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MTR-7170
NASA CR-144970

Evaluation of Satellites and Remote Sensors for Atmospheric Pollution Measurements

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SEPTEMBER 1976

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Abstract

for

Evaluation of Satellites and Remote Sensors for Atmospheric Pollution Measurements

This the final report in a two-part study of requirements for stratospheric measurements and capability to meet those requirements. This document reviews the physical and chemical features of the stratosphere as a basis for establishing measurement requirements. The measurement requirements presented are a composite derived from many studies and sources. A methodology is developed and presented for establishing priorities for measurement programs. The methodology considers how new measurement programs can improve present knowledge in the areas of: latitude and longitude coverage, measurement duration, diurnal coverage, season, and vertical coverage extent and resolution. The methodology is used to show the relative merits of several example satellite missions having varying measurement capabilities. The document also discusses some current instruments applicable to stratospheric measurements and how characteristics of these measurement techniques along with orbit parameters affect the measurements which can be obtained in a given satellite mission. A preliminary assessment is presented of the effect of expected on-orbit contamination from the Shuttle on atmospheric measurements.

MITRE Technical Report
MTR-7170
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ABSTRACT

This document provides an approach to the development of a prioritized list of scientific goals in atmospheric research. The results of the analysis are used to estimate the contribution of various spacecraft/remote sensor combinations for each of several important constituents of the stratosphere.

The evaluation of the combinations includes both single- and multiple-instrument payloads.

In addition to the development of the prioritization methodology, attention was turned to the physical and chemical features of the atmosphere as well as the performance capability of a number of atmospheric remote sensors. In addition, various orbit considerations were reviewed along with detailed information on stratospheric aerosols and the impact of spacecraft environment on the operation of the sensors.

ACKNOWLEDGMENTS

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1.0 INTRODUCTION AND CONCLUSIONS

1.1 Goals of the Study

This study is designed to address two major points that are important in the development of spacecraft experiments destined to perform valuable research on properties of the atmosphere. They are:

(1) Evolve a logical program development plan that defines the sequence and structure of the analysis required to develop the best possible program. The program plan begins with the synthesis of available information, incorporates the views of scientists and potential data users, and carries through to data analysis and archiving methodologies. The plan is described in Section 2.2 after definition of the mission goals in Section 2.1. Section 2.3 presents a program structure indicating the administrative, technical, and financial interactions between NASA and other members of the scientific/technical community concerned with research on the atmosphere.

(2) Carry out a program development exercise that results in a definition of scientific criteria and a description of the physical features of the species of interest, Sections 3.2 and 3.3. Sections 4.0, 5.0, and 6.0 then carry out as much of the program plan as possible by looking at the capabilities of various groups of instruments (Section 4.0), their performance on orbits of current interest (Section 5.0), and the scientific value of selected missions to measure the specific gases (Section 6.0).

1.2 Approach Taken by This Study

In most areas covered by this study, considerable effort had already been expended by many groups, both within NASA and in the private sector. MITRE's role was to collate and reconcile these sometimes disparate sources and to provide informed opinions in the areas where either no data existed or a consensus was absent. The following paragraphs summarize the major sections of this report. Figure 1-1 illustrates the structure of the study.

1.2.1 User Requirements

This subtask was, essentially, an update and refinement of a study produced in an earlier MITRE document (MTR-7007)[1]. Further data and study results have become available since the previous report was published. This new information was integrated with the earlier results to produce a more extensive and detailed list of species which, in turn, became candidates for inclusion in an atmospheric measurement program. The method of prioritization and the results of this process are given in Section 3.2. Pertinent properties of all of those candidate species appear in Section 3.3.

1.2.2 Instrument Performance

While the potential list of satellite sensors of atmospheric constituents is not particularly large, it represents an extremely dynamic field. Proposed instrumentation is continually being revised to include other constituents or to drop some that were initially

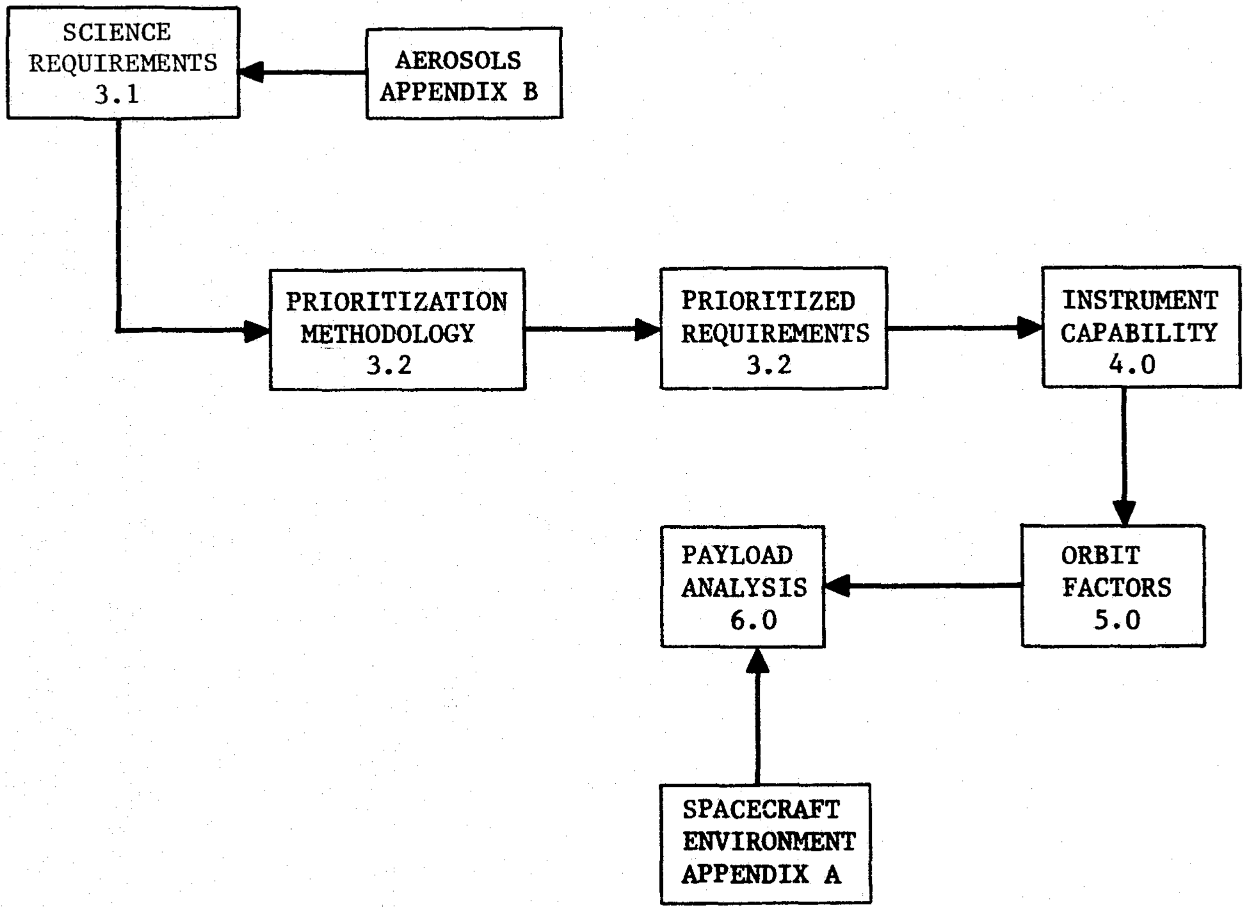

FIGURE 1-1
ELEMENTS OF THE STUDY AND THEIR SECTIONS

proposed. Concurrently, new designs are constantly being proposed for improved measurements of specific gases. Size, weight, and power constraints will often result in modifications to a sensor system that has already been flight-tested on aircraft platforms. Thus, any sensor evaluation is highly time-dependent.

For this subtask, those instruments that are at present considered by NASA to be suitable for space flight in the 1980 time frame were examined. The most recent technical parameters were provided by the principal investigators. This information is presented in Section 4.0. Candidate sensors were compared with the orbital constraints of Section 5.0 and with the prioritized list of constituents of Section 3.2. The actual evaluation of the various sensors appears in Section 6.0.

1.2.3 Orbit Considerations

From among the nearly infinite orbit combinations available, four were selected for detailed analysis in Section 5.0. Two of these, the 30° and 56° inclined orbits, represent the probable extremes of early Shuttle missions launched from the Eastern Test Range (ETR). The other two are sun-synchronous orbits of different, but typical, altitudes that will be possible when the Western Test Range (WTR) is equipped for Shuttle missions.

Computer-generated plots, prepared by NASA-LaRC, indicate the spatial and temporal aspects of each orbit for various generic sensor categories. These plots provide the framework for the overall evaluation of sensor-orbit-species combinations.

1.2.4 Payload Selection

In Section 6.0, the results from the earlier sections are used to provide an evaluation of the scientific value of certain spacecraft missions. The instrument types and orbits were constrained as explained above, and the constituents of interest were chosen from the prioritized list developed in Section 3.2.

The numerical values used in the evaluation have meaning only within their present context. The resultant rankings provide only a relative ordering among those sensors and orbits selected. Any extension or extrapolation would require a new start using the new variables. Results of the utilization of this method are provided in Section 6.0

1.2.5 Contamination in the Shuttle Environment

One of the subtasks of this study, with a pervasive influence on all of the others, was to examine the most probable impact of the Shuttle environment upon atmospheric remote sensors. This question, clearly, affects both present and proposed sensor systems and will prevail, to some degree, in any chosen Shuttle orbit. In view of the fact that the effects of contamination were independent of orbit, sensor, or species being measured, this material appears in Appendix A. While capable of influencing all sensor-orbit-species combinations, the existence of spacecraft effluents does not affect the payload selection methodology used in Section 6.0 and was, therefore, outside of the major goal of the study.

1.3 Recommendations and Conclusions

Section 6.0 presents the results of the specific sensor-orbit-species study undertaken by this task. Within the constraints imposed by the sensor complement examined and the choice of three orbits selected, the various sensor-orbit combinations are evaluated for each species of interest. For the stratospheric study, the limb-scanners scored significantly higher than either the nadir-viewing or the solar occultation class of instruments. This is attributable to the direct vertical profiles which the limb-scanners provide. Among the three orbits investigated, the 56° orbit scored higher than either the 30° or the sun-synchronous orbit. This may be understood by considering the offsetting effects of coverage provided by limb viewing instruments that measure emission and those that depend upon solar occultation. For limb emission instruments, the higher the inclination angle the greater the global coverage. However, the poorest latitudinal coverage of all the combinations examined is obtained in the case of solar occultation from sun-synchronous orbits. For limb emission and nadir-viewing instruments, the sun-synchronous orbit will provide excellent latitudinal coverage.

