MODIS Atmosphere Validation Plan

MODIS Atmosphere Discipline Team

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TABLE OF CONTENTS

Executive Summary

The MODIS Atmosphere Team will use several validation techniques to develop uncertainty estimates for its various data products. The methods include (i) comparisons with in situ data collected over a distributed network of ground validation sites, (ii) comparisons with data and products from other airborne and spaceborne sensors, and (iii) analysis of trends in atmosphere data products.

The primary validation techniques include collection of, and comparison with, field experiment data collected from collocated airborne field experiments, and intercomparison with long time series of ground-based observations at a selected set of ground validation sites worldwide. The imagery, data analysis, and field experiment data will be archived at either the Goddard or Langley DAAC, and made available to the outside scientific community.

MODIS Atmosphere validation work will involve:

☐ Comparisons with land validation sites in Africa, North America, and Australia

☐ Close cooperation with EOS validation investigators to meet specific product validation needs

☐ Interaction with established data networks (e.g., ARM, AERONET, radiosondes)

☐ Participation in community field campaigns (e.g., FIRE ACE, SAFARI 2000) and EOS-targeted field campaigns (e.g., WISC-T2000)

☐ Collaboration with other Terra, ADEOS II, and Aqua instrument teams

☐ Collaboration with a worldwide effort to derive column precipitable water from a network of surface GPS receivers

Taken together, these activities provide the foundation for operational product validation, and outlines the planned validation activities of the MODIS Atmosphere Discipline Team and collaborators from 1995 through 2002.

1.0 Introduction

This document describes the activities of the MODIS Atmosphere team and principal validation investigators aimed at assessing the accuracy, reliability, and representativeness of the atmosphere data products routinely derived from MODIS satellite data. It reviews recent activities as well as activities planned through 2002.

1.1 Scientific Objectives

We intend to collect a well-calibrated data set of high spectral and spatial resolution measurements to support radiometric calibration of the MODIS shortwave and longwave channels and the development of the following MODIS atmosphere algorithms:

- ☐ 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
  - aerosol 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

A summary of these algorithms can be found in King et al. (1992), as well as in detailed descriptions of each algorithm, to be found in Algorithm Theoretical Basis Documents (ATBDs) available at http://eospso.gsfc.nasa.gov/atbd/pg1.html.

1.2 Missions

MODIS will be carried onboard the first EOS spacecraft, designated Terra, to be launched December 1999. In addition to Terra, MODIS will fly aboard Aqua in December 2000. These two spacecraft will likely be repeated in the morning and afternoon orbits with advanced operational versions of MODIS, providing a consistent data set equivalent to MODIS from 2000-2018. In order to validate the MODIS atmospheric products to be derived from these data, it is necessary to validate specific geophysical parameters under a wide variety of atmospheric conditions from arctic stratus clouds in the summertime arctic, multi-layer cloud systems in the polar night, convective cloud systems in the intertropical convergence zone, aerosol properties over the ocean and several land surface covers for different aerosol types, precipitable water over a wide range of atmospheric conditions from the dry arctic to the humid tropics, total ozone content, atmospheric temperature and moisture profiles, and atmospheric stability.

1.3 Science Data Products

This MODIS atmosphere validation plan addresses the MODIS cloud mask as well as investigator science products characterizing cloud top properties, cloud radiative and microphysical properties, aerosol optical thickness and (over the ocean) aerosol size distribution, precipitable water vapor over the land and ocean sun glint regions, and atmospheric profiles of moisture and temperature. Validation of the shortwave and longwave radiances will also be assessed and discussed in this validation plan.

2.0 Validation Overview

2.1 Overall Approach

In order to validate MODIS atmosphere data products, it is necessary to validate specific atmosphere parameters under a wide variety of atmospheric conditions and solar illumination angles, and over a wide variety of ecosystems worldwide. The MODIS atmosphere team will use a wide variety of validation techniques to develop uncertainty information on its products. These include (i) coordination and collocation with higher resolution aircraft data, (ii) intercomparison with ground-based and aircraft in situ observations, (iii) intercomparisons with other Terra, ADEOS II, and Aqua instruments (e.g., MISR, AIRS, AMSR, GLI), and (iv) analysis of trends over time and consistency across boundaries (e.g., land *vs* ocean, day *vs* night).

Our validation approach relies heavily on the sources of the data that were used in the algorithm development, which consisted primarily of the MAS, a fifty channel visible, near-infrared, and thermal infrared imaging spectrometer with 50 m resolution at nadir (King et al. 1996), HIS, a 2 km resolution nadir-viewing (now modified for scanning, S-HIS) Michelson interferometer, AVIRIS, a 224

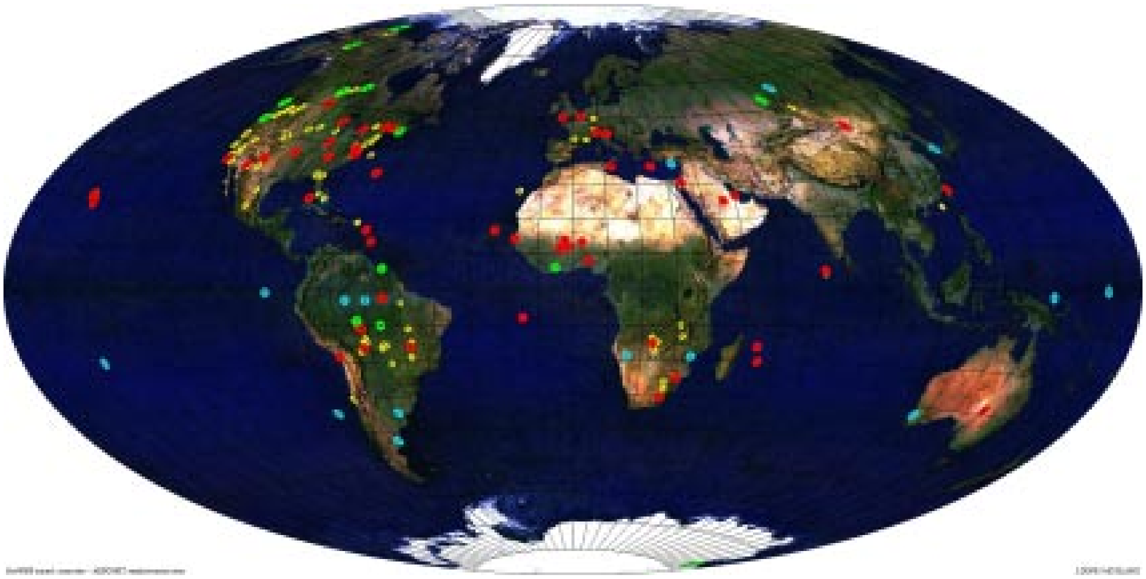


Figure. 1. Current and anticipated distribution of AERONET federated sites available for the launch of Terra in December 1999. The red symbols denote permanent sites, green seasonal sites, yellow for temporary sites, and blue for future sites. Figure courtesy of Jacques Descloitres, University of Maryland, and is based on a composite of clear-sky SeaWiFS data over a one year period from 1997-1998.

band imaging spectrometer from 0.4-2.5 µm with 20 m resolution at nadir (Vane et al. 1993). In addition, we plan to make extensive use of the AERONET (Aerosol Robotic Network), a network of ground-based sunphotometers established and maintained at Goddard Space Flight Center (Holben et al. 1998) that measures the directly transmitted solar radiation and sky radiance, reporting the data via a satellite communication link from each remotely-located Cimel sunphotometer to Goddard Space Flight Center from sunrise to sunset, 7 days a week (cf. Figure 1).

We also plan to utilize ground-based microwave radiometer observations to derive column water vapor and liquid water path, especially over the Atmospheric Radiation Measurement (ARM) CART (Clouds And Radiation Testbed) site in Oklahoma. North American Radiosondes (Figure 2), in conjunction with GOES retrievals, will be used to validate atmospheric properties (water vapor, stability). GOES retrievals provide the bridge to compare the MODIS retrievals with radiosonde measurements.

Well-calibrated radiances are essential for the development of accurate algorithms. The calibration of the S-HIS is such that it serves as a reference for line-by-line radiative transfer models. The MAS infrared channels are calibrated through two onboard blackbody sources that are viewed once every scan, taking into account the spectral emissivity of the blackbodies. Calibration of the shortwave infrared and thermal infrared channels will be routinely assessed through vicarious calibration and intercomparisons with the S-HIS flying on the same aircraft. The MAS solar channels are calibrated in the field, using a 30″ in-

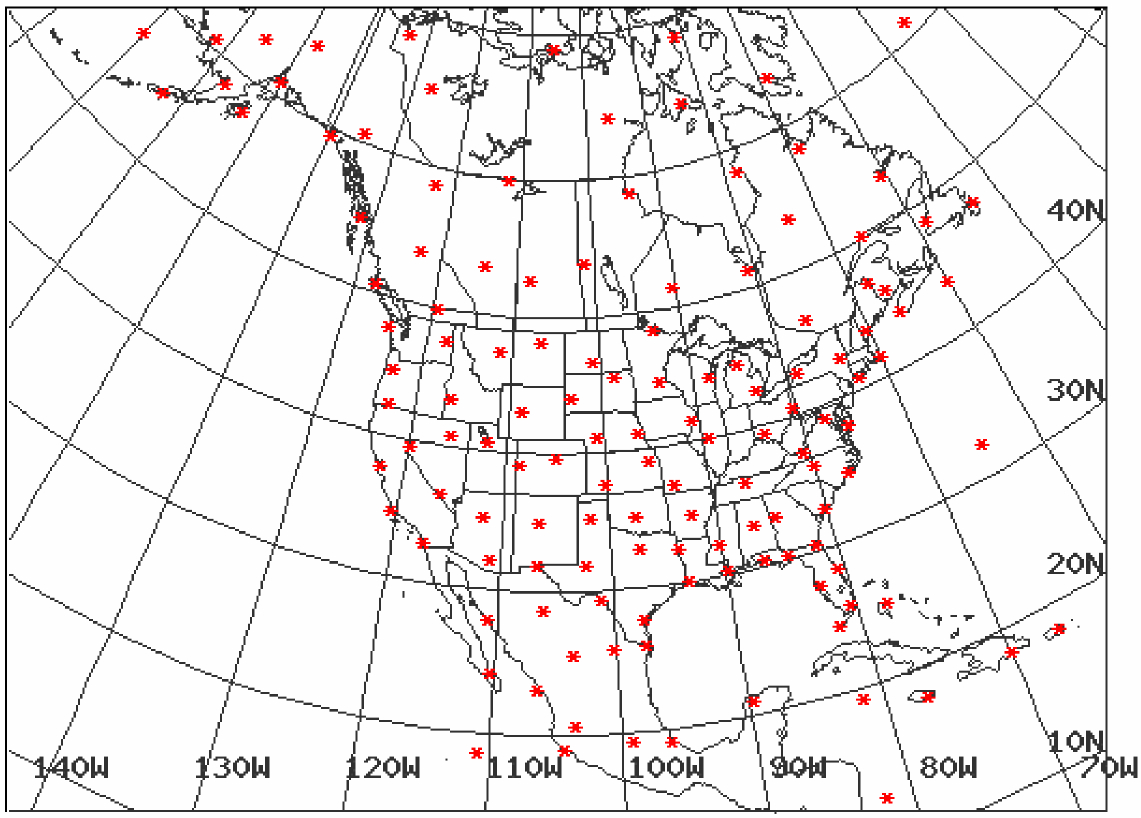


Figure. 2. North American radiosonde sites. Canadian and U.S. radiosondes report twice daily (00 and 12 UTC). Currently, Mexican sites are typically reporting once daily (00 UTC). These radiosondes (00 and 12 UTC) provide in excess of 200 reports per day.

tegrating sphere before and after each ER-2 deployment, as well as a 20” integrating hemisphere shipped to the field deployment site for periodic calibrations during a mission. A comprehensive description of both the shortwave and longwave calibration procedures, signal-to-noise characteristics, and thermal vacuum characterization of the MAS can be found in King et al. (1996). MODIS IR calibration will be evaluated using the AERI network at the ARM sites (Figure 3). The ARM SGP site will have five AERI instruments; ARM NSA and ARM TWP will each have two AERIs. These are zenith viewing instruments. The calibration accuracy of AERI surpasses that of S-HIS (calibration of AERI instruments is NIST traceable). In addition to the ARM sites, MODIS cold scene (<270 K) calibration will be validated using P-AERI ground based measurements at the South Pole. P-AERI may be pointed upward to view zenith or downward to view surface or any angle in between. Because atmospheric water vapor concentrations over the South Pole are typically small (~5% relative humidity), slant path effects on MODIS and P-AERI window band measurements will be small (<0.5°C). Importantly, P-AERI is capable of viewing the snow surface at the South Pole using the same viewing geometry as MODIS. This will minimize surface effects on the calibration validation exercise.

Comparisons with products from other platforms are also planned. Cloud

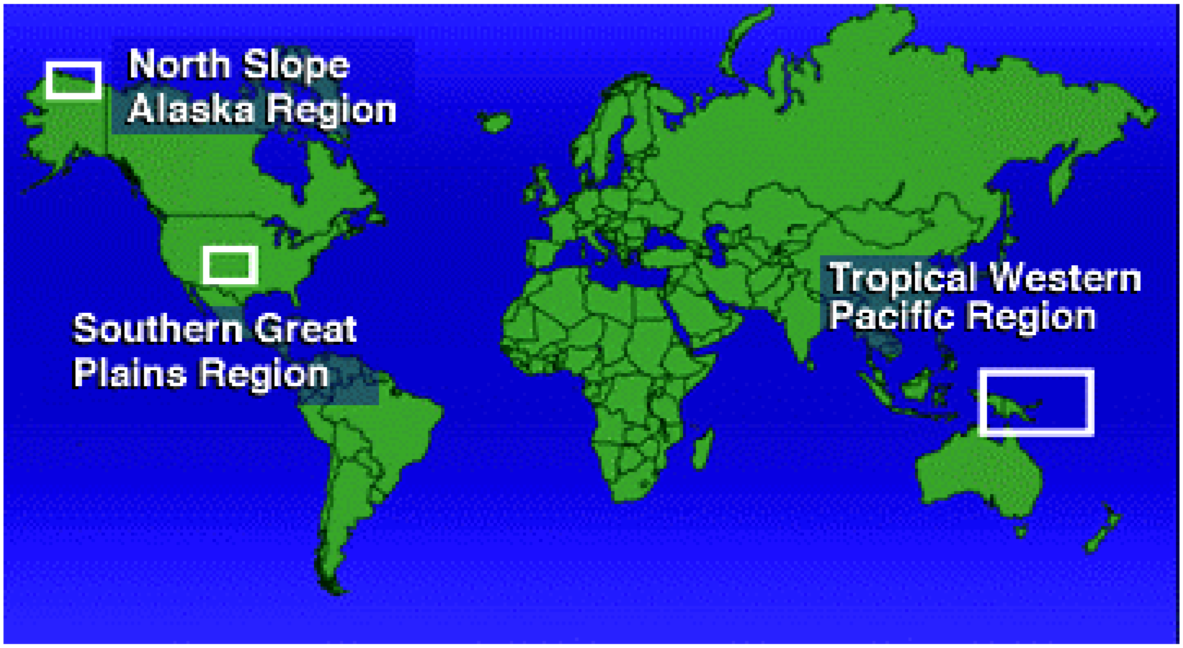


Figure. 3. ARM CART sites of the globe. Before the launch of Terra, five AERIs will be deployed at the SGP site, and two each at the NSA and TWP sites. These zenith viewing AERIs will be operated continuously. In addition, an AERI will be deployed at the South Pole (not shown on map) during Jan/Feb 2000 and again from Jan 2001 through Jan 2002. This P-AERI will be pointable from uplooking zenith to downlooking near nadir.

masks will be compared with those from AVHRR and HIRS/2 data, and ASTER and MISR (also on the Terra platform). The CERES cloud mask makes use of MODIS data (on Terra) and is essentially the same algorithm as MODIS, so no independent verification is thereby possible. Atmospheric profiles will be compared with those from HIRS, GOES, and AIRS/AMSU/HSB (also on the Aqua platform). Cloud properties will be intercompared with those derived from HIRS, CERES, and MISR (cloud top altitude), as well as from in situ aircraft (see below). Aerosol optical thickness and particle size retrievals from MODIS will be compared to MISR analyses as well as to AERONET measurements. Precipitable water vapor measurements will be compared to (i) radiosonde measurements over the continents, (ii) AERONET-derived column water vapor analysis, (iii) ground-based GPS soundings (~2000 worldwide, including 800 in Japan), (iv) ground-based microwave radiometer measurements at the ARM sites as well as surface measurements at the MODIS land validation site in Skukuza, South Africa, (v) ground-based Raman lidar measurements at the SGP CART site, and (vi) periodic differential absorption lidar measurements from the ER-2 aircraft (LASE; Dr. Edward Browell).

