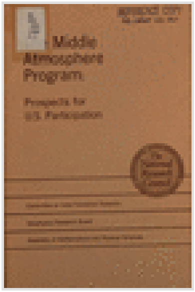

The Middle Atmosphere Program: Prospects for U.S. Participation (1980)

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THE MIDDLE ATMOSPHERE PROGRAM:

Prospects for U. S. Participation

Panel on the Middle Atmosphere Program
Committee on Solar-Terrestrial Research
Geophysics Research Board
Assembly of Mathematical and Physical Sciences
National Research Council

NATIONAL ACADEMY OF SCIENCES

Washington, D.C. 1980

NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the Committee responsible for this report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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PREFACE

The Middle Atmosphere Program (MAP) is an international cooperative enterprise scheduled for 1982-1985. Its chief objective is to obtain a comprehensive understanding of the structure, chemistry, energetics, and dynamics of the middle atmosphere. For the purposes of MAP, the middle atmosphere is defined to be the atmosphere from the tropopause to the lower thermosphere, that is, the region from about 10 km to 100 km in altitude. The factors enumerated above all interact with each other in such complicated ways that the study of each of them in isolation leads to unreliable or even anomalous results. This can be remedied by more integrated and unified attack--specifically by the coordination, in time and location, of observations of the various factors, and by cooperation in the interpretation of the results. This is the rationale for MAP.

The operational basis for MAP is an international plan for coordinated observations from spacecraft, ground-based facilities, aircraft, balloons, and rockets. It is based largely on what is already planned for 1982-1985, but also entertains the hope that participating countries will be able to complement the program with relatively inexpensive but important additions. The MAP plan also encourages cooperative data management, information exchange on all appropriate time scales, and interaction between observationalists, modellers, and theoreticians.

At the international level, the development of the plan for MAP is the responsibility of the MAP Steering Committee, established in 1977-78 under the auspices of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP) of the International Council of Scientific Unions (ICSU). The four international scientific unions concerned with the physical environment, the ICSU Committee for Space Research (COSPAR), and the World Meteorological Organization are all represented on the MAP Steering Committee. In 1978, ICSU recognized MAP as an important international program and commended it to the attention of its national members (academies, research councils, and similar representative institutions) and of their respective constituencies.

The complete development of the international plan depends on what programs each participating country can contribute to the global scheme. The MAP Steering Committee has therefore requested each participating country to prepare a report on the nature of its prospective participation; for example, what specific problems interest its scientific constituency; what the opportunities for participation will be (e.g., existing or planned individual research programs that can be coordinated with MAP to the benefit of all); and related matters.

The present report is the first U.S. response to the challenge of MAP. It was drafted by the Panel on the Middle Atmosphere Program established in 1978 by the Committee on Solar-Terrestrial Research (CSTR), which serves as the U.S. national committee for SCOSTEP. We are grateful to the some scores of specialists who have contributed to the report, which has been reviewed and approved by the CSTR in its present form. It approaches the goals of MAP mainly through a definition of the scientific problems to which research in the U.S. can contribute, with notes on the techniques appropriate to attacking those problems.

The practical aspects of implementing MAP will be the subject of a later report.

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1 SUMMARY OF RECOMMENDATIONS

In response to the invitation from the International Council of Scientific Unions to all countries to participate in the global Middle Atmosphere Program (MAP) in 1982-1985, the Committee on Solar-Terrestrial Research of the National Research Council's Geophysics Research Board, on the proposal of its Panel on MAP, recommends that the United States participate with a coordinated research program of ground-based, balloon, rocket, and satellite observations that includes such missions as the Upper Atmosphere Research Satellites and Space Shuttle sorties. Specifically, we recommend:

1. That a national MAP coordination office be established within an appropriate lead U.S. agency to act as a focal point for planning, implementing, and coordinating a U.S. program for MAP both among the agencies concerned and between those agencies and the scientific community at large. (See Section 2.4 for details.)

2. That the U.S. support the efforts of the international MAP Steering Committee to establish mechanisms for the collection and exchange of information and data on all appropriate time scales. (See Section 2.5 and 3.2 for details.)

3. That the U.S. scientific community in cooperation with the U.S. agencies concerned review the following areas (see Section 3.1 for details) in deciding what investigations to pursue, as these appear to be the areas in which the U.S. can make the most fruitful contributions: Ozone climatology; stratospheric composition; mesospheric composition; basic climatology of the middle atmosphere; planetary waves in the middle atmosphere; equatorial waves; tides, gravity waves, and turbulence; troposphere-stratosphere coupling; the influence of middle-atmospheric conditions on lower-level climate; aerosol forma-

tion and properties; solar radiation, especially in the ultraviolet; the effects of energetic particles and x-rays on the middle atmosphere; ion composition; and the electrodynamics of the middle atmosphere. These fourteen areas have been tagged observational or experimental "MAP initiatives" (MIs) and numbered for ready reference.

4. That theoretical studies and modeling be supported. (See Section 3.2, MI-15).

5. That a program of balloons and rockets that are still required for certain kinds of *in situ* observations and the launch facilities to go with them be supported. (Examples of the need for *in situ* observations will be found in eleven of the fourteen observational MAP initiatives referred to in Recommendation 3 above and described in Section 3.1, with special emphasis in MIs numbered 1, 2, 3, 4, 6, 7, and 13. Section 3.2, MI-16, contains a summary statement on *in situ* observations.)

