MODIS/MCST & Calibration WG Report

to

The Calibration Working Group

of the

MODIS Science Team

from

MCST (MODIS Characterization Support Team)

John L. Barker, Head

301/286 9498 or GSFCmail: JBarker

Joann M. K. Harnden

301/286-4133 or GSFCmail: JHarnden

Code 925 - Sensor Development and Characterization Branch

NASA / Goddard Space Flight Center, Greenbelt, Maryland 20771

FAX: (301) 286-9200

Attachment 3.1

Presented by:

John L. Barker

Contributions by

Harold Geller, Jon Burelbach, Barbara Grant, Doug Hoyt, Janie Nall

(301)286-9412 or (301)982-3700 GSFCmail:BGrant, JNall,

Research and Data Systems, Inc.

7855 Walker Drive, Greenbelt, MD, 20770

Fax: (301)286-9200 or (301)982-3749

Monday, 13 April 1992

Goddard Space Flight Center
Building 22, Room 365
Greenbelt, Maryland

Overview of MODIS/MCST & Calibration WG Report

MODIS Science Team Meeting Calib. WG Objectives
MCST Objectives, Priorities, Personnel and Interfaces

MODIS/MCST Calibration Data Products
- Strategy
- Data Products
- Calibration Plan
- Calibration Handbook

SBRC/MCST Instrument Characterization Activities
- Instrument Delivery Schedule
- Math Model
- Proposed Calibration Scenarios

MCST Simulation Activities
MCST Bulletin Board

Open Action Items from October, 1991
- MCST
- Calibration WG

Actions Required by Calibration Working Group

April 1992 MODIS Science Team Meeting Objectives and Required Calibration/MCST-Related WG Action

1. **Re-evaluate selection of science algorithms**
   as a result of current instrument selection.
   Required Action:
   Need Calibration WG endorsement of up-dated list of calibration products.

2. **Report on current status of algorithm development.**
   Required Action:
   Provide MCST Status Report

3. **Identify the planned level of algorithm development**
   in light of current budget and time constraints.
   Required Action:
   Examine and up-date or confirm 1991 MCST Priorities

4. **Your algorithm development plans and schedule for development.**
   Required Action:
   Develop schedule for peer review and delivery of algorithms

5. **Your current perception of planned stage of algorithm development**
   before entrusting to the Science Data Support Team (MSDST)
   Required Action:
   Indicate intent to provide peer-reviewed and working S/W to MSDST

MCST Priorities

unchanged from

1990 and 1991 MODIS Science Team Meetings

1. Instrument-Related Characterization/Calibration

2. Algorithms, Software and Hardware
   for EOC/MCST Monitoring of In-Orbit Data
   (monitor focal plane in flight)

3. Utility Products (in coord. w/ land group)

4. Simulated MODIS Imagery - JB will present material for SI changes at land group meeting

5. Cooperative Team Member and MCST
   Discipline-Related Product Sensitivity
   to Calibration

MCST Personnel

Civil Servants with Interfaces to MCST

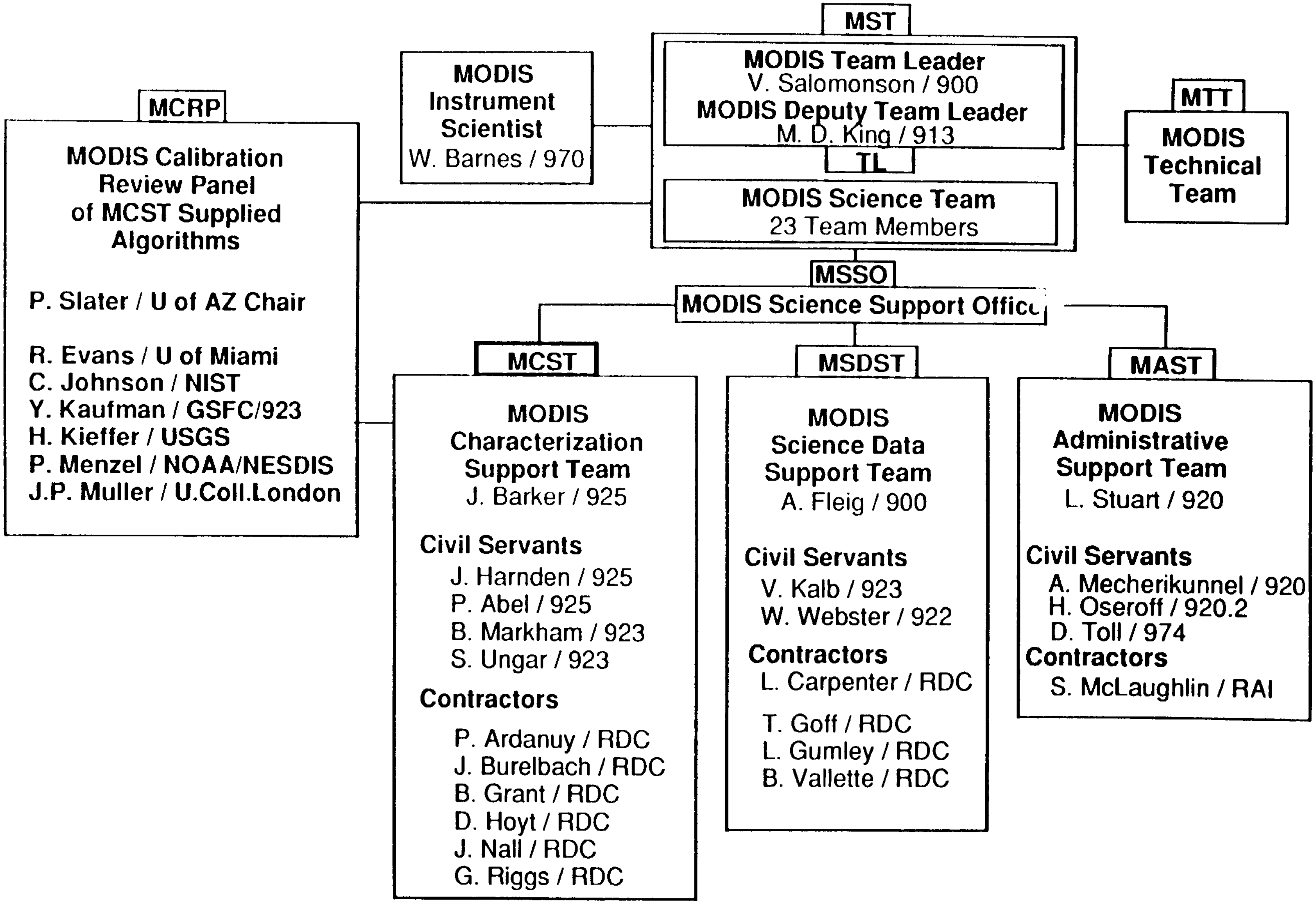
John Barker	(925)	MCST Head
Peter Abel	(925)	Aircraft Underflights / Thermal
Bill Barnes	(925)	MODIS Instrument Scientist / SeaWiFS
Ken Brown	(925)	MODIS Airborne Simulator (MAS)
Wayne Esaias	(697)	MODIS Ocean Discipline Head / SeaWiFS
Bruce Guenther	(925)	EOS AM Project Scientist / EOS Calibration Scientist
Forrest Hall	(923)	Image-Based Radiometric Rectification Calibration
Joann Harnden	(925)	Artificial Intelligence Information / Scene Simulation / Modeling
Chris Justice		MODIS Land Discipline Leader / AVHRR / NDVI
Michael D. King	(913)	MODIS Deputy Team Leader / Atmosphere Discipline Head / CERES
Brian Markham	(923)	Instrument Characterization/Field Calibration
Steve Ungar	(923)	MODIS Scene Simulation / Utility Algorithms

MCST Personnel

Contractors, RDC (Research and Data Systems Corporation)

Harold Geller	Out-Going Project Manager
Phil Ardanuy	Acting Project Manager
Jonathan Burelbach	Programmer / Analyst / Image Analysis
Barbara Grant	Optics Engineer / SBRC Interface / Calibration Plan
Doug Hoyt	Scientist / Solar Irradiance / MODIS Calibration Handbook
Janie Nall	Technical Editor / Meetings / Plans / MCST.BB
George Riggs	Scientist / Utility/Masking Algorithm / Snow / Ice

MODIS Science Team Organization Chart



MCST Interfaces

MODIS Team Leader/900

MST	MODIS Science Team Members
MTT	MODIS Technical Team
MAST	MODIS Administrative Support Team
MSDST	MODIS Science Data Support Team
MCRP	MODIS Calibration Review Panel

EOS Project/420

AM Platform
- MODIS Instruments
- Non-MODIS Instruments

PM Platform
- Non-MODIS Instruments

EOSDIS/GSFC DAAC
- FOS/EOC (Flight Operations System / EOS Operations Center) ← this activity will go/gp
- DADS (Data Archive and Distribution System) ↑ eventually this will be the conduit for users obtaining data

MODIS/MCST Calibration Strategy

1. Use Alternative MODIS Calibration Methodologies

Several alternative calibration methodologies
will be implemented throughout 15-year mission
to provide a robust unique "official" calibration algorithm ← which will evolve rapidly in 1st few months
and to allow for its validation by independent methods

2. Characterize Precision on a Time-Scale of Months

Post-launch quantitative characterization and monitoring
of the precision (repeatability) with which MODIS at-satellite radiances
are measured by various methods
will occur within 2 to 6 months

MODIS/MCST Calibration Strategy (continued)

3. Characterize Accuracy on a Time-Scale of Years

Post-launch quantitative characterization and monitoring
of the accuracy with which MODIS at-satellite radiances
are measured by various methods and on two in-orbit instruments
will occur within 3 to 5 years (as evolving process)

4. Validate Math Model in 10-15 Years

Validation of the components of the predictive radiometric math models
for each MODIS instrument
(with an expected life-time of five-six years each)
will occur over the fifteen year life-time of EOS mission

At-Launch MODIS Calibration Data Products*

Primary MCST Product Generation Responsibilities
Instrument-Related Characterization/Calibration

Files for Appending/Accessing with Raw Level-1A or -1B Imagery

- Radiometric Calibration/Correction Parameters / Characteristics
- Within-Image Geometric Pixel Location Correction or Characteristics
- Spectral Characteristics
- Radiometric Math Model Parameters/Characteristics

Will be made available to users as file appended to (or together) 1A or 1B data

Calibrated Level-1B Imagery

- At-Satellite Radiances

Derived Level-2 Imagery

- Earth-Sun Distance and Solar Zenith Normalized Exoatmospheric Reflectances
- Errors in At-Satellite Radiances

* MCST-generated algorithms and software for operational products,
including associated algorithms for automated quality assurance, metadata, and browse products,
are to be rehosted to EOSDIS by MSDST
At-Launch products will be up-dated after launch, as required.

Post-Launch MODIS Calibration Data Products*

Primary MCST Product Generation Responsibilities
Instrument-Related Characterization/Calibration

Files for Appending/Accessing with Level-1A or -1B Imagery

- Solar Calibration Datasets from the Solar Diffuser used for Calibration
- Lunar Calibration Datasets used for Calibration

Derived Level-2 Information or Imagery

- Solar Irradiances
- Lunar Irradiances
- Lunar Reflectances
- Errors in Reflectance after Atmospheric Correction
- Errors in Pixel GeoLocation without Topographic Correction
- Errors in Pixel GeoLocation with Topographic Correction

Derived Level--3 Information or Imagery with Critical Data Products (Resample data to some other coord system)

- Errors in Reflectance after Atmospheric Correction
- Errors in Pixel GeoLocation without Topographic Correction
- Errors in Pixel GeoLocation with Topographic Correction

could be used to propagate these errors into certain level 3 data products

* MCST-generated algorithms and software for operational products, including associated algorithms for automated quality assurance, metadata, and browse products, are to be rehosted to EOSDIS by MSDST

MODIS/MCST Calibration Data Products*

Discipline Group	Parameter :: Qualifier		Investigator	Time	Original Product Name (from Investigator)
	At-Launch Products				
CAL	Characteristics::MODIS Instrument	Level-1	Salomonson/Barker	AL	
CAL	Radiance::MODIS At-Satellite	Level-1	Salomonson/Barker	AL	At-Satellite Radiances
CAL	Model::MODIS Instrument	Level-1	Salomonson/Barker	AL	Math Model
CAL	Reflectance::MODIS Exoatmospheric	Level-2	Salomonson/Barker	AL	Exoatmospheric Reflectances
CAL	Error::MODIS Radiance	Level-2	Salomonson/Barker	AL	
	Post-Launch Products				
CAL	Radiance::MODIS Solar Diffuser	Level-1	Salomonson/Barker	PL	Solar Calibration Datasets
CAL	Radiance::MODIS Lunar Reference	Level-1	Salomonson/Barker	PL	Lunar Calibration Datasets
CAL	Irradiance::MODIS Solar	Level-2	Salomonson/Barker	PL	Derived Solar Irradiances
CAL	Irradiance::MODIS Lunar	Level-2	Salomonson/Barker	PL	Derived Lunar Irradiances
CAL	Reflectance::MODIS Lunar	Level-2	Salomonson/Barker	PL	Lunar Reflectances
CAL	Error::MODIS Reflectance	Level-2	Salomonson/Barker	PL	
CAL	Error::MODIS Geometric	Level-2	Salomonson/Barker	PL	
CAL	Error::MODIS Geometric	Level-3	Salomonson/Barker	PL	

* As currently carried in the EOS Science Data Product Database (Yun Chi Lu/936)

* The question of whether there are unique EOSAM, EOSPM or combined EOSAM/EOSPM calibration data products has not been examined.

MODIS/MCST Calibration Plan

Objective

Provide a comprehensive review and integration of all methodologies used to calibrate the MODIS instruments

Approach

Integrate calibration plans from all sources and for all phases of the mission: pre-launch, in-orbit, and on-board

Eventually, provide an on-going structure of the methodologies used to obtain the results in the MODIS Calibration Handbook - will also provide a subset for EOS cal handbook

Include references to supporting and more detailed publications

Context

Provide an executive summary of methodologies from both external peer reviewed articles on MODIS calibration and internal NASA readiness review documents

Schedule

Provide up-dated versions at
MODIS Science Team Meetings, and
EOS Calibration/Validation Panel Meetings

For E-mail correspondence address GSFCmail:JBarker or BGrant.
For updates on the latest events and available documents, CHECK MCST.BB bulletin board on GSFCmail.

MODIS/MCST Calibration Handbook

Objective

Provide results of calibration and sufficient supporting information
to be able to scientifically use and interpret MODIS data.

Approach

Produce a stand-alone scientific user's guide containing all one needs to know
about calibration of MODIS data
throughout the lifetime of the EOS mission

Provide handbook in hard copy and electronic form,
initially from MODIS/MCST Bulletin Board, and
operationally from EOS DADS (Data Archive and Distribution System)

Provide notification of up-dated version
initially to MODIS Science Team members, and
operationally to EOS Science Office Mailing List

Include references to supporting and more detailed publications

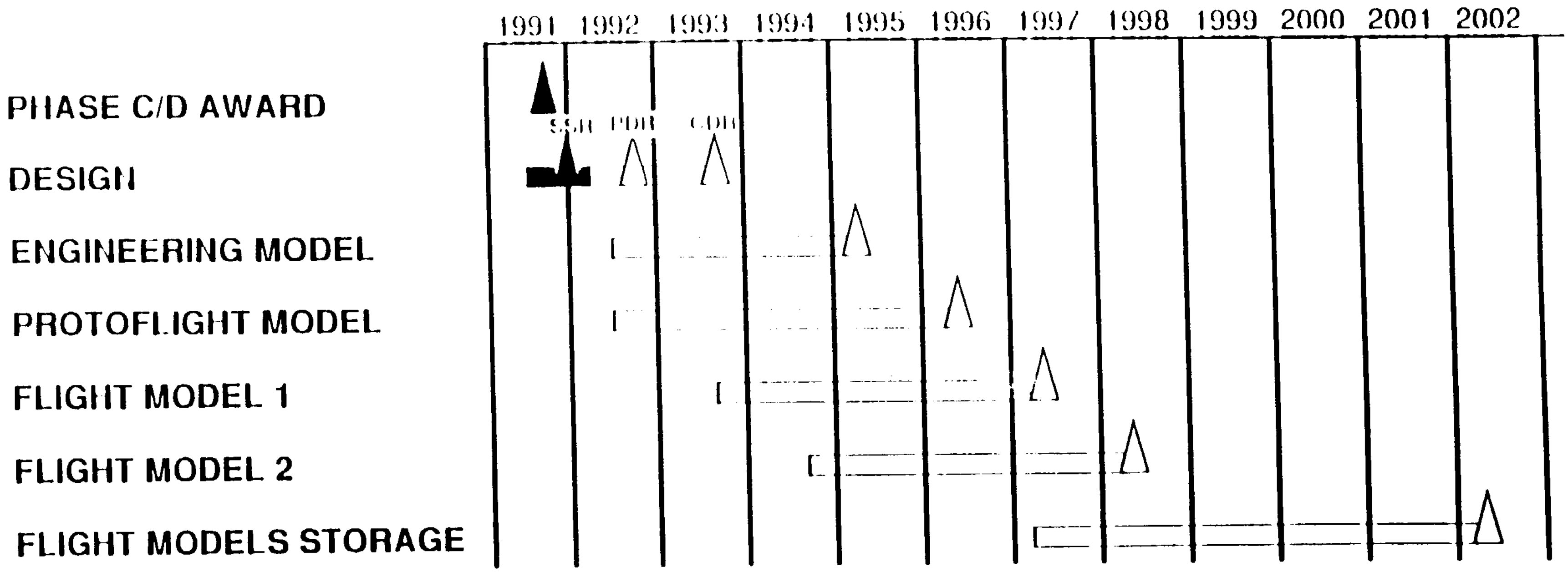
Context

Provide an executive summary of results in this handbook
from both external peer reviewed articles on MODIS calibration and
internal NASA readiness review documents

Schedule

Provide up-dated versions at
MODIS Science Team Meetings, and
EOS Calibration/Validation Panel Meetings

