each of the processes shown in the figure. Processes that can be further decomposed into subprocesses are indicated by the inclusion of an "*" in the diagram beside the process number. If there are no further subprocesses, the diagram will include a "p" beside the process number. The process specifications (p-specs) will be used to define the testing requirements for the Subsystem and will be documented in a subsystem Test Plan and Procedures document.

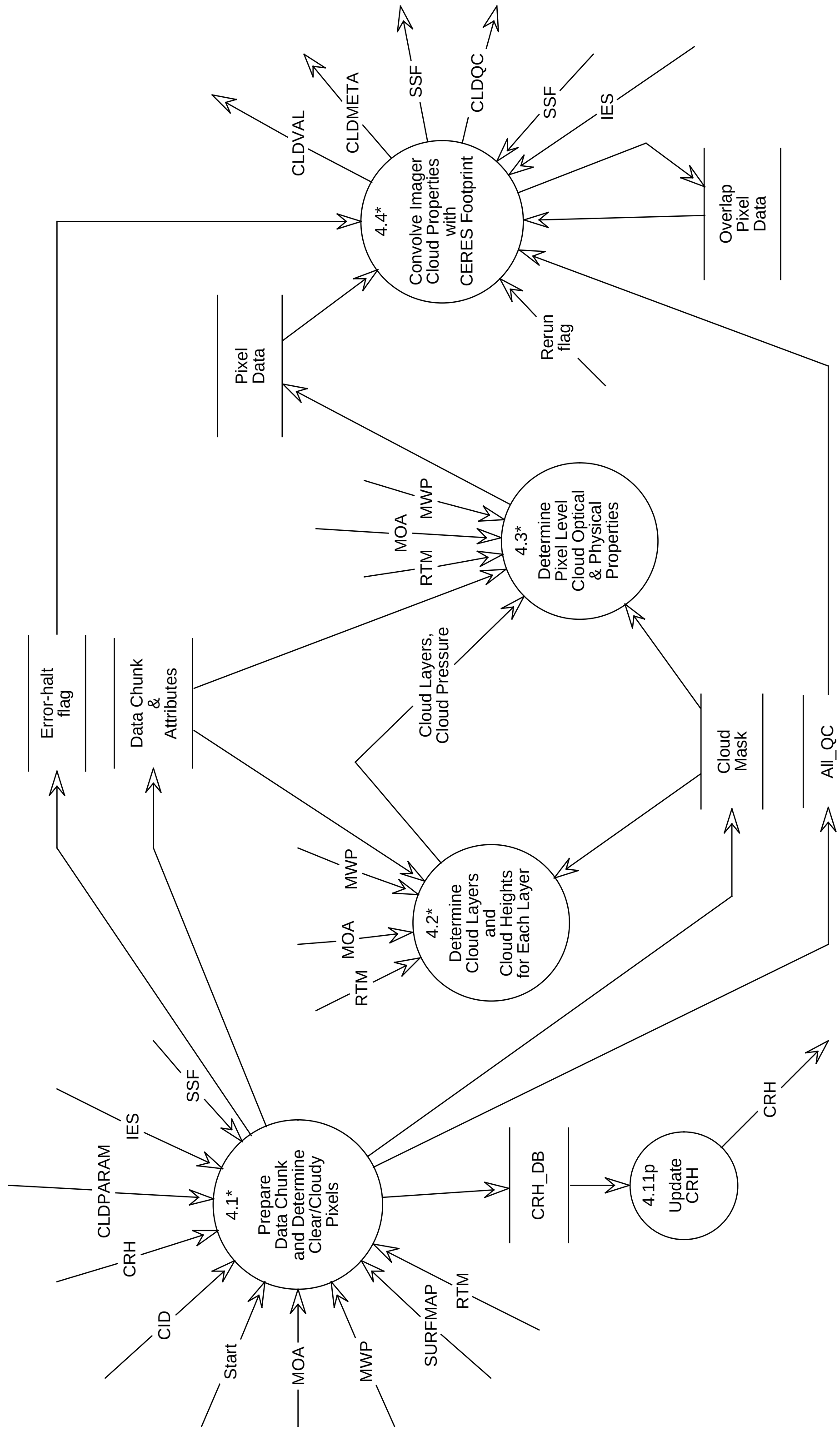

Figure 5-1. Data Flow Diagram for Level 0

5.2.1 Prepare Data Chunk and Determine Clear/Cloudy Pixels - Process 4.1

Input Data Flows

CID
CLDPARAM
CRH
IES
MOA
MWP
RTM
SSF
SURFMAP
Start

Output Data Flows

All QC
CRH DB
Cloud Mask
Data Chunk & Attributes
Error-halt flag

Process Description (Figure 5-1)

This process has four major subprocesses, which are shown on Figure 5-2:

1. "Initialize Cloud Process and Prepare Data Chunk" process validates all input file headers, inputs an imager data chunk, and attaches surface and clear-sky history parameters to each pixel in the chunk and attaches MOA data to each tile of pixels in the chunk.

2. "Perform Cloud Mask Tests" The cloud mask test code will be provided by the Cloud Working Group. More than one test may be performed on a single pixel, the results of which are stored in Cloud Mask. The test results of the individual cloud mask algorithms are either clear, cloudy, uncertain, or untested.

3. "Decide Cloud Presence" process makes a final determination of clear or cloudy for each pixel based on the results of all of the cloud mask algorithms.

4. "Output to CRH": This subprocess outputs various averaged attributes for clear pixels to CRH. Clear pixels are those imager pixels that are unobstructed between the top-of-atmosphere and the surface.

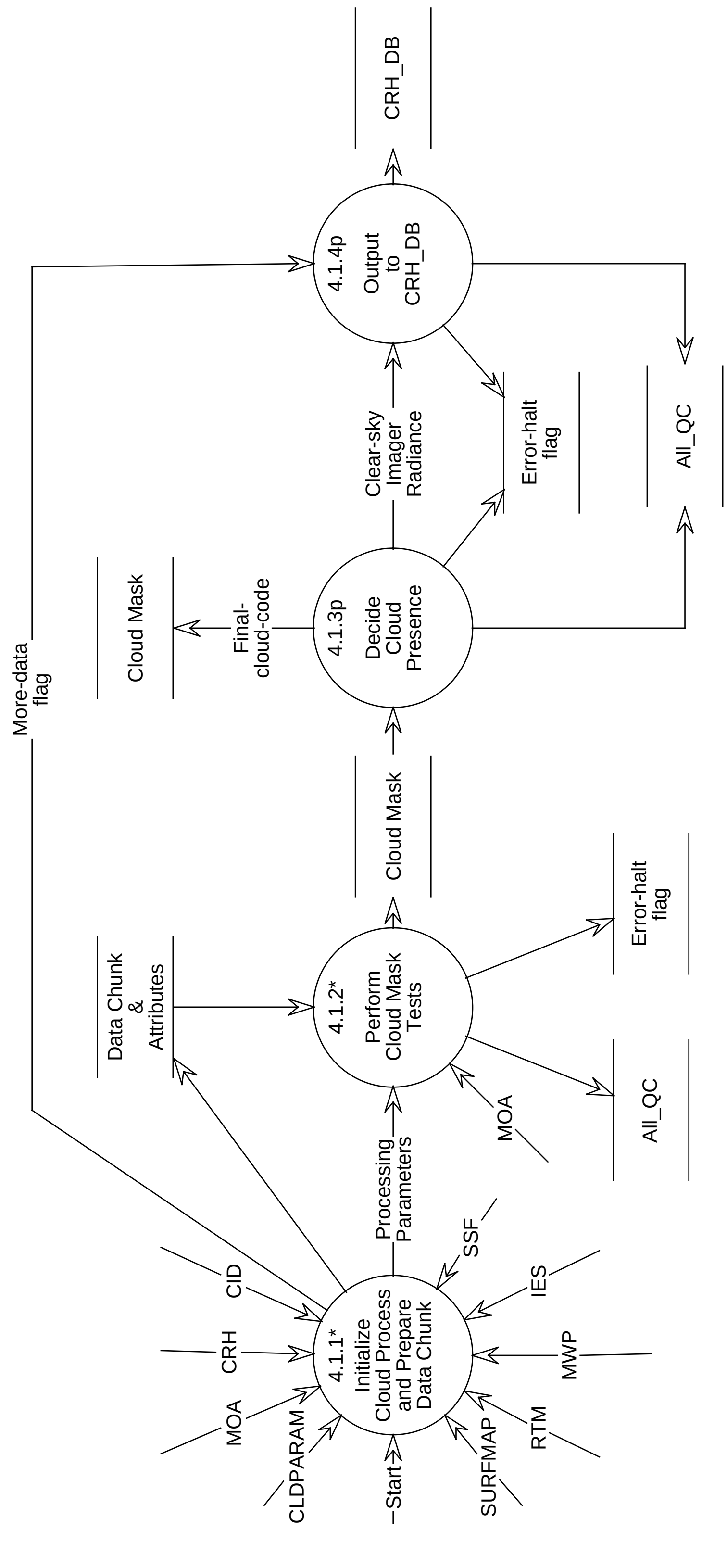

Figure 5-2. Data Flow Diagram for Prepare Data Chunk and Determine Clear/Cloudy Pixels

5.2.1.1 Initialize Cloud Process and Prepare Data Chunk - Process 4.1.1

Input Data Flows

CID
CLDPARAM
CRH
IES
MOA
MWP
RTM
SSF
SURFMAP
Start

Output Data Flows

Data Chunk & Attributes
More-data flag
Processing Parameters

Process Description (Figure 5-2)

This process includes the following subprocesses which are shown on Figure 5-3:

1. Read the CLDPARAM file to obtain the run-time processing information and then access and validate the input file headers
2. Input an imager data chunk
3. Attach the ancillary information from SURFMAP and CRH to each pixel in the data chunk, and attach the MOA data to each tile of pixels in the chunk

The subprocesses, which specify the detailed steps, shall send all quality control information, processing parameters, and any statistics to the Quality Control (All_QC) data store, which will be input to the "Produce Cloud Product & QC Report" process.

If processing errors occur in any of the subprocesses, execute abnormal processing procedures and then abort. The abnormal procedures are to set an error-halt-flag and call the "Produce Cloud Products & QC Report" process to wrap up any unfinished processes, close files, and write an abnormal report using the information in the All_QC data store. Send an error message to the PDPS and abort.

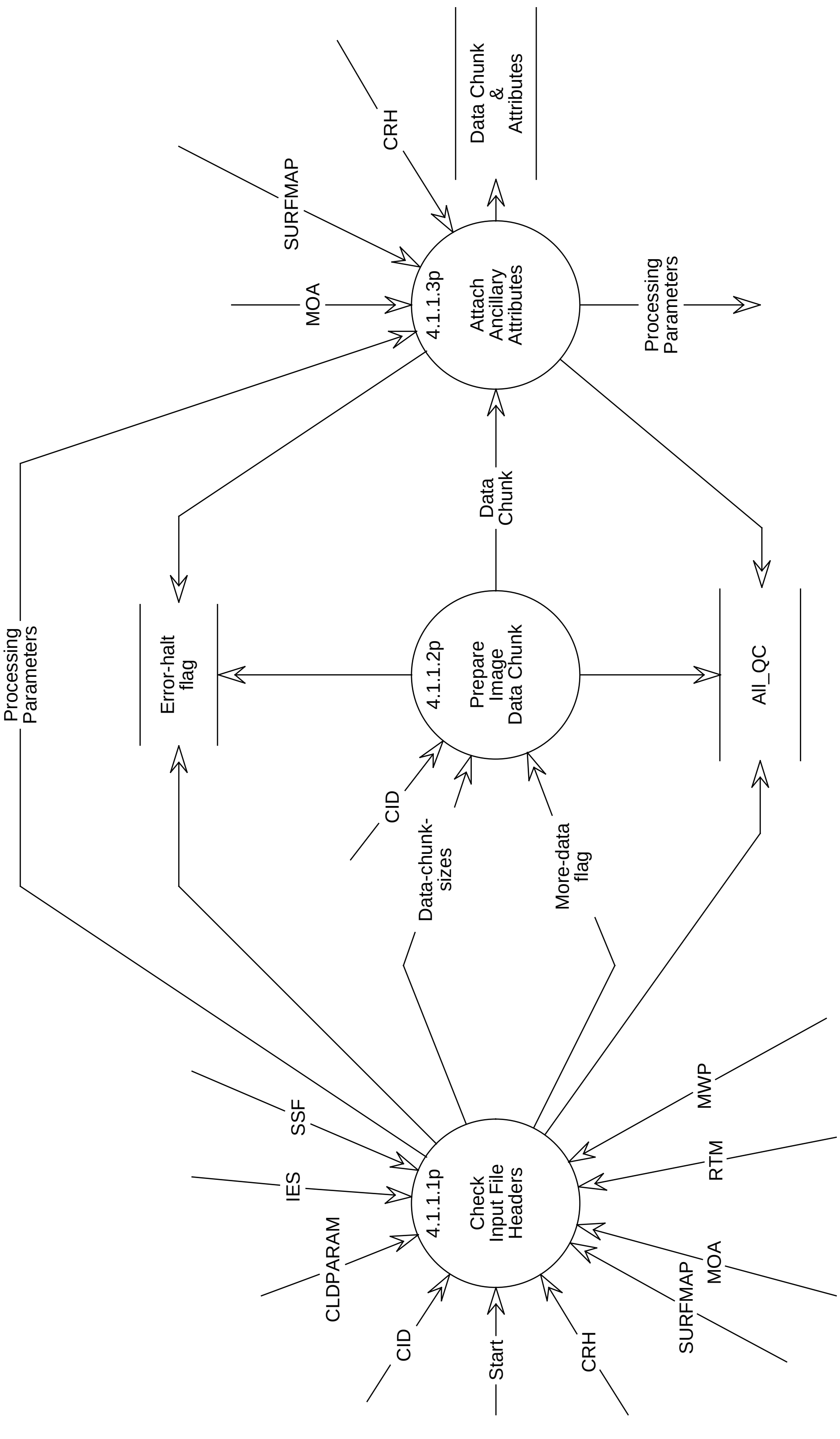

Figure 5-3. Data Flow Diagram for Initialize Cloud Process and Prepare Data Chunk

5.2.1.1.1 Check Input File Headers - Process 4.1.1.1

Input Data Flows

CID
CLDPARAM
CRH
IES
MOA
MWP
RTM
SSF
SURFMAP
Start

Output Data Flows

All QC
Data-chunk- sizes
Error-halt flag
More-data flag
Processing Parameters

Process Specification (Figure 5-3)

This process shall read and validate the input data header records by the following steps:

1. Read the CLDPARM file to obtain the run-time processing information. One of the parameters is the rerun-flag.
2. If the rerun-flag indicates a normal run, then read the IES header.
3. If the rerun-flag indicates a rerun, then read the SSF header.
4. Read the input file headers for CRH, MOA, SURFMAP, RTM, MWP and CID (2 or 3 of these are required for the beginning and ending overlap conditions).
5. Validate that the header information matches the run-time processing information for satellite, instrument, data date, and time.
6. If all header checks are valid, send the header and processing parameters to the All_QC store.
7. Set the More-data flag to the initial state.
8. If any header processing errors occur, set the error-halt-flag and post appropriate error messages into the Header QC report, and call the "Produce Cloud Products & QC Report" process to wrap up.

5.2.1.1.2 Prepare Image Data Chunk - Process 4.1.1.2

Input Data Flows

CID
Data-chunk- sizes
More-data flag

Output Data Flows

All QC
Data Chunk
Error-halt flag

Process Specification (Figure 5-3)

This process shall check the More-data flag and prepare the required amount of cloud imager data (CID) scan lines. The actual amount of data to read shall be parameterized in Data-chunk-sizes.

1. If the More-data flag indicates the first time through or the initial state, read a chunk of scan lines from the previous hour or from an overlap file if we choose to save the data from the previous run.

2. If the More-data flag indicates this is not the initial state, read a chunk of scan lines from the current hour.

3. If the More-data flag indicates this is the end of the current hour, read a chunk of scan lines from the next hour.

4. Count the number of scan lines successfully read, count the number with consecutive read errors, and count the total number of read errors.

5. If the number of consecutive read errors exceeds the maximum allowable consecutive read errors, but is less than the maximum allowable total read errors, reset the consecutive read error counter and set the More-data flag to the restart state. There is a limit to the number of scan lines that can be missing in the middle of a data chunk. If there are too many missing, this process shall start a new data chunk.

6. If the number of total read errors exceeds the maximum allowable total read errors, execute abnormal processing procedures, set the Error-halt-flag, enter the appropriate error messages into the Chunk_QC report, terminate this process, and return to the "Produce Cloud Products & QC Report" process.

5.2.1.1.3 Attach Ancillary Attributes - Process 4.1.1.3

Input Data Flows

CRH
Data Chunk
MOA
Processing Parameters
SURFMAP

Output Data Flows

All QC
Data Chunk & Attributes
Error-halt flag
Processing Parameters

Process Specification (Figure 5-3)

This process shall calculate and attach those calculated parameters listed below and extract and attach ancillary information from the SURFMAP product (see Section 4.1.7) and extract and attach clear-sky information from the CRH product (see Section 4.3.2) to each pixel.

1. Calculate brightness temperature from radiance for infrared and near-infrared channels and calculate reflectance from radiance for visible channels.
2. Read the solar declination file and calculate solar zenith angle, viewing zenith angle, and azimuth angle for every pixel.
3. Read surface elevation, SURFMAP(ECO) and SURFMAP(CONDENSED) using latitude and longitude of the pixel. Determine from the condensed surface map which of six "broad" surface types applies to each pixel and attach the surface type, the ecosystem type, and the elevation to the pixel. The "broad" surface types are:
    - desert
    - mountains
    - snow or ice
    - any other land
    - ocean
    - coastline
4. Read the CRH parameters using the latitude and longitude of the imager pixel. Compute CRH parameters for the current time and viewing angle, and attach the CRH parameters to the pixel.
5. Determine if a pixel is in a polar or nonpolar latitude range. If the latitude is less than some specified degrees, then flag the pixel as nonpolar. Otherwise, flag the pixel as polar.
6. Determine if a pixel is day or night. If the solar zenith angle associated with a pixel is less than some specified degrees, flag the pixel daytime. Otherwise, flag the pixel nighttime.

7. Read the MOA parameters.
8. If there are any read errors from the ancillary data files, perform abnormal termination procedures, set the Error-halt-flag, enter error messages into the Ancillary_QC, terminate this process, and return to the "Produce Cloud Products & QC Report" process.

The VIRS and MODIS CID data will already be calibrated and geolocated (Level 1B); but for Release 1, using AVHRR GAC and HIRS Level 1A data, the following three preprocessing steps are performed outside of this process.

1. Unpack CID_AVHRR data and CID_HIRS data.
2. Apply AVHRR and HIRS calibration information to convert raw counts to radiance.
3. Calculate latitude and longitude for each CID pixel from the navigation data.

5.2.1.2 Perform Cloud Mask Tests - Process 4.1.2

Input Data Flows

Data Chunk & Attributes
MOA
Processing Parameters

Output Data Flows

All QC
Cloud Mask
Error-halt flag

Process Description (Figure 5-2)

There are more than a dozen different cloud mask tests that are discussed in ATBD 4.1 (Reference 3). They will be implemented in early prototying efforts to assist in selecting a stable set of cloud mask tests which will determine whether each imager pixel is cloudy or clear. In addition, the nine single pixel tests specified in Reference 10 will be implemented in Release 1. Many of the tests specified here may disappear after extensive timing, sizing, and effectiveness tests are performed.

Because there are so many possible tests, they cannot be drawn on a single page. In an attempt to organize the tests in a reasonable presentation manner, it may appear that a design is suggested. That was not the intent. The organization chosen minimizes the number of times any test is repeated in these requirements. No one test is at this point favored over any other, and no hierarchical structure is required. After the timing and sizing performance testing and when a subset of the algorithms presented here are chosen by the cloud working group, a hierarchical structure and order may be specified. The final selected cloud mask tests, their order, and any required hierarchy will be kept as corrections to this document until they are formally specified in Release 2.

The tests use either imager temperature or reflectance values and selected threshold values to determine cloud presence. Depending upon the complexity of the test, pixels are processed one at a time or by analysis of pixel arrays (tiles). Some of the algorithms analyze daytime-only pixels and others analyze nighttime-only pixels, while others are general enough to apply to both day and nighttime pixels. Desert areas, snow/ice areas, rugged mountains, coastlines, and sun glint areas will be tested separately.

Many of the cloud mask tests contain constraints. That is, if certain conditions are true, then the algorithm can proceed. If certain other conditions are true, then the algorithm makes no decision for those pixels. Since many of the constraints are the same in many of the tests, the pixel and tile checking for certain conditions and constraints are done once by the pixel and tile manager. Only those pixels or tiles that pass the constraint tests are sent on to the appropriate algorithm. This is considered a performance requirement, but is certainly not the only way to approach the problem.

This process is decomposed into five subprocesses shown in Figure 5-4:

1. a manager to organize pixels by day/night pixel or tile
2. daytime tile tests
3. daytime pixel tests
4. nighttime tile tests
5. nighttime pixel tests

The manager process reads which of the cloud tests will be conducted for a particular group from the CLDPARAM Processing Parameters. For example, during analysis of the effectiveness of any single or combination of algorithms, the user will be able to specify which tests to run. The threshold values are also in the Processing Parameters, which the manager supplies to the cloud mask tests. The manager has knowledge of which algorithms need which types of pixels, the constraints on the pixels, and which threshold values or other data the algorithms need. Either the manager needs enough knowledge to assign the appropriate pixel or tile to an algorithm, or each algorithm must ask for pixels or tiles, and each algorithm determines if it is an appropriate pixel or tile. This is a design decision. The approach in these requirements, however, is that the manager will do all the screening and pixel selection for the algorithms. The final design approach may be different.

