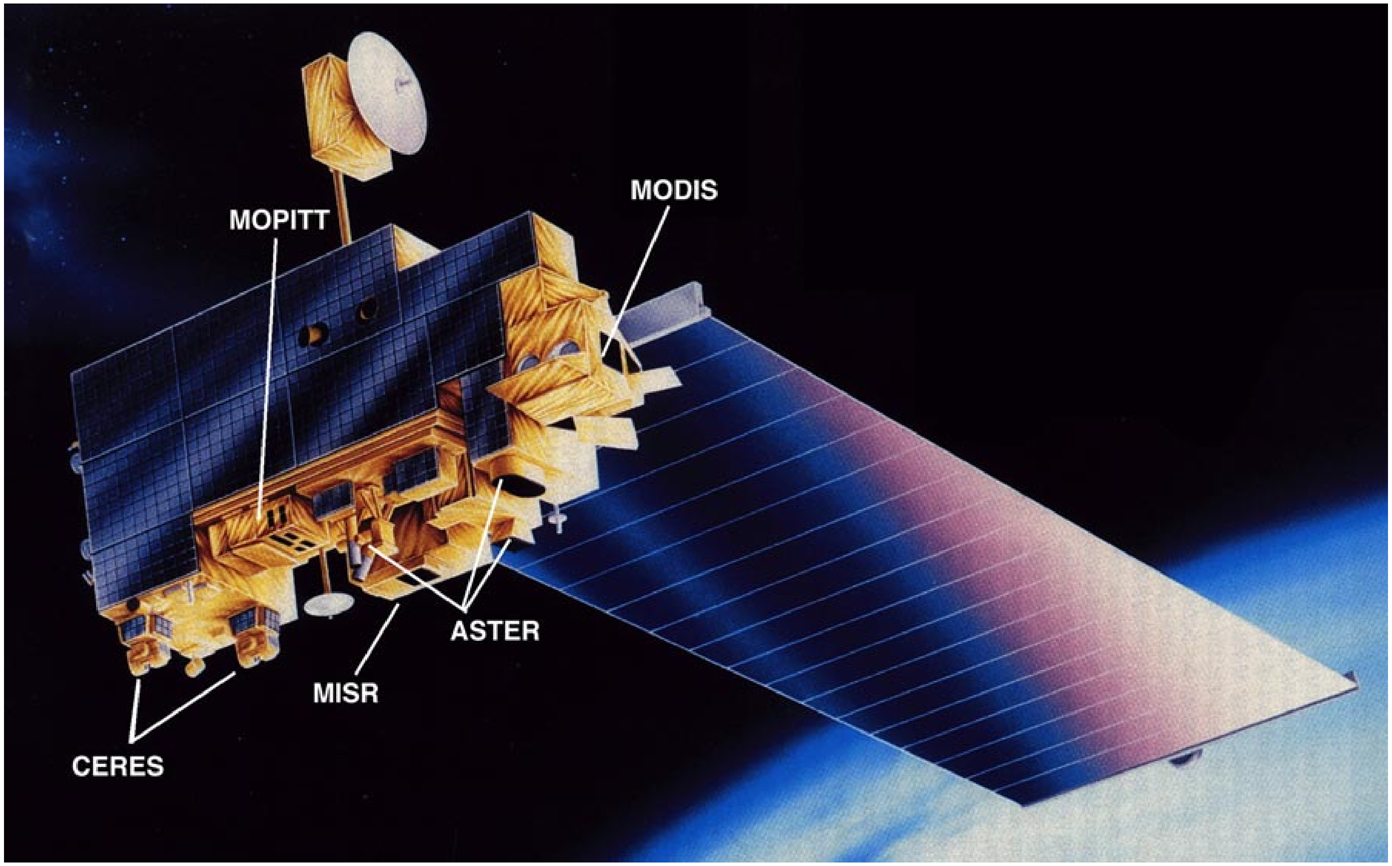
MODIS Atmosphere Validation Plan

Michael D. King, W. Paul Menzel, Yoram J. Kaufman,
Didier Tanré and Bo-Cai Gao

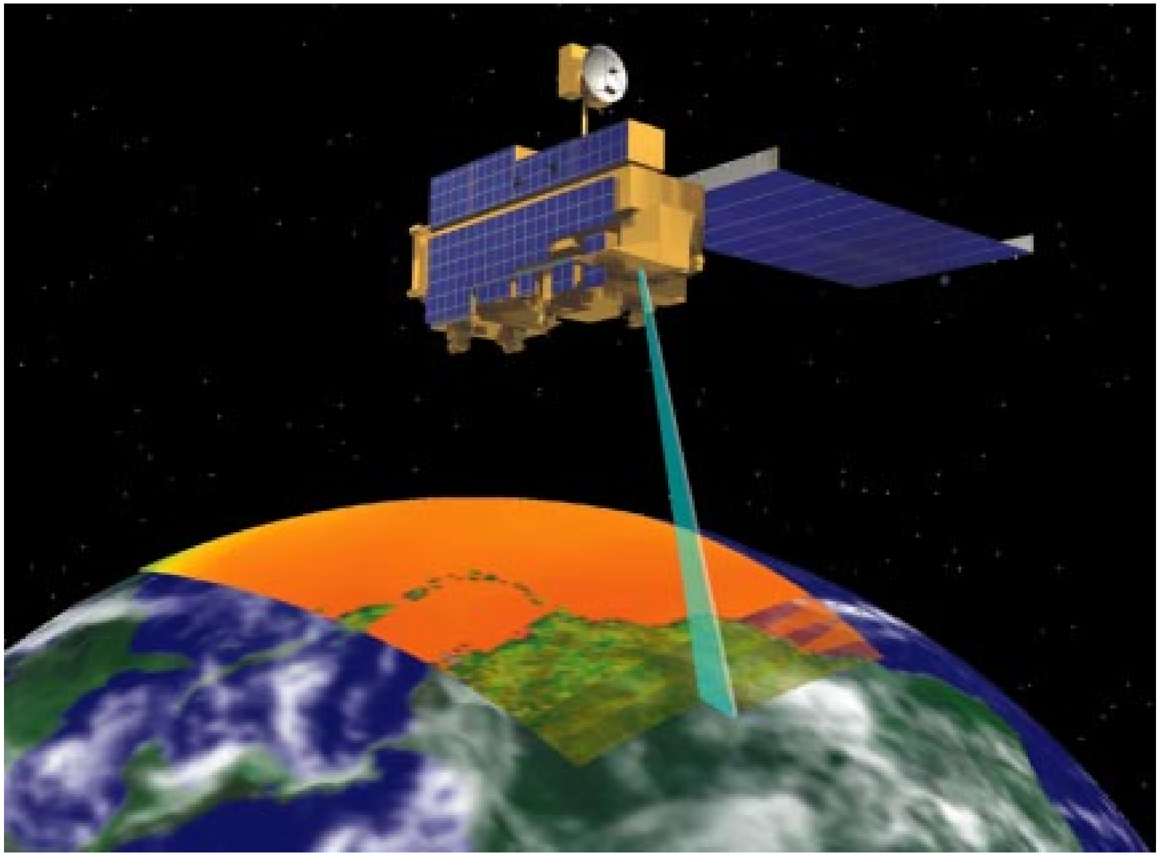
Validation Strategy

- **Field experiments for pre-launch and post-launch validation**
  - **Community field programs (e.g., FIRE ACE, SAFARI 2000)**
  - **MODIS-specific field campaigns (e.g, CALVEX-M, MOBY)**
- **Coordination with ground-based networks to optimize resources**
  - **Continuous basis at specific locations around the globe (e.g., ARM, AERONET, radiosondes)**
  - **Comparisons with land validation sites in Africa, North America, and Australia**
  - **Collaboration with a worldwide effort to derive column precipitable water from a network of surface GPS receivers**
- **Comparisons with data and products from other airborne and spaceborne sensors (e.g., Terra, ADEOS II, and PM-1 instruments)**
- **Close cooperation with EOS validation investigations to meet specific product validation needs**
- **Analysis of trends in atmosphere data products**