Hughes/SBRC MODIS Instrument Delivery Schedule
Protoflight Model (PF) for launch June 1998 on EOSAM-1
Flight Model-1 (F1) for launch June 2000 on EOSPM-1
MCST plans to analyze test data as it is generated



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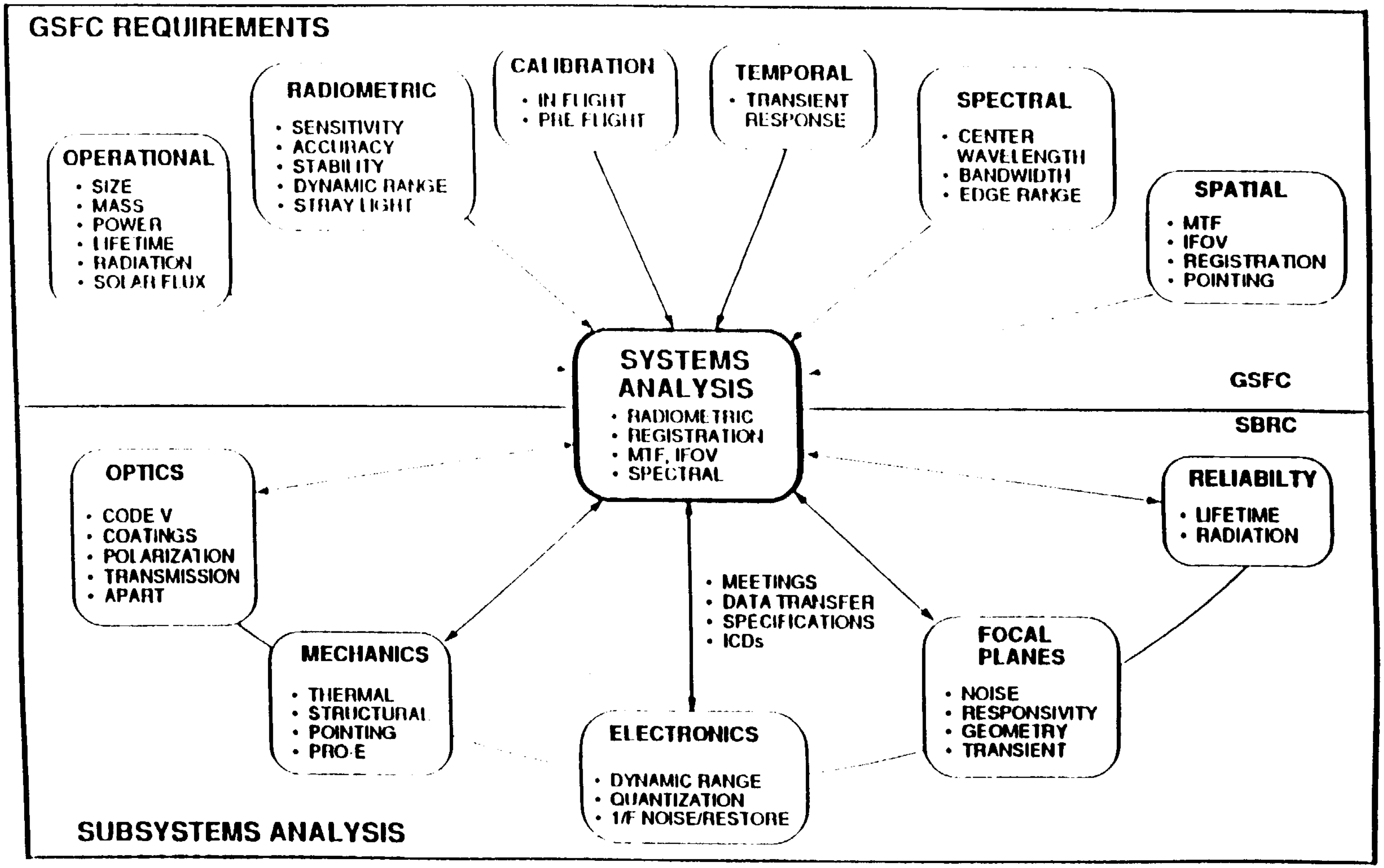
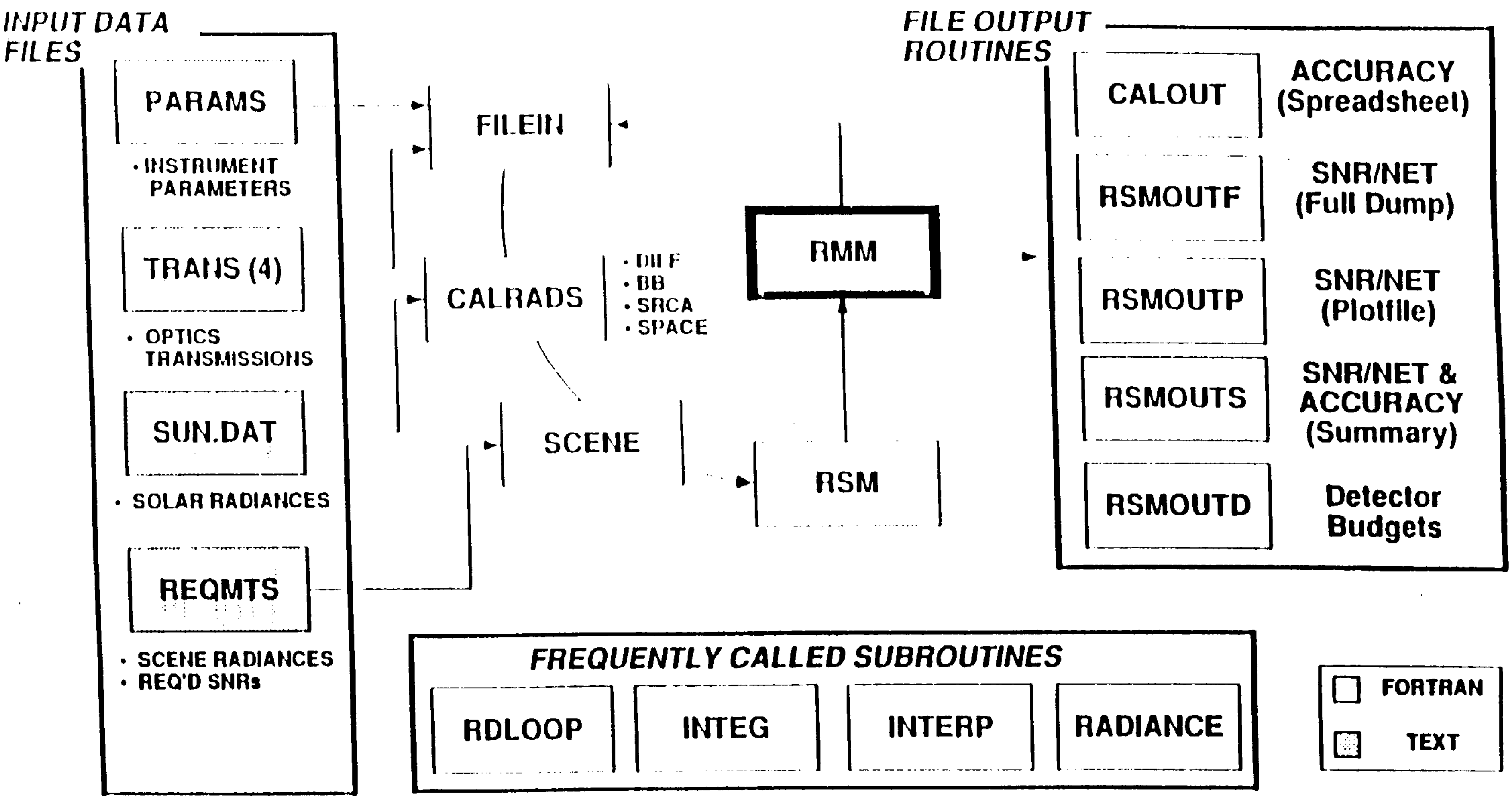
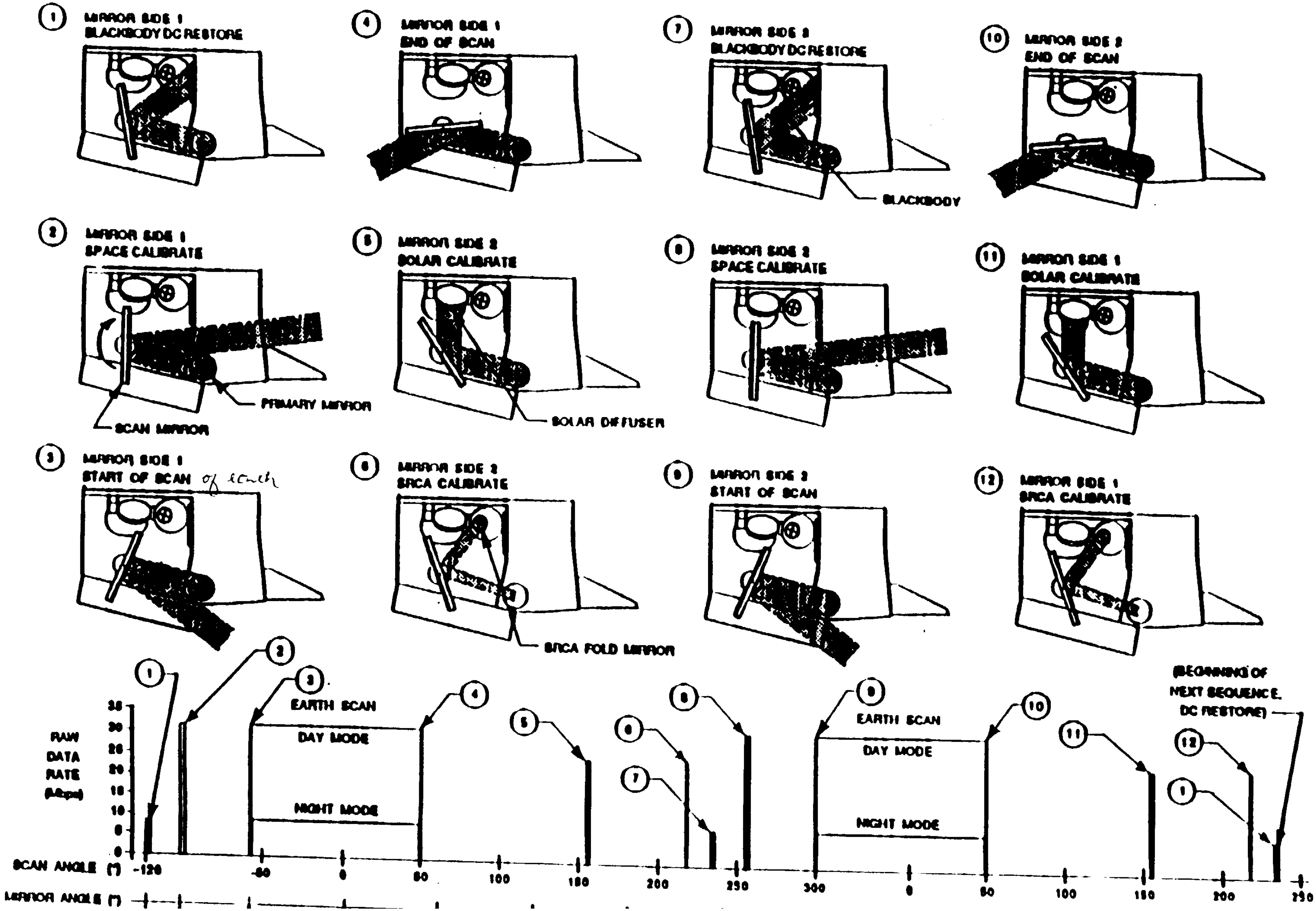
Hughes/SBRC MODIS Systems Analysis Overview including NASA/GSFC Instrument Requirements MCST plans to document scientific rationale for any changes



Hughes/SBRC MODIS Radiometric Math Model delivered to MCST on an as up-dated basis



Hughes/SBRC MODIS 2.6 sec 2-Mirror Scanning Sequence
Does this get reviewed by MODIS Calibration WG?



Hughes/SBRC Proposed MODIS Calibration Scenarios
Do these get reviewed by MODIS Calibration WG?

CALIBRATION DEVICE	ORBIT USE	ORBIT COLLECT	ORBIT PREP*	REMARKS
BB	CONSTANT	EACH SCAN	NA	DC RESTORE
BB HEATER	1X/MO	10 MIN	30 MIN	30 MIN WARMUP & 10 MIN EACH SCAN
SD	2 ORBITS 1X/WK	6 MIN	4 MIN	HIGH BRDF 1 ORBIT, LOW BRDF NEXT ORBIT; 3 MIN/SIDE; DOOR OPEN/CLOSE
SDSM	2 ORBITS 1X/WK	6 MIN	5 MIN	5 MIN WARMUP & 3 MIN/SIDE
SRCA RADIOMETRIC CAL	1X/MO	3X2 MIN	3X10 MIN	WARMUP & COLLECT 3 PTS/ORBIT FOR 36 MIN TOT
SRCA SPECTRAL CAL	1X/MO	65 MIN	10 MIN	10 MIN WARMUP & 45 MIN VIS/NIR & 20 MIN SWIR
SRCA SPECTRAL SELF CAL	1X/MO	45 MIN	10 MIN	10 MIN WARMUP & 45 MIN VIS/NIR
SRCA SPATIAL CAL	1X/3MO	3X2 MIN	3X10 MIN	WARMUP & COLLECT 3 PTS/ORBIT FOR 36 MIN TOT

* PREP CAN BE BEFORE, DURING OR AFTER COLLECTS DEPENDING ON CAL DEVICE

jm 3/5/92

Possible Recommendations for **Changes in** Hughes/SBRC MODIS 2.6 sec 2-Mirror **Scanning Sequence**

Longer Blackbody DC Restore, Solar and/or Space Look

Original considerations of time for DC restore, solar looks and space looks were predicated on the minimum possible impact by MODIS on satellite to ground transmission rate on the original 14-instrument EOS platform.

With fewer instruments on both EOSAM and EOSPM observatories, it seems reasonable to re-examine the actual potential for slightly larger data rates.

Current DC restore, solar and space look times are very small fractions of the total MODIS downlink rate.

Longer space looks would provide more potential for characterizing and potentially correcting systematic errors, many of which can not be expected to be identified until after launch.

Longer solar looks would provide potentially better solar calibration information and the solar diffuser is currently considered by the science community as the primary calibration mode.

Possible Recommendations for Changes in Hughes/SBRC Proposed MODIS Calibration Scenarios

Potential for Near-Continuous Operation of SRCA

Calibration mode represents peak power load for MODIS.
Current agreements between SBRC and GE call for no back-to-back calibration orbits.
Initial design called for 20 % increase in power to run the SCRA above that required for the normal daytime Earth scan mode, while current design only calls for a 10 % increase in power.
What are the real power constraints on the solar panels from the fixed fairing size given to GE by Code 421?
What is the relative power consumption using the SCRA without the blackbody on?

Potential for Near-Continuous Operation of the Solar Diffuser

The primary consideration for not deploying the solar diffuser continuously is the expectation that it will slowly degrade with time.
During the first few months of operation, it will be more important to establish the actual stability of the detector systems in space in order to empirically determine the optimum calibration requirements.

Outline of MCST Global Calibration Site Selection Procedure

Objective

Locate potential MODIS calibration targets on the Earth's surface
that are radiometrically homogeneous on a scale of 3 by 3 Km.

Approach

Initially use annual NDVI biweekly datasets of 1 Km AVHRR data
in the continental United States in 1990
to search for radiometrically homogeneous regions
using the standard deviation of a traveling 3X3 pixel area
as a measure of heterogeneity.

Context

Use calibration sites within the MODIS imagery to provide for
1) every-pass calibration potential
using a modified "radiometric rectification" methodology,
2) aircraft under-flight calibration support, and
3) occasional support of ground field calibration experiments

Schedule

Preliminary results for 1990 dataset from EDC (EROS Data Center)
will be reported at the Calibration Working Group sessions
of the April 14th MODIS Science Team Meeting

MCST Binary Land/Water Mask of Continental U. S. from EDC Biweekly 1990 1-Km AVHRR/NDVI Data Set

MCST.BB Electronic Bulletin Board

Objectives

Provide MODIS-related information on MCST activities,
for access by MODIS Science Team
and other members of scientific and engineering community

Approach

MCST contractors will maintain the bulletin board,
including provision for receiving feedback from it

Contents

Calibration Working Group Agenda
MODIS/MCST Calibration/Characterization Plan
MODIS/MCST Calibration Handbook
MCST Presentations

Procedure for Accessing

Gain access to GSFCmail by normal means.
At the "Command" prompt
enter <"CHECK MCST.BB">
after return, enter "SCAN ALL"
Use normal "Read" command to access posted documents by number

Open or Continuing Action Items for MCST from October 1991 MODIS Science Team Meetings

1. **Scientific Rationale for SPECS**: Develop a "Science Requirements Supporting Instrument Specifications" document to start capturing scientific rationale for some of the decisions associated with the instrument specifications.

2. **Field Validation Handbook**: Carol Bruegge (MISR at JPL) requested interaction between MCST and herself on a Field Validation Handbook.

3. **Figures from Hugh Kieffer**: Figures to supplement his discussion of lunar calibration for the MODIS/MCST Calibration/Characterization Plan were to be supplied by Hugh.

4. **MCST Calibration Site Selection Procedure**: Keep Chris Justice, Alan Strahler, John Townshend and Alfredo Huete informed about site selection procedure (3x3 moving std dev).

5. **MODIS Topographic Requirements**: Contact Mike Barnsley about topographical requirements and data.

6. **Simulated Band-to-Band Registration Requirements**: Enhance band-to-band registration studies by taking pixels and producing a more global area coverage band-to-band registration study.

