MODIS Image-Derived Characterization and Verification

Chapter 6
MODIS Calibration Plan

by

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Objectives

Verification

The objectives of the image-derived radiometric and geometric characterizations of the MODIS instruments are to:

provide channel-by-channel, pixel-by-pixel, instrument-independent algorithms and tools for quantitatively characterizing the image quality of both the raw uncalibrated unresampled Level-1A (L-1A) and calibrated L-1B MODIS data products throughout the lifetime of the mission.

Calibration

Relative channel-to-channel normalization of histograms for selected bands

Characterization

Relative spatial/geometric characterization

Absolute radiometric characterization

And noise characterization

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Illustrative Relative Radiometric Characterizations

1) Channel-to-channel within and between bands
2) Scan-to-scan
3) Focal plane-to-focal plane
4) Band-to-band
5) Orbit-to-orbit

Assumptions

1. Channels: Channel-to-channel variability will be the largest cause of any apparent "striping" within a band due to changes in responsivity of the MODIS detectors with time. Stripping will be visible after instrument-based calibration. Stripping can and will be reduced by channel normalization algorithms as part of the Level-1B processing.

2. Scan Mirrors: The two scan mirrors will remain relatively unchanged in their reflective properties due to "pitting" or contamination and that preflight characterizations of them can be used initially, i.e., there will be no expectation of post-calibration "banding" between scans.

3. Focal Planes: Radiometric effects of scattering and electronic crosstalk within a focal plan will be below the absolute calibration requirements in the specifications and the parameters for correction of "ghosting", if necessary, will be provided by pre-launch tests. The structural integrity of the MODIS instrument will be such that there will not be any movement of the rigidly connected optics and focal planes leading to changes in the pre-launch channel-to-channel geometric registration test results.

Assumptions

4. Bands: The ion-bombarded spectral interference filters and the band-specific analog-to-digital converters will be stable throughout the five year mission life, therefore, cross-calibration between bands will provide a check on the within-band calibrations.

5. Orbital Position: Thermal effects on the radiometric or geometric characteristics from changes in solar irradiance on the instrument as a function of position in an orbit will not be measureable.

6. Radiometric Noise: Coherent, stationary and systematic noise will be quantitatively characterized by looks at space for the emissive bands and by night-time scenes for the reflective bands, and will be sufficiently small that corrections prior to the calibration of the L-1A imagery will not be necessary.

Assumptions

7. Memory Effects: There will be no measurable image-dependent memory effects from the detectors or the electronics.

8. MTF: The biggest uncorrected source of radiometric error at edges and in non-homogenous regions will be due to the inherent nature of the two-dimensional point spread function, or Modulation Transfer Function (MTF) in frequency space, of the instrument, and that it will be possible to characterize the size of this on a pixel-by-pixel basis from pre-launch test data convolved with the actual observed imagery. This MTF inversion will be part of the initial Level 1-B algorithm. The MTF inversion algorithm will be available from the Product Generation System (PGS). The MODIS Team Leader Computer Facility (TLCF) will analyze and characterize selected images.

Assumptions

9. Scan-Mirror Scattering: The spatially most extensive radiometric anomaly will be scene-dependent out-of-field scattering off the scan-mirror, which will be characterized prior to launch and either masked or corrected post-launch (as with MTF effect).

10. Stability: It is assumed that the many of the 36 MODIS bands will be so much more stable than the minimum required specifications that the precision and accuracy of the on-board calibrator methodology will not be sufficient to fully characterize or utilize this strength. The image-based methodologies are intended to supplement the on-board calibrators by providing procedures to take advantage of this inherent stability of the instrument.

Methodology

Image-derived methods are discussed individually under the four major objectives:

1) Relative radiometric characterization

a) within-band histogram equalization

b) within-band overlapped pixel radiometry

c) between-band correlations and regressions

2) Relative spatial/geometric characterization

a) spatial Modulation Transfer Function (MTF) Inversion

b) geometric registration by correlation of overlapped pixels

3) Absolute radiometric characterization

a) "radiometric rectification"

b) unmonitored/monitored test sites

4) Noise Characterization

Relative Radiometric Histogram Equalization
Methodology

There are two standard methods for two-parameter destriping:

