History and Status of the Atmospheric Radiation Measurement Program - March 1994

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This document contains the summaries of papers presented at the 1994 Atmospheric Radiation Measurement (ARM) Science Team meeting held in Charleston, South Carolina. 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. The Program reflects an unprecedented collaboration among the various elements of the national research community, including a significant level of cooperation among the U.S. Department of Energy's (DOE) national laboratories. 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 very 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 support the level of effort proposed by DOE. 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, most notably the Tropical Ocean Global Atmosphere-Coupled Ocean Atmosphere Response Experiment (TOGA-COARE).

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. However, the science drivers were so important to the design of the facility, a series of scientific workshops were held in the spring and summer of 1990, concurrent with the initiation of a solicitation process to establish a Science Team, to clarify the scientific foundations of the program.

As these two tracks moved forward, several features of the Program emerged, the most significant of which was the pattern of collaboration with other programs. This collaboration was characterized on one hand by a series of collaborations with 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 Global Energy and Water Experiment (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.

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 relative costs of 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 has been heavily phased, supporting one aspect of the program, the radiative transfer segment, over the cloud life cycle segment. Similarly, the Program has 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 developing Oklahoma Mesonet.

The operational budgets also lagged early on, which led to a series of joint development activities. For example, rather than building a new data system for field data acquisition, the Program has instead developed a collaboration with the National Center for Atmospheric Research (NCAR), which has allowed us 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 several substantive changes including the cancellation of the mobile facility, the reduction of planned permanent field sites from five to three, slowed deployment and development of instruments and facilities, sharply less than hoped for support for campaign activities, and the delay in the implementation of the ARM Data Archive as a facility readily accessible to the wider scientific community.

Despite the 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, the Southern Great Plains facility development will be largely completed by the end of 1995.

In other areas, the initial deployment to the second permanent locale, the Tropical Western Pacific, will begin in the summer of the 1995, and deployment to the third permanent locale, the North Slope of Alaska, will be in the Spring of 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 Charleston Meeting

By the time of the Charleston meeting, the Southern Great Plains site central facility was largely complete and supporting the Instantaneous Radiative Flux related research of the Science Team. A major remote cloud sensing intensive operational period was being planned for the spring of 1994. The primary instruments in this IOP were largely instruments developed under the ARM Instrument Development Program and included cloud lidars and radars, Raman lidar for water vapor profiling, the FTIR Atmospheric Emitted Radiance Interferometer (AERI), and a whole sky imager. The capabilities of the central facility were being expanded significantly to host this IOP and were being anticipated to a basis for future support to instruments temporarily operational at the site. Boundary facilities to support single column modeling efforts had just recently been established based on balloon borne sounding systems. Sounding data was being recorded locally and transferred by disc to the central facility. Early results indicated a severe interference problem between the 405 MHz wind profilers and the 403 MHz radiosonde communications link to the ground station. Solutions to the problems encountered were just being formulated for implementation later in 1994. Nine extended facilities were partially installed, but only (four) were operational with a near full complement of instruments. Pending installation of telephone lines to the sites, some data was being recorded at the sites and transferred periodically to the site data system by disc. Approximately four additional extended facilities were anticipated to be completed during the summer of 1994.

As in 1993, ARM was the subject of a special session of the American Meteorological Society Annual Meeting in Nashville, Tennessee. The ARM Special Session ran in parallel with a special session on clouds and radiation at which several ARM investigators were releasing an initial finding that data from a number of sites worldwide were indicating that our understanding of solar radiation propagation from the top of the atmosphere to the ground was deficient and that the atmospheric absorption of solar radiation was exceeding model predictions by about 40 watts per square meter. Initial analyses were indicating that the “excess” loss was occurring in the presence of clouds, but that a causal explanation was not apparent. This became a focal point for ARM planning for a future IOP at the SGP site wherein a carefully designed experiment would be executed to provide data to help explain the observed anomaly. It was anticipated that this experiment would occur in the warm season of 1995.