Terra



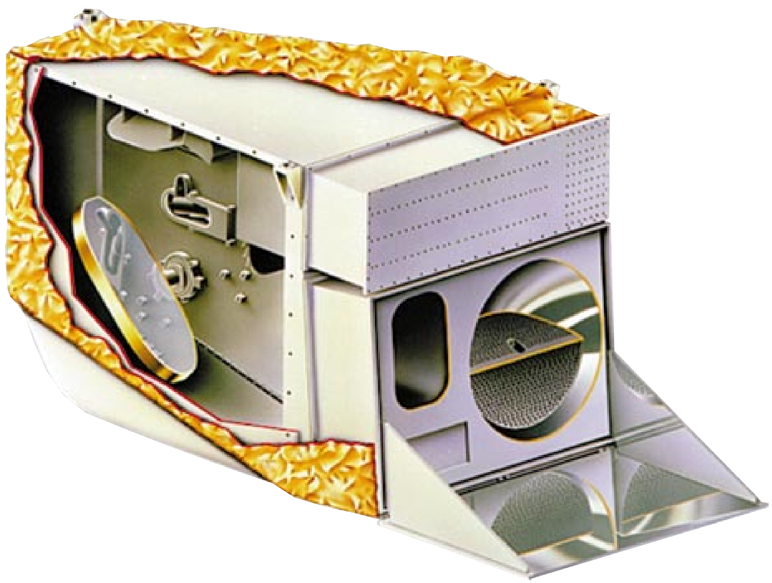
MODerate-resolution Imaging Spectroradiometer (MODIS)



- **MODIS is shown collecting image data of the Earth's surface**
- **SST & NDVI data are shown in the swath, which is 2330 km wide across track**

MODerate-resolution Imaging Spectroradiometer (MODIS)

- NASA, Terra & PM
  - launches 1999, 2000
  - 705 km polar orbits, alternating descending & ascending (10:30 a.m. & 1:30 p.m.)
- Sensor Characteristics
  - 36 spectral bands ranging from 0.41 to 14.385 µm
  - cross-track scan mirror with 2330 km swath
  - Spatial resolutions:
    - » 250 m (bands 1 - 2)
    - » 500 m (bands 3 - 7)
    - » 1000 m (bands 8 - 36)
  - Calibration
    - » 2% reflectance calibration accuracy
    - » onboard solar diffuser & solar diffuser stability monitor
    - » single blackbody viewed each scan
    - » spectral radiometric calibration assembly



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, 8-day, and monthly products**
  - **1° × 1° equal angle grid**
  - **Mean, standard deviation, marginal probability density function, joint probability density functions**

Overall Approach

Environmental Conditions

- **Validation involves intercomparisons under a wide variety of atmospheric conditions and solar illumination angles, and over a wide variety of ecosystems worldwide**
  - **Multilayer clouds systems in the Arctic, Southern Great Plains, and the Rocky Mountains**
  - **Aerosol properties over the ocean as well as land under a wide variety of aerosol sources and characteristics conditions**
  - **Water vapor analysis in both dry and humid conditions**

Approach

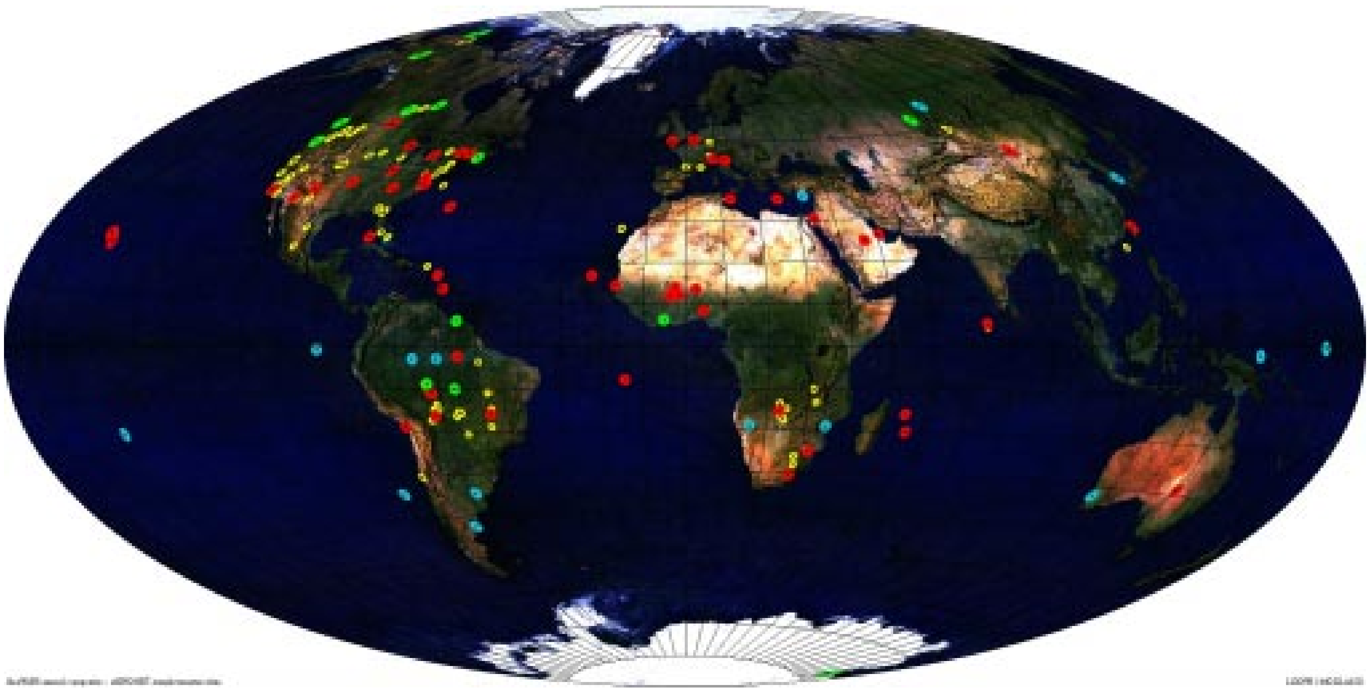
- **Coordination and collocation with higher resolution aircraft data**
- **Intercomparisons with other ground-based and aircraft in situ observations**
- **Intercomparisons with other Terra, ADEOS II, and PM-1 instruments (e.g., MISR, AIRS, AMSR, GLI)**
- **Analysis of trends over time and consistency across boundaries (e.g., land vs ocean, day vs night)**