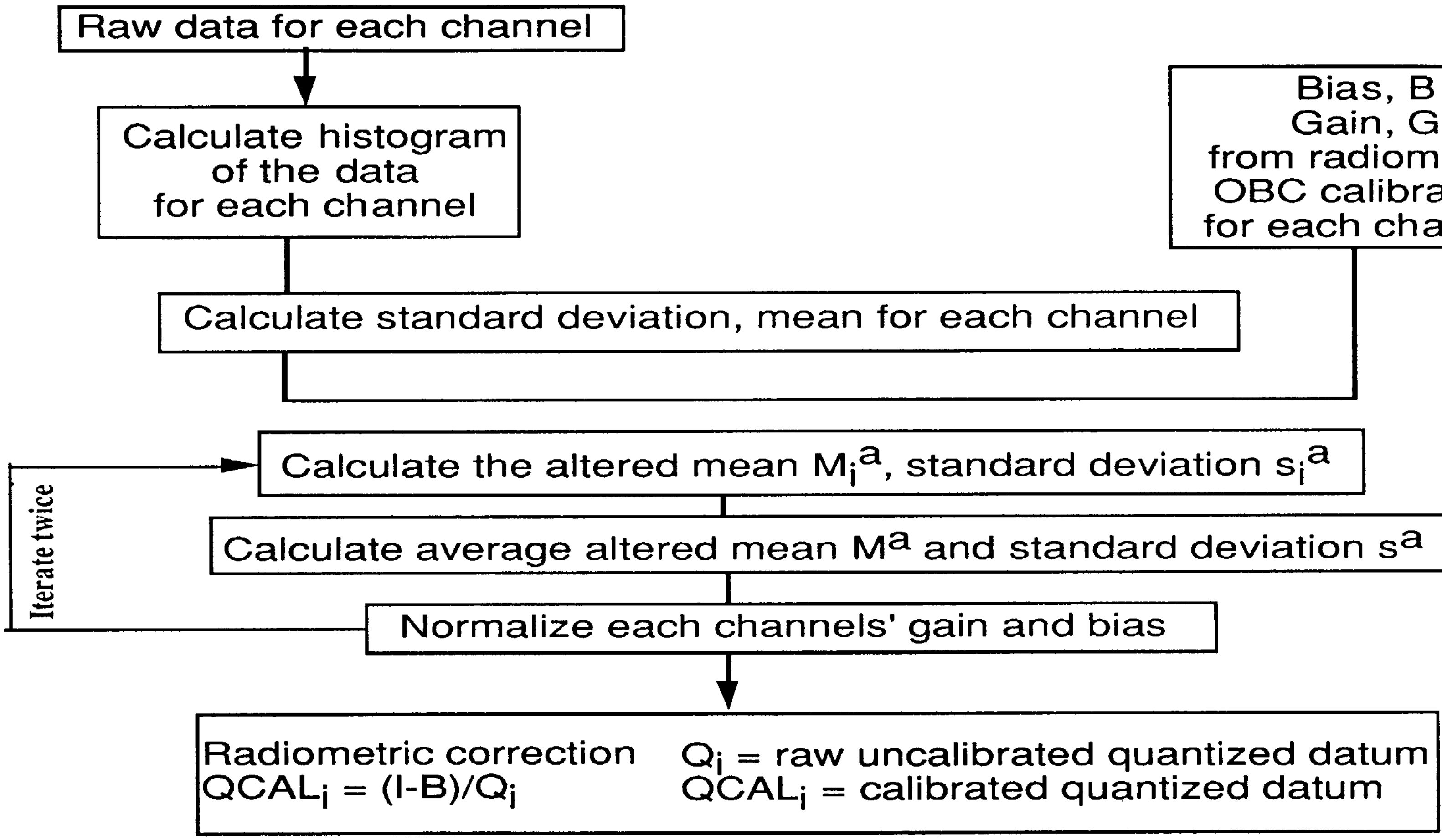
Method 1

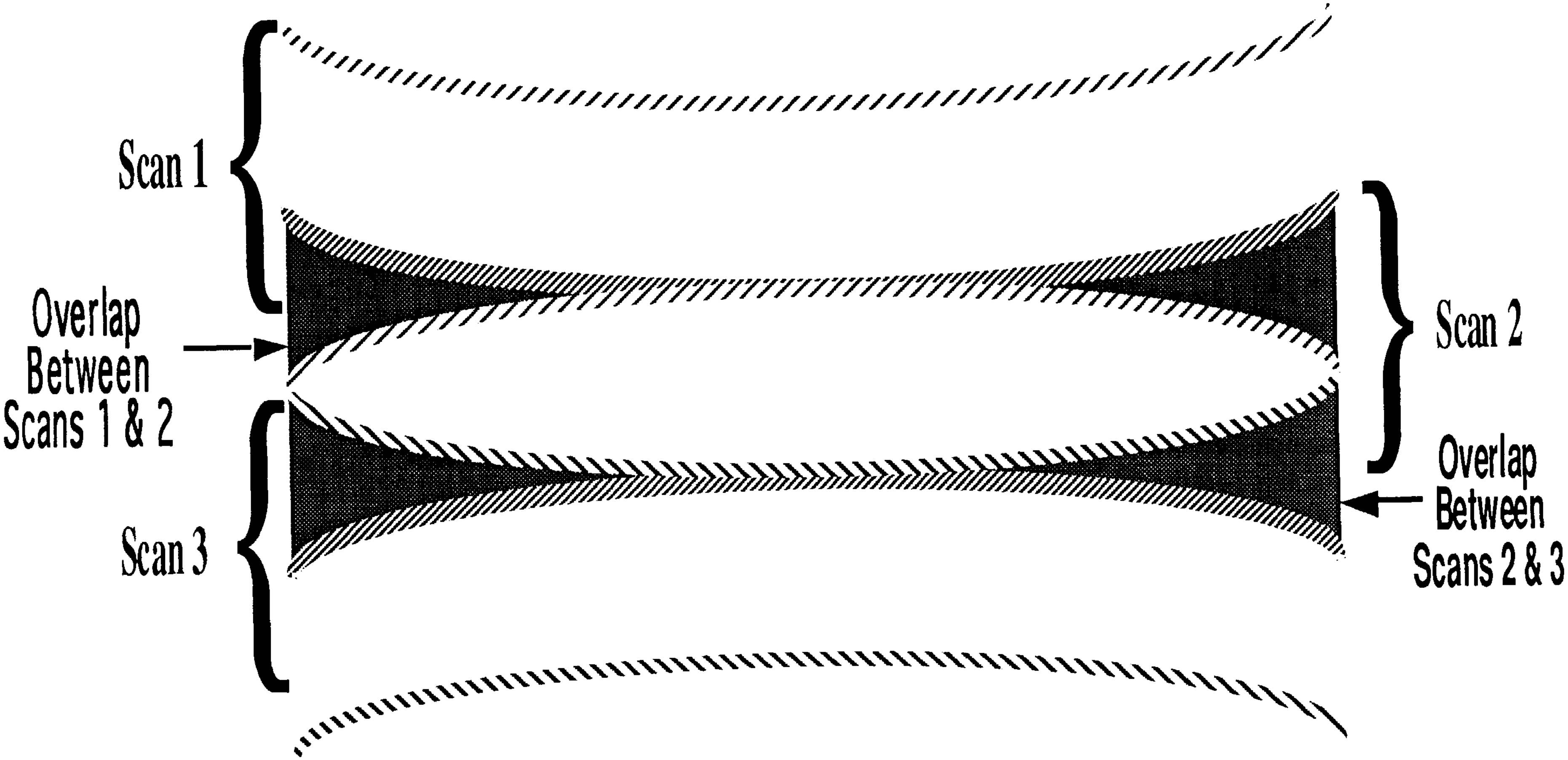
Normalization with respect to one channel. In this method, one stable channel is designated as a reference channel and all the histograms of the other channels are modified so that they match the designated channel's histogram. This is achieved by means of an inversion function represented by a look-up table. This method has been used for MSS imagery, and GOES imagery.