2
OVERVIEW

2.1 INTRODUCTION

The middle atmosphere is defined as the region extending upward from the tropopause to the lower thermosphere, or from roughly 10 to 100 km altitude. As such, it includes the stratosphere and the mesosphere, and it has long been recognized as the region of the atmosphere about which our knowledge is most deficient. Meteorologists have always been primarily concerned with the troposphere, which is the domain of the weather systems that directly influence man's everyday activities. Aeronomers, on the other hand, have until recently been mainly involved in problems of the thermosphere (above ~85 km), an interest that largely derived originally from the practical aspects of ionospheric radio propagation. No well-defined group of scientists claimed the middle atmosphere as their domain, although it had more than marginal interest for both meteorologists and aeronomers. Difficulties have always been compounded into this situation by the relative inaccessibility of the region to direct *in situ* measurements, in contrast to the troposphere, which can be studied by simple balloon techniques, and the thermosphere, which in recent decades has become accessible to satellites. While the lower stratosphere can be reached by relatively uncomplicated balloon techniques, the upper stratosphere and the entire mesosphere have been directly probed only by very large balloons and by rockets, which have several disadvantages, including high cost per observation, intermittency, and inevitable disturbances of the ambient environment.

Within recent years, remote-sensing techniques have been developed that allow satellites to probe the middle atmosphere with much improved but still limited vertical and horizontal resolution, with, however, the great advantage of global coverage; and ground-based remote-sensing techniques now permit very good resolution indeed. Coupled with this technological advance has grown the realization that the middle atmosphere is a region of direct practical concern to man. Studies of the influence of proposed supersonic transport fleets on the stratosphere led in the early 1970's to a major concern for the future of the ozone layer, which protects the entire biosphere from the potentially harmful ultraviolet radiation of the sun. This concern was given a dramatic impetus by later predictions that other human activities, including the increasing use of chlorofluoromethanes and even of artificial fertilizers, might pose an even larger danger to stratospheric ozone. The growing interest in climate and in the potential effects of climatic change on the world economy has also led to the realization that the middle atmosphere is an integral part of the climate system, and one about whose influence we know very little.

Three key elements needed to stimulate an area of scientific research thus exist: a growing public concern with a practical problem, an international body of scientists with the relevant interests and expertise, and major new technological advances. The principal objective of the Middle Atmosphere Program (MAP) is to provide an organizational framework around which a coordinated international attack on the unsolved problems of the middle atmosphere can be built.

MAP has now received recognition from the International Council of Scientific Unions (ICSU) as an approved international program, and responsibility for its development and operation at the international level rests with the ICSU Scientific Committee on Solar-Terrestrial Physics (SCOSTEP). The corresponding responsibility within the U.S.A. for development and operation of the U.S. contribution to MAP rests with the National Academy of Science's Geophysics Research Board through its Committee on Solar-Terrestrial Research (CSTR), which is the national body corresponding to SCOSTEP.

Recognizing that the satellite remote-sensing techniques are a central element of MAP, the SCOSTEP Steering Committee for MAP at its first meeting in 1978 selected the four-year period 1982-85 as the main phase of MAP. This period was chosen to coincide with the expected full implementation of the Space Shuttle program, which would involve the use of sophisticated multi-user remote-sensing facilities on short-duration manned space flights, and with the launch of the proposed Upper Atmosphere Research Satellites (UARS), which are currently just beyond the definition phase, and will carry payloads dedicated to middle-atmosphere remote sensing. In order to take advantage of remote-sensing satellites that will be launched before the initiation of MAP itself, the MAP Steering Committee has called for a series of preparatory or preliminary MAP projects (PMPs) that involve the coordination of rocket, balloon, and ground-based measurements with spacecraft observations. Several of these PMPs have been initiated by the MAP Steering Committee and four are described later. They will utilize principally Nimbus 7 (launched October 1978), the Stratospheric Aerosol and Gas Experiment (SAGE, launched February 1979), and the Solar Mesosphere Explorer (scheduled for launch in 1981, with a partial overlap with the main MAP time period).

The purpose of this document is to outline some of the chief scientific problems that need to be attacked within the framework of MAP, and to provide guidelines for development of a national contribution to MAP. Many of the key programs will be implemented regardless of the existence of MAP, whose principal goal is to attempt to maximize the scientific output from these large and expensive programs by ensuring that the necessary smaller programs are adequately recognized, funded, and coordinated. Of particular importance in this regard are rocket, balloon, and ground-based measurements. Often such measurements can provide a significant enhancement in the scientific output from a satellite experiment for a small fractional increase in cost; yet too often in the past their importance has been ignored.

Ultimately, the U.S. MAP program will depend on the individual proposals of scientists and on the availability of funds to support middle-atmosphere research. The areas in which such proposals and funding are most needed are discussed in this report.

2.2 RELATIONSHIP OF MAP TO EXISTING OR PLANNED PROGRAMS

A number of national and international programs concerned with the atmosphere have been initiated or planned within recent years. In order to provide some perspective, mention should be made of the relationship between these programs and MAP.

In terms of international scale of effort, the Global Atmospheric Research Program (GARP) is the largest. The chief concern of GARP, however, is with the troposphere, and the middle atmosphere has not become an explicit concern. Since the middle atmosphere does play a significant role in the radiative balance of the earth-atmosphere system, and may be significant in affecting tropospheric long waves, its influence on surface climate is not negligible. MAP will thus serve to complement GARP in certain areas, particularly in relation to the GARP initiative on climate. The same rationale applies to the relationship between MAP and the National Climate Program, which is currently in the planning stages.

