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Guidelines for the Aerosol Climatic Effects Special Study: An Element of the NASA Climate Research Program

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Guidelines for the Aerosol Climatic Effects Special Study: An Element of the NASA Climate Research Program

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PREFACE

The study of atmospheric aerosols has long been of great interest to many of NASA's science and applications oriented research programs. Their importance has again been emphasized in the recent planning for NASA's contribution to the National Climate Program. This document, prepared in collaboration with Drs. J. Pollack of the Ames Research Center and M. P. McCormick of the Langley Research Center, outlines the agency's planning for a special study directed at improving our understanding of how natural and manmade aerosols can affect climate and its predictability. This effort will coordinate and build on much of the theoretical and experimental research being conducted within the NASA Upper Atmospheric Research and Environmental Quality discipline programs and will complement the stratospheric aerosol observations provided by the Nimbus-G and SAGE research satellites.

It is expected that similar guideline documents will be prepared for other special study areas within the NASA Climate Research Program.

Robert A. Schiffer
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SUMMARY

NASA is currently sponsoring a number of studies concerning properties and effects of atmospheric aerosols. These studies include the Nimbus-G/SAM II and AEM/SAGE satellite experiments, which will map the global distribution of stratospheric aerosols within the next few years; the ground truth programs for these satellites, which will provide an initial data base of auxiliary aerosol properties during FY 79; a variety of aerosol experiments conducted from aircraft, balloon, and ground platforms; and a number of theoretical investigations of the climatic effects of aerosols and the formation of atmospheric aerosols.

A vigorous national climate research program is evolving. Scientific advisory groups to NASA have recommended that an aerosol effects study be a part of NASA's contribution to this effort in order to focus our activities on understanding the effects of aerosols on the Earth's climate. This document outlines a plan of action for a NASA Aerosol Climatic Effects special study, one element of NASA's Climate Research Program.

The objectives of this research are to help develop a better understanding of the role of aerosols in the Earth's radiative balance and to use natural volcanic injections of aerosols into the stratosphere to test our ability to understand and model any resultant evidence of climate change. The approach involves: (1) measurements from aircraft, balloon and ground-based platforms which complement and enhance the aerosol information derived from satellite data; (2) development of instruments required for some of these measurements; (3) theoretical and laboratory work to aid in interpreting and utilizing space-based and in situ data; and (4) preparation for and execution of concentrated observations of stratospheric aerosols following a future large volcanic eruption.

The research initially focuses on stratospheric aerosols, but at a later time the emphasis will shift to tropospheric aerosols, as a result of anticipated advances in the technology for remote observations of tropospheric aerosols from space. The work to be carried out within this special study will be performed by scientists at NASA centers and by outside investigators in academic and research institutions, under NASA sponsorship.

INTRODUCTION

Both the stratosphere and the troposphere contain significant populations of particles (aerosols). The lower stratosphere contains a layer of sulfate particles (probably sulfuric acid), which is formed by the photochemical conversion of sulfur-containing gases to sulfate particles; sources of these aerosols include volcanically injected material and gases transported up from the troposphere. The troposphere contains a variety of aerosol species that are distributed in a very nonhomogeneous manner. The particles are conveniently classified into a number of regional types that include urban aerosols (smog, sulfates), desert aerosols, agricultural aerosols, and marine aerosols.

Atmospheric particles can affect climate through their influence on the amount of sunlight absorbed and reflected by the Earth atmosphere system and on the amount of thermal radiation emitted to space. Both natural and anthropogenic factors lead to changes in the aerosol population and thereby induce climatic alterations. In the case of stratospheric aerosols, multiple volcanic explosions have been interpreted to have made significant contributions to some past climatic changes, such as the "Little Ice" age of 1450-1915. Careful assessments need to be made of future impacts of the material introduced into the atmosphere by supersonic aircraft, space shuttles, and fossil fuel burning. In the case of the troposphere, some calculations have indicated that regional buildups of aerosols due to man's activities may already be affecting climate on a regional and global scale.

In addition to their possible role as precursors for past climatic changes, volcanic aerosols may also serve a second important function in studies of climate. Once every several years, a volcanic event causes a very sizable, but temporary (~1 year) buildup in the population of stratospheric aerosols, which can affect the Earth's radiation budget. These radiative effects are translated into transitory perturbations to the stratospheric and tropospheric temperatures, as seems to have occurred, for example, following the Mt. Agung eruption of 1963. Since these are large-amplitude perturbations with well-defined time histories, such volcanic events represent ideal "natural" experiments for testing specific attributes of climate models.

The above discussion of the significance of aerosols for climate studies is summarized in table 1. This table also provides a more detailed listing of the major questions that need to be addressed in this regard.

TABLE 1.- MAJOR ISSUES INVOLVED WITH UNDERSTANDING AEROSOL EFFECTS ON CLIMATE

How successful are climate models in reproducing changes observed following a volcanic event?
Stratospheric Aerosols • Do they significantly heat or cool the Earth? • What is the relative importance of natural and anthropogenic sources?
Tropospheric Aerosols • Stratospheric issues plus: • Regional impact — what are their interactions with other climate factors such as precipitation and cloud cover? • Are there long-term changes in the number of tropospheric aerosols and, if so, what is the climatic significance of these changes?

To evaluate the current impact of aerosols on climate, it is necessary to have a good understanding of their present radiative properties. In order to predict their possible effects in the past and future, it is essential to have a sound understanding of the origin of the aerosols so as to deduce their radiative properties for different sets of circumstances. For example, from a knowledge of the processes controlling the formation and growth of the stratospheric sulfate particles, one could predict how their size distribution would vary with changes in the amount of sulfur gases in the stratosphere. Both types of evaluations may be accomplished by utilizing the results obtained from a comprehensive set of atmospheric measurements and auxiliary laboratory studies in a hierarchy of theoretical models that include, to varying degrees, relevant radiative transfer, dynamical, and aerosol formation processes.

