# History and Status of the Atmospheric Radiation Measurement Program - March 1995

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This document contains the summaries of papers presented at the 1995 Atmospheric Radiation Measurement (ARM) Science Team meeting held in San Diego, California. To put these papers in context, it is useful to consider the history and status of the ARM Program at the time of the meeting.

The history of the project has several themes. First, the Program has from its very beginning attempted to respond to 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. Indeed, the Program reflects an unprecedented collaboration among various elements of the federal research community, among the U.S. Department of Energy's (DOE) national laboratories, and between an agency's research program and the related international programs, such as Global Energy and Water Experiment (GEWEX) and TOGA. 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 showed that 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 the highly detailed line-by-line codes to the highly parameterized forms of the radiation codes used in climate models. Finally, the hierarchy of models that leads to the parameterizations of processes in climate models 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 with 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 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, 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 tie its deployment of facilities to 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. 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 jointly funded NASA-DOE Spectral Radiance Experiment (SPECTRE). 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, 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, 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 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 here also lagged, leading to a series of joint development activities. For example, rather than building a new data 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, slowed deployment and development of instruments and facilities, sharply fewer than anticipated campaign activities, and delays in the implementation of the ARM Data Archive as a facility readily accessible to the wider scientific community.

Despite budgetary limitations, development of the central facility for the southern Great Plains site began in May 1992, only one month later than originally planned. The initial deployment was meager, a single portable meteorological station borrowed from the National Center for Atmospheric Research. 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 Southern Great Plains facility development are continuing in FY 1995.

In other areas, the initial deployment to the second permanent locale, the Tropical Western Pacific, has been delayed to 1996, and deployment to the third permanent locale, the North Slope of Alaska, continues to be planned for 1997. This schedule is reflective of 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 San Diego Meeting

During the period between the Science Team Meetings at Charleston and San Diego, the major changes in the project involved additional instrumentation and facilities at the Southern Great Plains, the firm commitment to deploy the first instrumentation in the Tropical Western Pacific to the island of Manus, Papua New Guinea, and the initiation of planning activity to deploy to the North Slope of Alaska in 1997. Substantial links to external data sources were established and data were routinely being provided through the data system from U.S. Satellites, and the National Weather Service, the Oklahoma Mesonet land, the Kansas agricultural network, for example.

At the Southern Great Plains site, the central facility was largely complete by the end of 1994, but the extended facilities were still only about 50% complete by March of 1995. Work was in progress to establish the remaining extended facilities with much of the instrumentation being in hand. A tentative decision was in place to establish a set of three "intermediate" sites about halfway between the central facility and the boundary facilities. These sites would be comprised of 915-MHz boundary layer profilers with radio acoustic sounding systems to support research objectives in the planetary boundary layer and the routine characterization of site wide boundary layer fluxes. The 915-MHz systems would be deployed in 1996. In addition to routine site operations, intensive operational periods were becoming a regular event at the site, and the list below indicates the IOPs conducted up to the time of the San Diego meeting:

| Date | Intensive Operational Period |
|---|---|
| 11/92, 6/93 | Investigation of 915-MHz Profilers for PBL Measurements for 4DDA |
| 4/93 | IDP Field Evaluation for AERI |
| 6/93 | GPS Water Vapor Msmt Evaluation |
| 1/94, 4/94, 7/94, 10/94 | Single Column Model IOP |

The April, 1994 IOP period was noteworthy as the most complex IOP conducted to date. During April, three separate measurement programs were conducted in parallel, with outstanding success. 1) Sonde operations supported a single-column model data acquisition period; 2) a variety of instruments developed under the Instrument DevelopmentProgram were deployed to the site for field testing and participation in a cloud remote sensing IOP along with operational instruments, and 3) the ARM UAV program conducted a series of seven demonstration flights over the site providing confirmation that UAVs are viable data acquisition vehicles and revealed that their low noise environment provides for better data than that acquired from other airborne platforms. The IDP instruments deployed included two Raman lidars, a research grade polarization lidar for cloud microphysics, and three cloud radars, operating at either 35 or 95 Ghz. The cloud remote sensing IOP was also supported by the University of North Dakota Citation, made available through the grant of one of the investigators. While the UAV used for the demonstration flights had a limited altitude capability, the operations proved the value of the platform for scientific data acquisition and paved the way for future field programs.

At the 1993 American Meteorological Society annual meeting, ARM investigators revealed that measurements of satellite, airborne and groundbased radiometric measurements were in disagreement with model predictions by about 40 watts per square meter of solar energy not reaching the ground. During 1994 this became the basis for planning a major campaign to be conducted in 1995 to acquire the data necessary to understand why the measurements and models are in disagreement. The proposed campaign came to be called the ARM Enhanced Shortwave Experiment, or ARESE, and came to revolve around a series of UAV flights using a high altitude vehicle. It is anticipated that the 1996 ARM Science Team Meeting should see some of the data analysis from this program.

