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Identification, Recommendation, and Justification of Potential Locales for ARM Sites

Executive Summary

April 1991

U.S. Department of Energy
Office of Energy Research
Office of Health and Environmental Research
Atmospheric and Climate Research Division
Washington, D.C. 20585

ARM
Atmospheric Radiation Measurement

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Foreword

The Atmospheric Radiation Measurement (ARM) Program is a major component of the Department of Energy's Global Change research. This research is coordinated by the Committee on Earth and Environmental Sciences (CEES) of the Federal Coordinating Council for Science Engineering and Technology (FCCSET). ARM was initiated in FY 1990 in response to the emerging concensus that the "role of clouds" was the principal scientific uncertainty in climate change prediction. ARM is a field and modeling program and is based on the various model intercomparison studies that the Department has supported over the years, such as the study on the intercomparison of general circulation models (GCMs) and the Earth Radiation Budget led by Robert Cess; the program for climate model diagnosis and intercomparison led by Lawrence Gates; and the Intercomparison of Radiation Codes used in Climate Models (ICRCCM) cosponsored by DOE, the World Meteorological Organization and the International Radiation Commission.

This report is an account of a study that was undertaken within the ARM Program to examine locations suitable for establishing and maintaining experimental sites that meet the objectives of ARM and to recommend an ordered set of locales in which to locate sites, thereby creating the framework for site selection. Selection of specific ARM sites will come from further analysis based on the principles established in this report. The results of the study have been reviewed by several entities within the ARM Program and DOE, as well as leading scientists in the meteorological and atmospheric radiation community. This report incorporates the many helpful comments and suggested changes received from these reviews.

Ari Patrinos, Director
Atmospheric and Climate Research Division

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Executive Summary

The Atmospheric Radiation Measurement (ARM) Program is a major new research program initiated by the U. S. Department of Energy (DOE) to obtain improved understanding and quantitative description of radiative and cloud processes in the Earth's atmosphere. This program is a direct continuation of DOE's decade-long effort to improve General Circulation Models (GCMs) and related models for providing reliable simulations of regional and long-term climate change in response to increasing atmospheric concentrations of greenhouse gases. The objective of ARM will be achieved by measuring short- and long-wavelength radiation along with the physical and meteorological quantities that control this radiation, by simulating these measured quantities with numerical models, by comparing the measurements with the output of the models, and by refining both models and measurement procedures. Because of the dominant influence of clouds on both shortwave and longwave radiation, the ARM Program will place particular emphasis on development of improved descriptions of cloud formation, maintenance, and dissipation, and of interaction of radiation with clouds.

This report describes a systematic examination of the number and location of sites required to characterize and parameterize the processes controlling radiation transfer in the atmosphere sufficiently to meet the ARM objectives and presents the results of that examination. The examination has been guided by the ARM approach to meeting its objectives, namely, acquiring an understanding of the underlying physics of the pertinent processes, rather than empirically characterizing and parameterizing observations. This approach relieves any requirement of conducting measurements at all climatically significant locations, replacing it with a much less stringent requirement, namely, conducting measurements at a set of sites that will collectively experience, with appreciable frequency, the key phenomena controlling the transfer of radiation in the atmosphere. This approach provides assurance that the set of ARM sites will encompass locations experiencing the key processes responsible for cloud formation, maintenance, and dissipation; exchange of radiant energy, latent and sensible heat, and water in all its phases between the surface and the atmosphere; and transport of radiant energy, heat, and water within the atmosphere.

The ARM Program will provide improved understanding of radiative and cloud processes in the Earth's atmosphere.

Locale Recommendation Premises

In examining locations for ARM sites an important distinction was made between "sites" and "locales." A site is defined as the location of a future ARM measurement facility; a locale is defined as a contiguous geographical region with generally homogeneous climatic and surface properties (or some other unifying attribute) within which an ARM site could be established. The current study is concerned only with recommending a set of locales; later a suitable site within each locale will be chosen for the ARM facility. An underlying premise of this process is that locales can be selected on the basis of their utility in meeting the scientific objectives of ARM and on broad logistical considerations, whereas the actual location of a site within a locale would be based on specific logistical and operational considerations (with the proviso that the immediate region surrounding each site be suitably representative and homogeneous). This procedure is viewed as ensuring that both scientific and practical considerations will be addressed in selecting the set of ARM sites.

The recommendations in this report were developed by considering the processes to be studied and the models to be tested to achieve the ARM objectives, the ranges of atmospheric conditions and surface properties necessary to study these processes and test these models, and the ability of candidate locales, individually and collectively, to provide these conditions and properties.

The recommended ordered set of locales presented here has been reviewed by a number of entities within the ARM Program and DOE to examine its suitability from such perspectives as ability to meet the scientific objectives of ARM, operational feasibility, and budget.

The locales are ordered according to the increase in scientific understanding expected to be gained by establishing ARM sites at these locales and by logistical considerations. This set of locales consists of five primary locales recommended for long-term occupancy, seven to ten years, and four supplementary locales recommended for short duration or campaign occupancy (months to a year) to study processes unique to such locales.