Open Action Items for Calibration Working Group from October 1991 MODIS Science Team Meetings

1. **SBRC Document Delivery Dates**: Prepare Documents Expected from MODIS-N by expected delivery dates for the final plans, which are contractually due at PDR about October 23, 1992, and allowing 60 days prior to PDR for government review. (Dick Weber)

2. **Cross-Calibration with International Instruments**: Address cross calibration issues among international instruments in the Memorandums of Understanding (MOU). (Bruce Guenther)

3. **EOS Cal/Val Peer Review Instructions**: Regarding the recommendations for Peer Calibration PDR and CDR, perform an in-depth, technical review in a format that allows inputs from a peer panel of experts, no later than PDR and CDR, with the panel submitting a formal report to the engineering panel including action items and suggestions. (Bruce Guenther)

4. **Incident Angle of Sun on Diffuser**: Provide answer to Phil (regarding the Solar Diffuser Stability Monitor) about the angle of incident light on the solar diffuser. (Jim Young)

Open Action Items for Calibration Working Group from October 1991 MODIS Science Team Meetings (continued)

5. **Non-Uniform Contamination Study**: Continue examination of the spectrometer being non-uniform. (There was talk about the wide dynamic range of the optical system where F5 was the effective beam to specification and F100 is the sun.)
   (Jim Young)

6. **Solar Diffuser Material Study**: Regarding the selection of diffuser material, provide further study of two main candidates, Spectralon and YB71. (Carol Bruegge)

7. **Doped Spectralon Proposal**: Write a proposal to help fund the study of doped Spectralon, sending to Bruce. (Carol Bruegge)

8. **MODIS Filters for Lunar Observations**: Hugh Kieffer requests spare MODIS filters for lunar viewing (the witness pieces?).

Actions Required by the MODIS Calibration Peer Review Panel and/or the MODIS Calibration Working Group

1. Need endorsement to Science Team of MODIS/MCST calibration strategy.
2. Need endorsement to Science Team of up-dated list of calibration products.
3. Provide current status of calibration algorithm development.
4. Examine and up-date or confirm 1991 MCST Priorities
5. Develop schedule for peer review and delivery of calibration algorithms
6. Indicate intent to provide peer-reviewed and working S/W to MSDST.
7. Confirm need for access to both calibration data and raw data at the same time.
8. Provide feedback on Calibration Plan and Handbook, including approach.

Appendix to
MODIS/MCST & Calibration WG Report

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MODIS/MCST & Calibration WG Appendix

MCST Interfaces

- EOS Project Science Personnel
  - EOSAM Algorithm and Facility Delivery Schedule
- SBRC MODIS Program Organization

MODIS/SBRC Instrument Information

- Cutaway and Cross Section
- In-Orbit Calibration Capability
- Instrument Concerns
- Instrument Layouts

MCST Information

- Papers and Responses
- Outline of MODIS Calibration Handbook
- Outline for MODIS Calibration/ Characterization Plan
- Completed Action Items from October, 1991
- MODIS-T Action Items Dropped by MCST
- Simulated MODIS Imagery from Landsat TM
- Key MCST Algorithm Milestones

Requested Feedback from Attendees

- MODIS/MCST Calibration Handbook and Plan

EOS Project Science Personnel

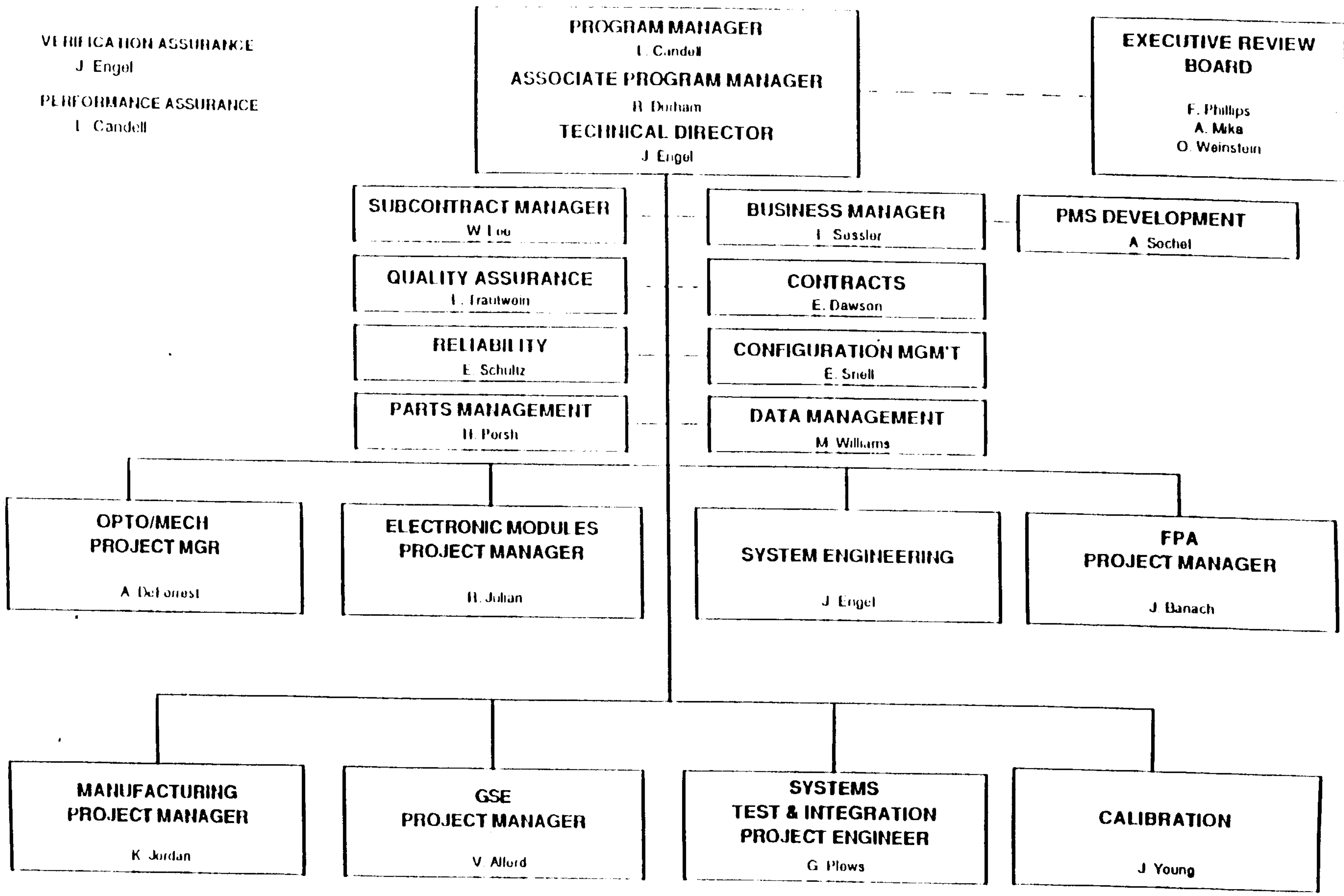
Jeremiah Madden	Associate Director for EOS
Richard Austin	Deputy Associate Director for EOS/Resources
Jeffrey Dozier	Project Scientist
Christopher Scolese	Project Manager, EOS Observatory Project
Kevin Grady	Deputy Project Manager, EOS Observatory Project
James Zerega	Deputy Project Manager, Resources, EOS Observatory Project
Martin Donohoe	Project Manager, EOS Instruments Project
Arlene Peterson	Deputy Project Manager, EOS Instruments Project
William Schiavone	Deputy Project Manager, Resources, EOS Instruments Project
Thomas Taylor	Project Manager, EOS Ground System and Operations Project
Hampapuram Ramapriyan	Deputy Project Manager, EOS Ground System and Operations Project
Jack Peddicord	Deputy Project Manager, Resources, EOS Ground System and Operations Project

EOS AM Instrument Science Algorithm and Science Computing Facility Delivery Schedule

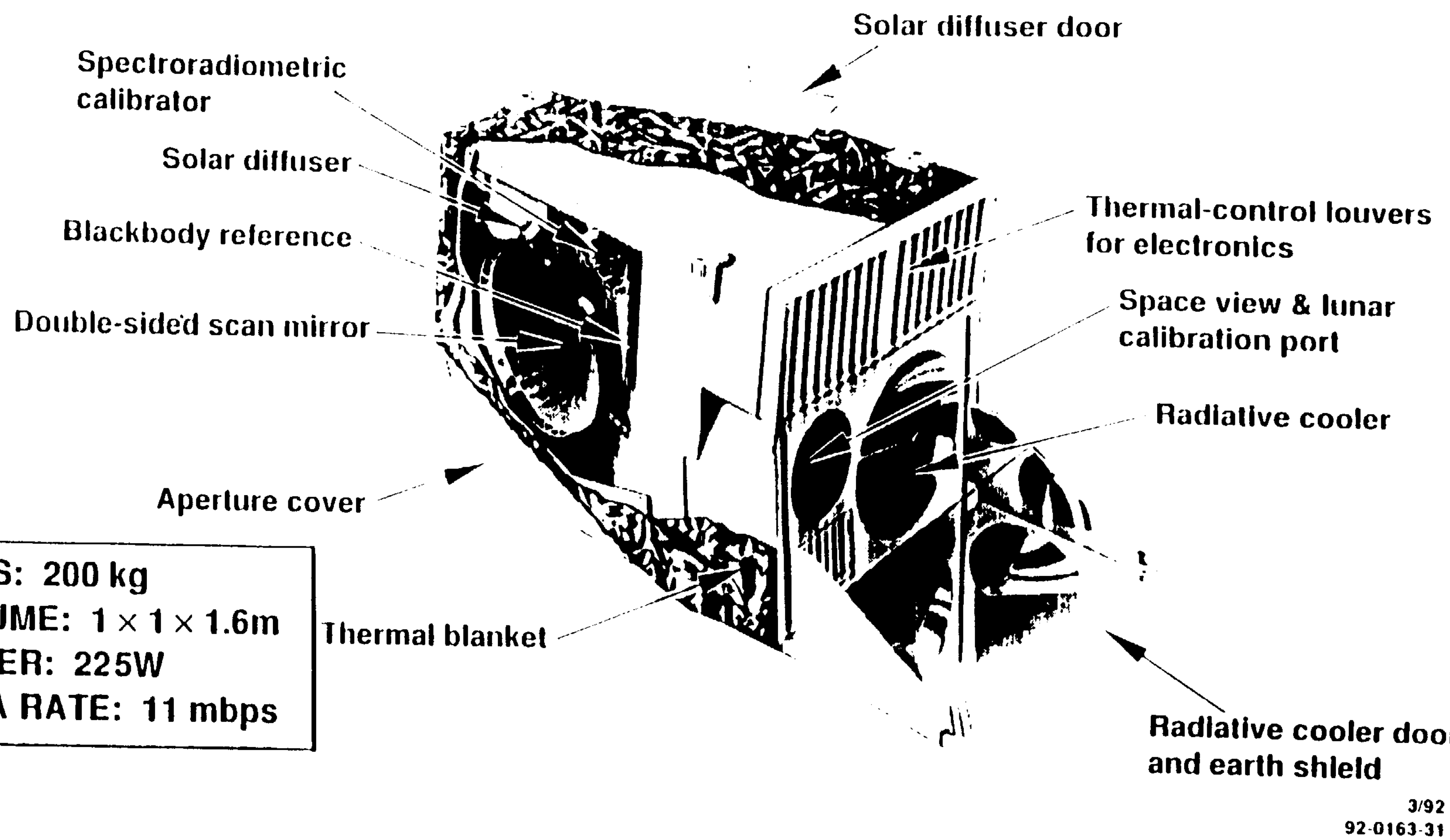
February 21, 1992

Deliverable	Date	Version
Software and Data Management Plan	6/92	preliminary
	6/93	draft
	6/94	revision
	6/95	final
Science Computing Facility Plan	6/92	preliminary
	6/93	draft
	6/94	revision
	6/95	final
	as needed	revisions
Calibration Plan	6/95	draft
	6/96	revision
	6/97	final
Software review materials	annually	
Software, test data, and documentation	launch -36m	Version 1
	launch -24m	Version 2
	launch -12m	Version 3
Status reports	monthly	