Primary Sensors used for Algorithm Development

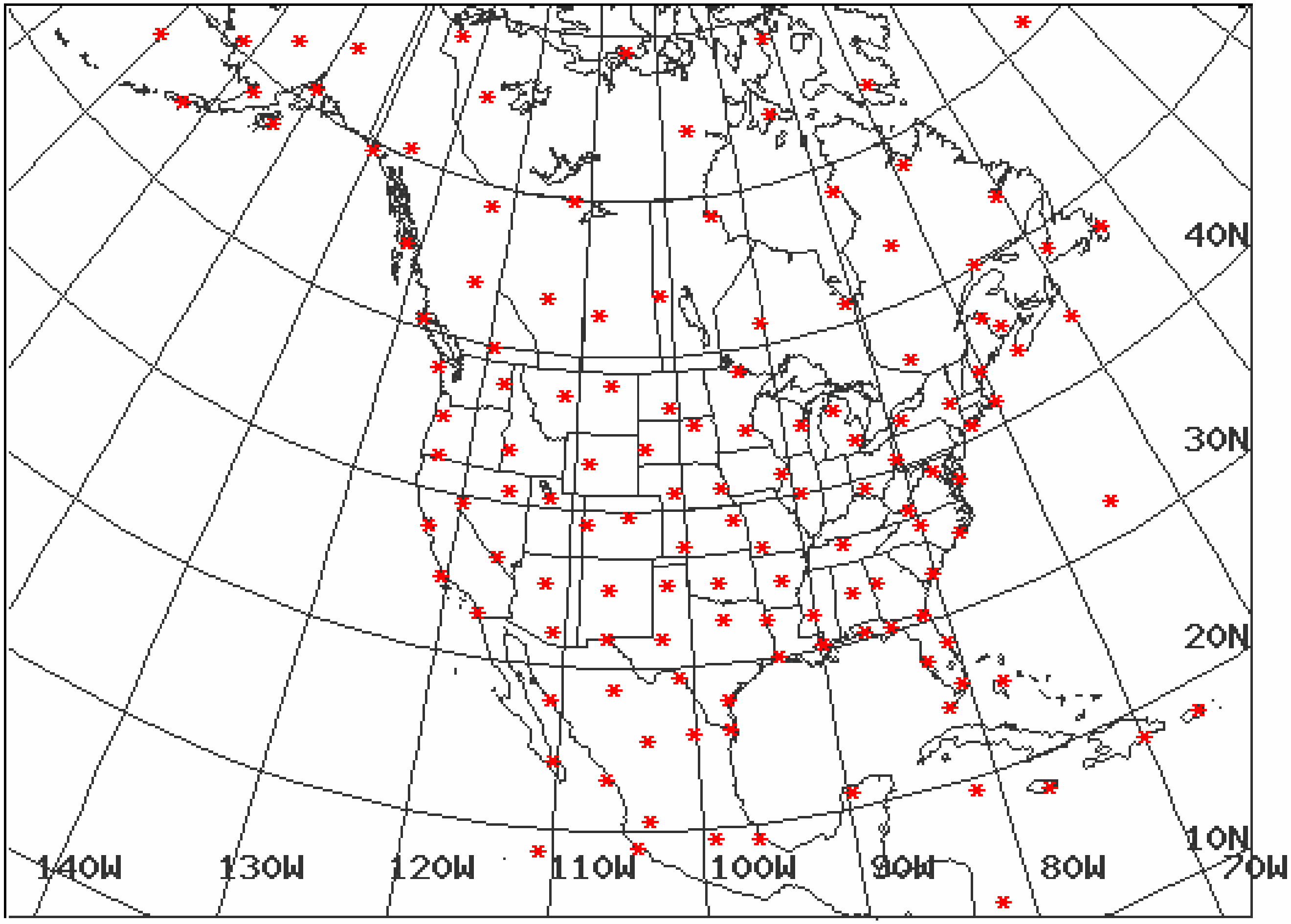
- ER-2 Aircraft
  - MODIS Airborne Simulator (MAS)
  - Scanning High-spectral resolution Interferometer Sounder (S-HIS)
  - Airborne Visible/Infrared Imaging Spectrometer (AVIRIS)
  - Cloud Lidar System (CLS)
- University of Washington CV-580
  - Cloud Absorption Radiometer (CAR)
  - Aerosol and cloud microphysics probes
    - CN and CCN spectrometer
    - aerosol and cloud drop size distribution
    - liquid water content and effective radius probes
- AERONET
  - Network of ground-based sun/sky photometers established and maintained at Goddard Space Flight Center
- Radiosonde Network
  - Used to develop and test water vapor and temperature retrieval algorithms using GOES sounder data

July 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



North American Radiosonde Sites



Terra Validation Investigations

Investigator	*Organization*	*Investigation*
Richard Ferrare	**NASA Langley**	**Validation of aerosol and water vapor profiles by Raman lidar**
Andrew Heymsfield	**NCAR**	**In-situ and remote sensing measurements in support of the EOS/MODIS retrieval algorithm validation program**
Merv Lynch	**Curtin University**	**Temperature and moisture profiles, surface radiation budget, and spectral radiance at the sensor (vicarious calibration sites)**
Gerald Mace	**University of Utah**	**Cloud property and surface radiation observations and diagnostics in support of EOS CERES, MODIS, and MISR validation efforts**
Alexander Marshak	**Univ. of Maryland**	**Validation of cloud optical depths retrieved from EOS/MODIS data**
Steven Platnick	**Univ. of Maryland**	**A study of uncertainties for MODIS cloud retrievals of optical thickness and effective radius**
Taneil Uttal	**NOAA/ETL**	**Validation of CERES cloud retrievals over the Arctic with surface-based millimeter-wave radar**

Sampling Requirements

- Availability of MODIS-derived data products globally from Terra and PM-1 will enable scientists, worldwide, to provide feedback and validation information that will enable improvements in retrievals
  - Not possible for small MODIS science team to assess products under all conditions worldwide
  - Nighttime retrievals will be especially difficult for aerosol and some cloud properties
- Seasonal statistics and trends will be monitored to assess unusual changes in selected geographic and climatologically significant regions