2.2 *Terra Validation Investigations*

The EOS Validation program funded 21 Type I (Research & Analysis) and 44 Type II (EOS Validation) investigations (ftp://eospso.gsfc.nasa.gov/sterling/Validation/NRA_selectees.pdf) as a result of a NASA Research Announcement issued in 1997. Six of these investigations are especially relevant to validation of MODIS atmosphere data products. In addition, international collaboration from Australia will play a valuable role in assessing the accuracy and reliability of MODIS atmosphere and land products at three surface sites on the Australian continent. Table 1 lists the validation investigations that are especially relevant to the MODIS atmosphere products.

Table 1. EOS Validation Investigations of relevance to the MODIS atmosphere data products.

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

2.3 Sampling Requirements

Comparison of MODIS radiances and products with those from other instruments should be made periodically (perhaps annually) in different seasons in daytime and nighttime conditions. We anticipate numerous opportunities, unspecified, in which scientists worldwide will intercompare MODIS-derived atmospheric, land, and ocean data products with local measurements of the geophysical property of interest. This wide-scale synthesis of data sets from scientists from Australia, Japan, China, Europe, South America, and Africa will greatly enhance the confidence that we place in the MODIS-derived products, and will, with time, aid our ability to assess the quality of the data products from a wide variety of climatic conditions and seasons. This would not be possible, nor appropriate, for the small MODIS Science Team to accomplish entirely on its own.

2.4 Measures of Success

Adjustments will be made to MODIS algorithms so that three sigma confidence will be achieved. This will take at least two years to assemble and implement the lessons learned from these validation assessments. As these assessments become known to the MODIS algorithm developers, adjustments will be made to the algorithms as required. We anticipate periodic reprocessing of the data set to periodically incorporate these refinements.

3.0 Validation Sites

In order to validate global atmosphere properties that can be derived from MODIS satellite data, a reasonable sampling of the global variability of these products is necessary. Each MODIS atmosphere product varies widely in space and time, so much of the difficulty in validating these global data products arises from sparse sampling of the range of values encountered by each variable. Hence, as outlined above, our strategy includes not only focussed field campaigns in specific locations and under specific environmental conditions, but also a long time-series of selected measurements from a select distribution of ground validation sites. Table 2 describes the primary surface validation sites, responsible investigators, and available data products to be acquired from this extensive network of stations.

Table 2. MODIS atmosphere ground validation sites.

Network	*Location*	*Responsible Investigators*	*Primary Purpose*
AERONET	Multiple locations in North America, South America, Europe, Africa, Asia, and Oceania (cf. Fig. 1)	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 (cf. Fig. 2)	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

Table 2. MODIS atmosphere ground validation sites (continued).

Network	Location	Responsible Investigators	Primary Purpose
P-AERI	South Pole	Paul Menzel Von Walden A. Heymsfield	Clear sky radiance (IR) and surface measurements for MODIS validation of cold scenes; videosondes on tethered balloons for cloud particle sizes & shapes
SMART	Skukuza, South Africa (cf. Fig. 5)	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

The distribution and location of these land validation sites being used by the MODIS atmosphere team is shown in Figure 4.

3.1 *University of Utah Facility for Atmospheric Remote Sensing (FARS)*

FARS is a permanent cloud research station located on the eastern edge of the University of Utah campus (40° 49′ 00″ N, 111° 49′ 38″ E). Its location overlooks the Salt Lake Valley from a branch of the Wasatch Mountains (1.52 km MSL) (cf. Figure 5). The facility was established in 1986 with joint funding from the Na-

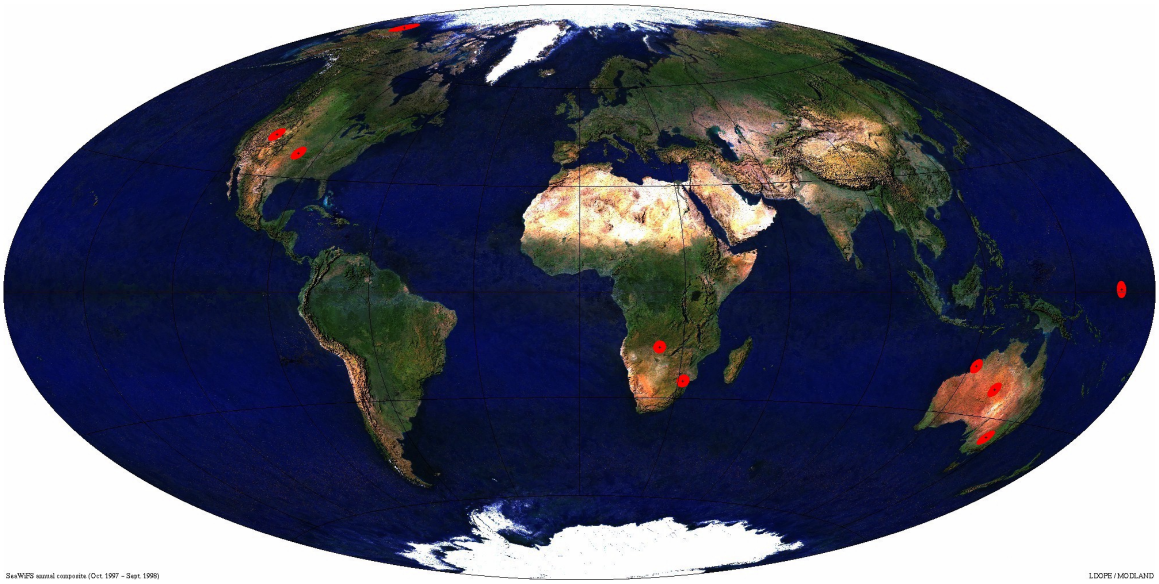


Figure. 4. MODIS Atmosphere surface validation site locations.

tional Science Foundation and the University of Utah to house a Cloud Polarization (ruby) Lidar. The diverse combination of portable and stationary equipment (Table 3) makes FARS the only research facility of its kind west of the Rocky Mountains. A unique feature of the FARS location is its proximity to a diversity of surface types. Within 50-100 km, the albedo can vary from one of the highest (salt flats and winter snow fields) to the lowest (Great Salt Lake) on the planet. Furthermore, the close proximity of a diverse range of land types (vegetated level ground to desert mountains) will allow for validation exercises to be conducted over many surfaces of interest to EOS investigators.

Table 3. Facility for Atmospheric Remote Sensing (FARS) instrumentation.

Instrument	*Specifications*
Passive remote sensors	
Net flux radiometers	
Narrow-beam (0.14°) radiometer (co-aligned with lidar)	9.5-11.5 µm
Infrared flux radiometer	broadband
Pyradiometer	0.3-2.8 µm
Rotating shadow band radiometer	a. 0.63-2.5 µm b. 6 channels, 0.14-0.94 µm (10 nm bandpass)
Pyrheliometer with solar tracker	0.63-2.8 µm
Sunphotometer	10 channels, 0.38-1.03 µm (10 nm bandpass)
All-sky 35 mm photography	
All-sky video time lapse imagery	
Active remote sensors	
Polarization Cloud Lidar (ruby)	a. 2 channels (0.694 and 0.347 µm), vertically pointed 3 Manually "tiltable" ±5° from zenith 4 0.1 Hz PRF (7.5 m maximum range resolution) 5 1-3 mrad receiver beamwidths 6 25 cm diameter telescope 7 1.5 J maximum output
Two-color Polarization Diversity Lidar (PDL)	a. 4 channels (0.532 and 1.06 µm, dual polarization) b. Vertical (0.532 µm) + horizontal (1.06 µm) polarizations c. Fully scannable (5° s^{-1}) d. 10 Hz PRF e. 1.5 m maximum range resolution f. 0.2-3.8 mrad variable receiver beamwidths g. 35 cm diameter telescopes (two) h. 0.45 J output
95 GHz Polarimetric Doppler Radar	a. 6 channels (two Doppler) b. Vertical + horizontal polarization transmitted c. Fully scannable (5° s^{-1}) d. 10 Hz-80 kHz PRF e. 7.5 m maximum range resolution f. 600 range gates g. 0.25° beamwidth h. 90 cm diameter dish (57 dB gain)

Table 3. Facility for Atmospheric Remote Sensing (FARS) instrumentation (continued).

Instrument	*Specifications*
95 GHz Polarimetric Doppler Radar (continued)	i. 1.2 kW peak power
Passive remote sensors	
Temperature	
Relative humidity	

The FARS site possesses extensive active and passive remote sensing instrumentation. Active systems include the vertically pointing ruby lidar (0.694 µm wavelength, with 7.5 m maximum range resolution; Sassen 1997), a portable high resolution two-color (0.532 and 1.06 µm, with 1.5 m maximum range resolution) Polarization Diversity Lidar (Sassen 1994), and a 6 channel 3.2 mm polarimetric Doppler radar (with 7.5 m maximum range resolution; Sassen and Chen 1995). The passive systems include a narrow-beam infrared (IR) radiometer (PRT-5, 9.5-11.5 µm), a broadband infrared radiometer (PIR), global visible pyranometer (PSP, 0.3-2.8 µm), normal incidence pyrheliometer (NIP, 0.63-2.8 µm), and a rotating shadowband radiometer (RSR, 0.63-2.8 µm). Recent additions to the site include a 9-channel sunphotometer, a multifilter rotating shadowband radiometer (MFRSR; Harrison et al. 1994) and a two-channel microwave radiometer.

The scientific objective of FARS has been the study of middle and high level

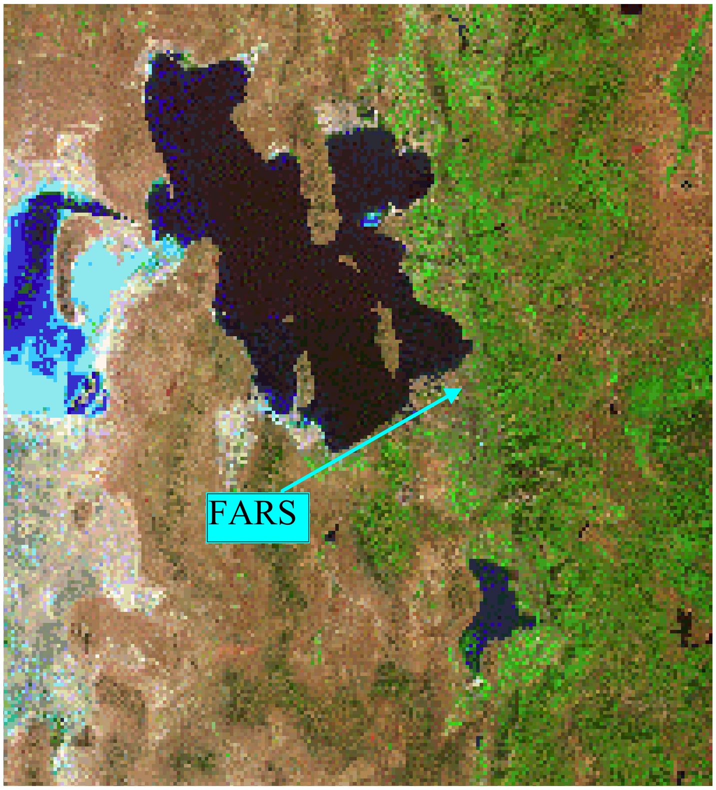


Figure. 5. Landsat image of the Salt Lake City region and the FARS location.

clouds for basic research, as well as supporting the satellite validation effort of the FIRE project's extended time observation (ETO) component. To this end, over 2200 hours of ruby-lidar and supporting data have been collected through the end of 1996.

The capability of FARS, like the ARM sites, is nearly ideal for use in validation of the EOS-derived cloud and radiation parameters. The particular combination of active and passive sensors will allow for a direct intercomparison of derived parameters, and, when combined with in situ data, will enable a thorough validation of many algorithms. The EOS validation program has funded approximately 20 hours of in situ data collection per year over the FARS instruments. Presently, we are subcontracting with Dr. Paul Lawson of SPEC Inc. to perform the in situ data collection. Our goal is to use the surface-based remote sensing observations validated by in situ data to derive a suite of products tailored for efficient use by the EOS science teams and to deliver these products along with any in situ data to the appropriate science team members or archival locations. Our scientific objective is to sequentially examine the assumptions underlying the surface and satellite retrievals with the ultimate goal being the convergence of the end results.

To this end, we will operate the FARS site in clear and cloudy conditions for periods bracketing satellite overpasses. The length of operation in each situation will be determined on a case by case basis but will in general consist of 1-3 hour periods. We are prepared to support roughly 15 overpasses each month. The overpasses we will support (high and low angle, day or night) will be determined in consultation with the EOS team scientists. In cloudy conditions, the full suite of FARS instrumentation will be operated. In clear conditions, the radiometric instrumentation and ruby lidar will be operated to map the vertical properties of aerosol layers. Additionally, we will perform one extended observing period each quarter where we will collect data for at least 12 hours centered on an overpass so as to characterize a representative cloud system.

