History and Status of the Atmospheric Radiation Measurement Program March 1996

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Introduction

This document contains the summaries of papers presented at the 1996 Atmospheric Radiation Measurement (ARM) Science Team meeting held at San Antonio, Texas. The history and status of the ARM Program at the time of the meeting helps to put these papers in context.

The basic themes have not changed. First, from its beginning, the Program has attempted to respond to the most critical scientific issues facing the United States Global Change Research Program. Second, the Program has been strongly coupled to other agency and international programs. More specifically, the Program reflects an unprecedented collaboration among agencies of the federal research community, among the U.S. Department of Energy's (DOE) national laboratories, and between DOE's research program and related international programs, such as Global Energy and Water Experiment (GEWEX) and the Tropical Ocean Global Atmosphere (TOGA) program. Next, ARM has always attempted to make the most judicious use of its resources by collaborating and leveraging existing assets and has managed to maintain an aggressive schedule despite budgets that have been much smaller than planned. Finally, the Program has attracted some of the very best scientific talent in the climate research community and has, as a result, been productive scientifically. This introduction covers the first three points–the papers themselves speak to the last point.

Initial Concept

The initial concept for ARM came out of a series of studies that fell under the auspices of the Intercomparison of Radiation Codes in Climate Models (ICRCCM). ICRCCM pointed to several key issues that are now central to the ARM approach and strategy. First, ICRCCM was based on an assertion that one must understand the quality of the physics inside a climate model if one is to understand the quality of the climate model itself. Next, it is possible, and in fact necessary, to understand the relatively coarse representations of physics contained in a climate model in terms of a hierarchy of process models. For radiation, this hierarchy ranges from highly detailed line-by-line codes to highly parameterized forms of the radiation codes used in climate models. Finally, the hierarchy of models that leads to the needed parameterizations must be built on a sound base of experimental verification.

Concurrently with the release of the ICRCCM results, it was becoming clear that the radiative transfer of energy in the atmosphere and the impact of clouds was, and remains, one of the greatest sources of error and uncertainty in the current generation of general circulation models (GCM) used for climate research and prediction. With this as a starting point, DOE proposed a major program targeted at improving the understanding of the role and representation of atmospheric radiative processes and clouds in models of the earth's climate. Initially, the DOE Program focused on the radiative aspects of the climate problem. As the scientific issue was studied in more detail, however, it was obvious that a study of radiative processes associated with clouds could not be decoupled from the problem of representing the processes by which clouds form, are maintained, and dissipate in climate models. As a result, the ARM Program was proposed to the then Committee on Earth Sciences of the Federal Coordinating Council on Science Engineering and Technology. The proposed program had two basic objectives:

- to improve the treatment of radiative transfer in climate models under all relevant conditions

- to improve the treatment of clouds in climate models, including the representation of the cloud life cycle and the prognosis of cloud radiative properties.

The "Approved" Plan

The ARM Program Plan was subjected to peer review in the fall of 1989. The key element of the proposed ARM effort was to be the Cloud and Radiation Testbed (CART). This user facility was proposed to consist of four to six semi-permanent observational facilities designed to allow detailed investigations of process models used in climate research. These more permanent facilities were to be supplemented with a mobile facility that would allow related measurements to be made at other locations on a campaign-oriented basis. The facility would include a data management and communications system capable of acquiring and quality-controlling site data; acquiring data from sources outside the program; and communicating that data to a Science Team. This Science Team would be selected through a peer review process open to all investigators nationally and internationally.

Based on the peer review, the subcommittee on Global Change Research of the Committee on Earth Sciences approved the Plan, noting several key things about how it should be carried out. First, the scope was broadened beyond radiative transfer to include clouds and cloud processes represented in GCMs, a change deemed necessary to adequately address those atmospheric properties important to radiative transfer in the atmosphere and the atmospheres's radiation balance. Next, the Committee recommended that the DOE implementation of this program involve the talents of other federal agencies to the extent possible and that an interagency steering group be formed to assist in that process. Finally, the relevance of ARM to several other climate programs was noted, and DOE agreed to coordinate its deployment of facilities with the schedules of other national and international programs.

