Anticipated results from the EOS Terra Multi-angle Imaging SpectroRadiometer

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JPL
Jet Propulsion Laboratory
California Institute of Technology
MISR
Multi-angle Imaging Spectro-Radiometer
Sunlight drives the Earth’s climate system and natural objects reflect and scatter sunlight diffusely—into all directions.

The amount of energy absorbed and reflected are fundamental climate parameters.

Accurate retrievals of geophysical quantities (e.g., aerosol optical depth, cloud albedo, vegetation productivity) require physical scene classification.

Multi-angle images provide such information, e.g.,
--aerosol type
--cloud height and morphology
--biome type
SCIENCE RATIONALE FOR NINE CAMERAS / FOUR BANDS

- Primary usage
  - OCEAN AEROSOLS
  - LAND AEROSOLS
- Secondary usage
  - CLOUD HEIGHTS
  - CIRRUS CLOUD DETECTION
  - SURFACE CLASSIFICATION
  - OCEAN COLOR
  - BROADBAND ALBEDO

<table>
<thead>
<tr>
<th>Band</th>
<th>Df</th>
<th>Cf</th>
<th>Bf</th>
<th>Af</th>
<th>An</th>
<th>Aa</th>
<th>Ba</th>
<th>Ca</th>
<th>Da</th>
</tr>
</thead>
<tbody>
<tr>
<td>446 nm</td>
<td>70.5°</td>
<td>60.0°</td>
<td>45.6°</td>
<td>26.1°</td>
<td>0.0°</td>
<td>26.1°</td>
<td>45.6°</td>
<td>60.0°</td>
<td>70.5°</td>
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<tr>
<td>558 nm</td>
<td></td>
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<td></td>
<td></td>
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<td></td>
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<td></td>
<td></td>
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<tr>
<td>672 nm</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>866 nm</td>
<td></td>
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</table>

36 channels

- AEROSOL / CIRRUS
- ALBEDO / BRDF
- STEREO
- GEO-LOCATION
- CROSS-CALIBR.
How do spatial and seasonal variations of different cloud types affect the planetary solar radiation budget? To what degree can clouds act to amplify or dampen the Earth’s response to global warming due to greenhouse gases?

- Regional studies of the role of clouds in radiation require measurements of radiation budgets as a function of scene type
- Coarse-resolution across-track scanners do not see the same region from different directions, rely heavily on scene identification algorithms to construct statistical populations, and can incur biases due to increasing target area with angle
- Nadir imagers cannot always detect cirrus clouds due to restricted phase angle coverage; must combine data from many geographic locations to generate BRDFs

MISR will provide:

- Scene-dependent anisotropic reflectance models and spectral radiative forcing
- Direct integration of multi-angle reflectances to obtain high spatial resolution spectral albedos with global coverage
- Validation of coarse resolution products from other sensors (CERES)
- Cloud elevations using stereo-imagery
- Parameterizations of cloud-radiative effects for GCMs
Is there a detectable trend in global aerosol loading, and if so, what are the anticipated climatic and environmental consequences?

- Human activities such as fossil fuel burning, slash-and-burn agriculture, and deforestation can lead to changes in the abundance and composition of tropospheric aerosols.

- Changes in aerosol burden can have significant climatic effects, either directly, or by causing changes to cloud properties.

- Net radiative effect of aerosols (i.e., whether they heat or cool the surface) depends on optical properties and albedo of underlying surface. Effect is regionally variable due to heterogeneity of land surface and spatial variability in aerosol types.

- Global aerosol burden and net effect on energy budget is currently undetermined.

**MISR will provide determinations of:**

- Aerosol optical properties and abundances over land and ocean, routinely.
- Regional and global trends.
- Aerosol forcing on shortwave radiative energy budgets.
- Cloud albedos in pristine and polluted environments.
What are the climatic implications of natural and human-induced modifications to the structure, distribution, and extent of the Earth’s forests, deserts, and cryosphere? How widespread are the effects of human activities, and how rapidly are changes occurring?

- Terrestrial surfaces are not lambertian and hemispherical albedos cannot be inferred from nadir reflectances
- Structural information cannot be retrieved from nadir spectral data alone

**MISR will provide, routinely and globally:**

- Bidirectional reflectance distributions (which are governed by surface optical properties and geometry) for soils, snow, ice, and vegetated surfaces, which will be used to improve radiative boundary conditions of climate models
- Improved surface cover classification using angular signature information
- Land surface topography at moderate resolution
What are the present fluxes of energy and mass (CO$_2$ and H$_2$O) across the vegetation-atmosphere interface? What is the impact of land surface processes on climate variables such as rainfall patterns?