Method 2

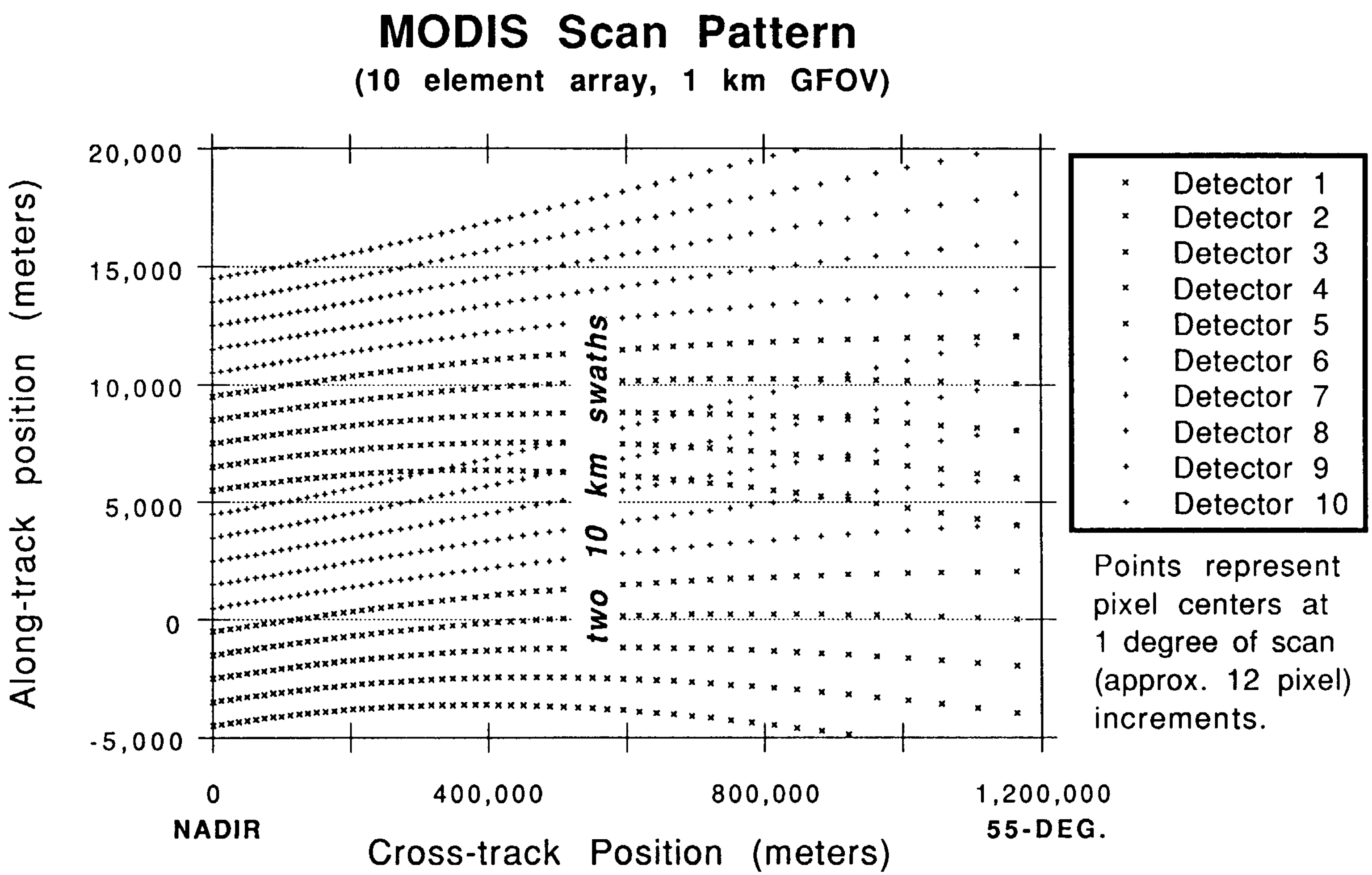
Normalization with Respect to Band Average. All channel biases and gains are averaged by an iterative process. The bias and gain are modified by the means and the standard deviations of the raw data. Two iterations are required. This method has been used for TM imagery and is the one chosen for MODIS destriping.

Image Normalization de-striping Algorithm Flow





Schematic Illustration of Overlap Between Adjacent MODIS Scans


MODIS Scan Pattern
(10 element array, 1 km GFOV)
Along-track position (meters)
20,000
15,000
10,000
5,000
0
-5,000
two 10 km swaths
0
NADIR
400,000
800,000
1,200,000
55-DEG.
Cross-track Position (meters)
Detector 1
Detector 2
Detector 3
Detector 4
Detector 5
Detector 6
Detector 7
Detector 8
Detector 9
Detector 10
Points represent pixel centers at 1 degree of scan (approx. 12 pixel) increments.

Illustrative Approaches

Within-Scan Data

- All Data
- Subsets of Data
    - Overlapped Regions/Pixels
    - "Pure" Pixels
    - Radiometrically "On-Scale" Pixels

Between-Scan Data

- Single Scene
- Single Orbits
- Multi-Orbit
- Multi-Date

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Relative Between-Band Correlation/Regression Methodology

The basis of between-band normalization is analogous to the winthin-band histogram equalization, in that small errors in calibration can be detected using a large relative reference sample of perhaps up to a half orbit of imagery that is not observed and removed by the primary absolute calibration reference. This can be done as a correlation process.

Between-band registration curve fitting is another approach. For the within-band case, the reflectance distribution from a large sample will be invariant from detector channel to detector channel, i.e., scan-line to scan-line. For the between-band case, no simple relationship exists because the bands view different spectral regions; however, spectral correlation can be observed and exploited in certain cases. Four spectral sources of known shape are available on MODIS:

1. Known solar irradiance spectrum
2. Known 2800 K SRCA lamp spectra
3. Known internal blackbody spectra (high and low temperatures)
4. Known ground reflectance for homogenous regions on the ground

Absolute Radiometric Rectification Methodology

A technique referred to as radiometric rectification has been included in the suite of MODIS calibration capabilities since it offers a means of normalizing the data from the same or multiple sensors without use of calibration sources or instrumented scene sites. The method is described by Hall, et. al. and is based on an earlier article by Hall and Badhwar. The technique can normalize multiple acquisitions at the same time and over time if the reference sites are invariant over the time scales of EOS/MODIS. The method can also be used to cross normalize other EOS instruments with the six MODIS instruments.