The Early Implementation

The implementation of ARM began in January 1990, proceeding on two coupled but parallel tracks. First, a multi-laboratory team was formed to plan the detailed implementation of the ARM facilities. The second track involved the formation of the Science Team. Because the science drivers were important to the design of the ARM facilities, a series of scientific workshops were held in the spring and summer of 1990 to clarify the scientific foundations of the program. In parallel, a solicitation process was initiated to establish the Science Team.

As these two tracks moved forward, features of the Program emerged. One of the most significant was a pattern of collaboration with other programs. This collaboration was characterized on one hand by a series of joint field campaigns and, on the other, by involvement in program planning for other major research efforts. In the field collaborations, ARM attempted to bring a value-added contribution to another agency's or group's planned effort, while at the same time trying to gain operational experience necessary to guide its own field deployment.

This strategy resulted in collaborations with the Federal Aviation Administration's Winter Icing and Storms Program (WISP) and First ISCCP Regional Experiment (FIRE) activities in Coffeyville, Kansas, and the Azores. In Coffeyville, early ARM concepts were tested in the Spectral Radiance Experiment (SPECTRE), jointly funded by the National Aeronautics and Space Administration (NASA) and DOE. It also led to ARM-fostered projects such as the Boardman-ARM Regional Flux Experiment which tested key aspects of surface and surface flux characterization.

From the standpoint of planning, ARM attempted to gain early involvement in the program planning of other programs that would be evolving in parallel with it. Most notable among these planning collaborations was the GEWEX. One of these joint planning activities culminated in the field deployment of the Pilot Radiation Observation Experiment (PROBE) to Kavieng, Papua New Guinea, as part of TOGA-COARE (Coupled Ocean Atmosphere Response Experiment), in the winter of 1992-3. Again, experience gained during TOGA-COARE has been a crucial influence in ARM planning.

A key convergence between science and facility planning tracks was the selection of a siting strategy for the ARM facilities. This process resulted in the identification of five locales in which ARM should locate its semi-permanent facilities and a comparable number of secondary locales in which the program should consider shorter, campaign-like activities. The primary locales in the order of their intended occupation were the Southern Great Plains of the United States, the Tropical Western Pacific, the North Slope of Alaska, the marine stratus zones of either the Atlantic or Pacific Ocean, and the Gulf Stream.

Budget Realities

While ARM was planned as a decade-long program with a cumulative funding level of almost $500M, it has always been clear that the annual rate of expenditure would not reach projected levels and that the Program's schedule would be changed and/or drawn out. This reality has been approached in several ways and needs to be understood in terms of several competing concerns: the cost of acquiring equipment, the tradeoff between capital and operating budgets, and the costs of facility design and deployment versus operating costs.

Early in the Program, capital equipment resources were inadequate to acquire the instrumentation necessary for the first site and the development of the associated data system. As a result, the deployment to the first site was phased, supporting one aspect of the program, the radiative transfer segment, over the cloud life cycle segment. Similarly, the Program sought opportunities to take advantage of existing equipment and data. This approach led, in no small way, to the decision to deploy the first site in the North Central Oklahoma/South Central Kansas area to take advantage of the existing National Oceanic and Atmospheric Administration (NOAA) profiler and radar facilities and the then-developing Oklahoma Mesonet.

The operational budgets also lagged, leading to a series of joint development activities. For example, rather than building a new system for field data acquisition, the Program instead developed a collaboration with the National Center for Atmospheric Research (NCAR) to build the data system around their campaign data management system, now known as Zebra.

Finally, the project has been rescoped annually. This rescoping has resulted in substantive changes including the cancellation of the planned mobile facility, the reduction of planned permanent field sites from five to three, the slowing of development and deployment of instruments and facilities, fewer than anticipated campaign activities, and delays in the implementation of the ARM Data Archive.