Much of the recent information on the properties and behavior of the stratosphere has been gained as a result of the Department of Transportation's Climatic Impact Assessment Program (CIAP), which was initiated as a result of early apprehensions about the potential effects of supersonic transport aircraft on the ozone layer. A continuing concern with effects of human activities on the stratosphere is being addressed by the Federal Aviation Administration's High Altitude Pollution Program (HAPP), and here again there is a complementary aspect. The ongoing HAPP effort is now building a base of data and results that will help to lay the foundation for several of the objectives of MAP.

The National Aeronautics and Space Administration's Upper Atmosphere Research Program is a major supporter of middle-atmosphere research and will have a direct interface with MAP. The objectives of UARP and those of MAP are very similar and close ties between the two programs are essential.

2.3 EXISTING PLANS FOR THE MAP PERIOD

The most important single development in middle-atmosphere research in the U.S. within the approved MAP time frame will be the launch of two Upper Atmosphere Research Satellites (UARS), assuming that the program receives final approval.

The two spacecraft will be launched with orbital inclinations of 56° and 70°, and each will carry instruments to make global measurements of temperature, winds, composition, solar flux, and radiance in the middle atmosphere and lower thermosphere. To a large extent the goals of MAP and of the UARS Program are identical, and an important aspect of the U.S. participation in MAP should be the provision of ground, balloon, and rocket programs that will complement the global measurements obtained by the UARS spacecraft.

An entirely different type of atmospheric research facility will be provided by the Space Shuttle, which will be able to carry heavy and complex instruments with high bit-rate requirements for short missions of one or two week's duration. Among the Shuttle Multi-User Facilities, the planned LIDAR and CLIR (Cryogenic Limb-Scanning Interferometer and Radiometer) instruments will be especially valuable for middle-atmosphere studies. Although individual Shuttle missions will be short, the program itself is likely to be of long duration, making it an ideal vehicle for an extended series of measurements of the solar flux at ultraviolet wavelengths, which is an important middle-atmosphere parameter.

On a smaller scale, the Solar Mesosphere Explorer (SME) is scheduled for launch in 1981 and will carry several instruments capable of measuring middle-atmosphere composition by remote sensing, with emphasis on the mesosphere and upper stratosphere. Again this spacecraft program will have many of the same objectives as MAP, and a coordinated program of ground, balloon, and rocket measurements should form an important MAP initiative.

The major objectives of these satellite programs will be the measurement of minor-constituent concentrations and of temperature fields by remote sensing. In extratropical regions, geostrophic winds can be deduced from the temperature fields, but any comprehensive study of middle-atmosphere winds and waves will require a considerable amount of additional information. In this area the recent developments in coherent (or Doppler) radar techniques should prove important. It is now possible to measure winds from the lower troposphere to the mesopause with good height resolution using high-powered radars, opening up a wide range of studies in atmospheric dynamics. By the time period of MAP, several radar facilities should be capable of measurements of this kind, and the coordination of their operations would be a significant goal for MAP.

2.4 NATIONAL MAP COORDINATION OFFICE

Although MAP is conceived as a program of basic research, its scope is such that it bears on the missions of several Government agencies. As a result, MAP-related activities within the U.S. are likely to take place in a piecemeal fashion as parts of individual agency programs. To avoid fragmentation and to ensure that these individual efforts are properly coordinated, it is essential that a lead agency for MAP be designated as soon as possible. Within this lead agency should be located a MAP Coordination Office, charged with the responsibility for continuing awareness of MAP-related programs within the U.S. and for ensuring that proper coordination of these programs takes place.

The MAP Coordination Office would have three principal functions:

It would act as the focal point for planning and implementing the U.S. Program for MAP. Some specific activities are:

(i) Provision of assistance to the MAP Panel of the Committee on Solar-Terrestrial Research of NAS/NRC in formulating the scientific objectives for the U.S. effort.
(ii) Development of program plans for new MAP initiatives that will attack existing unsolved problems that are uncovered.
(iii) Initiation of workshops and symposia in the U.S. for planning of MAP activities and for the discussion and evaluation of the results of MAP programs.
(iv) Designing and implementing plans for the handling and dissemination of MAP data gathered and supported by U.S. agencies.
(v) Coordination of information services for MAP within the U.S., in consultation with the World Data Center A's international MAP Information Office.
(vi) Provision of information to the U.S. scientific community regarding submission of proposals to government agencies for MAP-related research.

It would act as a resource for U.S. agencies on the scope of U.S. involvement in MAP. Some specific activities in this area are:

(i) Acting as liaison with other agency and interagency programs having a bearing on the objectives of MAP.
(ii) Acting as liaison with funding agencies and identifying areas in which budget requests need to be made.
(iii) Identifying contact points inside and outside the U.S. government for execution of MAP-related projects.

It would represent U.S. MAP-related activities in the international arena. Typical activities would include:
(i) Acting as an information resource to the international MAP Steering Committee of SCOSTEP.
(ii) Coordinating regional or bilateral scientific programs for MAP where these seem appropriate.
(iii) Coordinating proposals for U.S. workshops and symposia with the international MAP secretariat to avoid unnecessary overlap and time conflict, and to ensure appropriate international representation.