5.2.1.2.1 Manage Pixels and Tiles - Process 4.1.2.1

Input Data Flows

Data Chunk & Attributes
Processing Parameters

Output Data Flows

Classify QC
Daytime Pixel
Daytime Tile
Error-halt flag

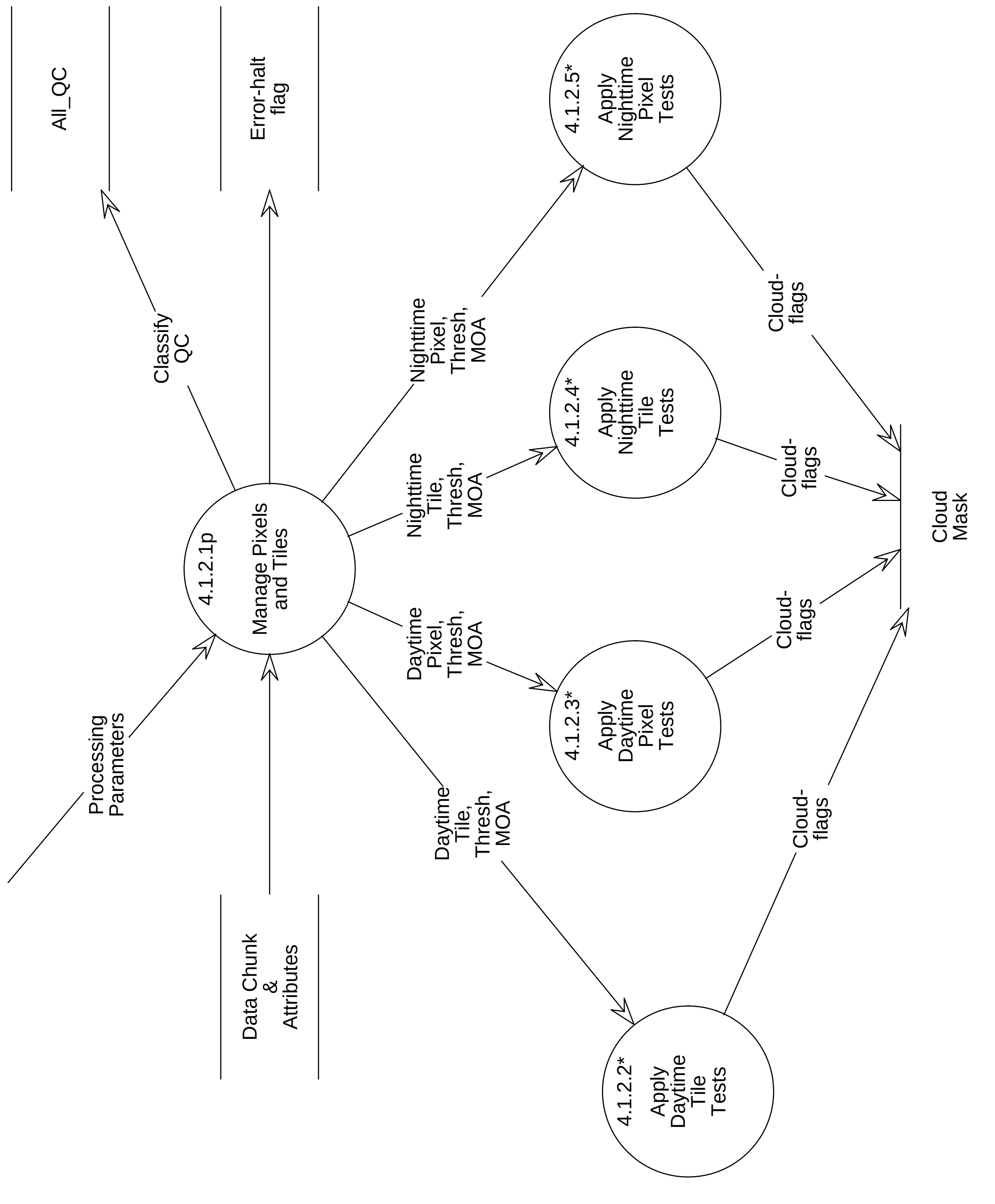

Figure 5-4. Data Flow Diagram for Perform Cloud Mask Tests

MOA
Nighttime Pixel
Nighttime Tile
Thresh

Process Specification (Figure 5-4)

This process selects a pixel or a tile from the data chunk, filters bad pixels, checks tiles for homogeneous ecosystems, and passes the "good" pixels to the cloud mask tests. The four types of pixels that are managed at this level are

- daytime tile tests
- daytime pixel tests
- nighttime tile tests
- nighttime pixel tests

This process shall include the following steps:

1. Initialize the cloud mask to uncertain and untested and initialize counters
2. Select tiles and their attributes from the data chunk and attributes data store
3. Apply the background surface filter tests to the pixels
   a) Perform the SERCAA sunglint test for *nonpolar daytime water region pixels* (Reference 10)

      If sun glint is present, flag the pixel night
      If a pixel with solar zenith angle > 85 degrees and no sun glint, flag the pixel night

   b) Perform the SERCAA spectral snow test (Reference 10). A positive result indicates clear snow background.

   c) Perform the SERCAA spectral desert background test (Reference 10). A positive result indicates clear desert background.
4. Send the "approved" single pixels to the pixel tests
5. Send the tiles to the Layered Bispectral Threshold Method (LBTM) cloud test. Note: LBTM doesn’t care about homogeneity.
6. Check tiles for homogeneity (all day, or all night, and all of same "broad" ecosystem category. The six broad ecosystem categories are desert, mountains, snow or ice, any other land, ocean, coastline. If the pixels in the tile are not all of the same general category, access the next tile. Send the tile to the tile tests that require homogeneity.
7. This process shall keep records of at least the following:
   - how many day/night pixels were found
   - how many of each type of the general category ecosystem tiles were found
   - how many day/night tiles were found

- the number of pixels affected by sun glint
- the number of pixels with high angles of illumination
- the number of pixels that passed the spectral snow test
- the number of pixels that passed the desert test
- the number of daytime land pixels
- the number of pixels deemed by a filter to go to nighttime processing

8. Send all quality control information to the All-QC store. If any processing errors occur, set the Error-halt-flag and begin error handling procedures.

5.2.1.2.2 Apply Daytime Tile Tests - Process 4.1.2.2

Input Data Flows

Daytime Tile
MOA
Thresh

Output Data Flows

Cloud- flags

Process Description (Figure 5-5)

This process organizationally manages the daytime tiles (n x m pixels) formed and screened by the pixel/tile manager. The daytime tile tests for Release 1 listed below are shown on Figure 5-5:

1. The Daytime Layered Bispectral Threshold Method Test (LBTM) (ATBD 4.2) (Reference 4)
2. The Daytime Artificial Intelligence Test (ATBD 4.1.5.5) (Reference 3)
3. The Daytime Polar Scene Test (ATBD 4.1.5.5) (Reference 3)
4. The Daytime ISCCP Spatial Temporal Analysis - short and long term (ATBD 4.1.3.3) (Reference 3)
5. The Daytime CLAVR Reflectance Uniformity test (ATBD 4.1.3.4) (Reference 3)

5.2.1.2.2.1 Perform Daytime Tile Channel Services - Process 4.1.2.2.1

Input Data Flows

Daytime Tile
MOA
Thresh

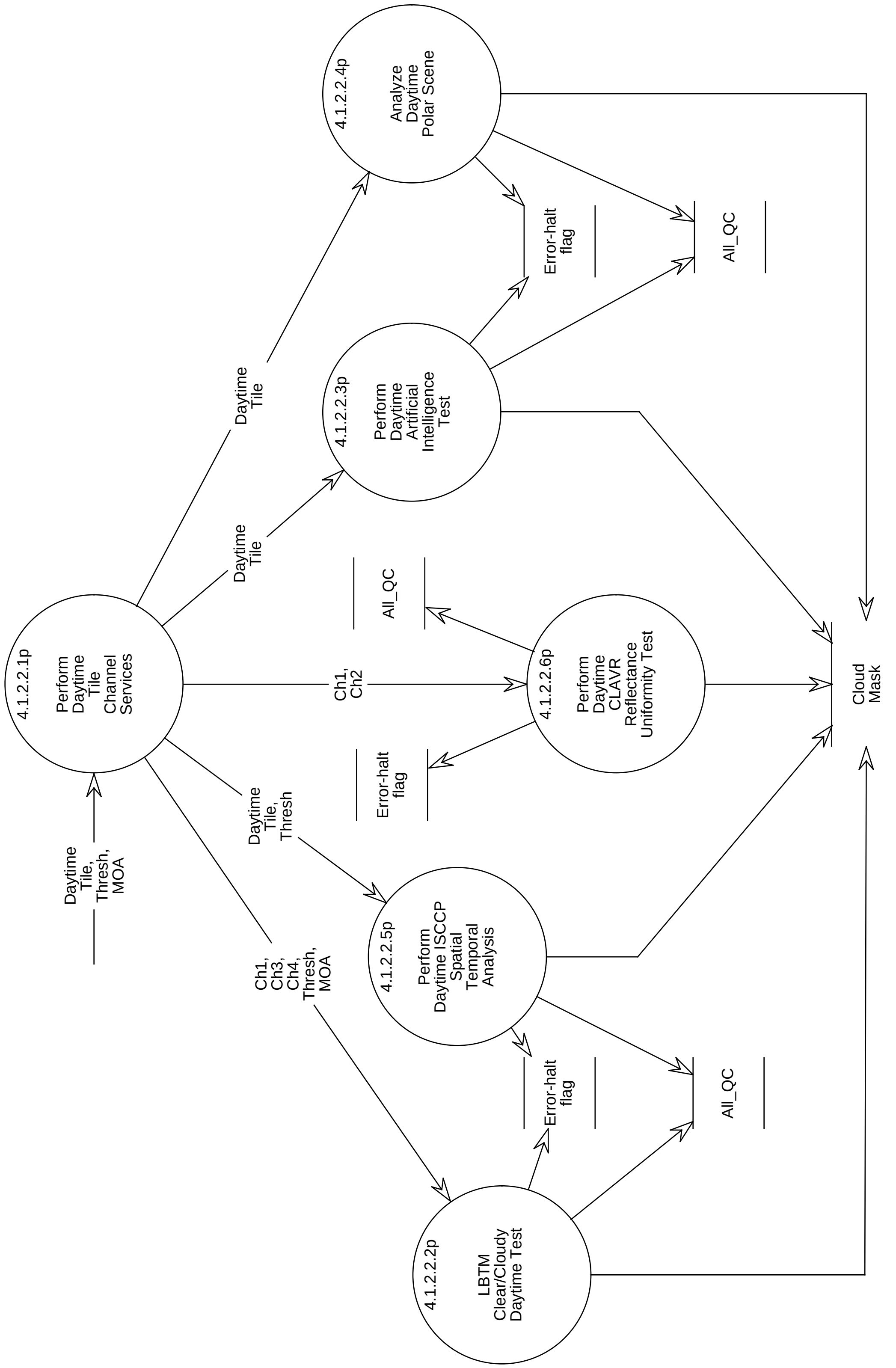

Figure 5-5. Data Flow Diagram for Apply Daytime Tile Tests

Output Data Flows

Ch1
Ch2
Ch3
Ch4
Daytime Tile
MOA
Thresh

Process Specification (Figure 5-5)

For Release 1, this process shall extract the required channel data depending on the specific requirements of the following daytime tile tests. The channel numbers are specific to CID_AVHRR. The channel data contain the surface, clear reflectance and temperature history data, and the MOA data. This process shall

1. Extract Channels 1, 3, and 4 data and send the tile to the Layered Bispectral Threshold Method (LBTM) (ATBD 4.2) (Reference 4)
2. Extract TBD Channel data and send the tile to the Daytime Artificial Intelligence Test (ATBD 4.1.5.5) (Reference 3)
3. Extract TBD Channel data and send the tile to the Daytime Polar Scene Test (ATBD 4.1.5.5) (Reference 3)
4. Extract TBD Channel data and send the tile to the ISCCP Spatial Temporal Analysis - short and long term (ATBD 4.1.3.3) (Reference 3)
5. Extract TBD Channel data and send the tile to the CLAVR Reflectance Uniformity Test (ATBD 4.1.3.4) (Reference 3)

5.2.1.2.2.2 LBTM Clear/Cloudy Daytime Test - Process 4.1.2.2.2

Input Data Flows

Ch1
Ch3
Ch4
MOA
Thresh

Output Data Flows

All QC
Cloud Mask
Error-halt flag

Process Specification (Figure 5-5)

This process is the clear/cloudy test extracted from the LBTM algorithm. The algorithm will be supplied by the Cloud Working Group (Pat Heck). The algorithm accepts any ecosystem or range of latitudes. The algorithm currently operates on a 16 by 16 tile, but other sizes are being considered. The algorithm needs the scene geotype, solar zenith angle, and latitude and longitude of each pixel. These attributes are attached to each pixel and will accompany the channel data. Other input required are the standard deviations of a 16 by 16 tile of temperatures possible from CRH. These temperature standard deviations represent a baseline climatology of clear-sky conditions.

This process shall:

1. Extract the appropriate threshold values from Thresh
2. Form a bi-spectral histogram from the Channel 1 and Channel 4 data
3. Compute standard deviations
4. Compare the standard deviations with those from CRH
5. Make a clear/cloudy determination for each pixel
6. Average the Channel 3 data over the input tile
7. Check the results of the bi-spectral histogram by comparing with the averaged Channel 3 data
8. Set the cloud flags to clear for clear pixels or to cloudy for the cloudy pixels

5.2.1.2.2.3 Perform Daytime Artificial Intelligence Test - Process 4.1.2.2.3

Input Data Flows

Daytime Tile

Output Data Flows

All QC
Cloud Mask
Error-halt flag

Process Specification (Figure 5-5)

If a tile is snow-covered, rugged terrain, or coastline, it will be analyzed using Artificial Intelligence (AI) classification techniques and not by traditional threshold methods. The algorithm, code, and documentation will be supplied by Dr. Ron Welch.

This process shall:

1. Keep a count of the total number of daytime nonpolar tiles processed.
2. Keep a count of the number of different scene classifications analyzed.

5.2.1.2.2.4 Analyze Daytime Polar Scene - Process 4.1.2.2.4

Input Data Flows
Daytime Tile

Output Data Flows
All QC
Cloud Mask
Error-halt flag

Process Specification (Figure 5-5)

This process shall implement the steps in ATBD 4.1.5.5 “Scene Classification for Daytime Polar Region Analysis” (Reference 3). The algorithm, code, and documentation will be supplied by Dr. Ron Welch.

This process shall:

1. Keep a count of the total number of tiles processed.
2. Keep a count of the number of different scene classifications analyzed.

5.2.1.2.2.5 Perform Daytime ISCCP Spatial Temporal Analysis - Process 4.1.2.2.5

Input Data Flows
Daytime Tile
Thresh

Output Data Flows
All QC
Cloud Mask
Error-halt flag

Process Specification (Figure 5-5)

This process compares the current temperature and reflectance values to those from previous clear days, which have been retrieved from CRH and attached to the pixel. The CRH albedo values must be converted to reflectance. A double-ended threshold test is applied to the absolute differences in all four input measurements between the current and previous clear day. The formulas are from ATBD 4.1, equations 4.1-2 to 4.1-9 (Reference 3).

This process shall:

1. Extract the thresholds (delta minimums and delta maximums) from Thresh
2. Convert CRH Ch1 and Ch2 albedo to reflectance
3. Calculate minimum differences

$$\left|T_B(i) - T_B(cs)\right| < \Delta_T^{min}$$

$$\left|\rho_1(i) - \rho_1(cs)\right| < \Delta_1^{min}$$

$$\left|\rho_2(i) - \rho_2(cs)\right| < \Delta_2^{min}$$

$$\left|\rho_3(i) - \rho_3(cs)\right| < \Delta_3^{min}$$

where

$T_B(i)$	is the present temperature measurement (Ch5)
$T_B(cs)$	is a previous clear-sky temperature (Ch5) attached to the pixel from CRH
$\rho_j(i)$	is the channel j reflectance for the present measurement (Ch1, 2, and 3)
$\rho_j(cs)$	is the previous clear-sky channel j reflectance (Ch1, 2, and 3)
$\Delta_T^{min} = 2.5K$	is the selected lower boundary for Channel 5
Δ_j^{min}	is the selected lower boundary for channel j (Ch1, 2, and 3)

4. If the differences are less than the minimum delta for all four measurements, it is probably clear. Set cloud flag-n to clear.
5. Calculate the maximum differences

$$\left|T_B(i) - T_B(cs)\right| > \Delta_T^{max}$$

$$\left|\rho_1(i) - \rho_1(cs)\right| > \Delta_1^{max}$$

$$\left|\rho_2(i) - \rho_2(cs)\right| > \Delta_2^{max}$$

$$\left|\rho_3(i) - \rho_3(cs)\right| > \Delta_3^{max}$$

where

$\Delta_T^{max} = 6K$ is the selected upper boundary for the thermal channel (Ch5)

Δ_j^{max} is the selected upper boundary for channel j (Ch1, 2, and 3)

6. If the differences are greater than the maximum delta for all four measures, it is probably cloudy. Set cloud flag-n to cloudy.
7. If the differences are between minimum and maximum delta for any measurement, it is undecided. Set cloud flag-n to uncertain.

The short-term period is approximately 9 days while the long-term period is approximately 25 days. The algorithm shall:

1. Compute statistics of the mean and standard deviation for both short-term and long-term periods over 32 by 32 pixel tiles of the same ecosystem
2. Compute the minimum and maximum values over the same region
3. If the present-day values are labeled as clear and if these values lie within one standard deviation of the short- and long-term values, then label the pixel definitely clear.
4. If the present-day mean value lies between the mean plus or minus the standard deviation, then label the pixel probably clear
5. Perform a similar test if the present day pixel is labeled cloudy

5.2.1.2.2.6 Perform Daytime CLAVR Reflectance Uniformity Test - Process 4.1.2.2.6

Input Data Flows

Ch1
Ch2

Output Data Flows

All QC
Cloud Mask
Error-halt Flag

Process Specification (Figure 5-5)

This algorithm is described in ATBD 4.1.3.4 (Reference 3). The algorithm and documentation will be provided by Dr. Stowe. The algorithm shall:

1. Compute maximum and minimum values of AVHRR Channel 1 or Channel 2 reflectances within a 2 by 2 pixel array
2. If pixel arrays with Channel 1 reflectance differences are greater than 9% over land or Channel 2 reflectance differences are greater than 0.3% over ocean, label the pixels as mixed.

5.2.1.2.3 Apply Daytime Pixel Tests - Process 4.1.2.3

Input Data Flows

Daytime Pixel
MOA
Thresh

Output Data Flows

Cloud Flags

Process Description (Figure 5-4)

This process manages the daytime single pixels screened by the pixel/tile manager. For Release 1, the candidate daytime tests that require one pixel at a time are shown in Figure 5-6 and are

1. The Daytime Polar Pixel Test (ATBD 4.1.5.5)
2. The Daytime Cirrus Cloud Test (SERCAA and ATBD 4.1.3.5)
3. The Low Cloud and Fog Test (SERCAA and ATBD 4.1.3.7)
4. The Precipitating Cloud Test (SERCAA and ATBD 4.1.3.8)
5. The Daytime Thin Cirrus Cloud Test (SERCAA and ATBD 4.1.3.9)
6. The Visible Brightness Test (SERCAA and ATBD 4.1.3.10)
7. The Daytime Cold Cloud Test (SERCAA and ATBD 4.1.3.6)
8. The Channel 1, 2 Ratio Test (SERCAA)

Note: ATBD 4.1 is Reference 3 and SERCAA is Reference 10.

The decomposition of this process is shown in Figure 5-6.