It must be emphasized that the present evaluation was performed for a limited number of instruments and orbits. The methodology is sufficiently flexible to allow new instruments to be included in

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subsequent analyses of this type. If any of the instruments considered should prove incapable of all the measurements for which they are credited, their relative standing in a later analysis would suffer proportionately.

In Section 6.3 an analysis of various instrument combinations is performed. The results confirm the relative superiority of limb viewing instruments for a stratospheric measurement program. In terms of scientific value, it is shown in Section 6.0 that a two-instrument mission which contains Limb IR Monitor for the Stratosphere (LIMS) and Correlation Interferometer for the Measurement of Atmospheric Trace Species (CIMATS) provided greater values than half of the three-instrument combinations and is nearly equal to the four-instrument combinations included. For all but one of the eleven combinations examined, the 56° orbit is seen to be capable of satisfying the greatest number of scientific requirements.

2.0 PROGRAM DEVELOPMENT

This section is devoted to the concepts for an overall program development plan for a series of spacecraft experiments to support atmospheric research. The goals of the section are to:

- Present a logical sequence of program development goals in as much detail as possible;
- Define methods of decision-making at key points in the program, in particular science criteria and mission analysis; and,
- Incorporate a suggested parallel management structure that supports the program.

In addition to discussing these very general topics required by the program development task, an analysis of measurements of scientific interest is included which both demonstrates the method of prioritization and provides material suitable for the payload selection study of Section 6.0.

2.1 Mission Goals

The program described below attempts to address two major mission goals: (1) development of an experiment of scientific value, and (2) utilization of the spacecraft as a test bed for instrument test and evaluation. The attempt to meet these goals will require a number of studies and analyses in such areas as orbit analysis, instrument performance, data analysis methods, etc. These and other elements of the program appear in more detail in the sections that follow. The program reflects the activities associated with the conceptual phase. At the completion of the identified tasks, sufficient knowledge should have been accumulated to allow the hardware phase to begin.

2.1.1 Science Goals

The science goals considered for a mission are quite similar to those normally addressed in evaluating a spacecraft observation of the earth. The goals are to provide accurate measurements of features of the earth's environment in such a way that diurnal, seasonal, and yearly variability as well as the spatial variability over the globe can be determined for the largest possible number of constituents that play a role in atmospheric processes.

It should be pointed out that, because missions of this type represent only a part of the atmospheric research being undertaken, a particular mission may be designed to investigate only one small sector of these extensive goals. Further, the decision as to which topics can be given the highest priority for study will depend upon the current knowledge of a constituent, the ability of the mission to improve upon that knowledge, and the relative importance of that knowledge to an understanding of the atmosphere.

Definition of the required accuracy and the spatial variability of most interest--vertical profile, meridional, zonal, etc., and the temporal features of the mission (time of launch, duration, sampling rate, etc.)--will require definition of the particular scientific objectives.

Thus, the science goal stated above represents the broadest possible range of observable features, and the experiment will be evaluated for its ability to address particular elements of the goal.

2.1.2 Sensor Development

The program plan that follows also attempts to include a role for the proposed missions as an instrument test and evaluation facility. This role complements the science objectives and facilitates the evolution of spaceborne remote sensors of the atmosphere.

In addition to allowing effective test and evaluation, even short missions will represent an opportunity to evaluate the cooperative interaction of the sensor complement on the spacecraft. Experiments of this type can help in predicting the effectiveness of subsequent missions.

2.2 Program Plan

In order to meet the very general requirements of Section 2.1 and the very specific requirements of Section 3.2, an organized and logical program planning method must be utilized. Such a plan is developed in this section along with general scheduling features. Section 2.3 describes the appropriate program structure.

The program plan that follows rests on several principles:

- The final program will be of value if it has been developed with clear and realistic measurement goals;
- The experiment cannot be developed without the cooperation of other researchers, data users, and experts in the causes and effects of changes in atmospheric composition; and,
- The program goals can be met only after development of a structured set of tasks, each of which plays a role in reaching the final goal.

Each of the tasks in the program development is discussed in the following paragraphs. The discussion is followed by a typical program schedule showing the duration and timing of each task. Figure 2-1 illustrates the interconnection and flow of information.

Task 1 CONSULT RELEVANT DOCUMENTS AND CENTERS OF EXCELLENCE PERTAINING TO SCIENTIFIC GOALS

A prerequisite to designing the experiment is a clear understanding of what aspects of the atmosphere and its components are of importance to the scientific community. These topics would possibly include atmospheric transport, chemistry, sources and sinks of various constituents, and other physical and chemical features of the atmosphere. The first task, therefore, must be to conduct, with the cooperation of the scientific community, a review of the uses to which the atmospheric data will be put. This review should include a study of previous recommendations such as those of several committees and groups of the National Academy of Science (NAS), Global Atmospheric Research Program (GARP), Climatic Impact Assessment Program (CIAP), and Inadvertent Modification of the Stratosphere (IMOS) studies. Each of these study groups is discussed in Section 3.0. Information from extant users' studies should also be included. A portion of this task has been performed in another part of this document.

Task 2 DEFINE SCIENTIFIC GOALS

In order to assure that the final experimental design satisfies the requirements of the scientific community, it is important that scientific goals be defined early in the study. This task will synthesize from the review conducted in Task 1 a well-defined set of objectives to be met by the experiment. This set of objectives must

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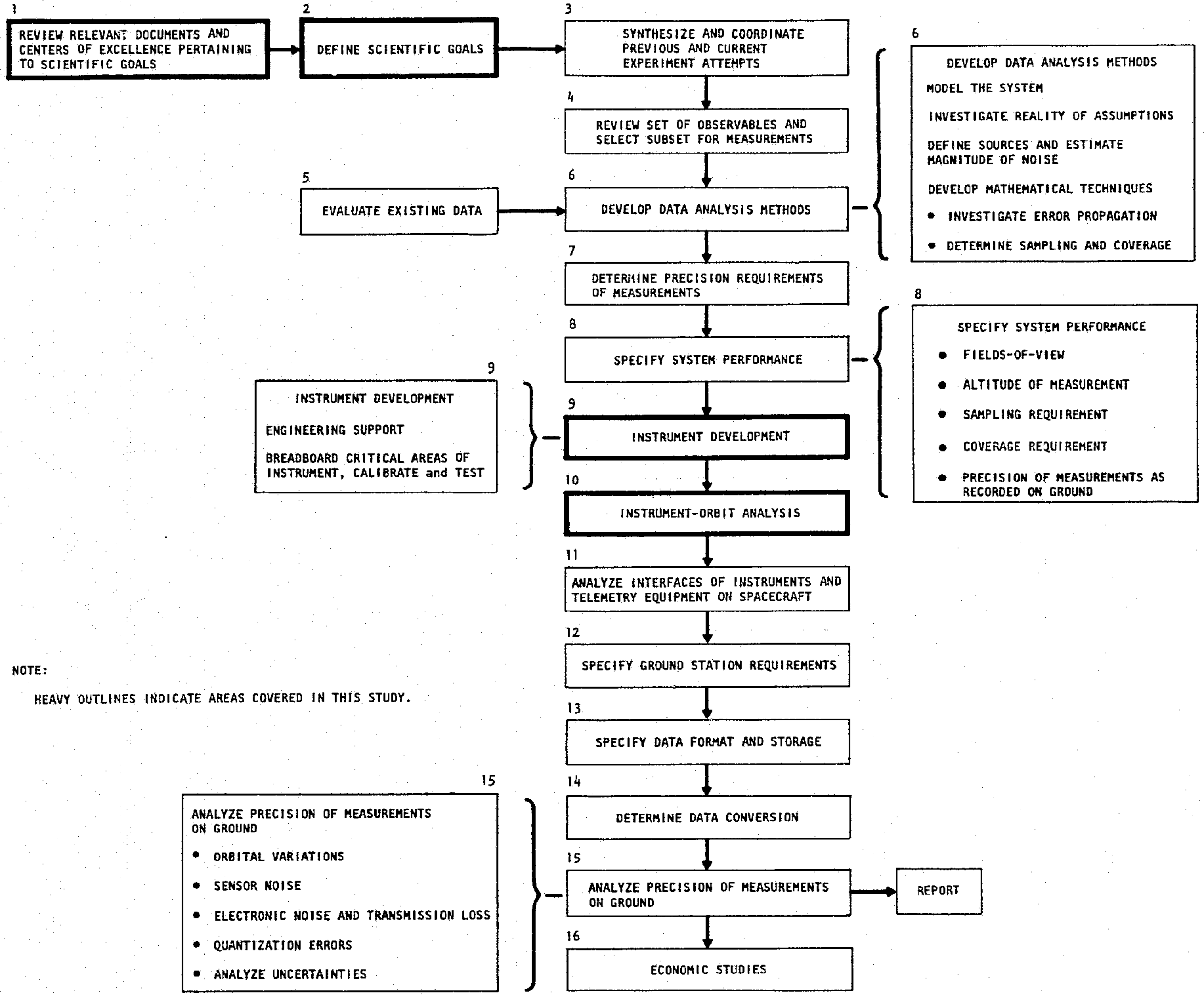

NOTE:

HEAVY OUTLINES INDICATE AREAS COVERED IN THIS STUDY.

FIGURE 2-1
PROGRAM EVOLUTION

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include precise statements concerning the information requirements, such as:

- Gases of interest;
- Diurnal, seasonal, yearly variability;
- Spatial variability (vertical and horizontal); and,
- Concentration.

A consensus of the scientific community concerning these goals at an early stage of the experimental design is essential. A prioritization of the goals will also be required for use at a later step in the program at which point decisions will be made as to those science goals that can be obtained from the mission (see Task 4). Preliminary results of a study of this type appear in Section 6.0 of this report.

Task 3 SYNTHESIZE AND COORDINATE PREVIOUS AND CURRENT EXPERIMENT ATTEMPTS

A number of experiments and programs have been designed to produce information concerning properties of the components of the atmosphere. A review of these previous attempts in light of scientific goals will give guidance to the design of the present experiment. A synthesis (of both program and instrument) may be possible from the previous experiments. This review should determine the reasons for any failure of the previous experiments to meet the current and past scientific goals and should include consideration of the following factors:

- Assumptions, both explicit and implicit, in the mathematical analysis used to reduce the data, and their validity;

- Completeness of the mathematical analysis;
- Weaknesses in the engineering design; and
- Sampling limitations due to the choice of instrument, platform, and orbit.

This is an appropriate point in the program to evaluate the performance objectives and techniques of others currently involved in similar research. Early coordination and cooperation, particularly between experiments to be performed on various platforms, would encourage an effective program. There is also a practical motivation for establishing what research is being done by others. It will allow determination of those constituents already being measured or to be measured as a part of other programs.