MODIS Program Organization for Hughes/SBRC

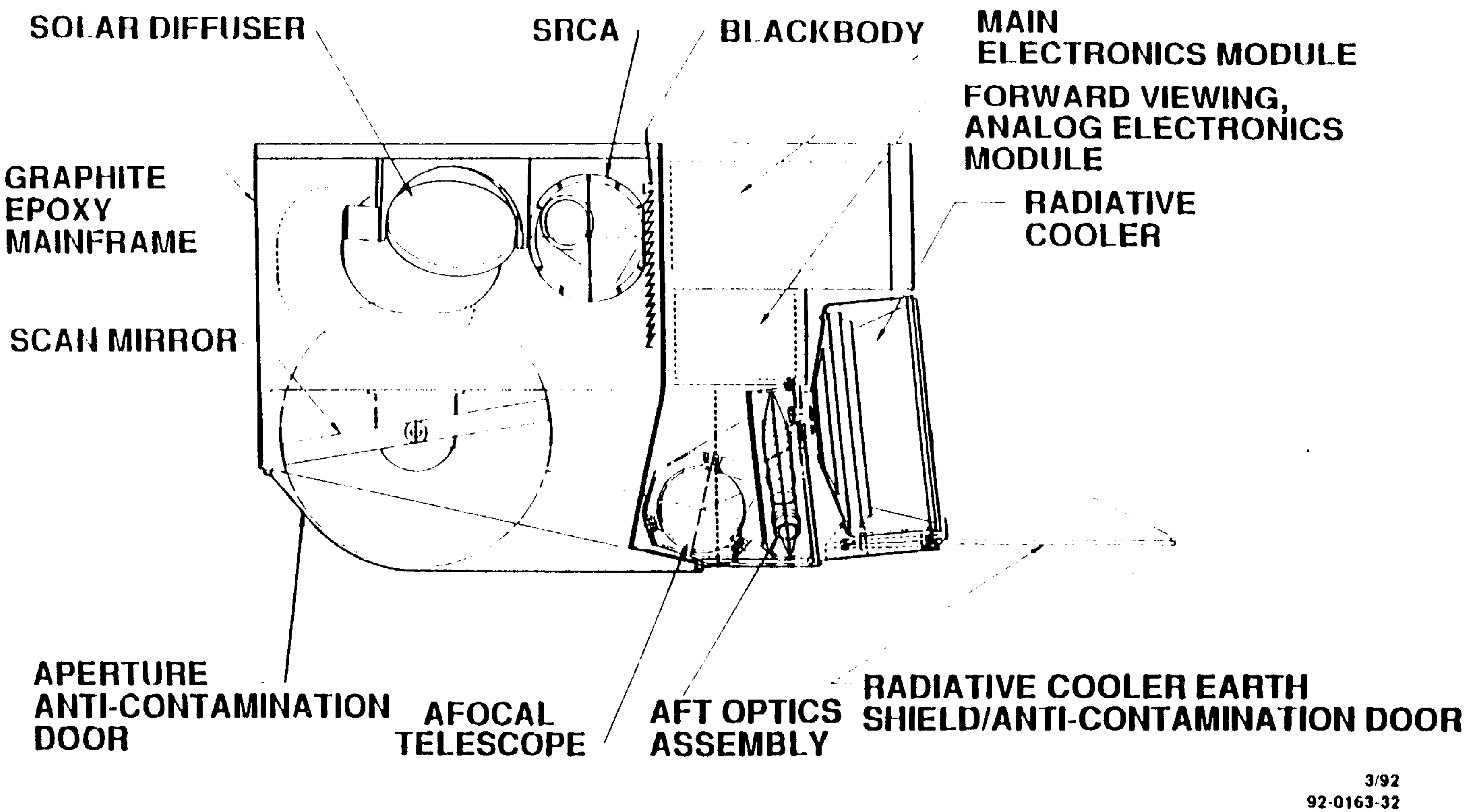


MODIS Cutaways from Hughes/SBRC



MASS: 200 kg
VOLUME: 1 × 1 × 1.6m
POWER: 225W
DATA RATE: 11 mbps

Cross-Section of MODIS from Hughes/SBRC



MODIS In-Orbit Calibration Capacity from Hughes/SBRC

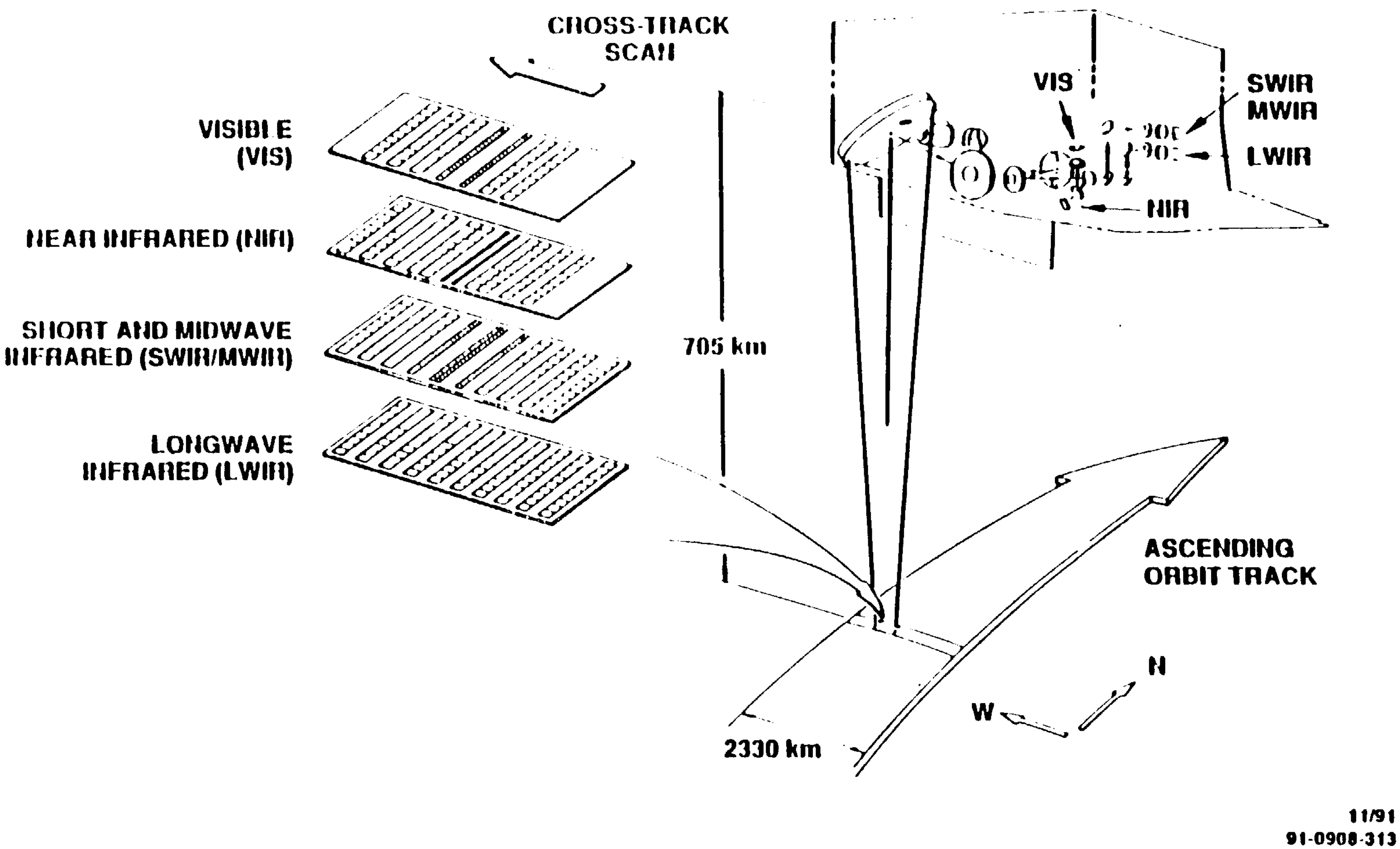
Type of Calibration	Source	Mechanism	Aperture	Spectral Bands	Usage Frequency (Max)	Other Comments
Zero Radiance	Space		Full	All	Once per scan line	
Radiometric	Sun	Solar illuminated diffuser	Full	VIS/NIR/SWIR Bands 1-7, 17, 18, 19	Once per orbit	Effective albedo 0.46 ± 0.03
Radiometric	Sun	Solar illuminated diffuser	Full	VIS/NIR/SWIR	Once per orbit	Effective albedo 0.046 ± 0.005
Radiometric & DC Restore	Blackbody	Blackbody	Full	MWIR/LWIR Restore (All)	Once per scan line	
Radiometric	Incandescent source	SRCA spectrally shaped collimator	Partial	VIS/NIR/SWIR	Available any time during orbit	
Spatial Registration	Incandescent source and IR source	SRCA	Partial	VIS/NIR/SWIR MWIR/LWIR	Available any time during orbit	
Spectral (MODIS-N)	Incandescent source	SRCA grating monochromator	Partial	VIS/NIR/SWIR	Available any time during orbit	Grating is rotated to produce λ scan
Spectral (monochromator)	Incandescent source with didymium glass	SRCA grating monochromator with photodiode	Full	0.40 μm ≤ λ ≤ 1.00 μm	Available any time during orbit	Grating is rotated to produce λ scan
Diffuser stability monitor	Sun	Spherical integrator with optical band pass filtered detector	Full	0.40 μm < λ ≤ 2.20 μm	Available once per orbit	Both high and low albedo levels

Technical Concerns about Instrument from Hughes/SBRC

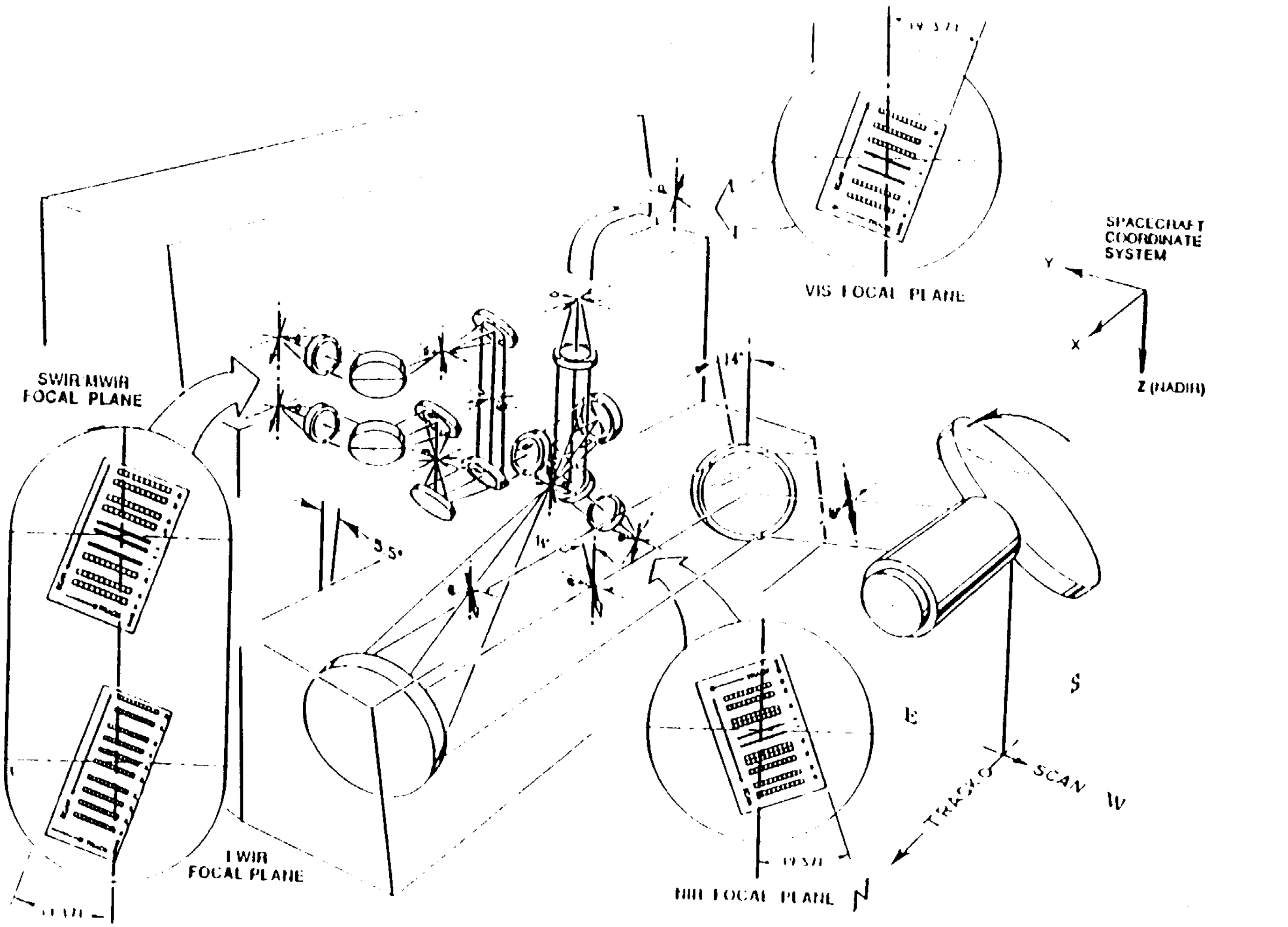
- **Maintaining performance against difficult requirements:**
  - Performance Margin: Bands 31-36 operating at 88K.
    - Pursuing improvements to the Radiative Cooler to reduce the operating temperature of the cooled detectors.
    - Investigating changes to improve the transmittance of the LWIR Objective Assembly.
    - Pursuing alternative PC detector processes (serpentine detectors, etc.).
  - Spectral Band Registration - Very complex and difficult series of design and integration issues.
    - Matched housings w/ fiducial features.
    - Proper tolerances on all assemblies.
    - Distortion uncertainties.
    - Tight EFL requirement ±0.2%.
    - Adjustment resolution and locking capability on objectives and FPA's.
    - Cold Stage shifts with cooldown. No ability for adjustment in vacuum.

JLE-17

Dichroic Beamsplitter Layout from Hughes/SBRC

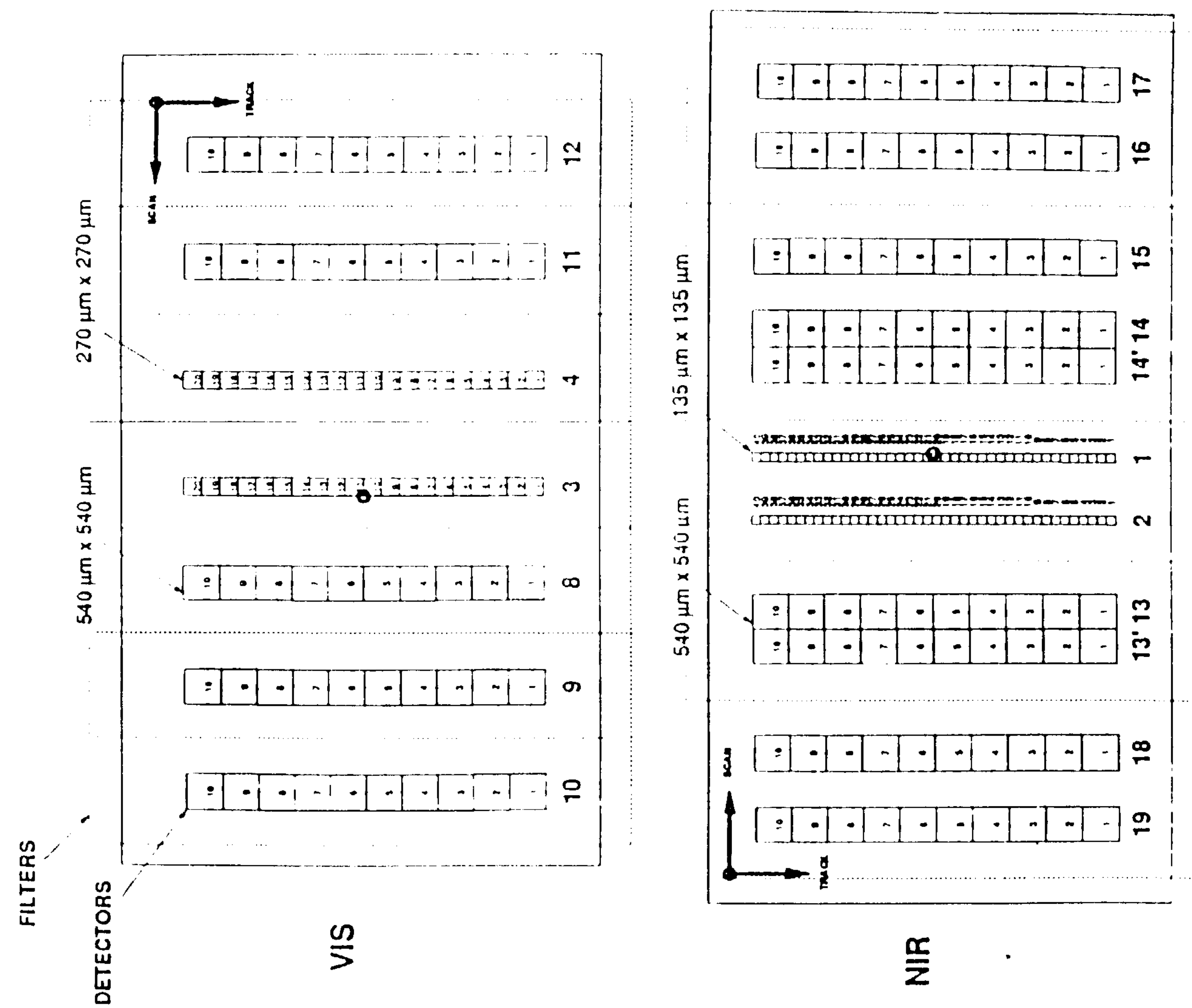


MODIS Focal Plane Layout from Hughes/SBRC

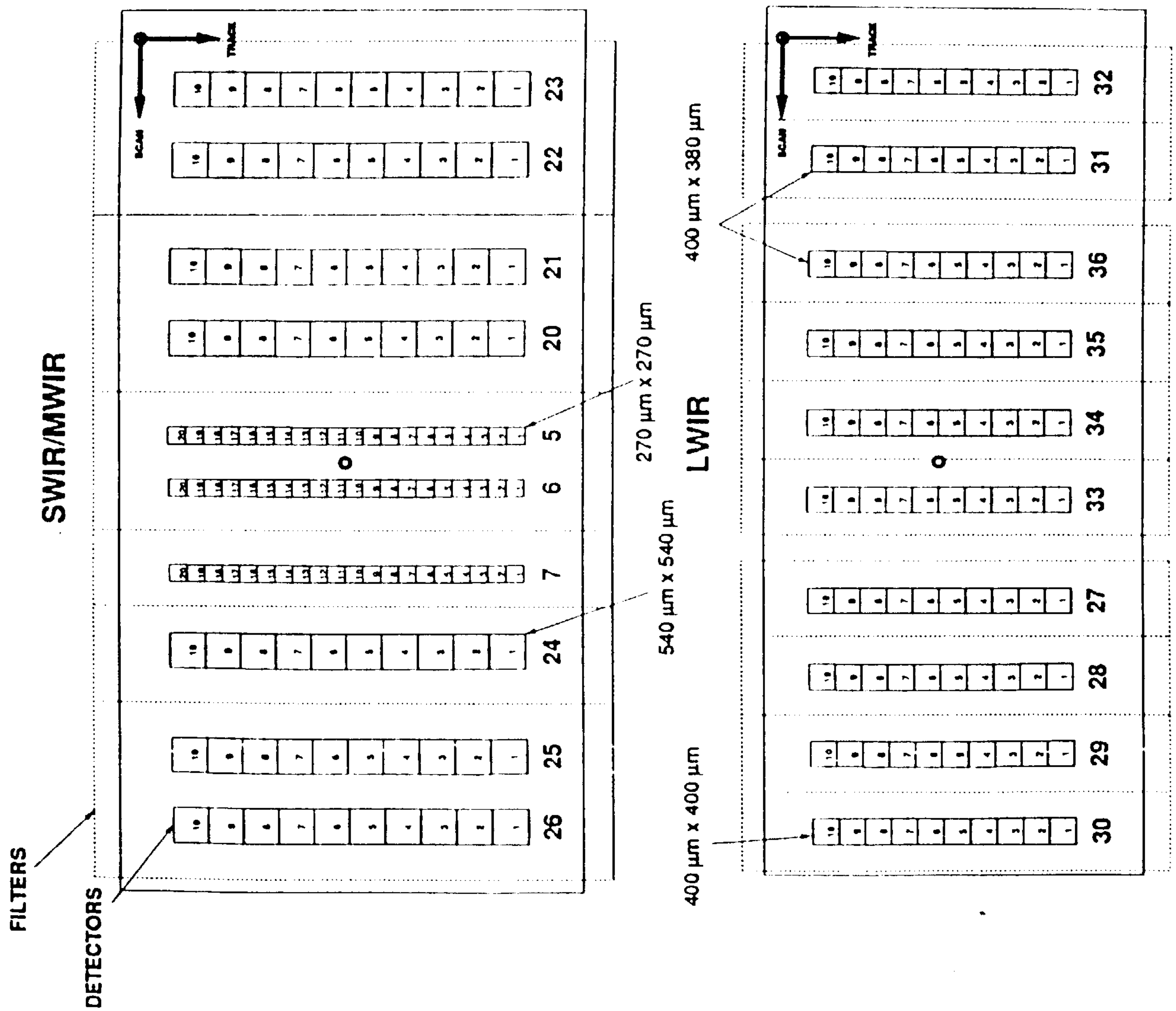


JLE-19

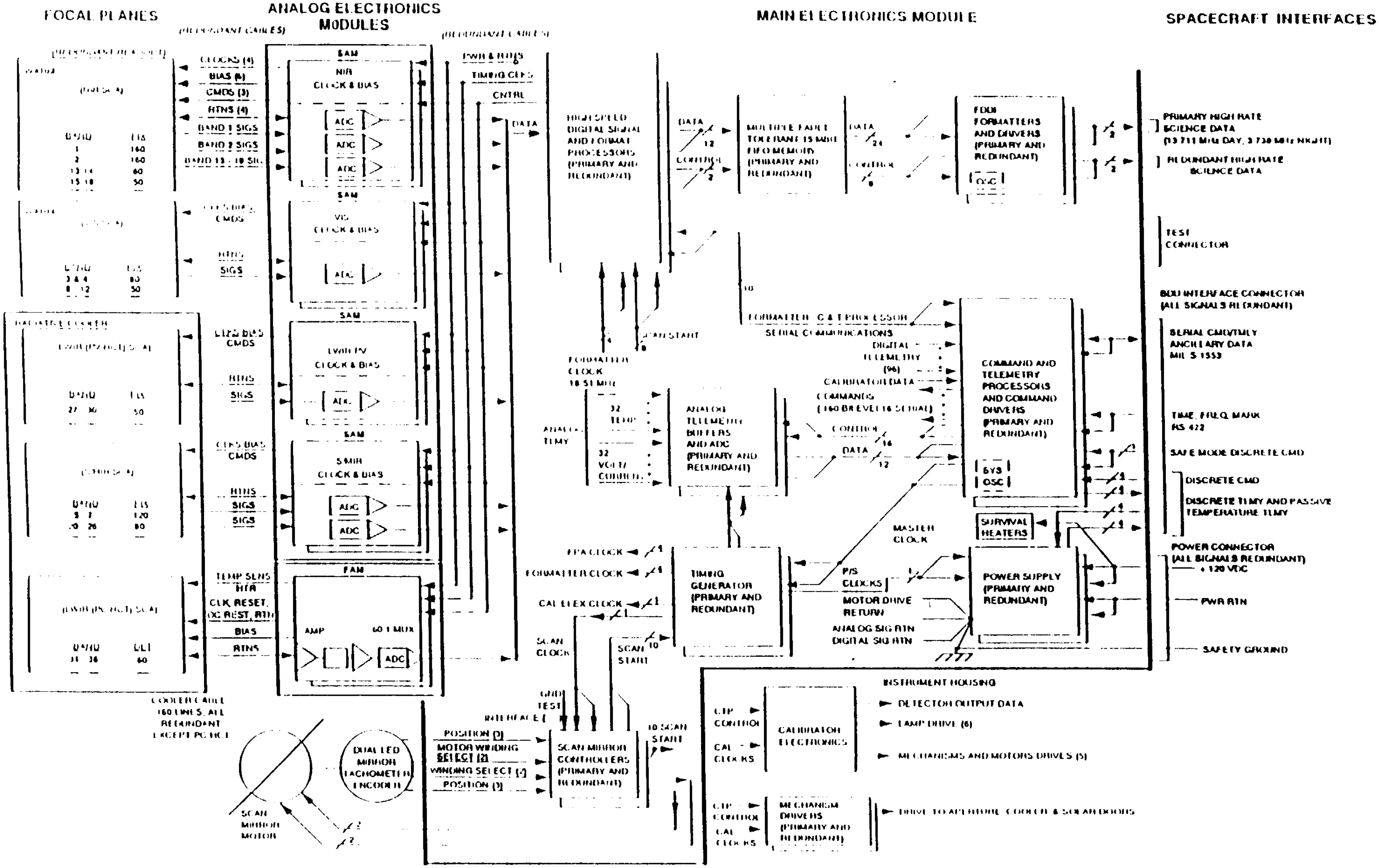
VIS/NIR Focal Plane Layout from Hughes/SBRC



SWIR/MWIR & LWIR Focal Plane Layout from Hughes/SBRC



Electronic Layout of MODIS from Hughes/SBRC



MCST Papers in Print

EOS Moderate Resolution Imaging Spectroradiometer: Phase C/D Status and Comments on Calibration and Georeferencing Approaches by Vincent Salomonson and John Barker, 15th Annual AAS Guidance and Control Conference, February 9-12, 1992, Boulder Colorado.