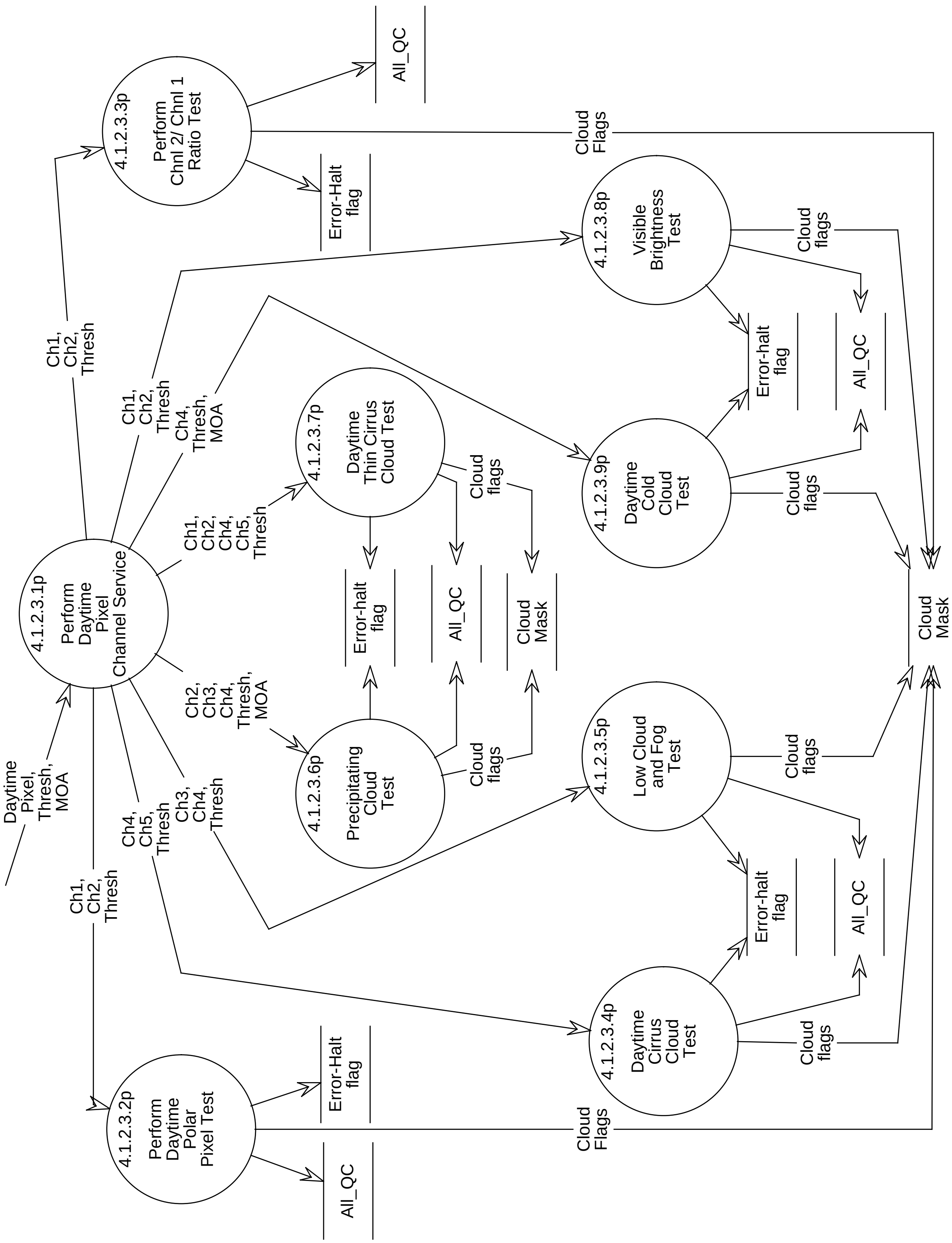

Figure 5-6. Data Flow Diagram for Apply Daytime Pixel Tests

5.2.1.2.3.1 Perform Daytime Pixel Channel Service - Process 4.1.2.3.1

Input Data Flows

Daytime Pixel
MOA
Thresh

Output Data Flows

Ch1
Ch2
Ch3
Ch4
Ch5
MOA
Thresh

Process Specification (Figure 5-6)

This process shall select specific channels from the daytime pixels and send them to the candidate cloud mask tests. For Release 1, the candidate tests that require one pixel at a time are listed below with the specific channel requirements. The data attached from SURFMAP, CRH, and MOA are also sent to the cloud mask tests. The channel numbers correspond to the AVHRR channels. This process shall:

1. Send the Daytime Pixel to the Daytime Polar Pixel Test (ATBD 4.1.5.5)
2. Extract Channels 4 and 5 from Daytime Pixel and send them to the Daytime Cirrus Cloud Test (SERCAA and ATBD 4.1.3.5)
3. Extract Channels 3 and 4 from Daytime Pixel and send them to the Low Cloud and Fog Test (SERCAA and ATBD 4.1.3.7)
4. Extract Channels 2, 3, and 4 from Daytime Pixel and send them to the Precipitating Cloud Test (SERCAA and ATBD 4.1.3.8)
5. Extract Channels 1, 2, 4, and 5 from Daytime Pixel and send them to the Daytime Thin Cirrus Cloud Test (SERCAA and ATBD 4.1.3.9)
6. Extract Channels 1 and 2 from Daytime Pixel and send them to the Visible Brightness Test (SERCAA and ATBD 4.1.3.10)
7. Extract Channel 4 from Daytime Pixel and send it to the Daytime Cold Cloud Test (SERCAA and ATBD 4.1.3.6)
8. Extract Channels 1 and 2 from Daytime Pixel and send them to the Channel 1, 2 Ratio Test (SERCAA)

Note: ATBD 4.1 is Reference 3 and SERCAA is Reference 10.

5.2.1.2.3.2 Perform Daytime Polar Pixel Test - Process 4.1.2.3.2

Input Data Flows

Ch1
Ch2
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

The Daytime Polar Pixel Test will be supplied by Dr. Ron Welch.

5.2.1.2.3.3 Perform Chnl 2/ Chnl 1 Ratio Test - Process 4.1.2.3.3

Input Data Flows

Ch1
Ch2
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

Pixels are excluded from this test if sun glint is present, or if the surface type from SURFMAP is desert, snow or ice, or coastline (screening previously done by pixel/tile manager).

This process shall:

1. Extract the humidity, lower and upper limit thresholds from Thresh
2. Calculate the ratio R of the Channel 2 reflectance to the Channel 1 reflectance
3. Test for high humidity by comparing the clear-sky brightness temperature T(clearsky) from CRH to a humidity threshold

    If T(clearsky) > Thresh(ratio_humid) then

        If the lower_threshold(ocean) < R < upper_threshold (ocean)
        then set the Cloud Flag-n to clear ocean pixel

else set the Cloud Flag-n to cloudy ocean pixel.

else

If the lower_threshold(land) < R < upper_threshold (land)
then set the Cloud Flag-n to cloudy land pixel
else set the Cloud Flag-n to clear land pixel.

Note: For initial testing, use the values shown in Table 5-1.

Table 5-1. Threshold Table

Variable	Value
Thresh(ratio_humid)	295K
Lower_threshold(ocean)	0.70
Upper_threshold(ocean)	1.00
Lower_threshold(land)	0.75
Upper_threshold(land)	1.10

4. If neither clear nor cloudy, set Cloud Flag-n to uncertain

5.2.1.2.3.4 Daytime Cirrus Cloud Test - Process 4.1.2.3.4

Input Data Flows

Ch4
Ch5
Thresh

Output Data Flows

All QC
Cloud flags
Error-halt flag

Process Specification (Figure 5-6)

Any pixels that pass the SERCAA spectral snow test are excluded from this test by the pixel/tile manager. The Daytime Cirrus Cloud Test (which is the same as the nighttime test) shall:

1. Extract the thresholds from the threshold file Thresh
2. Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.
3. If the SURFMAP scene type is not snow, then
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   then set the Cloud Flag for this process to cloudy.

4. If the SURFMAP scene type is snow, and
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   and if also Tpred - Ch4 > Thresh(cirrus_cloud_detection)
   then set the Cloud Flag for this process to cloudy.
5. If not cloudy, then set the Cloud Flag to clear

The details of the algorithm are in the SERCAA document (Reference 10). The code and documentation will be provided by the Cloud Working Group.

5.2.1.2.3.5 Low Cloud and Fog Test - Process 4.1.2.3.5

Input Data Flows
Ch3
Ch4
Thresh

Output Data Flows
All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

Any pixels that pass the spectral snow/ice test will be excluded from this algorithm by the pixel/tile manager. The Low Cloud and Fog Test shall:

1. Perform the spectral desert background test
2. Perform the sun glint test
3. Extract the thresholds from Thresh
4. If the solar zenith angle > 80 degrees and the SURFMAP scene type is desert, then
   if Ch3 - Ch4 > Thresh(low_cloud_fog_desert)
   then the pixel is classified as cloudy. Set the Cloud Flag to cloudy
5. If the solar zenith angle < 80 degrees and the spectral desert background test is positive, then
   if Ch3 - Ch4 > Thresh(low_cloud_fog_desert)
   then the pixel is classified as cloudy. Set the Cloud Flag to cloudy
6. If the sun glint test is positive, then
   If Ch3 - Ch4 > Thresh(low_cloud_fog_sunglint)
   then the pixel is classified as cloudy. Set the Cloud Flag to cloudy

7. If not desert and if no sun-glint, then
   If Ch3 - Ch4 > Thresh(low_cloud_fog)
   then the pixel is classified as cloudy. Set the Cloud Flag to cloudy
8. If not cloudy, then set the Cloud Flag to clear

The details of the algorithm are in the SERCAA document (Reference 10). The code and documentation will be provided by the Cloud Working Group.

5.2.1.2.3.6 Precipitating Cloud Test - Process 4.1.2.3.6

Input Data Flows

Ch2
Ch3
Ch4
MOA
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

Any pixels that pass the spectral snow test and whose solar zenith angle is greater than 80 degrees will be excluded from this algorithm by the pixel/tile manager.

The Precipitating Cloud Test (SERCAA Reference 10) is largely a cumulonimbus test that uses the reflective nature of thick ice clouds at 3.7 micron. The code and documentation will be provided by the Cloud Working Group. This test shall:

1. Extract the needed threshold values from Thresh
2. Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.
3. If Ch3 - Ch4 > Thresh(precipitation1)
   and If Tpred - Ch4 > Thresh(precipitation2)
   and If Ch2 > Thresh(precipitation3)
   then set Cloud Flag-n to cloudy
4. If not cloudy, then set the Cloud Flag to clear

5.2.1.2.3.7 Daytime Thin Cirrus Cloud Test - Process 4.1.2.3.7

Input Data Flows

- Ch1
- Ch2
- Ch4
- Ch5
- Thresh

Output Data Flows

- All QC
- Cloud Flags
- Error-halt Flag

Process Specification (Figure 5-6)

The Daytime Thin Cirrus Cloud Test (SERCAA Reference 10) uses both tests specified for the Daytime Cirrus Cloud Test and in addition, uses visible or near-IR "albedo" reflectance to discriminate thin cirrus. The code and documentation will be provided by the Cloud Working Group.

The process shall:

1. Extract the appropriate threshold values from Thresh
2. Assign the clear-sky value attached to the pixel from CRH to the predicted clear scene brightness temperature (Tpred)
3. If the scene type is not snow, then
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   then set the Cloud Flag for this process to cloudy.
4. If the scene type is snow, and
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   and if also Tpred - Ch4 > Thresh(cirrus_cloud_detection)
   then set the Cloud Flag for this process to cloudy.
5. Perform the additional tests depending on the surface background type:

   If water and Ch2 < Thresh(day_thin_cirrus_water)
   then set Cloud Flag-n to 1

   if land and Ch1 < Thresh(day_thin_cirrus_land)
   then set Cloud Flag-n to cloudy
6. If not cloudy, then set the Cloud Flag to clear

5.2.1.2.3.8 Visible Brightness Test - Process 4.1.2.3.8

Input Data Flows

Ch1
Ch2
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

Any pixels that have sun glint presence, or have a surface type of desert, snow or ice have been excluded from this algorithm by the pixel/tile manager. The code and documentation will be provided for this algorithm by the Cloud Working Group.

The Visible Brightness Test shall:

1. Extract the appropriate threshold values from Thresh
2. Set Tpred to the clear-sky temperature extracted from CRH
3. If land and Ch1 - Tpred > Thresh(land)
   then cloudy pixel and set Cloud Flag-n to cloudy.
4. If water and Ch2 > Thresh(water)
   then cloudy pixel and set Cloud Flag-n to cloudy.
5. If not cloudy, then set the Cloud Flag to clear

5.2.1.2.3.9 Daytime Cold Cloud Test - Process 4.1.2.3.9

Input Data Flows

Ch4
MOA
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-6)

Any pixels that pass the spectral snow test shall be excluded from this algorithm by the pixel/tile manager. This test is independent of scene solar illumination (i.e., applicable to both day and night). The daytime Cold Cloud Test process shall:

1. Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.
2. Extract the appropriate threshold values from Thresh
3. If water and Tpred - Ch4 > Thresh(water)
   then cloudy pixel and set Cloud Flag-n to cloudy
4. If land and Tpred - Ch4 > Thresh(land)
   then cloudy pixel and set Cloud Flag-n to cloudy
5. If coast and Tpred - Ch4 > Thresh(coast)
   then cloudy pixel and set Cloud Flag-n to cloudy
6. If desert and Tpred - Ch4 > Thresh(desert)
   then cloudy pixel and set Cloud Flag-n to cloudy
7. If snow/ice and Tpred - Ch4 > Thresh(snow/ice)
   then cloudy pixel and set Cloud Flag-n to cloudy
8. If not cloudy, then set the Cloud Flag to clear

The code and documentation will be provided for this algorithm by the Cloud Working Group.

5.2.1.2.4 Apply Nighttime Tile Tests - Process 4.1.2.4

Input Data Flows

MOA
Nighttime Tile
Thresh

Output Data Flows

Cloud Flags

Process Description (Figure 5-4)

This process manages the nighttime tiles (n x m pixels) formed and screened by the pixel/tile manager. For Release 1, the nightime tile tests shown in Figure 5-7 are:

1. The Nighttime Artificial Intelligence Test (ATBD 4.1.5.5)
2. The Nightime Layered Bispectral Threshold Method Test (LBTM) (ATBD 4.2)

3. The Nightime Polar Scene Test (ATBD 4.1.7.2)
4. ISCCP Spatial Temporal Analysis - short- and long-term (ATBD 4.1.3.3)
5. CLAVR Reflectance Uniformity Test (ATBD 4.1.3.4)
6. The Nighttime IR Brightness Temperature Difference Test (ATBD 4.1.3.5)

5.2.1.2.4.1 Perform Nighttime Tile Channel Selection - Process 4.1.2.4.1

Input Data Flows

MOA
Nighttime Tile
Thresh

Output Data Flows

Ch1
Ch2
Ch3
Ch4
Ch5
MOA
Nighttime Tile
Thresh

Process Specification (Figure 5-7)

For Release 1, this process shall extract the required channel data and the CRH, SURMFAP, and MOA attributes. The channel numbers listed are AVHRR. This process shall:

1. Extract TBD Channel data and send to the Analyze Nighttime Artificial Intelligence Test (ATBD 4.1.5.5)
2. Extract Channels 1, 3, and 4 data and send to the Nighttime Layered Bispectral Threshold Method (LBTM) Test (ATBD 4.2)
3. Extract TBD Channel data and send to the Nightime Polar Scene Test (ATBD 4.1.7.2)
4. Extract TBD Channel data and send to the Nighttime ISCCP Spatial Temporal Analysis - short- and long-term (ATBD 4.1.3.3)
5. Extract TBD Channel data and send to the Nighttime CLAVR Reflectance Uniformity test (ATBD 4.1.3.4)
6. Extract Channels 4 and 5 data and send to the Nighttime IR Brightness Temperature Difference Test (ATBD 4.1.3.5)

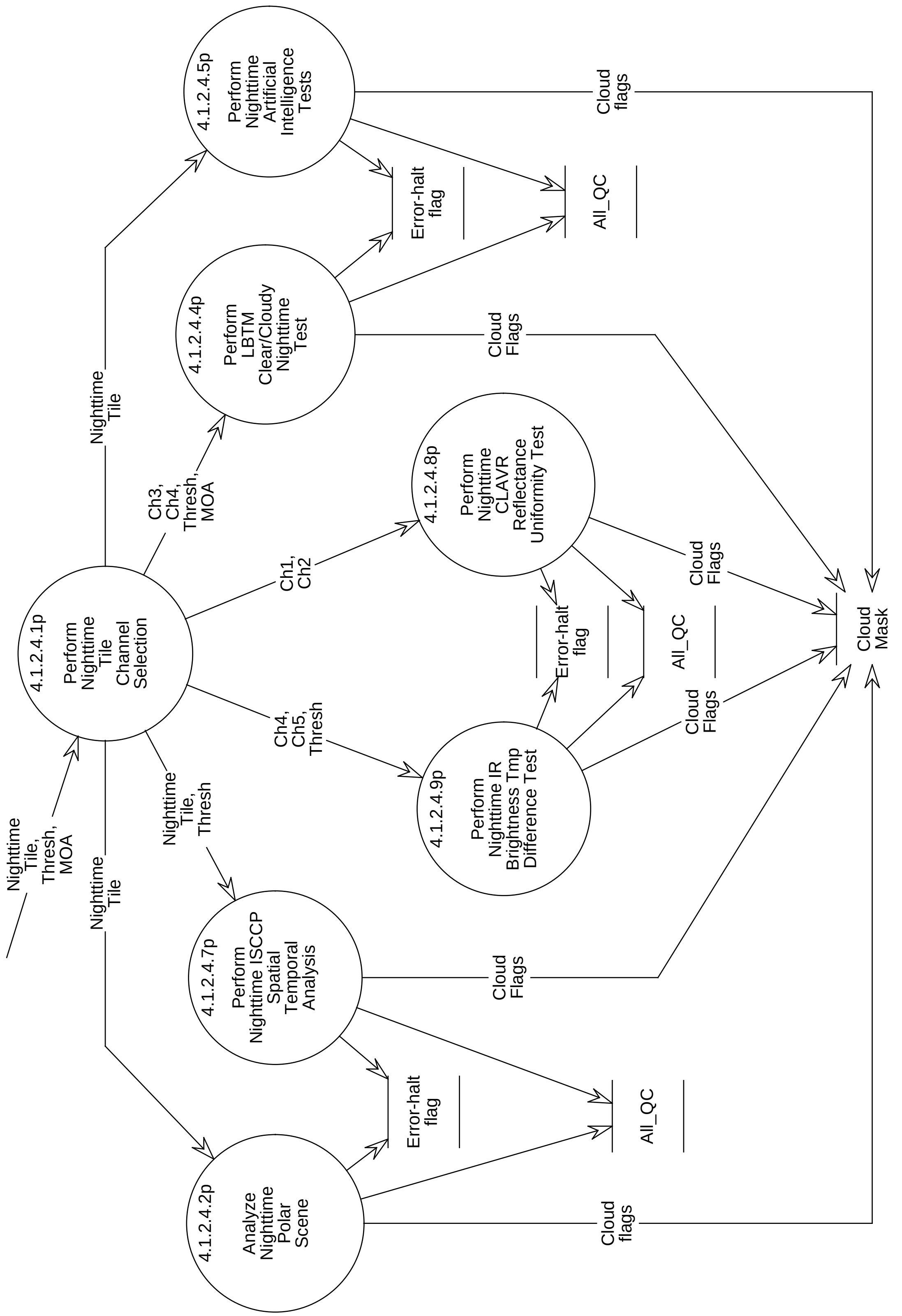

Figure 5-7. Data Flow Diagram for Apply Nighttime Tile Tests

5.2.1.2.4.2 Analyze Nighttime Polar Scene - Process 4.1.2.4.2

Input Data Flows

Nighttime Tile

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

This algorithm will be supplied by Dr. Ron Welch.

5.2.1.2.4.3 Perform LBTM Clear/Cloudy Nighttime Test - Process 4.1.2.4.4

Input Data Flows

Ch3
Ch4
MOA
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

This process is the clear/cloudy test extracted from the LBTM algorithm. The algorithm will be supplied by the Cloud Working Group (Pat Heck). The algorithm accepts any ecosystem or range of latitudes. The algorithm currently operates on a 16 by 16 tile, but other sizes are being considered. The algorithm needs the SURFMAP scene type, latitude, and longitude of each pixel. These attributes are attached to each pixel and will accompany the channel data. Other input required are the means and standard deviations of 16 by 16 tile temperatures from CRH. These temperature standard deviations represent a baseline climatology of clear-sky conditions.

1. Extract the appropriate threshold values from Thresh
2. Compute averages and standard deviations of the Channel 4 data from each tile
3. Compares Channel 4 averages with those from CRH
4. Make a clear/cloud determination for each pixel
5. Average the Channel 3 data over the input tile
6. Check the results of the bi-spectral histogram with the averaged Channel 3 data

7. Save the result in the Cloud Flag-n.

5.2.1.2.4.4 Perform Nighttime Artificial Intelligence Tests - Process 4.1.2.4.5

Input Data Flows

Nighttime Tile

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

If a tile is snow covered, rugged terrain, or coastline, it will be analyzed using Artificial Intelligence (AI) techniques and not by traditional threshold methods. The algorithm will be supplied by Dr. Ron Welch.

This process shall:

1. Keep a count of the total number of tiles processed
2. Keep a count of the number of different scene classifications analyzed.

5.2.1.2.4.5 Perform Nighttime ISCCP Spatial Temporal Analysis - Process 4.1.2.4.7

Input Data Flows

Nighttime Tile
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

This process compares the current temperature and reflectance values to those from previous clear days, which have been retrieved from CRH and attached to the pixel. The CRH albedo values must be converted to reflectance. A double-ended threshold test is applied to the absolute differences in all four input measurements between the current and previous clear day. The formulas are from ATBD 4.1, equations 4.1-2 to 4.1-9 (Reference 3).

This process shall:

1. Extract the thresholds (delta minimums and delta maximums) from Thresh
2. Convert CRH Ch1 and Ch2 albedo to reflectance
3. Calculate minimum differences

$$|T_B(i) - T_B(cs)| < \Delta_T^{min}$$

$$|\rho_1(i) - \rho_1(cs)| < \Delta_1^{min}$$

$$|\rho_2(i) - \rho_2(cs)| < \Delta_2^{min}$$

$$|\rho_3(i) - \rho_3(cs)| < \Delta_3^{min}$$

where

$T_B(i)$ is the present temperature measurement (Ch5)

$T_B(cs)$ is a previous clear-sky temperature (Ch5) attached to the pixel from CRH

$\rho_j(i)$ is the Channel j reflectance for the present measurement (Ch1, 2, and 3)

$\rho_j(cs)$ is the previous clear-sky Channel j reflectance (Ch1, 2, and 3)

$\Delta_T^{min} = 2.5K$ is the selected lower boundary for Channel 5

Δ_j^{min} is the selected lower boundary for Channel j (Ch1, 2, and 3)

4. If the differences are less than the minimum delta for all four measurements, it is probably clear. Set Cloud Flag-n to clear.
5. Calculate the maximum differences

$$|T_B(i) - T_B(cs)| > \Delta_T^{max}$$

$$|\rho_1(i) - \rho_1(cs)| > \Delta_1^{max}$$

$$|\rho_2(i) - \rho_2(cs)| > \Delta_2^{max}$$

$$\left|\rho_3(i) - \rho_3(cs)\right| > \Delta_3^{max}$$

where

$\Delta_T^{max} = 6K$ is the selected upper boundary for the Thermal Channel (Ch5)

Δ_j^{max} is the selected upper boundary for Channel j (Ch1, 2, and 3)

6. If the differences are greater than the maximum delta for all four measures, it is probably cloudy. Set Cloud Flag-n to cloudy.
7. If the differences are between minimum and maximum delta for any measurement, it is undecided. Set Cloud Flag-n to uncertain.

The short-term period is approximately 9 days while the long-term period is approximately 25 days. The algorithm shall:

1. Compute statistics of the mean and standard deviation for both short-term and long-term periods over 32 by 32 pixel tiles of the same ecosystem
2. Compute the minimum and maximum values over the same region
3. If the present day values are labeled as clear and if these values lie within one standard deviation of the short- and long-term values, then label the pixel definitely clear.
4. If the present day mean value lies between the mean plus or minus the standard deviation, then label the pixel probably clear
5. Perform a similar test if the present day pixel is labeled cloudy

5.2.1.2.4.6 Perform Nighttime CLAVR Reflectance Uniformity Test - Process 4.1.2.4.8

Input Data Flows

Ch1
Ch2

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

This algorithm is described in ATBD 4.1.3.4. The algorithm and documentation will be provided by Dr. Stowe. The algorithm shall:

1. Compute maximum and minimum values of AVHRR Channel 1 or Channel 2 reflectances within a 2 by 2 pixel array
2. If pixel arrays with Channel 1 reflectance differences are greater than 9% over land or Channel 2 reflectance differences are greater than 0.3% over ocean, label the pixels as mixed.