Task 4 REVIEW SET OF OBSERVABLES AND SELECT A SUBSET FOR MEASUREMENT

There are a number of observables from a space platform relating to the properties of the atmosphere. Some of these are:

- Radiation properties (solar, earth emitted longwave, earth reflected shortwave);
- Cloud features (type, altitude, IR, and visible characteristics); and,
- Atmospheric components (gases, aerosols).

In this task the set of observables will be reviewed to determine their usefulness in producing the specific information required by the scientific goals. This review should be guided by the results of Tasks 1 and 2. A result of this task will be an enumeration of the scientific measurements to be taken during the experiment.

This task must work in a feedback mode with Task 6 under which the mathematical analysis techniques are developed to obtain the information expressed by the scientific goals.

During this task a decision is required as to the use of existing instrumentation, which may already embody the particular measurement capabilities required, and on the development of new spacecraft remote sensing techniques. The instrument development discussed under Task 9 refers to the actual fabrication phase, which might use both existing and anticipated measurement methods.

This is also a point where the availability of data from other sources will shape the science goals of the mission. The results of Task 3 can be used to make this decision based on criteria discussed in Sections 2.1.1 and 3.2.

Task 5 EVALUATE USEFULNESS OF EXISTING AND ANCILLARY DATA FOR MODELING

Previous experimental designs have occasionally relied on the use of ancillary data in their data reduction techniques. In particular, many remote sensors of the atmosphere require information on the vertical profile of water vapor and/or temperature at the measurement point. Ancillary data requirements such as these must be evaluated in terms of the existence and quality of such data and any anticipated source of such data. It is particularly important to ensure that the ancillary data satisfy the requirements of the mathematical analysis.

This task should review the existence of data archives that may support this experiment, and should interact with the Data Analysis Task,

Task 6, in determining the quality and usefulness of the data as well as additional requirements.

Task 6 DEVELOP DATA ANALYSIS METHODS

The set of observables actually measured by the experiment may not, in themselves, satisfy all of the scientific goals of the experiment. A means must be found to reduce the data to yield the information specified by the goals. A number of subtasks will be required to fully develop the mathematical methods for the data reduction.

Subtask 6.1 Develop Observable/Goals Model

The relationships between the observables that are measured and the information goals of the experiment must be modeled. This modeling is necessary for the development of realistic data reduction techniques.

Subtask 6.2 Investigate Assumptions of the Model

Any modeling of a complex physical system will involve assumptions concerning the nature of that system and the relationships of its parts. This subtask has been made distinct from Subtask 6.1 because it is important that a critical examination of the assumptions of the model be made. This examination must determine the degree to which those assumptions reflect the real world.

Subtask 6.3 Define Sources and Estimate Magnitude of Noise

There are a number of sources of uncertainty in measurements from a space platform: sensor noise, electronic noise, orbital variations, etc. The total effect of all of these should be estimated at this point. More important, however, for nadir viewing instrumentation, is an understanding of the uncertainties related to scene variation. The effect of clouds can change scenes drastically on a time scale of an hour[2]. A quantitative understanding of the way clouds affect the measured quantities is necessary for the proper development of data reduction techniques.

Subtask 6.4 Develop Mathematical Techniques

Reduction of the data to satisfy the scientific goals will require that suitable mathematical techniques be developed. These techniques will depend on the system model and on an understanding of the variations that result in data uncertainties. The development must be complete in the following areas:

- A complete algorithm for reducing the data;
- An investigation of error propagation through the algorithm; and,
- A complete description of the sampling and coverage requirements.

Task 7 DETERMINE PRECISION REQUIREMENTS OF MEASUREMENTS

Most mathematical techniques for reducing the data operate on digitized data from computer tapes. Since a number of sources of error may be introduced by any complex measurement system, this task should determine the required precision of the input data to the reduction techniques. An approximate error budget must be developed in terms of the allowable uncertainties introduced by:

- Calibration;

- Orbit variations;
- Background noise;
- Electronic noise and transmission losses;
- Quantization errors; and,
- Scene variability.

Task 8 SPECIFY SYSTEM PERFORMANCE

As a result of the previous tasks, the system performance needed to achieve the scientific goals can be specified. This task will require the synthesis of the previous tasks and the extraction of particular system specifications. These will include:

- Types of sensors;
- Fields of view required;
- Altitudes of measurements;
- Sampling requirements;
- Coverage requirements; and,
- Precision measurements as recorded on the ground with an approximate error budget.

These specifications will be enumerated and communicated to the necessary components of the engineering system.

In addition, during this task, the effectiveness of the experiment as a test and evaluation of instrument performance can be estimated. As a subtask, a program for such an evaluation can be prepared that specifies goals, test procedures, calibration methods, and instrument comparisons.

Task 9 INSTRUMENT DEVELOPMENT

As noted earlier in this section, alternatives exist in the selection of instrumentation for the proposed missions. New concepts that may represent improved performance capability are certainly one alternative. However, the existing instrument hardware and concepts deserve consideration since they may represent an economical way of developing new capabilities designed to meet the science requirements.

Subtask 9.1 Instrument Definition and Modification

This subtask includes definition studies of instrumentation to determine instrument and spacecraft parameters. Use should be made of previous and/or concurrent work performed by the scientific and engineering community in remote sensing of atmospheric constituents. Tradeoffs of various spectral isolation techniques must be thoroughly investigated and an optimum configuration approach defined. Considerable attention should be given to modification of existing instrumentation as an alternative to the development of new instruments or concepts.

Subtask 9.2 Synthesized Instrument Definition Effort

The objective of this effort is to define an integrated instrument system that meets the stated science requirements. This task involves a tradeoff process between competing instruments, as well as consideration of the interrelationship of instrument studies with other related overall program study tasks. Among the many interactive factors that should be considered are orbit parameters, spacecraft

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requirements and constraints. Absolute accuracy, precision, and long-term stability must be optimized to assure that scientific objectives are met. Modularity concepts must be considered in these studies to assure wide flexibility in the accommodation of instrument packaging on board selected spacecraft.

Subtask 9.3 System Engineering Support

This subtask includes the following:

- Participation in overall program studies to support derivation of scientific and system engineering objectives and requirements that will be used as inputs for the instrument definition studies.
- Participation in overall program studies to characterize instrument parameters as inputs to other tasks (e.g., modeling, data analysis, tests of inversion techniques, etc.).

Subtask 9.4 Breadboard Critical Areas of Instrument, Calibrate and Test

Once the instrument studies and design approaches are resolved, a program is developed to "breadboard" some critical areas in the instrument subsystem. The criteria to be used in selecting breadboarding areas are:

- Proof of instrument feasibility;
- Proof of measurement uncertainty values;
- Lifetime or reliability proof or improvements; and,
- Long lead development tasks.

Task 10 ANALYSIS OF ORBITS AND INSTRUMENT MIX

At this point the interaction of instrument characteristics and orbit factors should be addressed. The goal of the study is to determine the most effective instrument mix for each mission in view of the orbit parameters, science requirements, instrument characteristics, and available data reduction methods.

Particular factors to be taken into account are instrument accuracy, sampling characteristics, altitude, and eccentricity effects, etc.

Task 11 ANALYZE INTERFACES OF INSTRUMENTS AND TELEMETRY EQUIPMENT ON SPACECRAFT

The spacecraft and instrument interfaces must be analyzed. Considerations include:

- Shadow and reflective effects from the spacecraft on the instruments;
- Conductive and radiative spacecraft/instrument thermal interface;
- Electrical interface with the spacecraft including power and memory requirements (size and rate), telemetry interface, and suggested redundancy;
- Mechanical interface such as weight, volume, and instrument mounting;
- Attitude control requirements (i.e., pitch, roll, and yaw), anticipated motion period and velocity, and resultant "smearing" of data; and,
- Impact of spacecraft gaseous environment on measurements (see Appendix A).

Task 12 GROUND STATION REQUIREMENTS

An assessment should be made of the impact on the NASA ground stations. Recommendations should be made regarding which ground stations around the world will be required in order to receive the data, at what rate and time interval, and for how long (years).

Transmit and receive frequencies should be defined and documented. Transmission requirements of the data from the ground receiver stations to the NASA-designated "data center" should also be addressed. The impact of interruptions of data flow should be evaluated from the point of view of data analysis requirements.

Task 13 DATA FORMAT AND STORAGE

Proposed data should be studied and recommendations made once the magnitude and type of data is resolved. Data storage techniques also must be evaluated. At this point, methods of getting the data from storage (archived) to the appropriate users of the information should be examined. The future tasks of data retrieval, formatting, correlating and transmitting to the user may now be estimated.

Task 14 DATA CONVERSION

Closely allied to the "data format and storage," Task 13, and the instrument definition, Task 9, is the effort to convert the instrument measurements expressed in volts to the actual observed spectral measurements and then into concentrations. This task should encompass the methodology to perform this with consideration of the actual instruments chosen, calibration uncertainties, and adequacy of supporting data and mathematical models.

Task 15 ANALYZE PRECISION OF MEASUREMENTS ON GROUND

After a complete experimental system has been designed, there must be a redetermination of the sources of error and their contributions to the total uncertainty in the measurements as recorded on the ground. This task must examine the complete system to determine that the system performance specifications have been satisfied. This will again require a study of the following sources of uncertainty based on the final engineering design:

- Orbital variations;
- Sensor noise;
- Electronic noise, and transmission losses;
- Quantization errors; and,
- Data analysis uncertainties.

Task 16 ECONOMIC STUDIES

At the conclusion of the program described and before formal implementation of the final hardware development, an economic study should be performed which assesses the costs to that point and estimates the future costs required to actually implement the program. Such an analysis performs two services: It allows, in conjunction with Task 1, an assessment of the costs and economic benefits of such a program, particularly as an alternative to airborne or ground-based instrument testing. It also provides the information needed by NASA management before instituting a hardware phase.

In summary, the 16 tasks illustrate a coordinated program of instrument and data analysis methods development which, at its conclusion, establishes the scientific value of alternative payloads. Advantages of the program include the participation from the earliest stages of the important and informed members of the scientific community, an assessment of ideal and realistic program goals, and a cooperative development of instrument and data analysis concepts.

2.3 Program Structure

In order to implement the program plan discussed in the previous section, it would be advantageous to identify an individual or individuals as shown in Figure 2-2 under Office of Program Development. The role of this office is several-fold. First, it is responsible for initial and continuing coordination between the scientific community and the engineering community. Second, it synthesizes progress in each of the task areas discussed previously, and third, it monitors the interaction of other interested groups and agencies with each other and itself, allowing it to offer an updated and informed view of the state of atmospheric science.