Validation Sites

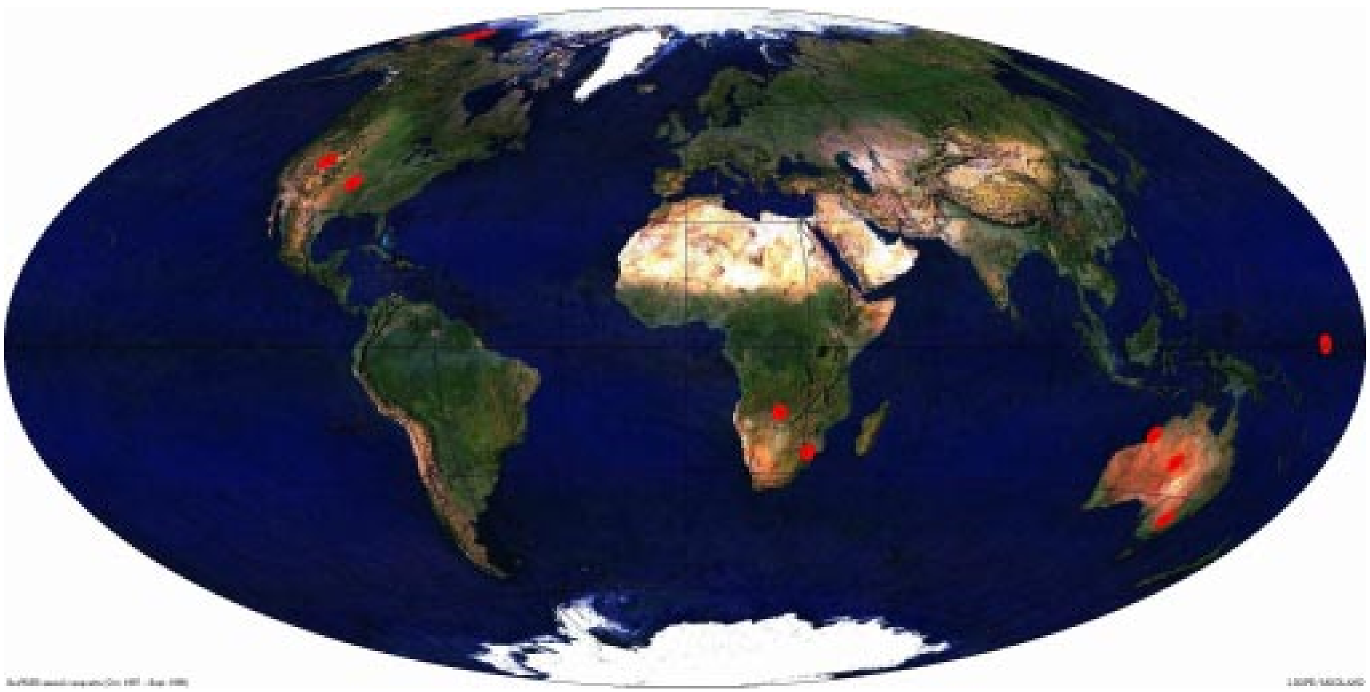
Network	*Location*	*Responsible Investigators*	*Primary Purpose*
AERONET	**Multiple locations in North America, South America, Europe, Africa, Asia, and Oceania**	**Brent Holben Yoram Kaufman Didier Tanré Lorraine Remer**	**Aerosol optical thickness, columnar aerosol size distribution, and precipitable water**
ARM	**Southern Great Plains, North Slope of Alaska, Western Tropical Pacific**	**Paul Menzel Gerald Mace Rich Ferrare Taneil Uttal**	**Cloud base height, temperature and moisture profiles, sky radiance, integrated liquid water path**
Radiosonde	**North America, Latin America**	**Paul Menzel Steve Ackerman**	**Temperature and moisture profiles, clear sky radiance (with forward model)**
FARS	**University of Utah**	**Gerald Mace**	**Cloud mask, cloud boundaries & microphysical structure, aerosol vertical profile**
CIGSN	**Australia**	**Merv Lynch Fred Prata**	**Surface irradiance, clear sky radiance for vicarious calibration of MODIS radiances, radiosondes, sunphotometer**

Validation Sites

Network	*Location*	*Responsible Investigators*	*Primary Purpose*
P-AERI	**South Pole**	**Paul Menzel** **Von Walden**	**Clear sky radiance (IR) and surface measurements for MODIS validation of cold scenes**
MSRN	**Skukuza, South Africa**	**Si-Chee Tsay** **Jeff Privette**	**Surface radiation budget, precipitable water and integrated liquid water path, cloud base altitude**
Balloon	**North America**	**A. Heymsfield**	**Balloon-borne ice crystal replicators for size distribution and habit of ice crystals in upper atmosphere**

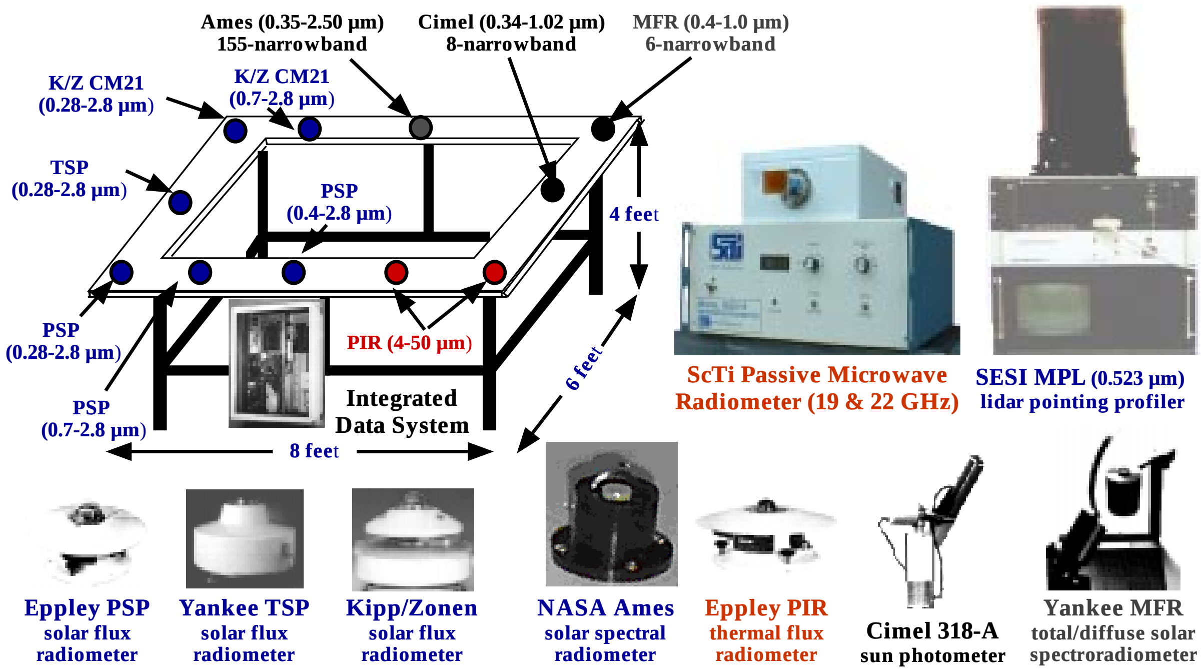
MODIS Atmosphere Surface Sites

- ❑ **Facility for Atmospheric Remote Sensing (FARS) - University of Utah**
- ❑ **Continental Integrated Ground site Network (CIGSN) - Australia**
- ❑ **Mobile Surface Radiation Network (MSRN) - South Africa & Zambia**
- ❑ **ARM - Raman lidar, radar, multi-wavelength backscatter lidar, radiometers**