5.2.1.2.4.7 Perform Nighttime IR Brightness Tmp Difference Test - Process 4.1.2.4.9

Input Data Flows

Ch4
Ch5
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-7)

This process shall calculate the Brightness Temperature Difference (BTD) between Channel 4 and 5 temperatures (Δ_{BTD}), where BTD is a selected threshold. The algorithm can be used over both land and water.

1. Average 4 pixels within the tile into one value
2. If the brightness temperature for Channel 4 is less than 260 K, the threshold is set to zero. $\Delta_{BTD}(\text{oceans}) = 0$ and $\Delta_{BTD}(land) = 0$
3. If the Channel 4 brightness temperature $T_{B_4}{}^{i} \geq 260$ K, then the equations 4.1-10 and 4.1-11 listed in ATBD 4.1 (Reference 3) are used to calculate the thresholds $\Delta_{BTD}(\text{oceans})$ and $\Delta_{BTD}(land)$.

$$\Delta_{BTD}(\text{oceans}) = \sum_{i=0}^{5} a_i T_{B_4}{}^{i}$$

$$\Delta_{BTD}(land) = \sum_{i=0}^{4} a_i T_{B_4}{}^{i}$$

Where the coefficient a_i from ATBD 4.1, Table 4.1-2 are:

Coefficient	Ocean	Land
a_0	9.27066×10^{4}	-1.34436×10^{4}
a_1	-1.79203×10^{3}	194.945
a_2	13.8305	-1.05635
a_3	-0.0532679	2.53361×10^{-3}
a_4	1.02374×10^{-4}	-2.26786×10^{-6}
a_5	-7.85333×10^{-8}	

Note: The coefficients shall be input parameters.

4. If the ocean pixels' BTD > Δ_{BTD} (oceans), then the pixel is cloudy - set Cloud Flag to cloudy.
5. If land pixels' BTD > Δ_{BTD} (land), then the pixel is cloudy - set Cloud Flag to cloudy.
6. Otherwise, set Cloud Flag to clear.

5.2.1.2.5 Apply Nighttime Pixel Tests - Process 4.1.2.5

Input Data Flows

MOA
Nighttime Pixel
Thresh

Output Data Flows

Cloud Flags

Process Description (Figure 5-4)

This process manages the single nighttime pixels screened by the pixel/tile manager. The candidate nighttime pixel tests for Release 1 shown in Figure 5-8 are

1. The Cold Cloud Test (SERCAA and ATBD 4.1.3.6)
2. The Cirrus Cloud Test (SERCAA and ATBD 4.1.3.5)
3. The Fog and Low Stratus Test (SERCAA and ATBD 4.1.3.13)
4. The Nighttime Thin Cirrus Cloud Test (SERCAA and ATBD 4.1.3.14)
5. The Nighttime Uniform Low Stratus Test (ATBD 4.1.3.13)

The SERCAA document is Reference 10 and ATBD 4.1 is Reference 3.

5.2.1.2.5.1 Select Channel Data for Nighttime Pixel Tests - Process 4.1.2.5.1

Input Data Flows

MOA
Nighttime Pixel
Thresh

Output Data Flows

Ch3
Ch4
Ch5
MOA
Thresh

Process Specification (Figure 5-8)

This process shall select the channels that each pixel algorithm requires from the nighttime pixel data. The data contain CRH, SURFMAP, and MOA attributes. The candidate nighttime pixel tests and their required channel data are

1. Cold Cloud Test (SERCAA and ATBD 4.1.3.6) : Channel 4
2. Cirrus Cloud Test (SERCAA and ATBD 4.1.3.5): Channels 4 and 5
3. Fog and Low Stratus Test (SERCAA and ATBD 4.1.3.13): Channels 3 and 4
4. Nighttime Thin Cirrus Cloud Test (SERCAA and ATBD 4.1.3.14): Channels 3, 4, and 5
5. Nighttime Uniform Low Stratus Test (ATBD 4.1.3.8 and ATBD 4.1.3.13) : Channel 4

The channels listed here are Release 1 AVHRR channels. The SERCAA document is Reference 10 and ATBD 4.1 is Reference 3.

5.2.1.2.5.2 Perform Nighttime Cold Cloud Test - Process 4.1.2.5.2

Input Data Flows

Ch4
MOA
Thresh

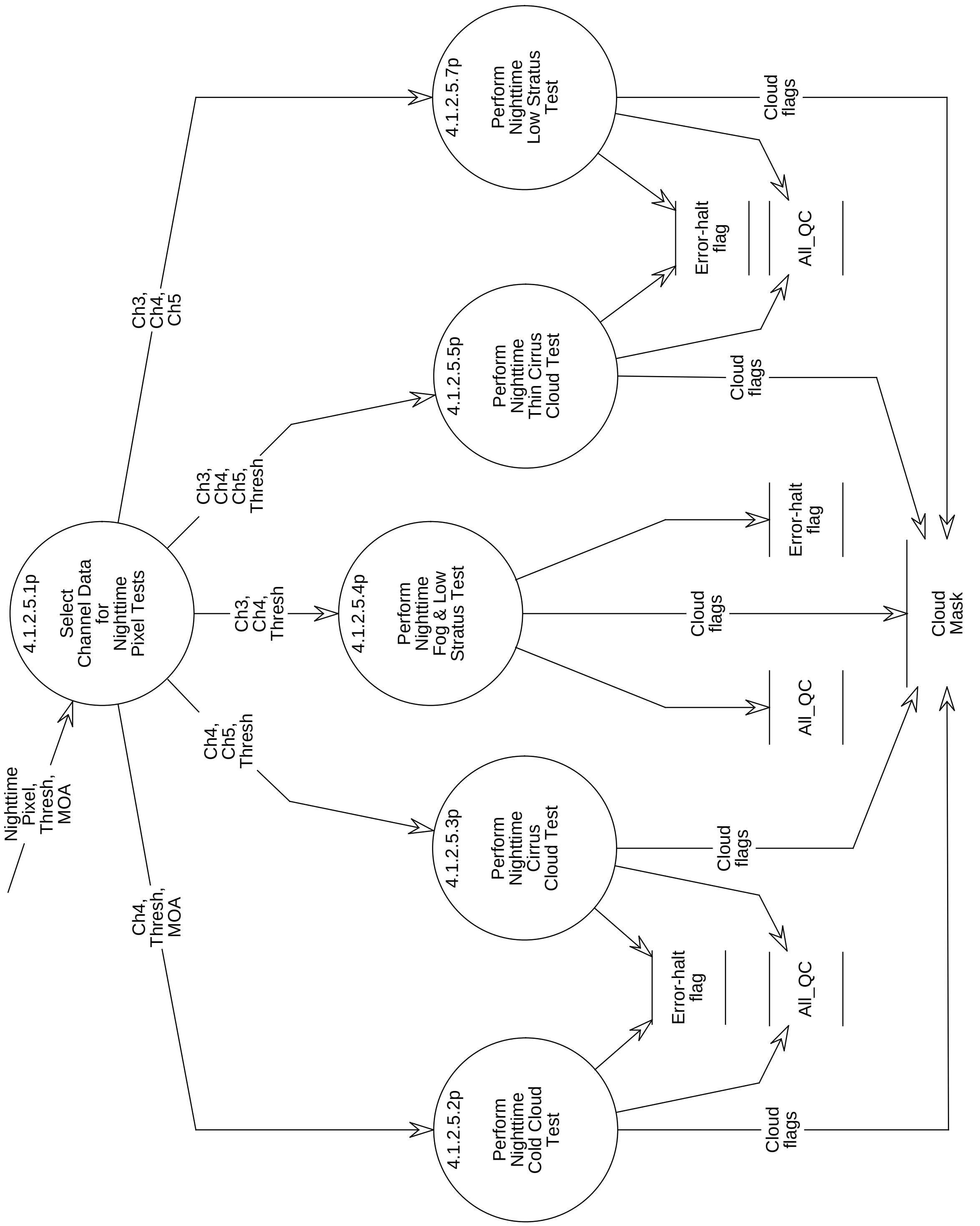

Figure 5-8. Data Flow Diagram for Apply Nighttime Pixel Tests

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-8)

Any pixels that pass the spectral snow test will be excluded from this test by the pixel/tile manager. This test is independent of scene solar illumination (i.e., applicable to both day and night). The nighttime cold cloud test process shall:

1. Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.
2. Extract the appropriate threshold values from Thresh
3. If water and Tpred - Ch4 > Thresh(water)
   then cloudy pixel and set Cloud Flag-n to cloudy
4. If land and Tpred - Ch4 > Thresh(land)
   then cloudy pixel and set Cloud Flag-n to cloudy
5. If coast and Tpred - Ch4 > Thresh(coast)
   then cloudy pixel and set Cloud Flag-n to cloudy
6. If desert and Tpred - Ch4 > Thresh(desert)
   then cloudy pixel and set Cloud Flag-n to cloudy
7. If snow/ice and Tpred - Ch4 > Thresh(snow/ice)
   then cloudy pixel and set Cloud Flag-n to cloudy
8. If not cloudy, then set the Cloud Flag to clear

The code and documentation will be provided for this algorithm by the Cloud Working Group.

5.2.1.2.5.3 Perform Nighttime Cirrus Cloud Test - Process 4.1.2.5.3

Input Data Flows

Ch4
Ch5
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-8)

Any pixels which pass the spectral snow test shall be excluded from this algorithm by the pixel/tile manager. The Nighttime Cirrus Cloud Test (which is the same as the daytime test) shall:

1. Extract the thresholds from the threshold file Thresh
2. Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.
3. If the scene type is not snow, then
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   then set the Cloud Flag for this process to cloudy.
4. If the scene type is snow, and
   if Ch4 - Ch5 > Thresh(Ch4, satellite zenith angle)
   and if also Tpred - Ch4 > Thresh(cirrus_cloud_detection)
   then set the Cloud Flag for this process to cloudy.
5. If not cloudy, then set the Cloud Flag to clear

The details of the algorithm are in the SERCAA document (Reference 10). The code and documentation will be provided by the Cloud Working Group.

5.2.1.2.5.4 Perform Nighttime Fog & Low Stratus Test - Process 4.1.2.5.4

Input Data Flows

Ch3
Ch4
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-8)

The nighttime Fog and Low Stratus Test shall:

1. Extract the appropriate threshold from Thresh
2. If Ch4 - Ch3 > Thresh(cloud_detection)
   then the pixel is classified as cloudy. Set the Cloud Flag for this process to cloudy
3. If desert background is present and if Ch4 - Ch3 > Thresh(desert)
   then the pixel is classified as cloudy. Set the Cloud Flag for this process to cloudy
4. If not cloudy, then set the Cloud Flag to clear

The details of the algorithm are in the SERCAA document (Reference 10). The code and documentation will be provided by the Cloud Working Group.

5.2.1.2.5.5 Perform Nighttime Thin Cirrus Cloud Test - Process 4.1.2.5.5

Input Data Flows

Ch3
Ch4
Ch5
Thresh

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-8)

The Nighttime Thin Cirrus Cloud Test (ATBD Section 4.1.3.14 Reference 3) code and documentation will be provided by the Cloud Working Group. The process shall:

1. Perform the SERCAA test:

   a) Extract the appropriate threshold values from Thresh

   b) If Ch3 - Ch5 > Thresh(nighttime_thin_cirrus_threshold)
      then set the Cloud Flag for this process to cloudy.

   c) Set the predicted clear scene brightness temperature (Tpred) to the clear-sky value attached to the pixel from CRH.

   d) Test for high humidity
      If Tpred > Thresh(high_humidity_threshold) then use Ch4 instead of Ch5

      if Ch3 - Ch4 > Thresh(nighttime_thin_cirrus_threshold)
      then set the Cloud Flag for this process to cloudy.

   e) If not cloudy, then set the Cloud Flag to clear

2. Perform the CLAVR test:

   a) Compute the CLAVR Cirrus threshold (CIRT)
      If Ch4 < 273 K then CIRT = 0.0
      Else If Ch4 > 292K then CIRT = 0.033
      Else CIRT = -0.485 + 0.001775 Ch4

b) If Ch3 - Ch5 > CIRT then thin cirrus exists - set Cloud Flag to cloudy
else set Cloud Flag to clear

5.2.1.2.5.6 Perform Nighttime Low Stratus Test - Process 4.1.2.5.7

Input Data Flows

Ch3
Ch4
Ch5

Output Data Flows

All QC
Cloud Flags
Error-halt Flag

Process Specification (Figure 5-8)

This process shall implement the CLAVR and SERCAA Low Stratus Test (LST). The CLAVR algorithm uses a dynamic threshold based upon the 11 micron brightness temperature Ch4.

1. Perform the CLAVR test:

   a) Compute the LST threshold Δ_{LST} (See formula 4.1-29, ATBD 4.1, Reference 3)

   $$\Delta_{LST} = \exp\{A + BCh4\} - C$$

   where

   A = -9.37528, B = 0.0341962, and

   C = 1.0 for ocean and C = 3.0 for land

   b) If Ch4 - Ch3 > Δ_{LST} the low stratus exists - set Coud Flag to cloudy

2. Perform the SERCAA test:

   If Ch4 - Ch3 > Thresh(LST) then set cloud flag to cloudy

   where

   Thresh(LST) is a surface-dependent cloud detection threshold

   Thresh(LST) = 1.0K over non-desert

   Thresh(LST) = 2.0K over desert

The final set of thresholds to be used will be determined through global analysis of AVHRR data.

5.2.1.3 Decide Cloud Presence - Process 4.1.3

Input Data Flows

Cloud Mask

Output Data Flows

All QC
Clear-sky Imager Radiance
Error-halt Flag
Final Cloud Code

Process Specification (Figure 5-2)

This process shall make the final determination of whether a pixel is clear or cloudy from the cloud mask tests and set Final Cloud Flag to cloudy or clear. This algorithm is TBD and will be supplied by the Cloud Working Group. Experience with global processing will shed light on which tests are the most reliable and for which conditions.

5.2.1.4 Output to CRH_DB - Process 4.1.4

Input Data Flows

Clear-sky Imager Radiance
More-data Flag

Output Data Flows

All QC
CRH DB
Error-halt Flag

Process Specification (Figure 5-2)

This process shall:

1. Write the CRH_DB header record if the More-data Flag is in the initial state
2. Compute the average of the solar angles for all clear imager pixels that fall within the CRH grid box
3. Compute the average and the standard deviation for all clear imager pixels that fall within the CRH grid box of the following parameters
    - albedos for Channels 1 and 2
    - temperatures for Channels 3, 4, and 5
4. Output the averages and standard deviations to the CRH_DB
5. Count the number of pixels output during a run

6. Send an error message if any write errors to the All_QC store
7. All write errors shall be counted, and if the number of write errors exceeds a predetermined maximum CRH_DB write error limit, the Error-halt Flag shall be set and processing terminated.

5.2.2 Determine Cloud Layers and Cloud Heights for Each Layer - Process 4.2

Input Data Flows

Cloud Mask
Data Chunk & Attributes
MOA
MWP
RTM

Output Data Flows

Cloud Layers
Cloud Pressure

Process Description (Figure 5-1)

This process consists of two steps as shown in Figure 5-9. In the first step, a given chunk of data is analyzed to determine whether one or more cloud layers is present. CRH data, SURFMAP data, and MOA data are included in the input data "Data Chunk & Attributes". In the second step, cloud-top pressures are calculated for up to two cloud layers in each imager pixel.

5.2.2.1 Find Cloud Layers - Process 4.2.1

Input Data Flows

Cloud Mask
Data Chunk & Attributes
MOA

Output Data Flows

Cloud Layers

Process Description (Figure 5-9)

The subprocesses used to determine whether single or multiple cloud layers are present within a given array of data shown in Figure 5-10 are

1. Perform management functions to:
   a) form the tiles for the layering algorithms

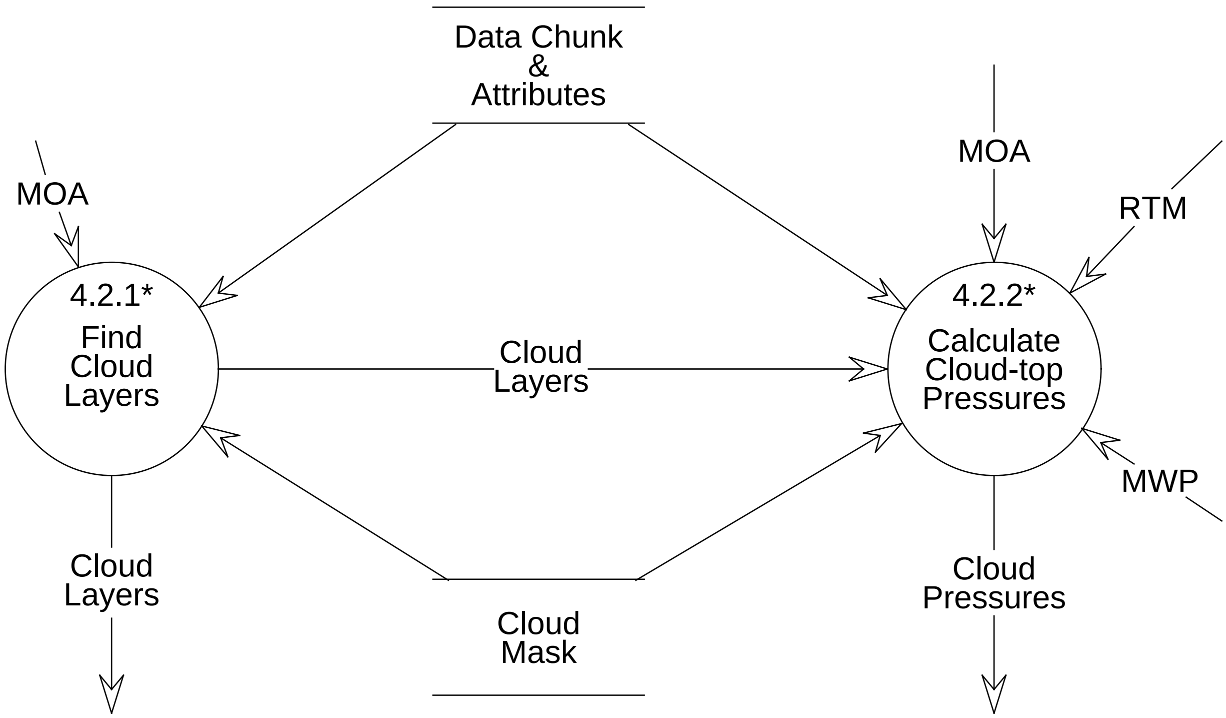

Figure 5-9. Data Flow Diagram for Determine Cloud Layers and Cloud Heights for Each Layer

   b) screen or filter the pixels according to the particular algorithm's requirements

2. Perform the Spatial Coherence Algorithm to determine well-defined cloud layers. This technique needs large tiles and assumes cloud layers are optically thick.
3. Perform CLAVR II Algorithm to determine cloud layering. This approach is a relatively simple threshold technique that works on tiles.
4. Perform Fuzzy Logic Classification Algorithm. This Artificial Intelligence (AI) approach uses both textural and spectral features to determine whether single-layer or multiple cloud layers are present.
5. Perform LBTM on tiles. This approach uses models and statistical thresholds to detect both thin and thick layers.
6. Peform decision functions that analyze the results from the layering algorithms to decide for each pixel if it is in a single cloud layer or two overlapping layers

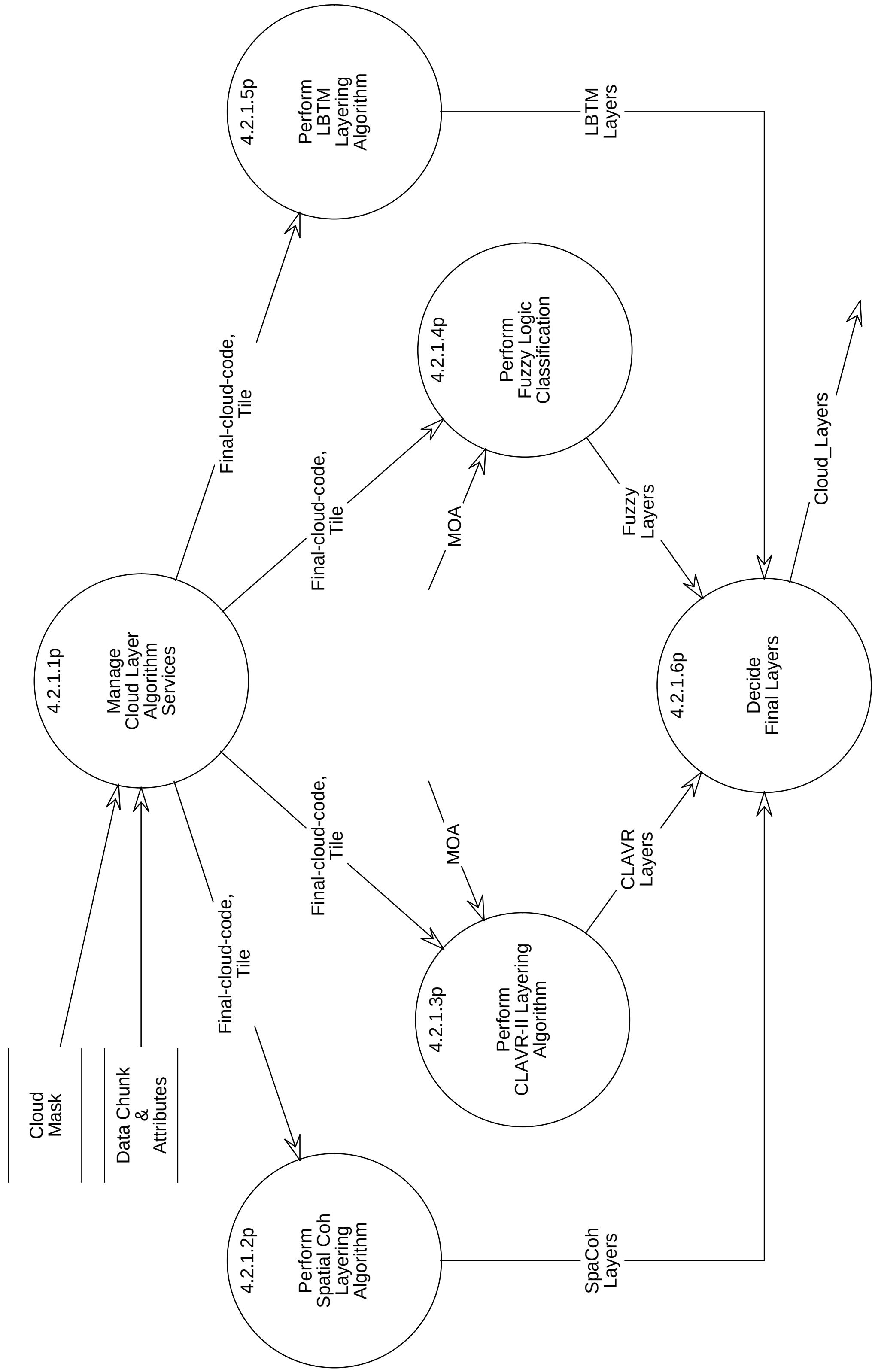

Figure 5-10. Data Flow Diagram for Find Cloud Layers

5.2.2.1.1 Manage Cloud Layer Algorithm Services - Process 4.2.1.1

Input Data Flows

Cloud Mask
Data Chunk & Attributes

Output Data Flows

Final-cloud-code
Tile

Process Specification (Figure 5-10)

This process shall:

1. Perform management functions to:
   a) identify the tiles for the layering algorithms.
   b) screen the pixels according to the particular algorithm's requirements, such as all ocean, or all land, or exclude coastline. The constraints are included in the particular algorithm's p-spec.
2. Send tiles to the Spatial Coherence Layering Algorithm
3. Send tiles to the CLAVR II Layering Algorithm
4. Send tiles to the Fuzzy Logic Classsification
5. Send tiles to the LBTM Layering Algorithm

5.2.2.1.2 Perform Spatial Coh Layering Algorithm - Process 4.2.1.2

Input Data Flows

Final-cloud-code
Tile

Output Data Flows

SpaCoh Layers

Process Specification (Figure 5-10)

Only homogeneous tiles are input to the Spatial Coherence Layering Algorithm. The algorithm detects well-defined cloud layers over relatively uniform surface backgrounds. The Spatial Coherence Layering method uses the pixel-to-pixel variability in emitted radiances to identify pixels that appear to be overcast by clouds that form a layer. The method depends on a single parameter -- the difference in radiances expected for cloud-free and overcast fields-of-view (ATBD 4.2, Reference 4). Note that the clear-sky values from CRH and surface types are attached to each pixel in the data chunk.