Locale Recommendations

The recommended ordered set of primary locales for long-term occupancy as ARM sites is as follows:

1. Southern U.S. Great Plains
2. Tropical Western Pacific Ocean
3. Eastern North Pacific Ocean or Eastern North Atlantic Ocean
4. North Slope of Alaska
5. Gulf Stream off Eastern North America, extending eastward

The locations of the primary locales are shown in Figure 1.

In addition to the primary locales, the following supplementary locales are recommended for short-term or campaign occupancy:

1. Central Australia or Sonoran Desert
2. Northwest U.S.-Southwest Canada Coast
3. Amazon Basin or Congo Basin
4. Beaufort Sea, Bering Sea, or Greenland Sea

The locations of the supplementary locales are shown in Figure 2. This set of supplementary locales is not an exhaustive or final list. As the ARM Program evolves, there may be substitutions or additions to this list based on experience. Establishment of ARM sites in supplementary locales will be accomplished with a mobile facility.

Rationale for Locale Recommendations

The rationale for recommending the locale for the initial primary ARM site (U.S. Southern Great Plains) was first that the locale be able to permit an ARM site to be established quickly and present few logistical constraints on conducting ARM measurements. Secondary considerations were that the locale be homogeneous spatially, exhibit a wide range of conditions temporally, be climatologically significant, and provide a high degree of synergism with other projects whose measurements and/or other activities would help ARM achieve its objectives. The highest priority in recommending subsequent locales was the ability of the set of ARM locales collectively to provide the best scientific information for ARM measurements and a variety of conditions and processes that could be characterized there beyond those prevalent at previously recommended locales. A set of locales selected using this rationale permits the characterization and parameterization of the key processes governing transfer of radiation in the atmosphere for use in GCMs and related models.