2.5 DATA AND INFORMATION: ARCHIVING AND EXCHANGE

One of the most important goals of MAP should be the provision of adequate mechanisms and facilities for exchange and dissemination of data. The existing World Data Centers have a natural role to play here, and in the U.S.A. NOAA's National Geophysical and Solar-Terrestrial Data Center at Boulder, Colorado, which houses the World Data Canter A for Solar-Terrestrial Physics, is already taking an active part in MAP planning.

Among the steps that have been taken or that are being planned by the MAP Steering Committee are the following:
(1) distribution of information on a regular basis through the medium of a MAP newsletter, to be published quarterly by World Data Center A for Solar-Terrestrial Physics, Boulder;
(2) establishment of a MAP Data Management Panel to provide continuing oversight of MAP data activities, including archiving, distribution, and preparation of data syntheses where appropriate;
(3) establishment of a MAP Data Bank for the initial purpose of locating and assembling primary data on geopotential height, temperature, and winds at pressure levels from 100 to 0.01 mb (about 15 to 81 km), suitable for compilation of time-averaged structure and of a series of synoptic maps of the middle atmosphere.

The U.S.A. will play a major role in these activities, since World Data Center A for Solar-Terrestrial Physics has already accepted the responsibility for publishing the MAP Newsletter, and since existing and planned U.S. spacecraft and other programs will be a primary source of much of the data.

2.6 PRELIMINARY OR PREPARATORY MAP PROJECTS

Since the main phase of MAP will not begin until 1982, and since a number of spacecraft and other major programs will come into existence before then, a series of preliminary or preparatory MAP projects (PMPs) is now being scheduled. Four of these were proposed by the MAP Steering Committee in June 1978, and brief descriptions follow. Additional PMPs will be proposed as opportunities arise.

PMP-1 A Coordinated Study of the Behavior of the Middle Atmosphere in Winter. The aim of this project is to study: (a) the interaction of planetary-scale waves of tropospheric origin with the mean flow in the stratosphere and mesosphere, (b) the role of the waves and the mean flow in transporting trace constituents, and (c) the effects of these waves on the electron and ion densities in the lower ionosphere.

The heart of the project will be the establishment of a meteorological data base that will permit the calculation of energy budgets, momentum and heat transports, and the transport of minor constituents by the large-scale motions. The main elements in the data base will be geopotential heights, temperatures, and winds from 100 to 0.01 mb, and the necessary maps are to be compiled in the first instance for the northern hemisphere winter seasons of 1978-79 and 1979-80, and if possible for the southern hemisphere winters of 1979 and 1980.

PMP-2 Equatorial Wave Dynamics. This project consists of a series of special observations of the equatorial stratosphere and mesosphere aimed at studying the large-scale equatorial waves associated with the semiannual and quasi-biennial oscillations. Spacecraft and rockets will be used to gather data on temperatures and winds, and the format of the data will take account of the special characteristics of these waves as compared to mid-latitude Rossby waves. The project was getting started in 1979, and will take advantage of the existence of Nimbus 7.

PMP-3 Study of Photochemical Processes in the Upper Stratosphere and Mesosphere by Complementary Spacecraft, In Situ, and Ground Measurements. This project seeks to take advantage of the various remote-sensing spacecraft that will be probing the middle atmosphere in the time period before 1982. Recognizing that the interpretation of chemical processes in the upper stratosphere and mesosphere is somewhat simpler than is the case for the lower stratosphere, the project has three aspects:

(1) to undertake comprehensive programs of direct comparison between satellite remote-sensing data and data obtained by other techniques in order to assess the accuracy of the satellite techniques;

(2) to perform coordinated experiments to provide simultaneous data on related minor species that are not measured by the satellite techniques;

(3) to obtain measurements of such fundamental parameters as the ultraviolet solar flux with the highest possible accuracy, and in compatibility with the available laboratory radiometric standards.

The project will be carried out using data from Nimbus 7 (launched 1978), SAGE (launched 1979), SME (scheduled for launch 1981), and early Spacelab missions.

PMP-4 Presentation of Meteorological and Chemical Variables in the Format of Monthly Mean Zonal Cross Sections. This project recognizes the need for information on the basic state of the middle atmosphere in the form of mean meridional cross sections of meteorological and chemical variables. Such information is required for verification of model calculations, and to provide improved background information for chemical, dynamical, and climatological studies.

Spacecraft experimenters would be requested to derive from their data monthly mean meridional cross sections of such parameters as temperature, horizontal and vertical wind velocities, and the more important minor constituents as well as their variances. The data would be available in hard copy or magnetic tape to any potential users.

3 GUIDELINES FOR A U.S. MAP PROGRAM

In June 1976 a MAP Planning Conference was held at the University of Illinois, and led to the publication of the *MAP Planning Document*. This contains an excellent survey of the outstanding scientific problems of the middle atmosphere as they existed at the time of the Conference. Few, if any, of these problems have disappeared since that time, although important advances have taken place, notably through the launch of Nimbus 7 in late 1978. It is still a little too early to assess the contributions that Nimbus 7 will make to our understanding of the structure and composition of the middle atmosphere, but they are likely to be substantial. The period since 1976 has also seen important advances in the use of the coherent VHF radar technique for studying middle-atmosphere dynamics, but again it is too early to assess the full impact of these developments.

