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Overview of the United States Department of Energy's ARM Program

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1. INTRODUCTION

The Department of Energy (DOE) is initiating a major atmospheric research effort, the Atmospheric Radiation Measurement Program (ARM). The program is a key component of DOE's research strategy to address global climate change and is a direct continuation of DOE's decade-long effort to improve the ability of General Circulation Models (GCMs) to provide reliable simulations of regional, and long-term climate change in response to increasing greenhouse gases. The effort is multi-disciplinary and multi-agency, involving universities, private research organizations and more than a dozen government laboratories.

The objective of the ARM Program is to provide an experimental testbed for the study of important atmospheric effects, particularly cloud and radiative processes, and to test parameterizations of these processes for use in atmospheric models. This effort will support the continued and rapid improvement of GCM predictive capability.

Over the past ten years, the research programs of DOE and other agencies have made significant progress toward understanding the potential for global climate change and the resulting consequences. Models of the global climate system have advanced to include realistic geography, the annual cycle of the seasons, and varying cloud cover. Very recently, models have begun to include coupling of the ocean-atmosphere system. Results of climate models suggest that projected greenhouse gas emission patterns may lead to a global climate warming of 1.5 to 4.5 degrees Celsius and to significant changes in water availability during the next century.

However, this decade of research has also revealed that considerable uncertainties in model estimates remain. For example, although the 1980s have been especially warm, the extent of global warming over the past century may have been two to three times less than that estimated by current models. Further, when the results of different models are compared, there are substantial differences among their estimates of temperature and precipitation changes in response to doubled CO_2. We therefore do not know with sufficient accuracy how large the climatic changes will be, how rapidly the changes will occur, or how the changes will be distributed over the globe.

The ARM Program consists of three components. Initial members of the Science Team will be selected this summer based on accepted peer reviewed research proposals. This group will set the scientific direction of the program and will be the primary recipient of the experimental data. The Clouds and Radiation Testbed (CART) team provides the experimental testbed for the program. An Instrument Development Program will provide for further development of new instrumentation in response to programmatic needs. Initial participants in the Instrument Development Program are also to be selected this summer based on accepted peer reviewed proposals. Activities are coordinated and directed through the ARM program office and the Atmospheric and

Climate Research Division of DOE:

2. ARM SCIENTIFIC PROGRAM REQUIREMENTS

The following scientific requirements emerge as the most critical for a program designed to remedy key weaknesses of current models:

A quantitative description of the spectral radiative energy balance profile under a wide range of meteorological conditions must be developed. Such descriptions must come from field measurements and must be quantified at a level consistent with climatologically significant energy flows of 1 to 2 W/m².

The processes controlling the radiative balance must be identified and investigated. Validation of our understanding of these processes must come from a direct and comprehensive comparison of field observations with detailed calculations of the radiation field and associated cloud and aerosol interactions.

The knowledge necessary to improve parameterizations of radiative properties of the atmosphere for use in GCMs must be developed. This requires intensive measurements at a variety of temporal and physical scales. A major emphasis must be placed on the role of clouds, including their distribution and microphysical properties.

Within this framework, the goals of ARM are two-fold. First, it will attempt to improve the treatment of radiative transport in GCMs for the clear sky, general overcast, and broken cloud cases. Second, it will provide a testbed for cloud parameterization models used in GCMs. The measures of the quality of the models will include their ability to reproduce observed wavelength and direction-dependent fluxes of longwave and shortwave radiation and the time-varying distribution of cloud type and amount.

3. EXPERIMENTAL APPROACH

ARM is an observational program driven by the theoretical and modeling requirements. The ARM Program must provide data that can improve and test the GCM parameterizations of clouds and their microphysical composition. The smallest domain explicitly represented in a GCM is the single grid cell. A GCM cell is orders of magnitude larger than the scale associated with important cloud characteristics. It is possible that over the next decade model resolution will increase substantially so that single grid cells will have dimensions of a few tens of kilometers (comparable to an ERBE pixel). Even so, since clouds can have dimensions less than a kilometer, subgrid parameterization will remain necessary.

