Status of the Multi-angle Imaging SpectroRadiometer instrument for EOS-AM1 and its application to remote sensing of aerosols

David J. Diner, Wedad A. Abdou, Carol J. Bruegge, James E. Conel, Ralph A. Kahn,
John V. Martonchik, Susan R. Paradise, and Robert A. West

Jet Propulsion Laboratory, California Institute of Technology
Mail Stop 169-237
4800 Oak Grove Drive
Pasadena, CA 91109 USA
T: 818.354.6319 F: 818.393.4619 EMail: djd@jord.jpl.nasa.gov

Abstract -- The Multi-angle Imaging SpectroRadiometer (MISR) instrument is currently under development at JPL for the AM1 spacecraft in the Earth Observing System (EOS) series. MISR consists of nine pushbroom cameras, and will provide global coverage in four visible/near-infrared spectral bands. This measurement strategy provides systematic multi-angle imagery of the Earth for studies of aerosols, surface radiation, and clouds. An On-Board Calibrator consisting of deployable solar diffusers and a set of stable photodiodes provides a high-accuracy detector-based calibration. In this paper we report on the progress of the instrument fabrication and testing and focus on the application of MISR's unique observational strategy to studies of tropospheric aerosols.

INTRODUCTION

EOS-AM1 is scheduled for launch in June 1998 and will be placed into a 16-day repeat 705-km Sun-synchronous orbit, with a local time at equator crossing of 10:30 am. The MISR instrument is currently under development at the Jet Propulsion Laboratory. Subsystem and system testing of the MISR Engineering Model (EM) is nearing completion, and fabrication of the flight cameras is underway.

MISR is being designed to provide multiple-angle, continuous imagery of the Earth in reflected sunlight. It will use nine separate charge coupled device (CCD)-based pushbroom cameras to observe the Earth at nine discrete angles: one at nadir, plus eight other symmetrically placed cameras that provide fore-aft observations with view angles, at the Earth's surface, of 26.1°, 45.6°, 60.0°, and 70.5° relative to the local vertical. Each of the cameras is manufactured using one of four optical prescriptions, varying in focal length from one design to another to equalize cross-track sample spacings. The sample spacing on the ground is 275 m and can be averaged, in flight via ground command, up to 1.1 km. Each camera contains four detector line arrays, each overlain by a spectral filter to provide imagery in bands nominally centered at 443, 555, 670, and 865 nm. The four unique optical designs are designated "A", "B", "C", and "D" (in order of increasing view angle) followed by the letter "f", "a", or "n" to indicate forward, aftward, or nadir viewing. Provision for both forward and aftward views yields wide coverage in scattering angle (the angle between the direction to the observer and the solar illumination direction). It takes about seven minutes to view any point on the sub-spacecraft track at all nine angles. The swath width of the MISR imaging data is 360 km, providing global multi-angle coverage of the entire Earth in nine days.

A number of measurement objectives are established for the MISR experiment. The combinations of the 36 instrument channels (9 angles x 4 bands) used to meet these objectives are illustrated in Fig. 1.

INSTRUMENT STATUS

Cameras

The MISR lenses range in focal length from 59.3 mm to 123.8 mm and are superachromatic, 7-element refractive f/5.5 telecentric designs. A double plate Lyot depolarizer is incorporated into each of the cameras in order to render them polarization insensitive. The lenses are mounted in aluminum barrels with some additional materials to accommodate thermally induced dimensional changes of the lenses during flight. Each MISR camera contains a camera head which houses the focal plane structure and to which is attached the driver electronics for the CCD's. The camera heads and electronics are identical for all nine cameras, leading to a modular design in which only the lens barrels are unique.

The MISR CCD architecture consists of four line arrays with 1504 active pixels per line, and is based on standard 3-phase, 3-poly, n-buried channel silicon detector technology. Thinning of the poly gate over the active pixels increases the detectors' quantum efficiency in the blue spectral region. Full well capacity is 10^6 electrons with read noise < 20 electrons, yielding a large dynamic range for the devices. The signal chains amplify and convert the CCD video into 14 bit digital numbers. To minimize dark current and radiation sensitivity, the CCD's are operated at -5° ± 0.1°C using a single stage Thermo-Electric Cooler (TEC) in each focal plane.