The scientific problems of the middle atmosphere thus remain more or less as they are described in the *MAP Planning Document*, and there would be little point in duplicating that description here. To some extent, however, it is possible to forecast the areas in which major advances are likely to take place as a result of existing or planned programs between the time of writing and the mid-1980s. The principal objective of MAP should be that of filling the gaps that will otherwise exist between the planned programs and the needs of a complete program of middle-atmosphere research. Several such potential gaps have been identified, and should form the basis for MAP initiatives (MIs) as described below. Several of these initiatives have strong ties with PMP projects described above, and the PMPs can be thought of as early starts to the initiatives. For example, PMP-1 is linked to MI-5, PMP-2 to MI-6, PMP-3 to MI-1, -2, -3, and -11, and PMP-4 to MI-4 and -17.

3.1 OBSERVATIONAL OR EXPERIMENTAL MAP INITIATIVES

MI-1 Ozone Climatology. Although a minor chemical constituent, ozone plays a dominant role in the middle atmosphere. It is formed from the free oxygen atoms released by ultraviolet radiation, and it is lost largely by reactions with such other minor constituents as the odd-nitrogen and odd-hydrogen compounds. Its chief environmental importance arises from the fact that it strongly absorbs the solar ultraviolet radiation that is biologically harmful, but this same absorption provides the principal energy input to the middle atmosphere. The balance between this powerful energy input and infrared cooling, mainly by carbon dioxide, determines the temperature profile of the middle atmosphere. The temperature increases with height through the stratosphere reaching a maximum at the stratopause, near 50 km altitude, and then decreases with height through the mesosphere, reaching its minimum value for the entire atmosphere at the mesopause, near 85 km.

Because of geographical variations in both ozone content and solar radiation, the middle-atmosphere temperature profile is variable, and the consequent horizontal variations of temperature lead to characteristic geostrophic winds in nonequatorial latitudes, just as they do in the troposphere. During the winter, there is little or no insolation at high latitudes, which lead to a strong equatorward temperature gradient near the stratopause, and to the development of strong westerly winds. Wind speeds can reach 100 m s^{-1} or more, forming what is known as the stratospheric polar-night jet and delineating a cyclonic polar vortex. During the summer, the situation is completely reversed. Heating by ozone reaches a maximum at high latitudes, where there is essentially continuous insolation, and the predominant temperature gradient is directed toward the pole. The resultant geostrophic winds are easterlies, in contrast to the situation in the mid-latitude troposphere, where temperature gradients are equatorward at all seasons, and the prevailing winds are westerly.

In the early 1970's it was realized that the chief sinks for stratospheric ozone were provided by catalytic reaction cycles involving odd-nitrogen and odd-hydrogen compounds, and that these cycles could be accelerated as a result of such human activities as high-altitude aircraft flights. More recently, the realization that chlorine also takes part in a catalytic ozone-loss cycle gave added impetus to studies of stratospheric ozone and of the concentrations of such potential chlorine sources as the inert chlorofluoromethanes. Much has been learned from the programs generated by this great upsurge of interest in stratospheric ozone, but our knowledge remains patchy and incomplete in many aspects.

The most basic requirement in any study of the climatology of ozone is for global monitoring of stratospheric ozone concentrations with adequate resolution in space and time. This need has been widely recognized, and has led to the implementation of the WMO Global Ozone Monitoring Program, and within the U.S.A. to the initiation of a Federal Plan for Ozone Monitoring and Early Detection of Stratospheric Change. These programs call for a combination of ground-based monitoring stations (chiefly Dobson spectrophotometers) and remote sensing from satellites to provide the needed data on both total ozone and the vertical profile of ozone on a global basis. There is no need for a separate MAP initiative in this direction, but the importance of global ozone monitoring to the success of MAP must be emphasized, and the significance of the 1982-85 time period must be underlined.

In terms of satellite monitoring, the requirement is for routine operational monitoring that will supply a long-term data base. While operational ozone monitoring will begin with infrared measurements of total ozone by the TIROS-N series of satellites, the addition of solar backscattered ultraviolet (SBUV) measurements is not currently being considered until 1983 or later. This will fall in the most active period of MAP, and should be encouraged as being an important U.S. contribution to MAP.

As for ground-based monitoring, alternative methods to the Dobson spectrophotometer should be developed and placed in operational status whenever feasible. For example, the use of a *complete* UV spectrum, instead of selected individual wavelengths, offers the prospect of integrated column ozone measurements to accuracies of a few tenths of a percent, and the potential usefulness of microwave techniques needs further study. Geographical coverage of the ground-based ozone monitoring network should be expanded, and the usefulness of current balloon and rocket ozonesonde flights should be evaluated in order to determine the desirability of expanding their coverage in space and time. The satellite remote-sensing measurements still have severe limitations in their altitude sensitivity and resolution, and an adequate program of *in situ* measurements is essential to complete the picture. Obviously, coordination between flights and satellite overpasses will be a feature of major importance.

MI-2 Stratospheric Composition. The stratosphere, particularly at lower levels, is characterized by a rich variety of trace species, many of which play important roles in the local photochemistry. Our knowledge of the distribution of these species has increased greatly in recent years, but is still in a fairly rudimentary state, particularly with regard to variations with latitude and season. Direct *in situ* sampling has necessarily been confined to a few locations, and remote sensing from the ground and from balloons, rockets, and satellites has been confined to a relatively small number of species.