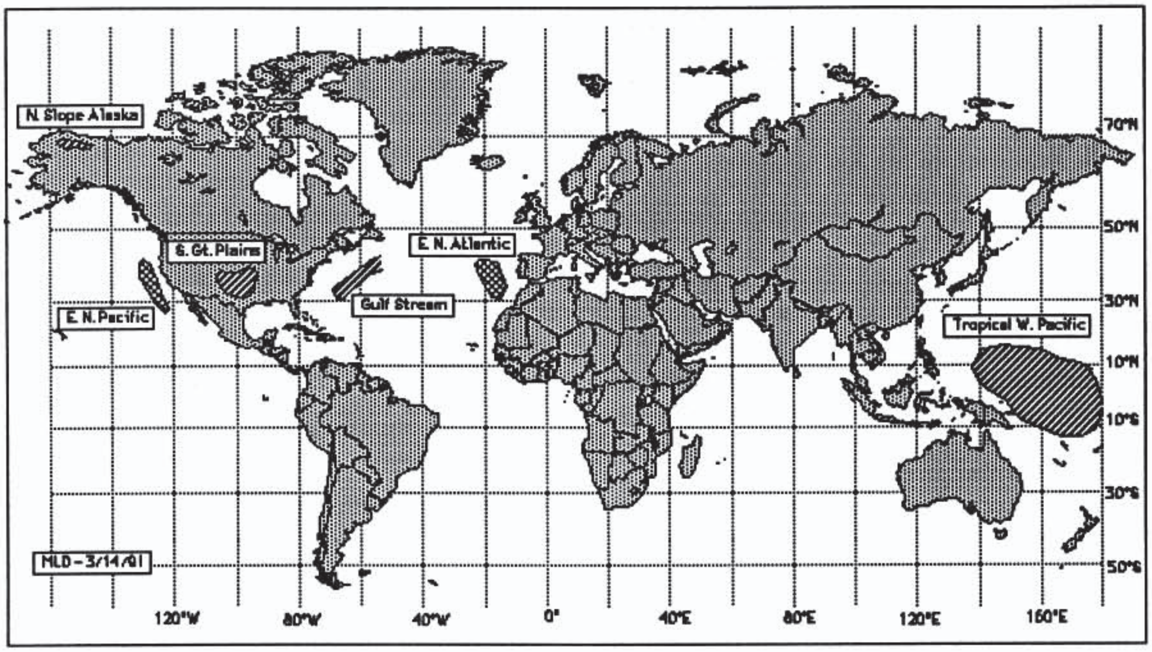

Figure 1. Recommended Primary Locales

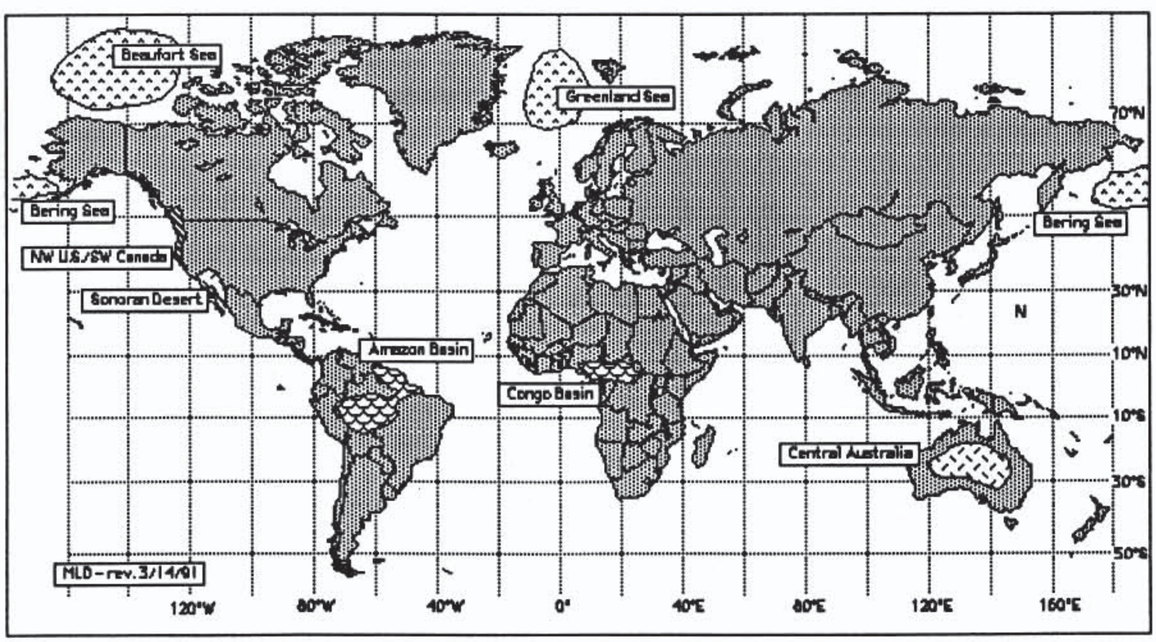

Figure 2. Recommended Supplementary Locales

The rationale for recommending establishment of ARM sites in each of the primary locales is summarized here:

- **Southern U.S. Great Plains**: Key requirements for the first ARM locale include favorable logistics; high geographical homogeneity; a wide variety of cloud types; large intra-annual variability of surface flux properties and weather, including cloud types, temperature, and specific humidity. These requirements are met by the Midwest U. S., Northern Great Plains, and Southern Great Plains locales. A mid-continental locale also was favored by the expected sensitivity of mid-continental locations to climate change and the consequent desire to obtain data for testing climate models at such a location. The Southern U.S. Great Plains locale was recommended as the first ARM locale because it additionally affords the opportunity for synergistic activity with other ongoing and planned meteorological projects and facilities. A key facility is the network of wind profiling stations that will be installed in this area as part of the planned National Oceanic and Atmospheric Administration (NOAA) Wind Profiler Demonstration Network; the high density of vertical atmospheric structure data from this network will be of paramount importance to a number of ARM experiments. Another pertinent project is the Global Energy and Water Cycle Experiment (GEWEX). Also the Southern U.S Great Plains, being at lower latitude than the other locales, is situated somewhat more favorably to the orbit of the Tropical Rainfall Measuring Mission (TRMM) satellite, which is expected to provide valuable measurements of key physical and radiative variables.

- **Tropical Western Pacific Ocean**: Ocean locales are important for ARM both because of the large fraction of the Earth surface covered by oceans and because of the globally important cloud types and meteorological situations that are found only at ocean locations. The Tropical Western Pacific Ocean (TWPO) is the best locale for characterizing deep tropical convection, which is responsible for the transport of water vapor to the high troposphere and for cirrus cloud distributions over much of the ocean. This locale is well suited for observing cumulonimbus clouds and for observing the distribution and radiative impacts of fair-weather cumulus clouds. It also experiences extreme high temperature and specific humidity for an ocean locale. The TWPO is the only candidate locale in which it is possible to observe the El Niño - Southern Oscillation (ENSO) and related phenomena. This locale is essential for several experiments that have been proposed for the ARM Program, e.g., the examination of anomalous infrared absorption at high sea surface temperature.

- **Eastern North Pacific Ocean or Eastern North Atlantic Ocean**: Eastern ocean margins represent another prevalent and climatologically important cloud and meteorological situation that is quite distinct from that represented by the TWPO. Both the Eastern North Pacific and the Eastern North Atlantic locales exhibit a high frequency of low-level marine stratus, which is a key cloud type governing the Earth radiation budget. Marine stratus clouds are less mixed with other cloud types in the Eastern North Pacific than at alternative locales; thus they can be observed in this locale in their purest form. This locale also experiences moderate latent heat fluxes and spans a range of conditions. The Eastern North Pacific Ocean permits observation of the formation and development of winter storms. Also, large variations in anthropogenic aerosols (from California) are expected for different synoptic situations, permitting the testing of aerosol influences on cloud optical properties. The region of the Eastern North Atlantic Ocean extending from the Azores to Africa also offers a variety of marine cloud types, including the transition from marine stratus to stratocumulus to fair-weather cumulus. In addition, this locale offers the potential for synergism with the First International Satellite Cloud Climatology Project (ISCCP) Regional Experiment (FIRE) Program. An ARM site in either of these locales would meet the requirements of an eastern ocean margin locale.