Absolute Radiometric Test Sites Methodology

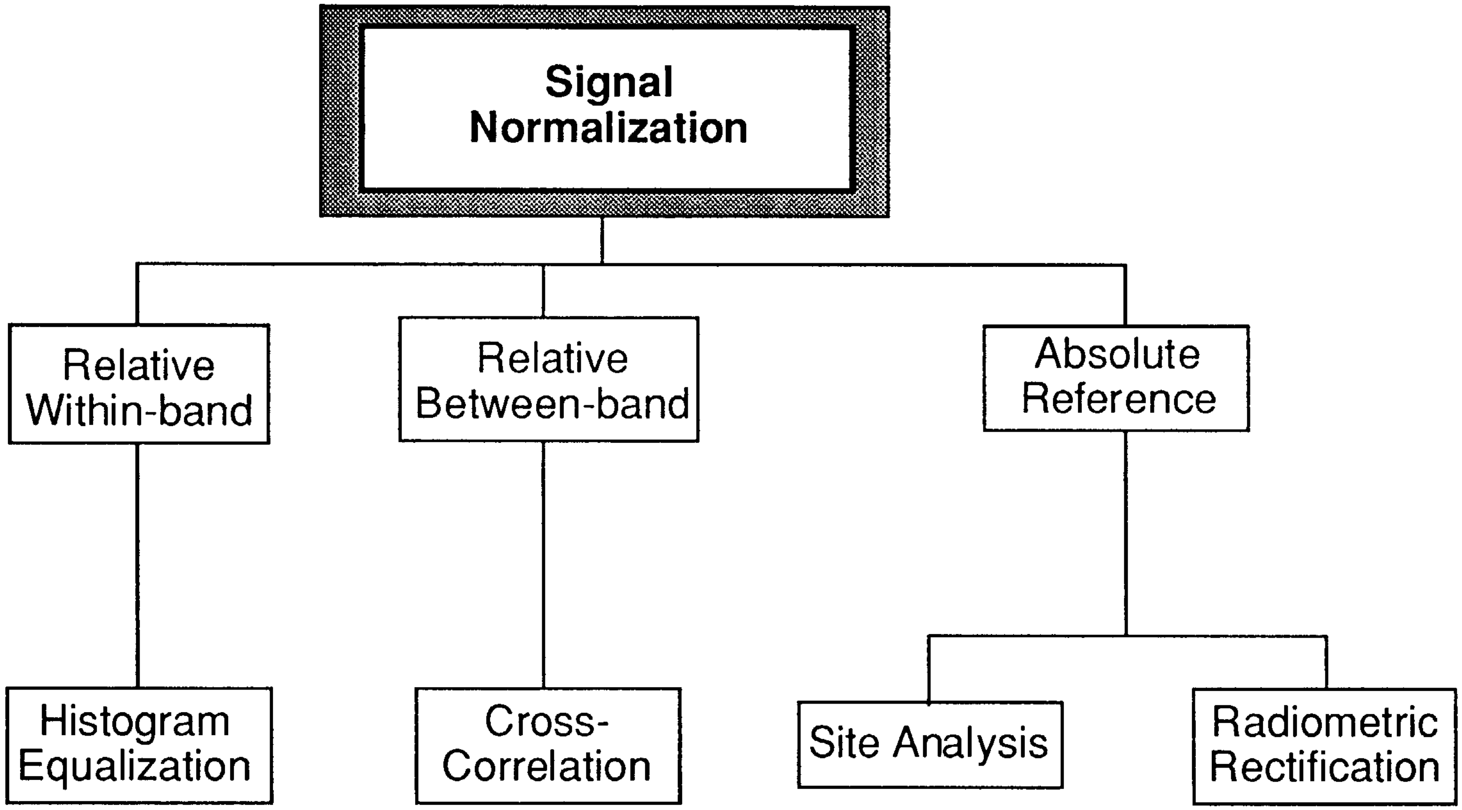
As part of the L-1 processing, several hundred radiometrically homogenous regions from around the world will be collected in raw L-1A and calibrated L-1B format. Using the MODIS ocean and land discipline atmospheric correction algorithms, these regions will be converted to at-surface bi-directional reflectance. The average bi-directional reflectance for each site has a predictable varying reflectance. Collection of sufficient data to allow testing of the trending stability model are anticipated to take about two years. This set of ground sites will be used as a global ensemble to provide relative radiometric consistency within a scene, an orbit, or longer lengths of time.

Initially, this will provide an independent consistency check of the on-board calibrator systems. As some of these sites are measured in an absolute sense by "vicarious" ground or aircraft measurements, this small subset of monitored sites will be used to bring the whole global data set of sites into individual sites, the inverse of the variance will be used as a weighting function in the combining of the global data set into one self-consistent set of unmonitored sites that can be used within any orbit to provide absolute radiometric calibration.