In acting as a liaison with the scientific community the office would be responsible for instituting the meetings and conferences that would play a role in Tasks 1, 2, and 4. At the same time, the office will sponsor similar meetings with the instrument and spacecraft groups and additional meetings between scientists and engineers to help foster the flow of information which is so essential in a program of this type.

As science criteria and engineering approaches evolve, it will be necessary to solicit the participation of a group such as the Committee on Atmospheric Science of the National Academy of Sciences to review the program progress and determine the value of the proposed solutions.

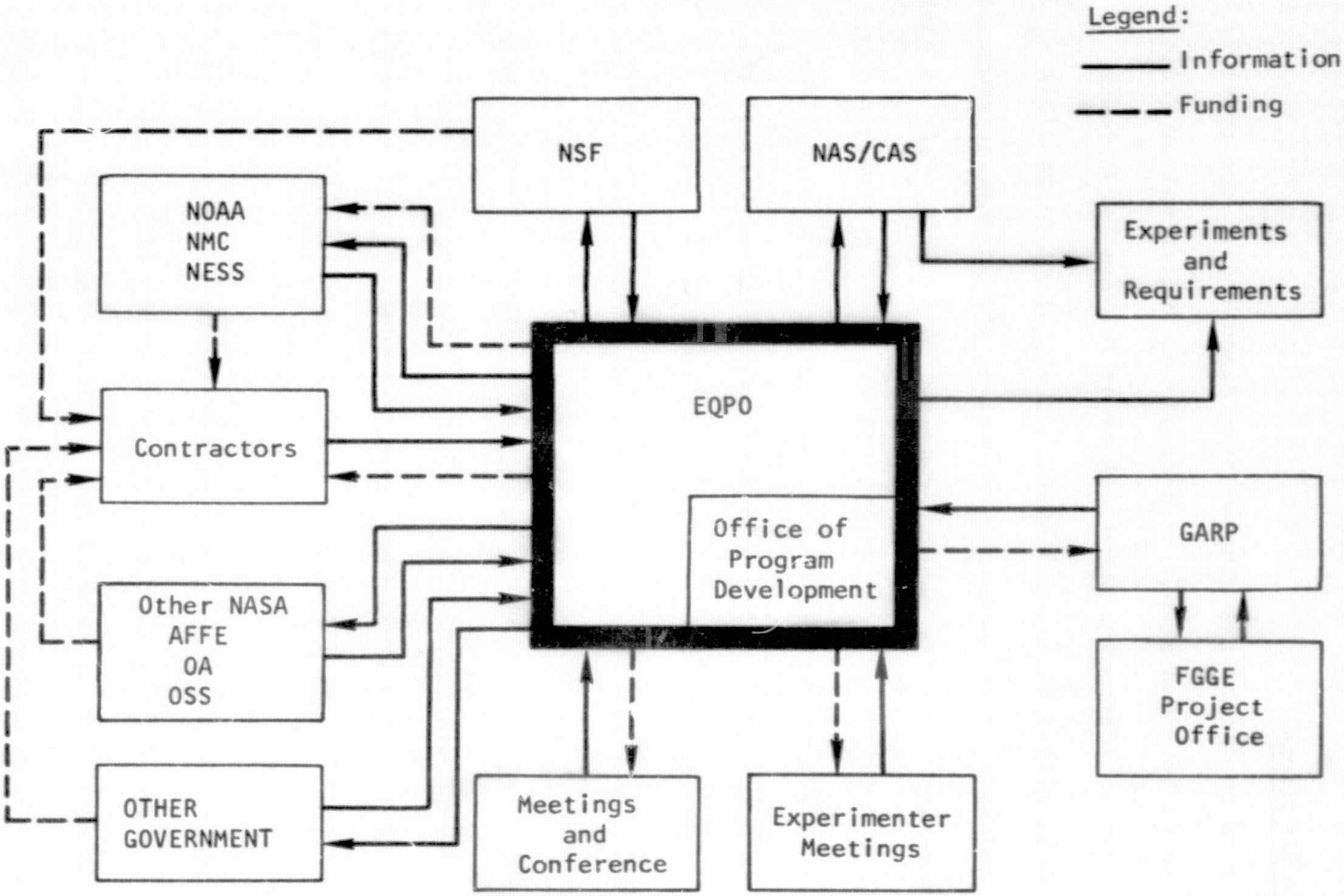

FIGURE 2-2
RECOMMENDED PROGRAM STRUCTURE

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While interacting with NASA staff and contractors in a program monitoring role, the office will participate in refining scientific goals, and evaluating engineering proposals. A liaison with other NASA programs (including Advanced Applications Flight Experiment Program) should also be carried out. Due to the diverse interests of NASA in atmospheric science such contacts will be essential to providing an up-to-date assessment of technical capability in this area.

A related liaison is required with the National Oceanic and Atmospheric Administration (NOAA), particularly the National Environmental Satellite Service (NESS). Their research, while generally directed toward climate and meteorology, is very much in the forefront of current knowledge. As a result, NOAA/NESS represents a source of important information on new programs, research results, and problems of pressing importance.

Another example of a contact that should be made is one with the National Science Foundation (NSF). In its role as a supporter of considerable atmospheric research, much of it through its support of the National Center for Atmospheric Research, NSF plays an important role in the selection of research problems and application of the results.

It should also be the function of this office to establish contacts with any and all other Federal agencies performing research or developing measurement requirements related to atmospheric properties.

Likely candidates include the Environmental Protection Agency (EPA), the Energy Research and Development Administration (ERDA), and the Department of Transportation (DOT). In addition, contact is required with international atmospheric research programs, such as the Global Atmospheric Research Program (GARP) and the First GARP Global Experiment (FGGE).

These various contacts should provide sufficient technical background to provide convincing arguments, both within NASA and to other Federal agencies, concerning the extensive group of interested parties and potential users.

In summary, this Section describes an overall program for atmospheric research from space, including the appropriate planning and structure. The remainder of this document will concentrate on but a small aspect of the program development, namely the definition of scientific goals (Task 2), initial instrument analysis (Task 9), and their relation to probable orbits (Task 10).

3.0 SCIENCE REQUIREMENTS

3.1 Background

A number of recent study groups (CIAP, GARP, etc.) have addressed the general question of man's interaction with and impact on the atmosphere. Further, considerable interest has developed recently concerning the effects of the atmosphere (and its constituents) on man's environment--particularly weather, climate, and the radiation environment.

In a previous document, "Stratospheric Measurement Requirements and Satellite-Borne Remote Sensing Capability" [1], MITRE reviewed the conclusions of the various study groups. A summary of material appears in Tables 3-I and 3-II indicating physical and chemical constituents of the stratosphere, their concentrations, and their required measurement accuracies.

These tables are reprinted from the above reference and are intended as background material only. A complete development of the properties and measurement requirements of stratospheric species is given later in Section 3.3.

3.1.1 Physical and Chemical Properties of the Atmosphere

The two major reasons for observing or monitoring the atmosphere are to gain a more complete understanding of the subject and to be able to predict changes in the environment. Inadvertent modifications of the atmosphere by pollutants can have far-reaching effects upon man's activities. Chemical and physical processes, in terms of both

TABLE 3-I
SCIENCE REQUIREMENTS FOR MONITORING IN THE STRATOSPHERE[1]

CONSTITUENTS	ACCURACY*	TEMPORAL SAMPLING	SPATIAL SAMPLING	SIGNIFICANCE
O_3	Vertical profile 10% Total column 1%	Daily	Global on 100 km grid	Key gas of stratosphere
HCl	AVM			1
Cl	AVM			1
ClO	AVM	After volcanic activity		1
CF_2Cl_2	AVM			1
$CFCl_3$	AVM			1
OH	AVM			1,2
CH_4	20%			1
O	AVM			1,2
NH_3	AVM			1,3
NO	50%			2
NO_2	50%			2
HNO_3	30%			2
N_2O	5%	Periodically		2
N_2O_5	AVM			2
Aerosols		After volcanic activity		
Particles		After volcanic activity		
SO_2	AVM	After volcanic activity		3
H_2S	AVM			3
H_2O	30%	After volcanic activity	Latitude variations	3

*AVM - Any valid measurement is a reasonable goal.

1- participates in ozone destruction utilizing chlorine
2- participates in ozone destruction utilizing NO_x
3- participates in aerosol formation

TABLE 3-II
STRATOSPHERIC CONSTITUENTS RECOMMENDED FOR MONITORING[1]

CONSTITUENTS	CONCENTRATION*	REQUIRED ACCURACY (%)**
O_3	6 ppmv	<10
HCl	~1 ppbv	AVM
Cl	Unknown	AVM
ClO	Unknown	AVM
CF_2Cl_2	Unknown	AVM
$CFCl_3$	Unknown	AVM
OH	10^{-4} ppbv	AVM
CH_4	1 ppmv	20
O	10^6/cc	AVM
NH_3	Unknown	AVM
NO	0.1 ppbv	50
NO_2	~ 2 ppbv	50
HNO_3	3 ppbv	30
N_2O	0.1 ppmv	5
N_2O_5	Unknown	AVM
SO_2	10^{-6} $\mu g/m^3$	AVM
H_2S	10^{-7} $\mu g/m^3$	AVM
H_2O	1 mg/m^3***	AVM
Aerosols	0.0 - 1.0 cm^{-3}	--

---

*Average concentration at 20 km.

**AVM - Any valid measurement is a reasonable goal.

***Extremely variable.

O_3 destruction and aerosol formation, will be summarized below to provide a background for later discussions of instrument performance and payload selection.

A series of atmospheric layers may be defined according to the temperature structure. These layers are:

- Troposphere,
- Stratosphere, and
- Mesosphere.

Averaged over reasonably long periods of time, the temperature of the troposphere decreases regularly with altitude. At an elevation that varies systematically with latitude and season, the temperature becomes isothermal. This property defines the tropopause, which lies between 8 and 16 km. The stratosphere is the region above the tropopause and below the stratopause. In this region, the temperature is typically constant or increasing with altitude. This increase is reversed at an altitude of about 45 to 50 km--the stratopause. The region above the stratopause is the mesosphere.

The vertical distribution of temperature in the tropical and the polar zones is shown in Figure 3-1[3]. The two temperature profiles of Figure 3-1 show substantial differences between polar and tropical regions. An indication of the temperature changes with latitude is illustrated by a series of such profiles. Another way of presenting such data is by the contour lines of zonally averaged temperatures. Figure 3-2[4,5] shows such contour lines for March 22 and January 15.