If we are ever to achieve a reasonable level of understanding of the global composition of the stratosphere, a systematic plan must be developed. Many species are members of tightly coupled families, such as the odd-nitrogen and odd-hydrogen groups. Relatively simple techniques already exist for measuring one or two of these individual family members, and a great deal of our existing information has been derived from such measurements. It is not always possible to account for the spatial and temporal behavior of an individual species, however, without parallel knowledge of the behavior of the other family members (for example, our understanding of the diurnal and seasonal variation of NO_2 would be immensely improved if we has simultaneous measurements of NO, NO_3, N_2O_5, and HNO_3). Emphasis should be placed on developing techniques for making such coordinated measurements, both by *in situ* sampling and by remote sensing. Since many of the photochemical reactions are highly temperature-sensitive, simultaneous measurements of the temperature and the radiation field are also essential.

Many of the important minor constituents of the middle atmosphere originate in the troposphere, and such tropospheric processes as rainout form the major sink for others. Any systematic study of stratospheric composition thus necessarily includes a study of the tropospheric sources and sinks. Aircraft, balloon, and ground-based measurements of such species as the fluorocarbons, N_2O, CO, and CH_4, are needed in both hemispheres, over land and ocean, and in both clean and polluted air.

The composition of the middle atmosphere is basically determined by photochemical reactions, modified by the effects of transport and dynamical processes. The fundamental role of photochemistry will lead to a continuing need for laboratory measurements of photolysis rates of the relevant species and for measurements of the appropriate chemical reaction rates. Of particular importance are reactions involving radicals, which by their very nature are difficult to study with conventional laboratory techniques, and it will be essential to apply new approaches as they become available to the study of reactions that are significant for the middle atmosphere. In many cases, temperature dependences of the reaction rates must also be determined for the appropriate range of temperatures, i.e., from about 200 to 300 K. Measurements of branching ratios and identification of product species are also of major importance.

MI-3 Mesospheric Composition. The photochemistry of the mesosphere should be considerably less complex than that of the stratosphere, since most of the species that diffuse up from the lower atmosphere are photolyzed before reaching the mesosphere, and since the typical time scales of photochemical reactions there are fast enough that transport has time to play only a less significant role. There are counterbalancing factors, however, and our knowledge of mesospheric composition is even more rudimentary than in the case of the stratosphere, mainly because of the great difficulties associated with *in situ* sampling and remote sensing. One of the principal objectives of MAP should be that of attaining a reasonably good understanding of mesospheric trace constituents, particularly of O_3, O, H_2O, and NO. Infrared limb-scanning experiments on such existing and planned spacecraft as Nimbus 7, SME, and UARS, combined with short periods of observation from Spacelab, should go part of the way toward meeting this objective, but a greatly expanded program of *in situ* sampling from rocket-borne experiments will be essential. The use of parachuted payloads from rockets appears to be a promising way to attack this problem, and should be vigorously pursued.

The question of mesospheric composition, including its variability in time and space, is central to our understanding of the middle atmosphere, and deserves high priority in terms of MAP planning.

MI-4 Basic Climatology of the Middle Atmosphere. Much of the basic climatology of the middle atmosphere is still unknown, and a detailed and long-term series of observations is needed in order to provide the needed information. The lower stratosphere is accessible to balloons, and a large amount of information on its climatology has been obtained by routine rawinsonde observations at a large number of stations. Presumably our knowledge of lower-stratosphere climatology will be increased through the results of the First GARP Global Experiment (FGGE), which was carried out in 1979, and planning for MAP should take into account the existence of FGGE data during the early 1980's.

Global coverage of such climatological parameters as temperature fields is best provided by satellite-borne remote-sensing techniques, and much progress has been made in recent years in developing these techniques and in utilizing them in the production of synoptic charts of the middle atmosphere. For many MAP-related objectives, however, the remote-sensing techniques are not able to supply the needed data with the precision and height resolution that are required, and *in situ* rocket measurements are essential. In particular, the detailed synoptic charts called for under PMP-1 cannot be constructed without the use of rocket data from several pressure levels in the middle atmosphere. Such data are presently being supplied on a regular basis by the Meteorological Rocket Network, with a routine schedule of small-rocket launches from several locations. Implementation of PMP-1 would be placed in jeopardy if the flow of MRN data were to be discontinued, and serious consideration needs to be given to continuation of the MRN, at least on a modified basis, throughout the period of MAP. In the long term, occasional rocket firings will continue to be needed to provide baselines for remote-sensing data, and to check their drift with time.

The upper stratosphere can be reached by superpressure balloons, and further use of this approach should be encouraged. A program of superpressure balloon measurements can provide useful information on basic climatological properties as well as contributing to individual research studies.

MI-5 Planetary Waves in the Middle Atmosphere. One of the most fundamental questions concerning middle atmosphere dynamics is that of the role of planetary waves and their interaction with the mean flow. The upward propagation conditions for planetary waves forced in the troposphere have been investigated theoretically, but more detailed information on the wave-number structure is needed, particularly in the mesosphere. In this connection, the dynamical behavior of the middle atmosphere in winter is expecially interesting. The most dramatic evidence for transient planetary-wave effects can be seen in the events accompanying a major stratospheric warming, and the behavior of the mesosphere during these events requires further study. Changes in the properties of the lower ionosphere are known to accompany many stratospheric warmings, and they probably reflect changes in the trace-constituent neutral composition. Such changes may be caused by changes in horizontal advection or by changes in vertical transport. The relative importance of these mechanisms remains to be determined.