- Explicit inclusion of a vegetation radiative transfer and evapotranspiration model in a GCM led to better agreement between calculated and observed energy and rainfall fluxes (Sellers et al., 1986; Sato et al., 1989)

- Realistic modeling of energy (radiation, heat) and mass (water, carbon dioxide) transfer between the biosphere and atmosphere requires determination of canopy structure and absorbed photosynthetically active radiation (APAR)

MISR will provide, routinely and globally:

- Surface hemispherical albedos in the visible and near-IR, which are needed for estimating surface energy balance and evaporation rates, vegetation canopy APAR, and canopy photosynthesis and transpiration rates
<table>
<thead>
<tr>
<th>Unique measurement</th>
<th>Comment</th>
</tr>
</thead>
</table>
| Top-of-atmosphere, cloud, and surface anisotropic reflectance                      | Needed for determining albedo and understanding how target geometry governs radiative properties. MISR is the only instrument capable of providing such data with all of these attributes:  
  - routine acquisition, within short time intervals for individual scenes  
  - global coverage  
  - sufficient spatial resolution to provide unambiguous scene identification and to minimize non-linear effects associated with scene heterogeneity  
  - very high off-nadir view angles, both fore and aft  |
| Aerosol burden, optical properties, and shortwave radiative forcing over land      | Needed for studies of aerosol sources, trends, climatic effects, and atmospheric corrections. MISR uses multi-angle information to separate out surface from atmosphere, and:  
  - is the only instrument with dedicated multi-angle imagery to monitor aerosols routinely over land  
  - enables aerosol retrievals over a much wider range of land surface and atmospheric conditions than possible with nadir imagers  |
<table>
<thead>
<tr>
<th>Unique measurement</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scattering phase functions of aerosols and cirrus clouds</td>
<td>Needed to determine whether net radiative effect is cooling or heating, and to improve and validate aerosol retrievals over ocean. MISR provides direct observations over a wide range of phase angles and offers the only way to observe geographic variations in cirrus scattering properties globally and consistently</td>
</tr>
<tr>
<td>Surface spectral albedo</td>
<td>Needed to determine:</td>
</tr>
<tr>
<td></td>
<td>• shortwave radiative fluxes, feedbacks between surface (biosphere, cryosphere) and atmosphere</td>
</tr>
<tr>
<td></td>
<td>• mass fluxes between terrestrial vegetation and the atmosphere</td>
</tr>
<tr>
<td></td>
<td>Can only be determined accurately with multi-angle observations and simultaneous atmospheric correction. MISR provides the required data routinely, globally, and with high spatial and temporal resolution, particularly in the climatically important ice- and snow-covered polar regions</td>
</tr>
<tr>
<td>Surface and cloud elevations</td>
<td>Needed for geomorphologic studies, topographic corrections, and cloud identification. Provided using MISR’s stereoimaging capability</td>
</tr>
</tbody>
</table>
MISR AND AirMISR INSTRUMENTS

MISR on Terra spacecraft

AirMISR on NASA ER-2 aircraft
<table>
<thead>
<tr>
<th>Parameter</th>
<th>MISR</th>
<th>AirMISR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of cameras</td>
<td>9</td>
<td>1 (gimballed)</td>
</tr>
<tr>
<td>View angles</td>
<td>0.0°, 26.1°, 45.6°, 60.0°, 70.5° (fore and aft)</td>
<td>Same</td>
</tr>
<tr>
<td>Spectral bands</td>
<td>446, 558, 672, 866 nm</td>
<td>Same</td>
</tr>
<tr>
<td>Ground sampling (georectified images)</td>
<td>275 m - 1.1 km</td>
<td>27.5 m</td>
</tr>
<tr>
<td>Swath width</td>
<td>360 km (9 day global coverage)</td>
<td>11 km</td>
</tr>
<tr>
<td>Time to observe single target</td>
<td>7 minutes</td>
<td>13 minutes</td>
</tr>
<tr>
<td>Azimuths relative to principal plane</td>
<td>From EOS-AM orbit 30° - 90°, depends on latitude/season</td>
<td>Selectable flight lines</td>
</tr>
<tr>
<td>Radiometric calibration</td>
<td>On-board and vicarious ± 3% at full signal</td>
<td>Laboratory and vicarious ± 3% at full signal</td>
</tr>
<tr>
<td>Signal-to-noise ratio</td>
<td>&gt; 700 at full signal</td>
<td>Same</td>
</tr>
<tr>
<td>Quantization</td>
<td>14 bits</td>
<td>Same</td>
</tr>
</tbody>
</table>
MISR DATA PROCESSING FLOW

Reformatting / Annotation Subsystem
Level 1A
- Raw data ingest
- Data reformatting
- Data annotation

Radiometric / Geometric Subsystems
Level 1B
- Radiance scaling
- Radiance conditioning
- Geometric rectification and registration
- Cloud detection

Top-of-Atmosphere / Cloud Subsystem
Level 2
- Reflecting level parameter generation
- Cloud classification
- TOA albedo calculation

Research / Modeling Subsystem
Level 4
- Model generation
- Data analysis
- Research publication

Gridding / Binning Subsystem
Level 3
- High-level parameter generation
- Global gridding
- Temporal binning

Aerosol / Surface Subsystem
Level 2
- Retrieval path determination
- Aerosol retrieval
- Surface retrieval

Validation and Quality Assessment
SOM PROJECTION PROVIDES REQUIRED CO-REGISTRATION