Despite budgetary limitations, development of the central facility for the Southern Great Plains (SGP) site began in May 1992, only one month later than originally planned. The initial deployment was meager, a single portable meteorological station borrowed from NCAR. By that fall, however, most of the infrastructure for the instrumentation was in place, and the major equipment was being delivered. Originally planned for completion in about one year, some aspects of the originally planned Southern Great Plains facility development will not completed until 1997.

In other areas, the initial deployment to the second permanent locale, the Tropical Western Pacific (TWP), was delayed to 1996. The deployment to the third permanent locale, the North Slope of Alaska, will delay operational status into 1998. This schedule reflects the impact of the limited budgets allocated to the program. The originally planned deployment schedule called for one site to be completed each year, implying a full deployment of five sites by mid-1997.

Project Status at the Time of the 1996 San Antonio Meeting

During the period between the Science Team meetings at San Diego and San Antonio, ARM's data streams from the SGP site, and from external sources such as satellites, began to mature with an increasing emphasis on data quality. Over the program as a whole, the intensity of activity was increasing. At the SGP site, a steady pace of intensive operational periods (IOPs) began to take shape as a viable operational paradigm while the implementation of additional instruments and facilities continued. As might be expected, each IOP was characterized by different scientific objectives as well as different instrument and logistical requirements. The paradigm was feasible because the IOPs could be superimposed on continuous site operations and the steady state acquisition of data as a type of "plug-in" activity. At the same time, the first Atmospheric Radiation and Cloud Station (ARCS) was being integrated and tested for use in the TWP locale. A siting plan for the North Slope of Alaska was developed, embodying a major collaborative field program in the Beaufort Sea and a concept for collocating the planned Barrow facility with the NOAA Climate Monitoring and Diagnostics Laboratory site already operating there.

The Southern Great Plains CART site became operational through a phased deployment that began during FY 1992 and continued into 1995 with additional instrumentation and facilities. By the time of the San Antonio meeting, the central facility at Lamont, Oklahoma, was complete, with the exception of the addition of several instruments and the radiometric calibration facility, which was expected to be operational by mid FY 1996. The design for the calibration facility was completed in FY 1995, and the engineering studies were being finalized about the time of the Science Team meeting. The aerosol measurement facility became operational late in FY 1995, but lacked data ingest and processing software; data were captured for post-processing. Instrumentation planned to become operational at the central facility in 1996 included a field-hardened Atmospheric Emitted Radiance Interferometer (AERI), a vertically pointing Raman Lidar for water vapor measurements, a day-night whole sky imager, a solar optical radiation transmission interferometer, and a millimeter wave cloud radar. The last extended facilities are being completed in mid FY 1996, with the exception of a forested site which will require a tower and additional environmental review. This will be completed in FY 1997. A new class of remote sites was being implemented for planetary boundary layer measurements using 915-MHZ wind profiler/radio acoustic sounding system instruments; three sites had been selected and instrument procurement initiated.

For the boundary facilities, planning for additional instruments indicated the real need for larger shelters. The shelters would ultimately house the balloon sonde electronics and data system, AERI instruments to provide continuous, height-limited, vertical profiles of temperature and water vapor; and improved data acquisition and data processing capabilities. Microwave radiometers were installed for column integrated water vapor measurements. When completed, this instrument suite at the boundary facilities is intended to provide continuous remote sensing of vertical profiles of data required for use in single-column models. Balloon sondes will continue to be required to provide higher altitude data.

Intensive operational periods and campaigns are an increasingly significant part of the annual data acquisition activity. Intensive operational periods completed during the year between Science Team meetings are summarized in the table below.