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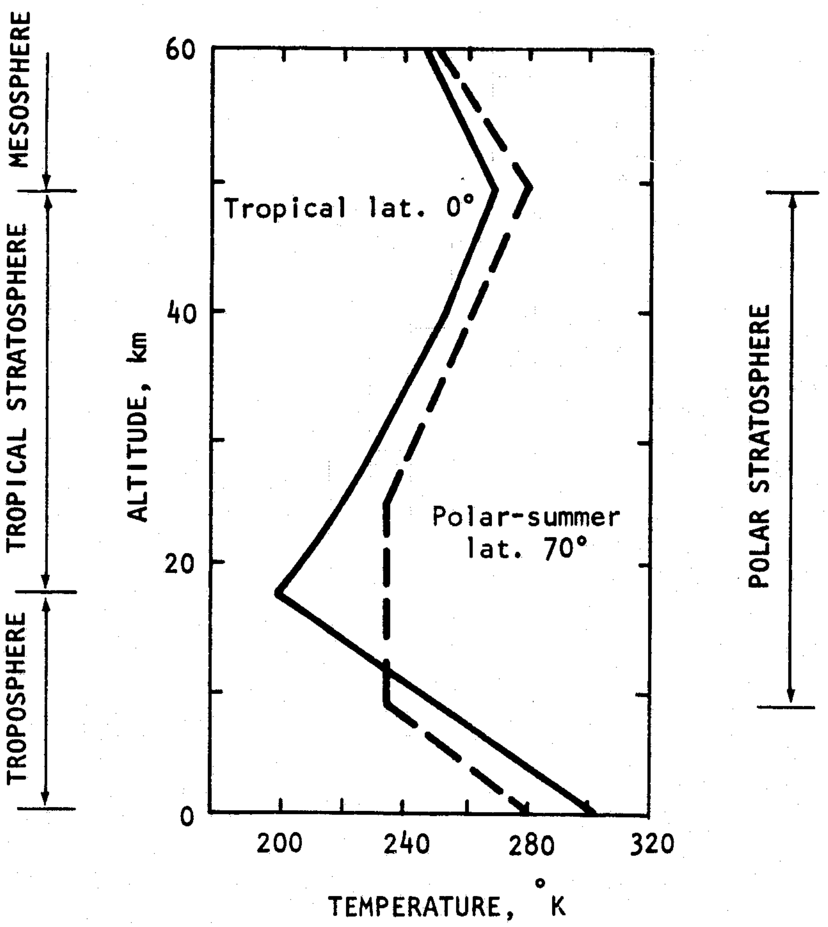

FIGURE 3-1
SAMPLE TEMPERATURE PROFILES AT TROPICAL AND POLAR ZONES [3]
(Troposphere, stratosphere, stratopause, and mesosphere defined in terms of vertical temperature profiles)

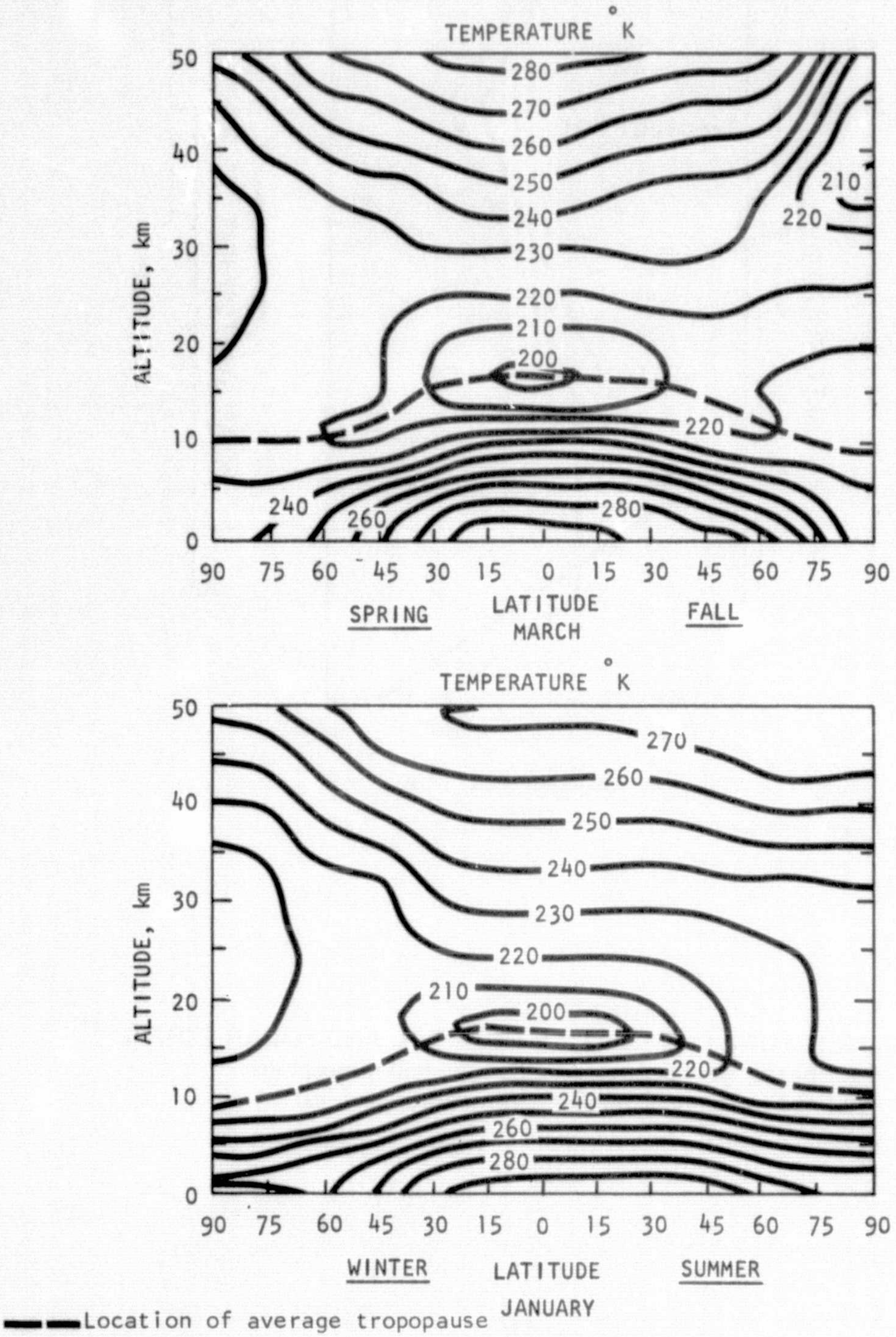

FIGURE 3-2
AVERAGE TEMPERATURE CONTOURS FOR MARCH 22[4], JANUARY 15[5]

The dotted lines in these figures are the approximate locations of the averaged tropopause as it changes with latitude. In addition to the latitudinal dependence, the height of the tropopause changes with season and synoptic weather conditions.

The special properties of the stratosphere--its temperature inversion and the resulting slow vertical mixing--are a consequence of the presence of O_3 (ozone), which is formed rapidly in the upper stratosphere. The formation of O_3 occurs at an altitude of 30 to 50 km by the photolysis of O_2 (molecular oxygen), producing O (atomic oxygen), which in turn recombines with O_2 to form O_3. Some of the physical reasons behind the temperature inversions at the tropopause will now be examined.

If heat from the ground were the only source of energy in the atmosphere, the vertical temperature at a given location would decrease monotonically with altitude. In contrast, measurement of the vertical temperature profiles shows that beyond the tropopause, to a height of about 50 km, the temperature increases. At this height, the stratopause, the temperature undergoes an inversion and again starts to decrease.

One to three percent of the incoming solar radiation is absorbed by the O_3 layer in the stratosphere. The absorbed energy heats adjacent layers. The model now contains two sources of energy in the atmosphere, one at the surface and the other at an altitude of about 30 to 50 km. From this simplified picture, it is evident that a temperature inversion should occur at a height between the two sources. The region where the inversion occurs defines the tropopause, which lies between 8 and 16 km depending on the season, latitude, and synoptic weather situation.

The constituents of the stratosphere may be separated into four categories. These are:

- Major chemical constituents,
- Minor chemical constituents,
- Trace chemical constituents, and
- Aerosols.

The major atmospheric constituents are N_2 (molecular nitrogen), O_2, A (Argon), and CO_2 (carbon dioxide). The accepted value for N_2 concentration is 78.08 percent by volume of dry air. Recent oxygen measurements show a concentration of 20.95 percent by volume when corrected to dry air conditions[6]. Argon has a stratospheric background concentration of 0.93 percent and carbon dioxide of 0.03 percent at about 20 km.

The minor constituents, such as O_3, H_2O (water vapor), CH_4 (methane), etc., have concentrations of a few parts per million in the stratosphere. Table 3-III summarizes some of the minor constituents at 20 km that are important in stratospheric chemistry and circulation. Table 3-IV summarizes for some of the important trace constituents, such as NO (nitric oxide), H_2O, etc., their concentrations at 20 km, their variability, and their role in stratospheric chemistry. These tables have been reprinted from a MITRE document [1] and are intended as

TABLE 3-III
MINOR ATMOSPHERIC CONSTITUENTS [1]

Species	Concentration at 20 km	Variability	Importance
O_3	6 ppmv	Factor of two or more diurnal, season, latitude and height.	UV-shield, radiative heating and cooling of stratosphere.
H_2O	3 ppmv	With latitude, season, and altitude.	Radiative balance, clouds, particle formation, O_3 chemistry.
CH_4	1 ppmv	Decreases with height above tropopause.	Chemical source of OH. Possible sink of Cl, indicator of tropopause interchange.
H_2	0.55 ppmv	Increases to a maximum of 0.8 ppmv at 28 km and decreases to 0.4 at 50 km.	O_3-chemistry.
N_2O	0.1 ppmv	Decreases with altitude, season, and latitude.	Source of stratospheric NO.
CO	0.05 ppmv	May decrease above tropopause, but actual profile and variations are unknown.	Indicator of troposphere-stratosphere exchange. By-product of CH_4 chemistry.

TABLE 3-IV
TRACE ATMOSPHERIC CONSTITUENTS [1]

Species	Concentration at 20 km	Variability	Importance
HNO_3	3 ppbv	With height, season, latitude and possibly diurnally.	O_3-chemistry specifically sink of NO_x, long residence time, therefore, useful as a tracer, and source of nitrate particles
NO_2	3 ppbv	5 ppbv at altitude >30 km unknown but seems to vary somewhat with altitude	Catalytic reaction with O_3
NO	0.1 ppbv	Unknown, some variation with altitude	Catalytic reaction with O_3
OH	10^{-4}ppbv (estimated)	Unknown - may be related to H_2)	Ozone chemistry, Aerosol chemistry, methane oxidation which generates CO
HCl	1 ppbv	Unknown	Ozone chemistry, Aerosol chemistry
Cl	10^{-5} ppbv (estimated)	Unknown	Ozone chemistry
ClO	Unknown	Unknown	Ozone chemistry
CH_2O	<2 ppbv	Unknown	May be important in OH budget
O	10^{-5} ppbv (estimated)	Unknown	Involved in a variety of photochemical reaction
NH_3	Unknown	Unknown	Particle formation, and involved in HCl chemistry
SO_2	Unknown	Unknown	Particle formation
<HC>	Unknown	Unknown	OH budget, particle formation

background material only. A complete development of the properties and measurement requirements of stratosphere species is given later in Section 3.3.