- **North Slope of Alaska**: The North Slope of Alaska experiences highly diverse atmospheric and surface properties: low temperatures, high albedo when covered with ice or snow, moist vegetation and low sun in summer, polar night at mid-winter. It also experiences a wide range in surface fluxes. The North Slope locale is quite diverse climatologically from previously recommended locales. Together, the two land locales, the Southern U. S. Great Plains and the North Slope of Alaska, span a wide range of atmospheric, surface-flux, and geographic conditions. This locale is situated in a region where climate feedbacks relating surface temperature, surface albedo, evaporation, cloud cover, and the polar atmospheric heat sink are thought to be large.
- **Gulf Stream off Eastern North America, extending eastward**: The Gulf Stream locale exhibits extreme ranges and variability in surface heat fluxes. Cold air outbreaks from the North American continent result in air-water temperature differentials that are greater here than anywhere else globally. It is a key locale for observing formation, distribution, and radiative properties of marine altostratus. This locale also provides the best opportunity to observe mature synoptic storms. These are the only such cloud systems that might actually be resolved by present and future GCMs and hence offer the possibility of testing cloud parameterizations without the usual difficulties associated with sub-grid variability.

Sites in the supplementary locales are intended for short-term or intermittent occupation or for research campaigns. Locales are recommended to address specific modeling needs that cannot be adequately addressed with measurements at the primary sites and/or to take advantage of activities in projects that are synergistic with ARM. The rationale for establishing ARM sites in each of the recommended supplementary locales is summarized here:

- **Central Australia or Sonoran Desert**. The high temperatures and low specific humidities of the Central Australian or Sonoran deserts permit substantial extension of the range of conditions over which infrared radiation transfer models can be tested. Totally clear sky is frequent, occurring at least 30% of the time in all seasons, enhancing the value of such studies in these locales. In addition, there is an identified need to improve parameterizations for latent and sensible heat exchange at desert surfaces, for dry and moist convection, and for coupling between soil moisture and downwind cloud formation and precipitation.
- **Northwest U.S.-Southwest Canada Coast**. A campaign in the Northwest United States over several winter months would provide a strenuous test of the ability of models to simulate the response of clouds to orographic inhomogeneity. This locale is very inhomogeneous and has abundant stratus/altostratus clouds strongly modulated by the presence of a mountain range. Summertime stratus occurs with a frequency of 40% on the seaward side of the Cascade range and only 15% on the lee side. Wintertime nimbostratus also occurs significantly more frequently on the seaward slopes of the mountains.
- **Amazon Basin or Congo Basin**. These locales are climatologically important regions with moderate intra-annual variability and little interannual variability. Deep convection occurs in these regions almost daily. Surface latent heat fluxes are large and the specific humidity is often very high. These are good locales for testing the accuracy of treatment of the water vapor continuum and radiative transfer in penetrating convective clouds. These are also good locales for testing models of exchange of heat and moisture between the surface and the air and of redistribution of these quantities within the atmosphere. Also, smoke from biomass burning varies substantially, allowing tests of effects of this aerosol on radiative transfer and cloud microphysics.
- **Beaufort Sea, Bering Sea, or Greenland Sea**. The Beaufort Sea, the Bering Sea, and Greenland Sea are key locales for studying important issues associated with the ocean-ice edge, including changes in albedo and

surface fluxes accompanying the growth and decay of sea ice and possible albedo compensation of changes in ice cover by the decay or growth of marine stratus clouds. The Beaufort Sea locale is the most appealing logistically. It is frozen in winter and melts in summer, providing ample opportunity for ice-edge studies. The proximity to the North Slope of Alaska locale affords the opportunity for studies in conjunction with a site in that locale.

Summary of Increases in Information to be Gained by Establishing ARM Sites at Successive Primary Locales

Southern U.S. Great Plains. The first locale, the Southern U.S. Great Plains, was selected because it is the logistically most favorable locale where conditions exist that will stress ARM models with respect to a wide variety of climatically important properties and because it affords the opportunity for synergistic activities with the planned NOAA Wind Profiler Demonstration Network (WPDN) and GEWEX. The availability of data from the WPDN is central to four-dimensional data assimilation to be used in testing cloud parameterization models in ARM.

The Southern U.S. Great Plains experiences a wide variety of cloud types and amounts. Extratropical cyclones pass through the area regularly in the fall to spring seasons, and occasionally in the summer, with resulting stratus, imbedded convective and cirrus clouds. Stratus, stratocumulus, altostratus or altocumulus clouds are frequently observed during the winter. These clouds, which are formed as a result of circulations that for the most part are resolved by GCMs, are important test cases for the treatment of stratiform clouds in GCMs, and are important climatologically. Cirrus clouds are also frequently observed in winter, often in the absence of other underlying cloud types. These clouds, which have a strong influence on the emission of infrared radiation to space, may be too thin to be resolved by present GCMs. During spring and summer convective clouds (cumulonimbus, fair weather cumulus) are relatively common. The effects on temperature and water vapor due to transport and condensation associated with these clouds are parameterized in present GCMs as sub-grid scale processes. The Southern U.S. Great Plains locale would provide an important data base for verifying such cumulus parameterization. In addition, parameterization of the radiative effects of such clouds, which are poorly treated in present GCMs, can also be developed.