Since the San Diego Science Team meeting, three 3-week, single-column model (SCM) IOPs have been conducted successfully, two in conjunction with other efforts. The April SCM IOP was conducted in parallel with a follow-on to the April 1994 Remote Cloud Sensing IOP in order to further test and evaluate cloud remote sensing capabilities. The April 1995 effort featured field testing and evaluation of the following instruments: the prototype of the Raman lidar being developed by Sandia National Laboratories, the 0.1 wave number AERI-X being developed by the University of Denver, a DIAL lidar under development at NOAA, Martin Platt's lidar system, and the dual frequency cloud radar from the University of Massachusetts. The April 1995 effort primarily focused on intercomparison studies. The ground-based measurement program was complementary to an airborne measurement effort conducted in collaboration with NOAA's Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) Program. VORTEX brought the NOAA WP-3 to Oklahoma during the tornado season, but also conducted measurements in collaboration with the ARM site. NOAA agreed to provide a number of flight hours to ARM to acquire data on cloud optical properties using on-board sensors plus a new Gerber liquid water sensor acquired by ARM. The on-board instrumentation included recently calibrated broadband radiometers. A unique data set on cloud optical and radiative properties was acquired and will be available to ARM Science Team members after reduction from aircraft tapes.

The other exceptionally significant IOP period was in September and October 1995. During this period, a SCM IOP was conducted in parallel with the ARM Enhanced Shortwave Experiment (ARESE). ARESE was primarily an effort of the ARM Unmanned Air Vehicle Program supported with ground-based measurements at the SGP central facility and three extended sites. ARESE conducted a series of instrumented flights to measure the interaction of solar energy with clear and cloudy skies, focusing on two scientific objectives:

1. the direct measurement of the absorption of solar radiation by clear and cloudy atmospheres and the placement of bounds on these measurements

Date	Intensive Operational Period
April 1995	Multiple IOP Period - Ground-based Remote Sensing (4 weeks) - Cloud Optical Properties (4 weeks) - Support to NOAA VORTEX Program (4 weeks) - Single-Column Model (3 weeks)
June 1995	Multiple IOP Period - Planetary Boundary Layer Characterization Using 915-MHZ Wind Profiler/ RASS Systems - Surface Energy Budget
July 1995	Single-Column Model
Sept - Oct 1995	Multiple IOP Period - ARM Enhanced Shortwave Experiment (9/25 to 10/31) - Single-Column Model

2. the investigation of the possible causes of absorption in excess of the model predictions.

At the heart of the effort was a “stacked” formation of the UAV, an Egrett, and its chase aircraft, a Twin Otter, creating a “cloud sandwich” with the Otter at 1500 - 5000 ft and the Egrett at 43,000 ft. This was overflown by an ER-2 at 65,000 ft, providing periodic coincident measurements from all three aircraft. All aircraft carried identical up- and down-looking “Valero” radiometers and flew over identical up-looking radiometers at the CART central and extended facilities. Radiance measurements from the Geostationary Operational Environmental Satellites were used to retrieve top-of-the atmosphere fluxes. These flux measurements were supplemented by a variety of cloud property measurements from the ground, the Egrett and the ER-2, including radar, lidar and multispectral measurements.

ARESE flights were conducted over the CART site from September 25 through November 1, 1995. Twelve scientific data flights accumulated approximately 60 hours of in-flight data under a variety of atmospheric conditions ranging from clear to solid overcast. The flights included efforts to explore cloud forcing under scattered, broken, and solid overcast conditions including low, mid-, and high-level cloud decks; clear sky column absorption and surface albedo; clear sky flux profiling; and in-flight, co-altitude intercomparisons of flux measurements made from the Egrett and the Twin Otter. The data appear to be of excellent quality and comprise a unique data set for testing our understanding of the absorption of solar radiation in both clear and cloudy atmospheres.

As a consequence of the ARESE campaign, several sets of "Valero” radiometers were acquired by ARM and will be permanently installed at the Southern Great Plains site.