Besides these chemical constituents, a layer of particles several kilometers thick exists in the stratosphere. This layer, called the "Junge layer", is located several kilometers above the tropopause. The Junge, or sulfate, layer has a particle density of two to ten times that exhibited above and below this layer. The particle size is predominately in the 0.1 to 1.0 μm radius range. The particle distribution shows a decreasing concentration with increasing size. The particles consist mainly of sulfuric acid solutions and are probably in a supercooled liquid state.

The stratosphere contains many different kinds of reactive chemical species. Any one of these species can react with a number of others, or be generated by a variety of other reactions in which it does not directly take part.

As related to stratospheric chemistry in general, three types of reactions may be distinguished. These are:

- Photochemical reactions,
- Homogeneous reactions, and
- Heterogeneous reactions.

Photochemical reactions involve the interaction of electromagnetic radiation of varying wavelengths with constituents of the stratosphere. Photochemical interactions are the only known source of stratospheric ozone production.

Homogeneous reactions are those reactions in which both the reactant species and the products are in a gaseous phase. If in these reactions a "third body" is needed to carry off energy to prevent dissociation of the product, that third body is a gas molecule.

Heterogeneous reactions are those reactions in which a particle, solid or liquid, interacts with gaseous species. The interaction may be catalytic, or the particle itself may take part in the reaction.

The photochemical reaction scheme that involves the decomposition of O_3 by NO_x (NO, NO_2, NO_3, etc.) is at present considered to be dominant in the natural ozone balance. The complete nitrogen cycle included in the stratospheric mathematical models is shown in Figure 3-3. A simple description of the NO_x picture in the stratosphere is essentially as follows. NO is formed in the stratosphere by the reaction

$$O(^1D) + N_2O \rightarrow 2NO, \qquad (1)$$

where $O(^1D)$ is produced by Hartley dissociation of ozone, as described above, while N_2O (nitrous oxide) is formed on the ground through biological processes and diffuses upward. Once NO is formed, a photochemical steady state is established between NO and NO_2 (nitrogen dioxide). The reactions involved are:

$$2NO + O_2 \rightarrow 2NO_2, \qquad (2)$$

$$NO + O_3 \rightarrow NO_2 + O_2, \text{ and} \qquad (3)$$

$$NO_2 + h\nu \rightarrow NO + O. \qquad (4)$$

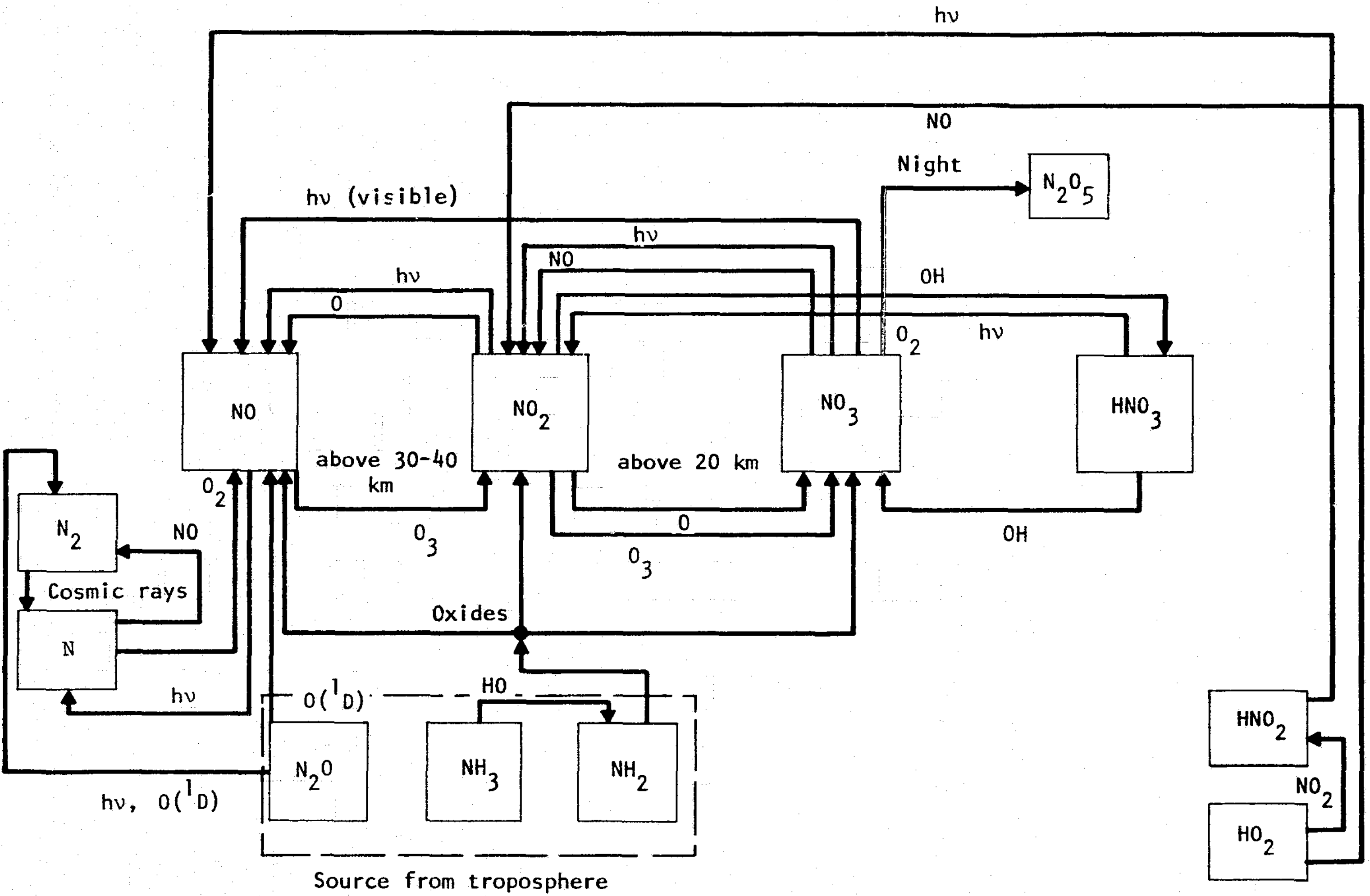

FIGURE 3-3
COMPLETE NITROGEN CYCLE [1]

This results mainly in NO_2 at night and NO in the daytime. This is followed by:

$$NO + HO_2 + (M) \rightarrow HNO_3 + (M), \qquad (5)$$

$$NO_2 + OH + (M) \rightarrow HNO_3 + (M), \text{ and} \qquad (6)$$

$$NO + OH \rightarrow HNO_2 + (M) \qquad (7)$$

which may possibly proceed through heterogeneous reactions involving ambient sulfate droplets or particles. HNO_2, and especially HNO_3 (nitric acid), are the only presently known sinks of stratospheric NO_x.

Another chemical compound which has recently been recognized as essential in the stratospheric ozone chemistry is HCl (hydrogen chloride)[7]. HCl can produce free chlorine which can, in turn, interact catalytically with O_3. A simplified diagram shows the interaction mechanisms, Figure 3-4.

The reactions described so far are homogeneous and photochemical. Recent investigations indicate that the effects of heterogeneous reactions may be quite significant in the overall stratospheric chemistry[8]. For this reason, further work in this direction is presently being conducted by several groups.

Of at least equal importance to stratospheric processes is the concentration and composition of stratospheric aerosols. The concentration of these sub-micron aerosols has been observed to vary over the years depending upon the frequency and magnitude of volcanic eruptions.

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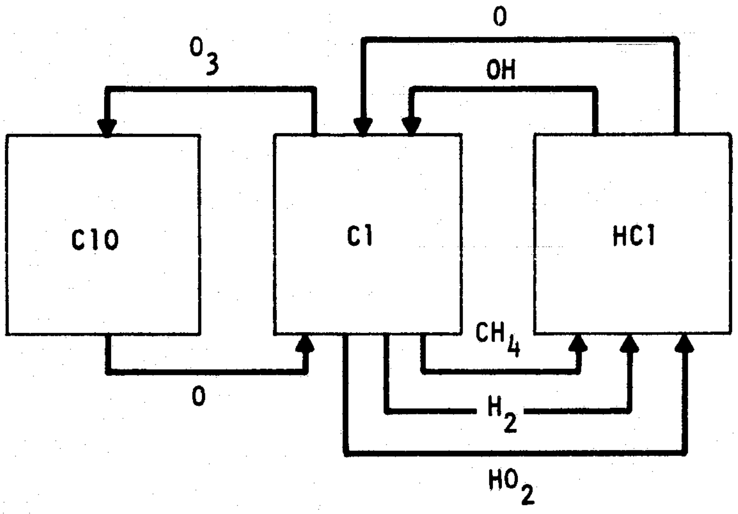

FIGURE 3-4
CHLORINE CYCLE [1]

The Junge, or sulfate layer, which is predominately composed of sulfate aerosols is located at about 20 kilometers altitude, more precisely between 6 and 10 kilometers above the tropopause. Several studies have been conducted to assess the effect these aerosols could have upon the earth's energy budget. Although the concentration of stratospheric aerosols is less than that of the *in situ* gases, these studies suggest that variations in the aerosol population can significantly affect atmospheric process. It is, therefore, useful to understand their sources and sinks.

A summary of recent papers on the formation and chemical composition of stratospheric aerosols is used to evolve an aerosol chemical model presented in Appendix B. This appendix also contains the meso-scale vertical and latitudinal distributions of atmospheric aerosols and an aerosol-size distribution model for three stratospheric altitudes.