3.2 Continental Integrated Ground Site Network (CIGSN)

Australia's Continental Integrated Ground Site Network (CIGSN) currently has two operational sites - one is 50 km E of Hay (New South Wales) on the Uardry sheep station, referred to hereafter as the Uardry site, and the other is 100 km WNW of Alice Springs (Northern Territory) on the Amburla brahman cattle stud, referred to hereafter as the Amburla site. The CIGSN is producing accurate and long time series data of surface radiative fluxes and meteorological parameters such as surface temperature, air temperature, relative humidity, wind speed and surface pressure. A third site is situated on Thangoo station, 40 km SSE of Broome in the Kimberley region of Western Australia. This site should be operational by mid 1999.

The Uardry site has been providing near-continuous surface measurements since July 1992. This site is near the center of the largest and most uniform plain on the Australian continent. The layout consists of a central data logging and processing site coupled with 8 "satellite" sites that telemeter data via a radio communications link to the central site up to 6 times per minute. The solar powered, low maintenance, autonomous data collection system can handle up to 48 channels of 16-bit resolution data stored onto a computer hard disk. Upward and downward shortwave and longwave irradiances are monitored. The upwelling irradiances are obtained from instruments mounted on a boom extending from a 15 m tower. Air and ground temperatures are monitored at points across a 1 km^2 area.

The Amburla site has been providing near-continuous surface measurements since March 1995. This instrumentation is on a 12 x 12 km^2 plain, which is sparsely covered with grass tufts. The layout consists of a central data logging site coupled with 6 "satellite" sites. Electronics, communications and geophysical variables monitored are similar to those at the Uardry site.

The Thangoo site lies about 3 km from the coastal plain surrounding Roebuck Bay, SSE of Broome. The landcover for the region varies from broad mud flats near the coast on which little grows, often under water during the wet season and because of the large tidal range (typically 8 - 10 m), to mangrove swamps, grassy plains and extensive coverage of acacia bush (wattle) which grows up to 5 m in height. The soil is typically sandy and red-colored. The layout consists of a central data logging site coupled with "satellite" sites in a similar fashion to the other two sites. Electronics, communications and geophysical variables monitored are also similar to those at the other sites.

For all three sites, measurements of the surface irradiances and surface temperature are made at a spatial scale that matches the resolution of satellite imagers such as MODIS, the Along-Track Scanning Radiometer (ATSR), and the Advanced Very High Resolution Radiometer (AVHRR). Therefore the CIGSN measurements constitute a highly valuable data set with which to calibrate and validate satellite remote sensing data. The CIGSN data set has greatly assisted efforts in developing algorithms for land surface temperature (LST) and also surface-leaving shortwave (SW) irradiance from ATSR 1.6 µm top-of-the-atmosphere (TOA) radiances.

The CIGSN was designed to provide ground-truth temperature data for comparison with satellite-derived LSTs. Results from measurements made at Uardry have been published (Prata 1994).

Further information can be found at the CSIRO Division of Atmospheric Research web site: http://www.dar.csiro.au; follow links to the Atmospheric Processes-Surface Processes page.

3.3 Surface Measurements for Atmospheric Radiative Transfer (SMART)

Si-Chee Tsay has developed suite of surface radiation and remote sensing in-

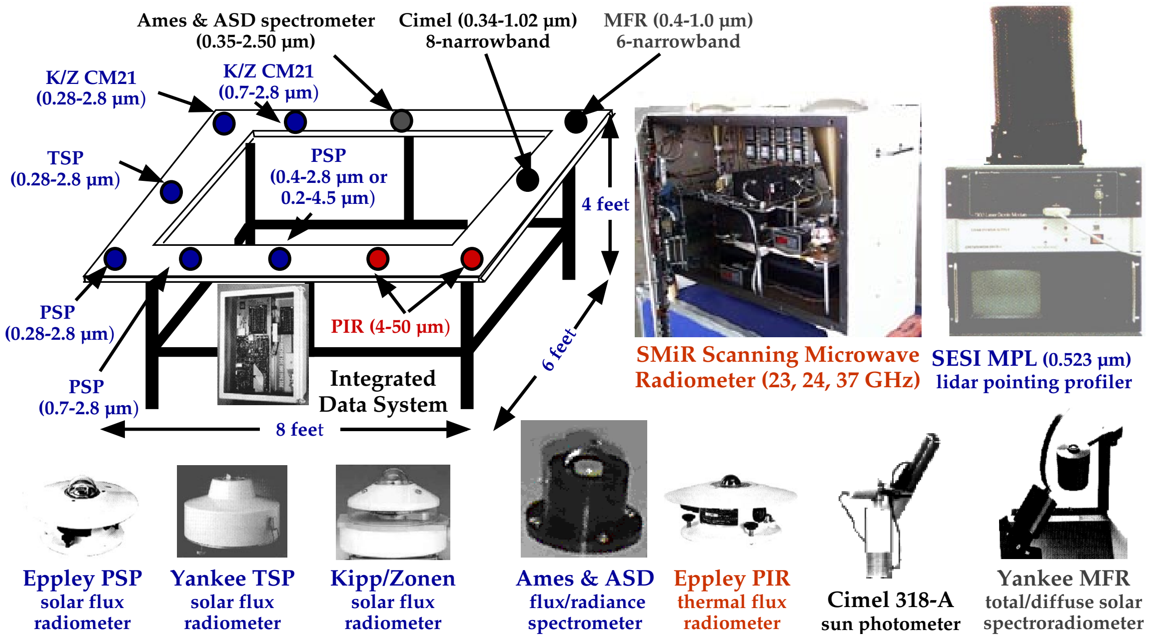


Figure. 6. Current and anticipated components of the Surface Measurements for Atmospheric Radiative Transfer (SMART).

struments for field deployment, known as the SMART (Surface Measurements for Atmospheric Radiative Transfer). Figure 6 depicts the instrumentation setup, to be mobilized and operated readily in most remote locations in conjunction with satellite overpasses that serve to enhance the AERONET database and provide data for intercomparisons. The SMART consists of three Eppley-PSP (0.3-2.8 µm, 0.7-2.8 µm, 0.2-4.5 µm) radiometers, two Kipp/Zonen-CM21 (0.3-2.8 µm, 0.7-2.8 µm) radiometers, two Eppley-PIR (4.0-50 µm) radiometers, one Yankee-MFR (0.42, 0.50, 0.61, 0.67, 0.87, and 0.94 µm narrowband and 0.3-1.0 µm broadband) total/diffuse radiometer, one Yankee-TSP (0.3-2.8 µm) radiometer, one Cimel-318 (0.34, 0.38, 0.44, 0.50, 0.67, 0.87, 0.94, and 1.02 µm narrowband) sunphotometer, one ASD-FR (0.35-2.5 µm) spectrometer, one GSFC-SMiR scanning microwave (23, 24 and 37 GHz) radiometer, and one SESI-MPL (0.52 µm) micro-pulse lidar. Our strategy is to configure these instruments to:

- ☐ measure the broadband downwelling/upwelling shortwave and longwave radiation to derive albedo/emissivity, and to investigate the direct radiative forcing through collocated satellite and surface remote sensing measurements

- ☐ acquire, compare, and synthesize radiometric_measurements of the broadband total/diffuse (MFR), total shortwave (PSP/TSP/CM21 with WG295 filter), and shortwave-infrared (PSP/CM21 with RG695 filter) radiation, and correlate these data with satellite measurements for radiation budget studies

- ☐ acquire, compare, and synthesize radiometric_measurements from the sun photometer (Cimel narrowband transmitted and sky radiances), narrowband total/diffuse irradiance (MFR), transmitted and reflected spectral radiance (FR) and 22-36 GHz microwave emission (SMiR), focusing on the retrieval of atmospheric parameters (e.g., column water vapor amount, aerosol loadings, aerosol size distribution, etc.) and to seek the correlation between the broadband and narrowband radiation measurements

- ☐ measure the lidar backscattering intensity to infer the vertical profiles of aerosols and cloud parameters for comparison with the retrieved results from radiometric measurements, and to initialize the atmospheric aerosol profile in the forward computation of radiation models

This SMART can be easily transported to field sites of interest throughout the duration of Terra and Aqua, and will be collocated with the EOS Validation site in Skukuza, South Africa, during Austral Spring 2000 (SAFARI 2000 period, see below).

Currently, the Eppley-PSP, Kipp/Zonen-CM21, Eppley-PIR, Yankee-TSP radiometers, Yankee-MFR total/diffuse radiometer, Cimel-318 sunphotometer, GSFC-SMiR scanning microwave radiometer, and the SESI micro-pulse lidar are operational and continuously operated at all time. In most field deployments, this system requires two operators to set up and field calibrate the system within about 8 working hours. Then, it can run in automatic mode, but requires data to be downloaded about once a month for the radiometers and micro-pulse lidar. The sunphotometer has satellite-link transmission (like all AERONET systems). Only the ASD-FR spectrometer is operated. A brief summary of the instrument specifications and processing status is given in Table 4.

Table 4. Summary of surface remote sensing and radiation measurements in the SMART.

Instrument	*Specifications*	*Processing Status*
PSP Shortwave Radiometers	a. 0.3 - 2.8 µm b. 0.7 - 2.8 µm	Calibrated for dark current and off-set corrections
CM21 Shortwave Radiometers	a. 0.3 - 2.8 µm b. 0.7 - 2.8 µm	Calibrated for dark current and off-set corrections
TSP Shortwave Radiometer	0.3 - 2.8 µm	Calibrated for dark current and off-set corrections
PIR Longwave Radiometer	4.0 - 50 µm	Calibrated for dark current, off-set and temperature (preliminary) corrections
MFR/7 Shadowband Radiometer	0.4-1.0 µm, 416, 502, 616, 674, 869, and 938 nm	Calibrated against laboratory light source and constant field monitoring with Li-Cor calibrator light source
ASD-FR Shortwave Spectrometer	0.35 - 2.5 µm	Calibrated against laboratory Mercury-Argon source with 0.1 nm bandpass monochromator

Table 4. Summary of surface remote sensing and radiation measurements in the SMART (continued).

Instrument	*Specifications*	*Processing Status*
Cimel Sunphotometer	340, 380, 440, 670, 870, 940, and 1020 nm	Calibrated against laboratory light source and thin-cloud screening
Micro-pulse lidar	0.52 µm	Calibrated for dead-time, after-pulse, and overlap corrections
Scanning Microwave Radiometer	22.8, 23.8, 37.0 GHz	Cryogenic calibration, 77 K to ambient temperature

3.4 Raman Lidar

The Department of Energy ARM program has developed and operates a Raman lidar system at the SGP CART site. Rich Ferrare leads an investigation that uses data from this lidar system as well as the Goddard Scanning Raman lidar to evaluate the aerosol retrieval algorithms used by MODIS and MISR and, in particular, to investigate over an extended period of time the (i) vertical variability of aerosol extinction and backscattering, (ii) relative humidity effects on aerosol properties, and (iii) effects of clouds on aerosol properties. The SGP CART Raman lidar system operates in the vertical mode only, and is in nearly continuous operation (~60% of the time since March 1998). A 3-phase uninterruptible power source (UPS), which was installed in February 1999, should significantly increase the operating time of this Raman lidar. It measures vertical profiles of aerosol extinction and backscatter (355 nm), depolarization (355 nm), and water vapor mixing ratio (from Raman shifted backscattering at 408 nm); these profiles of aerosol extinction and water vapor mixing ratio are integrated to derive measurements of aerosol optical thickness and precipitable water vapor.

Figure 7a shows a correlation with CART Raman lidar analyses of aerosol optical thickness and nearly coincident Cimel sunphotometer measurements and Fig. 7b shows a correlation with CART Raman lidar analyses of precipitable water vapor and coincident microwave radiometer measurements. These figures show the capabilities for validation of aerosol optical thickness and precipitable water vapor. Perhaps more importantly, Raman lidar also provides detailed information on the vertical distribution of aerosols and water vapor that cannot be obtained from either the sunphotometer or microwave radiometer alone. In addition, this lidar provides information on the correlation between aerosol extinction and relative humidity.

3.5 Radar and Lidar Measurements

Between September 1997 and September 1998, a ground-based millimeter wave radar and depolarization lidar were operated on the Arctic ice pack as a part of

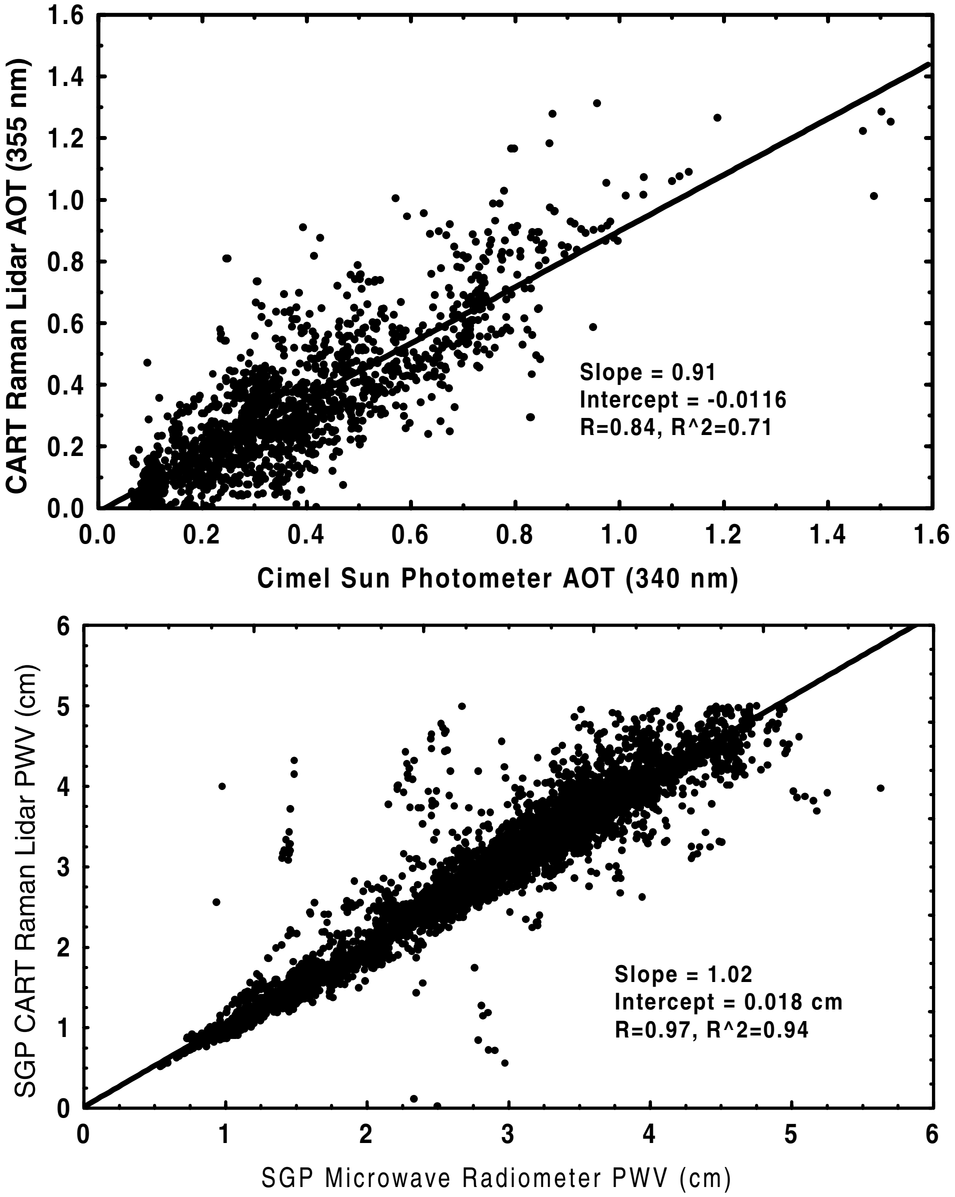


Figure 7. Comparison between CART Raman lidar and (a) Cimel sunphotometer analyses of aerosol optical thickness, and (b) microwave radiometer analyses of precipitable water over the SGP CART site (Ferrare et al.).

the National Science Foundation Surface Heat Budget of the Arctic (SHEBA) program. This activity was closely coordinated with the FIRE-ACE program described in section 4.1.6. In addition, an identical millimeter wave radar began operation in Barrow, Alaska in March 1998 as part of the ARM NSA site (Section 3.0) with an anticipated operation period of at least 10 years. Some of the specific Arctic cloud properties that can be validated with these radars are the determination of cloudy vs. clear pixels, cloud top heights, and cloud base heights. When used in combination with surface based radiometers, additional retrieved parameters can be derived, for example phase, particle size, optical thickness, emittance, and integrated water path.