Of all the subgrid-scale characteristics that may affect radiation, cloud inhomogeneities and surface albedo variations are most important. Uncertainties in climate models will be reduced substantially when a reliable cloud parameterization is developed that will consistently apply under important mean climate conditions. Data that characterizes the statistics of clouds on a subgrid-scale is necessary for the development of improved cloud models.

The ARM experiment will consist of coordinated sets of instruments at each of four to six permanent base sites. These sites are the primary experimental resource of CART. Each ARM site will have three closely associated components. Each component is briefly described here:

3.1 The Central Facility

A critical experimental task of ARM is to make intensive measurements of the radiation field and the physical conditions that control the radiative transfer. Therefore, ARM will field two classes of equipment at the central facility: those for measuring the radiation field directly and those intended to characterize the local radiative circumstances, such as surface and cloud properties. The focus of the observations at the central facility will be the detailed characterization of the atmospheric column above the facility and high spectral resolution radiometric instruments.

3.2 The Three-Dimensional Mapping Network

A series of auxiliary stations will surround the central facility within a 20-km radius (this radius was derived from consideration of the scale height of the atmosphere). These stations will contain instrumentation designed to measure the three-dimensional structure of the atmosphere near the base site and will make use of fundamental profiling equipment, as well as basic radiometric and meteorological equipment. A focus of the specialized stations will be the reconstruction of the cloud geometry surrounding the base site using state-of-the-art photogrammetric methods. This cloud 'visualization system' will be supplemented with a system of wind profilers capable of measuring large-scale vertical velocities.

3.3 Extended Observing Network

Surrounding the central facility and the mapping network will be 16 to 25 extended observing stations. These stations will support the development and study of methods used to generalize detailed atmospheric models for use in GCMs and related models through the process of parameterization. The extended observing area of a base site will include a region of the order of magnitude expected for GCM grid cells in the near future, approximately 200 x 200 km. The instruments at the extended stations will be designed to collect the basic radiometric information and conventional meteorological data needed to characterize the radiative transfer throughout the extended area. Only limited vertical information will be collected, with the more extensive and demanding profiling equipment reserved for the base sites and mapping stations. Wind profilers will, however, be employed on this scale as well to observe the general vertical motions associated with mesoscale phenomena.

3.4 The Mobile Observing System and Campaign Studies

In addition to the permanently placed equipment at the base and extended sites, ARM will maintain a mobile version of the basic experimental equipment found at the central facility and additional instrumentation for use in directed campaign studies. The ARM Program will take several approaches to planning campaigns which will supplement the more operational and continuous observations at the base sites. First there will be a series of short-term operations aimed at the exploration of specific physical mechanisms and processes. An example might be the deployment of the mobile system to support an intensive field experiment in conjunction with another program. The second approach will be through longer-term operation and data acquisition at a site chosen to reveal experimental or climatological anomalies at the base sites. Another approach might deploy equipment at a location chosen to verify models for conditions intermediate to those of the base sites.

A campaign may also involve the addition of instruments to the basic instrument suite at a permanent site in order to achieve a specific scientific or technical objective. Examples might include a comprehensive calibration experiment on a highly specialized prototype or an intensive set of observations aimed at understanding an extraordinary transient climate condition.

3.5 Aircraft and Satellite Observations

Despite all of the advances in remote sensing technology in the past two decades, ground-based instrumentation alone will not meet all of the observational requirements of ARM. As a result both aircraft and satellite observations will play an important role in the experimental strategy. Aircraft will be involved in two ways. First, some aircraft observations will be used on a regular basis to support, for example, calibration of remote sensing systems and to profile the radiation field as a function of altitude. Next, aircraft will be used for direct sampling of key atmospheric constituents in support of intensive campaign periods.