3.1.2 Sources of Stratospheric Pollutants

The contaminants introduced into the stratosphere originate from both man-made and natural sources. Whether the contaminants are directly introduced into the stratosphere, or are diffused from the troposphere, two categories of man-made sources should be identified. To the first category belong the supersonic (SST) and subsonic aircrafts, flying above the tropopause, and the Shuttle booster. The additional nitrogen oxide produced by the aircraft engines increases the rate of catalytic chemical reactions between NO_x and O_3, and may seriously diminish the ozone layer which protects the earth from the UV rays of the sun. In addition to this, the aircraft engine effluents, such as SO_2 (sulfur dioxide) and H_2O, may form sulfuric acid particles which alter the heat transfer to and from the earth and affect the earth's climate. In the case of the Shuttle, the engine effluent of concern is HCl. Hydrogen chloride acts as a catalyst to NO_x, thereby reducing the ozone. This is demonstrated in Section 3.1.1. The Al_2O_3 (aluminum oxide) particles emitted by the Shuttle engines play a similar role to produce sulfuric acid particles which affect the radiation balance on the earth's surface.

The second category of man-made sources is contaminants released in the troposphere and which diffuse into the stratosphere. Chlorofluoromethane gases $CFCl_3$ and CF_2Cl_2, known as Freon 11 and 12 respectively, are used as propellants in aerosol sprays and as a refrigerant. In the troposphere, Freons are themselves chemically inert, and do not react directly with ozone or ordinary oxygen atoms. However, after diffusing into the stratosphere they absorb short wavelength ultraviolet radiation (1900 to 2250Å) and each chlorofluoromethane molecule decomposes to release atomic chlorine. Atomic chlorine attacks O_3 through the catalytic chain reaction. More recently it has been suggested that bromine may be considerably more potent in destroying stratospheric ozone, but so far no bromine carriers similar to the Freons have been found.

The investigation of the natural sources of stratospheric pollutants is in its early stages. In general, volcanos, oceans, and plants have been suggested as natural sources of stratospheric contaminations. Preliminary estimates of the annual emission of HCl, HF, and SO_2 to the stratosphere from volcanic eruptions consider such emissions as nonsignificant[9]. Exceptions, however, are possible for short periods following very intense volcanic activities.

The contaminants introduced in the stratosphere by these sources have two consequences:

(1) Reduced O_3 concentrations, and

(2) Increased aerosol concentrations.

Since O_3 concentration controls the amount of UV-B radiation (280-320 nm) that reaches the surface of the earth, a reduction in O_3 concentration will increase the amount of this radiation, which has been shown to cause skin cancer and other biological effects[10]. The increase in aerosol concentrations (besides increasing the potential for hetrogeneous reactions whose effects are not well understood at present) will perturb the radiation balance of the earth's atmosphere and may lead to climatic changes, affecting sunshine, temperature, and precipitation. In addition to these, CO_2 and H_2O vapor introduced into the stratosphere by aircraft or Space Shuttle vehicles may increase the greenhouse effect and lead to stratospheric warming, which would perturb the natural circulation of the stratosphere. In general the interrelationships among pollution sources and their implications, which are schematically presented in Figure 3-5, belong to two chains. These chains are the UV chain and the climate chain.

3.1.3 The Role of Atmospheric Constituents in Climate

A number of components of the atmosphere can be identified as playing a role in climate and its variability. Among these are CH_4, N_2O, O_2, O_3, CO_2, and H_2O, whose role and impact are fairly well understood, and aerosols, whose effects are not so well understood[11].

In each case there is considerable interest in man's ability to alter the natural concentration and location of these constituents either by their direct release or by the emission of constituents which interact in a physical or chemical way with components of the atmosphere. Furthermore, as depicted in Section 3.1.1, a complex chemical balance exists in the atmosphere among its many constituents. Among these constituents are those mentioned above as well as others which do not directly participate in determination of the climate in an important way but which indirectly affect climate by their interaction with other, more important species.

Generally, the connection between the concentration of gases and climate parameters is by way of the electromagnetic absorption, emission and scattering properties of the material. For example, the gases mentioned above participate in the establishment of the vertical temperature profile of the atmosphere by way of their absorption spectra[12] (see Figure 3-6). Considerable ultraviolet radiation is

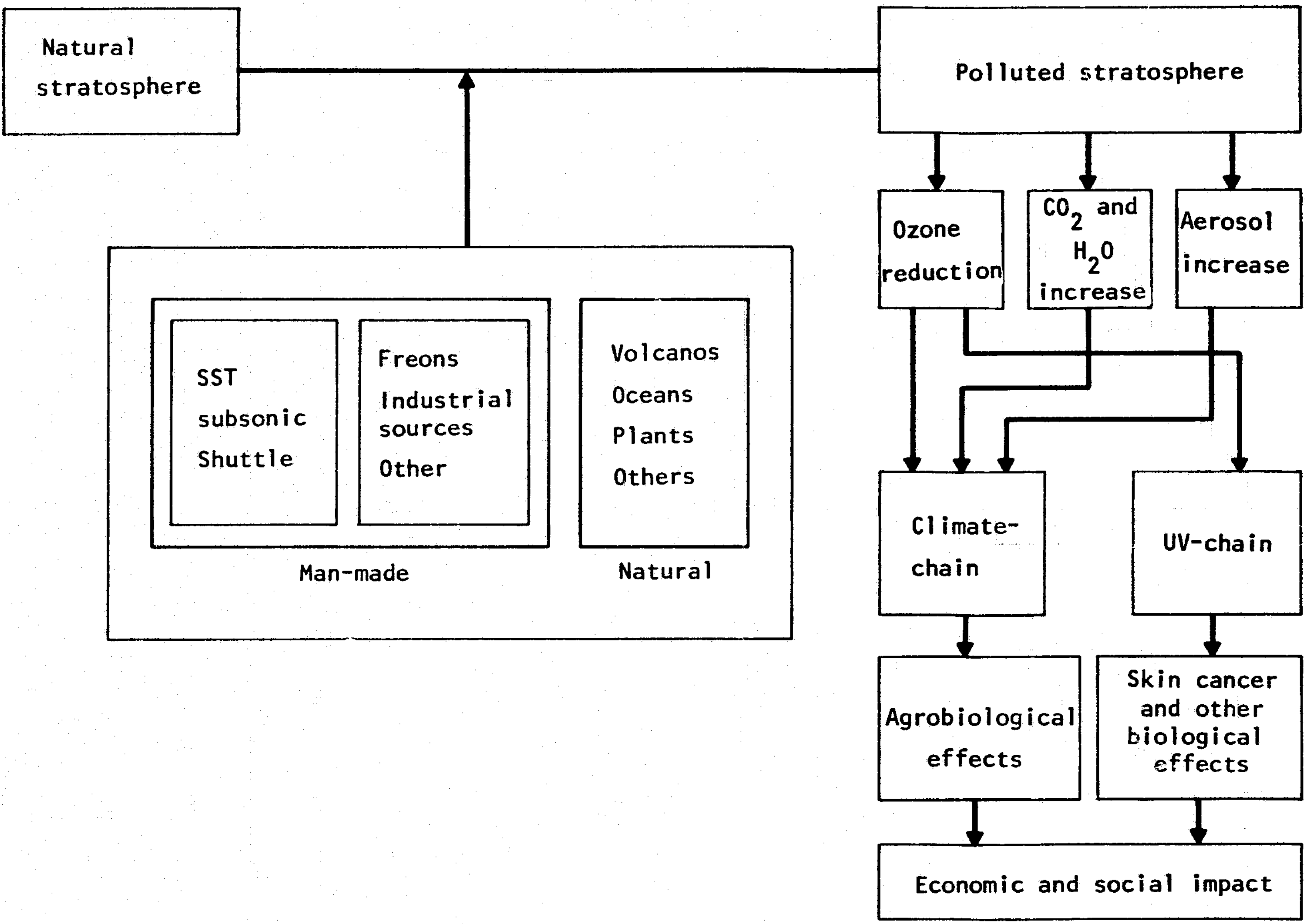

FIGURE 3-5
STRATOSPHERIC POLLUTION EFFECTS [1]

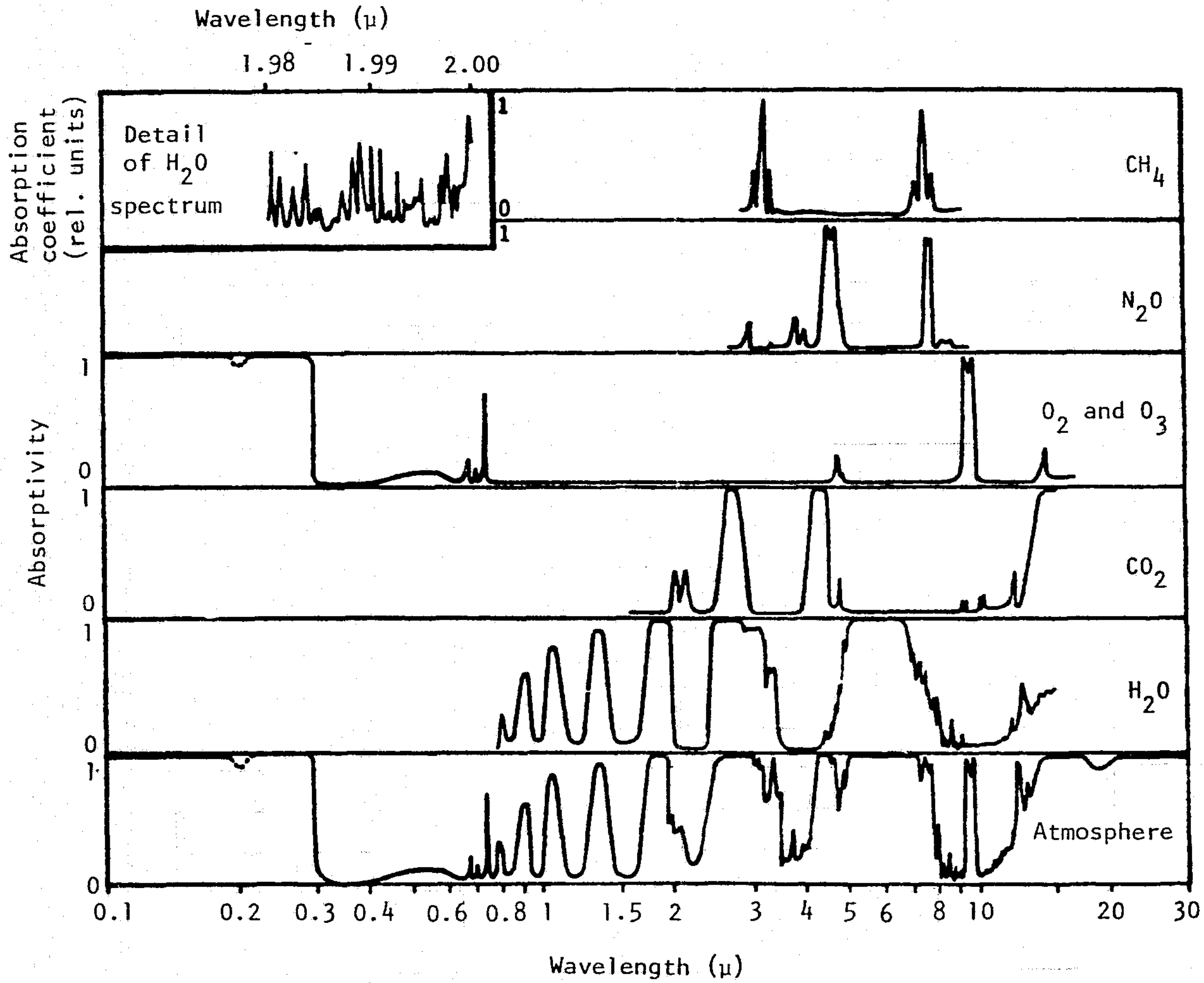

FIGURE 3-6
ABSORPTION SPECTRA FOR H_2O, CO_2, O_2, O_3, N_2O, CH_4
AND THE ATMOSPHERE[12]