The Spatial Coherence Algorithm currently requires a tile of data. The most commonly selected tile size is 250 km square, and statistics are formed on either 4 km or 8 km squares within the tile. The number of means and standard deviations needed is about 1000, which is adequate to provide a normal histogram distribution.

The steps shall include:

1. Input thresholds or cutoff values used with equation 4.2-8 in ATBD 4.2.
   Use 20 mW m^{-2} sr^{-1} cm over ocean and 60 mW $m^{-2}sr^{-1}$ cm over land for Release 1
2. Perform the algorithm.

The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.1.3 Perform CLAVR-II Layering Algorithm - Process 4.2.1.3

Input Data Flows
Final-cloud-code
MOA
Tile

Output Data Flows
CLAVR Layers

Process Specification (Figure 5-10)

The CLAVR Phase II algorithm is a candidate for determining overlapping cloud layers. Multi-layered cloud systems are commonly found in frontal areas where cirrus overlaps altostratus or stratus cloud (ATBD 4.2, Reference 4). The CLAVR Phase II algorithm classifies certain cloud types as belonging to low stratus, thin cirrus, deep convective, or middle mixed (all other types). The cloud types are used in the overlapping cloud layering analysis. The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.1.4 Perform Fuzzy Logic Classification - Process 4.2.1.4

Input Data Flows
Final-cloud-code
MOA
Tile

Output Data Flows
Fuzzy Layers

Process Specification (Figure 5-10)

The Fuzzy Logic Classifier is a candidate algorithm for determining and analyzing overlapping multi-layered clouds. The algorithm will use tiles from all five of the satellite data channels on AVHRR, or VIRS, or five comparable channels on MODIS. This process uses automated feature recognition techniques as described in ATBD 4.1 Reference 3). The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.1.5 Perform LBTM Layering Algorithm - Process 4.2.1.5

Input Data Flows

Final-cloud-code
Tile

Output Data Flows

LBTM Layers

Process Specification (Figure 5-10)

The LBTM algorithm, code, and documentation will be provided by the Cloud Working Group (Pat Minnis and Pat Heck)

5.2.2.1.6 Decide Final Layers - Process 4.2.1.6

Input Data Flows

CLAVR Layers
Fuzzy Layers
LBTM Layers
SpaCoh Layers

Output Data Flows

Cloud Layers

Process Specification (Figure 5-10)

After the requested single layer algorithms and the overlapping layer algorithms have completed, a final process analyzes results from each algorithm and arrives at consensus. The final results are output in Cloud_Layers.

This process shall:

1. Set Cloud_Layer to a default value
2. Set the value for the number of cloud layers in Cloud_Layers to either an invalid pixel, a clear pixel or no layers, one cloud layer, or two cloud layers

A Layer Mask is written with the results of each layer test along with the final results, much like the Cloud Mask, which stores the results of each cloud mask test along with the final mask results. The Layer Mask is output for graphical analysis. The logic for achieving consensus among the algorithms for the final layering results will be specified by the Cloud Working Group.

5.2.2.2 Calculate Cloud-top Pressures - Process 4.2.2

Input Data Flows

Cloud Layers
Cloud Mask
Data Chunk & Attributes
MOA
MWP
RTM

Output Data Flows

Cloud Pressures

Process Description (Figure 5-9)

The subprocesses that are used to determine the cloud-top pressure of well-defined cloud layers shown in Figure 5-11 are:

1. Perform management functions to:
   a) form the tiles for the pressure algorithms
   b) screen the pixels according to the particular algorithm’s requirements
2. Perform the Spatial Coherence Algorithm to determine cloud-top pressures of well-defined cloud layers (mainly used for retrieving low-cloud pressures)
3. Perform the Layered Bispectral Threshold Method (LBTM) Algorithm to determine the cloud-top pressures of well-defined cloud layers
4. Perform CO2 slicing algorithm to determine mid- to high-level cloud top pressures
5. Perform CLAVR II algorithm to determine cloud-top pressures
6. Perform decision functions that analyze the results from the various cloud pressure retrievals in order to make the "final"decision

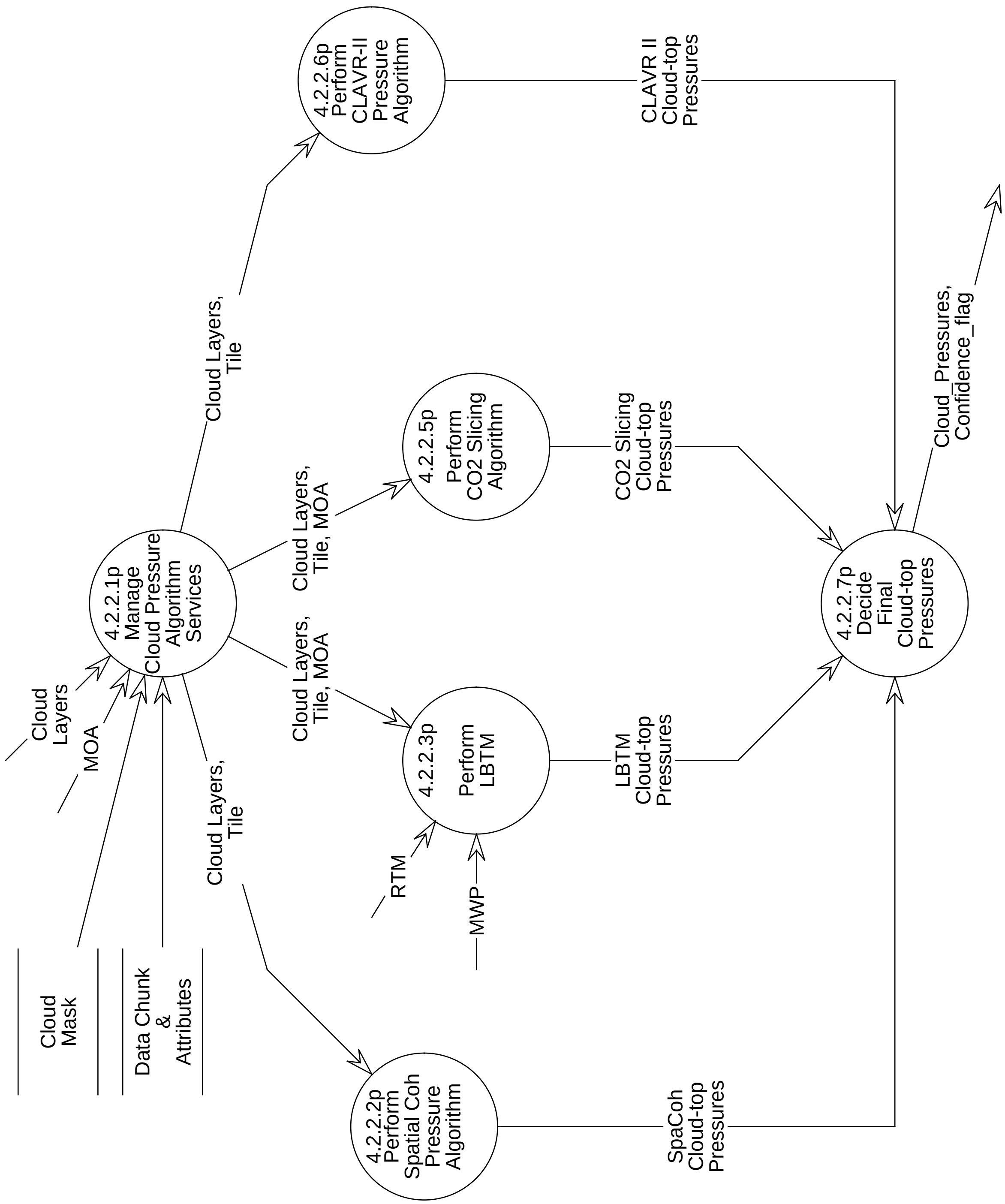

Figure 5-11. Data Flow Diagram for Calculate Cloud-top Pressures

5.2.2.2.1 Manage Cloud Pressure Algorithm Services - Process 4.2.2.1

Input Data Flows

Cloud Layers
Cloud Mask
Data Chunk & Attributes
MOA

Output Data Flows

Cloud Layers
MOA
Tile

Process Specification (Figure 5-11)

This process shall:

1. Perform management functions to:
   a) select the tiles for the pressure algorithms
   b) screen the pixels according to the particular algorithm's requirements, such as all ocean, or all land, or exclude coastline. The constraints are included in the particular algorithm's p-spec
2. Send tiles to the Spatial Coherence Pressure Algorithm
3. Send tiles to the LBTM Algorithm
4. Send pixels to the CO2 slicing Algorithm
5. Send tiles to the CLAVR II Pressure Algorithm

5.2.2.2.2 Perform Spatial Coh Pressure Algorithm - Process 4.2.2.2

Input Data Flows

Cloud Layers
Tile

Output Data Flows

SpaCoh Cloud-top Pressures

Process Specification (Figure 5-11)

The Spatial Coherence Pressure Algorithm detects the cloud-top pressure of well-defined cloud layers over relatively uniform surface backgrounds. The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.2.3 Perform LBTM - Process 4.2.2.3

Input Data Flows

Cloud Layers
MOA
MWP
RTM
Tile

Output Data Flows

LBTM Cloud-top Pressures

Process Specification (Figure 5-11)

The Layered Bispectral Threshold Method (LBTM) is a multi-spectral approach used for computing cloud presure. For daytime, the LBTM computes a histogram of the visible Channel 1 versus the thermal Channel 4 and divides the histogram into three layers. For nighttime, the LBTM computes a histogram of Channel 3 or Channel 5 versus the thermal Channel 4. The algorithm uses ice-crystal reflectance models for high clouds (RTM), bidirectional reflectance models for clear scenes (CRH), and a parameterization of the Earth-atmosphere system reflectance (RTM). The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.2.4 Perform CO2 Slicing Algorithm - Process 4.2.2.5

Input Data Flows

Cloud Layers
MOA
Tile

Output Data Flows

CO2 Slicing Cloud-top Pressures

Process Specification (Figure 5-11)

The CO2 slicing method is accurate for mid- to high-level cloud pressure retrieval and operates on single pixels within the tile. The algorithm requires clear-sky estimates, which are extracted from CRH, and surface characteristics, which are extracted from SURFMAP and are already attached to the input data chunk. The algorithm also requires surface temperature and pressure and temperature and humidity profiles, which are extracted from the MOA product.

The CO2 Slicing algorithm will be implemented in Release 1 and 2 using HIRS test input data in preparation for the MODIS data. MODIS has channels with spectral ranges similar to those on HIRS. However, the VIRS instrument, on board TRMM, does not have these channels. The documentation, code, and test data will be provided by the Cloud Working Group.

5.2.2.2.5 Perform CLAVR-II Pressure Algorithm - Process 4.2.2.6

Input Data Flows

Cloud Layers
Tile

Output Data Flows

CLAVR II Cloud-top Pressures

Process Specification (Figure 5-11)

The CLAVR Phase II algorithm is a candidate for computing cloud-top pressures of well-defined cloud layers. The documentation, code, and test data will be supplied by the Cloud Working Group.

5.2.2.2.6 Decide Final Cloud-top Pressures - Process 4.2.2.7

Input Data Flows

CLAVR II Cloud-top Pressures
CO2 Slicing Cloud-top Pressures
LBTM Cloud-top Pressures
SpaCoh Cloud-top Pressures

Output Data Flows

Cloud Pressures
Confidence Flag

Process Specification (Figure 5-11)

After the requested different pressure algorithms have completed, a final process analyzes the algorithm results, performs consensus logic, and determines a confidence factor for the results. Each pixel could have cloud-top pressures calculated for 0, 1, or 2 cloud layers. The final results are output in Cloud_Pressures.

This process shall:

1. Set a default value in Cloud_Pressures
2. Determine the cloud-top pressure of each layer and assign the pressure to each pixel in the layer
3. For overlapping layer pixels, determine two pressures for those pixels

5.2.3 Determine Pixel Level Cloud Optical & Physical Properties - Process 4.3

Input Data Flows

Cloud Layers
Cloud Mask
Cloud Pressure
Data Chunk & Attributes
MOA
MWP
RTM

Output Data Flows

Pixel Data

Process Description (Figure 5-1)

This process shall a) get a tile of pixels with CRH, SURFMAP, and MOA attributes and b) derive the cloud optical properties, using multispectral imager pixel radiance and reflectance as shown in Figure 5-12. The optical properties are

1. Temperature and Pressure
2. Particle phase
3. Particle size
4. Optical depth (0.6 µm)
5. Emittance (10.8 µm)
6. Liquid/ice water path
7. Cloud fraction
8. Cloud top and base altitudes
9. Cloud vertical aspect ratio

Several distinct approaches will be used in these determinations, including both daytime and night-time algorithms. Some of the algorithms require analysis of pixel tiles. Results will be assigned at the individual pixel level.

At the present time, no useful algorithm has been proposed for determination of the cloud vertical aspect ratio; it is listed here as a place holder.

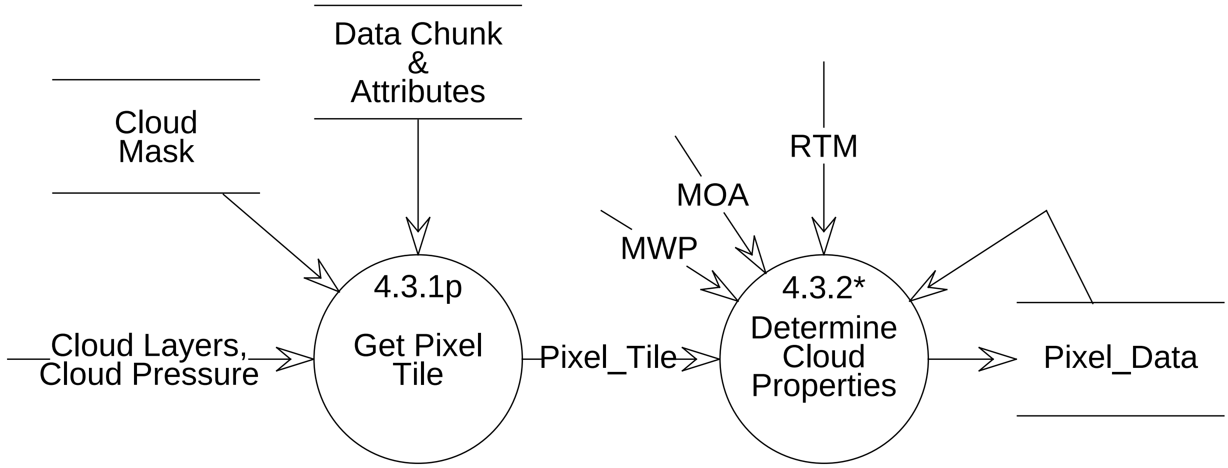

Figure 5-12. Data Flow Diagram for Determine Pixel Level Cloud Optical & Physical Properties

5.2.3.1 Get Pixel Tile - Process 4.3.1

Input Data Flows

- Cloud Layers
- Cloud Mask
- Cloud Pressure
- Data Chunk & Attributes

Output Data Flows

- Pixel Tile

Process Specification (Figure 5-12)

This process shall combine pixel-level data from the cloud mask, the raw data chunk and attributes, and the previously determined cloud layers and pressures associated with each pixel, and shall create pixel tiles as needed by the various subprocesses in 4.3.2 for determination of cloud properties.

5.2.3.2 Determine Cloud Properties - Process 4.3.2

Input Data Flows

MOA
MWP
Pixel Data
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Description (Figure 5-12)

This process has nine subprocesses, shown in Figure 5-13, each to determine a specific cloud property at the pixel level. Most of the subprocesses include multiple algorithms representing different, independent approaches to the determination of the specific cloud property. The algorithm for Subprocess 4.3.2.9 (Determine Vertical Aspect Ratio) is under development.

Input to this process will include the pixel-level data in Pixel_Tile, accessible both at the individual pixel scale and tile scale, as required by the specific subprocesses and a set of Radiative Transfer Models (RTM), largely in the form of indexed coefficient arrays. In addition, this process utilizes atmospheric profiles of temperature, pressure, and altitude provided in the MOA data, which are attached to the tile.

This process creates the Pixel_Data product used as the primary pixel-level input data store by process 4.4 (Convolve Imager Cloud Properties with CERES Footprint).

5.2.3.2.1 Determine Cloud Temperature and Pressure - Process 4.3.2.1

Input Data Flows

MOA
MWP
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Description (Figure 5-13)

This process is decomposed into five subprocesses, shown in Figure 5-14, including three methods for daytime and two methods for nighttime determination of cloud temperature and pressure.