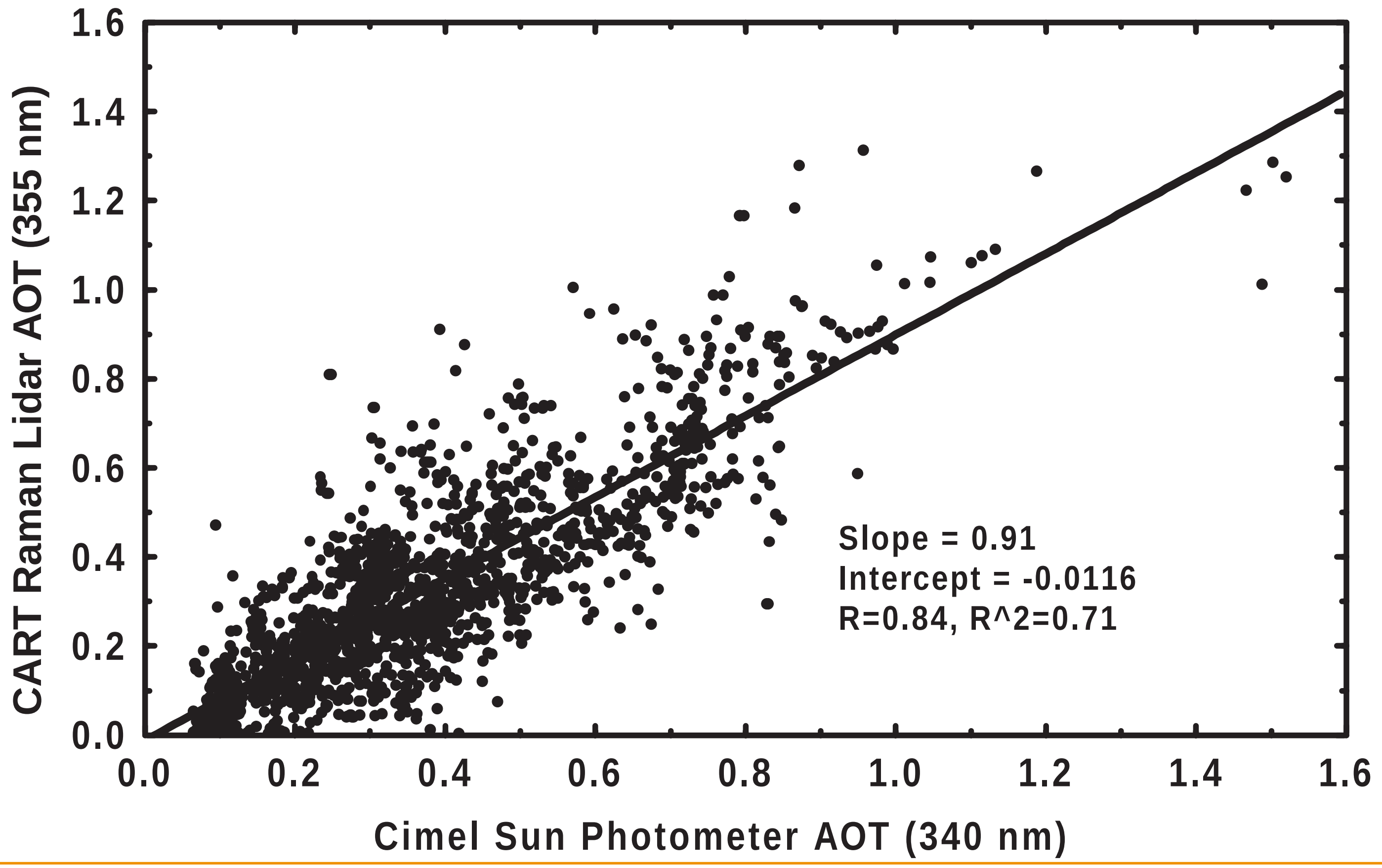
Mobile Surface Radiation Network

- Broadband downwelling/upwelling shortwave and longwave radiation
- Sunphotometer and multi-filter shadow band radiometer for aerosol optical thickness, column water vapor, and diffuse/direct ratio
- Lidar backscattering intensity to infer vertical profiles of aerosols and clouds
- Passive microwave radiometers for column water vapor measurements



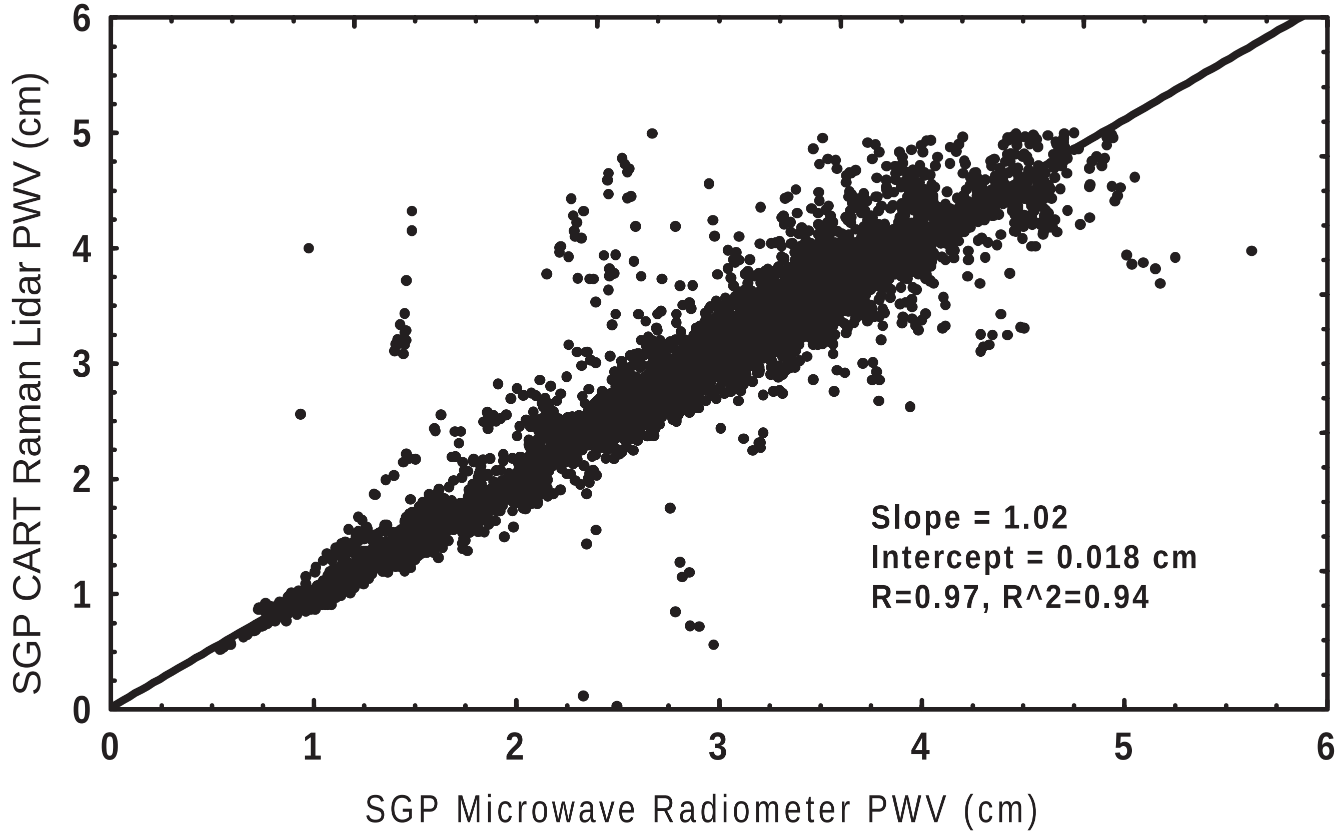
Raman Lidar - Aerosol Validation

- **Comparison of CART Raman lidar and Cimel sunphotometer-derived aerosol optical thickness (Ferrare et al.)**