Although NASA's role in the National Climate Program and potential future role in Global Atmospheric Research Program (GARP) climate activities are based principally on its remote sensing capabilities, complimentary research, including theoretical and laboratory studies, and in situ measurements are essential to the design, interpretation, and application of the satellite data to the climate problem. For this reason, the NASA Climate Plan Science Working Group[1] recommended that a broad aerosol climatic effects special study be conducted by NASA; this recommendation was endorsed by a second Climate Science Working Group[2] and more recently at an OSTA Aerosol Workshop.[3]

The importance of aerosols to the climate issue is thus solidly reflected in the above NASA climate planning activities, as well as in those of the Global Atmospheric Research Program (GARP). The GARP Joint Organizing Committee (JOC) Board for the Climate Dynamics Subprogram has included a Working Group on Aerosols and Climate[4] as an integral part of their organization. The plan for a NASA coordinated Aerosol Climatic Effects special study described in the following is in consonance with the objectives and recommendations set forth by these groups.

This document includes an overview of the present and proposed NASA programs in aerosol research related to the Earth's environment and climate, and outlines an Aerosol Climatic Effects special study to be initiated in FY 79. The program will span several years and will consist of coordinated sets of aerosol measurements made from aircraft and balloon platforms in addition to ground measurements that will complement data obtained from spacecraft aerosol experiments. In addition, as an integral part of this program, relevant

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[1]This working group helped draft the basic NASA planning document entitled "Proposed NASA Contribution to the Climate Program, July 1977." Its membership included A. P. Ingersoll (Chairman), K. Bryan, W. Campbell, J. P. Friend, J. Hansen, W. W. Kellogg, C. E. Leith, C. Leovy, M. McElroy, L. Myrup, P. P. Niiler, J. B. Pollack, O. B. Toon and T. Vondar Haar.

[2]Convened in December 1977 and March 1978 to review the evolving priorities and strategies for implementing the NASA Climate Research Program.

[3]Convened in June 1978 to review and discuss current research on the major scientific issues dealing with aerosol effects on climate.

[4]A subprogram of GARP Climate Dynamics Board. Present members are J. H. Joseph (Chairman), R. Charlson, K. Ya. Kondratyev, Ch. Junge, J. London, and M. P. McCormick.

theoretical, laboratory, and auxiliary observational efforts will be supported to provide the necessary supplementary information for guidance and data interpretation.

OVERVIEW OF ONGOING AND PROPOSED RESEARCH

Our ability to resolve the aerosol/climate issues listed in table 1 is severely limited at present by several major gaps in our knowledge and in the existing aerosol data base. These gaps include a lack of global information of the spatial distribution and temporal variations of the aerosols, a lack of simultaneous, multiple parameter data sets, and an incomplete understanding of basic aerosol composition and formation mechanisms. The NASA spacecraft aerosol experiments described below will provide information on global variations and their associated ground truth programs will make a start towards filling the second gap. The Aerosol Climatic Effects (ACE) special study will enhance these measurements. The study will be primarily directed towards eliminating both the second and third types of deficiencies.

Table 2 provides a summary of approved and contemplated NASA satellite experiments to measure the properties of stratospheric and tropospheric aerosols. This table also indicates the supporting ground truth portions of these missions, as well as all major elements of the study which are described more fully in the next section of this document.

As shown in table 2, two satellite experiments for studying stratospheric aerosols, SAM II and SAGE, will be launched within the next year. The observations will provide valuable data about the three-dimensional distribution and optical depth of these aerosols. A vigorous plan for validating these data through coordinated aircraft and balloon observations has been set up and is indicated by the term "ground truth." Details of the SAM II and SAGE ground truth plans are given in appendixes A and B. A partial list of the initial investigations to be performed by their science teams[5] is listed in appendix C. In the early to mid-1980's information on the spatial distribution of tropospheric aerosols is expected to be provided by lidar experiments carried on the Space Shuttle. At the present time there is no viable satellite technique for obtaining these data. Such data are essential for the assessment of the climatic impact of tropospheric aerosols because of the extremely heterogeneous spatial distribution of this material.

A strong foundation for the contemplated ACE study is provided by the aerosol research projects that NASA has supported over the last several years. In particular the Office of Space Science and the Office of Space and Terrestrial Applications are presently supporting aerosol research in many areas. These include aerosol formation studies (modeling and laboratory work), the