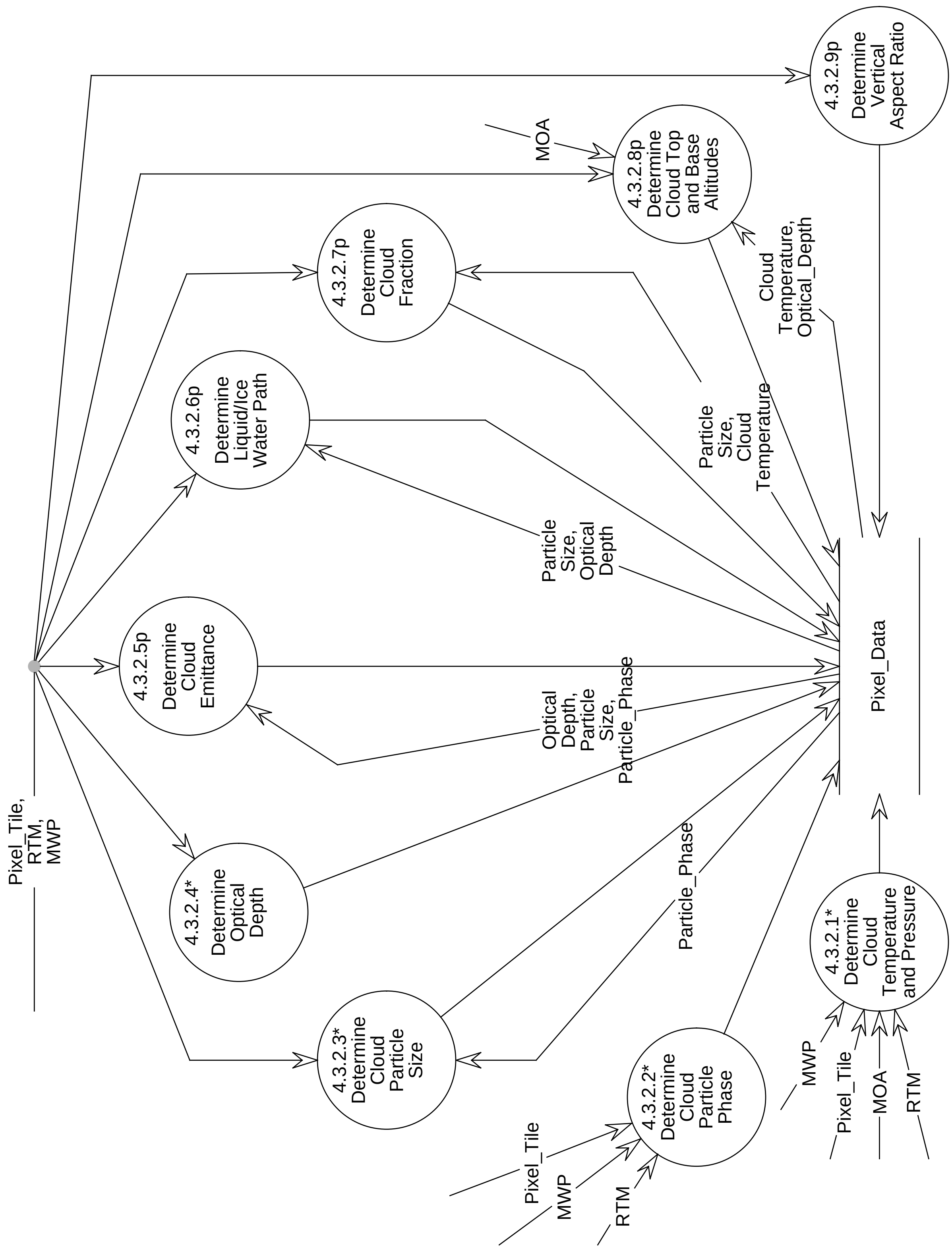

Figure 5-13. Data Flow Diagram for Determine Cloud Properties

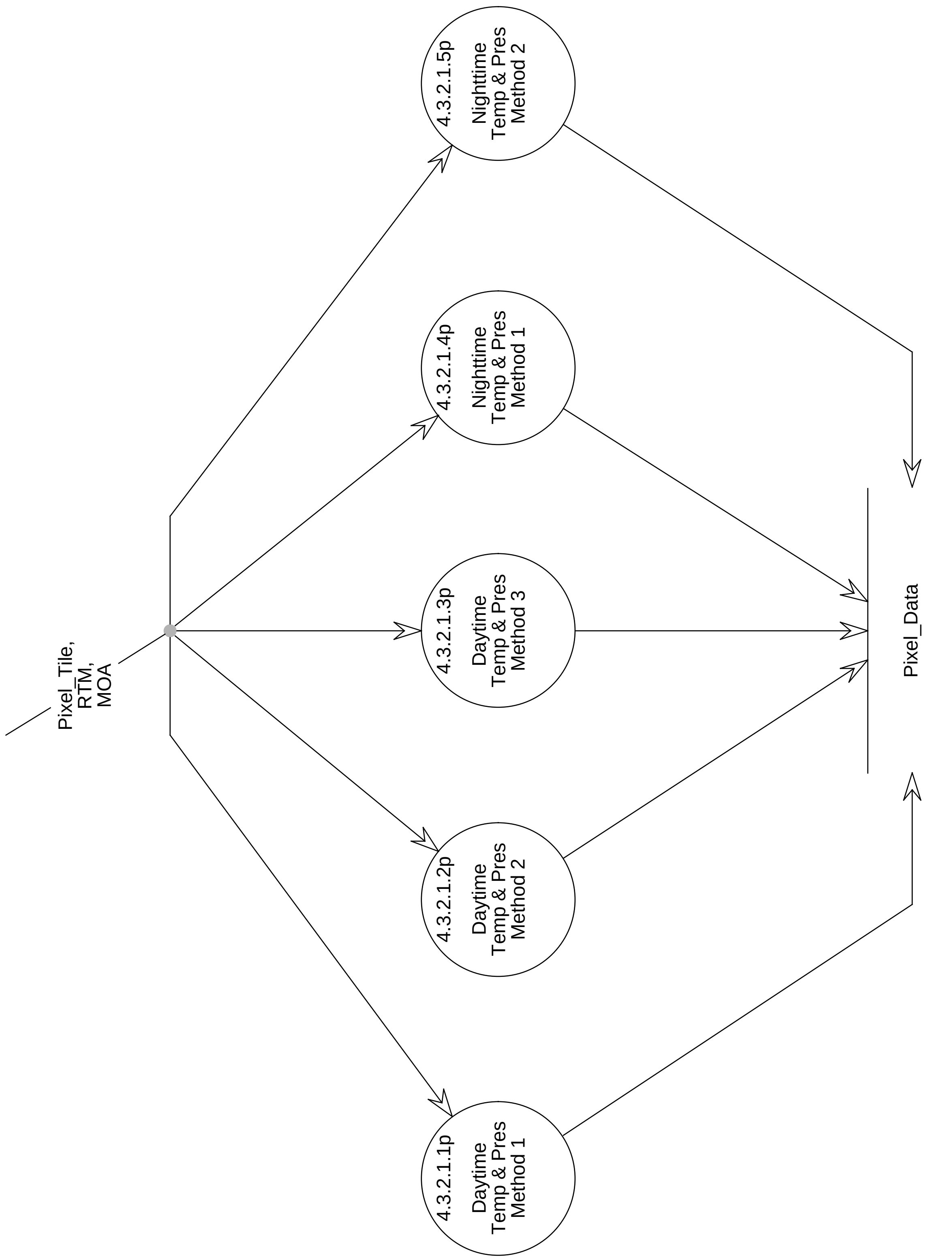

Figure 5-14. Data Flow Diagram for Determine Cloud Temperature and Pressure

5.2.3.2.1.1 Daytime Temp & Pres Method 1 - Process 4.3.2.1.1

Input Data Flows

MOA
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-14)

This process shall:

1. Apply the 3-channel reflectance/emittance technique (using 0.65, 3.75 and 10.8 µm as one channel set, and 0.65, 1.60, and 10.8 µm as an alternate channel set for CERES/VIRS)
2. Solve iteratively for effective cloud temperature (T_{cld})
3. Calculate cloud-top temperature T_t using the approach described in CERES ATBD Section 4.3.4.4 (Reference 5), and find the equivalent cloud-top altitude Z_t from the MOA sounding corresponding to T_t
4. From the calculated values for cloud-top altitude Z_t and cloud base altitude Z_b (reference process specification for Process 4.3.2.8), find cloud base and top pressures corresponding to Z_b and Z_t in the MOA vertical profiles of Z(p) and T(p)

5.2.3.2.1.2 Daytime Temp & Pres Method 2 - Process 4.3.2.1.2

Input Data Flows

MOA
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-14)

This process shall:

1. Apply the 2-channel reflectance technique that uses similarity principles to derive phase, particle size, and optical depth
2. Determine cloud temperature (T_{cld}) by correcting the observed 10.8 µm brightness temperature for transparency using the retrieved optical depth

3. Calculate cloud-top temperature T_t using the approach described in CERES ATBD Section 4.3.4.4 (Reference 5), and find the equivalent cloud-top altitude Z_t from the MOA sounding corresponding to T_t

4. From the calculated values for cloud-top altitude Z_t and cloud base altitude Z_b (reference process specification for Process 4.3.2.8), find cloud base and top pressures corresponding to Z_b and Z_t in the MOA vertical profiles of Z(p) and T(p)

5.2.3.2.1.3 Daytime Temp & Pres Method 3 - Process 4.3.2.1.3

Input Data Flows

MOA
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-14)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 µm for CERES/VIRS); for MODIS also use the 8.55 µm channel
2. Solve for effective cloud temperature for optically thin clouds

5.2.3.2.1.4 Nighttime Temp & Pres Method 1 - Process 4.3.2.1.4

Input Data Flows

MOA
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-14)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 µm for CERES/VIRS); for MODIS also use the 8.55 µm channel
2. Solve for phase, particle size, optical depth, and effective cloud temperature (T_{cld}) for optically thin clouds

3. Use brightness temperature difference (BTD) between different infrared channels to infer effective cloud temperature (T_{cld}); various approaches are available for this determination and are referenced in ATBD Sections 4.3.2.2 and 4.3.4.2.1 (Reference 5)
4. Calculate cloud-top temperature T_t using the approach described in CERES ATBD Section 4.3.4.4, and find the equivalent cloud-top altitude Z_t from the sounding corresponding to T_t
5. From the calculated values for cloud top altitude Z_t and cloud base altitude Z_b (reference process specification for Process 4.3.2.8), find cloud base and top pressures corresponding to Z_b and Z_t in the vertical profiles of Z(p) and T(p)

5.2.3.2.1.5 Nighttime Temp & Pres Method 2 - Process 4.3.2.1.5

Input Data Flows

MOA
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-14)

This process shall:

1. Interpret pixel radiances for a single layer cloud deck as

$$B(T) = (1\text{-}C)B(T_{cs}) + C(\varepsilon B(T_{cld}) + tB(T_{cld}))$$

(reference ATBD 4.3 equation 4.3-16) (Reference 5)

2. Use statistical methods to determine a single value of temperature (T_{cld}) and particle size for the entire group of pixels constituting the cloud deck
3. Calculate cloud-top temperature T_t using the approach described in CERES ATBD Section 4.3.4.4, and find the equivalent cloud-top altitude Z_t from the sounding corresponding to T_t
4. From the calculated values for cloud-top altitude Z_t and cloud base altitude Z_b (reference process specification for Process 4.3.2.8), find cloud base and top pressures corresponding to Z_b and Z_t in the vertical profiles of Z(p) and T(p)

Note: This technique is limited to conditions where a single cloud deck is easily discernible. The temperature derived for the deck tends to be the coldest observed brightness temperature for the given set of pixels because it is defined by those pixels essentially having the greatest brightness temperature difference between Channels 4 and 5 for a given Channel

4 temperature. This process is referenced in CERES ATBD Sections 4.3.4.2.2 and 4.3.4.4 (Reference 5)

5.2.3.2.2 Determine Cloud Particle Phase - Process 4.3.2.2

Input Data Flows

MWP
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Description (Figure 5-13):

This process is decomposed into four subprocesses, shown in Figure 5-15, including three daytime methods and one nighttime method for phase determination.

5.2.3.2.2.1 Daytime Phase Method 1 - Process 4.3.2.2.1

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-15)

This process shall:

1. Apply the 3-channel reflectance/emittance technique (using 0.65, 3.75, and 10.8 µm for CERES/VIRS).
2. Solve iteratively for phase.

5.2.3.2.2.2 Daytime Phase Method 2 - Process 4.3.2.2.2

Input Data Flows

Pixel Tile
RTM

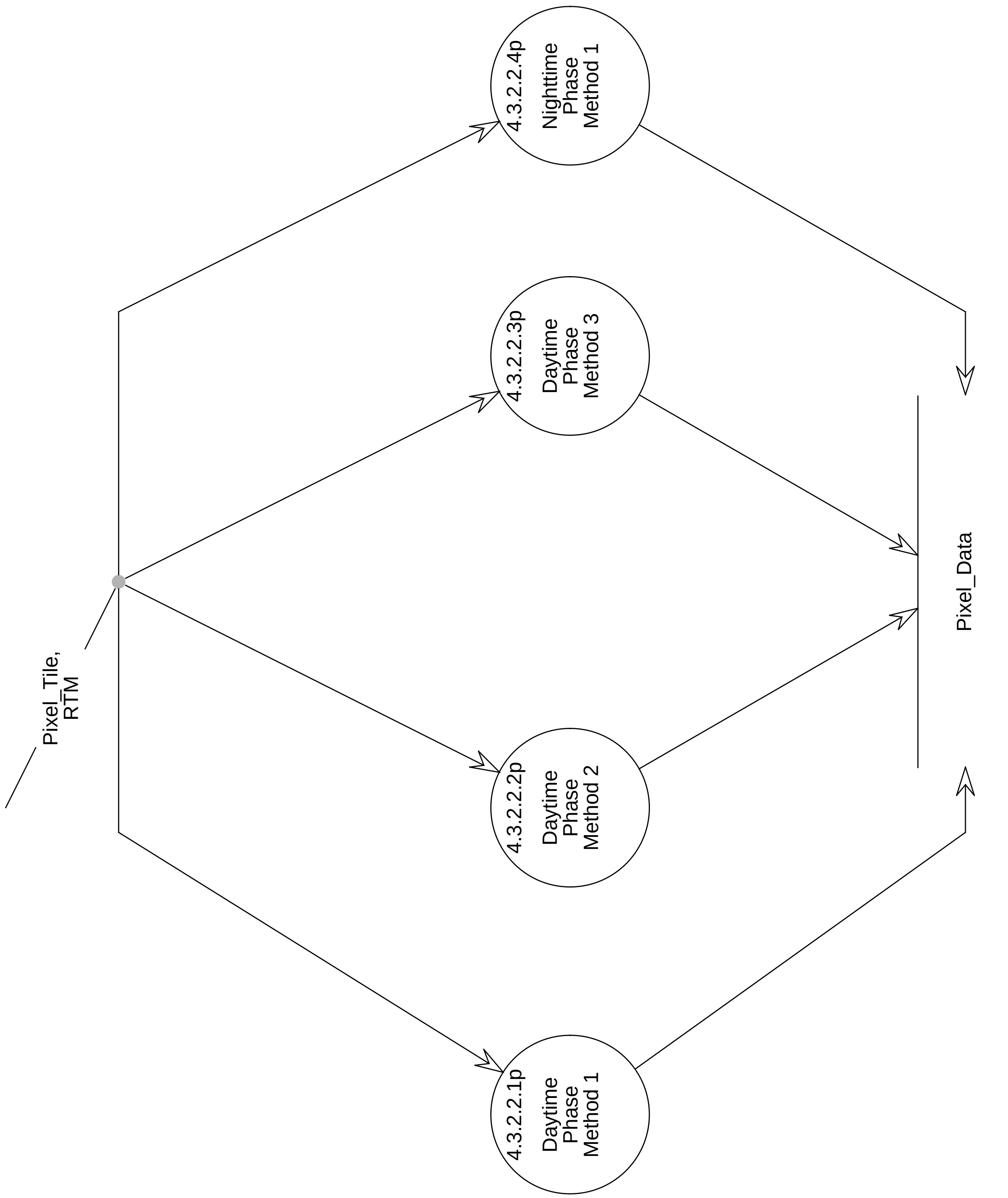

Figure 5-15. Data Flow Diagram for Determine Cloud Particle Phase

Output Data Flows

Pixel Data

Process Specification (Figure 5-15)

This process shall:

1. Apply the 3-channel reflectance technique (using 0.65, 1.6, and 2.12 μm) that uses similarity principles to derive phase.
2. Compare the ratios of reflectances at two different wavelengths, one that is a conservative scatterer for both ice and water and one that has strong absorption for ice and weak absorption for water.
3. For VIRS and AVHRR, the 2.12 μm channel is not available, and this method will be used only with the other two channels.

5.2.3.2.2.3 Daytime Phase Method 3 - Process 4.3.2.2.3

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-15)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 μm for CERES/VIRS); for MODIS also use the 8.55 μm channel.
2. Solve for phase for optically thin clouds.
3. Use brightness temperature difference (BTD) between different infrared channels to distinguish between water and ice clouds.

5.2.3.2.2.4 Nighttime Phase Method 1 - Process 4.3.2.2.4

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-15)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 μm for CERES/VIRS); for MODIS also use the 8.55 μm channel.
2. Solve for phase for optically thin clouds.
3. Use brightness temperature difference (BTD) between different infrared channels to distinguish between water and ice clouds.

5.2.3.2.3 Determine Cloud Particle Size - Process 4.3.2.3

Input Data Flows
MWP
Particle Phase
Pixel Tile
RTM

Output Data Flows
Pixel Data

Process Description (Figure 5-13)

This process is decomposed into five subprocesses, shown in Figure 5-16, including three daytime and two nighttime methods for particle size determination.

5.2.3.2.3.1 Daytime Particle Size Method 1 - Process 4.3.2.3.1

Input Data Flows
Pixel Tile
RTM

Output Data Flows
Pixel Data

Process Specification (Figure 5-16)

This process shall:

1. Apply the 3-channel reflectance/emittance technique (using 0.65, 3.75, and 10.8 μm for CERES/VIRS).

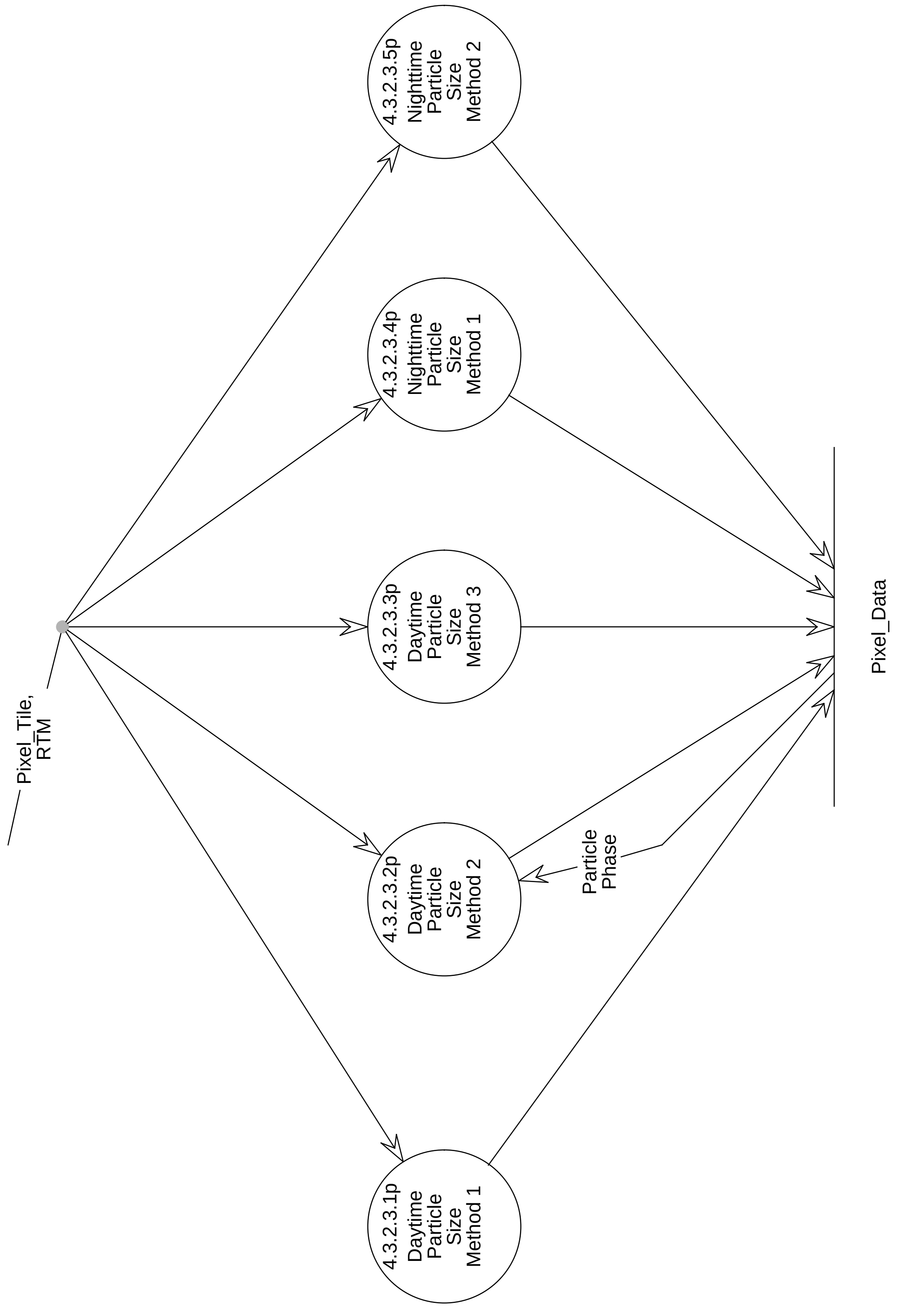

Figure 5-16. Data Flow Diagram for Determine Cloud Particle Size

2. Solve iteratively for particle size; the iterative process is described in Section 4.3.4.1.1 and Figure 4.3-10 of the CERES ATBD (Reference 5). The iterative process includes a test to distinguish between ice particles and water droplets, and returns either r_e (radius of water droplets) or D_e (diameter of ice particle).

5.2.3.2.3.2 Daytime Particle Size Method 2 - Process 4.3.2.3.2

Input Data Flows

Particle Phase
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-16)

This process shall:

1. Apply the 3-channel reflectance technique that uses similarity principles to derive particle size.
2. After determination of phase, a least squares approach is applied to match the multispectral radiances to a set of model calculations simulating the reflectances for clouds having a range of particle sizes and optical depths. During TRMM, this method will use the VIRS 0.65, 1.60, and 3.75 μm data. It is anticipated that CERES/EOS will use the 3-channel reflectance method employing the 2.13 μm MODIS channel. In the Release 2 software design, the reflectance method may serve as the primary particle size retrieval method.

5.2.3.2.3.3 Daytime Particle Size Method 3 - Process 4.3.2.3.3

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-16)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 μm for CERES/ VIRS); for MODIS also use the 8.55 μm channel.

2. Solve for particle size for optically thin clouds.
3. Use brightness temperature difference (BTD) between different infrared channels to infer either water droplet effective radius (r_e) or ice particle effective diameter (D_e); various approaches are available for this determination and are referenced in ATBD Section 4.3.2.2 .(Reference 5).

5.2.3.2.3.4 Nighttime Particle Size Method 1 - Process 4.3.2.3.4

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-16)

This process shall:

1. Apply the 3-channel emittance technique (using 3.75, 10.8, and 12 µm for CERES/VIRS); for MODIS also use the 8.55 µm channel.
2. Solve for particle size for optically thin clouds.
3. Use brightness temperature difference (BTD) between different infrared channels to infer either water droplet effective radius (r_e) or ice particle effective diameter (D_e); various approaches are available for this determination and are referenced in ATBD Section 4.3.2.2 (Reference 5).

5.2.3.2.3.5 Nighttime Particle Size Method 2 - Process 4.3.2.3.5

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-16)

This process shall:

1. Interpret pixel radiances for a single layer cloud deck as

$$B(T) = (1-C)B(T_{cs}) + C(\varepsilon B(T_{cld}) + tB(T_{cld}))$$

(reference ATBD 4.3 equation 4.3-16) (Reference 5)

2. Use statistical methods to determine a single value of temperature and particle size for the entire group of pixels constituting the cloud deck.
3. Use emittance models to determine particle size for the cloud deck.
4. This technique is limited to conditions where a single cloud deck is easily discernible. The particle size derived for the deck tends to be the smallest observable particle size for the given set of pixels because it is defined by those pixels essentially having the greatest brightness temperature difference between Channels 4 and 5 for a given Channel 4 temperature.