MODIS/MCST Calibration/Characterization Plan Version 1.0 (13 April 1992)

MODIS/MCST Calibration Handbook Version 1.0 (13 April 1992)

MCST Papers in Progress

Simulating MODIS Data from TM Imagery by John Barker, Brian Markham, and Jonathan Burelbach, to appear in the 1992 ASPRS/ACSM Convention Proceedings, August 1992, Washington, D.C.

Evolution of a Snow Cover Algorithm for the Moderate Resolution Imaging Spectrometer-NADIR (MODIS-N) by George Riggs, Dorothy Hall, John Barker, and Vincent Salomonson, to appear in the 1992 ASPRS/ACSM Convention Proceedings, August 1992, Washington, D.C.

Outline for
MODIS Calibration/ Characterization Plan

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Outline of MODIS Calibration Handbook

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- 7.3 References

MCST Responses to Questions

GE Platform Questionaire

EOS Cross-Calibration Questionaire

Pointing Requirements Memorandum

Simulated MODIS Imagery

Objectives / Approach

Introduction:

The method described below is an attempt to simulate the near nadir spatial resolution of the MODIS-N instrument using LANDSAT TM CCT-PT data.

Description:

The 28.5 m TM data are spatially filtered to produce MODIS-N resolution data. The spatial filtering is performed in the frequency domain for efficiency due to the large dimension of the filter required to go from 28.5 to 250+ meters. The 28.5 meter TM data are forward Fourier transformed, multiplied by the transfer function of an appropriate Gaussian blur filter and the resultant image is inverse Fourier transformed. This was done using PV-Wave on the Silicon Graphics 4D310-VGX IRIS PowerSeries workstation. The following table shows the TM and MODIS-N bands used. All TM bands have 28.5m resolution except band 6 which is a 120m resolution band.

TM Band #	Band Location (um)	Corresponding MODIS-N Band #	Band Location (um)	Spatial Resolution (m)
1	0.45-0.52	3	0.470 +/- 0.005	500
2	0.52-0.60	4	0.555 +/- 0.005	500
3	0.63-0.69	1	0.659 +/- 0.005	250
4	0.76-0.90	2	0.865 +/- 0.005	250
5	1.55-1.75	6	1.640 +/- 0.008	500
6	10.40-12.50	31	11.030 +/- 0.055	1000
7	2.08-2.35	7	2.130 +/- 0.010	500

Procedure:

1) Due to memory constraints on the SGI 4D310 and the fact that the PV-Wave FFT software requires the full input and output square arrays to be in memory the current system cannot handle FFTs on arrays larger than about 2500x2500, so the TM quad was subset to produce a 2500x2500 input array (img2), that does not contain any border fill pixels.

2) A TM to MODIS Gaussian blur filter was produced using the PV Wave routines:

```
d = DIST(m)/m
filter = exp(-2*(pi)^2*(n)^2*(d/28.5)^2)
```

where

m = the size in pixels of the image,
28.5 = the resolution of the input image in meters,
n is a filtering factor to match the MODIS MTF at the Nyquist frequency.
n= 123.5 for 250m, 247.0 for 500m, and 494.0 for 1000m,

and

DIST is a function that produces a mxm floating point array, in which:

```
result(i,j) =  sqrt(F(i)^2 + F(j)^2)
```

where,

```
F(x) = x if 0 <= x <= m/2
```

or

```
F(x) = m - x if x > m/2
```

3) A forward Fast Fourier Transform (FFT) was then applied to the nxn image array to convert the image from the TM spatial domain to the TM frequency domain. This created an array in complex format, fftimg.

```
fftimg = FFT(img2,-1)
```

4) The MODIS frequency domain image, ft, is created by multiplying

the TM to MODIS filter array by the TM frequency domain image.

ft = fftimg * filter

5) A inverse Fast Fourier Transform was applied to the product image (ft) to return the image to the spatial domain.

imgout = FFT(ft,1)

6) Since the imaginary portion of the transformed image equaled zero, it was truncated to obtain a real image.

7) This floating point image was then converted from TM dynamic range to a 12bit MODIS dynamic range. Spectral radiance was used to convert TM imagery into MODIS imagery by converting TM digital values (Qcal) into spectral radiance using equations from Markham and Barker, 1986. The data were multiplied by the ratio of MODIS Lcloud to TM Lsolar in order to account for differences in MODIS and TM bandwiths. Then the data were scaled to 12 bit values in the range 32-3686.

8) This resulting image of 250m MODIS-N pixels was still a 2500x2500 oversampled array. The image was then reduced using a nearest neighbor resampling to 285x285 pixels for the 250m images, and finally saved as 16bit integers in an unformatted dataset.

Simulated MODIS Imagery

Procedures for Accessing

from a UNIX machine:

% ftp highwire.gsfc.nasa.gov
Connected to highwire.nasa.gov
220-

Welcome to the MODIS Characterization Support Team (MCST)
at NASA/Goddard Space Flight Center, Greenbelt, MD

220 highwire ftp server ready
Userr: *anonymous*
331 Guest login ok, send ident as password.
Password: *user@host*
230 Guest login ok, access restrictions apply.
Remote system type is UNIX
Using binary mode to transfer files.

from a Macintosh:
I suggest using a utility like Fetch or Xfer-it or the BYU version of NCSA Telnet which allows anonymous ftp

from a PC:
?

Simulated MODIS Imagery

Current Contents

```
DIRECTORY OF highwire:anonymous ftp files

% ll -R /usr/people/ftp/pub/modis
total 597
-rw-r--r--   1 burel    user      286400 Nov 29 16:15 MAS.716x400.img
-rw-r--r--   1 burel    user        3471 Feb  1 18:11 PROCEDURE
-rw-r--r--   1 burel    user        3171 Feb  1 18:42 PROCEDURE.cctpt
-rw-r--r--   1 burel    user        3910 Apr  9 11:49 PROCEDURE.cctpt.rev01
drwxr-xr-x   2 burel    user         512 Apr  9 11:55 cal_site_select/
drwxr-xr-x   2 burel    user        1024 Apr  9 14:15 chernobyl/
drwxr-xr-x   2 burel    user         512 Apr  9 11:47 cloud_sim/
drwxr-xr-x   2 burel    user         512 Apr  9 11:44 kennedy/
-rw-r--r--   1 burel    user        5040 Feb  1 18:11 modis_sim.pro

/usr/people/ftp/pub/modis/cal_site_select:
total 25874
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```

```
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-rw-r--r--   1 burel    user         8192 Apr  9 13:48 29apr.ch2.500m.64.i
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-rw-r--r--   1 burel    user         8192 Apr  9 13:48 29apr.ch5.500m.64.i
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-rw-r--r--   1 burel    user         8192 Apr  9 13:48 29apr.ch7.500m.64.i
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-rw-r--r--   1 burel    user        32768 Apr  9 13:21 6jun.ch3.250m.128.i
-rw-r--r--   1 burel    user        32768 Feb 25 11:12 6jun.ch4.250m.128.i

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-rw-r--r--   1 burel    user       121032 Feb  2 09:22 clouds.b4.250m.246.i