In addition to exhibiting a variety of cloud types, the Southern U.S. Great Plains locale experiences a wide range of temperature and specific humidity. Seasonal mean temperatures range from 7°C in winter to 25°C in summer. Synoptic and diurnal variability expand the range to -25°C to 45°C, which represents a large fraction of the temperature range over the entire Earth. Such a wide range in temperature is necessary to test the temperature dependence of the water vapor continuum in the clear sky. Completely clear sky occurs 10% of the time in summer and 20% of the time in winter. Typically clear sky occurs during periods of cold air intrusion from the Arctic. Seasonal mean specific humidity ranges from 3 g/kg in winter to 10 g/kg in summer; values as low as 1 g/kg and as high as 15 g/kg are observed at times. Such a specific humidity range nearly spans the global range of 0.1 to 20 g/kg. Thus, much of the sensitivity of the clear sky radiative flux to water vapor can be evaluated from the Southern U.S. Great Plains locale.

Tropical Western Pacific Ocean. One of the critical uncertainties in the prediction of climate change is the response of deep tropical convection to increases in ocean surface temperature. Do cumulus clouds in the tropics penetrate higher in the atmosphere when ocean surface temperatures are higher, and if so, what is the effect of the cloud response on the water vapor and condensed water distributions and on the planetary radiation balance? GCM simulations predict higher penetration of convective clouds in a warmer climate, which should, by decreasing the temperature at which clouds radiate energy to space, contribute to planetary warming. However satellite measurements of the planetary radiation balance in the tropics indicate a remarkable balance between solar and infrared cloud radiative forcing, regardless of ocean surface temperature. What processes are responsible for maintaining such a balance? Does the tropical upper troposphere dry as a result of the higher penetration of cumulus clouds in a warmer climate? What is the response of tropical cirrus cloud cover to warmer ocean temperatures? What is the role of the water vapor continuum absorption? Are these processes adequately treated in present GCMs? These important questions must be addressed by the ARM Program.

The ideal location for the investigation of these issues is the TWPO, the second recommended ARM locale. Sea surface temperature (SST) is higher here than in any other extensive region, so that convective clouds commonly attain their highest altitudes, up to 18 km. Although convective clouds also are observed in the Southern U.S. Great Plains locale during summer, they rarely penetrate so high, and their organization is different from tropical convection (e.g., squall lines rather than clusters); these differences permit examination of effects of cloud geometry on their radiative properties. The influence of surface temperature on cloud height and cloud radiative properties, a critical climate issue, is difficult to address at the Southern U. S. Great Plains locale because of the short time scale of variability in surface temperature associated with the diurnal cycle.

The TWPO is also a favorable location for observing fair-weather maritime cumulus cloud fields. These clouds are widespread over the tropical oceans. The fractional cloud cover associated with these clouds is crudely parameterized in present GCMs, largely because of a lack of understanding of the lifetime of such clouds. Although fair weather cumulus clouds are also observed in the Southern U.S. Great Plains (20% of the time during summer), they occur much more frequently in the TWPO (45% of the time). An additional distinction between the Southern U.S. Great Plains and the TWPO is that cloud droplets in marine clouds are generally much larger than those in the Southern U.S. Great Plains, so that cloud lifetimes and albedos may be quite different.

In order to evaluate the influence of SST on deep convection, the ocean surface temperature must change for some substantial period of time. In addition to seasonal and annual variations, there are variations in SST over a widespread area of the TWPO associated with the ENSO, which occurs irregularly with a characteristic period of two to three years. SST can change by as much as 1°C and sea-surface radiative fluxes can change by as much as 50 to 60 W/m^2 over the El Niño cycle. The ENSO cycle can thus serve as a proxy for climate change in the TWPO. Since high ocean temperatures drive this convection, changes in SST associated with El Niño cycles would be a unique means of studying this dependence. Such studies would require measurements over at least one and preferably two or more El Niño cycles. Because of the unique attributes of the TWPO, if a primary ARM site were not established in this locale, it would be necessary to conduct extensive measurements in this locale on a supplementary basis.

Key requirements for the first ARM locale are met by the Southern U.S. Great Plains.

