MODIS Atmosphere Data Products and Status

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Outline

- MODIS atmosphere data products
- Physical principles behind the remote sensing of selected parameters
- Surface bidirectional reflectance function
  - Examples of recent datasets obtained in the Arctic
  - Progress in analysis of all acquired datasets
MODIS Atmosphere Products

- Cloud mask for distinguishing clear sky from clouds
- Cloud radiative and microphysical properties
  - Cloud top pressure, temperature, and effective emissivity
  - Cloud optical thickness, thermodynamic phase, and effective radius
  - Thin cirrus reflectance in the visible
- Aerosol optical properties
  - Optical thickness over the land and ocean
  - Size distribution (parameters) over the ocean
- Atmospheric moisture and temperature gradients
- Column water vapor amount
- Gridded time-averaged (level-3) atmosphere product
  - Daily (1° × 1°)
  - 8-day (1° × 1°)
  - Monthly (1° × 1°)
  - Mean, standard deviation, marginal probability density function, joint probability density functions
Cloud Mask

- Some cloud types (viz., cirrus, low stratus, and small cumulus) are difficult to detect using visible & infrared thresholds alone
- MODIS cloud mask will use multispectral imagery to indicate whether the scene is clear, cloudy, or affected by shadows
- Cloud mask is input to rest of atmosphere, land, and ocean algorithms
- Mask will be generated at 250 m and 1 km resolutions
- Mask will use, for the first time, 17 spectral bands ranging from 0.55 - 13.93 µm (including new 1.38 µm band)
- Algorithm based on radiance thresholds in the infrared, and reflectance thresholds in the visible and near-infrared
- Mask uses different spectral tests for 10 different processing paths

<table>
<thead>
<tr>
<th></th>
<th>Tested</th>
<th></th>
<th>Total Tests</th>
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<tbody>
<tr>
<td></td>
<td>Daytime</td>
<td>Nighttime</td>
<td>Daytime</td>
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<tr>
<td>Desert</td>
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<td>4</td>
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</tbody>
</table>
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October 16, 1998
Cloud Properties

- Twelve MODIS bands will be utilized to derive cloud properties
  - Visible and near-infrared bands
    » daytime retrievals of cloud optical thickness and effective radius
    » 1.6 µm band will be used to derive thermodynamic phase of clouds during the daytime (post-launch)
  - Thermal infrared bands
    » determination of cloud top properties, including cloud top altitude, cloud top temperature, and thermodynamic phase
    » thermal band at 11.03 µm will be used to make thermal emission corrections to the 3.75 µm band
The reflection function of a nonabsorbing band (e.g., 0.66 μm) is primarily a function of optical thickness.

The reflection function of a near-infrared absorbing band (e.g., 2.14 μm) is primarily a function of effective radius.
- Clouds with small drops (or ice crystals) reflect more than those with large particles.

For optically thick clouds, there is a near orthogonality in the retrieval of \( \tau_c \) and \( r_e \) using a visible and near-infrared band.
Scattering Phase Function: Ice Cloud Model

Yang and Liou (1996)
Weighting Functions for CO$_2$ Slicing

- CO$_2$ slicing method
  - ratio of cloud forcing at two near-by wavelengths
  - assumes the emissivity at each wavelength is same, and cancels out in ratio of two bands
- The more absorbing the band, the more sensitive it is to high clouds
  - technique the most accurate for high and middle clouds
- MODIS will be the first sensor to have CO$_2$ slicing bands at high spatial resolution
Aerosol Properties

- Eight MODIS bands will be utilized to derive aerosol properties
  - 0.47, 0.55, 0.65, 0.86, 1.24, 1.64, 2.13, and 3.75 µm
  - Ocean
    - reflectance contrast between cloud-free atmosphere and ocean reflectance (dark)
    - aerosol optical thickness (0.47-2.13 µm)
    - size distribution characteristics (ratio between the assumed two log-normal modes, and the mean size of each mode)
  - Land
    - dense dark vegetation and semi-arid regions determined where aerosol is most transparent (2.13 and 3.75 µm)
    - contrast between Earth-atmosphere reflectance and that for dense dark vegetation surface (0.47 and 0.66 µm)
    - enhanced reflectance and reduced contrast over bright surfaces (post-launch)
    - aerosol optical thickness (0.47 and 0.66 µm)
Aerosol Properties

The diagram illustrates the transmission properties of different satellite instruments across various wavelengths. The x-axis represents wavelength in micrometers (µm), ranging from 0.3 to 1.0. The y-axis represents transmission values.

Each instrument is color-coded and marked with specific symbols indicating their use for different types of observations, such as ocean, land, land-ocean, and cloud mask. Some instruments are not used for aerosols.