By March 1995, the TWP siting strategy that had been proposed at the Charleston meeting led to visits to potential sites in the Tropical Western Pacific locale. As anticipated, Manus Island in Papua New Guinea was confirmed as the best choice as the site for the first observational capability to be deployed. Nauru was selected as the second site from several island locations to the east of Manus; land availability, the island's infrastructure, accessibility, and its relatively "open" ocean location were all elements influencing the decision. Initial discussions with the governments in both locations were encouraging, but left much to be done in 1995, prior to deployment. In parallel, the design of the Atmospheric Radiation and Cloud Station (ARCS) was being refined in accordance with the siting and observational strategy and integration of the facility was beginning at Sandia National Laboratory, Albuquerque. Deployment of the first ARCS to Manus was anticipated for late fall, 1995. The primary path for data to be returned to the ARM Experiment Center remained as periodic shipping of tapes of recorded data. "Health of Station" data would be transmitted periodically through a GOES relay and would be used for diagnosis and status determination of the various systems comprising the ARCS.

For the North Slope of Alaska, a siting and strategy document was in preparation encompassing several deployment scenarios. The first was an option to participate in the proposed SHEBA experiment in the Spring of 1997 and then to deploy the first permanent observing capability to a location near Barrow, Alaska later in that same year. Several variations from this basic theme were also being discussed based largely on the firmness of plans for SHEBA. The instrumentation used to participate in SHEBA would, at the completion of the SHEBA ice camp deployment, become the core of the initial observational capability at an inland site, probably near the village of Atkasuq, 50 km south of Barrow.

Collaboration with other programs continued to be a hallmark of ARM. Between the Charleston and San Diego meetings, collaboration between GEWEX and ARM continued. During the summer of 1994, ARM sonde operations supported GEWEX and were, in part, supported by GEWEX in order to provide data for periods of time beyond the normal ARM IOP periods. A proposal from the University of Oklahoma to the NOAA program office for the GEWEX Continental Scale International Project (GCIP), was submitted and accepted to provide support for the acquisition and installation of soil water and temperature (SWAT) measurement systems to be installed at each of the ARM extended facilities. The systems were planned for acquisition in FY 1995 and installation at ARM extended facilities in 1996. ARM will operate these instruments as if these were ARM instruments. Discussions were initiated to modify three ARM extended facilities to make them better able to meet the observational needs of the ecological community. Funding for this activity was initially identified, but did not materialize. Plans remain in place to modify ARM extended facilities as necessary should the support to do so comes available.

ARM continued to plan towards participation in the Marine Continent Thunderstorm Experiment (MCTEX) as part of the initial deployment to the TWP and the Surface Heat Budget of the Arctic (SHEBA) as part of the initial deployment to the NSA. ARM and EOS continued to plan towards a joint Science Plan pending completion of respective program Science Plans.

The existence of the Southern Great Plains site and its data was attractive to NOAA's Verification of the Origins of Rotation in Tornadoes Experiment (VORTEX) research program. In collaboration with ARM, VORTEX planned for use of a NOAA WP-3 for tornadic research in the vicinity of the ARM site and provided a number of flight hours for ARM-related research data to support objectives of several ARM Science Team members from NOAA, NASA and the University of Oklahoma. In addition to the normal complement of instrumentation, NOAA agreed to mount a Gerber liquid water probe acquired by ARM. This program was planned for the May 1994 time frame overlapping with the regular ARM IOP period.

Against this broad range of activity, the Science Team began to deal with real data from the SGP site and began to furnish valuable feed back to the instrument and data experts within the infrastructure to improve the quality of the data flow. From a research standpoint, the Science Team began to focus on specific objectives yielding many of the papers presented as posters at the Science Team Meeting and in the extended abstracts presented in this volume. Many of these efforts fall into two of the general measurement strategies that have been extensively discussed in the course of the evolution of ARM; these are the use of single-column models and a focus on the instantaneous radiative flux through the atmosphere; these are predominantly reflected in the IOPs being conducted on a regular basis. A third general area of activity is closely aligned with establishing the lower boundary of the single column model, but is still an area of activity important to several programs interested in interacting with ARM and is sufficiently distinct to warrant being recognized - that is the area of planetary boundary layer behavior and its role in controlling lower boundary heat and moisture fluxes into the single-column model. Approaches previously discussed using hierarchical diagnosis and data assimilation are coming to be more widely recognized as tools or approaches to be applied to single-column model or instantaneous radiative flux research questions. Drawing from earlier descriptions, these are defined as follows:

- single-column model - Many of the key process models and parameterizations that compose GCM-based climate models appear to be testable by extracting a single vertical array of cells from the model and operating the array in what is referred to as a single-column model. This single-column c8927.ore retains the subgrid scale physics that must be represented in GCMs, and it offers a promising approach to testing the parameterization of this physics. The CART facility around Lamont, Oklahoma, was designed to support this strategy.

- instantaneous radiative flux - Accurate treatment of radiation is essential in climate models, and testing of radiation transfer models is central to the objectives of ARM. In principle, testing of radiation transfer models calls for complete specification of the state of the atmosphere and the surface. The ICRCCM (Ellingson and Fouquart 1991) has emphasized that the state-of-the-art in radiative modeling cannot be advanced by further model intercomparisons. Progress can be achieved only by supplementing intercomparisons with field observations. CART provides a facility for such observations.

## Reference

Ellingson, R., and Y. Fouquart. 1991. The intercomparison of radiation codes in climate models: an overview. J. Geophys. Res. 96:8925-8927.