In a closely related activity to ARM, in 1993 the DOE Unmanned Air Vehicle (UAV) Program Office arranged for flight qualified instruments to be packaged and flown in an engineering test flight on a leased UAV, a GNAT 750 from General Atomics. The success of the engineering test flights over Edwards Air Force Base resulted in planning for a field experiment of about five flights over the CART site in Oklahoma in the Spring of 1994. This IOP was tentatively planned, at the time of the Charleston meeting, for the April-May time frame to coincide with the spring single column model IOP and the remote cloud sensing IDP IOP periods. Initial measurements made during the engineering test flights indicated that the UAV is an extremely quiet environment for sensitive instruments and that the data acquired is of very high quality. It was anticipated that the UAV would be a significant element of the anomalous radiation absorption experiment if the flights being scheduled for 1994 were successful.

Interest in the Tropical Western Pacific and North Slope of Alaska sites began to increase as deployment plans began to take on identifiable milestones. By the time of the Charleston meeting, it was anticipated that the first TWP site would be proposed to be on the island of Manus in Papua New Guinea in 1995 and that three to five such sites would eventually deployed to the east and west from Manus along the equator. The 1995 deployment is approximately a one year delay from the originally anticipated deployment date. For the North Slope, initial deployment planning focused on Barrow and Atqasuk, but with instrumentation being made available to participate in the interagency Surface Heat Budget of the Arctic (SHEBA) ice island experiment to be conducted for 18 months beginning in the Spring of 1997. A semi-autonomous facility called the ARM Radiation and Cloud Station (ARCS) had been proposed for both sites. Facility design and instrumentation plans were presented in the TWP Science and Siting Strategy document which was accepted as the deployment concept for the TWP. While not to the point of making any initial deployment decisions, the thought process for the North Slope was being captured in an analogous siting strategy document, which was in its initial draft stages at the time of the Science Team meeting.

Collaboration continued as a fundamental concept within ARM, but the range and scope of collaboration had started to become clearer. Earlier ARM had negotiated a Memorandum of Participation with the International GEWEX Program Office, wherein each program committed to a philosophy of collaboration and data sharing. ARM committed to participate in the Marine Continent Thunderstorm Experiment (MCTEX) as part of its initial deployment activity to the TWP. In the North Slope environs, ARM agreed to participate in the SHEBA field experiment with a complement of instruments representative of the radiometric instruments in an ARCS to be deployed to Barrow. On a broader scale, ARM and EOS began discussion about the time of the Science Team meeting to explore the level and extent of collaboration between the programs; further meetings were scheduled for later in 1994. The value of the ARM site in the SGP began to be assessed for its applicability to ecological and hydrological research activities, both within and without DOE.

Against this broad background of site implementation activity, increasing data, new instrumentation and broader opportunities for collaborative research, the Science Team continued to evolve and expand the activities of the working groups originally founded around the three general measurement strategies encompassing most of the research approaches of the Science Team. Many of the extended abstracts that appear in the volume are couched in references to these strategies. Recapping from previous documents, these general measurement strategies are:

- 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 core 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.
- hierarchical diagnosis - GCMs may be viewed as part of a hierarchy of models and modeling systems whose representation of atmospheric physics ranges from the highly aggregated to the highly specific. GCMs and single-column models are necessarily characterized by highly aggregated physics and by coarse spatial and temporal resolution. To understand the limitations imposed by such aggregation and, ultimately, to improve the models, observations must be analyzed and interpreted using higher resolution models. A critical part of the ARM implementation is deciding how to select and obtain the observations on a finer space and time scale. Equally important is deciding which variables not normally carried in a GCM must be observed in order to credibly construct a sound parameterization of a meteorological process in a GCM.
- data assimilation - Meteorological observations are, by necessity, made at discrete locations and times, and they sample only limited portions of the atmosphere. However, the data needed to test models on a variety of scales and to run a single-column model must be continuous in space and time. Consequently, much of the data supplied to ARM experimenters will be in the form of objectively analyzed fields produced by standard four-dimensional data assimilation techniques.
- 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.