/usr/people/ftp/pub/modis/kennedy:
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-rw-r--r--   1 burel    user       162450 Feb 25 09:48 21aug82.modis2.285.int
-rw-r--r--   1 burel    user          803 Feb  2 09:22 kennedy.hdr
-rw-r--r--   1 burel    user       162450 Feb  1 18:41 kennedy.modis1.285.int
-rw-r--r--   1 burel    user       162450 Feb  1 18:41 kennedy.modis2.285.int
%
```

Completed Action Items for MCST from October 1991 Meetings

1. Provide general distribution of the Response to GE Platform Questionnaire before another version goes out to GE.

2. Release Version 1 of the MODIS/MCST Calibration/Characterization Plan April 1992 at the next MODIS Science Team meeting.

3. Release Version 1 of the MODIS Calibration Handbook to the 5th EOS Reflected Solar Panel A of the Calibration/Validation Panel meeting in Boulder, Colorado, April 1992.

4. Devise a materials test program for the Russian opal material (a possible solar diffuser material). Material deemed unuseable due to its hydroscopic nature.

5. Provide spectral passband information on MODIS-N/T and SBRC documents from Jim Young (preliminary Calibration Plan) for Hugh Kieffer.

Completed Action Items for MCST from October 1991 Meetings (continued)

6. Get from Hugh Kieffer:
   a) platform perturbation documents (for lunar viewing scenarios)
   b) PDS document on instrument descriptions

7. Distribute copies of MODIS-N/T Calibration presentations to the Cal/ Val group.

8. Carol Bruegge requests updates on MODIS-N/T cross-calibration questionnaires.

9 With Stewart Biggar - design a Kaleidagraph spreadsheet to demonstrate sensitivity of sphere thru-put to small changes in spere efficiency (for MODIS-T calibration discussion).

Action Items Dropped by MCST from October 1991 Meetings

1. Prepare Documents Expected from MODIS-T by expected delivery dates for the final plans, which are contractually due at PDR about October 23, 1992, and allowing 60 days prior to PDR for government review. (John Barker)

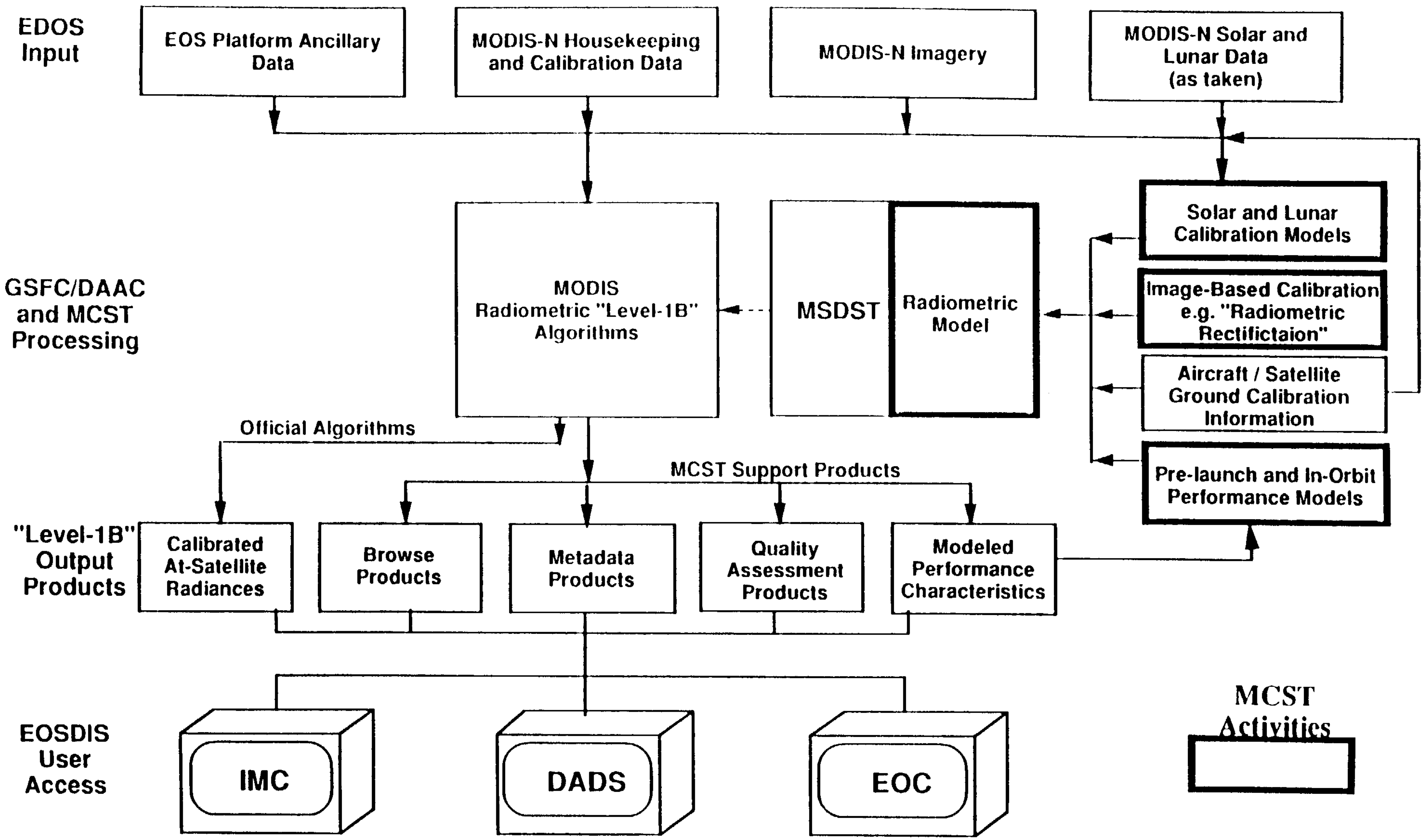
2. Pass the MODIS end-to-end model development by the current manager for Code 700 (Bill Stabnow), in order to determine if this is still the general consensus regarding the end-to-end modelling efforts. (John Barker)

Key MCST Algorithm Milestones

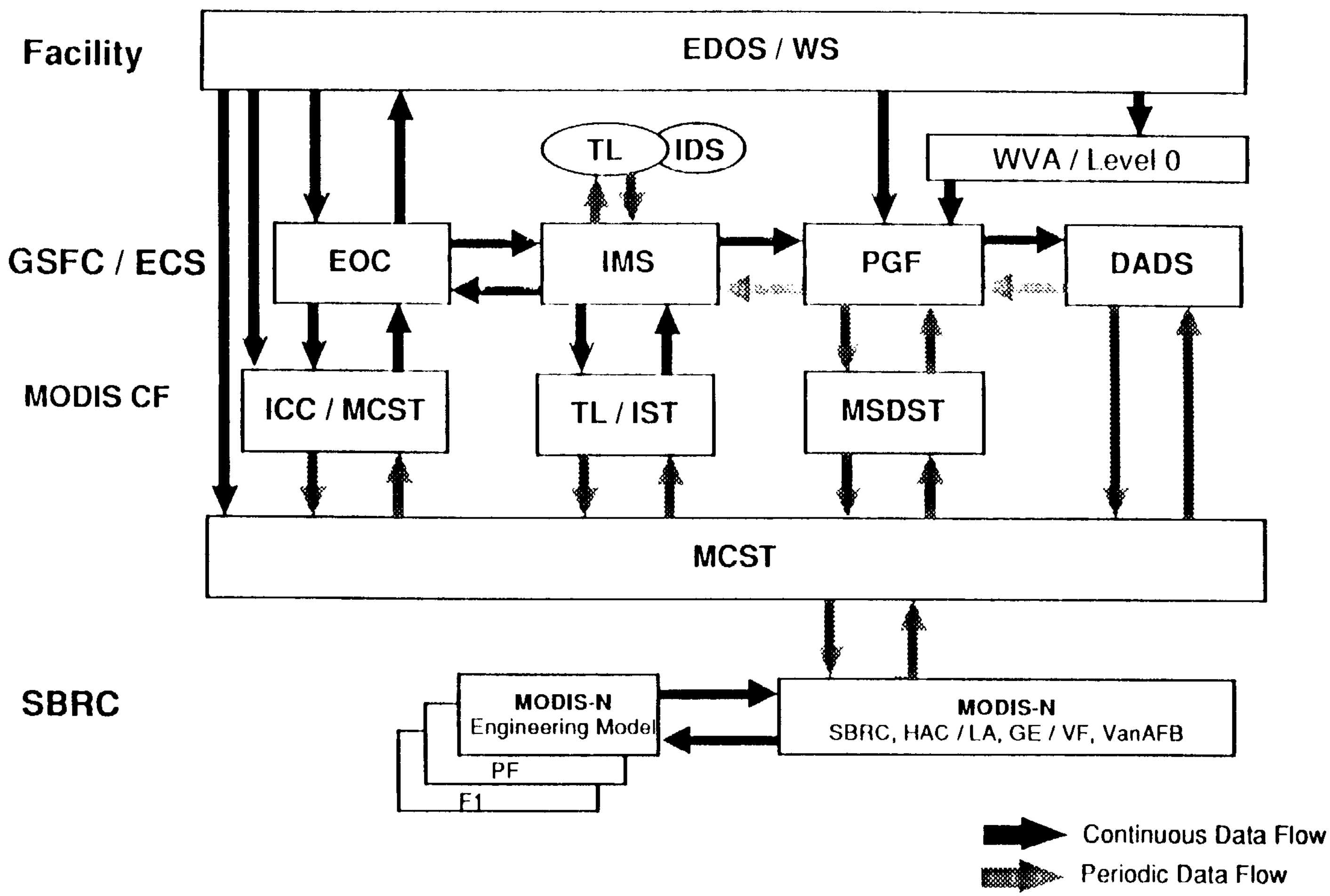
MCST Algorithm Deliveries

October 1992	Peer Review of Algorithms
January 1993	Version 0 Algorithms to MSDST
January 1994	Version 0 Algorithms for MSDST Integration
January 1994	**ECS PDR**
June 1995	Version 0 Algorithms for MSDST Test and Delivery
June 1995	Version 1 Algorithms to MSDST
January 1996	Version 1 Algorithms for MSDST Integration
June 1996	Version 1 Algorithms for MSDST Test and Delivery
June 1996	**ECS Version 1 Delivery**
October 1996	Version 2 Algorithms to MSDST
April 1997	Version 2 Algorithms for MSDST Integration
June 1997	Version 2 Algorithms for MSDST Test and Delivery
June 1997	End-to-End Software Test
June 1997	**ECS Version 2 Delivery**
January 1998	Post-Launch Algorithm Development
June 1998	**Launch of EOS-AM Platform**

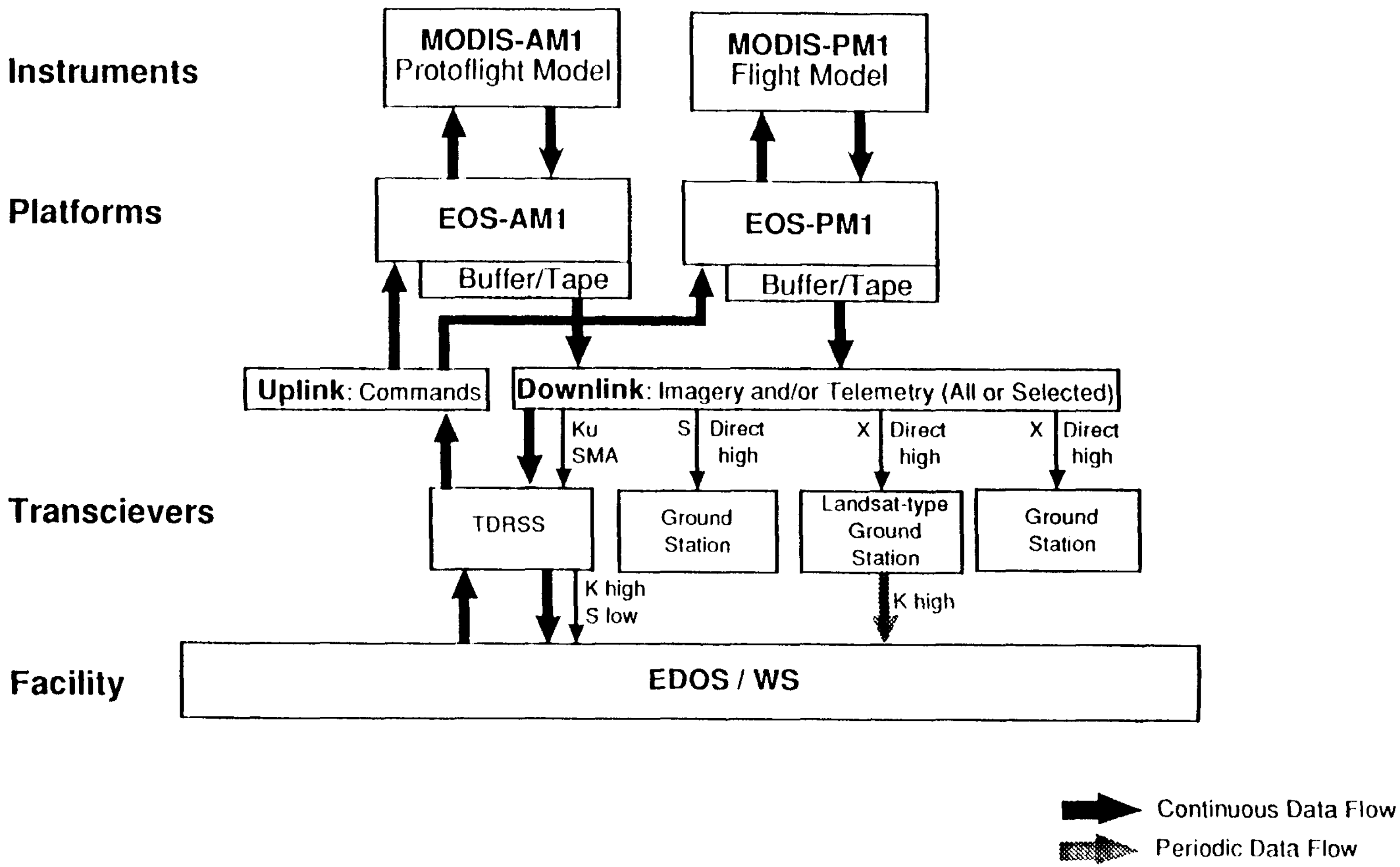
Illustrative Flow Diagram
MODIS "Level-1B" Radiometric Processing



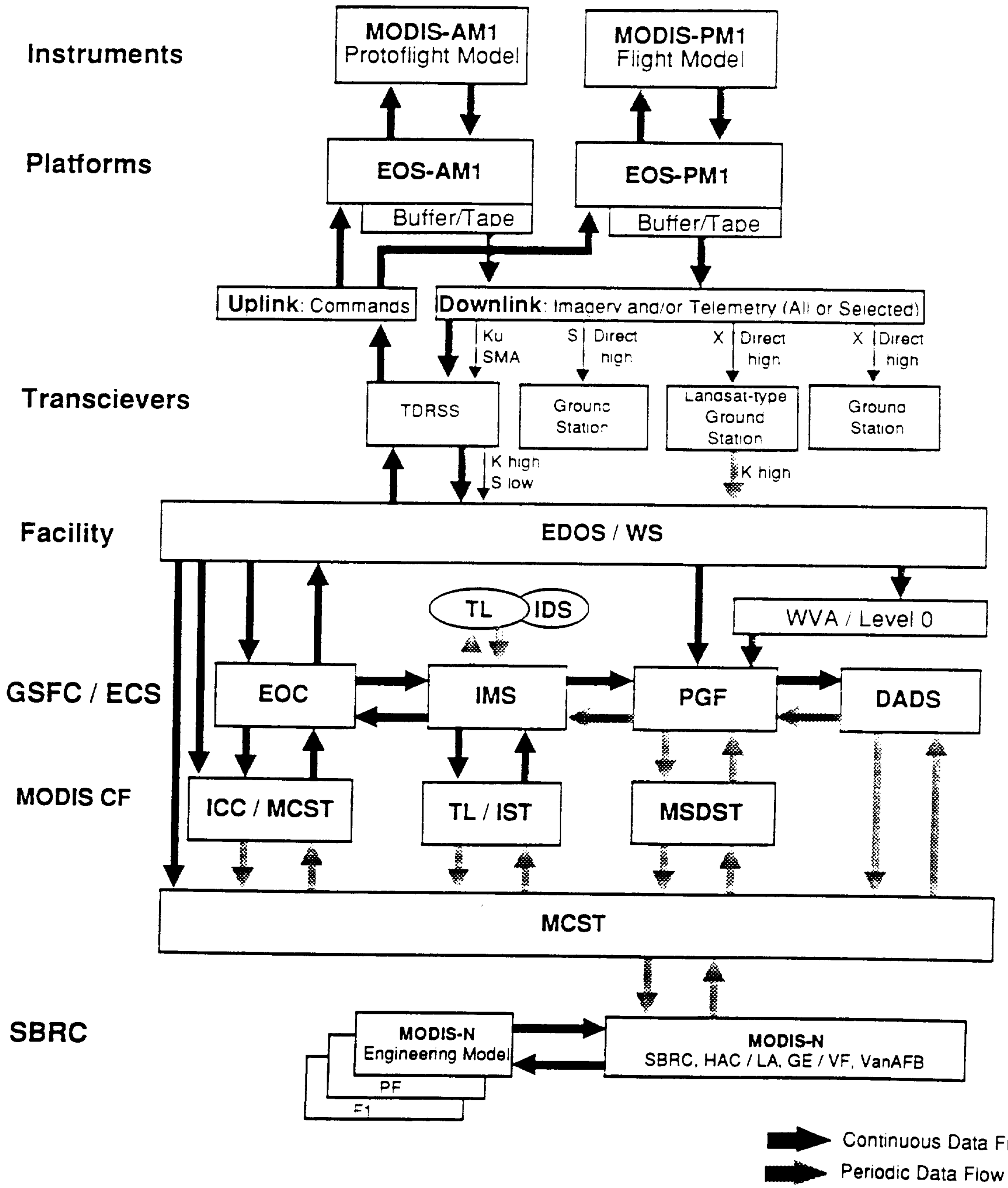
EDOS to MCST Communication Links for MODIS



Instrument to EDOS Communication Links for MODIS



Communication Links for MODIS Scenerios



MODIS/MCST Feedback Sheet

on MODIS Calibration Handbook and MODIS Characterization/Calibration Plan

Questions ? **Concerns ?**

Suggestions ? **Actions for Next Meeting?**

Name: **Date:**

For E-mail correspondence address GSFCmail:JBarker or BGrant.

For updates on the latest events and available documents, CHECK MCST.BB bulletin board on GSFCmail.

MODIS/MCST Calibration/Characterization Plan

Version 1.0

edited by MCST
(MODIS Characterization Support Team)

John Barker (925)/MCST Head

Peter Abel (925)/Aircraft Underflights/Thermal
Bill Barnes (970)/MODIS Instrument Scientist/SeaWiFS
Ken Brown (925)/MODIS Airborne Simulator (MAS)
Wayne Esaias (971)MODIS Ocean Discipline Head/SeaWiFS
Bruce Guenther (925)/EOS AM Project Scientist/EOS Calibration Scientist
Forrest Hall (923)/Image-Based Radiometric Rectification Calibration
Joann Harnden (925)/Artificial Intelligence Information
Yoram Kaufman (913)/Atmospheric Corrections
Michael D. King (913)/Deputy MODIS Team Leader/Atmospheric Discipline Head
Brian Markham (923)/Instrument Characterization/Field Calibration
Steve Ungar (923)/MODIS Image Simulation
NASA Goddard Space Flight Center
Greenbelt, MD 20771

Vern Vanderbilt/MODIS Team Member/Polarization
Ames Research Center
Moffett Field, CA 94035

Phil Ardanuy
Harold Geller
Barbara Grant
Doug Hoyt
RDC (Research and Data Systems Corporation)
Greenbelt, MD 20770

Otis Brown
Bob Evans
Howard Gordon
University of Miami
Miami, FL 33149

Hugh Kieffer/Lunar Calibration/HIRIS Cross-Calibration
U. S. Geological Survey
Flagstaff, AZ

Alfredo Huete
Phil Slater
University of Arizona
Tucson, AZ 85721

TABLE OF CONTENTS

1 Introduction

1.1 MODIS/MCST Calibration/Characterization Plan Objectives

MCST will evaluate, integrate, and update calibration plans and related information for pre-launch and in-orbit phases of the MODIS mission. Vendor calibration information will be included by reference in the MCST documentation. These plans will be reviewed by the MODIS calibration review committee, and will be included in the MODIS calibration plans to be delivered to EOSDIS. Updated versions of MCST's Calibration/Characterization Plan will, in general, be available at the times of the MODIS Science Team meetings.

MCST will be the primary source of information on the MODIS instrument for the many science data users who will need instrument characterization and calibration information. This document is intended to provide a thorough discussion of the plans for pre-launch and in-orbit radiometric calibration, spectral characterization, and geometric characterization of the MODIS instrument. References to other published literature are included when possible. A list of helpful acronyms follows the technical sections. Administrative information, including schedule information and related organizations and responsibilities, may be obtained in the MODIS/MCST Calibration Management Plan.

1.2 Document Overview

Chapter 1 discusses the MODIS/MCST Calibration/Characterization Plan Objectives and provides an overview of all chapters.

Chapter 2 describes the pre-launch calibration and characterization methodologies. The MODIS-N Preliminary Calibration Management Plan provided by Hughes Santa Barbara Research Center (SBRC) and dated September 17, 1991, is the primary source of information for this chapter.

Chapter 3 contains information on cross-calibration plans. MODIS instruments will be compared to one another and to other instruments with comparable fields-of-view and spectral coverage. These comparisons will enhance the calibration data base and provide a more thorough understanding of instrument performance. Other sensors whose output will be compared to the MODIS instruments include AIRS, ASTER, EOSP, MISR and SeaWiFS on the EOS Platforms; and the Landsat Thematic Mapper.

Chapter 4 discusses the transfer of calibration and characterization from pre-launch to in-orbit phases using the on-board calibrators. Historically, this transition has been among the least well-understood aspects of the calibration process. The MODIS instrument utilizes a Spectroradiometric Calibration Assembly (SRCA) to transfer calibrations and characterizations between pre-launch and in-orbit states. Once in orbit, the solar diffuser is intended to provide the primary relative and absolute radiometric calibration.

Chapter 5 describes the in-orbit radiometric calibration and characterization methodologies. Discussed here are the instrument-based methods using the calibrators noted in Chapter 4; target-based methods, including the use of ground targets and ocean phenomena to achieve a calibration; and image-related methods including radiometric rectification and class-specific scene equalization techniques.

Chapter 6 contains information on in-orbit geometric characterization.

Chapter 7 describes in-orbit spectral chracterization.

Chapter 8 discusses the official MODIS calibration algorithm.

Chapter 9 provides a strategy for the MODIS calibration algorithm validation and upgrade. In order to provide a reliable model for MODIS behavior throughout the 15 year life of the EOS mission, the calibration algorithms and their associated error functions will be routinely examined to determine when, and if, changes are desiable in the official calibration algorithms.

Chapter 10 includes a list of acronyms, definitions, and references appropriate to the topics considered.

1.3 Applicable Documents

Documents which contain pertinent information relative to this MODIS/MCST Calibration Plan include, but are not limited to the following, some of which are still in planning stages:

1) Earth Observing System (EOS) Project Calibration Plan, 29 July 1989, GSFC 420-0 3-01
2) Earth Observing System (EOS) Project Configuration Management Plan, GSFC 420-02-02
3) 1990 Reference Handbook, EOS
4) MODIS Calibration Management Plan from SBRC
5) MODIS Verification Plan from SBRC
6) MODIS Calibration Data Books for each instrument from SBRC
7) MCST Interface Control Document with SBRC
8) MODIS Calibration Handbook from MCST

1.4 Overview of Instrument Design

MODIS–N is an imaging scanning spectro–radiometer. It views the Earth from an orbit of 705 km. and continually scans across its nearly polar orbit through the nadir to $\pm 55^{\circ}$. The instrument measures the at–satellite radiance in 36 bands from 0.408 µm to 14.385 µm. The footprint of the detectors varies from 0.25 km. (2 bands) to 0.5 km. (5 bands) to 1 km. (29 bands).

The spectro–radiometer itself is a 2–mirror off–axis Gregorian design. Radiation from the Earth passes through dichroic beamsplitters which reflect/transmit the light onto four focal planes. Discrete interference filters over the detectors provide the higher spectral resolution.

1.5 Single Official Calibration Algorithm

It is the responsibility of the MCST, together with review by the MODIS science team, to select a single calibration algorithm which will be used as the official calibration algorithm for producing Level-1B products (radiance images). This algorithm may be selected from various methods, although early versions will depend heavily on the internal instrument methodolgy provided by the vendor. This algorithm will change with time as understanding of the instrument, data characterization, and calibration methods improve.

1.6 Multiple Parallel Approaches

In order to have confidence that the required precision and accuracy have been met, several independent methods will be used in parallel. In addition to the pre-launch calibrations and characterizations, there will be in-orbit (on-board) calibrations routinely using the SRCA and a solar diffuser. Occassionally lunar images, as well as in-orbit ground truth calibrations using reflectance and radiance based methods (both on-ground and aircraft) will be used. The primary purpose of these multiple pathways is to obtain, through independent means, a "calibration table" which can be used to convert instrument quantized DN's (digital numbers) to radiance on a routine basis (the MODIS/MCST calibration algorithm) and to be able to quantitatively assess both its precision and its accuracry.

1.7 Radiometric Math Model Development

The contractor (Hughes/SBRC) will develop and transfer to MCST a mathematical model of critical components of each MODIS instrument to allow performance prediction, uncertainty modeling, environmental sensitivity studies, and degradation and failure analyses. The characterization of the MODIS subcomponents will be of sufficient accuracy to allow meaningful analyses to be performed with this model, thus this guideline defines the subcomponent calibration specifications. Initially, reports will be produced by SBRC to document analyses and the impact of the code on instrument characterization. The radiometric math models may be a coherent set of indivdual models or software packages. After in-orbit checkout, MCST will take over the routine monitoring of the MODIS performance, which will include using these math models, especially to understand changes in performance both within and among MODIS instruments.

1.8 Comprehensive Documentation Trail

The contractor (Hughes/SBRC) will provide system-level calibrations (radiometric, geometric, and spectral) which are traceable through documentations of data, procedures, and data analysis techniques, and the contractor will radiometrically calibrate to a set of physical units as expressed in the Systeme International (SI) set of units. In addition, the contractor will adhere to a common set of calibration terminologies, as sanctioned by the EOS Calibration Advisory Panel. These will be supplemented, as needed, for clarification or instrument-specific procedures.

2 Pre-Launch Calibration/Characterization Methodologies

2.1 Objectives/Rationale

Prior to launch, the MODIS instrument shall undergo radiometric, geometric, and spectral calibrations. These values will be compared with on-orbit results to obtain a measure of performance of the MODIS sensor over time. In addition, the instrument shall be well-characterized before launch for properties including, but not limited to, linearity, signal-to-noise ratio, coherent noise, scan modulation, and band-to-band stability. The Modulation Transfer Function (MTF) will be measured along-track and across-track. Spectral band shapes and out-of-band responses will be measured. The transient response, including rise time and overshoot or undershoot, will be tested. Polarization sensitivity will be measured. The spectral band registration along-track and across-track will be measured. Most of these tests will be performed under both ambient and vacuum conditions. A total of 29 different types of characterization tests are currently planned.

As part of EOS calibration planning, MODIS and all EOSAM and EOSPM observatory instruments will be cross-calibrated using a common known source and/or a traveling standard radiometer. These activities are in the early planning stages.

The primary source of information for this section comes from the Preliminary Calibration Management Plan for the MODIS instrument provided by Hughes/SBRC, the prime MODIS contractor.

2.2 Radiometric Calibration

MODIS Preliminary Calibration Management Plan, Hughes Santa Barbara Research Center, September, 1991

Pre-launch radiometric calibration of the MODIS Instrument and the On-Board Calibrators will be performed. For the solar reflective bands of MODIS below 3000 nm, an absolute one sigma accuracy of 5% is required, with a 2% reflectance calibration requirement relative to the Sun, once in orbit. For the thermal emissive bands above 3000 nm , this requirement is 1%, one sigma.

2.2.1 Absolute Calibration

Source-based calibration techniques, with sources traceable to NIST primary standards, will be used to perform the pre-launch calibration of MODIS. A spherical integrating source (SIS) will be used for the VIS, NIR, and SWIR bands, and a full-aperture blackbody will be used for the MWIR and LWIR bands. These measurements express digitized output as a function of input radiance. The repeatability in the measurements constitutes their precision, while the deviation of the results from a true value is the calibration accuracy.

2.2.2 Relative Calibration

The pre-launch absolute calibration of MODIS is the first data point in the MODIS calibration history. Subsequent calibrations will enable assessment of sensor performance as a function of time, allowing a relative calibration history to be documented. Relative comparisons are also performed by ratioing the output of one sensor band to another, or comparing the outputs of different detectors within a band.

2.3 Geometric Characterization

The pointing accuracy of MODIS will be sufficient to locate any pixel on the Earth's surface to within $\pm$ 0.5 times the length or width of the pixel. Registration of pixels to 0.1 pixel or better will be made, but a pointing knowledge of 30 arc seconds and alignment changes of 60 arc seconds will reduce the overall pointing knowledge to 0.5 pixels.

2.4 Spectral Characterization

Pre-launch spectral characterization of the MODIS instrument will based on relative spectral response measurements made with a grating monochromator coupled to the MODIS calibrator. Accuracy of this test device will be traceable to NIST silicon photodiode reference detectors for the VIS and NIR, and to Naval Ocean Systems Center (NOSC) for reference pyroelectric or thermocouple detectors.

3 Instrument Cross-Calibration

3.1 Pre-Launch Cross-Calibration

3.1.1 Cross-Calibration Among MODIS Instruments

The radiometric calibrations of different MODIS instruments will be compared. Cross-calibrations will occur between MODIS instruments on morning and afternoon platforms; and between MODIS instruments on different EOS platforms. Plans for these activities are currently under consideration. A standard radiometer may be used to transfer calibrations among integrating sphere sources.

3.1.2 Cross-Calibration Between MODIS and Other Instruments

MODIS shall be inter-compared after integration with all other optical instruments operating in the same spectral regions (e.g. ASTER, MISR, AIRS, SeaWiFS, and also with HIRIS for the C platform) using a single source. A cross-calibration between MODIS sensors and the Landsat Thematic Mapper will also be performed.

3.2 In-Orbit Cross-Calibration

3.2.1 Cross-Sensor/Within Platform

Phil Slater et al., University of Arizona; Doug Hoyt, RDC

Introduction

Several passive remote sensors using visible radiation are planned for the EOS–A platform. Each instrument will be independently calibrated. After corrections for differences in footprint size, spectral resolution, and pointspread functions are made, the radiances measured by the separate should agree to within their stated accuracies. If they do agree, it tells us that any biases, whether the bias is zero or not, are the same. If they do not agree, an opportunity exists to investigate the reasons for the disagreements. The more instruments that agree, the more confidence we can have that correct measurements are being made. Potential comparison instrument include MODIS (am) to MODIS (pm), AIRS, ASTER, EOSP, and MISR. Several of these potential configurations are discussed below.

AIRS (Atmospheric Infrared Sounder) has a 56 km. nadir footprint with five channels in the visible region from 0.4 to 1.1 microns. Inter–comparison to MODIS will consist of combining many MODIS pixels, weighted by the AIRS pointspread function, to form an image like a single AIRS pixel. Because MODIS also appears to have better spectral resolution in the visible, several appropriately weighted MODIS bands will be required to match the AIRS resolution. Comparison of many hundreds of AIRS pixels with MODIS simulated AIRS pixels should give a reasonable indication of the amount of agreement.