In using surface-based data as validation sets for satellite, several important issues need to be addressed. First, the absolute accuracy of the surface data sets must be determined before they can be useful. For instance, it has been shown that radar and lidar often do not agree on observed cloud boundaries (Uttal et al. 1995). Also, radar-radiometer retrieval methods for detecting cloud microphysical properties utilize a number of assumptions (such as the shape of the particle size distribution) that have yet to be tested extensively with in situ data. The FIRE-ACE program conducted over 30 research flights over the SHEBA surface site, which will allow detailed comparisons between in situ cloud properties and those remotely detected with the radars. Given the difficulties that satellites have in determining cloud properties over cold snow and ice surfaces in the Arctic, it is expected that these measurements will be invaluable for testing the ground-based data sets that will be used to evaluate the performance of MODIS over the Arctic. Figure 8 shows an example of a time height cross-section of the often-complex cloud structure over the SHEBA ice station during one of the FIRE-ACE aircraft campaigns.

After some knowledge is obtained about the accuracy of the cloud retrievals for Arctic clouds, the radar and radiometer data from the ARM NSA site will be processed through an automated cloud processing procedure to generate a continuous ground-based cloud data set for the life time of the Terra satellite. Because Terra is a high altitude satellite, and Barrow, Alaska is a high latitude site, it

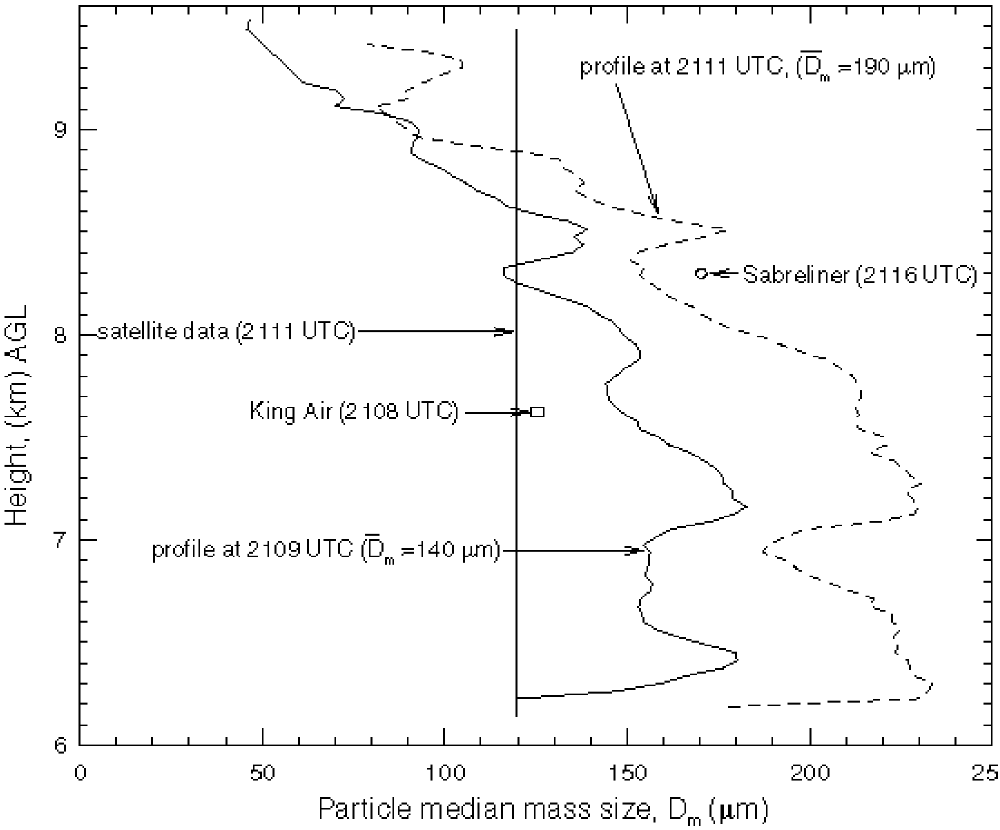


Figure 8. Comparison of cloud particle sizes from radar-radiometer techniques, in situ aircraft, and AVHRR satellite retrievals.

is projected that there will be on the order of 7-8 overpasses/day. Over a 3 year period this will allow 8×365×3 = 8760 coincident satellite-surface intercomparisons and, therefore, cloud properties from the surface site will be calculated on at least an hourly basis. Comparisons will be made based on point-by-point measurements where a short time average of surface data will be compared to the closest coincident satellite pixel (cf. Fig. 9). In addition, weekly, monthly and annual statistics will be computed to test for any systematic biases in the frequency distribution of such quantities as cloud top heights, detection of cloudy vs. clear pixels, cloud particle sizes and so forth.

4.0 Pre-launch Activities

In addition to establishing validation site locations, working with EOS Validation investigators from the US and Australia, the MODIS atmosphere team is working during the pre-launch time period to collect field and imagery data useful for validation and testing of algorithms being developed for operational processing of MODIS data. These pre-launch activities serve as examples of what will be undertaken post-launch.

4.1 Field Experiments

Pre-launch validation will be accomplished using MAS, AVIRIS, CLS (Spinhirne et

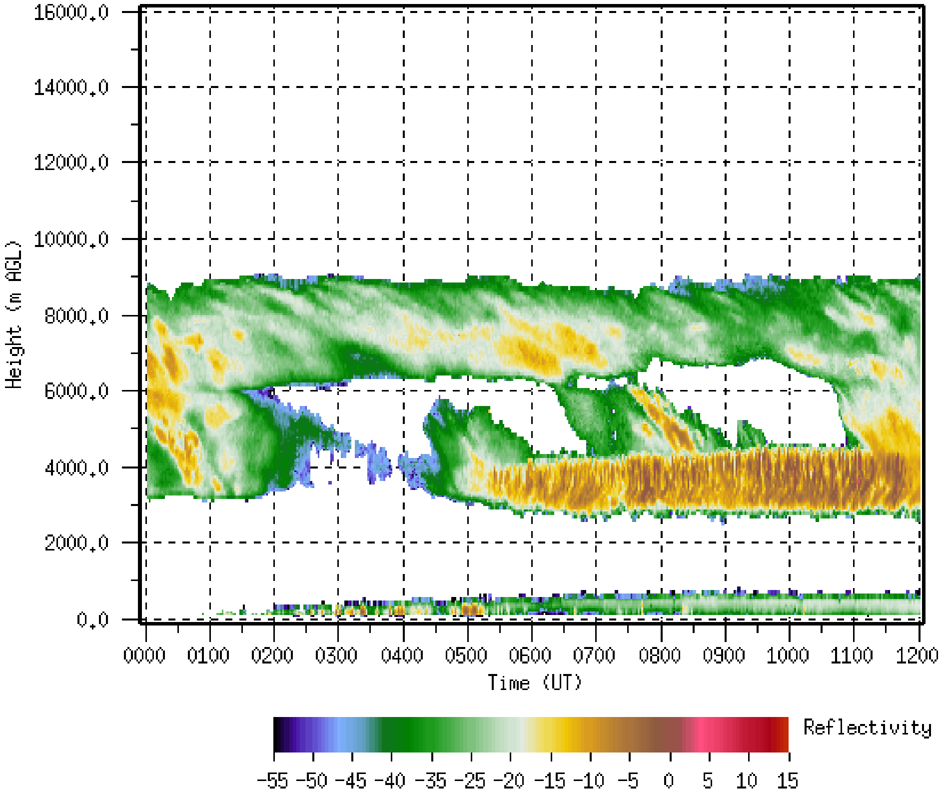


Figure 9. Time height cross section of radar reflectivities for a 12 hour period on 18 May 1998 over the SHEBA ice camp.

al. 1989), CAR (King et al. 1986) and HIS data already gathered in various field campaigns; data that are especially valuable in combination with nearly coincident airborne in situ microphysical measurements. A sampling of data sets already in-hand, along with key sensors and responsible investigators are given in Table 5.

In addition, numerous data sets obtained with the CAR of the internal scattered radiation field in smoke (Kuwait oil fires), clouds (FIRE marine stratocumulus experiment, ARMCAS), and many additional measurements of the bidirectional reflectance function of natural surfaces such as tundra, sea ice, oceans, smoke, cerrado, rainforest, desert, and the Great Dismal Swamp, add immeasurably to a data set on the surface reflectance characteristics of natural surfaces. The analyses of these data sets are being conducted by Michael King, Si-Chee Tsay, Tom Arnold, Peter Soulen, and Jason Li. Examples of BRDF measurements thus far obtained can be found in King (1992), Tsay et al. (1998), Curry et al. (2000), Soulen et al. (2000), and Arnold et al. (2000). An example of BRDF measurements obtained over tundra in early spring (subfreezing) conditions and late spring (melting) conditions can be found in Fig. 7 (for three CAR bands). Spectral albedo has also been computed for each BRDF case and compared to the nadir reflectance.

Table 5. Pre-launch Field Experiments involving MODIS atmosphere investigators.

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
ARMCAS	June 1995	ER-2 C-131A	MAS, CLS, AVIRIS, CAR, microphysics	Si-Chee Tsay Michael King Steve Platnick Steve Ackerman	arctic stratus clouds over sea ice; multilayer clouds; surface bidirectional reflectance (sea ice & tundra)
SCAR-B	Aug-Sep 1995	ER-2 C-131A surface	MAS, CLS, AVIRIS, CAR, microphysics, AERONET	Yoram Kaufman Lorraine Remer Michael King Si-Chee Tsay Elaine Prins	smoke, clouds and radiation from biomass burning in the cerrado, Pantanal, and Amazon rainforest; BRDF
SUCCESS	Apr-May 1996	ER-2 surface	MAS, CLS, HIS, AERI	Steve Ackerman Paul Menzel Si-Chee Tsay	mid-latitude cirrus clouds over continents
TARFOX	July 1996	ER-2 C-131A surface	MAS, LASE, CAR, AERONET	Didier Tanré Yoram Kaufman Lorraine Remer Si-Chee Tsay	sulfate aerosols, water vapor, and radiative forcing of aerosols; surface BRDF
WINCE	Jan-Feb 1997	ER-2	MAS, HIS, CLS	Paul Menzel Steve Ackerman Chris Moeller Dorothy Hall	cloud detection and properties over snow/ice covered land and lakes

Table 5. Pre-launch Field Experiments involving MODIS atmosphere investigators (continued).

Experiment	*Dates*	*Plat-forms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
FIRE ACE	May-June 1998	ER-2 CV-580 surface	MAS, CLS, AirMISR, MIR, SSFR, AMPR, HIS, CAR, micro-physics	Michael King Steve Platnick Steve Ackerman Si-Chee Tsay	arctic stratus clouds over sea ice, surface BRDF (tundra & sea ice)
CALVEX-N	Dec 1998	ER-2 surface	MAS, MIR, S-HIS, AERI	Paul Menzel Chris Moeller	underfly NOAA-15 as a calibration/ validation exercise
WINTEX	Mar 1999	ER-2 surface	MAS, S-HIS, NAST-I, NAST-M, AERI	Paul Menzel Steve Ackerman Chris Moeller	cloud detection and properties over snow/ice covered land and lakes

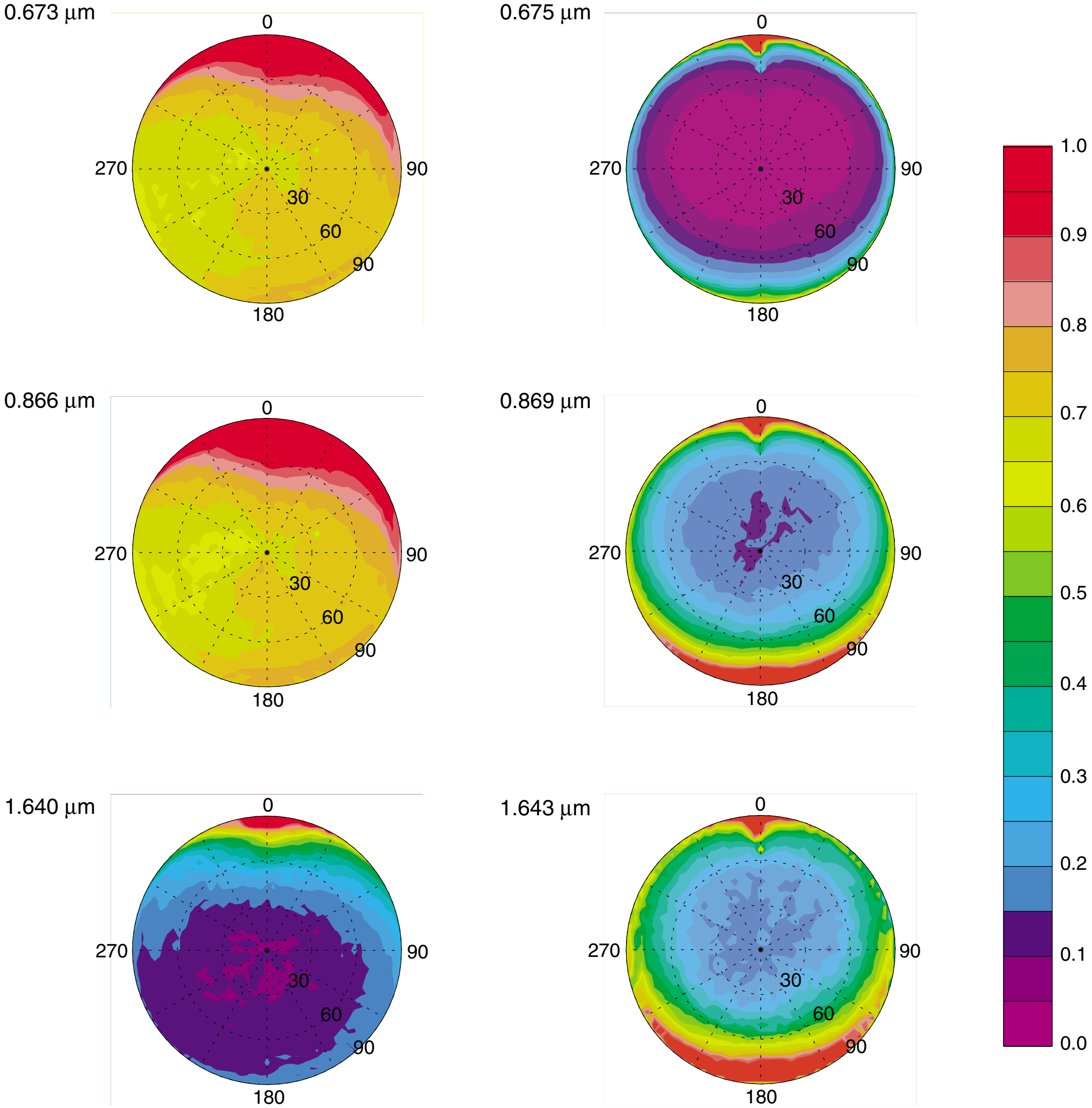
Limited validation will also be carried out using collocated HIRS and AVHRR data sets by Paul Menzel and Steve Ackerman, focusing on surface emissivity effects. This data set has the advantage of global coverage, but the spatial scale is far removed from that of MODIS, with spectral bandwidths that are much wider and off-center from those of MODIS.