This process is referenced in CERES ATBD Section 4.3.4.2.2. (Reference 5).

5.2.3.2.4 Determine Optical Depth - Process 4.3.2.4

Input Data Flows
MWP
Pixel Tile
RTM

Output Data Flows
Pixel Data

Process Description (Figure 5-13)

This process is decomposed into two subprocesses, shown in Figure 5-17, including one daytime and one nighttime method for determination of visible optical depth.

5.2.3.2.4.1 Determine Daytime Optical Depth - Process 4.3.2.4.1

Input Data Flows
Pixel Tile
RTM

Output Data Flows
Pixel Data

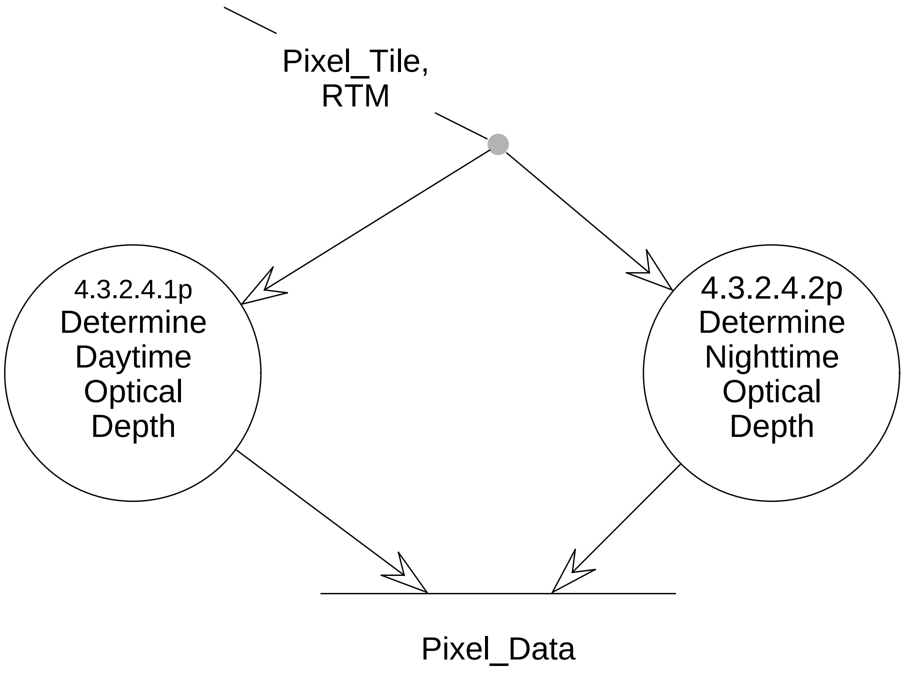

Figure 5-17. Data Flow Diagram for Determine Optical Depth

Process Specification (Figure 5-17)

This process shall:

1. Apply the 3-channel reflectance/emittance technique (using 0.65, 3.75, and 10.8 µm for CERES/VIRS);
2. Solve iteratively for optical depth.
3. Use the observed visible reflectance $\rho_{0.65}$ to determine visible optical depth τ by matching the observed reflectance to a parameterization of radiative transfer calculations of reflectance in terms of cloud optical depth. The model is described in Section 4.3.4.1.1 of the CERES ATBD (Reference 5).

5.2.3.2.4.2 Determine Nighttime Optical Depth - Process 4.3.2.4.2

Input Data Flows

Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-17)

This process shall:

1. Apply an iteration-interpolation method based on brightness temperature differences (BTD) between Channels 3, 4, and 5 to determine visible optical depth.
2. This technique attempts to determine τ, T_{cld}, and particle size through an iterative process that minimizes the difference between model-derived and observed values of BTD_{3-4} and BTD_{4-5} for a particular observed T_4. The method is described in Section 4.3.4.2.1 of the CERES ATBD.

5.2.3.2.5 Determine Cloud Emittance - Process 4.3.2.5

Input Data Flows

MWP
Optical Depth
Particle Size
Particle Phase
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-13)

This process shall:

Determine cloud emittance ε_λ (λ = 10.8 μm) from the previously calculated optical depth, using:

$$\varepsilon_\lambda = 1 - \exp(-\tau_\lambda / \mu)$$

where

τ_λ = effective optical depth, and

μ = viewing zenith angle cosine.

5.2.3.2.6 Determine Liquid/Ice Water Path - Process 4.3.2.6

Input Data Flows

MWP
Optical Depth
Particle Size
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-13)

This process shall:

1. Calculate liquid water path W_{liq} using:

   $$W_{liq} = c_1 \delta_{liq} r_e \tau / Q_e$$

   where

   c_1 = variable coefficient,
   δ_{liq} = density of liquid water,
   r_e = effective droplet radius,
   τ = optical depth, and
   Q_e = extinction efficiency.

2. Calculate ice water path W_{ice} using:

   $$W_{ice} = \delta_{liq} \tau D_e (c_2 + c_3 D_e)$$

   where

   c_2, c_3 = variable coefficients,
   δ_{liq} = density of liquid water,
   D_e = ice-crystal effective diameter, and
   τ = optical depth.

5.2.3.2.7 Determine Cloud Fraction - Process 4.3.2.7

Input Data Flows

Cloud Temperature
MWP
Particle SizeA.
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-13)

This process shall use one or more of the following methods to determine cloud fraction C:

Method 1 (Pixel-clustering technique):

1. Use a pixel clustering method to determine T_{cld} for a scene.
2. For each pixel outside the cluster, interpret the difference between the observed T and T_{cld} as cloud fraction $C < 1$.

Method 2 (Single-layer, fixed-size technique):

1. Interpret pixel radiances for a single-layer cloud deck as

$$B(T) = (1\text{-}C)B(T_{cs}) + C(\varepsilon B(T_{cld}) + tB(T_{cld}))$$

2. Use statistical methods to determine a single value of temperature and particle size for the entire group of pixels constituting the cloud deck.
3. Use emittance models to determine particle size and phase for the cloud deck.
4. The assumed values of cloud temperature and particle size define a set of solutions to equation (1) that envelope most of the pixels representing the cloud deck.
5. Determine emittance and cloud fraction for each pixel within the envelope by simultaneous solution of equation (1) using the 10.9 and 11.9 µm channels.

5.2.3.2.8 Determine Cloud Top and Base Altitudes - Process 4.3.2.8

Input Data Flows

Cloud Temperature
MOA
MWP
Optical Depth
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-13)

This process shall:

1. Calculate cloud top height Z_t as the lowest altitude from the MOA sounding corresponding to T_{cld}
2. Use empirical means to calculate cloud thickness ΔZ:
   a) For clouds below 4 km, $\Delta Z = c_1 \tau^{1/2} - c_2$, where c_1 & c_2 are parameterized coefficients
   b) When $\Delta Z < c_t$ km, set $\Delta Z = c_t$ km, where c_t is a parameterized threshold of the order of 0.02 km
   c) For other clouds, $\Delta Z = c_3 - c_4 T_c + c_5 \ln \tau$, where c_3, c_4 & c_5 are parameterized coefficients
3. Calculate cloud base altitude as $Z_b = Z_t - \Delta Z$

5.2.3.2.9 Determine Vertical Aspect Ratio - Process 4.3.2.9

Input Data Flows

MWP
Pixel Tile
RTM

Output Data Flows

Pixel Data

Process Specification (Figure 5-13)

This process shall determine the cloud vertical aspect ratio

$$(\Delta Z_c) / (\Delta X_c)$$

where

ΔZ_c is the vertical extent of the cloud structure and ΔX_c is the horizontal scale length of the cloud. At present, no specific algorithm has been proposed for this determination.

5.2.4 Convolve Imager Cloud Properties with CERES Footprint - Process 4.4

Input Data Flows

All QC
Error-halt flag
IES
Overlap Pixel Data
Pixel Data
Rerun flag
SSF

Output Data Flows

CLDMETA
CLDQC
CLDVAL
Overlap Pixel Data
SSF

Process Description (Figure 5-1)

This process shall determine the cloud properties over the CERES footprint. We use imager data at high resolution to get the necessary cloud properties. The statistics include weighted means and standard deviations where the weighting is the value of the point spread function (PSF) at the pixel location. The footprint is defined as that area throughout which the calculated PSF value for the imager pixels exceeds a specified, parameterized threshold value. For the initial implementation, it is expected that a threshold value of 0.095 will be used. This value represents the PSF contour which contains 95% of the total integrated energy of the PSF distribution. The PSF value is determined solely by the location of the imager pixel at TOA with respect to the centroid of the CERES field-of-view (FOV).

This process will be executed for each hourly record of CERES footprints. However, the process requires imager pixel data from the hours before and after the current hour as well as the current hour, due to the need for 100-200 km of overlap data at both the front and rear of the imager data swath. (For TRMM, the required overlap is about 100 km, while for the EOS-AM and EOS-PM platforms, about 200 km overlap will be required.) In other words, this process will be executed one hour in arrears of the most current CERES and imager data to allow for the required overlap. This process will manage the reading and writing of the overlap data segments in accordance with the overlap geometry appropriate to the specific imager instrument and platform.

The steps shown in Figure 5-18 shall:

1. Read the IES (if performing a normal, first-time run) or the SSF (if performing a rerun) sequentially to obtain the colatitude and longitude of the centroids of CERES footprints. Footprint records are organized in the SSF and IES in order of increasing along-track angle.
2. Read in a swath of pixel-level cloud properties. The minimum swath dimension is 400 km in the along-track direction and the length of the scanline in the cross-track dimension. This allows for pixel data 200 km both forward and to the rear of the CERES footprint centroid in the along-track dimension. The swath must include overlap sections at the front and rear of the current hour's imager pixel data, as described previously. The actual along-track dimension of this swath will be established on the basis of computational efficiency, due to the very large imager data volume.
3. Locate the imager pixels that are within the CERES footprint.
4. Calculate the cloud statistics over the CERES footprint using the PSF to weight the contribution of each pixel to the footprint.
5. Read the Pixel_Data File for more pixel data in the current area of convolution, if the footprint is within 200 km of the end of the current swath.
6. Determine for each footprint whether enough pixel data have been found to adequately characterize the footprint. This determination will be made based on the integrated PSF values for all pixels selected for inclusion in the footprint. In the initial implementation, an integrated PSF value of 95% will be required. If this is not satisfied, the footprint will be accepted but flagged as a partial footprint, if the integrated PSF is at least 75%. If not, the footprint will be flagged as incomplete.
7. Write the completed footprint to the intermediate SSF.
8. Continue this process with successive CERES footprints organized spatially along the satellite groundtrack.
9. Following processing of the last CERES footprint, close SSF and IES and write the cloud metadata, the cloud validation data, and the cloud QC report.
10. Update the Overlap_Pixel_Data File in preparation for the next hour's run.

5.2.4.1 Locate Imager Pixels within a CERES Footprint - Process 4.4.1

Input Data Flows

IES
Overlap Pixel Data
Pixel Data
Read FOV Flag
Rerun flag
SSF

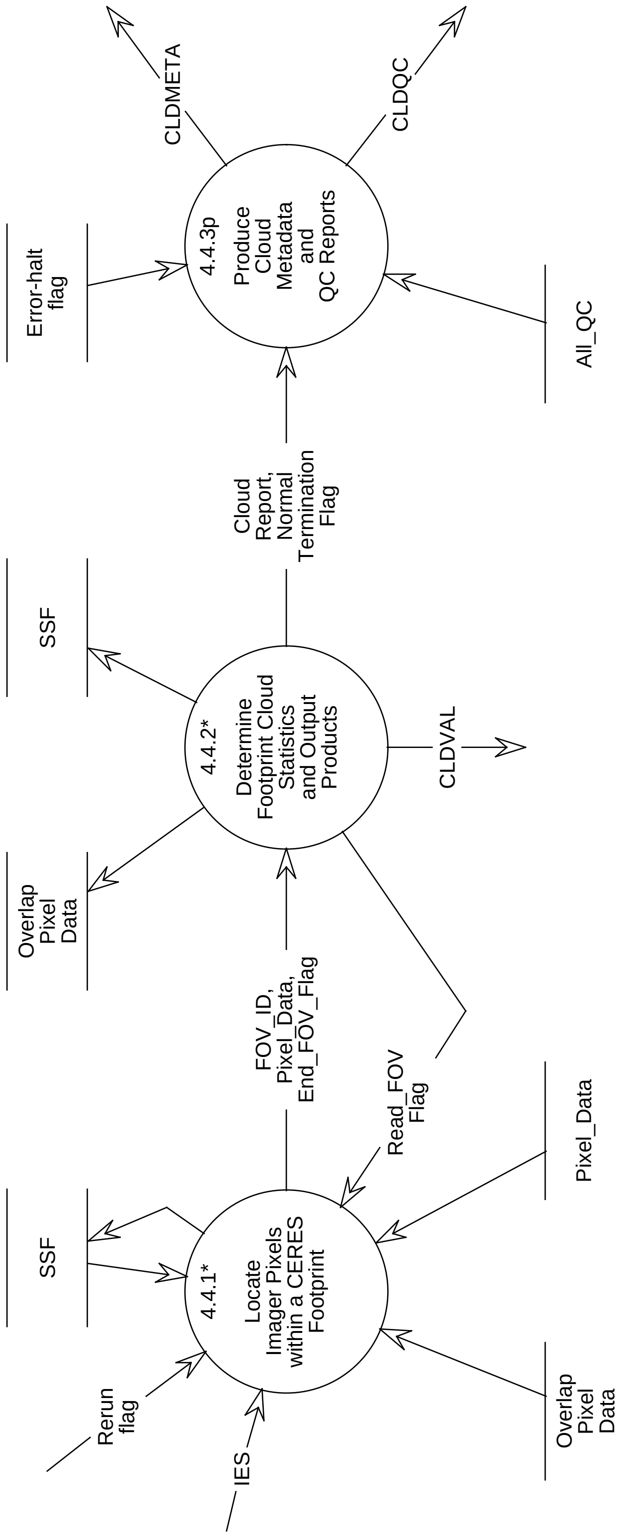

Figure 5-18. Data Flow Diagram for Convolve Imager Cloud Properties with CERES Footprint

Output Data Flows

End FOV Flag
FOV ID
Pixel Data
SSF

Process Description (Figure 5-18)

The process has three subprocesses, shown in Figure 5-19 which:

1. If not reprocessing, then while in the initial state, write the SSF header record
2. Read either an IES footprint record (if not in a rerun state) or a SSF footprint record (if in a rerun state) to obtain the CERES footprint FOV data
3. Find the imager pixels that fall within the footprint

5.2.4.1.1 Write Header Data to SSF - Process 4.4.1.1

Input Data Flows

IES
Rerun Flag

Output Data Flows

SSF

Process Specification (Figure 5-19)

This process shall:

1. If the rerun flag is false and if in the initial state, write the SSF header record to the "pre" SSF file. The SSF header record shall include the data product code, the spacecraft identification, the instrument identification code, data date, time, processing data and time, and the software version number. Other EOSDIS header standards shall also be adhered to.
2. If the rerun flag is true, then update the process date in the SSF header record.

Note: If the rerun flag is false, this is the first step in building the hourly SSF. Place-holders are provided in the SSF for data elements which will be added in the convolution, inversion, and surface processes.

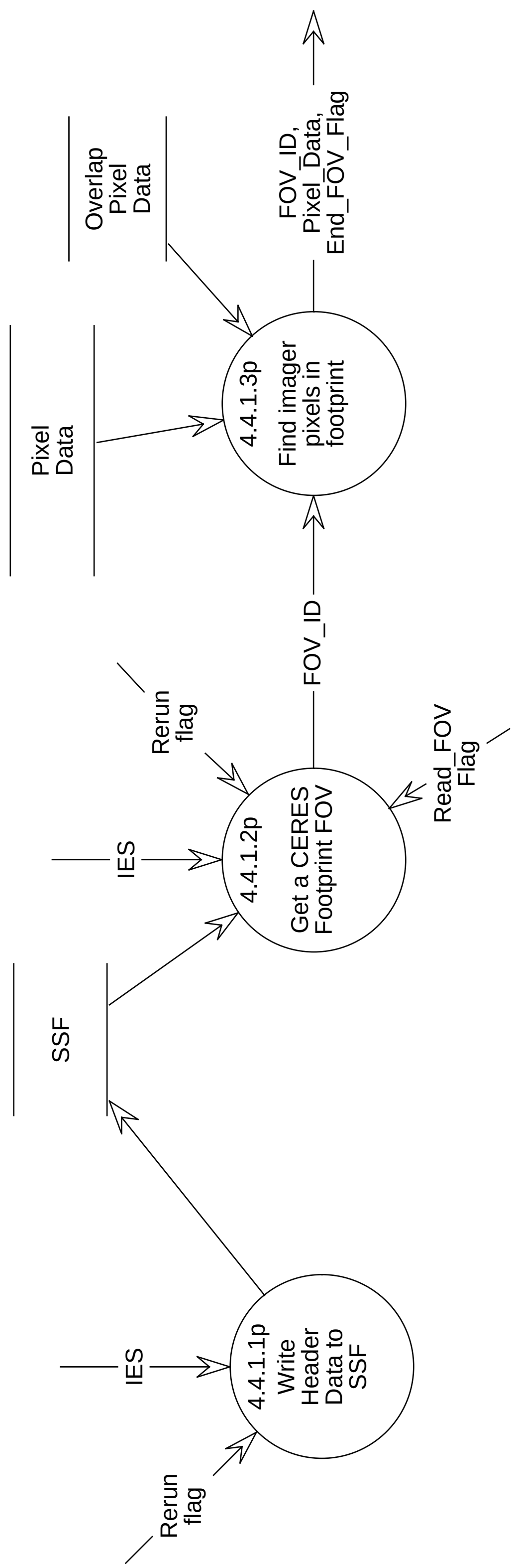

Figure 5-19. Data Flow Diagram for Locate Imager Pixels within a CERES Footprint

5.2.4.1.2 Get a CERES Footprint FOV - Process 4.4.1.2

Input Data Flows

IES
Read FOV Flag
Rerun Flag
SSF

Output Data Flows

FOV ID

Process Specification (Figure 5-19)

This process shall:

1. If the Rerun Flag is false, read an IES footprint record.
2. If the Rerun Flag is true, read an SSF footprint record.
3. Extract FOV data from the footprint record, including:
   a) Colatitude and longitude of the FOV centroid
   b) Colatitude and longitude of the spacecraft subpoint at the time of observation of this footprint
   c) Earth-central along-track and cross-track angles for this footprint, relative to the start of the CERES 1-hour dataset
   d) Satellite altitude at the time of observation of this footprint
   e) Start time of the current CERES one-hour dataset

4. Calculate intermediate viewing geometry elements which are constant for this FOV to be used for the selection of imager pixels within the footprint.

5.2.4.1.3 Find imager pixels in footprint - Process 4.4.1.3

Input Data Flows

FOV ID
Overlap Pixel Data
Pixel Data

Output Data Flows

End FOV Flag
FOV ID
Pixel Data

Process Specification (Figure 5-19)

This process shall:

1. Use the FOV location and timing data passed from Process 4.4.1.2 as the basis for selecting imager pixel data associated with the current footprint.

2. Calculate the along-track distance in kilometers between the FOV along-track position and the nadir pixels for the first and last scans in the Pixel_Data currently in memory. The FOV location must be between the first and last imager scans and must be at least 100 kilometers from each of them for TRMM (for MODIS, this margin must be at least 200 km); if not, read more data from Pixel_Data to ensure adequate coverage.

3. Locate, in Pixel_Data and/or Overlap_Pixel_Data, the pixel nearest to the FOV centroid (using the "find-first-pixel" algorithm, prototyped in subroutine FNDPXL). Store the scanline and pixel numbers for this pixel (SCANID, PIXNUM) as the basis for subsequent pixel-search logic.

4. Use the colatitude and longitude of the pixel identified in Step 3) and the FOV data from Step 1) to determine the along-scan and cross-scan angles δ and β for use in calculating point spread function (PSF).

5. Calculate PSF(δ, β) for this pixel. If the PSF value is not less than 0.095, then the pixel is within the 95% energy envelope for this FOV, and the pixel cloud data will be included in the statistics for this footprint.

6. If the PSF value at the first pixel is less than 0.095, then perform a search routine to locate a pixel within the 95% envelope. The search routine shall use the following logic:

    a) Obtain the colatitude and longitude of a pixel adjacent to the pixel identified in Step 3, and calculate its along-scan and cross-scan angles δ and β and PSF(δ, β)

    b) Compare the PSF value at this pixel to that of the pixel identified in Step 3; if greater, then continue to test pixels in that direction until either the PSF value begins to decrease or until a pixel is found with a value greater than or equal to 0.095; if $\geq$ 0.095, then go to Step 7; else, go to the pixel with the highest PSF value in this scanline and continue the search in the orthogonal direction (i.e., if previous search direction was along a scanline, begin this part of the search at the same pixel number of an adjacent scanline).

    c) If the PSF value for the pixel found in Step 3 is 0.0, perform the same search logic as described in Steps a and b above, but compare the values of the along-scan and cross-scan angles δ and β; move in a direction that decreases both angles, and continue to calculate PSF(δ, β) until a value $\geq$0.095 is obtained; then, go to Step 7.

7. If the pixel passes the PSF 95% test, perform the required processing and statistical analysis for this pixel relative to this footprint. All processing will be done incrementally, i.e., calculate running sums, sums of squares, and ordered arrays for histograms; and immediately discard the pixel data, rather than loading arrays of pixel data or pointers for subsequent processing.