Eastern North Pacific Ocean or Eastern North Atlantic Ocean. The principal cloud type considered important for climate that is not experienced at either the Southern U.S. Great Plains locale or the Tropical Western Pacific Locale, is marine boundary-layer stratus. The third recommended locale, located in the subtropical Northeastern Pacific off the coast of Southern California, or, alternatively the Eastern North Atlantic extending from the Azores islands to the coast of Africa, was selected on the basis of a high frequency of such marine stratus. Marine stratus clouds are widespread in the subtropical oceans. These clouds exert a strong influence on solar radiation absorbed at the surface and by the climate system, but, because of their low cloud-top altitudes, they exert only a weak effect on infrared radiation emitted to space. Thus, marine stratus clouds have a strong cooling effect on the planetary radiation balance and hence are very important to climate. However, these clouds are poorly represented in present GCMs. Key aspects of the formation, maintenance, and dissipation mechanisms for marine stratus are unknown or poorly understood at present. An ARM site located in the Eastern North Pacific, which experiences marine stratus 55% of the time during winter and 70% of the time during summer, would provide extensive information about marine stratus and the transitions between marine stratus, stratocumulus, and broken cumulus in the marine boundary layer. Without such a locale this information would not be available, and development of marine stratus parameterization could not proceed.

Because marine stratus clouds are common over much of the subtropical oceans, the third locale might have been selected from any of several locales. The Eastern North Pacific, off the coast of Southern California, is favored on the basis of an additional factor, namely the high probability of experiencing a wide range in aerosol concentration. When westerlies prevail, most air masses in the Eastern Pacific are largely free of anthropogenic aerosols having traversed the North Pacific since the last previous contact with land. When easterlies prevail, the air masses have travelled the short distance from Southern California and hence are often moderately to highly influenced by anthropogenic aerosols. The expected wide range in aerosol concentration in the Eastern North Pacific, depending on whether westerlies or easterlies prevail, affords the possibility of evaluating the influence of aerosols on cloud droplet size distribution, cloud albedo, and precipitation processes within clouds.

An alternative to the Eastern North Pacific, the Eastern North Atlantic locale presents certain logistical advantages (the availability of islands from which to conduct measurements or to serve as bases for aircraft or ships). This locale offers the prospect of conducting ARM measurements with a variety of cloud types, particularly the transition from marine stratus to stratocumulus to fair-weather cumulus. This locale also would permit synergistic interaction with the FIRE Program.

North Slope of Alaska. This tundra locale exhibits a very strong seasonal cycle of surface properties, atmospheric radiation, and cloud cover. In the summer the surface is very regular, with waterlogged tussock-grass and open ponds overlying permafrost; in winter the surface is snow covered. The attendant changes in albedo and surface heat and moisture fluxes are dramatic, leading to a strong seasonal modulation in surface energy exchange with the atmosphere (including radiation).

Net radiation at the surface is positive only in summer, when the area is free of snow, coinciding with the period of maximum cloud cover (80 to 90%). The clouds are mostly Arctic stratus. During the winter, when surface albedo is high and insolation is low, the cloud cover is much less (< 30%), giving rise to large radiative losses to space. The polar region is thus acting as a global heat sink.

The seasonal cycles of surface albedo, heat and moisture fluxes, cloud formation, and atmospheric radiation provide an interacting system of climate feedback mechanisms in an area where climate change signals in GCMs may be most pronounced.

Gulf Stream off Eastern North America, extending eastward. In midlatitudes the largest contribution to the total cloud cover comes from stratiform clouds associated with extratropical synoptic storms. Significant cloud types formed by these storms include stratus, altostratus, altocumulus, and cirrus. The horizontal scale of these clouds, typically 100 km, is large enough to be resolved by some of the finer-resolution GCMs; in coarser GCMs the sub-grid scale fraction must be parameterized. The formation mechanism, uplift associated with baroclinic instability, is believed to be treated fairly well in some present GCMs. However, the parameterization of cloud fraction and of cloud microphysical processes, which determine how much of the condensed water remains as cloud water, have not been evaluated on such scales. An important component of ARM is to provide a testbed for the performance of cloud microphysics parameterization and cloud fraction parameterization in synoptic storms. These storms are most active, in terms of cloud formation and precipitation, at the western boundaries of the oceans during winter, where the gradient in surface temperature is largest and water vapor is abundant. It is therefore recommended that a fifth ARM site be established near the Gulf Stream, where wintertime storms are particularly active. Winter stratus and altostratus each occur with a frequency of 50% in this locale. Such clouds are also observed in the Southern U.S. Great Plains locale, but the storms there are generally not so well developed. The mature, occluded phase of synoptic systems is notably absent at the Southern U.S. Great Plains locale.

A locale near the Gulf Stream would also provide numerous instances of wintertime convection associated with cold air outbreaks over the warm side of the Gulf Stream. The extremely large latent heat fluxes during such events provide a rigorous test of convection schemes in GCMs. No other locales globally exhibit such a range in latent heat fluxes.

Locale Recommendation Principles

Recommendation of locales for ARM sites was guided by the following principles:

- The set of locales should stress models describing radiation transfer in the atmosphere and atmospheric properties influencing such radiation transfer by spanning, as greatly as possible, the domain of radiation-influencing attributes.
- The climatological and surface-property attributes of each locale should be homogeneous within the locale, except when a locale is intentionally chosen to be inhomogeneous to permit testing of the ability of models to treat atmospheric processes influenced by geographic inhomogeneities.
- The logistics of establishing and operating an ARM site within a locale should be favorable or at least tractable.
- Insofar as possible, locales should be selected so as to maximize opportunities for cooperation between the ARM Program and other programs with similar objectives.