4.1.1 ARMCAS

The Arctic Radiation Measurements in Column Atmosphere-surface System (ARMCAS) experiment was conducted in the Beaufort Sea, Alaska during June 1995, with the goal of determining the radiative properties of Arctic stratus clouds over sea ice in the summertime Arctic. Special emphasis was placed on acquiring MAS data that could be used to test the MODIS cloud mask for distinguishing clouds, clear sky, sea ice, and tundra, and to use these data to retrieve cloud radiative and microphysical properties over highly reflecting surfaces. These measurements, acquired from the ER-2 aircraft along with the CLS, were intercompared with in situ microphysical measurements obtained from the University of Washington C-131A. Bidirectional reflectance measurements were also made of sea ice, tundra, and clouds (cf. Fig. 10). Further details of the spectral bidirectional reflectance and plane albedo of snow, sea ice, and tundra, can be found in Arnold et al. (2000).

4.1.2 SCAR-B

The Smoke, Clouds, and Radiation–Brazil (SCAR-B) experiment was conducted in Brazil during August-September 1995, with the goal of studying biomass burning, emphasizing measurements of surface biomass, fires, smoke aerosol and trace gases, clouds, and radiation. It was conducted using both the NASA



Early Spring (snow covered)

Late Spring (no snow)

Figure 10. Tundra reflectance in early and late spring [from Arnold et al. (2000)].

ER-2 high altitude research aircraft as well as the University of Washington C-131A, and was coordinated with numerous AERONET sunphotometer sites throughout Brazil. From this experiment we found that MODIS, simulated by the MAS on the ER-2 aircraft, proved to be very useful for monitoring smoke, water vapor, cloud, fire, and surface properties, and the impacts of smoke on radiation and climate (cf. Kaufman et al. 1998 for further details).

4.1.3 SUCCESS

The Subsonic Aircraft Contrail and Cloud Effects Special Study (SUCCESS) field experiment was conducted in April-May 1996, with the goal of determining the radiative properties of cirrus contrails, and of contrasting them with naturally occurring cirrus. To assess the radiative impact of these clouds required a well-calibrated set of radiation measurements and "ground (or in situ) truth" observations. We acquired MAS and HIS multispectral observations along with CLS cloud height measurements from the NASA ER-2 aircraft by coordinating over flights of the ER-2 with in situ aircraft and ground based measurements. The MAS and HIS measurements were employed to address the very important relationship between cirrus radiative properties and the thermodynamic environment (atmospheric temperature and moisture conditions) wherein cirrus clouds form and are maintained. The HIS provided accurate measurements of the thermodynamical properties supporting the cirrus life cycle and the MAS measured the cirrus areal extent and radiative properties. Additional emphasis was placed on developing and validating methods of detecting upper tropospheric clouds and defining their areal extent with infrared (e.g., 13.9 µm) and near infrared (e.g., 1.88 µm) channels; these being similar to the MODIS channels and hence the MAS cirrus detection, thereby having direct relevance to the MODIS cloud mask algorithm. The CLS data were used to validate MAS upper tropospheric clouds.

Several studies have demonstrated the sensitivity of spectral radiances to cloud particle size and shape distributions. The MAS and HIS instruments provide accurate spectral measurements that can be used to assess differences in the radiative signatures between contrails and naturally occurring cirrus clouds. One difficulty in assessing the impact of high-altitude subsonic aircraft on cirrus formation and modification is the natural variability of the atmosphere and the potentially small signal of the radiative perturbation. Variations in the atmospheric spectral properties for contrail and natural cirrus conditions will be assessed with the two ER-2 instruments in conjunction with in situ and ground-based observations.

4.1.4 TARFOX

The Tropospheric Aerosol Radiative Forcing Observational Experiment (TARFOX, 10-31 July 1996) campaign measured atmospheric aerosols emanating from industrial centers in North America transported over the Atlantic Ocean. Their extent, radiative properties, and transport mechanisms were studied from satellite, aircraft, ship, and ground-based sensors. The MAS on the NASA ER-2 aircraft and the GOES Imager on GOES-8 were the primary sensors of interest to the atmosphere group (Didier Tanré, Yoram Kaufman, Paul Menzel). The monitoring effort focused on the corridor extending from Wallops Island, Virginia to Bermuda. In situ aircraft (UK Meteorological Office C-130H, University of Washington Convair C-131A, Naval Postgraduate School Pelican, and NASA ER-2), ground measurements (Lidar, AEROCE, AERONET), and satellite observations (AVHRR, ATSR-2, GOES) were used to measure the direct effects of tropospheric aerosols on regional radiation budgets of the cloud-free ocean-atmosphere system, while simultaneously measuring the chemical, physical, and optical properties of the predominant aerosols. The suite of measurements made during TARFOX and subsequent collaborative analyses will provide a better understanding of the impact of these aerosols over the US eastern seaboard and western Atlantic Ocean and will be used to assess the degree of closure (consistency) between aerosol radiative forcing calculations and various measurements of aerosol properties and other satellite-derived parameters. This study provided a means to validate current and future satellite remote sensing methods and products (aerosol optical thickness τ_a, aerosol size distribution $n_c(r)$, and earth radiation budgets), as demonstrated by Tanré et al. (1999). Observations were also acquired of the spectral bidirectional reflectance of the Atlantic Ocean and Great Dismal Swamp, as reported in Soulen et al. (2000).

4.1.5 WINCE and WINTEX

The Winter Cloud Experiment (WINCE; January-February 1997) and Winter Experiment (WINTEX; March 1999) investigated the difficulties in detecting clouds and estimating their properties in winter conditions (Steve Ackerman, Paul Menzel, Chris Moeller). These field campaigns were conducted from Madison, WI. During WINCE, cirrus and thin clouds over frozen tundra and lakes in the northern US and Canada were measured with the MAS, HIS, and CLS, along with the GOES-8, AVHRR, and surface AERI measurements. One of the missions investigated the product stability under nighttime conditions (infrared only). In addition, two ground sites in New England measured snow and ice cover during MAS/HIS overflights in clear sky condition (in collaboration with Dorothy Hall and George Riggs working on the MODIS snow/ice product). Examples of the MAS cloud mask were distributed to science team members so that they can determine its effect on their MODIS products.

During WINTEX, the ER-2 will be instrumented with MAS, S-HIS, NAST-I, NAST-M, and a camera system (RC-10), which will overfly ground-based instrumentation that includes uplooking lidar, AERI, and radiosondes. During WINTEX, the ER-2 will fly from six to eight missions over snow, bare ground, and vegetated surfaces with and without partial cloud cover. Day and night flights will be conducted. Plans also include collecting cloud microphysical profiles (dropped from aircraft) to supplement the ER-2 measurements of clouds. The ER-2 measurements will be used to continue assessment of the MODIS cloud mask and cloud top properties as well as evaluate absolute calibration of the interferometers (S-HIS, NAST-I); S-HIS and NAST-I will be used to validate MODIS IR calibration after the Terra launch in July 1999. WINTEX missions will be flown in southern Canada (winter scenes), over the Great Lakes (snow and bare ground), and around the midwest (spring greening phase) including the SGP CART site (calibration validation).

4.1.6 FIRE Arctic Cloud Experiment

FIRE, the First ISCCP (International Satellite Cloud Climatology Project) Regional Experiment, has previously conducted four successful field missions focused on cloud remote sensing and modeling studies as they relate to climate. FIRE Phase III (Arctic Cloud Experiment, or ACE) was conducted in the Arctic between April and July 1998, with the component of interest to the MODIS science team being confined to a 5 week period consisting of the University of Washington CV-580 along with a 3 week period of high-altitude ER-2 overflights (cf. Curry et al. 2000 for further details). The CV-580 was equipped with an extensive set of PMS cloud microphysics probes, a Gerber PVM-100A liquid water content and effective radius probe, Johnson-Williams and King hot wire probes, a newly developed Gerber cloud integrating nephelometer (g-meter) for measuring extinction coefficient and asymmetry factor, thermodynamic state variable measurements, and a SPEC Inc. Cloud Particle Imager (CPI). In addition, the ER-2 participated as the upper level aircraft from May 18-June 6, with the MAS, CLS, HIS, a multispectral along-track scanning radiometer (AirMISR), a Microwave Imaging Radiometer (MIR), a Solar Spectral Flux Radiometer (SSFR), and an Advanced Microwave Precipitation Radiometer (AMPR). All of these ER-2 sensors are of interest to Goddard Space Flight Center (Michael King, Si-Chee Tsay, Steve Platnick), as well as the CAR on the CV-580 and numerous in situ microphysics probes that will be invaluable in accessing the accuracy of cloud retrievals of the microphysical and radiative properties of Arctic stratus clouds over a bright (sea ice) surface. This valuable data set is being used by the University of Wisconsin group for testing the cloud mask algorithm for readiness at-launch. The suite of measurements made during FIRE ACE and subsequent collaborative analyses will provide a means to validate current and future satellite remote sensing methods and products (cloud optical thickness τ_c, effective radius r_e, single scattering albedo ω_0), the cloud mask, and precipitable water.

4.1.7 CALVEX-N

CALVEX-N, the Calibration/Validation Experiment – NOAA-15, was an early effort in a series of ER-2 activities focused on validating infrared band calibration of MODIS. CALVEX-N, conducted in December 1998 from Dryden Flight Research Center (DFRC), used NOAA-15 underflights to exercise the instrumentation and strategies that will be used to validate MODIS IR calibration during WISC-T2000 (first effort underflying MODIS on Terra in March 2000). The ER-2 instrumentation included MAS, S-HIS, MIR, and a high-resolution video camera system. During the three NOAA-15 missions (December 18, 21, and 22), the ER-2 flew along the sub-orbital track of NOAA-15 collecting scenes of clear ocean and uniform low stratus cloud. To characterize the atmosphere, special radiosonde launches along the southern California coast were coordinated with the ER-2 flights. A ground-based AERI instrument capable of upward and downward viewing was deployed on Rogers dry lakebed at Edwards AFB for comparisons with the ER-2 instrumentation. The MAS and S-HIS data sets are highly complementary. The high spectral resolution S-HIS provides accurately calibrated IR radiances for each nominal 2 km spatial resolution footprint; MAS provides the high spatial resolution data in the visible through thermal infrared. Through this synergism, data to characterize spatial (MAS) and spectral (S-HIS) dependencies of MODIS calibration were collected. The data collection phase of CALVEX-N was successfully completed. Of particular interest, the MIR 183 GHz radiances will be compared to the AMSU-B 183 GHz observations to gain insight into AMSU-B absolute calibration and the calibration dependence on scan angle. Finally, and perhaps most importantly, the CALVEX-N data analysis will be used to expose any weaknesses in the instrumentation or data collection procedures, and will provide insight into how one might address special MODIS IR calibration challenges (e.g. PC band crosstalk correction) during WISC-T2000 activities.

4.2 Operational Surface Networks

Data from various surface observing networks are incorporated into pre-launch validation activities, as well as selected data from the ARM site. These are collected and archived daily at the University of Wisconsin on the Man-computer Interactive Data Access System (McIDAS), which is connected to Paul Menzel's Science Computing Facility (SCF). In addition, data from the AERONET are archived at Goddard Space Flight Center by Brent Holben and are invaluable to the aerosol pre-launch validation activities of Yoram Kaufman and Didier Tanré.

4.3 Existing Satellite Data

All of the MODIS pre-launch studies at the University of Wisconsin (Paul Menzel) rely on AVHRR, HIRS, and GOES data for field experiment support and validation. These data are archived at the University of Wisconsin and accessible on McIDAS. Additional AVHRR data collected in support of MAST, ARMCAS, and various other pre-launch validation activities are available to Goddard Space Flight Center through the archive appropriate to that experiment (Langley Research Center DAAC, Goddard Space Flight Center DAAC, or the Naval Postgraduate School). Finally, pre-launch activities that are coordinated with Landsat-TM data sets are archived at Goddard by Yoram Kaufman.

4.4 Instrument Development

New improvements/additions to the SMART suite of surface radiation and remote sensing instruments are currently under development:

- ☐ a sun-sky-surface sensor (S^4) head to replace the Cimel sunphotometer, consisting of 14 spectral channels (without filter-wheel) ranging from 0.30 to 2.5 µm (including linear polarization) and using Si (UV-Vis-NIR) and InGaAs (SWIR, not cooled) for detectors

- ☐ collocated measurements of surface moisture and temperature with SMiR brightness temperature (22.8. 23.8 and 37.0 GHz) of the surface are sought for characterizing various types of surface emissivity. A future addition of tunable frequencies at 60 GHz (oxygen resonance line) for retrieving temperature profiles is also planned

- ❑ an upgrade of solar power for passive SMART instruments and larger data logging memory are planned

The S^4 project is scheduled to produce prototypes for testing in the SAFARI 2000 campaign in August-September 2000.

5.0 Post-launch Activities

The validation strategies and experience gained from pre-launch activities will guide the activity after launch. The pre-launch field activities have been used most effectively for testing MODIS-like algorithms in a wide variety of atmospheric and environmental conditions. Post-launch validation will apply these lessons to future field work and to the intercomparisons with actual MODIS data, both from Terra and Aqua (2001 and beyond).