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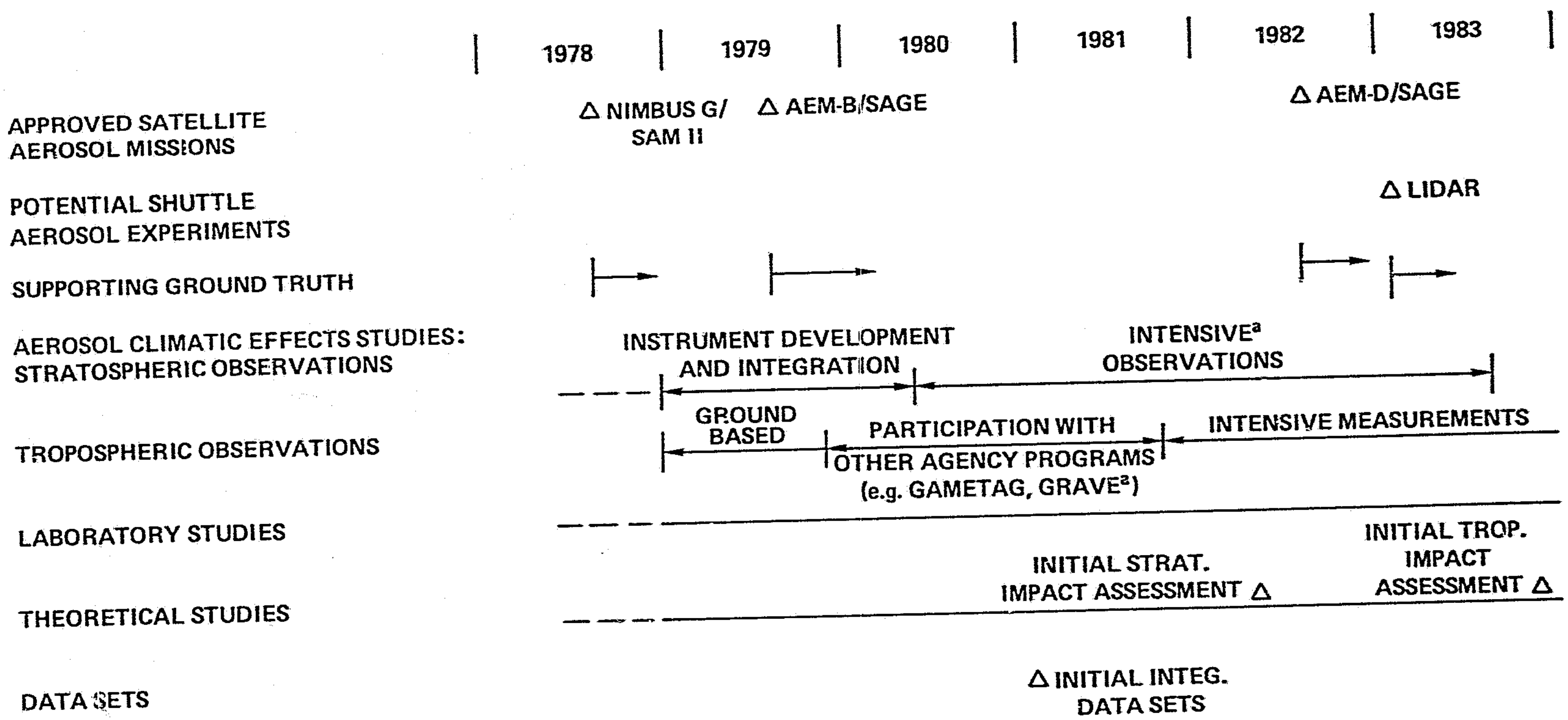
[5]SAM II Science Team — G. Grams, B. M. Herman, M. P. McCormick, J. M. Pepin, P. B. Russell. SAGE Science Team — R. A. Craig, D. Cunnold, G. Grams, B. M. Herman, D. Miller, M. P. McCormick, D. C. Murcray, T. J. Pepin, W. Planet, P. B. Russell.

TABLE 2.- SUMMARY OF CONTEMPLATED AND APPROVED NASA AEROSOL MEASUREMENT ACTIVITIES.

MILESTONES



[a] PROVIDES THE CAPABILITY FOR REACTING IN A TIMELY FASHION TO A VOLCANIC EVENT.

development of radiative transfer codes and their use in remote sensing and climate effects, the development of various transport and climate models, and, of course, an observational program that includes satellite, ground-based, aircraft and balloon-borne measurements. This work which spans the Environmental Quality, the Upper Atmospheric Research, and Climate Research Programs all contribute to the aerosol/climate issue either in a very direct or peripheral manner. It is being carried out at a number of university, NASA, and government laboratories.

DESCRIPTION OF AN INITIAL AEROSOL CLIMATIC EFFECTS (ACE) SPECIAL STUDY

There are three purposes for the ACE special study. First, it will provide complementary information to that obtained from satellite measurements of atmospheric aerosols so that collectively a comprehensive data set can be obtained to address, through appropriate modeling, the climate problems of interest. Second, ACE, in conjunction with satellite experiments, will provide the capability for taking full advantage of the opportunity presented by the volcanic injection of material into the stratosphere. Such an event would represent an ideal "natural" experiment for helping to validate climate models as described earlier. Third, although not a prime driver of the program, ACE will provide a data base for assessing and, if need be, factoring out the interfering effects of aerosols on satellite measurements, which are intended to remotely sense certain properties of the atmosphere and surface. For example, satellite observations of radiation emanating from the stratosphere may contain an important component due to aerosol scattering or emission, while scattering by tropospheric aerosols aliases studies of the surface albedo from satellite platforms.

The proposed initial ACE subprogram has the following basic elements:

1. Observational Program: measurements of a number of aerosol properties will be obtained from aircraft, balloon, and ground platforms. These data, in conjunction with those obtained from satellites, will provide comprehensive data sets for addressing the climate problem.

2. Instrument Development: in order to satisfy item 1, it will be necessary to support the development of some new or improved instruments.

3. Theoretical and Laboratory Program: to help guide the observational program and to provide the necessary analysis of the data, relevant modeling and experimental studies will be involved in the overall program. Support will be given to the improvement and development of relevant aerosol climate models.

4. Coordination with Satellite Observations: ACE will emphasize those areas that help support existing and planned satellite systems for remotely sensing aerosols and its observational program will be run in conjunction with available satellite observations.

5. Response to a Volcanic Event: ACE will be set up in such a way that it can react in a timely fashion to the sudden injection of material into the stratosphere by a volcanic event. This reaction will involve intensive observations and analysis conducted in accordance with a plan to be developed early in the program.

Below, we describe the general characteristics of the study in greater detail and indicate how it will meet its basic objectives.

Observational Program and Instrument Development

Prioritized Set of Information to be Collected by the Aerosol Climatic Effects Study- In table 3, we list key areas in which information needs to be collected by ACE and the associated spacecraft aerosol experiments in order to meet the study goals. While it would be desirable to obtain all the information listed, we are aware of the limited resources that will be available and have therefore ordered these areas as to priority, i.e., item 1 has the highest priority. For both the stratospheric and tropospheric aerosols, a determination of aerosol radiative properties was assigned the top priority because it is through their radiative effects that aerosols principally impact climate. Thus, no assessment of their climatic impact is possible without this information. Also, the other two goals of the program are met by measuring the current radiative properties of the aerosols. Other items listed in this table provide a basis for generalizing the current properties to other situations so as to assist in the assessment of past and future impacts.

In the stratosphere, the second priority is to better understand the mechanisms of particle growth and formation. Such knowledge allows many particle characteristics to be calculated under perturbed circumstances since well-developed models of stratospheric aerosols exist. In the troposphere, the complexity of the aerosols does not permit elaborate models to be successfully constructed at present. Hence, the second priority for tropospheric aerosols is to determine their sources and sinks. Such knowledge would allow assessment of the contributions by human activity in creating aerosols and it would help to unravel how each component of the complex mixture of aerosols in various sampling locations came to be present.