MI-6 Equatorial Waves. The horizontal component of the Coriolis force is a dominant factor in planetary-wave propagation at middle and high latitudes. At low latitudes, however, this component vanishes, and other effects dominate the waves that are known to exist in the equatorial middle atmosphere. It now appears that the quasi-biennial oscillation in stratospheric winds is driven by vertically propagating wave modes, including eastward propagating Kelvin waves and westward propagating mixed Rossby-gravity waves. Both of these types of waves are probably related to large-scale tropospheric processes, but the mechanism remains unknown. There is a need for direct *in situ* measurements with good height resolution, using rocket and balloon techniques coordinated with satellite remote-sensing measurements.

MI-7 Tides, Gravity Waves, and Turbulence. Diurnal and semidiurnal tides are known to exist in the middle atmosphere, driven largely by solar heating of ozone and water vapor. Their growth in amplitude with increasing altitude makes them especially important to the basic flow state in the mesosphere, and their unstable breakup may be a major source of turbulence in the mesopause region. Although their general features can be understood on the basis of tidal theory, their seasonal variation and the existence of stationary continental-scale tides driven by zonally asymmetric forcing are not well explained.

Gravity waves propagating upward from the troposphere also assume major importance in the middle atmosphere, and their dissipation in the upper mesosphere is probably the major source of turbulent mixing. Whereas the large-scale planetary waves are best studied by satellite remote-sensing techniques, the smaller-scale gravity waves require the use of *in situ* and ground-based methods. Among the latter, the recently developed Doppler radar techniques should prove exceptionally valuable, especially in the high-power mesosphere-stratosphere-troposphere (MST) version. A properly designed program of rocket soundings, combined with VHF radar measurements and appropriate model studies, could be used to investigate the structure and life history of individual gravity-wave events from their source in the troposphere to their eventual decay and breakup in the upper mesosphere. A few well-documented case histories of this kind could provide considerably more insight into gravity-wave mechanisms than volumes of statistical results.

MI-8 Troposphere-Stratosphere Coupling. Coupling between the troposphere and stratosphere through the tropopause is a mechanism of central importance to the middle atmosphere. It allows tropospheric forcing of large-scale stratospheric waves, and it gives rise to chemical mixing of the two regions. This is an area in which observations by aircraft equipped with inertial platforms have an important role to play, particularly when carried out in coordination with balloon and ground-based radar and lidar measurements. Tracer injection experiments may be especially valuable and their international aspects might best be handled if they are carried out as part of MAP, or through designation of a preparatory MAP Project (PMP).

Troposphere-stratosphere coupling requires intensive study in at least the following three distinct areas: (a) the region of the tropical Hadley cell, where upward movements of tropospheric air carry trace species into the stratosphere directly; (b) mid-latitude synoptic-scale disturbances and jet streams; and (c) tropopause penetration in severe mesoscale convective storms. The relative importance of these mechanisms needs assessment.

MI-9 The Middle Atmosphere and Climate. Changes in middle-atmosphere composition affect the radiative balance of the earth-atmosphere system, and can thus have a direct effect on lower-atmosphere and surface temperatures. Several preliminary studies of these effects have been carried out, but a more comprehensive investigation is needed, with particular emphasis on potential feedback loops. Such feedback may exist through the dependence of middle-atmosphere temperature and motion fields on the ozone distribution, and the simultaneous dependence of the ozone distribution on the large-scale motions.

This initiative calls mainly for model studies, although additional information is also needed on the infrared spectrum of the important minor constituents. It is also closely linked to several of the experimental initiatives.

MI-10 Aerosol Formation and Properties. Aerosols are known to have an important effect on surface insolation as well as on local atmospheric heating. Since impulsive volcanic injection events appear to have produced a signal in global climate records in the past, the recent surge of interest in climate-related problems has focused attention on the aerosol content of the middle atmosphere. Our knowledge of the height distribution of the larger stratospheric aerosols with radii larger than about 0.1 μm is reasonably good, and there is presently a growing effort in the direction of measuring concentrations of smaller aerosols and condensation nuclei with radii as small as 0.01 μm. This effort will be aided materially by the various planned satellite remote-sensing experiments, and in particular by SAGE (Stratospheric Aerosol and Gas Experiment), launched in 1979. Proper assessment of the radiative effects of aerosols, however, requires more complete information on the real and imaginary refractive indices of the particles in the visible and infrared. Advances in this area are likely to come from expanded *in situ* sampling experiments and from laboratory work on aerosol formation and the associated heterogeneous chemistry.

The question of aerosols in the mesosphere requires clarification at the present time. The sporadic occurrence of noctilucent clouds in the vicinity of the high-latitude summer mesopause is direct evidence of the occasional presence of aerosols, but satellite evidence for the existence of a semipermanent mesospheric cloud layer over the sunlit summer polar cap needs verification. The possible existence of aerosol particles at lower altitudes in the mesosphere at midlatitudes also requires careful investigation.

MI-11 Solar Radiation. Solar ultraviolet radiation provides the driving force for middle-atmosphere photochemistry and dynamics. The most basic need is for information on the average values and the variability of the solar output at these wavelengths, particularly in the spectral regions responsible for the dissociation of oxygen and thus for the production of ozone. Other regions of the ultraviolet spectrum are also of concern, including the Lyman-alpha line at 1216 Å that is responsible for ionizing nitric oxide and thereby providing the main ionization source of the D-region of the ionosphere. Present indications are that the intensity of this line varies by about a factor of two during the 11-year solar cycle, and by about 30% during the 27-day solar rotation period.