In preparation for deployment to the TWP, a ruggedized, semi-autonomous system known as an Atmospheric Radiation and Cloud Station (ARCS) was being integrated (spring of 1996) into four 20-ft containers. Testing was being completed and plans called for the system to be shipped and installed on the island of Manus, Papua New, Guinea in the last quarter of FY 1996. Coordination with the government of Papua New Guinea was proceeding successfully with additional agreements for collaborative establishment and operation of the facility. Negotiations were already underway with the government of the Republic of Nauru for placing the second ARCS on that island in FY 1997. Collaboration with two programs in the area, the "Schools of the Pacific Rainfall Climate Experiment” and "South Pacific Regional Environmental Program,” provided valuable contributions to the scientific and logistical planning for each site. Data transfer plans for the TWP continued to involve tapes to be shipped to the Experiment Center on a regular basis. Small amounts of data to monitor the performance of the station and to schedule maintenance trips would be transmitted back to the site project office through low data rate satellite links.

For the North Slope of Alaska site at Barrow, site planning continued in coordination with local authorities. A measurement system specifically designed for the Arctic but drawing upon the systems integrated for the TWP ARCS will be deployed to one or more sites, but will be augmented with additional instrumentation as required. The in situ demonstration of a sound source mimicking 449-MHZ and 915-MHZ radar acoustic sounding systems was completed with no adverse impacts on wildlife or the local population. Instrumentation is being tested in Arctic conditions at the University of Alaska at Fairbanks. Planning for collaborative participation in the interagency Surface Heat Budget of the Arctic Ocean (SHEBA) program continued, with the Site Program Manager and several members of the ARM Science Team actively engaged in planning and coordination activity. The suite of instrumentation for SHEBA will be housed in small portable modules and will ultimately compose part of a relocatable measurement facility for the North Slope pending more permanent facilities in several years, the first of which will be in the village of Atqasuk, 50 km inland from Barrow.

As in the past, ARM continued its high level of collaboration with other related programs. In the summer of 1995, collaboration between ARM and GEWEX continued, highlighted by a decision by the NOAA program office that the GEWEX Continental-Scale International Project would fund a University of Oklahoma proposal to install Surface Water and Temperature Sensors (SWATS) at each of ARM’s extended facilities. The SWATS acquires soil water and temperature profiles down to a depth of several meters. These were to be installed over the next year. Data would be acquired and provided through the ARM data system, and ARM would provide for routine maintenance.

ARM planned to support the Marine Continent Thunderstorm Experiment (MCTEX), but was not able to complete testing of the first ARCS system in time for the effort. ARM did, however, provide several fundamental instruments and supported science team participation. Radiometers, a cloud radar, and a microwave radiometer were among the instrumentation supported by ARM in a highly successful field program in November and December of 1995. These instruments were then moved to Manus to participate in callaborative measurements with the NOAA ship, *Discover*, visiting Manus during a cruise in early 1996.

ARM continued to plan towards the multi-agency-sponsored SHEBA experiment. Although final plans were not in place for either a ship or an ice-island-based program, ARM was proceeding with plans that would permit accommodation to either platform. At the time, SHEBA was planning for a FY 1997 deployment in spring or fall, depending on the selected platform.

One of ARM's most important evolving collaborations is with the NASA Earth Observing System (EOS) program. ARM and EOS management are planning a continuing collaboration including a Joint Science Plan. Key elements of ARM's support to EOS will involve EOS retrieval validation efforts and the EOS Ground Test Site Program. ARM was originally designed to take advantage of EOS satellite data and is planning toward the launch of the EOS platforms.

This broad range of site and instrument activity resulted in an increasingly robust data stream and supported Science Team research efforts as reflected in the approximately 140 posters presented at the Science Team meeting and whose abstracts are contained in this volume. Less tangibly, the Science Team contributed to the increasing robustness of the data stream by furnishing feedback to the instrument and data specialists to improve the quality of the data being provided.

Science Team research efforts largely fall into the two fundamental strategies through which ARM seeks to achieve its programmatic objectives and to focus its scientific efforts. These strategies are also the basic organizing principle behind defining the requirements for individual IOPs and determining what additional measurement capabilities are required. The first strategy, and the one that was at the heart of the priorities that led to the initial focus on the implementation of the SGP central facility, is the "instantaneous radiative flux" measurement and modeling effort. The second is single-column modeling to evaluate the cloud and radiative process models either used in, or being developed for, general circulation models being used for climate studies. A third focused area of activity, related to establishing the lower boundary condition for both single- column model evaluations and instantaneous radiative flux (IRF) calculations, is the effort to characterize surface fluxes, surface radiative properties and planetary boundary layer behavior on scales appropriate to GCMs.