Table 3 also provides a listing of the minimum data sets that need to be collected to provide adequate information in a given area, examples of currently available instruments for measuring a given variable, and directions of emphasis of future instrument development. Several comments are relevant about this portion of table 3. First, various offices of NASA have helped to support in-house and outside scientists, who have been studying the atmosphere with many of the devices listed in the fourth column. ACE will focus these efforts in an integrated manner described in the next section. Second, there are several areas in which instrument development work is needed. One of these is the development of instruments — both in situ and collectors — that avoid possible problems associated with volatile aerosol species.

Coordinated Sets of Experiments- In the past, most observations of atmospheric aerosols have consisted of determinations of only a few of their

TABLE 3.- PRIORITIZED LIST OF REQUIRED AEROSOL CHARACTERISTICS

Aerosol type	Information	Minimum data set	Example of measuring devices	Instrument development needed
Stratospheric	1. Radiative	Optical depth	SAM II and SAGE occultation exp.	More wavelength channels
	Properties	Major composition	Collection and lab chemistry	*In situ* devices
		Visible absorption coefficient	Collection and lab transmission measurement	Ibid
		Size distribution	Collection and lab microscopy	Ibid and new satellite sensor
		Phase function	*In situ* scattering exp.	-----
		Morphology	Collection and lab microscopy	-----
	2. Aerosol formation and growth mechanisms	Precursor gases	Gas collection and lab analysis	Satellite simult. gas/aerosol capabilities
		Condensation nuclei	CN counter	High-altitude flight capability
		Aerosol composition	See item 1	
	3. Sources of material volcanic effluents	Precursor gases	See item 2	
		Aerosol composition	See item 1	
		Vertical fluxes	Tracer vertical profiles	
	Troposphere-stratosphere interchange		Airborne lidar	
	4. Transport of source material and aerosols in stratosphere	Horizontal fluxes	Tracer horizontal profiles	Shuttle lidar
			SAM II, SAGE, airborne lidar	
Troposphere	1. Radiative properties	See item 1 under stratosphere, lidar soundings from the Space Shuttle		
	2. Sources and sinks	Production rates	Tracer profiles	
		Elimination rates	Tracer profiles	
	3. Transport	See item 4 under stratosphere		
	4. Growth and formation	See item 2 under stratosphere		

properties at a given time. In order to obtain the information needed to assess aerosol effects on climate, all relevant properties need to be measured at the same time and place. Thus, for example, if one is interested in obtaining the radiative properties of stratospheric aerosols, a group of experiments that measure such properties as size distribution, chemical composition, and scattering characteristics should be flown on an aircraft operating in the stratosphere. At the same time and location, information on the vertical distribution of the aerosols can be obtained with a lidar system carried on an aircraft flying in the upper part of the troposphere and/or a balloon ascending through the stratosphere. Finally, these measurements can be timed to coincide with optical depth measurements being obtained by the SAGE experiment.

Theoretical and Laboratory Work

Collecting data is an insufficient exercise in itself when answering the scientific questions of interest. What is the climate impact of various natural and anthropogenic sources of atmospheric aerosols? Observational efforts need to be supplemented by relevant laboratory and theoretical work.

The laboratory work is directed primarily at simulating the formation of secondary aerosols, especially sulfate aerosols, under controlled conditions. It will aid in the development of a predictive capability for determining the change in aerosol properties under perturbed conditions. Other important areas of laboratory studies include measurements of scattering by nonspherical particles and aerosol optical constants.

The final synthesis of the observational and laboratory data will be realized through a series of sensitivity studies and impact experiments implemented with the aid of one-, two-, and three-dimensional numerical models. These models will include, to varying degrees, radiative effects of the aerosols, dynamical transport, and the formation and growth processes of secondary aerosols.[6] For the purpose of testing the response of climate models to aerosols, the observed properties of volcanic aerosols will be incorporated into general circulation models such as the Goddard Laboratory for Atmospheric Science (GLAS) GCM, and the predicted changes in atmospheric characteristics compared against variations observed during a natural volcanic eruption. These efforts must be integrated into a comprehensive systematic study of the sensitivity of climate to all relevant processes and parameters (including clouds, precipitation, air/sea interactions, and others) to be conducted within the NASA Climate Research Program. For the purpose of assessing aerosol effects on remote sensing schemes, the observed and deduced aerosol properties will be incorporated into radiative transfer programs to perform sensitivity tests and, when necessary, the remote sensing scheme will be appropriately modified. Finally, the observed radiative properties of the stratospheric and tropospheric aerosols will be used in a variety of models ranging from one-dimensional heat balance models to GCM's to assess their current impact on climate. Through validating aerosol formation models, especially for the

[6]Much work remains to be done on the theory of formation of secondary aerosols.

stratospheric aerosols, a "predictive" capability will be gained to allow similar assessments to be made for past and future situations.

In order to carry out these final steps towards realizing the study objectives, some model development will be required. One-dimensional radiative-convective models have already been extensively developed, but additional research is still required in the modeling of scattering by nonspherical particles. The two- and three-dimensional models are currently at an intermediate state of development. Future development includes improved parameterizations of certain physical processes, such as cloud formation, so that key feedback effects can be properly included in the calculations. Finally, much work is needed to understand the origin of the aerosols. For example, both laboratory and theoretical studies of sulfate aerosol formation are at a very incipient stage, with promising developments taking place, but with basic differences among various investigators on such key issues as the nucleation mechanism most relevant for stratospheric aerosols. Table 4 provides a summary of the scope of the envisioned laboratory and theoretical components of ACE.