A focal plane filter assembly defining the four optical bandpasses is placed about 1.5 mil above the CCD. The camera filters are mosaicked arrays of four separate medium band

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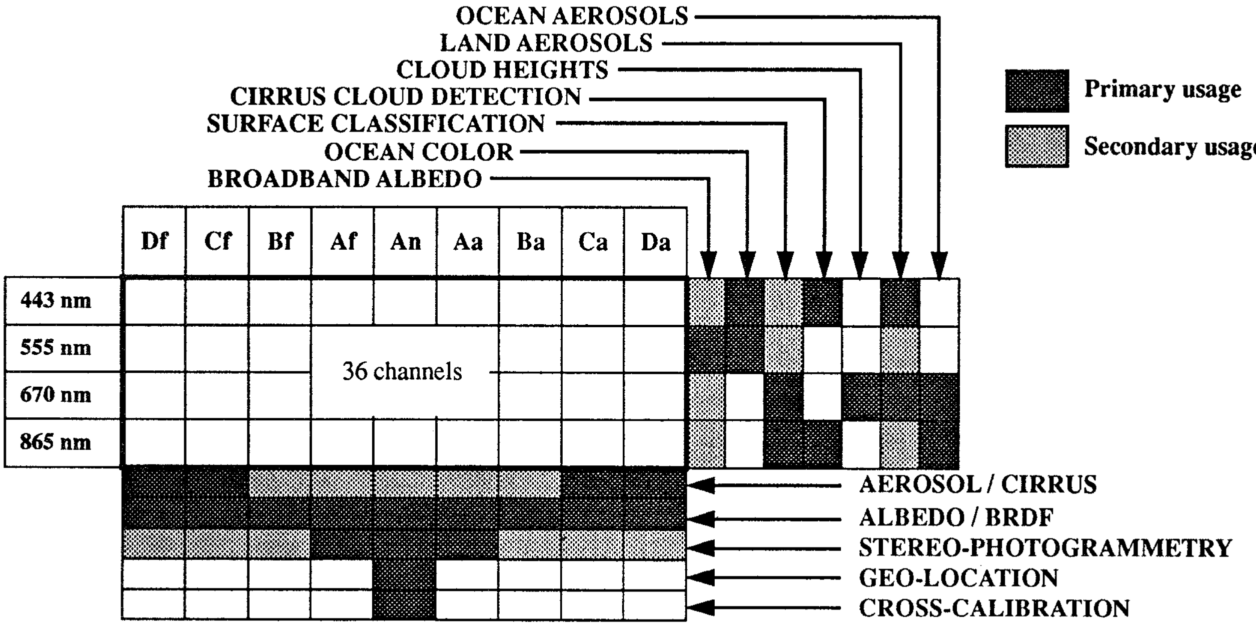

Figure 1. Measurement objectives of the nine cameras and four bands of the MISR instrument

filters. Masks are placed over the epoxy bond lines between the different filters in order to prevent white light from leaking to the focal plane. The filters use ion assisted deposition technology to insure stable and durable coatings which will not shift or degrade with age or environmental stresses.

Two complete cameras incorporating "A" and "D" lenses were manufactured for the MISR EM . Thorough testing at the lens and camera levels has been performed in order to characterize the camera signal-to-noise ratios, point-spread and modulation transfer function response, distortion, radiometric response, and spectral and polarimetric characteristics. For the most part, the camera performance has verified the engineering design, and excellent optical performance, signal-to-noise ratio, dynamic range, and radiometric linearity has been observed. One camera has been placed through and survived stand-alone vibration testing.

EM camera testing has been invaluable in uncovering a number of mechanical and optical performance anomalies in the cameras for which fixes have been identified and for which camera re-testing has established the efficacy of the design corrections. Camera manufacture has now progressed from the EM stage to fabrication of the flight cameras.

Structural Design

The MISR instrument configuration includes the optical bench and the primary support structure (PSS). The optical bench holds the nine cameras at their light-admitting end with the detector end cantilevered into the instrument cavity. The fore-aft cameras are paired in a symmetrical arrangement and set at fixed view angles on the optical bench. In addition to the cameras, the optical bench contains calibration hardware, described in the next section. The PSS provides kinematic attachment to the spacecraft bus and is designed to maintain rigid support for the optical bench. The instrument enclosure provides a structural mount for the nadir-facing radiators. In addition, it houses the optical bench assembly, the instrument system electronics, and the flight computer.

The integrated EM instrument has recently successfully undergone vibration testing. The EM optical bench and PSS will be refurbished for use on the flight instrument.

CALIBRATION

Because both absolute radiometric accuracy (±3% uncertainty at maximum signal) as well as angle-to-angle accuracy (±1% uncertainty at maximum signal) are important to the MISR experiment, specialized hardware has been incorporated into the instrument design. Among the primary elements of the MISR On-Board Calibrator (OBC) are two deployable sun-reflecting calibration plates containing diffusely reflecting panels of Spectralon, a high reflectance, nearly lambertian material. The two symmetrical calibration plate devices are fastened to the optical bench. MISR will be recalibrated, in-flight, at approximately monthly intervals. As MISR employs detector standards to achieve a radiometric scale, the OBC contains four stationary packages of radiation resistant photodiodes, two facing the nadir and two aligned with the "D" cameras; four high quantum efficiency (HQE) diode packages; and the goniometer, a modular assembly containing an actuated radiation resistant diode package on a swinging arm to view the calibration plates over a range of view angles.

REMOTE SENSING OF AEROSOLS

A principal observational goal of the MISR experiment is to monitor global and regional trends in abundance and optical properties of aerosols in the Earth's troposphere. Aerosol information derived from MISR will also be used in the atmospheric correction of MISR surface imagery.