Instruments include:
- AVHRR
- TOMS
- ATSR-2
- OCTS
- POLDER
- SeaWiFS
- MISR
- MODIS
- MERIS
- GLI

Each instrument has different transmission characteristics across the wavelength spectrum, with some marked as 'Not Used for Aerosols.'
**Aerosol Properties**

**Near-infrared and thermal infrared**

![Graph showing transmission vs. wavelength for different sensors: TOMS, ATSR-2, OCTS, MODIS, GLI. The graph compares transmission in the near-infrared and thermal infrared regions, highlighting which wavelengths are not used for aerosol properties.](image-url)
Aerosol Effects on Reflected Solar Radiation over Land

Biomass burning
Cuiabá, Brazil (August 25, 1995)

R = 0.66 µm
G = 0.55 µm
B = 0.47 µm

θ₀ = 36°

R = 1.65 µm
G = 1.2 µm
B = 2.1 µm
Ångström Exponent

POLDER
April 1997

Angstrom Exponent

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14  December 16, 1998
Aerosol Optical Thickness

OCTS
April 1997

Aerosol Optical Thickness (0.500 µm)

No Data 0.0 0.1 0.2 0.3 0.4 0.5

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December 16, 1998
Three near-infrared bands will be used for column water vapor over reflecting surfaces (land) during the daytime
- 0.905, 0.936, and 0.94 µm

Reference (nonabsorbing) bands will be compared to water vapor absorbing bands
- 0.865 and 1.24 µm

Uncertainties
- 0.01 error in transmittance translates into a 2.5 % error in precipitable water

Four thermal infrared bands will be used to derive total column water vapor under clear sky conditions using sounding techniques
- 6.72, 7.33, 11.03, and 12.02 µm
Column Water Vapor Retrieval

Green and Conel (1995)
Rogers Dry Lake

R = 0.66 µm
G = 0.55 µm
B = 0.47 µm

θ₀ = 36°
Black = 1.2 cm
White = 1.5 cm
June 1999 AERONET (Aerosol Robotic Network)

- Automatic recording and transmitting Sun/Sky Photometers
- Data Base: Aerosol optical thickness, size distribution, phase function & precipitable water
- Collaborative: NASA – instruments/sites and centralized calibration & database
  Non-NASA – instruments/sites
MODIS Atmosphere Status

- MODIS Software
  - All PGEs have been delivered and accepted, with the exception of the level-3 ‘weekly’ product
    » This weekly product is a new addition, but is virtually identical with the monthly product - expected in January 1999

- Documentation
  - All 6 ATBDs developed by the MODIS atmosphere group have been updated and delivered to the EOS Project Science Office
  - Validation Plan currently being updated to include the following new features
    » Input from investigations selected through the validation NRA
    » Recent plans for SAFARI 2000 field campaign in southern Africa in August-September 2000
    » Extended planning through 2004 (current plan ends at December 2000)
    » Updated launch status of AM-1 and PM-1
Cloud Absorption Radiometer

- Goddard Space Flight Center
  - developed in 1982-1983

- University of Washington
  - integrated & flown in 1984 (B-23)
  - principal data from 1987-97 (C-131A)
  - flights after 1998 (CV-580)

- Sensor Characteristics
  - 13 spectral bands ranging from 0.30 to 2.29 µm
  - scan ±95° from horizon on right-hand side of aircraft
  - field of view 17.5 mrad (1°)
  - scan rate 1.67 Hz (100 rpm)
  - data system 8 channels @ 10 bit
  - 395 pixels in scan line
  - 4% reflectance calibration accuracy
Bidirectional Reflectance Measurements

- Roll: ~20°
- Time: ~2 min
- Speed: ~80 m s⁻¹
- Height: ~600 m
- Diameter: ~3 km
- Resolution
  - 10 m (nadir)
  - 270 m (θ = 80°)
- Channels
  - 7 continuously sampled:
    - 0.30 (0.75), 0.47 (0.51), 0.67, 0.87, 1.04, 1.22, and 1.27 µm
  - 2 filter wheel channels used for BRDF measurements
    - (1.64 & 2.20 µm)
Reflection Function

\[ l = 1.64 \, \mu m \]
\[ l = 0.68 \, \mu m \]

Bidirectional Reflectance—Sea Ice

June 23, 1998
\[ \theta_0 = 54.45^\circ \]

\[ \lambda = 1.64 \, \mu m \]
Bidirectional Reflectance—Arctic Stratus

\[ \lambda = 0.68 \, \text{µm} \]

May 29, 1998

\[ \theta_0 = 53.65^\circ \]

\[ \lambda = 1.64 \, \text{µm} \]
Summary

- Surface bidirectional reflectance measurements acquired under the following conditions
  - Cerrado and dense forest (Brazil)
  - Dense smoke layers over forest (Brazil)
  - Snow over tundra and open tundra (Alaska)
  - Fast, first year, and multi-year sea ice (Alaska)
  - Ocean with sun glint (Persian Gulf, Atlantic Ocean, Strait of Juan de Fuca)
  - Great dismal swamp (Virginia)
  - Desert (Saudi Arabia)
  - Oil Fire Smoke (Kuwait)
  - Water and ice clouds (various)