Prioritization of these principles in order to recommend locales for the first and subsequent ARM sites is summarized in Figure 3. The set of locales should be as small as possible, consistent with the need to establish the applicability of models over a range of conditions that is sufficiently wide as to give confidence in their general applicability.

Locale Recommendation Procedure

Based on the locale recommendation principles, the following sequence of steps of the locale selection process was formulated by the Site Selection Team and the ARM Management Team:

1. Identify the domain of attributes that must be spanned by ARM sites, as based upon information provided by the ARM Program Plan, the ARM Site Mission, and input from leading scientists from the atmospheric radiation, meteorology, and general circulation modeling communities.
2. Identify candidate locales for ARM sites.
3. Examine the values of the pertinent attributes of these locales with respect to the scientific requirements of the ARM experiment.
4. Identify logistical constraints that may preclude conducting ARM measurements in these locales or impose major logistical hurdles.

Recommend Locale 1:

Priority ↑

- Favorable logistics
- Homogeneity of geographical and climatological properties
- Synergism with other programs
- Stress the models

Recommend Locale *i*, *i* = 2 . . . *n*

Priority ↑

- In combination with locales 1 to (*i* - 1) stress the models
- Homogeneity of geographical and climatological properties
- Synergism with other programs
- Favorable logistics

Figure 3. Locale Recommendation Priorities

5. Identify other programs conducting atmospheric research in the locales that may provide synergism with an ARM site.
6. Recommend a set of locales that will best satisfy the scientific goals of ARM, taking into account the ordered selection criteria and budgetary constraints.
7. Submit the recommended set of locales, including the recommendation procedures and the justifications for the recommendations, for review by the ARM Science Team and the broader scientific community.
8. Consider suggested revisions to the procedures and revise the recommendations as appropriate.

Application of the Locale Recommendation Procedure

The locale recommendation procedure outlined above was the basis of a formal examination and recommendation process consisting of identifying potential and candidate locales; examining the radiation-influencing, logistical, and synergistic attributes of those locales; preparing candidate sets of locales; and finally recommending the sets of primary and supplementary locales. The participants in this procedure, representing a wide range of experience in atmospheric science and in the conduct of field projects such as ARM, were drawn largely from the DOE national laboratories participating in CART. (CART, the Clouds and Radiation Testbed, is the name given to the ARM infrastructure activity that has been designing the field portion of the ARM Program on behalf of DOE, and which will assume responsibility for conducting those operations.) The personnel who participated in this activity and their roles in this activity are listed in the back of the main report.

The first step of the locale recommendation procedure was to develop a list of potential locales for ARM sites. This list was prepared by identifying the major categories of locales globally and identifying locales within those categories. An initial list of candidate locales was identified as a subset of the list of potential categories, with the objective of retaining a broad representation of the major locale categories. The initial lists of potential and candidate locales were circulated within ARM management and CART to elicit additional locales to receive detailed examination as candidate ARM locales, and it was possible throughout the entire locale recommendation procedure for additional candidate locales to be added to the list upon the suggestion of any of the participants of the locale recommendation procedure. The full list of potential locales identified by this process is given in the body of the report. Table 1 presents the list of candidate locales whose radiation-influencing, logistical, and synergistic attributes received thorough examination by the teams charged with such examination.

Table 1. Locales Evaluated as Candidates for ARM Sites (Listed by Locale Category)

NOTES: 31 locales were selected for detailed examination, including 17 land locales and 14 ocean locales. (IH) denotes locale categories that were selected as intentionally heterogeneous to permit testing of the ability of models to treat this heterogeneity.

LAND LOCALES

Temperate East Coastal Plains
- Mid-Atlantic U.S.
- Southeast U.S. Coastal Plain

Subtropical Grasslands
- Southern U. S. Great Plains

Midlatitude Continental Prairies
- Northern U. S. Great Plains

Midlatitude Humid Continental Plains
- Midwest U.S. North of Ohio River

High Latitude Continental Boreal Forest
- West Siberian Boreal Forest
- Canadian Boreal Forest

Equatorial Rainforest
- Amazon Basin
- Congo Basin

Tabel 1. (contd)

Tropical Monsoon Region
- Southern Indian Subcontinent

Continental Deserts/Arid Regions
- Sonoran Desert (southwest U. S./northern Mexico)
- Central Australia

High Latitude Ice Plateau
- Greenland Plateau
- Antarctic Plateau

Tundra
- North Slope of Alaska (inland from coast)