The primary parameters to be retrieved are tropospheric aerosol optical depth and a compositional model identifier. Implementation of the aerosol retrieval strategy requires pre-launch generation of a dataset containing the physical and optical properties of aerosol particles representative of a wide range of environmental conditions. Following this, a dataset containing predicted top-of-atmosphere (TOA) radiances for this range of models is generated, for three surface boundary conditions: (1) dark water, i.e., a Fresnel reflector roughened by wave facets and whitecaps; (2) dense, dark vegetation (DDV), containing a set of pre-determined surface bidirectional reflectance models; and (3) a black surface. The first case is used primarily over ocean, and a land/water mask is used to identify its applicability. If no dark water is present in the scene, a vegetation index is calculated to determine the presence of DDV. Finally, an algorithm developed for use over land surfaces containing spatial contrasts is applied, if dark water or DDV are not present. This algorithm uses the black surface case as input, and differs from the dark water and DDV retrieval methods in that it does not use the observed radiances directly, but instead uses the presence of spatial contrasts to derive an Empirical Orthogonal Function (EOF) representation of the angular variation of the scene reflectance, which is then used to estimate the scene path radiance (the radiance field reflected from the atmosphere without interacting with the surface). The TOA radiances for the suite of aerosol models are contained in the Simulated MISR Ancillary Radiative Transfer (SMART) Dataset. Residuals between quantities derived from the observed MISR radiances and SMART radiances are minimized to establish the best-fitting aerosol optical depth and compositional model. For each of the three retrieval paths, optical depth constraints, such as the maximum allowable optical depth, based on the darkest radiance observed in the scene, are calculated. Conceptual flow diagrams of the retrieval pathways are shown in Fig. 2. Calculations have demonstrated that a retrieval accuracy in optical depth of the larger of 0.05 or 10%, and distinguishability between different compositional and size models based on their angular signatures, are feasible for a wide range of aerosol types.

ACKNOWLEDGMENTS

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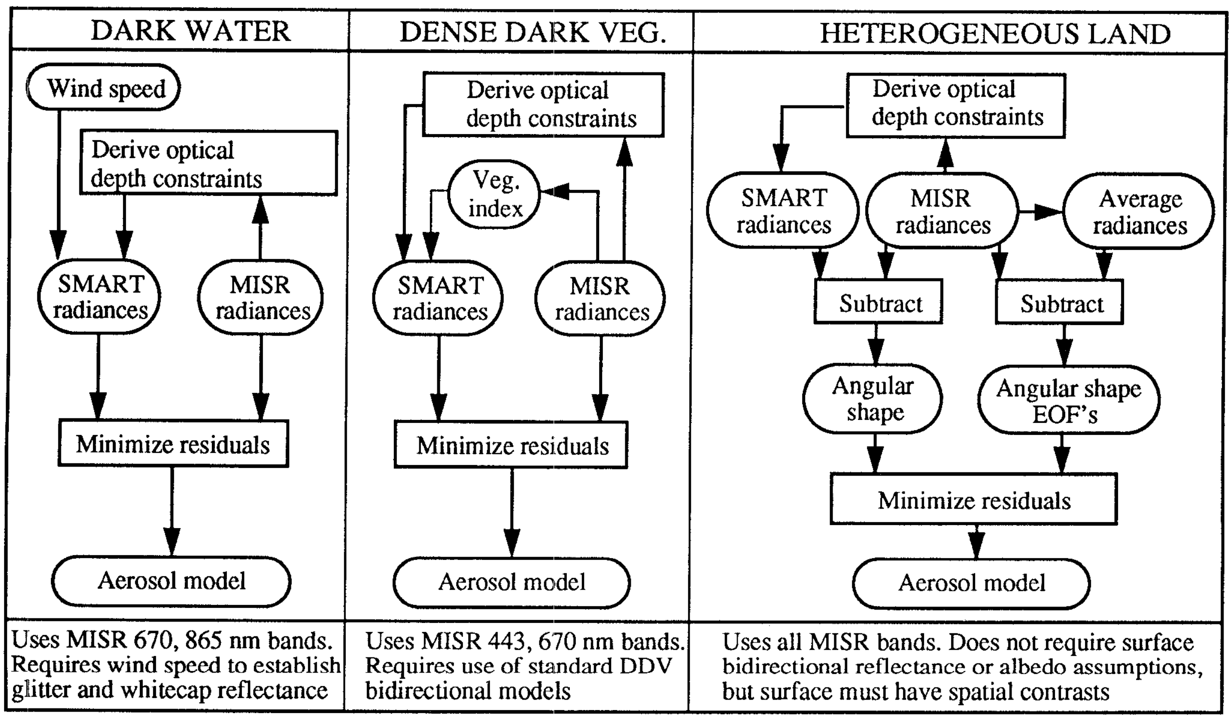

Figure 2. MISR aerosol retrieval strategies