Both AIRS and MODIS also make thermal infrared measurements which allow comparisons to be made. At each thermal wavelength, contributions are coming from all layers of the atmosphere and the surface usually expressed through atmospheric weighting functions. If the two instruments do not have similar bandpasses, the comparison is made difficult since the same layers of the atmosphere are not sampled equally. It is likely that radiances in the thermal bands for these two instruments will not be compared directly, but a derived geophysical parameter such as sea surface temperature will be used for the inter–comparison. The thermal cross–calibration technique for this pair of instruments and for other pairs of instruments is a topic requiring further study.

ASTER (Advanced Spaceborne Thermal Emission and Reflection) has a 30 meter nadir footprint and one near infrared band from 850 to 920 nm. Since MODIS–N has bands centered at 865 and 905 nm an inter–comparison is possible using appropriate weights or filter factors for the two instruments. Spatially the MODIS–N pixel can be simulated by summing up the ASTER pixels using the MODIS–N pointspread function as the weighting function. Inter–comparisons in the thermal infrared are also possible for these two instruments.

EOSP (Earth Observing Scanning Polarimeter) has a 10 km. nadir footprint and several spectral bands in the visible region. MODIS–N radiances can be spatially re–mapped, using the EOSP pointspread function, and spectrally re–mapped, using the EOSP filter transmission functions, to match the EOSP radiance observations.

MISR (Multi–angle Imaging Spectro–radiometer) has four viewing angles which can be duplicated by MODIS–N. Four other MISR viewing angles cannot be matched by MODIS–N. MISR has spectral bands centered at 440 and 860 nm which are closely matched by MODIS–N bands at 443 and 865 nm. The wavelength resolution for MISR is not available, but probably is less than MODIS–N. By spectrally re–mapping MODIS–N and spatially re–mapping MISR, a matching image for the two instruments appears possible which will allow them to be inter–compared.

Approach

One method for the cross-calibration of different instruments on the same platform is identical to that used by the University of Arizona for the calibration of AVHRR with respect to TM. It should be emphasized that cross-calibration of instruments on the same platform eliminates uncertainties associated with different illumination and viewing geometries.

The University of Arizona group plans to make in-orbit calibrations of high spatial resolution EOS sensors such as ASTER (and HIRIS for the C platform) using a reflectance-based method which references a well characterized ground site such as White Sands [1]. MODIS in-orbit calibration with reference to a ground site shall be done with a method similar to its AVHRR work [2].

Results

The University of Arizona group has found that the responsiveness of channels 1 and 2 of the AVHRRs on NOAA-9 and -10 has degraded significantly since launch [2]. The group has refined its reflectance-based method and applied the refinements to its TM calibrations [3]. The group has also developed a refinement to its reflectance-based method which uses measurements of the diffuse and total irradiance at the surface [4].

The University of Arizona group is currently and analyzing channels 1 and 2 of the AVHRR on NOAA-11. Preliminary investigations show degradation of approximately 5 and 15 percent in channels 1 and 2.

The University of Arizona group plans to continue with this type of work with future AVHRR and follow-on sensors and a MODIS simulator if it becomes available. The group plans to refine its methods to include the use of a field SWIR spectrometer, a solar radiometer designed to measure total column water vapor, and an imaging solar radiometer which will be used to study the solar aureole. The aureole is a sensitive indicator of aerosol scattering and the group hopes to improve its knowledge of the scattering phase function with this future instrument.

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3.2.2 Cross-Platform/Among Sensors

The University of Arizona group has investigated the calibration of a low spatial resolution imaging sensor by reference to a higher resolution "calibrated" sensor [1,2]. This work has been funded under a NASA grant and is ongoing. The AVHRR sensors on the NOAA 9, 10, and 11 satellites have been calibrated with reference to the Thematic Mapper (TM) and Systeme Probatoire d'Observation de la Terre (SPOT) HRV cameras. The high resolution sensor is calibrated with reference to a ground site such as White Sands, New Mexico. This calibration is normally done using a ground reflectance-based method. Pixels from a high resolution calibrated image (taken nearly coincident with the low resolution image) are spatially registered and then are aggregated to the spatial resolution of the AVHRR image. Corrections are made for sensor spectral response differences and for the ground target bidirectional reflectance factor (BRF) if the sensor acquisition geometries are significantly different. The ground reflectance is determined from the calibrated high resolution image [3]. Spatially uniform areas on a scale of multiple low resolution pixels are used in a reflectance-based method to determine the calibration of the AVHRR sensor. The atmospheric correction is normally done using spectral optical properties measured from the ground at the target site during the high resolution image acquisition.

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3.2.3 Target related/aircraft

Peter Abel, Code 920, GSFC, Greenbelt, MD 20770

Introduction

Satellite radiometers observing the Earth in the visible and near infrared (visnir) spectrum (~400 to 1100 nm) have usually suffered significant losses in gain while in orbit. For example, Advanced Very High Resolution Radiometer (AVHRR) visnir channels have shown gain loss rates ranging from 7% per year (NOAA-9) [1] to nearly zero (NOAA-6), and CZCS results for the four years after launch indicate that degradation is more rapid at shorter wavelengths (average degradation rate of 7% per annum for Channel 1 at 443 nm, falling to less than 1% per annum for Channels 3 and 5, at 550 and 670 nm respectively [2]). A primary objective of aircraft studies is therefore to measure the absolute gain of the MODIS visnir channels and their rate of change in orbit. Based on results from other satellite sensors, it would be necessary to collect such measurements at least twice a year (more frequently immediately after launch) to establish the gain to the accuracy required for useful application in global change science.

MODIS will have an onboard radiance calibration system for the visnir channels, but the system represents technology that is unproven in space. A second objective is therefore to provide independent calibration data to validate the performance of the onboard system.

Either MODIS instrument's scan mirror, if contaminated in space, will cause the channel gains to become dependent on scan angle. No measurements of this dependence will be available from the onboard calibration systems, so a third objective is to measure gain as a function of scan angle.

Approach

Figure 3.3.1 illustrates the method, which uses a sunlit, optically stable, highly reflective and cloud-free ground target as a transfer standard between a well-calibrated spectroradiometer on the aircraft and the radiometer on the satellite. The method depends on accurate prediction of the satellite-target viewing geometry, which is necessary to enable the aircraft spectroradiometer to be coaligned with the satellite view vector during satellite overpass. Small corrections must be applied to account for the effects of the atmospheric path between the aircraft and the satellite, and to account for the difference between the footprints of the two instruments on the target. These corrections, and knowledge of the spectral response function of a given channel of the satellite radiometer, allow the calculation of equivalent sets of radiance values (from the aircraft measurements) and count values (from the satellite measurements) that correspond to the altitude of the satellite radiometer and the field-of-view of the aircraft spectroradiometer. These sets are augmented in the case of AVHRR, for example, by the measurement of the count corresponding to the radiance of space, which is assumed to be zero. A least squares fit between the sets gives the gain (i.e. count output divided by radiance input) of the satellite radiometer's channel as the slope of the best-fit line.

The atmospheric correction is minimized by operating the aircraft in the stratosphere, so the necessary corrections are limited to stratospheric aerosol and stratospheric ozone. In this case the atmospheric correction for reasonable observation geometry is calculated to be less that 3% for channel 1 of AVHRR and is smaller for channel 2. The correction may be calculated to adequate accuracy, in the absence of recent additions of aerosols of volcanic origin, by adopting climatological averages for stratospheric composition, and calculating the correction with the LOWTRAN-7 [3] computer code. The aircraft spectroradiometer collects data for a period of approximately 3 minutes over the target. Satellite data encompassing the spatial range of the aircraft data are collected from the satellite radiometer for approximately 3 seconds in the middle of this period, and the method assumes that the two data sets correspond to identical states of scene structure and illumination.

The footprint correction is achieved by making the footprint of the aircraft spectroradiometer much larger that that of the satellite radiometer. The footprint used as the transfer standard is then the footprint of the aircraft spectroradiometer, which is well-characterized compared to that of the satellite radiometer. Initial navigational uncertainties between the aircraft and satellite pointing vectors amount to the equivalent of several footprints of the aircraft spectroradiometer. It is therefore necessary to search the satellite image to find the image displacement from nominal alignment that corresponds to maximum correlation between the set of aircraft radiance measurements and the equivalent set of counts from the satellite radiometer. This approach to fine-tuning of the navigation implies that the correct displacement is that which corresponds to the best (in a least-squares sense) linear relation between radiance and counts, and the approach is therefore unsuited to a determination of the linearity of response of the satellite radiometer. Over effectively uniform targets (such as clear ocean surface) this restriction does not apply.

The method assumes that the spectral response functions of the satellite radiometer channels have not changes since being measured before launch, and all observed changes in response in orbit are attributed to changes in gain. For NOAA-11 AVHRR the preliminary results reported here show that the gain ratio of channel 1 to channel 2 during the period November, 1988, to October, 1990, is constant to within $\pm$ 1%. This strongly suggests that neither channel has changes its spectral response during this period.

The spectroradiometer has been radiance and wavelength calibrated on an irregular schedule since the equipment was acquired for NOAA in March, 1988. The system was calibrated in a NASA/GSFC laboratory at Greenbelt, MD, before and after most flights, but the time intervals between flight and calibration usually exceeded 1 month. All calibration data were collected under ambient laboratory conditions and without the aircraft window in place. The window transmittance as a function of incidence angle was measure separately, and included in the calculations as a correction term.

Figure 3.3.2 illustrates the experimental arrangement in the laboratory to radiance-calibrate the 1.22 m diameter hemisphere calibration source. The spectral irradiance spectrum of a secondary standard lamp supplied by Optronic Laboratories, Inc., is transferred to an Optronic model 740A spectroradiometer equipped with a small integrating sphere at its entrance port. The purpose of the integrating sphere is to render the 740A's response to input irradiance effectively independent of the angular (and spatial) distribution of input irradiance elements at the entrance aperture of the 740A system. The (740A) irradiance to (hemisphere) radiance transfer requires accurate measurement of the diameters of the apertures in the sphere and the hemisphere, and of their separation.

The 1.22 m diameter hemisphere source is internally coated with a barium sulfate pigment embedded in a polyvinyl alcohol binder. Twelve 200W coiled-coil tungsten filament lamps are arranged internally along the great circle of the hemisphere adjacent to the flat face. Light from the lamps is baffled by a barium sulfate coated internal cylindrical section that prevents direct illumination of the exit aperture, and the flat internal face of the hemisphere is painted matt black. The lamps are independently switchable, and are run at a current of 6.500 $\pm$ 0.001 amps. Results for the uniformity, accuracy, and stability of the radiance calibration of the hemisphere have been published elsewhere [4]. Uniformity of the radiance field (with all 12 lamps lit) as a function of spatial and angular displacement from a position observing along the axis of the hemisphere was reported to be better than $\pm$0.3%.

The spectroradiometer is mounted on a gimbal in the aircraft that allows its optical axis to be directed to a range of angles to the right and below the aircraft axis. These motions are controlled by an onboard minicomputer through azimuth and elevation drive motors with a positioning accuracy of approximately 1^{o}. The optical axis passes through the center of an uncoated quartz or infrasil window (both have been used) set into the floor of the aircraft.

The silicon detector and preamplifier (EG&G HUV 4000B) is hermetically sealed behind its window. The detector responsivity near 400 nm and especially near 1000 nm is temperature dependent, so the detector temperature is actively controlled at approximately 17 C with a Peltier heat exchanger. Heating pads are wound around the body of the spectroradiometer to minimize internal temperature gradients. Under flight conditions the temperature of the supporting frame measured close to the spectroradiometer is in the range of 0 to 10 C.

The onboard minicomputer also acts to control motion of the second blocking filter and the beam blocking actuator, and supervises the recording of spectral and housekeeping data. Data are recorded with a resolution of 12 bits, and include the spectral data, frame and detector temperatures, power supply voltage, time from a dedicated clock, and gimbal azimuth and elevation. The pitch, roll, heading, and altitude of the aircraft are recorded by the separate aircraft Inertial Navigation System (INS), which has its own dedicated clock.

White Sands, NM, has been the target of choice for recent measurements, but the CZCS was successfully calibrated in 1983 by this method using clear ocean surface as the target. High reflectivity targets, such as snow and stratus cloud fields are attractive candidates for future evaluation as suitable targets.

Results

Figure 3.3.3 show preliminary results [5] obtained for the NOAA-11 AVHRR from 6 ER-2 flights over White Sands, NM, between November 1988 and December 1990.

The method has several major advantages: it is the only absolute method now available (excluding on-board systems), it has high intrinsic accuracy traceable to NIST standards, it requires no field work, and it can be configured for rapid response to a request for calibration information. Figure 3.3.3 also shows the results from Kaufman and Holben, using selected desert areas observed at annual intervals with the same observation and illumination geometry, and the results of Che et al., using White Sands to transfer the calibration of the SPOT Haute Resolution Visible (HRV) channel to AVHRR. These two methods represent, respectively, the more precise relative methods now available, and the methods for cross-calibrating sensors on the same or different platforms. The trend of gain decreasing with time shown by the aircraft results is confirmed by Che et al., and is consistent with the results of Kaufman and Holben, although the aircraft-measured absolute gain is displaced from the other results for channel 2. Figure 3.3.3b gives the results expressed as the ratio of gains for channels 1 and 2. Normalized Difference Vegetation Index (NDVI) is a function of gain ratio, which must be held constant (or measured accurately) to provide useful estimates of NDVI. The aircraft measurements indicate that the gain ratio is within $\pm$ 1%, which agrees with the results of Kaufman and Holben for the February/March periods, and disagrees with their results for August/September and with the results of Che et al.

This project is now reducing data collected from the GOES-7 VISSR/VAS and from NOAA-9 AVHRR. Underflights of NOAA and GOES satellite sensors are planned for spring and fall of 1992.

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4 Transfer of Calibration between Pre-Launch to In-Orbit Using On-Board Calibrators

4.1 Objectives/Rationale

Instrument behavior during the period between pre-flight calibration and the first in-flight calibration is currently not well quantified. On-board calibrators have been designed for the MODIS instrument to aid in bridging the gap between ground and in-flight calibrations. These calibrators, including a solar diffuser and Spectroradiometric Calibration Assembly (SRCA), will transfer the radiometric, geometric and spectral calibrations of MODIS between pre-launch and in-orbit phases of the mission by providing a relationship between calibrator effective radiance and sensor digitized output. **An assumption critical to this process is that the on-board calibrators themselves will not change calibration after insertion into the space environment.**

4.2 Radiometric Calibration

The full-aperture blackbody source for the On-Board Calibrator (OBC) will be calibrated pre-flight with traceability to a NIST temperature standard. Similarly, redundant tungsten lamps will be calibrated with NIST traceability. The solar diffuser for on-orbit reflectance calibration will be calibrated pre-flight and traceable to NIST reflectance standards. BRDF measurements to determine the diffuser's response as a function of wavelength and angle of incidence will also be made.

4.3 Geometric Characterization

4.4 Spectral Characterization

5 In-Orbit Radiometric Calibration /Characterization Methodologies

5.1 Objectives/Rationale

In-orbit calibration of the MODIS instruments is crucial to assessing the performance of the instruments during the lifetime of the mission. In-orbit techniques, combined with pre-flight and ground truth calibrations, provide the necessary redundancy to ensure thorough knowledge of instrument operation.

5.2 Instrument Based Calibration

<u>MODIS Preliminary Calibration Management Plan,</u> Hughes Santa Barbara Research Center, September, 1991.

The MODIS sensor includes the capability for in-orbit calibration using instruments specifically designed for this function. Included are the Spectroradiometric Calibration Assembly (SRCA), a solar diffuser and its stability monitor (SDSM), and an on-board blackbody source for calibration of the MODIS thermal bands.