Calibration

Any of the image-derived characterization methodologies which generate count/radiance pairs are candidates for use in checking the calibration. The weighted count/radiance pairs will be combined just as the various on-board calibrator (OBC) sources are, i.e., used as the basis for a regression fit to the calibration function for a given band, with the suggested calibration coefficients being the regression coefficients. Image-derived calibration coefficients and noise characterizations will be included in the metadata; in addition, if the coefficients can be used to improve the calibration, then they may be applied.

Imaged-Based Calibration



Relative Channel-to-Channel Characterization (Destripping)

Histogram Equalization

(Heritage: MSS, TM, AVHRR and GOES)

ERRORS

- Statistical Convergence Requirement Proportional to Sample Size
- Channels at Edges of Focal Planes will be More Precise than Internal Ones
- Potential Exists for 0.1% Relative Precision

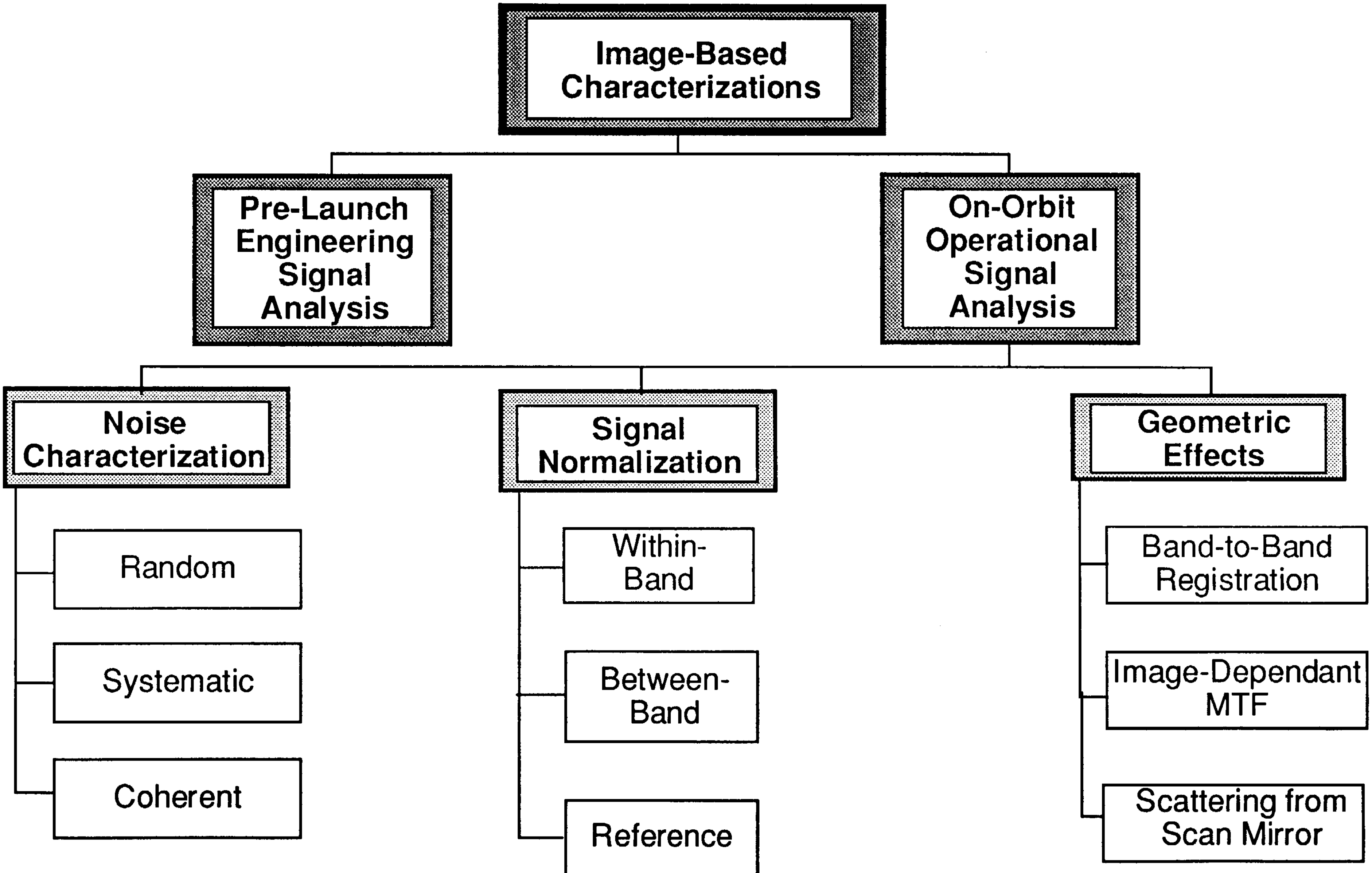
Validation/Verification

The primary methods of pre-launch validation of image-based algorithms will be from pre-launch engineering and signal analysis of the engineering and protoflight MODIS instruments and from tests on simulated MODIS images created from Landsat Thematic Mapper (TM) scenes.