In the IRF strategy, the effort consists of collecting data on the distribution of radiation and the radiatively active constituents of the atmosphere and the radiative properties of the lower boundary. The radiative properties of the atmosphere and the lower boundary are used as input to radiative transfer models, including both detailed models with high spectral and angular resolution and simplified models suitable for use as parameterizations in climate models. The results produced by the models can then be compared with the radiation measurements as depicted in Figure 1.

The IRF approach is crucial to ARM, but it is not sufficient. Specifically, it does not address the large-scale processes that lead to cloud distribution and structure and the resultant cloud radiative properties that are important to understanding the instantaneous radiative fluxes. Using a single-column model approach allows the testing of models and parameterizations intended to represent cloud property life cycles in GCM grid cells. Thus the fundamental idea of the SCM is to measure the external forces at work on a column of the atmosphere that corresponds to a single GCM grid column, to use transfer processes inside the column, and to evaluate the results produced by the models by comparing them with additional observations, in much the same manner as the IRF example in Figure 1.

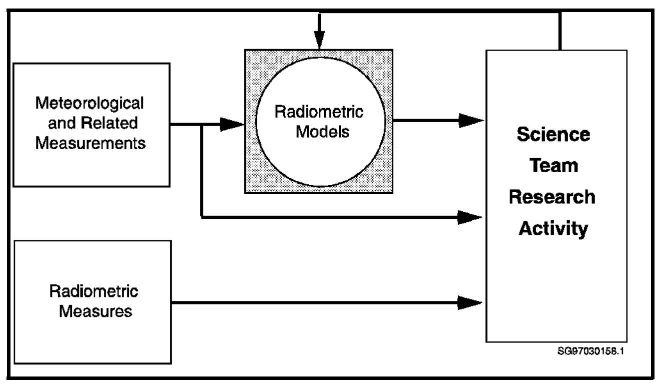

Figure 1. Experiment-based radiative model test scheme.

References

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Abbreviations and Acronyms

ACP	anvil cirrus parameterization
ADT	anomalous diffraction theory
AER	Atmospheric and Environmental Research, Inc.
AERI	atmospheric emitted radiance interferometer
AERI-X	Atmospheric Emitted Radiance Interferometer-Extended Resolution
AGL	above ground level
ALFA	AER Local Forecast and Assimilation (model)
AMIP	Atmospheric Model Intercomparison Project
ARCS	Atmospheric Radiation and Cloud Station
ARESE	ARM Enhanced Shortwave Experiment
ARM	Atmospheric Radiation Measurement
ASRC	Atmospheric Sciences Research Center
ASTEX	Atlantic Stratocumulus Transition Experiment
ASTI	Absolute Solar Transmission Interferometer
AVHRR	advanced very high resolution radiometer
BARFEX	Boardman ARM Regional Flux Experiment
BBSS	balloon-borne sounding system
BLP	boundary layer profiler
BNL	Brookhaven National Laboratory
BORCAL	broadband outdoor radiometer calibration
BTAs	back trajectory analyses
BSI	Biospherical Instruments Inc.
BSRN	Baseline Surface Radiation Network
CAGEX	CERES/ARM/GEWEX
CAMEX-2	Convection and Moisture Experiment 2
CAPE	convective available potential energy
CART	Cloud and Radiation Testbed
CCD	charge-coupled device
CCM	Community Climate Model (National Center for Atmospheric Research)
CCM2	Version 2 of the NCAR Community Climate Model
CCN	cloud condensation nucleus
CERES	Clouds and Earth's Radiant Energy System
CEPEX	Central Equatorial Pacific Experiment
CI	cloudiness index
CIMMS	Cooperative Institute of Mesoscale Meteorological Studies
CIRA	Cooperative Institute for Research in the Atmosphere
CIRES	Cooperative Institute for Research in Environmental Sciences
CMDL	Climate Monitoring and Diagnostics Laboratory
CMI	crop moisture index
CN	condensation nuclei
COAMPS	Coupled Ocean/Atmosphere Mesoscale Prediction System
COARE	Coupled Ocean Atmosphere Response Experiment
COR	Coriolis
CPRS	Cloud Profiling Radar System
CRADA	Cooperative Research and Development Agreement
CRF	cloud radiative forcing
CRM	cloud resolving model