TABLE 4.- SCOPE OF THEORETICAL AND LABORATORY ACTIVITIES

Laboratory studies of material properties and aerosol formation mechanisms
• Gas-to-particle conversion
• Scattering by nonspherical particles
• Aerosol optical constants
Theoretical studies
Model development
• Aerosol formation and growth
• Radiative transfer (scattering by nonspherical particles)
• Dynamical feedback effects
Data analysis
• Model validations from comparisons with the effects of a volcanic event
• Assessment of past, present, and future impact of aerosols

Coordination With Satellite Observations — Timing

During the first several years of the study, emphasis will be placed on stratospheric aerosols, both to complement the information that will be obtained beginning in the fall of 1978 from satellite observations, and to provide the capability for reacting in a timely fashion to a volcanic event. During FY 79 much of the activities of ACE will be directed towards the initial development of needed instruments. During the same time period, limited but useful sets of data will be collected by the satellite ground truth program. In FY 80, the major observational portion of ACE will commence. It is essential that early planning lay the foundation for the development of needed instruments and analysis capabilities. Such timely action will promote the maximum utilization of the aerosol data provided by the SAM II and SAGE satellites. These data, when combined with the *in situ* and laboratory results of ACE, will provide the comprehensive set of information needed to address climate questions involving stratospheric aerosols.

In order to prepare for the information expected from a future Space Shuttle lidar about tropospheric aerosols, incipient studies of these aerosols should commence and an adequate set of measurement capabilities should be developed and deployed over the next several years. During this period, a gradual switch in emphasis from stratospheric to tropospheric aerosols will occur.

Table 2 summarizes the time intervals and efforts that will characterize the stratospheric and tropospheric portions of ACE. A number of field studies will be required for both the tropospheric and stratospheric aerosols so as to obtain an adequate body of information on the temporal and latitudinal variations of aerosol properties to provide a sound basis for analysis and to provide a useful response in the case of a volcanic perturbation.

Response to a Volcanic Event

Because one cannot predict when or where the next major injection of material into the stratosphere by a volcanic explosion will occur, it becomes difficult to set up a program based solely on the desire to exploit this opportunity. The development of a vigorous program to study the present stratosphere will provide the tools necessary to fully exploit the opportunity to study the time evolution of the stratospheric aerosols subsequent to such an event. Also, by carrying out a continuous long-term program of studying stratospheric aerosols, information will be available on aerosol characteristics prior to the volcanic explosion, so the change in these properties can be accurately determined and used to model their climatic effects.

We envision the following response to a volcanic perturbation. A team of volcanologists and atmospheric scientists will be available and prepared to leave for the eruption site as soon as news of the eruption is received. As described more fully below, they will conduct measurements on the ground and in the air close to the volcano. Aircraft and balloons will be flown through the spreading volcanic veil and in conjunction with the satellite data sets to accurately determine the temporal evolution of stratospheric aerosol properties. Note that the veil is expected to spread with extreme rapidity in the zonal direction, but more slowly latitudinally. Finally, these efforts will be coordinated with, and supplemented by, meteorological data sets being assembled by other groups to provide information on possible changes in the state of the atmosphere due to the volcanic perturbation.

The above information will provide the basis for testing climate models. It will also enhance our understanding of the nature of volcanic perturbations so possible past and future climatic effects of multiple volcanic explosions can be assessed. In part, the latter objective will be realized by determining the temporal evolution of the radiative properties of the stratospheric aerosols and by measuring parameters that permit the testing and further development of stratospheric aerosol formation models. In addition, atmospheric and geological measurements made close to the volcano will be useful for studying further the gas-to-particle conversion process, investigating the physics of explosive events, and obtaining a complete inventory of gaseous and particulate materials emitted by the volcano. Similar investigations at other volcanoes displaying less spectacular explosive phases may lead to generalizations on the above processes and assessments of the variability in the properties of materials that volcanoes inject into the stratosphere.

Organization

Figure 1 provides a summary of the proposed organization of the ACE special study. It defines the internal and external OSTA interfaces and study elements. A key element in this organization is the Science Working Group, which will periodically review the progress made to date, provide scientific guidance, and assess plans for future research emphasis. This working group will be composed of scientists from universities, NASA, and other federal agencies with expertise in aerosols and other disciplines of concern to ACE (e.g., volcanologists, climatologists, atmospheric scientists).

Relationship to Studies by International Organizations, the United States and Other Government Agencies

NASA should avoid duplication of the efforts already underway by other organizations to study the characteristics of atmospheric aerosols. Therefore, we are emphasizing areas where gaps exist, such as coordinated studies of stratospheric aerosols, and are pointing out situations where NASA might augment existing programs, as indicated below.

There are a number of coordinated programs that are "zeroing-in" on various aspects of the aerosol/climate problem. The aforementioned JOC Working Group on Aerosols and Climate, for example, has developed specific recommendations to GARP. These state that the aim of the GARP aerosol program should be the establishment of global observations of sufficient resolution in space and time and adequate instrumental capabilities to provide the necessary base for climate modeling. The activities described in tables 2-4 are in consonance with the JOC recommendations and this kind of coordination will help drive the NASA efforts including its satellite observational programs.

In addition, there are a number of ongoing intensive aerosol measurement programs supported by other Federal agencies, universities and research organizations. For example, NSF is supporting attempts to measure properties of tropospheric gases and aerosols on a global scale using aircraft; DOE is assessing the properties of particles generated by power plants; EPA is studying the aerosol component of pollution; the University of Arizona has organized a ground-based program for studying tropospheric aerosols; and SRI International is conducting a study of tropospheric aerosols in the boundary layer from an instrumented tower. As part of ACE, NASA may augment some of these programs by supporting investigators who can supply needed instruments or additional analysis capability and by supplying useful additional platforms.