Leeward Slope of Mountain Range (IH)
- Eastern Slope of U. S. Rockies

Wet Temperate West Coastal (IH)
- Northwest U.S./Southwest Canada

OCEAN LOCALES

Central Gyres
- Sargasso Sea (N. Atlantic)
- Central North Pacific

Equatorial-Tropical Oceans
- Tropical Western Pacific Ocean
- Tropical Atlantic

High Latitude Ice-Free Seas
- Circumpolar Southern Ocean
- Norwegian Sea

High Latitude Ocean/Ice Edge (IH)
- Beaufort Sea
- Greenland Sea
- Bering Sea

Western Boundary Currents (IH)
- Gulf Stream off Eastern N. America

Eastern Boundary Currents
- Eastern North Pacific (28-40°N, 120-130°W)
- Eastern South Pacific

Eastern Margins of the Gyres
- Eastern Atlantic Ocean, Azores to Africa (35-38°N, 20-35°W)

Semi-Enclosed Seas
- Australia-Indonesia Semi-enclosed Sea

Each candidate locale was examined by several teams charged with assessing pertinent site attributes according to the following categories: climate, atmospheric properties, surface energy fluxes, surface properties, logistical considerations, and synergism with other programs. Each team determined the criteria it used to evaluate the sites relative to its specific area of responsibility and examined the candidate locales from the perspective of meeting those criteria. The criteria developed by the teams as well as the results of the examinations are given in detail in the reports of the teams presented in Appendixes B through F of the main report. Each team examining the scientific attributes was directed to select one or more sets of locales that would adequately stress the pertinent models by spanning a wide range of climatological, atmospheric, and surface property conditions that affect radiation and clouds.

After the teams had determined the pertinent criteria and prepared initial evaluations, a meeting of the several teams was held to develop a consensus on a single set of locales that would adequately span the several attribute spaces, while meeting the criteria of homogeneity, logistical feasibility, and programmatic synergism. This meeting resulted in the ordered set of primary locales that is presented above, together with the set of supplementary locales that is recommended for short-term or campaign occupation.

Conclusion

The process summarized here and presented in detail in the full report has constituted a systematic examination of the attributes governing the transfer of radiation in the atmosphere, and of the values of these attributes in all the climatologically significant categories of locales globally. This process has led to recommendation of a set of locales in which to establish ARM sites. The process also has provided a framework by which to assess the ability of such a set of locales to span the pertinent attributes and thereby achieve the objective for selection of a set of sites for ARM measurements, namely that this set of sites collectively will experience with appreciable frequency the key phenomena controlling the transfer of radiation in the atmosphere.

In the view of the several teams participating in this effort, the ARM objective is largely achieved with the set of five recommended primary locales. However, it was the view of the teams that sufficient differences existed between certain near-equivalent locale categories as to necessitate a short duration occupancy of several supplementary locales to assess the ability of the primary sites to adequately capture and describe the key phenomena controlling the transfer of radiation in the atmosphere.

A concern noted by the Locale Recommendation Team is that because of the logistical difficulties associated with some of the recommended locales, especially the Gulf Stream locale, alternatives to these locales must continue to be considered. For the Gulf Stream locale, more than one alternative locale (one for clouds, another for fluxes, etc.) may be required to adequately observe these phenomena elsewhere. On the other hand, rather than deal with multiple alternatives, it may be preferable to use a campaign approach to obtain the necessary data at the Gulf Stream locale.

If it becomes necessary at any time to amend the set of primary locales for ARM sites, it is emphasized that changes should not be made arbitrarily, but should involve considerations of the attributes of the locale being eliminated, and establishing that these attributes are adequately represented in the replacement locale or locales. The framework and methodology developed in this study and described in this report should be employed in any such changes in locales for ARM sites.

The recommended set of supplementary locales is not to be construed as an exhaustive or final list. In particular, a concern, noted in the review of the set of recommended locales by the Science Team, is that because of the intense orography coupled with the land-ocean boundary, the single locale specifically recommended for testing ability of models to treat geographical inhomogeneities, the Northwest U.S.-Southwest Canada Coast locale, might actually be an overly severe test of models, at least as an initial intentionally heterogeneous locale. The possibility of less intense orography was suggested, perhaps by examining coastal effects at lower latitude on the west coast of the United States. A study at such lower latitude may be desirable also because of synergism by proximity to the primary ARM site in the Eastern Pacific Ocean. Alternatively, it was suggested that locales might better be chosen to incorporate heterogeneities one at a time. Suggested possible locales included the eastern slope of the U.S. Rockies and coastal areas adjacent to the southeastern U. S. coastal plains.

Additional supplementary locales were suggested in the review of this document as valuable in permitting examination of specific processes or phenomena not captured in the recommended set of primary and supplementary locales. The Southern Circumpolar Ocean exhibits high frequencies of marine stratus clouds and very low aerosol concentrations, in contrast to the Eastern North Pacific and Eastern North Atlantic locales, permitting isolation of aerosol influences on cloud microphysical and radiative properties. A supplementary locale in the Central Equatorial Pacific, in conjunction with the locale in the Tropical Western Pacific, would permit examining processes linking the warm pool with water vapor and cloud transport by the equatorial easterlies (Walker Cell) and trade winds (Hadley Cell). The necessity of establishing supplementary ARM sites in these locales will have to be resolved as experience is gained in the early years of the program.

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