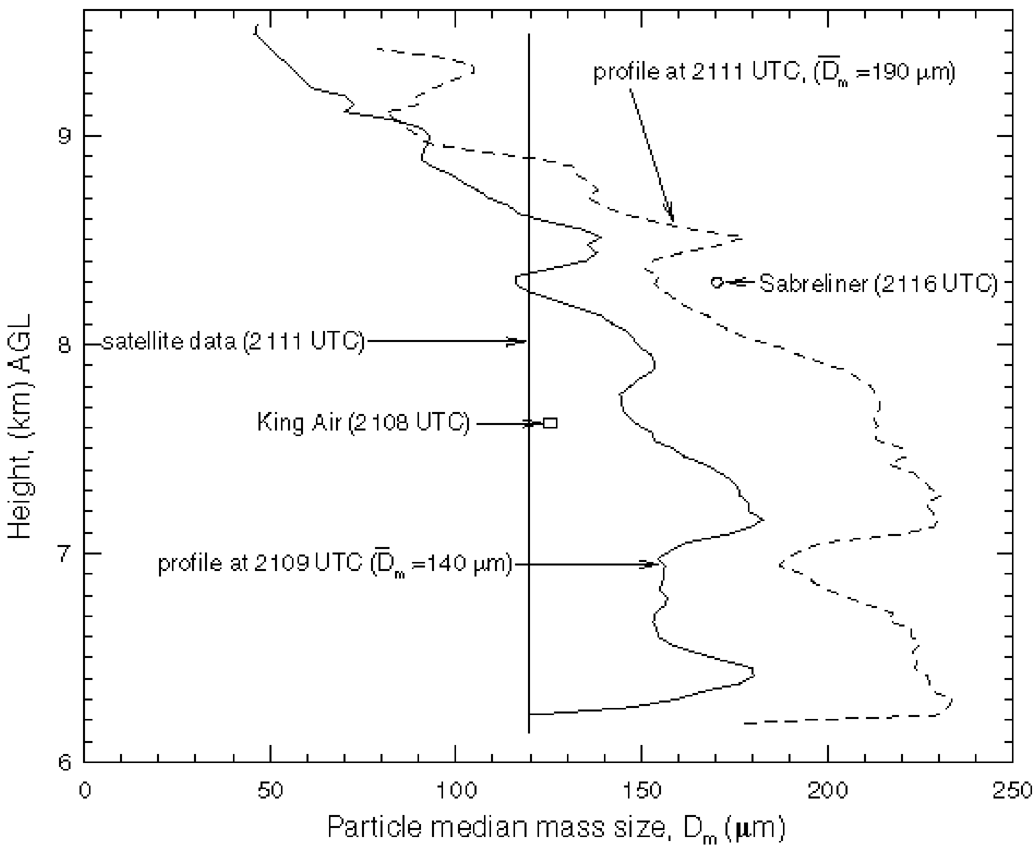
Raman Lidar - Precipitable Water

- Comparison of CART Raman lidar and microwave radiometer-derived total precipitable water (Ferrare et al.)



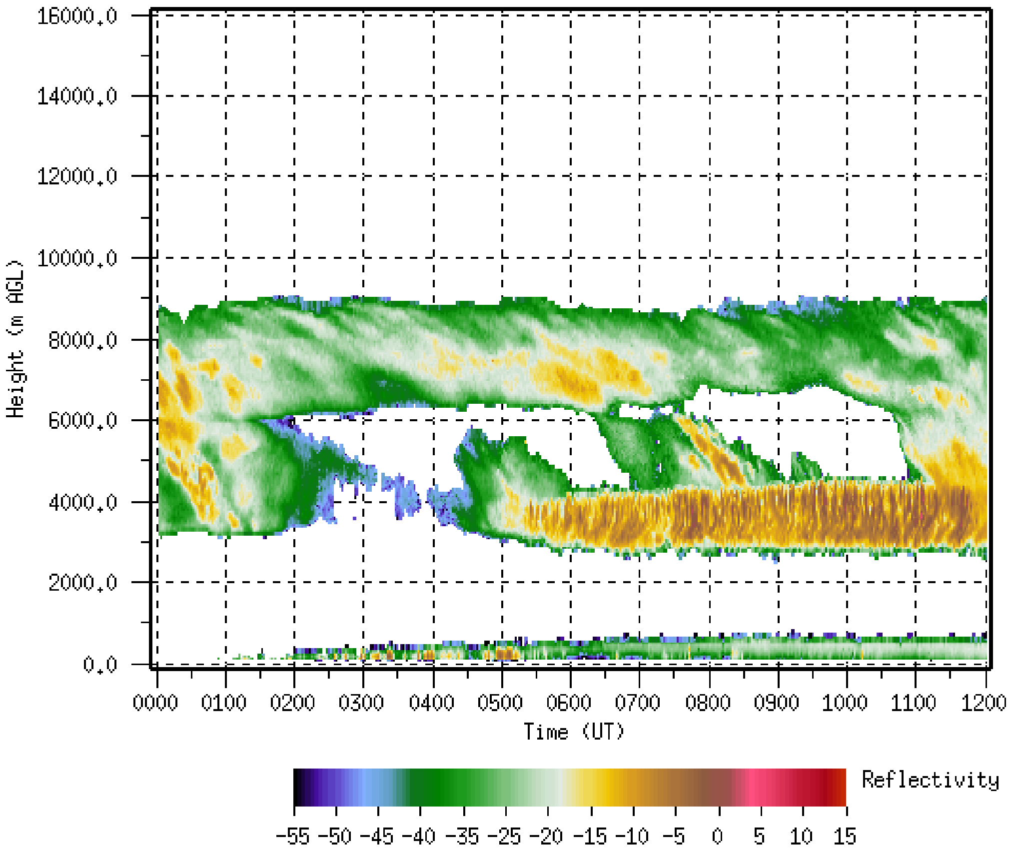
Millimeter Wave Radar - ARM NSA

- **Comparison of SHEBA radar-radiometer techniques, in situ aircraft, and AVHRR satellite retrieval of cloud particle size (Uttal et al.)**



Millimeter Wave Radar - ARM NSA

- **Time-height cross section of radar reflectivities for a 12 hour period over the SHEBA ice station (Uttal et al.)**