CRS	Cloud Radiation Spectroradiometer
CSU	Colorado State University
DAR	Division of Atmospheric Research
DIAL	infrared differential absorption lidar
DISORT	discrete ordinate radiative transfer
DLF	downward longwave flux
DMSP	Defense Meteorological Satellite Program
DOE	U.S. Department of Energy
DQR	data quality report
DVN	daytime versus nighttime
DWR	dual wavelength ratio
EBBR	Energy Balance Bowen Ratio
EBTs	Equivalent Blackbody Temperatures
ECLIPS	Experimental Cloud Lidar Pilot Study
ECMWF	European Centre for Medium Range Weather Forecasting
EM	explicit microphysics
EML	Environmental Measurements Laboratory
ENSO	El Niño-Southern Oscillation
EOS	Earth Observing System
ER	equivalent radius
ERL	Environmental Research Laboratories
ERBE	Earth Radiation Budget Experiment
ETL	Environmental Technology Laboratory
FASCODE	Fast Atmospheric Signature Code
FASE	FASCODE for the Environment
FCC	fractional cloud cover
FDDA	four-dimensional data assimilation
FDI	field data ingestor
FFT	fast Fourier transform
FIRE	First ISCCP Regional Experiment
FIRE-II	Second ISCCP Regional Experiment
FOV	field of view
GARP	Global Atmospheric Research Program
GATE	GARP Atlantic Tropical Experiment
GCM	general circulation model
GCSS	Global Energy and Water Cycle Experiment Cloud Systems Study
GEWEX	Global Energy and Water Experiment
GISS	Goddard Institute for Space Studies
GMS	geostationary meteorological satellite
GOES	Geostationary Operational Environmental Satellite
GSFC	Goddard Space Flight Center
HAcc	horizontal advective acceleration
HAD	horizontal diffusion
HDiv	horizontal divergence
HIS	High-resolution Interferometer Sounder
HSRL	High Spectral Resolution Lidar

ICET	Integrated Cumulus Ensemble and Turbulence
ICRCCM	intercomparison of radiative codes in climate models
IMC	ice mass content
IN	ice nuclei
IOP	intensive observation period
IPA	independent pixel approximation
IR	infrared
IRF	Instantaneous Radiative Flux
ISCCP	International Satellite Cloud Climatology Project
ITCZ	intertropical convergence zone
JACCS	Japanese Cloud and Climate Study
JFD	joint frequency distribution
KF	Kain-Fristch (deep convection model)
KF	Kalman filtering
LAI	Leaf Area Index
LASE	Laser Atmospheric Sensing Experiment
LBL	line-by-line
LBLRTM	Line-by-Line Radiative Transfer Model
LCL	lifting condensation levels
LDRD	Laboratory Directed Research and Development
LDRs	linear depolarization ratios
LES	large-eddy simulation
LFC	level of free convection
LIRAD	lidar/radiometer
LLJ	low-level jet
LST	local solar time
LW	longwave
LWC	liquid water content
LWP	liquid water path
MACE	Multi-spectral Atmospheric Column Extinction
MAPS	Mesoscale Analysis and Prediction System
MAS	MODIS Airborne Simulator
MBL	marine boundary layer
MC	Monte Carlo (simulation)
MCC	Mesoscale convective complex
MCS	mesoscale convection system
MCTEX	Marine Continent Thunderstorm Experiment
MFRSR	multifilter rotating shadowband radiometer
MJO	Madden Julian Oscillations
ML	mixed layer
MLO	Mauna Loa Observatory
MLS	mid-latitude summer
MODTRAN	Moderate Resolution Transmittance (model)
MPL	Micro Pulse Lidar
MSL	mean sea level
MWR	microwave water radiometer
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research