5.1 Field Campaigns

In the first three years following the launch of Terra, we anticipate collecting numerous data sets for the purpose of validating MODIS algorithms and data products through direct intercomparisons of MODIS data with in situ and airborne remote sensing data sets. These campaigns will be EOS-targeted campaigns as well as participation in broader community research and analysis programs of direct relevance to assuring the accuracy of MODIS-derived data products. These post-launch field campaigns are summarized in Table 6.

Table 6. Post-launch Field Experiments involving MODIS atmosphere investigators.

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
WISC-T2000	Mar 2000	ER-2 Citation Learjet Twin Otter surface	MAS, S-HIS, CLS, AERI, CPI, Raman lidar, microwave sensors	Steve Ackerman Paul Menzel Chris Moeller Gerald Mace Rich Ferrare A. Heymsfield	overflights of the SGP ARM site; mid-latitude cirrus over continents, clear sky radiance; ice crystal habit
PRIDE	Jun-Jul 2000	Navajo, surface	Chemistry, microphysics, SMART, microtops	Si-Chee Tsay Lorraine Remer Yoram Kaufman	Transport of Saharan dust across the Atlantic ocean to the Caribbean

Table 6. Post-launch Field Experiments involving MODIS atmosphere investigators. (continued).

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
SAFARI 2000	Aug-Sep 2000	ER-2 CV-580 surface	MAS, S-HIS, AirMISR, MOPITT-A, CLS, SSFR, LAS, CAR, AERONET, microphysics	Michael King Steve Platnick Si-Chee Tsay Steve Ackerman	smoke, clouds and radiation from biomass burning in the Savannah; marine stratocumulus off Namibian desert; surface BRDF
Antarctica	Jan-Dec 2001	surface	P-AERI	Paul Menzel Chris Moeller	clear sky radiances for MODIS IR cold scene radiance validation over Antarctica
CLAP-T2001	Spring 2001	ER-2 surface	MAS, S-HIS, CLS, LAS, AERI, Raman lidar, microwave	Paul Menzel Steve Ackerman Chris Moeller	cloud properties, atmospheric profiles, Level-1b (Terra)
COVE	Jul-Aug 2001	ER-2 CV-580 surface	MAS, AirMISR, LAS, SSFR, CLS, AERONET, CAR, BSRN, AATS-14, microphysics	Michael King Si-Chee Tsay Steve Platnick Tom Charlock Ralph Kahn	clear sky radiances, ocean BRDF, surface SW radiation fluxes, cirrus cloud properties, aerosol over ocean
CLAP-A2001	Fall 2001	ER-2 surface	MAS, S-HIS, CLS, LAS, AERI, Raman lidar, microwave	Paul Menzel Steve Ackerman Chris Moeller	cloud properties, atmospheric profiles, Level-1b (Aqua)
California	Dec 2001 Jul 2002	ER-2 CV-580	MAS, CLS, AirMISR, LAS, CAR, microphysics	Michael King Steve Platnick Si-Chee Tsay	marine stratocumulus and valley fog
MOBY	Jan 2002	ER-2 surface	MAS, S-HIS, MOBY, AERONET	Paul Menzel Steve Ackerman Bo-Cai Gao	cirrus clouds and atmospheric correction over the ocean
ACE-Asia	Mar-Apr 2001 Mar-Apr 2004	surface	Chemistry, SMART, microtops, microphysics	Si-Chee Tsay Steve Ackerman Lorraine Remer Yoram Kaufman Bo-Cai Gao	Transport of Gobi desert dust across the polluted industrial area to the Pacific ocean

Table 6. Post-launch Field Experiments involving MODIS atmosphere investigators. (continued).

Experiment	*Dates*	*Platforms*	*Primary Sensors*	*Responsible Investigators*	*Primary Purpose*
CRYSTAL-FACE	Aug 2002	ER-2	MAS, S-HIS, CLS, in situ microphysics	Steve Ackerman A. Heymsfield Bo-Cai Gao Si-Chee Tsay	subtropical cirrus clouds in Florida area
CRYSTAL-WTP	Jul-Aug 2004	ER-2 WB-57F	MAS, S-HIS, CLS, in situ microphysics	Steve Ackerman Michael King Steve Platnick Si-Chee Tsay, A. Heymsfield Bo-Cai Gao	cirrus clouds in western tropical Pacific

5.1.1 WISC-T2000

The first EOS-targeted campaign after the December 18, 1999 launch of Terra was the WISC-T2000 (Wisconsin Snow and Cloud Experiment – Terra 2000) experiment. The MODIS-related objectives of WISC-T2000 included snow cover detection, cloud detection, cloud height, and top-of-atmosphere (TOA) radiance determination, all for the purpose of validating MODIS Level-1B (L1B) and Science Products. L1B validation results will be shared with the MODIS Characterization Support Team (MCST). The field exercise was conducted between February 24 and March 13, 2000, and included an ER-2 (based in Madison, WI) equipped with the MAS, S-HIS, CLS and AirMISR instruments, ground-based AERI, lidar, and radar measurements (at the CART SGP site), and class-sonde balloon launches (CART SGP and Madison). Flights over the Western Great Lakes, snowfields in the Upper Midwest and New England, and over the Southern Great Plains (SGP) ARM site in Oklahoma were conducted to meet the objectives. Flights over the SGP ARM site were coordinated with Cloud IOP 2000 (UND Citation, Learjet, ground-based radars, lidars) and ARESE II (Twin Otter) activities, which collected in situ and radiometric measurements to enhance the data set for cloud validation. S-HIS and MAS measurements will be used to assess MODIS emissive band L1B calibration accuracy and Atmospheric Profiles science product. CLS and MAS will be used together to assess the MODIS Cloud Mask, Snow Mask, and Cloud Top Properties science products. AirMISR and MAS will be used to assess MISR instrument performance. The Terra satellite was underflown on each of the eight science missions, plus on the ferry mission back to California by the ER-2 (total of nine underflights) to provide a range of satellite view angles and surface/atmospheric conditions. Of the eight science underflights of Terra, three were in clear skies, three were with broken or overcast low cloud, and two were with patchy high cloud. The three flights over the SGP ARM site take advantage of a broad suite of instruments at SGP. Lidar and radar observations of cloud boundaries will be used to validate the presence of cloud as well as cloud top pressure. Raman lidar will be used to derive aerosol and water vapor profiles, precipitable water vapor, and aerosol optical thickness under clear sky conditions. Class-sonde and AERI measurements will be used to define atmospheric temperature and moisture profiles. Whole sky imagers can be compared to ER-2 and Terra observations of cloud amount. Finally, optical depth measurements derived from lidar will aid in specifying the limit of thin cirrus detection in the cloud mask algorithm.

5.1.2 PRIDE

The field experiment on and near the island of Puerto Rico, known as PRIDE (Puerto Rico Dust Experiment), was designed to measure the properties of Saharan dust transported across the Atlantic Ocean to the Caribbean. PRIDE, conducted between June 26 and July 24, 2000, was a collaborative endeavor with the Office of Naval Research and the University of Miami. It involved a twin engine Piper Navajo aircraft carrying the Ames Airborne Tracking Sunphotometer (AATS), SSFR, and microphysics probes (PCASP and FSSP), a well-equipped ground-based site containing the SMART radiometer and lidar system, and the University of Puerto Rico oceanographic research vessel that included both sunphotometer measurements of the aerosol and bio-optical observations of sea water and chlorophyll.

In the summer months moderate quantities of desert dust are observed in the Caribbean. AVHRR and AERONET typically report mid-visible aerosol optical thicknesses of 0.2-0.7 in July. Puerto Rico is the first significant landfall for the dust travelling across the ocean from Africa. Dust arriving on the eastern end of the island should not be affected by other types of man made aerosol pollutants. This will minimize complications in the analysis.

We will determine the extent to which properties of dust particles and the spectral surface reflectance of the ocean need to be known before remote sensing systems can accurately determine optical thickness and radiative flux. Currently our knowledge of transported Saharan dust is extremely limited. Even basic characteristics of gross physical properties such as horizontal and vertical extent and horizontal homogeneity have never been measured on the western side of the Atlantic. We also have a poor understanding of dust optical, microphysical and chemical properties. Dust single scattering albedo and nonsphericity are especially significant parameters.

Our main purpose in PRIDE was to make simultaneous aerosol optical thickness and precipitable water vapor measurements from the SMART, oceanographic research vessel, and low flying aircraft at the time of the MODIS overpass, and then to compare these ground-based observations with the MODIS retrievals over both land and ocean. PRIDE gives us the opportunity to test the MODIS ocean aerosol optical thickness algorithms. The inclusion of flux measurements allows for the determination of dust aerosol radiative flux in addition to measurements of loading and optical thickness. We intend to use the data acquired in PRIDE to develop new, experimental, MODIS remote sensing algorithms including retrieval of dust single scattering albedo.

5.1.3 SAFARI 2000

In collaboration with the MODIS Land Group as well as MOPITT, MISR, CERES and ASTER, we plan to conduct a 6 week experiment on biomass burning in the Savannah region of southern Africa. Biomass burning occurs in August-September, as in South America, so we plan to conduct this experiment between August 12 and September 26, 2000, well after the launch of Terra. Opportunities to study Namibian marine stratus clouds at the end of the main SAFARI 2000 experiment are also planned for the final 2 weeks of the experiment in September. This experiment, like SCAR-B in 1995, will entail both the NASA ER-2 aircraft as well as the University of Washington CV-580, with the ER-2 based in Pietersburg, South Africa. The CV-580 will be based in Pietersburg, South Africa for approximately 3 weeks, Lusaka, Zambia for about 1 week, and Walvis Bay, Namibia, for the final 2 weeks. Primary instruments of interest for the ER-2 are the MAS, S-HIS, CLS, AirMISR, MOPITT-A, LAS, and SSFR (cf. Fig. 11). The latter instrument is to characterize spectral and broadband flux of particular relevance to CERES objectives. As in Brazil (SCAR-B), we will coordinate the ER-2 with in situ aerosol, radiation, and chemistry measurements on the CV-580 and overfly numerous AERONET locations in Namibia, South Africa, Zambia, and Botswana and over the SAVE/SMART site in Skukuza, South Africa and Mongu, Zamiba. Figure 11 shows the planned instrument compliment on the ER-2 for this experiment.

5.1.4 Antarctica

As part of a National Science Foundation program, a surface-based Polar-AERI (P-AERI) will be deployed to the Amundsen-Scott South Pole Station for one year beginning January 2001. P-AERI measurements will include downward

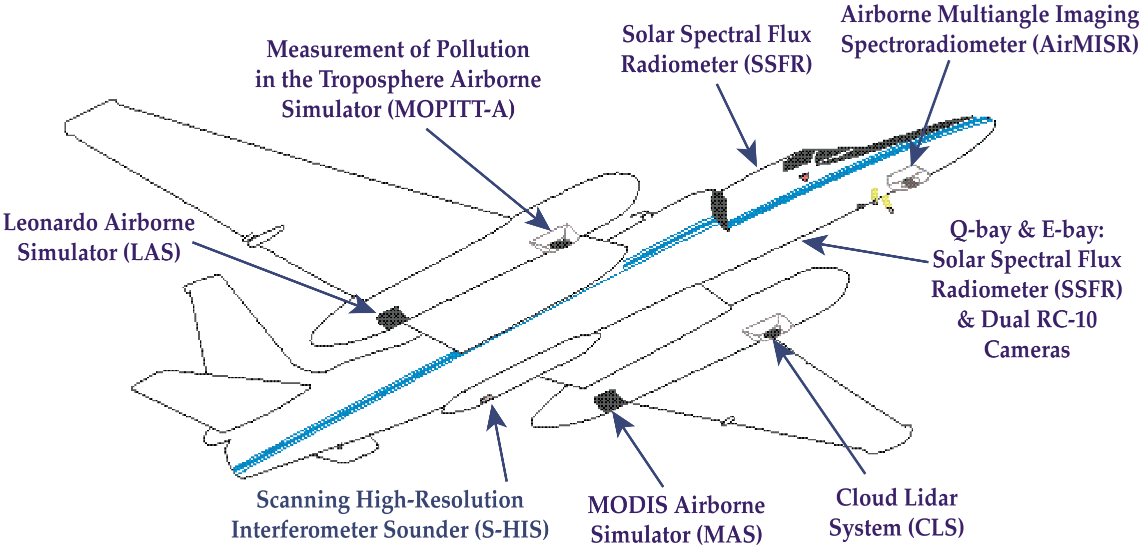


Figure 11. NASA ER-2 configuration for SAFARI 2000.

looking surface measurements from a platform about 5 meters above the snow surface as well as uplooking measurements to document the clear sky downwelling radiance. During MODIS overpasses the downward-looking and upward-looking measurements can be collected for the angular viewing geometry of MODIS. Balloon launches will be used to complete the atmospheric characterization. These measurements are useful to evaluate MODIS (on both Terra and Aqua) emissive band calibration accuracy at temperatures typical of cold clouds. Clear sky Antarctica top-of-atmosphere (TOA) brightness temperatures are comparable to tropospheric cloud top temperatures in the mid-latitudes and tropics.

5.1.5 CLAP-T2001 and CLAP-A2001

The SGP ARM site and Gulf of Mexico are the targets of choice for the Clouds and Atmospheric Profiles - Terra 2001 {CLAP-T2001) experiment slated for Spring 2001. The objectives of CLAP-T2001 are validation of MODIS cloud, atmospheric properties, and emissive band L1B products. This activity is timed to occur within about one year of MODIS first light, after the transfer from prelaunch to post-launch calibration has been completed. The ER-2 payload includes MAS, S-HIS, LAS, and CLS to provide calibration accuracy and thin cloud definition. All flights (SGP ARM and Gulf of Mexico) will be coordinated with MODIS (on Terra) overpasses. Overflights of SGP CART will take advantage of ongoing ground-based measurements (class-sonde, AERI, tower measurements of temperature and moisture, microwave moisture measurements, uplooking lidar and radar observations, whole sky imagers) for cloud and atmospheric profiles validation. An ARM SCM is also tentatively scheduled for next spring in coordination with the International H_2O Project (IHOP). The Gulf of Mexico is an important uniform scene background for assessing MODIS emissive band performance and characterization in the L1B algorithm (e.g., scan mirror performance, optical crosstalk, etc.). Thin single layer cloud will be sought for cloud top properties and cloud mask validation. Fine-tuning of cloud mask thresholds will result from this validation activity. Clear sky profiles will be validated using the abundant atmospheric moisture and temperature characterization at the SGP CART. An important goal of CLAP-T2001 will be to measure atmospheric profiles under varying atmospheric moisture content. The turbid coastal zone of Louisiana will be overflown to assess the impact of in-water turbidity on the MODIS cloud mask.