Pre-launch Field Experiments

Datasets already in-hand for algorithm development

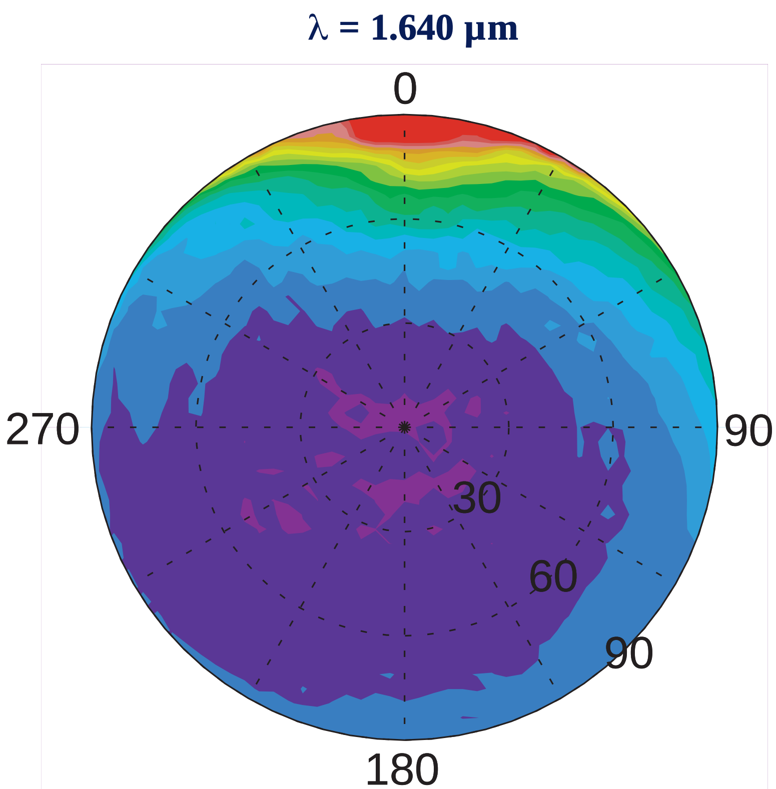
Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
ARMCAS	**June 1995**	**ER-2 C-131A**	**MAS, CLS, AVIRIS, CAR, microphysics**	**Tsay, King, Platnick, Ackerman**	**Arctic stratus clouds over sea ice; BRDF of sea ice & tundra**
SCAR-B	**Aug-Sep 1995**	**ER-2 C-131A surface**	**MAS, CLS, AVIRIS, CAR, microphysics, AERONET**	**Kaufman, Remer, King, Tsay, Prins**	**Smoke, clouds and radiation from biomass burning in Brazil; surface BRDF**
SUCCESS	**July 1996**	**ER-2 surface**	**MAS, CLS, HIS, AERI**	**Ackerman, Menzel, Tsay**	**Mid-latitude cirrus over continents**
TARFOX	**Jan-Feb 1997**	**ER-2 C-131A surface**	**MAS, LASE, CAR, AERONET, microphysics**	**Tanré, Kaufman, Remer, Tsay**	**Tropospheric aerosol and cirrus over ocean; surface BRDF**
WINCE	**May-June 1998**	**ER-2**	**MAS, HIS, CLS**	**Paul Menzel, Ackerman, Moeller, Hall**	**Cloud detection & properties over snow/ice covered**

Pre-launch Field Experiments

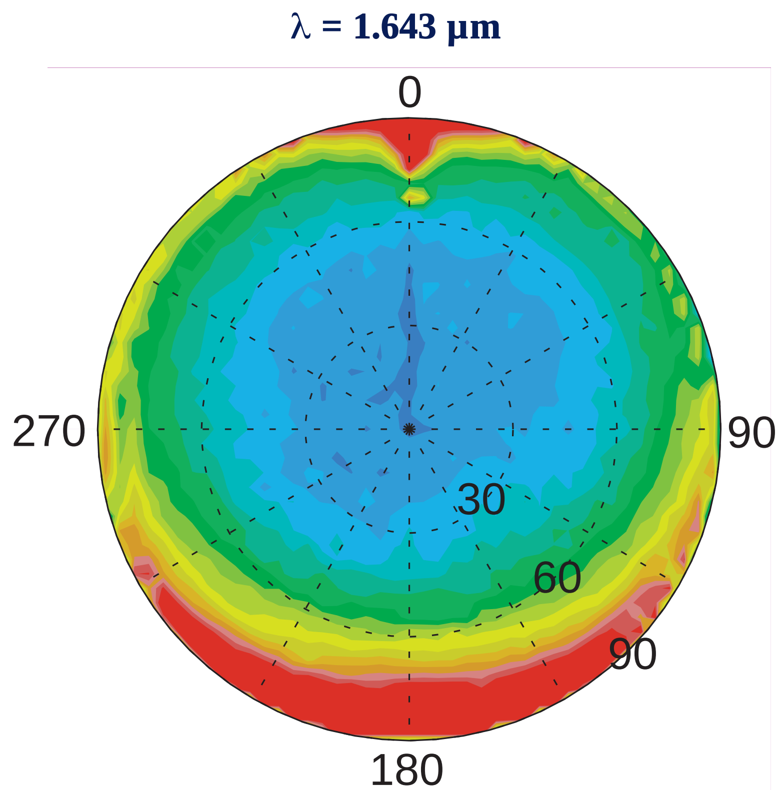
Datasets already in-hand for algorithm development

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
FIRE ACE	**May-Jun 1998**	**ER-2 CV-580 surface**	**MAS, CLS, AirMISR, MIR, SSFR, AMPR, HIS, CAR, microphysics**	**King, Platnick, Ackerman, Tsay**	**Arctic stratus clouds over sea ice; BRDF of sea ice & tundra**
CALVEX-N	**Dec 1998**	**ER-2 surface**	**MAS, MIR, S-HIS, AERI**	**Menzel, Moeller**	**Underfly NOAA-15 as a calibration/validation exercise**
WINTEX	**Mar 1999**	**ER-2 surface**	**MAS, S-HIS, NAST-I, NAST-M, AERI**	**Menzel, Ackerman, Moeller**	**Cloud detection & properties over snow/ice covered land and lakes**

Bidirectional Reflectance - Tundra



Early Spring (snow covered)



Late Spring (no snow)

Instrument Development

MSRN Enhancements

- Acquisition of new quartz domes with high transmittance in the UV and SWIR for better coverage of the entire solar spectrum
  - Addition of robust solar tracker for separating the direct and diffuse radiation
- A light-weight, weather-proof, and temperature-controlled case for the micropulse lidar for operation in remote locations
- A new sun-sky-surface sensor (S^4) to replace the Cimel sunphotometer
  - 14 spectral bands without using a filter wheel (0.3-2.5 µm)
  - Polarization sensitivity for some bands
  - Ability to scan surface for bidirectional reflectance function
- A new scanning microwave radiometer (SMiR)
  - Zenith scanning
  - Three frequencies (22.8, 23.8, and 37 GHz) for retrieving column water vapor amount and cloud liquid water
  - Future addition of tunable frequencies in 60 GHz region (oxygen resonance line) to retrieve temperature profiles