On-orbit evaluation of the image-based algorithms will be by comparing derived calibration coefficients with independency determined ones from the on-board calibrators (OBCs). The time dependence of the instrument-based calibration techniques will be analyzed and compared. The time domains for the Earth-viewing methodologies will be analyzed and compared. The assumption is that instrument independent image-based methodologies will be a major contributor to the verification of the instrument-dependent methodologies.

Image-Based Characterizations

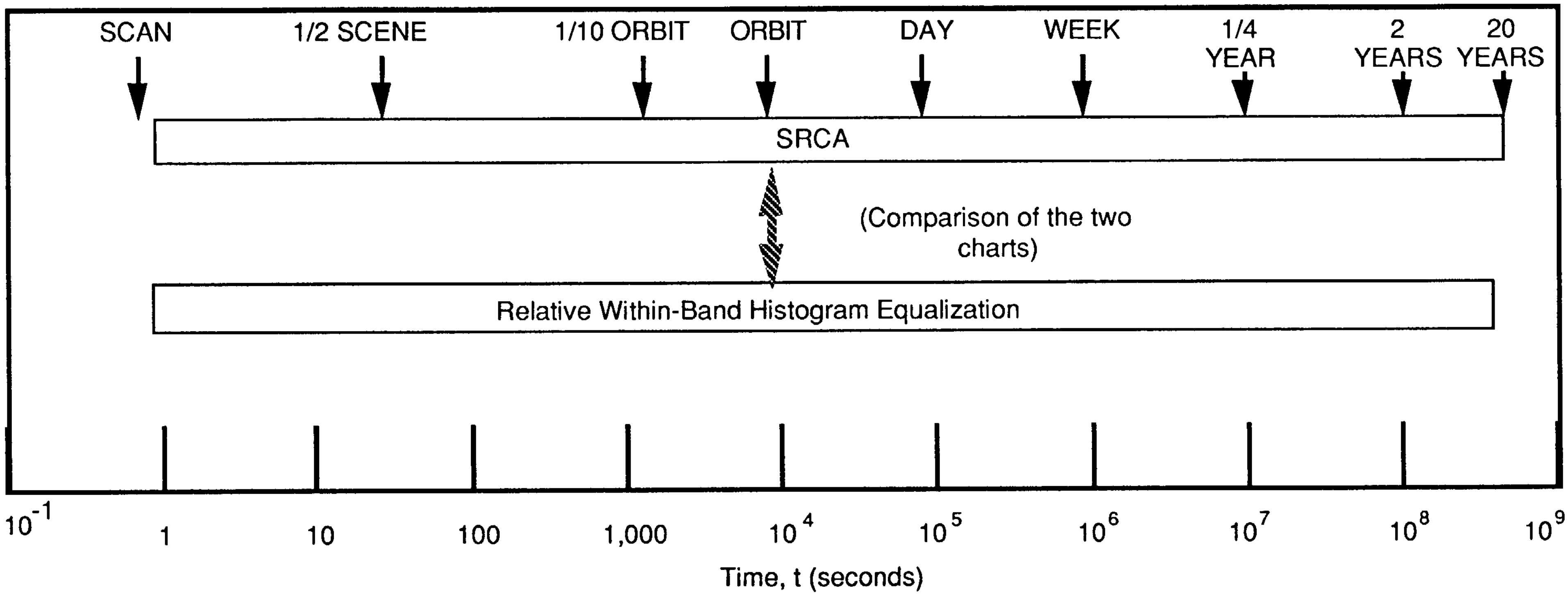
MODIS Science Calibration Methodology



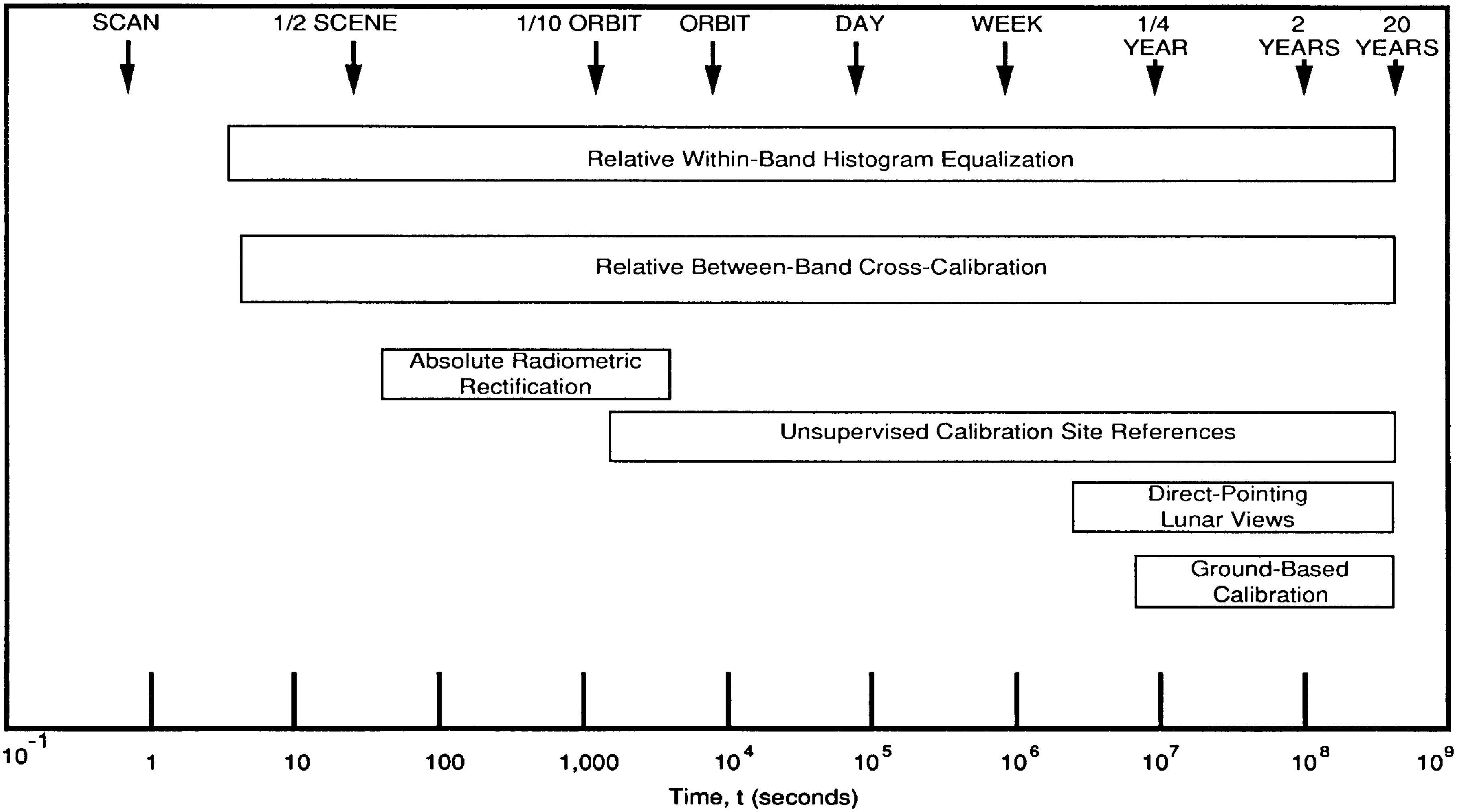
Time-Dependent Radiometric Characterization

Time Scale	Characterization Technique	Availability
Within a Scan Line	Scene-dependent MTF inversion	Post-Launch
Within a Scan	Bias Offset measurements Blackbody as DC-restore Space view	At-Launch
	Relative cross-correlation of detectors both within and between bands	At-Launch
Within a Half Orbit	Radiometric rectification over known radiometrically homogeneous sites	Post-Launch
Between Orbits	SRCA in Radiometric mode	At-Launch
Between Days	Solar Diffuser	At-Launch
Between Months	Lunar Pointing	At-Launch
	Vicarious Measurement Methods aircraft and ground-based	Post-Launch
Between Years	Lunar Views	At-Launch
	Radiometric Math Model	Post-Launch

Example of Potentially Redundant Calibration



Time Domains of Image-Based Characterization Methodologies



Risk Assessment

There is little risk in implementing the MODIS L-1B Algorithm, because the only proposed image-based method is the relatively well understood and straightforward histogram equalization algorithm.

There is a medium level technical risk that some of these image-based techniques might not be sufficiently precise or robust when compared to the requirements developed out of the pre-launch MODIS characterization and calibration tests. There is also risk associated with the actual integration of any image-derived calibration coefficients into the overall L-1B MODIS Calibration Algorithm.

There is a relatively high programmatic risk of not developing the other methodologies for use as either metadata with L-1B, or as off-line analysis tools because there is currently no funded effort for the analysis and software development associated with either the pre-launch MODIS instrument tests or the development of appropriate simulated MODIS images and associated analysis software.

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