Image grid

"Physical" MISR instrument

9 angles x 4 bands

Earth's surface

36 non-registered images

"Virtual" MISR instrument

9 angles x 4 bands

36 co-registered images

WGS84 ellipsoid

SOM grid
## MISR LEVEL 2 ATMOSPHERE PRODUCTS

<table>
<thead>
<tr>
<th>Product</th>
<th>Process</th>
<th>BRDF Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflecting level (cloud or surface) altitude</td>
<td>Multi-angle stereoscopic retrieval</td>
<td>None</td>
</tr>
<tr>
<td>Aerosol optical depth and compositional type</td>
<td>Aerosol retrieval over dark ocean, dense dark vegetation (DDV), or heterogeneous land</td>
<td>Heterogeneous land: Empirical Orthogonal Function angular expansion&lt;br&gt;DDV: Rahman-Pinty-Verstraete (3 parameter) empirical BRF model&lt;br&gt;Ocean: Cox-Munk glitter + whitecaps</td>
</tr>
<tr>
<td>Top-of-atmosphere BRFs and albedos</td>
<td>Geometric registration of multi-angle data to reflecting level altitude, and angular integration</td>
<td>Clear sky: Linearized form of Rahman-Pinty-Verstraete model&lt;br&gt;Cloudy sky: Physically based Monte-Carlo radiative transfer models</td>
</tr>
</tbody>
</table>

BRF - Bidirectional Reflectance Factor
<table>
<thead>
<tr>
<th>Product</th>
<th>Process</th>
<th>BRDF Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spectral HDRFs and BHR</td>
<td>Requires aerosol retrieval and atmospheric correction of multi-angle measurements</td>
<td>Surface-leaving radiance form: ( L(\mu, \phi - \phi_0) = L_0(\mu) + L_1(\mu) \cos(\phi - \phi_0) )</td>
</tr>
<tr>
<td>Spectral BRFs, DHR, and BRF model parameters</td>
<td>Inversion of multi-angle HDRFs using a multi-parameter BRF model</td>
<td>Linearized form of Rahman-Pinty-Verstraete model</td>
</tr>
<tr>
<td>Biome type, LAI, and FPAR</td>
<td>Spectral BRFs and BHR/DHR compared to values for various canopy/soil models in a look-up table (LUT)</td>
<td>3-D radiative transfer and physically-based canopy models</td>
</tr>
</tbody>
</table>

HDRF - Hemispherical-Directional Reflectance Factor (proportional to surface-leaving radiance)
BHR - Bihemispherical Reflectance (albedo under ambient illumination)

BRF - Bidirectional Reflectance Factor
DHR - Directional-Hemispherical Reflectance (albedo under direct illumination only)
AirMISR
ANGULAR REFLECTANCES

- Grassy area
  12/5/98
  Pasadena, CA
  BRF vs. View zenith angle (deg.)

- Urban area
  12/5/98
  Pasadena, CA
  BRF vs. View zenith angle (deg.)

- Dry lake bed
  12/11/98
  Rogers Dry Lake, CA
  BRF vs. View zenith angle (deg.)

- Stratus cloud
  6/3/98
  SHEBA Station, Alaska
  BRF vs. View zenith angle (deg.)
Statistical summaries of Level 2 products
- Means, covariances, and frequencies

Component products:
- Global Aerosol Product
- Global Land Surface Product
- Global Reflecting Level Product
- Global Cloud Classification Product
- Global Albedo Product

Joint products:
- Global Climate Product

1° x 1° equi-angle grid
Generated monthly
### Global Aerosol Product
- Overall best estimate optical depth
- Model class optical depths and retrieval fit measures (clean, industrial, biomass burning, and dusty—continental and maritime)

### Global Land Surface Product
- Bidirectional reflectance analytical model parameters
- Biome type histogram (frequency of barren, water, grasses and cereal crops, shrublands, broadleaf crops, savanna, broadleaf forest, needle forest)
- Directional hemispherical reflectance (albedo): spectral and PAR-integrated
- Leaf Area Index and Fractional Absorbed Photosynthetically Active Radiation

### Global Reflecting Level Product
- Reflecting Level Reference Altitude (derived stereoscopically)
**Global Cloud Classification Product**

- Land and water fractions
- Altitude-binned clear/cloud fractions

**Global Albedo Product**

- Scene classifiers (cloudy/clear, surface type, high cloud presence, cloud phase, cloud altitude, cloud texture)
- Top-of-atmosphere spectral albedo
- Bidirectional Reflectance Factors at MISR’s 9 angles, red band
<table>
<thead>
<tr>
<th>Global Climate Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Best estimate aerosol optical depth</td>
</tr>
<tr>
<td>Top-of-atmosphere spectral albedo</td>
</tr>
<tr>
<td>Cloudy/clear scene classifier</td>
</tr>
<tr>
<td>Biome type/ocean scene classifier</td>
</tr>
<tr>
<td>Reflecting level reference altitude</td>
</tr>
<tr>
<td>Fractional absorbed photosynthetically active radiation</td>
</tr>
<tr>
<td>Normalized difference vegetation index</td>
</tr>
<tr>
<td>Leaf area index</td>
</tr>
</tbody>
</table>