8. After processing the nearest pixel (located in Step 3 or Step 6), increment the pixel number (i.e., PIXNUM = PIXNUM+1) and test the pixel at that location, applying Steps 4 and 5. Continue this process until the current pixel fails the 95% test.
9. Reset the pixel number to the original PIXNUM determined in either Step 3 or Step 6, and test the pixels in the opposite direction (i.e., PIXNUM = PIXNUM-1) until a pixel is found that fails the 95% test. Process each pixel that passes the 95% test.
10. Reset the pixel number to the center PIXNUM determined in either Step 8 or Step 9, and increment the scanline (i.e., SCANID = SCANID+1). Test the pixel at this location; if it satisfies the 95% test, repeat the process in Steps 8 and 9. Repeat this process (Step 10) until the first pixel fails the 95% test
11. Reset the pixel and scanline numbers to those determined in either Step 3 or 6, and decrement the scanline (i.e. ,SCANID = SCANID-1). Test the pixel at this location; if it satisfies the 95% test, repeat the process in Steps 8 and 9. Repeat this process (Step 11) until the first pixel fails the 95% test. At this point, set the End_FOV_Flag TRUE.
12. Test each footprint for adequacy of coverage. If the integrated PSF values for all pixels in the footprint exceed 95%, then the footprint is considered adequately covered. If the integrated PSF values are less than 95% but not less than 75%, then the footprint is accepted but is flagged as a partial footprint. If the integrated PSF is less than 75%, the footprint is flagged as incomplete.

5.2.4.2 Determine Footprint Cloud Statistics and Output Products - Process 4.4.2

Input Data Flows

End FOV Flag
FOV ID
Pixel Data

Output Data Flows

CLDVAL
Cloud Report
Normal Termination Flag
Overlap Pixel Data
Read FOV Flag
SSF

Process Description (Figure 5-18)

This process, shown in Figure 5-20, consists of the following subprocesses:

1. Assign a pixel into a cloud category (clear, low, lower middle, upper middle, and high) by the effective pressure parameter (parameters #13 and #25 in Table 4.4-4 of ATBD 4.4) (Reference 6). A two layer cloud will be assigned to two of the cloud categories. Assign a pixel to one of the 11 cloud overlap conditions.

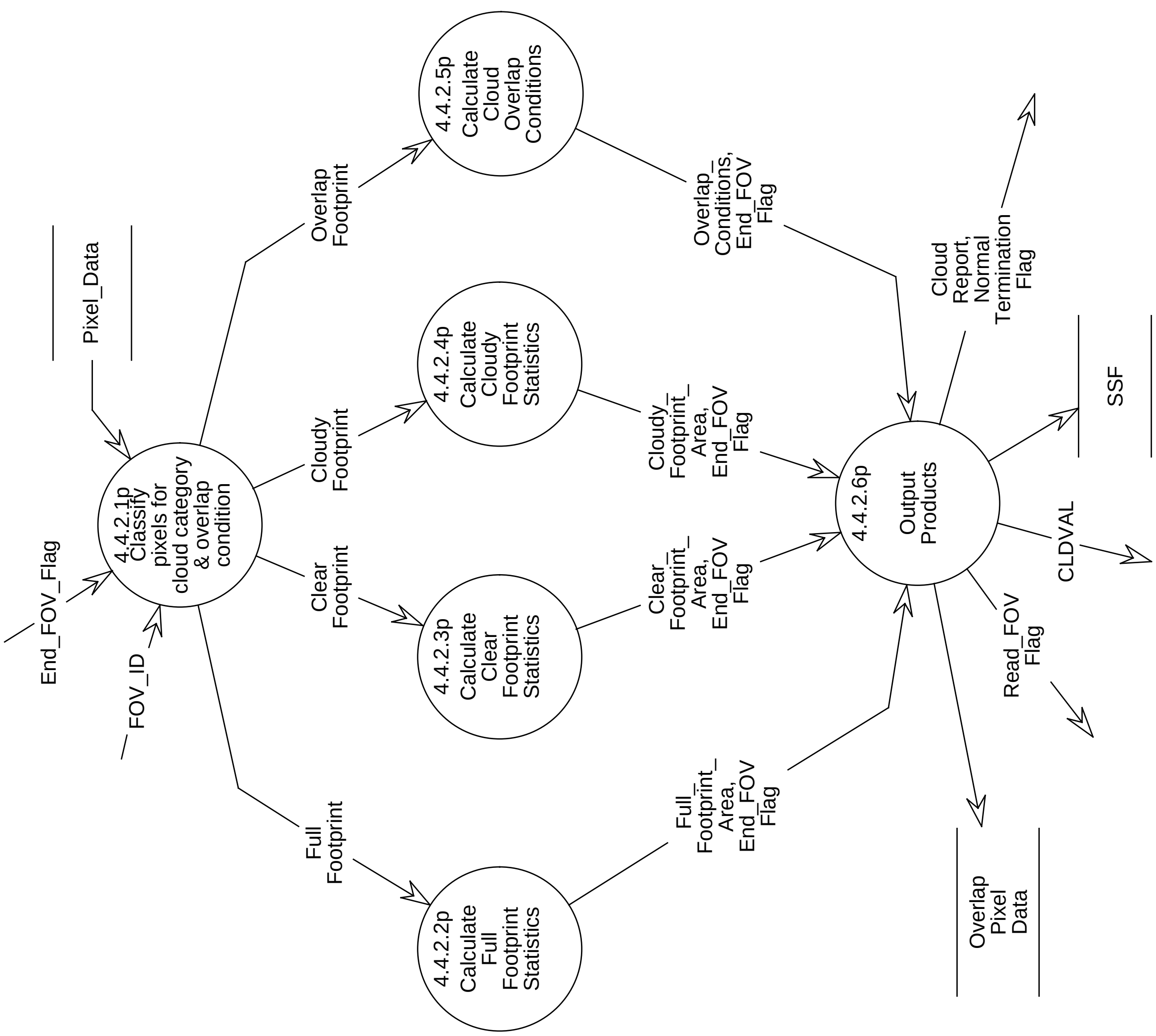

Figure 5-20. Data Flow Diagram for Determine Footprint Cloud Statistics and Output Products

2. Calculate the statistics for the full footprint area.
3. Calculate the statistics for the clear area of the footprint.
4. Calculate the statistics for the cloudy area of the footprint for four cloud categories.
5. Calculate the statistics for the 11 cloud overlap conditions. Form ordered arrays to calculate percentiles and complete statistics. Use sums and sums of squares to calculate means and standard deviations.
6. Output footprint records to SSF. Output the CLDVAL browse data. Send the cloud report and normal termination flag to Process 4.4.3, Produce_Cloud_Metadata_and _QC_Reports. Update Overlap_Pixel_Data for the next hour's run.

5.2.4.2.1 Classify pixels for cloud category & overlap condition - Process 4.4.2.1

Input Data Flows

End FOV Flag
FOV ID
Pixel Data

Output Data Flows

Clear Footprint
Cloudy Footprint
Full Footprint
Overlap Footprint

Process Specification (Figure 5-20)

This process shall for each CERES footprint and for each imager pixel within that footprint:

1. Assign a pixel as clear if there are no cloud layers or into a cloud category (low, lower middle, upper middle, and high) by the effective pressure parameter for each layer. A pixel with two cloud layers will be assigned to two of the cloud categories.
2. Assign each pixel to one of the 11 cloud overlap conditions, using the classes shown in Table 5-2.

Table 5-2. Eleven Cloud Overlap Conditions

Index	Definition	Symbol	
No layer			
1	clear (no clouds)	CLR	0
One layer			
2	low cloud only (cloud effective pressure > 700 hPa)	L	1
3	lower middle cloud only (700 ≥ eff. pressure > 500 hPa)	LM	2
4	upper middle cloud only (500 ≥ eff. pressure > 300 hPa)	UM	3
5	high cloud only (eff. pressure ≤ 300 hPa)	H	4
Two layers			
6	high cloud over upper middle cloud	H/UM	43
7	high cloud over lower middle cloud	H/LM	42
8	high cloud over low cloud	H/L	41
9	upper middle cloud over lower middle cloud	UM/LM	32
10	upper middle cloud over low cloud	UM/L	31
11	lower middle cloud over low cloud	LM/L	21

5.2.4.2.2 Calculate Full Footprint Statistics - Process 4.4.2.2

Input Data Flows

Full Footprint

Output Data Flows

End FOV Flag

Full Footprint Area

Process Specification (Figure 5-20)

This process shall calculate the following statistics for the full footprint area (i.e., calculations are made using all imager pixels in the footprint regardless of cloud condition):

1. Total number of cloud height categories
2. Total number of imager pixels within the footprint.
3. Radiance 0.6 µm (mean, 5-percentile, 95-percentile)
4. Radiance 3.7 µm (mean, 5-percentile, 95-percentile)
5. Radiance 11.0 µm (mean, 5-percentile, 95-percentile)
6. Bidirectional reflectance or brightness temperature (array of dimension11)
7. Precipitable water
8. Angles at TOA (mean viewing zenith angle, mean relative azimuth angle)

9. Notes for general procedures, texture algorithm, multilevel cloud algorithm, spatial coherence algorithm, infrared sounder algorithm, threshold algorithm, visible optical depth algorithm, infrared emissivity algorithm, cloud particle size algorithm, and cloud water path algorithm
10. Clear-sky/full-sky Flag (flag = 1 if all pixels are clear, flag = 0 otherwise)

5.2.4.2.3 Calculate Clear Footprint Statistics - Process 4.4.2.3

Input Data Flows

Clear Footprint

Output Data Flows

Clear Footprint Area
End FOV Flag

Process Specification (Figure 5-20)

This process shall calculate the following parameters for clear footprint area (i.e. the calculations are made using only the pixels within the footprint with cloud overlap condition = 1 (no cloud):

1. Number of (clear) imager pixels
2. PSF weighted area fraction
3. Weighted radiance 0.6 μm (mean and standard deviation)
4. Weighted radiance 3.7 μm (mean and standard deviation)
5. Weighted radiance 11.0 μm (mean and standard deviation)
6. Stratospheric Aerosol (visible optical depth, effective particle radius)
7. Total Aerosol (visible optical depth, effective particle radius)

5.2.4.2.4 Calculate Cloudy Footprint Statistics - Process 4.4.2.4

Input Data Flows

Cloudy Footprint

Output Data Flows

Cloudy Footprint Area
End FOV Flag

Process Specification (Figure 5-20)

This process shall calculate the following parameters for the cloudy footprint area for each of the four height categories:

1. Number of imager pixels in each category
2. Number of overcast pixels
3. PSF weighted area fraction
4. PSF weighted overcast fraction
5. PSF weighted broken cloud fraction
6. Radiance 0.6 µm (mean and standard deviation)
7. Radiance 3.7 µm (mean and standard deviation)
8. Radiance 11.0 µm (mean and standard deviation)
9. Visible optical depth (mean and standard deviation)
10. IR emissivity (mean and standard deviation)
11. Liquid water path (mean and standard deviation)
12. Ice water path (mean and standard deviation)
13. Top pressure (mean and standard deviation)
14. Effective pressure (mean and standard deviation)
15. Effective temperature (mean and standard deviation)
16. Effective height (mean and standard deviation)
17. Bottom pressure (mean and standard deviation)
18. Water particle radius (mean and standard deviation)
19. Ice particle radius (mean and standard deviation)
20. Particle phase (mean and standard deviation)
21. Vertical aspect ratio (mean and standard deviation)
22. Visible optical depth (daytime)/ IR emissivity (nighttime) (13 percentiles)

All means and standard deviations (# 6-21 above) are PSF weighted.

The weighted area fraction (#3) is a function not only of count but also the pixel cloud fraction. Define the area fraction f_i of each category using formula 4.4-1. Similarly, define overcast fraction (#4) by restricting the summation in formula 4.4-1 to the overcast pixels. Broken cloud fraction is defined as 1 minus (clear fraction + overcast fraction).

$$f_i = \frac{\sum_{\text{category i pixels}} PSF \times \text{cloud fraction}}{\sum_{\text{all pixels}} PSF} .$$

for i = 1 to 4

The water path and particle radius are sorted into two separate parameters (11 and 12, 18 and 19) according to particle phase (0-ice, 1-water) of imager pixels.

Record the visible optical depth frequency distribution (#22) during daytime. For each of the four categories, order the imager pixel visible optical depth and record the following 13 percentiles : 1, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 95, 99. This requires a vector of 4 x 13 = 52. At night, the optical depth distribution is replaced by a frequency distribution of 11 µm infrared emissivity.

5.2.4.2.5 Calculate Cloud Overlap Conditions - Process 4.4.2.5

Input Data Flows

Overlap Footprint

Output Data Flows

End FOV Flag
Overlap Conditions

Process Specification (Figure 5-20)

This process shall calculate the following statistics for each of 10 cloud overlap conditions. The overlap condition with index i = 1 is the case of no clouds (clear), which is excluded from this calculation.

1. Number of imager pixels in each overlap class in the footprint
2. PSF weighted area fraction f_i for pixels in each condition, as defined by

$$f_i = \frac{\sum_{\text{condition i pixels}} PSF}{\sum_{\text{all pixels}} PSF}$$

for i = 2 to 11

Note that the area fraction for the 10 overlap conditions does not use cloud fraction. It follows that the 10 overlap condition area fractions plus the area fraction of clear pixels (no clouds) sum to unity.

5.2.4.2.6 Output Products - Process 4.4.2.6

Input Data Flows

Clear Footprint Area
Cloudy Footprint Area
End FOV Flag
Full Footprint Area
Overlap Conditions

Output Data Flows

CLDVAL
Cloud Report
Normal Termination Flag
Overlap Pixel Data
Read FOV Flag
SSF

Process Specification (Figure 5-20)

This process shall build and output the intermediate SSF product, update the Overlap_Pixel_Data, and output the cloud report and validation products.

The intermediate SSF product:

- Write footprint-based records to the intermediate SSF file, when triggered by the End_FOV_Flag
- Count the number of records written to the intermediate SSF file
- Return a Read_FOV_Flag to Process 4.4.1.2, Get_a_CERES_Footprint_FOV

Overlap_Pixel_Data:

- Copy overlap segment from current hour's Pixel_Data to Overlap_Pixel_Data, for use in next hour's execution

CLDVAL:

- Write imager values for selected geographic regions to the validation product
- Collect statistics on values written to the validation product
- Output limited set of values from which to build a time history
- The Cloud Mask has been output by process 4.1, Prepare_Data_Chunk_and _Determine_Clear/Cloudy_Pixels

Cloud Report:

- Write the Cloud Report
- Set Normal_Termination_Flag TRUE and send it to Process 4.4.3 - Produce_Cloud_Metadata_and_QC_Reports

5.2.4.3 Produce Cloud Metadata and QC Reports - Process 4.4.3

Input Data Flows

All QC
Cloud Report
Error-halt flag
Normal Termination Flag

Output Data Flows

CLDMETA
CLDQC

Process Specification (Figure 5-18)

This process shall at termination (when processing is complete, or the system has generated an Error-halt_Flag anywhere in the system):

1. Derive the metadata from the QC information and output the metadata for SSF and CRH_DB
2. Close all files
3. Complete any last record processing
4. Calculate processing statistics for this hour of CERES footprints
5. Write the QC report. There will either be a normal processing QC report or an abnormal processing QC report, which will list any and all error codes activated by the Clouds Subsystem, including, whenever possible, the module from which the error code was generated. The QC report shall include the Cloud Report passed from Process 4.4.2., Determine_Footprint_Cloud_Statistics_and_Output_Products

Under normal processing conditions (no Error-halt_Flag generated) this process is initiated by the receipt of a Normal_Termination_Flag (in the TRUE state) from Process 4.4.2., Determine_Footprint_Cloud_Statistics_and_Output_Products.

5.2.5 Update CRH - Process 4.11

Input Data Flows

CRH DB

Output Data Flows

CRH

Process Specification (Figure 5-1)

This process shall:

1. Bin the pixel clear-sky values into the CRH grid boxes using the pixel latitude and longitude and the CRH grid box corner latitude and longitude
2. Average the pixel clear-sky values over the CRH grid
3. Interpolate the gridded clear-sky values to the nearest hourly CRH
4. Determine if the new clear-sky value should replace the old clear-sky value
5. If the old value is replaced, update the number of days since an update to zero

5.3 Design Goals and Constraints

The design goal is to be flexible enough that subsequent releases can be addressed with minimum impact. Every attempt is made to specify the requirements such that trading in and out of algorithms will cause minimum change to the organization. Therefore, the software design must be modular, must allow for optional processing choices, and must use a mechanism for specifying the options outside of the software itself. Parameterization and table-driven input will be required.

The languages used will be ANSI C and FORTRAN 90. The cloud framework must be able to interface with both languages.

The design constraints are the EOSDIS PDPS operating environment, the SDP Toolkit, the limits of computer CPU, data throughput, network capacity, and system complexity. Metadata and error handling will conform to the EOSDIS requirements and standards.

Any bad data in the input data products (CID, IES, and ancillary data) are expected to be flagged as bad by the time cloud processing takes place. Limit checks to ensure that the data are within reasonable limits will be implemented. Data that are outside these limits will be excluded from further processing, and a diagnostic message will be generated.

A design issue will be how to process both IES products in the same PGE for the EOS spacecraft that carry two CERES instruments. Two SSF products will be produced, one for the Rotating Azimuth Plane Scanner (RAPS) mode and one for the Fixed Azimuth Plane Scanner (FAPS) mode. This approach minimizes reading the imager data and determining the cloud properties.

There are several design options to satisfy the Overlap Portions requirement that begins the rolling data chunk and ends the rolling data chunk (Section 2.0 Key Concepts). The cloud process will not start until all three consecutive CID hourly input files are available for an IES hourly input file. It might prove prudent to save the data chunk with the ancillary attributes from the previous hour into an "overlap" file instead of searching through the previous CID file to a position 300 km before the current CID file. Saving an overlap file would change the requirement from three consecutive CID files to two consecutive CID hourly files. If the CID granule is less than 1-hour, other scenarios will be considered.

Another design issue related to the "Chunking" is that the cloud retrieval requirements for data chunks are not the same as those for ATBD 4.4 (the "Cookie Cutter").

Due to the complexity in the cloud retrieval process, nonstop processing from beginning to end is not feasible in the prelaunch releases. An approach is to use a processing option parameter to indicate the selected steps and options to produce several generated internal data products. For example, it is highly possible that the cloud masking algorithms will be rerun many times using different methods. We plan to save the cloud mask and surface conditions as validation products, although the processing steps are not defined yet. This function is considered a necessary requirement for Release 1. This strategy might be changed at later releases, due to the trade-offs between CPU time and storage space.

5.4 Resource Use

All preliminary estimates suggest that the cloud processing might exceed foreseeable growth in computer resources.

The estimated size of an SSF hourly product is 154 MB. There will be 24 SSF data products per day, and 720 per month. The CPU load requirement has been estimated based on research code. The cloud processing time is dominated by the number of CID pixels processed. The estimates require 4940 Floating Point Operations (FLOP) per pixel. There are 3.08×10^6 pixels for each VIRS channel and 4.84×10^7 pixels for each MODIS channel. This translates to 9 hours of processing time for VIRS and 900 hours for MODIS on a Sun SPARC2 for a 1-hour product.

Because the Cloud Subsystem is an hourly process, there are an average of 720 (24 hours x 30 days) Product Generation Executables (PGEs) per month after the TRMM launch, 1440 PGEs following EOS-AM1 launch, and 2160 PGEs following EOS-PM1 launch per month (ATBD 0, Reference 8), assuming all three satellites are operational at the same time.

References

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9. NOAA Polar Orbiter Data User Guide (TIROS-N, NOAA-6, NOAA-7, NOAA-8, NOAA-9, NOAA-10, NOAA-11, NOAA-12), July 1991.

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Abbreviations, Acronyms, and Symbols

ADM	Angular Distribution Model
AI	Artificial Intelligence
ATBD	Algorithm Theoretical Basis Document
AVHRR	Advanced Very High Resolution Radiometer
BTD	Brightness Temperature Difference
CADM	CERES Angular Distribution Model
CERES	Clouds and the Earth's Radiant Energy System
CID	Cloud Imager Data
CLDMETA	Cloud Metadata
CLDQC	Cloud Quality Control Reports
CLDVAL	Cloud Validation Data
CRH	Clear Reflectance, Temperature History (CERES Archival Data Product)
CRH_DB	Clear Reflectance, Temperature History (CERES Internal Data Product)
DAAC	Distributed Active Archive Center
DPC	Data Products Catalog
EOS	Earth Observing System
EOS-AM	EOS Morning Crossing Mission
EOSDIS	EOS Data Information System
EOS-PM	EOS Afternoon Crossing Mission
ERBE	Earth Radiation Budget Experiment
FAPS	Fixed Azimuth Plane Scanner
FOV	Field-of-view
GAC	Global Area Coverage (AVHRR data mode)
HBTM	Hybrid Bispectral Threshold Method
HIRS	High Resolution Infrared Radiation Sounder
IES	Instrument Earth Scans (CERES Internal Data Product)
IR	Infrared
ISCCP	International Satellite Cloud Climatology Project
IWP	Ice Water Path
LaRC	Langley Research Center
LBTM	Layered Bispectral Threshold Method
LWP	Liquid Water Path
MIMR	Multifrequency Imaging Microwave Radiometer
MODIS	Moderate-Resolution Imaging Spectroradiometer

MWH	Microwave Humidity
MWP	Microwave Water Path
MOA	Meterological, Ozone, and Aerosol Product (CERES Internal Data Product)
NASA	National Aeronautics and Space Administration
NMC	National Meteorological Center
NOAA	National Oceanic and Atmospheric Administration
PAT	Processed Archival Tape (ERBE S-8 Data Product)
PDPS	Planning and Data Processing System
PGE	Product Generation Executable
PSF	Point Spread Function
RAPS	Rotating Azimuth Plane Scan
RTM	Radiative Transfer Model
SAGE	Stratospheric Aerosols and Gases Experiment
SDPF	Science Data Processing Facility
SERCAA	Support of Environmental Requirements for Cloud Analysis and Archival
SSF	Single Satellite CERES Footprint TOA and Surface Fluxes, Clouds
SURFMAP	Surface Properties and Map (CERES Input Product)
TMI	TRMM Microwave Imager
TOA	Top-of-the-Atmosphere
TRMM	Tropical Rainfall Measuring Mission
VIRS	Visible Infrared Scanner