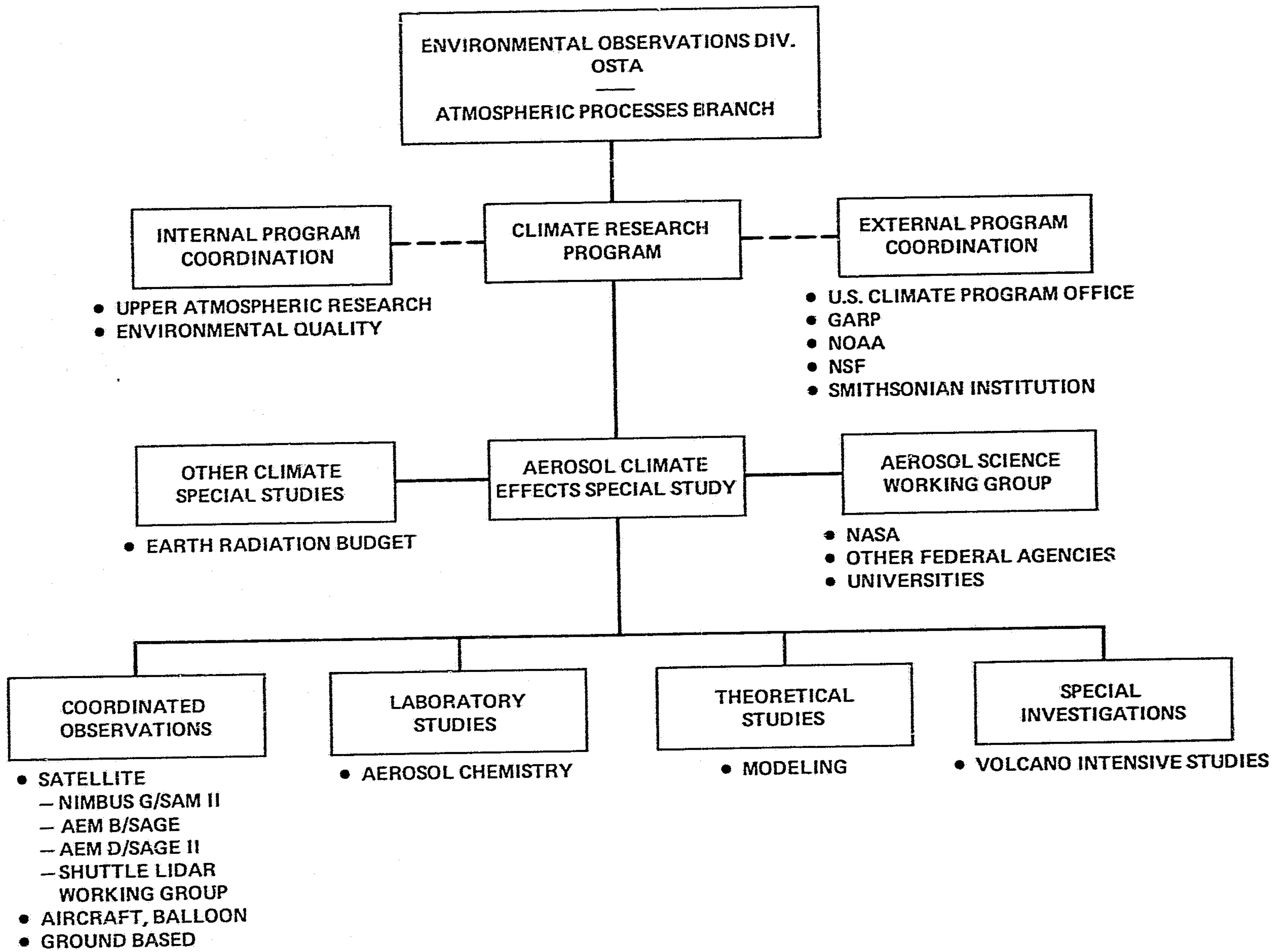


Figure 1.- Aerosol climate effects special study organization.

Relationship to Data Set Activities

In an effort to make the information collected about the Earth's climate available to the science community in a useful and easily accessible format, NASA is organizing broad, climate data set-related activities. These activities will consist of assembling the data from measurements made from NASA satellite platforms along with complementary data obtained as part of the ACE study. This general approach has been adopted with regard to the Nimbus 7 payload (SAM II is one sensor onboard) and SAGE where their respective science teams have developed data formats and validation plans for archiving the satellite and ground truth data at the National Space Science Data Center, Goddard Space Flight Center, Greenbelt, Maryland. In addition, the science teams will demonstrate the initial usefulness of the data sets with limited investigations, some of which are directed to aerosol/climate problems. The data sets will be available to the general science community upon their validation (approximately 6 months after launch).

Advanced Program

Outlined above are areas that warrant emphasis in the next several years based on current knowledge of requirements. In doing so, judgments have been made on the basis of planned satellite activities and the ease of carrying out the task. The approved FY 79 NASA aerosol related research program is summarized in appendix D. Present capabilities and knowledge should be reviewed and iterated by the aerosol and climate science community in order to define future thrusts in development of measurement techniques and their understanding. One key area not touched upon by the plan as outlined above is the possible effect of aerosols on cloud characteristics. This topic will be addressed at a later time by ACE and coordinated with the other relevant climate special studies being formulated (e.g., Radiation Budget). Thus, the special study may progress from emphasizing stratospheric aerosols to tropospheric aerosols, and finally to tropospheric aerosols/water/ice clouds. In so doing, it would lead to increasingly more complicated situations, taking advantage of the lessons learned from earlier phases of the study.

APPENDIX A

OVERVIEW OF SAM II GROUND TRUTH EXPERIMENT SCHEDULE

Observation	1[a]	2	3	4[b]
Approximate date	Sept. 25-28 1978	Late Nov. 1978	Mid-Dec. 1978	Late May-early July 1979
Site	Laramie, WY	Sondrestrom, Greenland	Palmer, Antarctica	Sondrestrom, Greenland
Lat.	41° 18' N	67° 01' N	64° 46' S	67° 01' N
Long.	105° 42' W	50° 43' W	64° 03' W	50° 43' W
Airborne lidar	1 flight	8 flights	7 flights	8 flights
Staging site	Laramie	Sondrestrom	Rio Grande, Argentina	Sondrestrom
Dustsonde	1 flight	2 flights	----	2 flights
Balloon sunphotometer	1 flight	1 flight	----	1 flight
Radiosonde	2 flights	16 flights	----	16 flights
Airborne *in situ* observations	1 flight	8 flights	----	8 flights

[a]Practice comparative experiment.