5.2.1 Internal sources/assemblies

5.2.1. Spectroradiometric Calibration Assembly (SRCA)

The SRCA will allow in-orbit capability for radiometric calibration of the VIS, NIR, and SWIR bands; and for spectral calibration of the VIS and NIR bands. It utilizes an incandescent source and internal optics to collimate a beam directed to the MODIS scan mirror for relay into the MODIS instrument.

5.2.1.2 Blackbody

MWIR and LWIR bands use a full-aperture blackbody for in-flight calibration. The blackbody, operated at ambient temperature, will have excellent temperature uniformity across its surface and provision for directing residual reflection toward similar temperature surroundings. The blackbody cavity design is similar to that used for SBRC's ground test, utilizing an aluminum plate with V-grooves cut at 25-degree half-angles.

5.2.1.3 Solar Diffuser Panel and Solar Diffuser Stability Monitor (SDSM)

The solar diffuser is a panel with two BRDF levels for extended dynamic range of operation. The solar diffuser stability monitor periodically compares the reflectance properties of the panel to the sun and measures any changes. The optical system of the SDSM consists of a Czerny-Turner grating spectrograph with a fixed entrance slit, grating, and exit slit detector. The fore-optics can image either the diffuser or the sun, and can provide attenuation allowing the signals to come within two orders of magnitude of one another, where comparisons can be made.

5.2.2 External solar

5.2.3 External lunar

H.H. Kieffer and R.L. Wildey, U.S. Geological Survey, Flagstaff, AZ 86001

<u>Introduction</u>

In-flight calibration of imaging instruments is a difficult task. Calibration subsystems themselves are subject to offset and drift, and many do not calibrate the entire optical system, which can be done only by having external, full aperture sources, such as solar diffuser surfaces. Calibration can be done through the use of well characterized ground targets, but this requires near-simultaneous measurements, a substantial ground campaign, and a difficult correction for the atmosphere.

The objective of this work is to provide new radiometric information needed to allow the moon to be used as a well-characterized radiometric source for calibration of earth-orbiting instruments that can view it. In addition to direct use of the radiometric information, such detailed knowledge of the lunar brightness enables better use of the moon for measurement of the MTF and scattered light performance of the instruments.

Background

The moon has several unique properties: it is within the dynamic range of most imaging instruments, it is surrounded by a black field in both reflective and thermal band, and its surface brightness distribution can be better known than that of any other natural object at which most instrument can be safely pointed. Although the moon's photometric properties are thought to be intrinsically constant over long time scales (natural rate of change estimated at 10^{-9} percent per year [1]), the effects due to the variation of illumination conditions and observation geometry must be considered. These in turn are related primarily to the lunar photometric function and the lunar libration

The libration of the moon, the change of the position of the sub-earth point on the moon, results from the axial inclination and the small change in the angular velocity of the moon around the earth due to eccentricity of the lunar orbit (optical libration) and small nonuniformity in the rotation rate of the moon (physical libration). These combine to yield a variation of about $\pm 7^{o}$ in both latitude and longitude, both with a period of near one month, but with small differences that require the dual precessional cycle of 18.6 years (accidently approximately the same length as the Saros cycle) to complete.

The variations of albedo over the face of the moon are common knowledge. Quantitatively, at modest spatial resolution the normal albedo (in V band) ranges from 9% to 23%, with a mean value near 12.5% [2]. Albedo variegation extends to scales below the limit of telescopic resolution. The moon appears gray in the visible, but has a general increase in reflectivity into the near infrared [3]. Variation of color between different locations on the moon is small, and those spectral features that do exist are relatively broad [4,5].

The moon does not behave as an ideal diffuse reflector. As the phase angle (sun-moon-observer angle) becomes small, the moon brightens dramatically; this is called the "opposition effect" [6], which increases up to the point that lunar eclipse begins. Current knowledge of the lunar photometric function is limited to a few wavelengths, and to a few small areas or for the spatially-integrated lunar brightness (the phase function) [7,8].

The moon has several additional characteristics that require consideration in treating it as a radiometric standard. Light from the whole moon has small negative polarization at small phase angles, becoming most negative at ~ -1.2% near a phase angle ~ 12^{o}, then increasing through 0 polarization near 24^{o} up to about +8% at phase angles near 90^{o}. Individual areas (appropriate for HIRIS spatial resolution) typically have polarization at phase angles less than 15^{o} of 1.2% or less at 361 nm, and polarization decreases toward longer wavelengths out to at least 1 μm [9]. The degree of polarization is approximately inversely proportional to albedo, begin greatest for dark areas, and least for bright areas [6]. Variations with albedo are small for phase angles less than about 40°. Early work indicated that near full moon, polarization near the limb of the moon was about 0.1-0.2% parallel to the limb [10].

Because the surface of the moon can become as hot as 400 K[11], thermal emission becomes important for longer wavelengths. Thermal emission at 400 K contributes about 0.1% at 1.8 μm, 1% at 2.0 μm, and 10% at 2.3 μm. Thermal models and prior infrared measurements [12] would allow correction for thermal emission to about 1/5 of these levels. Simultaneous measurements of lunar radiance near 3.5 μm would allow correction for thermal emission to better than 0.5%.

Approach

Current knowledge of the radiometry of the moon is limited to attempts to calibrate the absolute spectral reflectance at a few points [13], and measurements of the integrated lunar brightness at a few wavelengths [7]. In order to support the spatial resolution of EOS instruments, especially HIRIS, extensive radiometric observations will be made with spatial (angular) resolution of 4.4 arcsec, twice as fine as HIRIS. The wavelengths of reasonable transparency of the earths' atmosphere between 0.3 and 2.5 μm will be covered. Because the technology to do radiometry with imaging spectrometers has not yet been developed, radiometry will be at a discrete set of passbands by use of interference filters; on the order of 20 wavelengths will be used.

Two filter imagery systems will operate simultaneously, one in the VIS and one in the VNIR. Each will have its own telescope, boresighted and supported on a common mount. No beam splitter or fold mirrors will be involved and each telescope and detector system will be axial, so that the detection systems should be polarization-insensitive.

For wavelengths from 0.3 to 1.0 μm, a conventional astronomical silicon CCD will be used, with 512 x 512 pixels. No "off-the-shelf" photometric arrays are available for wavelengths longer that 1 μm, and this project had planned to use an array produced as part of the HIRIS development. The exact type of infrared array to be used is still under study, but it is assumed that a 256-square array with characteristics similar to HIRIS test arrays will be available.

An in-dome radiometric standard will be observed at least as often as the beginning and end of astronomical observations each night. This standard will utilize a NIST-traceable halogen standard lamp and a nearly ideal diffusing surface large enough to illuminate the full aperture of the telescopes. Our plan is that this facility be part of the circuit for the EOS portable radiometer standard (Phil Slater proposal), and the connection to NIST be established every 6 months.

The telescope system will be highly automated and entirely under computer control. Most of the telescope time will be spent observing standard stars, especially those in a band along the moons' orbit. This both allows quantitative determination of atmospheric extinction (needed to correct to exo-atmospheric radiances) and ties the radiometric system to the existing standard star system. Experiments "trailing" stars at different rates will be done to determine the best radiometric techniques and to determine the high-frequency variation of apparent radiance due to atmospheric lensing (scintillation).

Design and planning for this lunar radiometry facility has begun, and routine observations are scheduled to begin in the fall of 1993. Observations would continue at least 4 1/2 years; observations over at least 1/4 the Saros cycle are required to cover the range of lunar libration.

Observations will be made each month when the moon is at 90° phase or less (the bright two weeks of each lunation) on all photometric nights (at the planned observatory site in Flagstaff, there are approximately 100 photometric nights each year). In order to develop a photometric model for each resolution element on the moon, all observations will be reduced to a special projection that incorporates all areas of the moon visible from the earth over the full range of libration, yet has minimum distortion from the appearance of the moon for a single observation. Observations will be reduced to produce a photometric model of each pixel in this projection for each wavelength band.

Initial error budget analysis that the expected long-term precision is ~0.8%, and absolute radiance ~2.3%. The largest contribution to uncertainty of absolute radiometric accuracy is the calibration of the standard lamp.

For the nominal EOS platform orbit, the average angular size of the moon is equivalent to a nadir target of 6.73 km. Instruments of 15 m , 30 m, 250 m, and 1 km resolution would have 425, 212, 25.5 and 6.4 pixels across the moon, respectively.

Because the moon is darker than most terrestrial scenes, spacecraft calibration observations of the moon should be made at small phase angles if possible to avoid being low in the dynamic range of the instrument. Spacecraft observations could be made at any phase angle greater than 1.5^{o}, where lunar eclipse phenomena begin. The moon attains a minimum phase angle of less than about 6^{o} each month, and near zero twice a year.

Expected Results

For any specific spacecraft observation, the precise illumination and observation geometry will be used to calculate a radiometric image of the moon at full model spatial resolution in each wavelength. This radiometric image will then be geometrically transforms to match the resolution and orientation of the spacecraft instrument image. (The spatial uncertainty in resampling to a specific HIRIS observation increases the overall radiometric uncertainty 0.1%, other instruments would be similar for pixels that are fully on the moon). The team for that instrument would produce a radiometric image based on their calibration files. The ratio of the two images represents the factor between the two calibration systems.

Such radiometric images can also be used in reduction of instrumental scans across the moon for study of MTF and scattered light sensitivity [1], although for these purposes the spatial resolution and radiometric precision of this study would rarely be needed.

Preliminary calculations of lunar radiance levels, with about 15% uncertainty, are now available for use in design of instrument gain settings.

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5.3 Target-Based Calibration

5.3.1 Target related/ground reflectance

The reflectance of a ground target large enough to have a stable spectral reflectance over many sensor pixels is carefully measured when the image is taken by the sensor to be calibrated. At the same time, the extinction optical depth of the atmosphere is measured along with certain necessary meteorological parameters. The aerosol particle size distribution is inferred from the spectral optical depths. A radiative transfer code which accounts for multiple scattering and absorption is used to predict the in-band radiance at the entrance pupil of the sensor being calibrated. This radiance is used along with the average digital counts of the pixels corresponding to those measured on the ground to compute the calibration [1, 2]. This same method has been applied to calibrate the AVIRIS sensor in an ER-2 [3] and a Daedalus 1268 operated by EG&G in both a jet aircraft and a helicopter [4]. This method is NOT directly applicable to MODIS as the MODIS pixel size is too large for a ground crew to adequately sample the ground reflectance over multiple pixels. An modified approach, provided by the University of Arizona, is described below.

The University of Arizona group plans to make in-orbit calibrations of high spatial resolution EOS sensors such as ASTER (and HIRIS for the C platform) using a reflectance-based method described above. MODIS in-orbit calibration with reference to a ground site shall be done with a method similar to its AVHRR work [5]. The U of A group plans to continue with this type of work with future AVHRR and follow-on sensors and a MODIS simulator if it becomes available. The group plans to refine its methods to include the use of a field SWIR spectrometer, a solar radiometer designed to measure total column water vapor, and an imaging solar radiometer which will be used to study the solar aureole. The aureole is a sensitive indicator of aerosol scattering and the group hopes to improve its knowledge of the scattering phase function with this future instrument.

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5.3.2 Bio-optical oceans

Water leaving radiances over the many ocean locations at wavelengths greater than about 700 nm are close to zero. The satellite radiance therefore is arising entirely from the path radiance. An accurate radiative transfer model allows the path radiance to be calculated. This path radiance provides a known source which allows MODIS to be calibrated. The technique makes the instrument calibration and the radiative transfer model self-consistent.

Buoy measurements of pigment concentration can be compared with MODIS determined pigment concentrations. A discrepancy between the two may be resolved by altering the calibration of the satellite. This technique can be introduced into the routine processing and is called bio-geochemical normalization.

5.4 Image Related

5.4.1 External image related radiometric rectification

Certain regions on Earth contain areas which are radiometrically stable. For example, exposures of bedrock may have a relatively stable reflectance over long periods of time. These radiometrically stable areas within images can be used to correct other portions of an image so that they are internally self-consistent with the stable portions of the image. The technique is generally applied to high resolution images such as those produced by Landsat or SPOT. The applicability of the technique to MODIS images will be researched and applied.

5.4.2 Class-specific scene equalization

A generalization of the within image radiometric rectification technique in which multiple scenes are used will also be employed for monitoring the MODIS stability.

6 In-Orbit Geometric Characterization

A deployable line ruled recticle will on occasion be placed in the field of view of the instrument. The alignment of the sensor will thus be periodically checked.

7 In-Orbit Spectral Characterization

8 Official MODIS/MCST Calibration Algorithm

8.1 Objectives/Rationale

During routine processing, one calibration algorithm will be used to determine the Level-1B radiances. This "official" algorithm may be one of the techniques described above, but it is more likely to be a combination of methods.

8.2 Minimization of Instrument Systematic Noise Sources

The contractor will work to ensure that sources of systematic noise, which will detract from the absolute instrument performance, are minimized during the design and build phases.

8.3 MCST Calibration Flow

The calibration algorithm produced by MCST shall take into account all instrument components, both optical and electronic, between the radiance input and the digitized output of the sensor. Components in each optical path will be accounted for. In this manner, the propagation of error in the calibration process can be more meaningfully quantified.

9 MODIS/MCST Calibration Algorithm Validation and Upgrade

9.1 Algorithm Correction for Systematic Errors

Systematic error sources that have not been eliminated from the hardware will be processed out by application of the software algorithm. These error sources yield image-related effects including, but not limited to, drifts within scan, "memory effect" which is manifested as pixel-to-pixel aliasing, and the effects of the array's fixed pattern noise.

9.2 Inclusion of In-Flight Calibration Information

Additional information on MODIS performance will be available after the instrument is launched. On-board calibrators and solar calibration will provide data that will be analyzed to further validate and upgrade the software algorithm.

9.3 Creation of Calibration Error Images

A two-dimensional image, representing the error in the calibration on a pixel-by-pixel basis, will be created after each calibration procedure.

10 Definitions and References

10.1 Data Dictionary/Glossary

10.2 Acronyms

A

AIRS Atmospheric Infrared Sounder
ASTER Advanced Spaceborne Thermal Emission and Reflectance
AVHRR Advanced Very High Resolution Radiometer
AVIRIS Airborne Visible/Infra-Red Imaging Spectrometer

E

EOS	Earth Observing System
EOSAM	EOS AM polar orbiting observatory, with a 10:30 AM equatorial crossing time
EOSPM	EOS PM polar orbiting observatory, with a 1:30 PM equatorial crossing time
EOSP	Earth Observing Scanning Polarimeter

G

GOES	Geostationary Operational Environmental Satellite

H

HIRIS	High Resolution Imaging Spectrometer

M

MCST	MODIS Characterization Support Team
MERIS	Medium Resolution Imaging Spectrometer
MISR	Multi-angle Imaging Spectro-Radiometer
MODIS	Moderate Resolution Imaging Spectrometer
MTF	Modulation transfer function

N

NASA	National Aeronautics and Space Administration
NIST	National Institute of Standards and Technology
NOAA	National Oceanic and Atmospheric Administration

S

SeaWiFS	Sea Viewing, Wide Field-of-View Sensor
SBRC	Santa Barbara Research Center
SDSM	Solar Diffuser Stability Monitor
SRCA	Spectro-radiometric Calibration Assembly

10.3 Additional References

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MODIS/MCST Feedback Sheet

on MODIS Calibration Handbook and MODIS Characterization/Calibration Plan

Questions ? **Concerns ?**

Suggestions ? **Actions for Next Meeting?**

Name: **Date:**

For E-mail correspondence address GSFCmail:JBarker or BGrant.

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