Satellite observations offer critical data for ARM. Top of the atmosphere radiative fluxes and profiling atmospheric conditions in regions beyond the range of sondes and ground based sensors will be crucial. Alternatively, ARM sites will themselves offer extraordinary opportunities for providing ground-truth for satellite sensors. The ARM data system will be designed to support what appears to be a highly synergistic relationship.

4. MEASUREMENT STRATEGY AND INSTRUMENT SELECTION

In order to meet the goals of ARM, the instrument selection must support:

the measurement of key aspects of the radiation field under a range of climatologically significant meteorological conditions sufficient to constrain detailed radiative calculations;

detailed studies of atmospheric trace gas, aerosol, and water-vapor distributions;

detailed studies of meteorological variables, including cloud type and distribution, wind field, temperature, etc.;

measurement of large-scale vertical velocities; and

measurement of critical microphysical properties of clouds.

To support these measurements, it will be necessary to have a support infrastructure with:

near real-time processing of data and execution of models

state-of-the-art calibration methods, including on-site calibration at facilities explicitly designed to support the measurement systems and redundant measurement suites providing near real-time evaluation of instrument performance.

The intent of the measurements in ARM is to test the predictive power of the models. The instrumentation will be improved continuously. Specialized research instruments, either developed through this program or by others, may be brought to an operational state and then added to the complement of instruments. Observing protocols may also be changed to increase the quality of the tests. All critical measurements will be systematically replicated. The Science Team will have a critical role in the selection of instruments and their evolution at particular sites. The instrument complement for a specific site may be tailored to individual site characteristics.

5. SITE SELECTION

In response to the nature of the problem of studying subgrid phenomena, the experimental equipment will be deployed at a series of field sites. These sites will be chosen on the basis of their climatological significance and ability to support a systematic exploration of the performance of radiation cloud parameterization and cloud formation models under a wide range of climatologically significant conditions.

The site-selection process for ARM will be complicated. The choices must incorporate the optimal combination of characteristics in several areas. The general groupings of the criteria are: climatic significance, appropriate climatic sampling, synergistic potential with other programs, scientific viability, and logistical viability.

6. COLLABORATION WITH OTHER PROGRAMS

During the ARM Program, DOE will collaborate extensively with existing programs at other agencies, such as the National Oceanic and Atmospheric Administration (NOAA), the National Science Foundation (NSF), and the National Aeronautics and Space Administration (NASA) as well as programs outside of the United States. The collaborations will include joint participation in campaigns, the exchange of data, and direct involvement in experimental design and instrument development. ARM's objectives make it necessary to acquire data generated by other agencies and programs and ARM intends to provide access to the data sets it will generate to other scientific investigators.

7. SUMMARY AND STATUS

The ARM Program is a highly focused observational and analytical research effort that will compare observations with model calculations in the interest of accelerating improvements in both observational methodology and GCMs.

The initial program plan (DOE 1990) for ARM outlined the classes of observational tools which are capable of meeting the observational requirements discussed in section 4. The instrumentation is currently undergoing extensive review in light of the detailed experimental requirement of the individual ARM investigators. This review will include pilot observational programs in late 1990 and early 1991. These observational campaigns will be supported by sensitivity studies of models conducted during the same period. The data system for ARM is in the design phase and the conceptual design will be reviewed twice during the summer of 1990.

The Science Team for the Program will convene for the first time in November 1990. Current plans call for initial occupation of the first ARM site in 1992.

Other programs interested in suggesting potential sites, providing or receiving data, or participating in campaigns should contact Dr. Gerald M. Stokes, Technical Director, ARM Program Office, Pacific Northwest Laboratories, Battelle Boulevard, Richland, WA 99352, USA.

The ARM scientific program requirements as well as details on the logistics of the program are discussed in a paper by Patrinos etal which is soon to be published.

8. REFERENCES

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