[b]SAM II - SAGE comparisons.

APPENDIX B

SAGE GROUND TRUTH EXPERIMENT SCHEDULE

(To be supplemented by Ad Hoc Ground Truth Groups and others as appropriate)

Experiment	1	2	3	4	5	6	7	8
Approx. date	Late Feb. 1979	Late Feb. 1979	Late Feb. 1979	(Sunrise-sunset)	Late May-early June 1979		Sept. 1979	Dec. 1979
Cluster	C1	C2	C3	C2	C4	C5	C2	C2
Sites	Laramie Boulder	Wallops I. Hampton	Albuquerque White Sands Palestine	Wallops I. Hampton	Sondrestrom	Fortaleza Natal	Wallops I. Hampton	Wallops I. Hampton
Latitude Longitude	40°- 41° N 105°-106° N	37°-38° N 75°-76° W	32°- 35° N 96°-107° W	37°-38° N 75°-76° W	67° N 51° W	3°- 5° S 35°-38° W	37°-38° N 75°-76° W	37°-38° N 75°-76° W
P3 lidar	x	x	x	x	x	x	x	x
P3 spectrom.	x	x	x	x	x	x	x	x
Langley lidar		x		x			x	x
NCAR lidar	x							
Dustsonde (+O_3)	x				x	x	x	x
O_3 balloon	(NCAR)	x	x	x	x	x	x	x
O_3 rocket		K,H		H(2)	K	K	K	K
Murcray balloon spectrometer			x					
Pepin balloon (phot and spec)	x				x			
LIP			x					
Noxon spec	x							
Dobson	x	x	x	x		x	x	x
Double monochrom	x							
Schmeltikopf	x							
NCAR Sabreliner[a]					x			

[a]Includes polar nephelometer, quartz crystal microbalance, and possibly Dasibi O_3 sensor.

APPENDIX C

INITIAL SAM II AND SAGE SCIENTIFIC INVESTIGATIONS

Investigator	Objective	Approach
Herman	• Determine influence of polar stratospheric aerosol on the Earth — atmospheric radiation budget	• Use Radiative Transfer and Radiative Equilibrium models to determine perturbation on radiation field and temperature
Grams	• Determine stratospheric heating rates	• Use SAM II aerosol profiles, optical properties and albedo to generate heating rates
Pepin	• Identify sources and sinks of aerosols	• Use SAM II seasonal and transient data with software to recognize events
Grams	• Develop improved optical model of stratospheric aerosols	• Use of SAM II and correlative measurements
Grams	• Determine occurrence and extent of nacreous and noctilucent clouds, circumpolar dust layers and extra terrestrial dust particles	• Develop software to recognize these layers with aid of correlative data and other data sets

APPENDIX D

NASA-SUPPORTED STUDIES OF AEROSOLS IN FY 79

This appendix summarizes the aerosol research that NASA is currently supporting with SR&T funds and indicates how they help meet the guidelines for aerosol climate research set forth in this document.

NASA funds a wide range of observational, laboratory, and theoretical studies of aerosols. Such studies are intended to meet the objectives of several programs within NASA. These include assessments of the climate impact of stratospheric and tropospheric aerosols, understanding the role aerosols play in the chemistry of the stratosphere, evaluating the aerosol component of pollution, and determining their composition and mode of formation. In practice, a given investigation contributes to several of these objectives and, indeed, many of them have relevance to climate studies and are therefore discussed further below.

In addition to these continuing investigations, FY 79 funding has been allocated by the NASA Climate Program to commence an Aerosol Climatic Effect (ACE) Special Study. The Special Study involves coordinated aerosol experiments that are jointly flown on the U-2 aircraft, together with supporting theoretical and laboratory studies. The aircraft will fly near the peak of the stratospheric aerosol layer and provide complementary information on both the radiative properties and formation of these aerosols to that being obtained by the SAM II and SAGE satellite sensors. During FY 79 Special Study funding will be used chiefly to develop certain instruments and sample analytical procedures so that intensive observations can begin in FY 80.

Table 5 summarizes both the continuing SR&T work on aerosols and the component studies of the Special Study, with the latter being indicated by superscripts. The separate investigations have been organized into general categories in order to better relate them to ones recommended in the guidelines. For each investigation, a brief description is given together with the principal investigator and his/her home institution. As can be seen, investigators from NASA centers, universities, and other research organizations are involved in these efforts. Table 6 and the footnotes to table 5 provide a more detailed description of the various experiments that are part of the Aerosol Special Study program.

Tables 5 and 6 are useful in assessing the ways in which the current SR&T aerosol program meets the guidelines given in this document. As noted earlier, a major initiative is the commencement of the Special Study. As can be seen from table 6, the coordinated experiments to be flown on the U-2 aircraft, in conjunction with the data from the SAGE and SAM II satellite sensors, will provide a comprehensive data set for addressing climate problems involving stratospheric aerosols. A number of these instruments are to be built in FY 79 so as to insure that almost all of the proposed instruments are available in a timely fashion. The U-2 suite of aerosol experiments will also be available to react quickly to a major volcanic perturbation to the stratosphere.