The Cloud and Atmospheric Profiles - Aqua2001 {CLAP-A2001) experiment is designed very much like that of CLAP-T2001, except the focus is on the Aqua satellite with MODIS and AIRS onboard. The SGP ARM site and Gulf of Mexico are the planned targets for the ER-2 flights. The ER-2 payload of MAS, S-HIS, LAS, and CLS provides accurate high spectral resolution emissive band calibration and thin cloud definition for radiometric, cloud top property, and atmospheric profile validations. Overflights of SGP CART will take advantage of the excellent atmospheric water vapor characterization provided by ground based instruments (class-sonde, AERI, tower measurements of temperature and moisture, microwave moisture measurements, radar) while uplooking lidar and whole sky imagers contribute to cloud product validation. Clear sky flights over the Gulf of Mexico provide a uniform background for MODIS and AIRS radiometric evaluation; cloud validation over water will benefit from cirrus cloud scenes over the Gulf. Although CLAP-A2001 is focused on Aqua, Terra can also be underflown to assess synergism between Terra and Aqua.

5.1.6 COVE

The CERES Ocean Validation Experiment (COVE) is planned between July and August 2001, and its focus is on verifying cloud-free aerosol retrievals over an ocean background. It is coordinated with both the CERES and MISR teams, and centers on the Chesapeake Bay Lighthouse located about 25 km off the coast of Virginia Beach, Virginia. The primary purpose of this CERES validation site is to collect Baseline Surface Radiation Network (BSRN) measurements of downwelling shortwave radiation at the ocean surface, together with AERONET sunphotometer measurements and a micropulse lidar, all over as uniform and dark a background as possible. This will allow careful discrimination of surface and atmospheric radiation, and to assess the impact of clouds, aerosols, water vapor, and surface temperature on the radiation budget. CERES funds the Chesapeake Bay Lighthouse from its EOS validation funds. The focus of the COVE field campaign is to coordinate MODIS, CERES, and MISR observations of aerosol over the ocean with coincident surface measurements from the Lighthouse and airborne measurements from the NASA ER-2 and University of Washington CV-580 aircraft. The ER-2 payload of interest for this experiment is the MAS, AirMISR, CLS, SSFR, and the recently developed LAS, which enables studies of the MODIS cloud mask, aerosol retrieval over ocean, and surface reflectance characterization. The CV-580 should contain both its standard in situ aerosol microphysics (PCASP, FSSP, etc.) and chemistry measurements, and carry the CAR instrument for bidirectional reflectance measurements over the ocean and nearby land surfaces, and the SSFR and AATS-14 instruments from Ames Research Center for spectral flux and aerosol optical thickness measurements.

5.1.7 California Stratus and Valley Fog

Once the MODIS is in orbit and returning regular data, we envision two focused periods of ER-2 overflights, to be coordinated with the Terra orbit, in California (the first one over valley fog in the central valley of California in December 2001, and the second over marine stratocumulus clouds located over the ocean between Monterey and San Diego in July 2002). These experiments would entail ER-2 flights from home base in California (Dryden Flight Research Center), and would consist, once again, of the MAS, AirMISR, LAS, and CLS, together with coordinated underflights by the University of Washington CV-580 with its in situ microphysics probes. This data set, of special interest to Goddard Space Flight Center (Michael King, Steve Platnick, Si-Chee Tsay) would help to validate the cloud optical thickness and effective radius between MODIS and the smaller spatial resolution airborne sensors on the ER-2.

5.1.8 MOBY

The MOBY (Marine Optical Buoy) positioned near Lanai, Hawaii will be used in January 2002 to validate MODIS sea surface temperature (SST) and VNIR water leaving radiances. Emissive band L1B, cloud mask, and cloud top properties will also be validated for cirrus over ocean. The cloud mask validation will be an important component of validating SST. The effect of elevated water leaving radiances (caused by suspended materials or sub-aqueous bottom reflectance) on the cloud mask will be investigated. MOBY will validate these products for MODIS on both the Terra and Aqua platforms.

5.1.9 ACE-Asia

The International Global Atmospheric Chemistry program has organized a series of aerosol characterization experiments (ACE) to acquire data sets needed for assessing aerosol effects in major regions of the globe. ACE-Asia is designed to study the compelling variability in spatial and temporal scale of both pollution-derived and naturally-occurring aerosols, which often exist in high concentrations over eastern Asia and along the rim of the western Pacific. The phase-I of ACE-Asia will be conducted from March-April 2001 in the vicinity of the Gobi desert, east coast of China, Yellow Sea, and Japan, along the pathway of Kosa (severe events that blanket East Asia with yellow desert dust, peaked in the Spring season).

Although central Asia is one of the most important dust sources, its climatic impact is less well studied than that of Saharan dust. Asian dust typically originates in desert areas far from polluted urban regions. During transport, dust layers can interact with anthropogenic sulfate and soot aerosols from heavily polluted urban areas. Added to the complex effects of clouds and natural marine aerosols, dust particles reaching the marine environment can have drastically different properties than those from the source. Thus, understanding the unique temporal and spatial variations of Asian dust is of special importance in regional-to-global climate issues such as radiative forcing, the hydrological cycle, and primary biological productivity in the mid-Pacific Ocean.

In collaboration with international chemists, our main goals in ACE-Asia are to measure continuously aerosol optical/radiative properties, column precipitable water amount, and surface reflectivity over homogeneous areas from the SMART. The inclusion of flux measurements permits the determination of dust aerosol radiative flux in addition to measurements of loading and optical thickness. At the time of the MODIS overpass, these ground-based observations can provide valuable data to compare with MODIS retrievals over land. Even without dust events, the homogeneity of the Gobi desert serves as an excellent calibration target. Thus, SMART observations in the vicinity of dust sources are our first priority. A less instrumented SMART version will be set up in the marine environment.

5.1.10 CRYSTAL-FACE and CRYSTAL-TWP

The Cirrus Regional Study of Tropical Anvils and Layers (CRYSTAL) experiment, planned to be conducted in two phases, the Florida Area Cloud Experiment (FACE) in August 2002 and the Western Tropical Pacific (TWP) in August 2004, focuses on modeling and observing tropical cirrus cloud systems and their role in regional and global climate. As with the previous FIRE field experiments, remote sensing is a central theme of both CRYSTAL-FACE and CRYSTAL-TWP, and validation of satellite retrievals of cloud properties is a focus of CRYSTAL. The validation approach is to combine the satellite observations with in situ observations from field campaigns and continuous ground-based observations. Comparison of the satellite observations with the continuous ground-based data provide a statistical meaningful sample for assessing the retrievals over a long time period. Comparisons with in situ measurements provide detailed case studies with cloud macrophysical and microphysical properties to assess cloud algorithm performance. This experiment includes observations from the NASA ER-2 aircraft as well as in situ aircraft. Primary instruments of interest for the ER-2 are the MAS, S-HIS, and CLS. This experiment will focus on the validation of cirrus properties including: detection by cloud mask algorithm, cloud top height, cloud water phase, and cloud microphysical properties. An emphasis will be on retrieving the properties of thin cirrus often observed near the tropopause.

5.2 Other Satellite Data

MODIS retrievals will be compared to those determined from in situ radiosonde measurements, the NOAA HIRS operational retrievals, the GOES sounder operational retrievals, NCEP analysis of all available data, and retrievals from the Atmospheric Infrared Sounder (AIRS) on the Aqua platform. Total ozone will be compared to Total Ozone Mapping Spectrometer (TOMS) measurements as well as the operational NOAA ozone estimates from HIRS. In addition, MODIS aerosol retrievals will be compared to POLDER and ILAS II on ADEOS II.

5.3 In Situ Measurement Needs at Calibration/Validation Sites

In order to assure that the cloud, aerosol and water vapor products are properly derived from our satellite-based data processing algorithms, it is necessary to coordinate many of the above-specified airborne campaigns with in situ cloud microphysics, aerosol sampling, and meteorological sampling. For this purpose we plan to make use of our long-standing collaboration with Prof. Peter V. Hobbs, University of Washington, and coordinate many of our cloud and aerosol campaigns from the ER-2 and Terra with in situ sampling from the University of Washington CV-580 aircraft.

In addition, we envision intercomparing MODIS-derived column aerosol products with AERONET and ARM sites, as appropriate. These are all surface networks with *long-term* measurements that will enable long-period assessments of our derived products through intercomparisons with these data (aerosol optical thickness, aerosol size distribution, and precipitable water). Precipitable water vapor will be also validated using ground-based microwave radiometers, WMO radiosonde sites, Raman lidar systems, and a global network of GPS stations (~2000 worldwide). Some of the AERONET sites will be equipped with micropulse lidars to measure the vertical distribution of aerosol and their optical properties (extinction coefficient and backscattering).

5.4 Needs for Instrument Development

We envision no need to further develop any airborne or in situ instruments, but rather to continually assess the performance of the MODIS Airborne Simulator and to perform regular calibration and characterization experiments, upgrading the spectrometer as required. Based on recent operational experience, we anticipate a number of improvements, enhancements of capability, and laboratory tests. Laboratory measurements planned for the near future include: (i) measuring and characterizing the polarization sensitivity of the MAS as a function of wavelength, (ii) measuring the modulation transfer function and point spread function of the MAS, (iii) viewing a calibrated high-temperature blackbody source, and (iv) characterizing the spectral response functions periodically with high spectral resolution interferometric sources. Finally, we plan to improve the stability of the 20 in integrating hemisphere that accompanies the MAS on field deployments by incorporating variable power supplies that are servo-controlled by reference detectors.

Similarly, the CAR and HIS will be upgraded or have parts replaced, as necessary, to maintain their usefulness in field validation activities. For example, the HIS has been upgraded to have scanning capability in 1998 (S-HIS), and the CAR will have the following improvements: (i) addition of two UVA channels at 0.34 and 0.38 µm (like TOMS), (ii) replacing the filter wheel with simultaneous channels in a linear array (upgrading the instrument from 8 to 15 simultaneous channels), and (iii) upgrading the data system from 10 bit to 12 bit with the higher data rate necessary to support the additional channels.

In addition to the airborne radiometers mentioned above, there is a continuing need to develop new instruments for better measurements of the aerosol single scattering albedo, CCN spectrum, size dependent chemical composition, and phase function of ice crystals. We plan to collaborate with other groups in this regard, and not to initiate or develop this capability ourselves.

5.5 Geometric Registration Site

None are required for validating MODIS atmosphere algorithms.

5.6 Intercomparisons

Post-launch validation of the thermal infrared cloud phase product with other MODIS products will consist of close inspection of sections of data representing differing cloud regimes and surface types, including cross checks during the day mode with the visible reflection function technique of King et at. (ATBD-MOD-05) and consistency with the cloud top properties results.

Validation of the MODIS cloud products will also be done post-launch using products derived from the ASTER, CERES, and MISR sensors on the Terra, CERES on TRMM, and GLI on ADEOS II.

The MODIS Cloud Mask will be compared to the ASTER Polar Cloud Mask to ensure consistent classification of polar cloud cover. The ASTER product will include a classification for each pixel poleward of 60°N or 60°S using a bit map with the following bit flags: unknown, ice cloud, water cloud, shadow, land, ice, wet ice, and water. The high spatial resolution of the ASTER data (30 m at nadir) will help to ensure that sub-pixel effects are properly accounted for in the MODIS data. Because the ASTER channels are mostly located in atmospheric window regions, however, it will still be difficult to correctly identify thin cirrus clouds over polar regions from ASTER data. The 1.38 µm MODIS channel should easily allow the detection of thin cirrus clouds over polar regions during the daytime, and this comparison with the ASTER cloud mask may prove invaluable to both algorithms.

The MODIS Cloud Mask and Cloud Properties (cloud top pressure and temperature, effective emissivity, cloud optical thickness, thermodynamic phase, and effective radius) products will be compared to the CERES Single Satellite Footprint (SSF) and Single Satellite Gridded products that include cloud top pressure and temperature, cloud optical thickness, effective radius and phase, and cloud category (lower, lower-middle, upper-middle, high). CERES is heavily dependent on MODIS observations for cloud detection, so it will be important to ensure that the MODIS and CERES-derived cloud products are consistent. The MODIS Cloud Mask and Cloud Properties (cloud top pressure) products will also be compared to the MISR Top-of-Atmosphere/Cloud Product. The components of the MISR product that will be used are Reflecting-Level Reference Altitude (retrieved using MISR stereo imagery), Angle-by-angle cloud masks, Cloud shadow mask, and Altitude-binned cloud fraction. The MODIS and MISR Cloud Masks will be compared to ensure consistency of cloud identification, and the MISR stereo cloud heights will be compared with the MODIS cloud top heights to geometrically validate the MODIS radiometrically derived cloud height data.

We plan to compare the MODIS aerosol product with the aerosol product derived from MISR (MIS05). Using field experiments as well as AERONET, we plan to investigate the relative success of each of these techniques as a function of aerosol type, season, surface cover, and view and illumination directions. This will be an ongoing research endeavor involving Yoram Kaufman and Didier Tanré of the MODIS Team, and Jim Conel, Ralph Kahn, John Martonchik, and Dave Diner of the MISR Team.

For atmospheric water vapor, the MODIS precipitable water product will be compared to column water vapor derived from numerous AERONET sunphotometers worldwide, as well as with precipitable water estimates derived from passive microwave and Raman lidar measurements at the SGP (Oklahoma) ARM CART site, North American radiosondes, microwave measurements from the SMART, and surface GPS soundings, where available.

5.7 Modeling Studies and Quality Assessment

Steve Platnick and Robert Pincus plan to use model calculations and analysis of MODIS and MAS data to assess the accuracy of the MODIS Cloud Product retrievals of liquid water cloud optical thickness and effective radius (MOD06). A component of their investigation includes the effects of vertical stratification of cloud droplet sizes on the retrievals, especially discrepancies between retrieved effective radii made from reflection measurements in different near-infrared bands. They also plan to develop forward models for assessing biases due to horizontal inhomogeneity. Results should provide quantitative guidance for the assessment of quality assurance parameters for the MODIS cloud retrieval algorithm. It is anticipated that in situ cloud measurements from planned MODIS Atmosphere Team validation campaigns will help in the modeling of realistic clouds, as well as for retrieval validation. They are especially interested in sufficient vertical profiling of clouds and long horizontal legs. To this end, relatively plane-parallel like marine stratus clouds are desired as a starting point in their investigation. This includes the California stratus and valley fog deployments, as well as opportunities such as Namibian stratus off the coast of Namibia during SAFARI 2000.

In situ validation of cloud optical thickness fields is quite limited with current surface and aircraft capabilities. We need some validation tools for the optical thicknesses retrieved from MODIS data at locales where no other in situ measurements are available. Alexander Marshak proposes to use a theoretical method that should provide important information on how accurate operational cloud retrievals are. As a first step, this investigation will be applied to stratocumulus clouds. This method will help to better understand errors related to cloud horizontal inhomogeneity in operational cloud retrievals and set error bounds on the inferred values, especially for the 250 m pixel data. The method is based on estimating the effect of photon horizontal fluxes on the retrieval of cloud optical properties. To validate this theoretical model, microwave radiometer data at two ARM sites (SGP and TWP) will be used. Marshak will also use 15 m spatial resolution ASTER VNIR (visible and near-infrared) data set of stratocumulus clouds over these two ARM sites.