Post-launch Field Experiments

Post-launch Field Experiments involving MODIS atmosphere investigators

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
SCAR99	**Sep-Oct 1999**	**ER-2 surface**	**MAS, MOPITT-A**	**Kleidman, Remer, Ward, Kaufman, Hao, Drummond**	**Smoke & radiation from forest fires**
CALVEX-M	**Mar-Apr 2000**	**ER-2 surface**	**MAS, S-HIS, CLS, AERI, M-AERI, Raman lidar, Microwave**	**Ackerman, Mace, Menzel, Moeller, Ferrare**	**Overflights of SGP ARM site and Gulf of Mexico**
California	**Dec 2000 Jul 2001**	**ER-2 CV-580**	**MAS, CLS, AirMISR, CAR, microphysics**	**King, Platnick, Tsay**	**Marine stratocumulus & valley fog**
SAFARI 2000	**Aug-Sep 2000**	**ER-2 CV-580 surface**	**MAS, S-HIS, AirMISR, CLS, MOPITT-A, SSFR, CAR, AERONET, microphysics**	**King, Platnick, Tsay, Kaufman, Remer, Ackerman**	**Smoke, clouds, and radiation from biomass burning; surface BRDF; Namibian stratus**

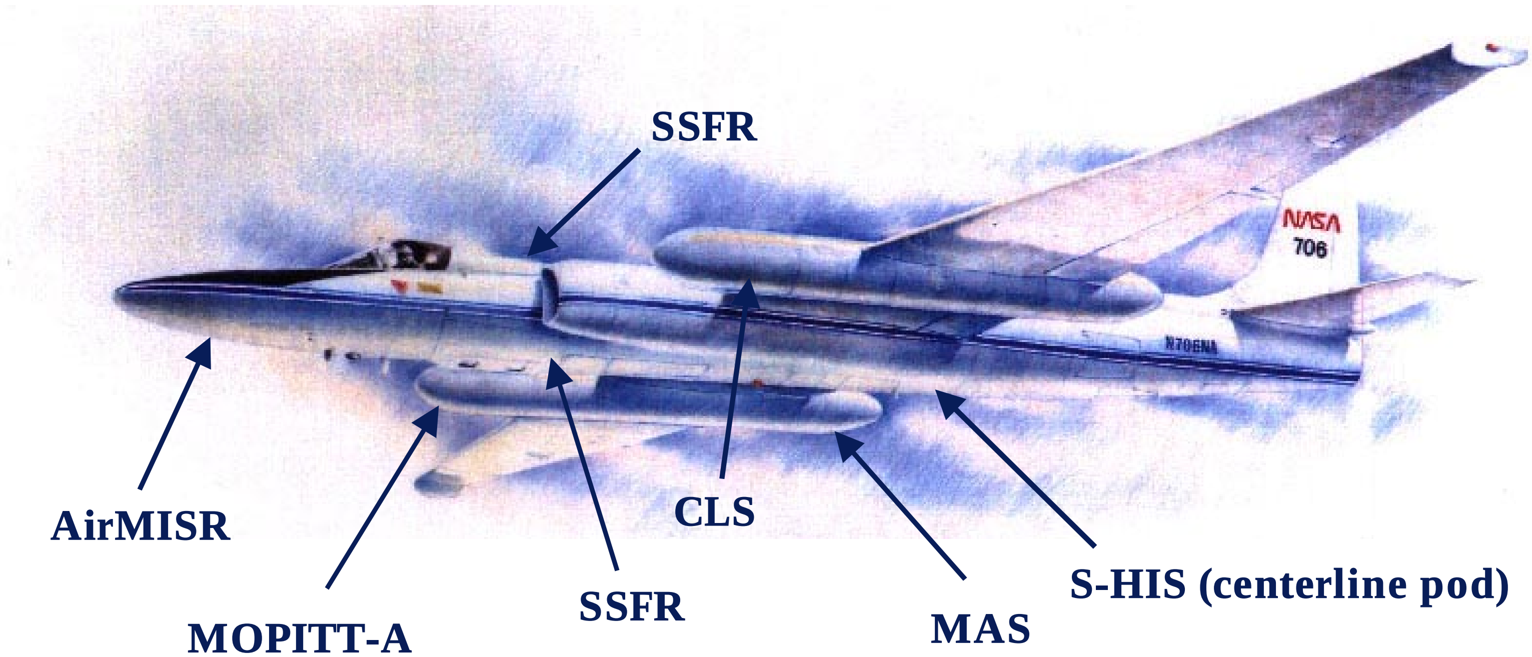
Post-launch Field Experiments

Post-launch Field Experiments involving MODIS atmosphere investigators

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
MOBY	**Jan 2001**	**ER-2 surface**	**MAS, S-HIS, MOBY, AERONET**	**Menzel, Ackerman, Gao**	**Cirrus clouds & atmospheric correction over ocean**
CRYSTAL	**Aug 2001**	**ER-2 WB-57F**	**MAS, S-HIS, CLS, in situ microphysics**	**Ackerman, Heymsfield, Gao**	**Tropical cirrus clouds**
Antarctica	**Jan-Feb 2000 Jan-Feb 2001**	**Surface**	**P-AERI**	**Menzel, Moeller**	**Clear sky radiances for MODIS IR cold scene validation over Antarctica**

SAFARI 2000

NASA ER-2 Aircraft



Intercomparisons

- **Cloud mask**
  - The MODIS and ASTER cloud mask will be compared in polar regions
  - The MODIS and MISR cloud mask will be compared worldwide
  - Aircraft and ground-based lidar and radar
    - » GLI will be an additional cloud mask and cloud property dataset after launch on ADEOS II in 2000
- **Cloud top properties**
  - Cloud top altitude derived from MISR stereo imagery will be compared to MODIS-derived cloud top altitude (pressure), which is based on CO_2 slicing, a very different technique that is applicable both day and night
  - Aircraft and ground-based lidar and radar
  - GOES stereo cloud heights
  - HIRS cloud heights
- **Cloud optical thickness and effective radius**
  - In situ aircraft (microphysical properties)
  - Comparisons between MODIS, CERES (SSF), and MISR cloud products (Terra) should yield evidence of inconsistency in assumptions
  - Ground-based lidar and radar

Intercomparisons (continued)

- **Cloud particle phase**
  - **Aircraft-based in situ measurements**
  - **Dual-polarization lidar**
- **Cirrus reflectance in the visible**
  - **Aircraft remote sensing measurements with multispectral radiometers (MAS, AVIRIS)**
- **Aerosol optical thickness and size distribution**
  - **Intercomparison with MISR as a function of aerosol type, season, surface cover, and view & illumination directions**
  - **Surface measurements from AERONET sunphotometer/sky radiometer sites (~60 worldwide)**
  - **Aircraft-based in situ measurements**
- **Atmospheric moisture and temperature gradients**
  - **Microwave radiometer and Raman lidar retrievals over the SGP ARM site**
  - **C IGSN network of Australian soundings**
  - **North American radiosondes**
  - **GOES and AIRS (PM-1) retrievals**
  - **LASE profiles**

Intercomparisons (continued)

- **Atmospheric stability**
  - ARM CART temperature and moisture measurements
  - CIGSN network of Australian soundings
  - North American radiosondes
  - GOES and AIRS (PM-1) retrievals
- **Precipitable water**
  - Precipitable water will be compared with ground-based Cimel sunphotometer measurements derived from AERONET
  - Microwave radiometer and Raman lidar retrievals over the SGP ARM site
  - North American radiosondes
  - Microwave radiometer measurements from the MSRN
  - Surface GPS soundings where available (~2000 worldwide)
- **Gridded level-3 atmosphere product**
  - Intercomparisons and consistency checks

Airborne Validation Strategy