TABLE 5.- AEROSOL CLIMATE INVESTIGATIONS SUPPORTED IN FY 79 BY NASA SR&T PROGRAMS

Description	Principal investigator(s)	Institution
Observations		
Ground and A/C lidar	McCormick	NASA LaRC
Ground lidar	Fernald	U. Denver
Balloon aerosol sampling	Hoffman/Rosen	U. Wyoming
A/C particle collection/analysis	Cadle	NCAR
Balloon/AC particle collection/chemical analysis[a,b]	Lazrus	NCAR
Chemical composition analysis	Sedlaeck	LASL
Airborne aerosol sampling/size and composition analysis[a,c]	Farlow	NASA ARC
Gas sampling/analysis[a,d]	Inn	NASA ARC
Aerosol absorption in situ composition[a]	Charlson	U. Washington
In situ aerosol size[a]	McCormick	NASA LaRC
Aerosol phase function[a]	Grams	Georgia Tech.
Small-particle size distribution[a,c]	Whitby	U. Minnesota
Satellite instrument development		
Shuttle lidar[e]	Browell/Harris	LaRC
Stratospheric aerosol sensors[e]	McCormick	LaRC
Aerosol formation - laboratory/theoretical		
Heterogeneous chemistry/particle formation	Castleman	U. Colorado
Heterogeneous chemistry	Golden	SRI
One- and two-dimensional aerosol formation/growth model[f]	Pollack, Whitten, Toon	NASA ARC
Two-dimensional aerosol model	Kiang	Georgia Tech.
Two-dimensional aerosol model	Remsberg	LaRC
Theoretical radiative transfer/dynamics		
One-, two-, and three-dimensional aerosol climate models[a,g]	Pollack	NASA ARC
GCM climate model	Hansen	NASA GISS
Analysis atmospheric transmission data	Angione	San Diego State U.
Strategies for remote detection of aerosols[h]	Holland	NASA WFC
Radiation transfer theory	Fymat	JPL

See Footnotes on next page.

TABLE 5.- CONCLUDED

Footnotes

[a]Part of the Aerosol Special Study Program (Pollack - P.I.).

[b]Continuing investigation. During FY 79 his filter collectors will be mounted on the U-2.

[c]Continuing investigation. During FY 79, he will be funded from the special study to investigate Raman spectroscopy for performing chemical analyses.

[d]During FY 79, he will be funded from the special study to develop gas chromatography techniques for measuring gaseous precursors of the stratospheric aerosols.

[e]Funding status in FY 79 is uncertain.

[f]Collaborators.

[g]Research includes the development of a method for treating scattering by nonspherical particles. The theoretical models will be used in subsequent fiscal years to assess the climatic impact of the stratospheric aerosols, using the data collected by the various special study experiments.

[h]Also performing laboratory measurements of the scattering properties of nonspherical particles.

TABLE 6.- U-2 INSTRUMENT PACKAGE

P.I.	Instrument	Variable measured	Method[a]	Range	Status[b]			Area	
					Instr.	A/C	Lab	Radiative properties	Aerosol formation
Neil Farlow, NASA-Ames	Wire collector	Particle size, morphology	Electron microscope (L)	≥0.1 µm	F	IN	F	X	
	Film collector	Particle composition	Raman spectroscopy ion microprobe, x-ray diffractometer, electron microprobe and scope (L)	Elemental abundances including C; major compounds	F	IN	D-'79	X	X
Allen Lazrus, NCAR	Multiple filter collector	Particle composition	Wet chemistry (L)	Anion, cation abundances	F	MT-'79	F	X	X
Robert Charlson	Integrating nephelometer	Scattering cross-section	Light scattering (IS)	≥ several × 10^{-8} m^{-1}	D-'79	MT-'80		X	
	Glass collector	composition	Heat inlet (IS)	Volatile species ~5%	D-'80	MT-'81		X	X
		Absorption coefficient	Transmission (L)		F	MT-'79	F	X	
M. Patrick McCormick, NASA-Langley	Quartz microbalance	Particle size	Impactor separation, weight (IS)	≥0.05 µm	F	MT-'79		X	
Kenneth Whitby, U. of Minn.	Charge analyzer	Particle size	Charge separation, CN counter (IS)	0.01 - 0.3 µm	D-'79 '80	MT-'80		X	X
Edward Inn, NASA-Ames	Cryogenic collector	COS, SO_2, and other sulfur gases	Gas chromatograph (L)	≥ few parts per trillion	F	IN	D-'79	X	X
Gerald Grams, Gerogia Tech.	Polar nephelometer	Particle phase function	Light scattering (IS)	5-175° scattering angle	D-'79	MT-'80		X	
	Spectrophone	Particle absorption	Acoustic (IS)		D-'80			X	

[a]After each method, the letters "L" or "IS" in parentheses denote laboratory analysis is performed on collected sample and in situ measurement, respectively.

[b]The column headings are: Instr. for instrument, A/C for aircraft installation, and Lab for laboratory analysis. Under each column, the state of readiness is indicated, with "F," "IN," "MT," and "D" referring to the instrument is finished, the instrument has been installed on the U-2, it needs to be mounted on the U-2, and requires development, respectively. In cases where work is needed, the fiscal year when this will occur is indicated.

A number of the other observational efforts listed in table 5, aside from ones involved in the special study, will complement the data obtained from the U-2. For example, the A/C lidar of McCormick and the balloon experiment of Hoffman and Rosen will provide some data at altitudes above that sampled by the U-2. Efforts will be made to fly the U-2 in coordination with some of these other observational capabilities.

As summarized in table 5, McCormick will be developing more sophisticated sensors for studying stratospheric aerosols from satellite platforms, while Browell and Harris will be investigating the feasibility of mapping tropospheric aerosols from the Space Shuttle. These efforts will provide a basis for the more advanced aerosol satellite measurements listed in table 2 of the main test of the guidelines.

The laboratory and theoretical studies of aerosol formation will provide the basis for determining critical experiments to be conducted in some of the observational investigations. Interactions between these two parts of the program ultimately will lead to a verified model of aerosol formation and growth that can provide the basis for extrapolating measurements of the aerosols' present properties to past and future situations.

The other theoretical efforts listed in table 5 will provide an analysis capability for making the climate aerosol assessments, given data provided by the observational program. In addition, these studies will also make available some past characteristics of the aerosols and provide a theoretical basis for more sophisticated ways of extracting aerosol information from remote-sensing observations of their radiative interactions.

In an effort to insure coordination between various parts of the aerosol climate program, the science working group being formed for the special study will include representatives from the satellite aerosol experiments and other aerosol measurement programs, and a number of scientists involved in theoretical and laboratory studies of aerosols.

Thus, the aerosol activities being supported by NASA's SR&T program have all five of the basic elements of the ACE subprogram given on pages 6 and 7 of the main text. They also address the higher priority items given in tables 3 and 4 of the main text.