6.0 Implementation of Validation Results

6.1 Approach

The MODIS atmosphere algorithms for the cloud mask, cloud properties, aerosol properties, precipitable water, and atmospheric profiles will evolve in the first year after MODIS is launched in accordance with seasonal changes and validation results. Thereafter, algorithm changes will be restrained to occur once per year as needed. We anticipate assessing the performance of the MODIS algorithms initially by processing every other day, as well as specific time periods with validation experiments of special relevance, as outlined above. After initially looking at one year's data, consistency checks, quality assessment flags, validation campaigns, as appropriate, and intercomparisons with other instruments (especially on Terra), we will begin whole-scale reprocessing, including every month. This initial stage may take in excess of one year, during which time the MODIS calibration algorithm will likely undergo additional refinement. Continual refinement of the MODIS "operational" algorithms will largely be conducted at the Team Members SCF as well as at the Atmosphere Group's Computing Facility (Windhoek), as many of the algorithms are dependent on results from other algorithms (like calibration). Only periodically (after say 1.5 years following launch), the first reprocessing at the MODIS Data Processing System (MODAPS) will be initiated.

6.2 Role of EOSDIS

To investigate algorithm changes, past data sets (covering different seasons and ecosystems) will be necessary. We expect that these data will be archived and available through EOSDIS. The bulk of the data sets that we have thus far obtained (including CAR, MAS, and University of Washington C-131A in situ data) have been archived and are available through relevant EOS DAACs. The specific point of data distribution for MAS data is clearly identified as part of the browse imagery archive portion of the MAS World Wide Web site (see Section 9).

6.3 Archival, Processing, and Distribution of Validation Data

The MODIS Science Team plans to gather all relevant data from various validation exercises and make these data available through EOSDIS. We anticipate that the MODIS home page on World Wide Web will soon establish a link to the location and availability of all MODIS-related validation data sets.

7.0 Summary

This plan represents the thought process of all MODIS atmosphere team members, associates, and close colaborators. This discipline group has considerable field campaign experience as well as experience with other satellite and surface network data. Putting all such validation schedules together, we obtain the "master schedule" for MODIS atmosphere validation activities, for the focussed, field-campaign portion of this plan (cf. Figure 12).

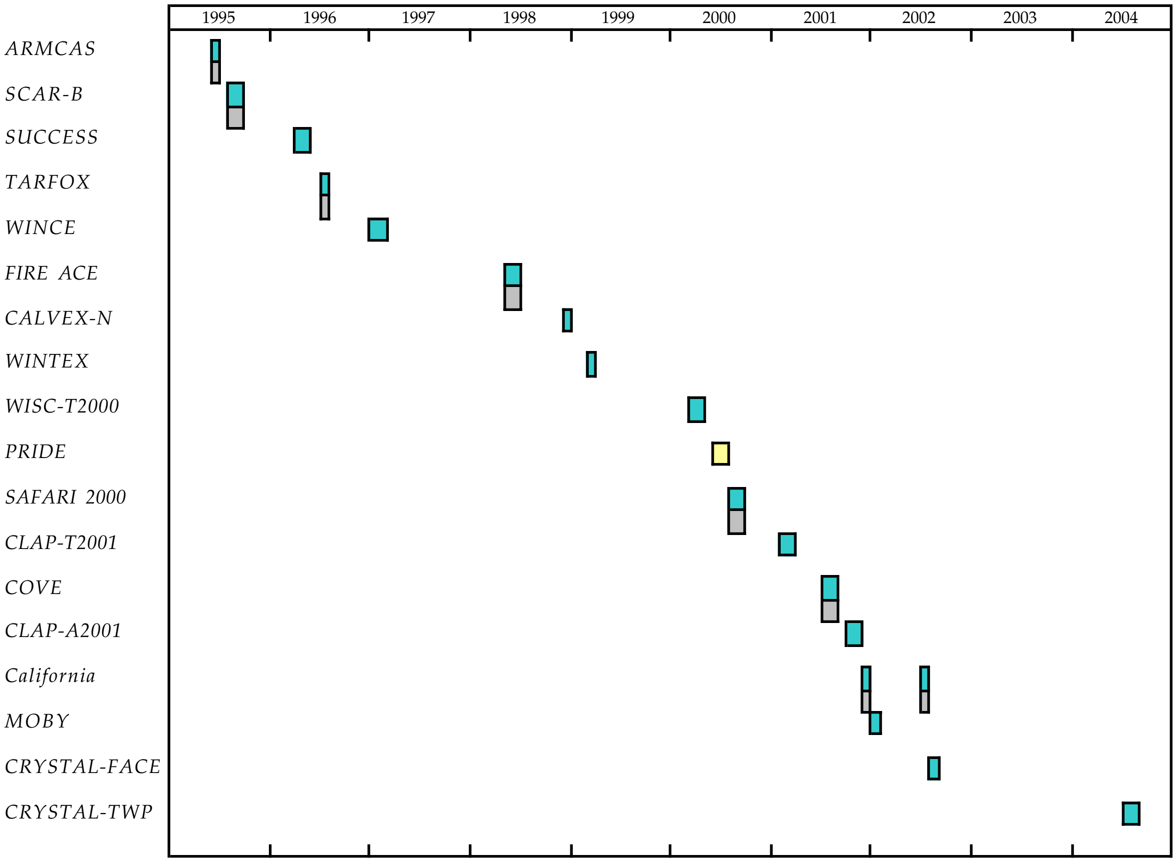


Figure. 12. Airborne validation strategy for the MODIS Atmosphere Group from 1995 (pre-launch) through 2004 (post-launch). The blue boxes are for the NASA ER-2, the gray boxes denote the University of Washington C-131A or CV-580 research aircraft, and the yellow boxes denote other aircraft.

Table 7 summarizes the validation methods being used by atmosphere data product.

Table 7. Summary of validation measurements by data product.

MODIS Product	***Validation PI***	***Validation Measurements***
Cloud mask	Steve Ackerman	Aircraft and ground based lidar and radar, MAS, ASTER, MISR, AVHRR cloud masks, Level-3 product statistics
Cloud top pressure, temperature, and effective emissivity	Paul Menzel	Aircraft and ground based lidar, radar, GOES stereo cloud heights, HIRS, MISR and CERES cloud heights

Table 7. Summary of validation measurements by data product (continued).

MODIS Product	*Validation PI*	*Validation Measurements*
Cloud optical thickness and effective radius	Michael King	In situ aircraft, remote sensing aircraft and ground based lidar and radar, MISR and CERES cloud optical thickness
Cloud particle phase	Steve Ackerman	Aircraft based in situ measurements, dual polarization lidar, CERES cloud phase
Cirrus reflectance in the visible	Bo-Cai Gao	Aircraft remote sensing with multispectral radiometers (MAS and AVIRIS)
Aerosol optical thickness and size distribution	Yoram Kaufman Didier Tanré	Surface measurements from AERONET sun/sky radiometers, aircraft based in situ measurements
Atmospheric moisture and temperature gradients	Paul Menzel	CART microwave and in situ measurements, CIGSN network of Australian soundings, North American radiosonde network, HIRS, GOES, AIRS, LASE
Atmospheric stability	Paul Menzel	CART temperature and moisture measurements, CIGSN network of Australian soundings, North American radiosonde network, HIRS, GOES, AIRS
Precipitable water	Bo-Cai Gao Yoram Kaufman Paul Menzel	AERONET, CART microwave and Raman lidar measurements, North American radiosonde network, ground-based GPS network, SMiR
Gridded level-3 atmosphere product	All	Intercomparisons and consistency checks

Additional contributions from the wider scientific community are described in this document. Other opportunities are widely sought.

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9.0 World Wide Web Links for Validation

AERI	http://cimss.ssec.wisc.edu/aeriwww/aeri
AERONET	http://aeronet.gsfc.nasa.gov:8080/
AVIRIS	http://makalu.jpl.nasa.gov/aviris.html
CAR	http://ltpwww.gsfc.nasa.gov/CAR
CIGSN	http://www.dar.csiro.au
CLS	http://virl.gsfc.nasa.gov/er2cls.html
EOS Project Science Office	http://eospso.gsfc.nasa.gov
HIS	http://cimss.ssec.wisc.edu/his/hishome.html
MAS	http://ltpwww.gsfc.nasa.gov/MAS
MODIS	http://ltpwww.gsfc.nasa.gov/MODIS/MODIS.html
MODIS Atmosphere	http://modis-atmos.gsfc.nasa.gov

10.0 Acronyms

AATS	Ames Airborne Tracking Sunphotometer (NASA Ames Research Center)
ACARS	ARINC (Aeronautical Radio Inc.) Communications, Addressing and Reporting System
ACE	Arctic Cloud Experiment (Chukchi Sea, Alaska, May-June 1998)
ACE-Asia	Aerosol Characterization Experiment-Asia
ADEOS	Advanced Earth Observing Satellite (Japan)
AERI	Atmospheric Emitted Radiation Interferometer
AEROCE	Aerosol/Ocean Chemistry Experiment
AERONET	Aerosol Robotic Network
AirMISR	Airborne MISR
AIRS	Atmospheric Infrared Sounder
AMPR	Advanced Microwave Precipitation Radiometer
AMSU	Advanced Microwave Sounding Unit
ARM	Atmospheric Radiation Measurement Program
ARMCAS	Arctic Radiation Measurements in Column Atmosphere-surface System (Beaufort Sea, Alaska, June 1995)
ASTER	Advanced Spaceborne Thermal Emission and Reflection radiometer
ATBD	Algorithm Theoretical Basis Document
ATSR	Along Track Scanning Radiometer
AVHRR	Advanced Very High Resolution Radiometer
AVIRIS	Airborne Visible/Infrared Imaging Spectrometer
BRDF	Bidirectional Reflectance Distribution Function
BSRN	Baseline Surface Radiation Network
CALVEX-N	Calibration Validation Experiment - NOAA-15
CAR	Cloud Absorption Radiometer
CART	Clouds and Radiation Testbed
CEPEX	Central Equatorial Pacific Experiment (Fiji, February-March 1993)
CERES	Clouds and the Earth's Radiant Energy System
CIGSN	Continental Integrated Ground Site Network (Australia)
CLAP-A2001	Clouds and Atmospheric Profiles - Aura 2001
CLAP-T2001	Clouds and Atmospheric Profiles - Terra 2001
CLS	Cloud Lidar System
COVE	CERES Ocean Validation Experiment
CPI	Cloud Particle Imager
CRYSTAL	Cirrus Regional Study of Tropical Anvils and Layers
DAAC	Distributed Active Archive Center
EOS	Earth Observing System
EOSDIS	EOS Data and Information System
ETO	Extended Time Observation
FACE	Florida Area Cloud Experiment

FARS	Facility for Remote Sensing (University of Utah)
FIRE	First ISCCP Regional Experiment (California, June-July 1987, Beaufort Sea, Alaska, April-June, August 1998)
FSSP	Forward Scattering Spectrometer Probe
GLAS	Geoscience Laser Altimeter System
GLI	Global Imager
GOES	Geostationary Operational Environmental Satellite
GPS	Global Positioning System
HIS	High-spectral resolution Interferometer Sounder
HIRS	High Resolution Infrared Radiation Sounder
HSB	Humidity Sounder from Brazil
ILAS	Improved Limb Atmospheric Spectrometer
ISCCP	International Satellite Cloud Climatology Project
LAS	Leonardo Airborne Simulator
LASE	Lidar Atmospheric Sensing Experiment
LBA	Large Scale Biosphere-Atmosphere Experiment in Amazonia
LEADEX	Lead Experiment (Beaufort Sea, Alaska, April 1992)
M-AERI	Marine-Atmospheric Emitted Radiation Interferometer
MAS	MODIS Airborne Simulator
MAST	Monterey Area Ship Tracks Experiment (Monterey and nearby Pacific Ocean, June 1994)
McIDAS	Man-computer Interactive Data Access System
MISR	Multi-angle Imaging Spectro-Radiometer
MOBY	Marine Optical Buoy (Lanai, Hawaii)
MODAPS	MODIS Data Processing System
MODIS	Moderate Resolution Imaging Spectroradiometer
MOPITT	Measurement of Pollution in the Troposphere
MOPITT-A	Airborne MOPITT
NASA	National Aeronautics and Space Administration
NAST	NPOESS Atmospheric Sounder Testbed
NAST-I	NAST-Interferometer
NAST-I	NAST-Microwave
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction (NOAA)
NOAA	National Oceanic and Atmospheric Administration
NPOESS	National Polar Orbiting Environmental Satellite System
NSA	North Slope of Alaska
PCASP	Passive Cavity Aerosol Spectrometer Probe
POLDER	Polarization and Directionality of Earth's Reflectances
PRIDE	Puerto RIco Dust Experiment (Puerto Rico, Jun-Jul 2000)
PRF	Pulse Repetition Frequency
PSR	Polarimetric Scanning Radiometer
SAVE	South Africa Validation of EOS
S-HIS	Scanning HIS
SAFARI 2000	Southern African Regional Science Initiative 2000 (Southern Africa, August-September 2000)

SCAR-A	Sulfate, Clouds, and Radiation–Atlantic (Delmarva Peninsula and nearby Atlantic Ocean, July 1993)
SCAR-B	Smoke, Clouds, and Radiation–Brazil (Brazil, August-September 1995)
SCAR-C	Smoke, Clouds, and Radiation–California (Pacific Northwest, September 1994)
SCF	Science Computing Facility
SeaWiFS	Sea-viewing Wide Field-of-view Sensor
SGP	Southern Great Plains
SHEBA	Surface Heat Budget of the Arctic Ocean
SMART	Surface Measurements for Atmospheric Radiative Transfer
SMiR	Scanning Microwave Radiometer
SSFR	Spectral Solar Flux Radiometer (NASA Ames Research Center)
SST	Sea Surface Temperature
SUCCESS	Subsonic Aircraft Contrail and Cloud Effects Special Study (April-May 1996)
SW	Shortwave
TARFOX	Tropospheric Aerosol Radiative Forcing Observational Experiment (Delmarva Peninsula and nearby Atlantic Ocean, July 1996)
TLCF	Team Leader Computing Facility
TM	Thematic Mapper
TOMS	Total Ozone Mapping Spectrometer
TRMM	Tropical Rainfall Measuring Mission
TWP	Tropical Western Pacific
UPS	Uninterruptible Power Source
VNIR	Visible and Near-Infrared
WINCE	Winter Cloud Experiment (Upper Midwest, Canada, and New England, January-February 1997)
WINTEX	Winter Experiment (Upper Midwest, March 1999)
WISC-T2000	Wisconsin Snow and Cloud Experiment – Terra 2000
WMO	World Meteorological Organization