NDVI	normalized-difference vegative index
NH	northern hemisphere
NIGEC	National Institute for Global and Environmental Change
NIS	near infrared source
NOAA	National Ocean and Atmospheric Administration
NREL	National Renewable Energy Laboratory
NSA	North Slope of Alaska
NWS	National Weather Service
OLR	outgoing longwave radiation
OLS	Operation Line Scanner
OML	ocean mixed layer
PBL	planetary boundary layer
PCMDI	Program for Climate Model Diagnosis and Intercomparison
PDF	probability distribution function
PDL	Polarization Diversity Lidar
PGF	pressure gradient force
PIR	precision infrared radiometer
PMS	particle measuring system
PNNL	Pacific Northwest National Laboratory
POP	profiler online program
PP	plane parallel
PRF	pulse repetition frequency
PROBE	Pilot Radiation Observation Experiment
PRT	precision radiation thermometer
PSP	precision spectral pyranometer
PW	precipitable water
PWV	precipitable water vapor
QME	Quality Measurement Experiment
RAMS	regional atmospheric modeling system
RASS	Radio Acoustic Sounding System
RCM	Regional Circulation Model
RCMs	radar coded messages
RCS	Remote Cloud Sensing
RH	relative humidity
RH_c	critical relative humidity
Rn	net radiometer
RRTM	rapid radiative transfer model
RSS	rotating shadowband spectroradiometer
RT	radiation transport
RTNEPH	Real-Time Nephanalysis
RW	required warming
RWPs	Radar Wind Profilers
SAGE	Stratospheric Aerosol and Gas Experiment
SARB	Surface and Atmospheric Radiation Budget
SCMs	single column models
SEPM	stochastic entraining parcel model
SGP	Southern Great Plains
SH	southern hemisphere

SHEBA	Surface Heat Budget of the Arctic Ocean
SIB	simple biosphere
SIROS	solar and infrared observing system
SMOS	surface meteorological observation system
SNR	signal-to-noise ratio
SORTI	Solar Radiance Transmission Interferometer
SPECTRE	Spectral Radiance Experiment
SRL	Scanning Raman Lidar
SRRB	Surface Radiation Research Branch of NOAA
SSM/I	Special Sensor Microwave Imager
SSM/T1	Special Sensor Microwave Temperature Sounder
SSM/T2	Special Sensor Microwave Water Vapor Sounder
SST	sea surface temperature
STATSGO	State Soil Geographic (database)
SW	shortwave
SWATS	Surface Water and Temperature Sensors
TAdv	temperature advection
TAO	Tropical Atmospheric Ocean
TEM	trajectory ensemble model
TKE	turbulent kinetic energy
TOA	top of the atmosphere
TOGA-COARE	Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment
TOMS	Total Ozone Mapping Experiment Spectrometer
TOVS	TIROS Operational Vertical Sounder
TP	tropospheric profiler
TRES	Tomsk Radiation Experiment in Siberia
TWP	Tropical Western Pacific
TWTA	traveling wave tube amplifier
USSA	U.S. Standard Atmosphere
UT	Universal Time
UW	University of Wisconsin
VAD	Velocity-Azimuth Display
VDU	vertical diffusion
VORTEX	Verification of the Origins of Rotation in Tornadoes Experiment
WISP	Winter Icing and Storms Program
WPDA	Wind Profiler Demonstration Array
WSI	Whole Sky Imager
WSR-88D	Weather Surveillance Radar - 1988 Doppler
WVR	water vapor radiometer
WWCB	Weekly Weather and Crop Bulletin (Department of Agriculture Publication)

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