The need for long-term series of measurements of solar ultraviolet flux and irradiance with precision of the order of 1% is now so widely recognized, that no separate MAP initiative may be required, although we should probably not take this for granted. Measurements over a period of several years, such as would be needed to detect a solar-cycle variation, may best be accomplished by a series of short flights of standard instrumentation on the Space Shuttle, augmented by satellite measurements whenever possible. An earlier start can be provided by individual rocket flights.

MI-12 Effects of Energetic Particles and X-Rays. Energetic particles of solar origin and high-energy electrons and x-rays associated with auroral activity can at times provide a significant energy input to the middle atmosphere, and can even cause appreciable alterations in minor-constituent composition. Their influence is much more pronounced in the lower thermosphere, where heating by auroral electrons, together with associated electric-field effects, generate their own global wind systems. The extent to which these effects penetrate the middle atmosphere is unknown, and requires both theoretical and experimental study. A full assessment of the importance of this energy input and its variability is needed, and calls for both remote-sensing and direct *in situ* measurements.

MI-13 Ion Composition. The ion composition of the middle atmosphere is an area of growing interest that presently lacks a systematic approach. While the influence of ion chemistry on neutral composition is likely to be small, except possibly during such major ionization episodes as solar-proton events, ions may play an important role in nucleation processes and in aerosol formation, as well as in determining the electrical parameters of the middle atmosphere.

The positive-ion composition of the mesosphere is fairly well understood at present, but there are serious deficiencies in our knowledge of the positive-ion composition of the stratosphere, and of the negative-ion composition of the entire middle atmosphere. Measurements to date have produced conflicting results with no apparent resolution in sight, and the most urgent need is for further development of mass spectrometers capable of operating in the high-pressure environment of the middle atmosphere without alteration of the ambient ion composition through instrumental effects. Such instruments should be adapted to use in both balloons and rockets, and operated in planned campaigns that involve the simultaneous measurement of other relevant parameters.

MI-14 Electrodynamics of the Middle Atmosphere. Electric fields generated in the troposphere by thunderstorm activity penetrate to the middle atmosphere, as do electric fields generated in the outer magnetosphere by the solar wind. These electric fields give rise to global current systems that are highly variable in both time and space. Several attempts to find a mechanism for explaining correlations between solar activity and weather have invoked the coupling of electric fields from the outer magnetosphere to the troposphere, and the reality of these effects requires both observational and theoretical study.

Systematic measurements of the electrical parameters of the middle atmosphere under a wide variety of conditions is needed, and is likely to involve both balloon and rocket techniques. This initiative has strong links with other initiatives, notably those involving ion composition and the effects of energetic-particles and x-rays.

3.2 OTHER MAP INITIATIVES

MI-15 Support for Theoretical Studies and Modeling. The essential link between theory and experiment in the geophysical sciences is provided by the construction of models. Models are built to incorporate the observed facts, and are then used to generate new predictions that can be directly tested by new observations. Modeling efforts in the middle atmosphere have mainly been concerned with the stratosphere in recent years, with a heavy emphasis on the problems of minor-constituent composition. There has been a great deal of activity in the area of one-dimensional modeling, using crude parameterization of vertical transport in the form of eddy-diffusion coefficients. Less effort has gone into the construction of two- and three-dimensional models using realistic horizontal motion fields.

On the dynamical side, the full-scale general circulation models are being gradually extended upward to encompass the middle atmosphere, though as yet without including self-consistent photochemistry. Within the next decade, it seems likely that this step will have been taken, and that full dynamical and photochemical models of the entire atmosphere from the surface of the earth to the lower thermosphere will exist. For many purposes, however, these large models are unnecessary, and there is a real need for development of a hierarchy of smaller and more specialized models aimed at the treatment of specific classes of problems. An initiative that addresses the development of models and their interfacing with observations appears to be required.

MI-16 Balloon and Rocket Facilities. Although the satellite remote-sensing techniques form the core of the MAP program, they fall far short of providing the full range of data at the resolutions that will be needed to understand the middle atmosphere and its relation to the total environment. They will not supplant the direct *in situ* measurements that can only be carried out by balloons and rockets, and in fact the extraction of the maximum possible scientific output from the satellite experiments will require a major expansion in *in situ* measurement programs.

The existing network of facilities for launching rocket and balloon payloads needs to be examined, with the aim of determining its adequacy to meet the needs of the MAP time period. In this connection, serious consideration should also be given to the possibility of organizing a systematic program of superpressure balloon launches in both northern and southern hemispheres. This is a very promising *in situ* technique that is still in its infancy, and requires serious evaluation. International cooperation will be needed in solving the problems of constructing an adequate network of balloon and rocket launch facilities, but the main initiative should probably come from the U.S.A., which is likely to be the primary user of such facilities.

MI-17 Data Archiving, Dissemination, and Exchange. As mentioned elsewhere in this document, the problems of data flow and archiving are important ones that need to be addressed at an early stage in the preparation for MAP. They are also international in nature, and a forward step has been taken by the creation of the MAP Data Management Panel. Although this area is thus under active consideration, it is sufficiently important to the overall operation of MAP that a separate MAP initiative appears to be justified.