absorbed in the upper atmosphere by O_2 and in the stratosphere and mesosphere by O_2 and O_3 . In the lower stratosphere and troposphere O_2, H_2O, CO_2, clouds and particulates participate in the absorption process. As shown in Figure 3-7, this entire absorption process consumes 22 percent of the incident solar radiation[13]. In addition to the absorption of solar radiation, the constitutents of the atmosphere participate in radiation and absorption processes in the infrared wavelengths which determine both the atmospheric temperature profile and the amount of radiation lost from the earth-atmosphere system to space. The loss of radiation from various levels from the atmosphere to space is balanced by convective transport of warmer air of the lower atmosphere. It is in this convection process that the latent heat of condensation is released during the formation of clouds.

3.1.4 Research Programs

Climatic programs received the earliest impetus with United Nations actions of the early 1960s. The immediate result was the formation of the World Weather Watch within the auspices of the World Meteorological Organization (WMO). By 1967, the concept of the Global Atmospheric Research Program (GARP) was being formulated. The GARP is continuing to provide worldwide data such as that collected during the recent GARP Atlantic Tropical Experiment (GATE). Similar programs are collecting data in polar regions (POLEX) and in the monsoon areas (MONEX). The above programs will continue until the

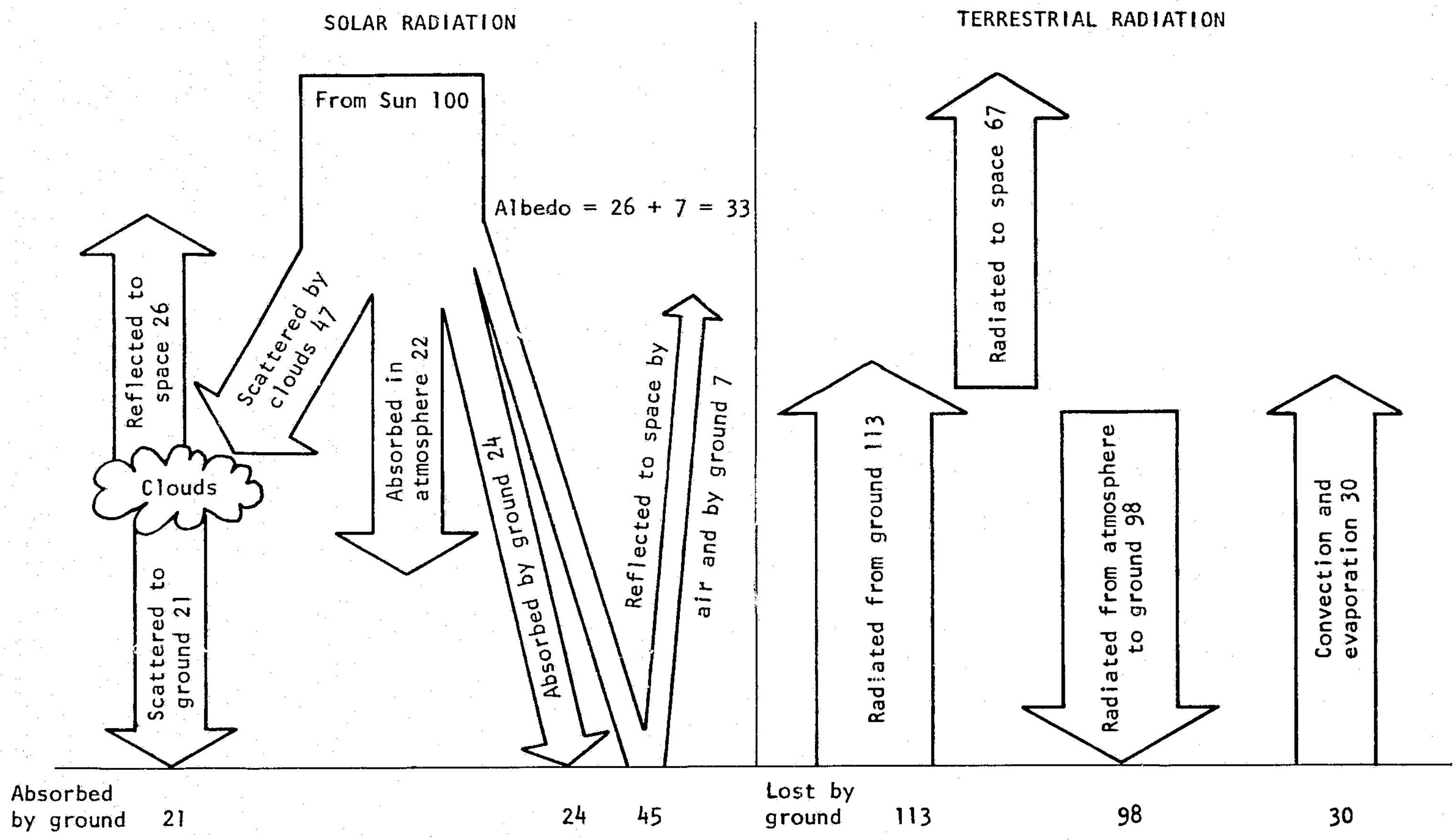

FIGURE 3-7
RADIATION BUDGET OF THE ATMOSPHERE AS A PERCENT OF INCOMING SOLAR RADIATION [13]

major global monitoring program FGGE (First GARP Global Experiment) begins to collect data, in 1977-78. FGGE represents the largest international program yet devised to monitor the Earth's atmosphere.

Current and planned domestic programs include those of NASA, NOAA and various Defense Department activities. NASA will continue its role in satellite development well into the 1990s, with planned spacecraft such as TIROS-N, NIMBUS-G, SEASAT and SAGE. Some subsequent Shuttle missions will have atmospheric monitoring and meteorological emphasis. With NOAA, The National Weather Service and the National Ocean Survey have continuing operational requirements which will extend the atmospheric data base.

Concern with man's modification of the atmosphere in general, and the stratosphere in particular, resulted in the Climatic Impact Assessment Program (CIAP) within the Department of Transportation (DOT) in 1971. The National Academy of Sciences (NAS) formed a Climatic Impact Committee to advise DOT[5] on the results of CIAP[6]. Both reports have now been released and will foster continued research in atmospheric processes. Each study reflected concern for the earth's ozone layer, from the action of both oxides of nitrogen and chlorofluoromethanes (CFMs). The latter concern led to the formation of the Federal Interagency Task Force on Inadvertant Modification of the Stratosphere (IMOS) in 1975. The results from all of these committees have been twofold: an increase in our understanding of the atmosphere and the realization of how much more information is required in order to make future decisions. This is certain to result in the continuation of many existing monitoring programs and the creation of new activities.

3.2 Development of Scientific Criteria

The scientific criteria developed for stratospheric pollution measurements must have as their bases the major objectives of the entire stratospheric program. These objectives may be primary or secondary depending upon the nature of their interaction with man and his environment. The primary objectives are:

- Monitoring climatic changes caused by changes in the concentrations of the various stratospheric trace constituents, particularly aerosols; and,
- Monitoring changes in ultraviolet received at the earth's surface as a result of changes in the concentrations of the various stratospheric trace constituents, particularly ozone.

The secondary objectives may be considered as indirect objectives of the entire program. These are:

- Increased understanding of the chemistry and physics of the stratosphere and its constituents; and,
- Increased understanding of the meteorology and hydrodynamics of the stratosphere.

Obviously there is considerable overlap between the primary and secondary objectives, since the latter have a much broader scope which includes the former.

The next section presents a discussion that supports the prioritization of the measurements into the various groupings shown.

3.2.1 Prioritization of Measurements

The list of stratospheric measurements has been presented in six groups which are considered to be of descending order of importance in terms of the absolute need for the measurement without regard to present knowledge or measurement capability. However, it must be emphasized at this point that none of these groups is considered unimportant. The groupings merely show the degree of importance, and relative placement within a group has no significance.

The rationale for placement of a required measurement in any one of the categories is given below:

Group 1. This group contains those properties and species which are considered to be directly related to changes in climate and/or the ultraviolet flux. For example, ozone is directly related to the major absorption of ultraviolet while the Freon compounds are not. This group has been subdivided into Group 1A which lists direct measurement of stratospheric properties such as temperature; and Group 1B which lists measurements of stratospheric species directly associated with changes in climate and/or ultraviolet flux such as ozone.

Group 2. Groups 2 through 5 list the various components of the major chemistry chains of the stratosphere, such as the chlorine chain or the nitrogen oxides chain. The four species shown in Group 2 have been so identified since they are associated with two or more of these chemistry chains.

Group 3. In this group are listed the components of the basic reactions involved in the direct production or depletion of the ozone concentration in the stratosphere (except for atomic oxygen and the hydroxyl radical which are already shown in Group 2). These species participate in the principal chemical equations which directly involve ozone. These equations are given below for each of the significant chemistry chains:

Pure oxygen reactions:

$$O_3 + h\nu(\lambda: 450\text{-}650\,\text{nm}) \longrightarrow O + O_2$$

$$O_3 + h\nu(\lambda: 310\text{-}340\ \text{nm}) \longrightarrow O_2\ (1\ ) + O(^3P)$$

$$O_3 + h\nu(\lambda < 310\,\text{nm}) \longrightarrow O\ (^1D) + O_2$$

$$O + O_2 + M \longrightarrow O_3 + M$$

$$O_3 + O \longrightarrow O_2 + O_2$$

Hydrogen-oxygen reactions:

$$H + O_3 \longrightarrow OH + O_2$$

$$OH + O_3 \longrightarrow HO_2 + O_2$$

$$HO_2 + O_3 \longrightarrow OH + 2O_2$$

Nitrogen-oxygen reactions:

$$O_3 + NO \longrightarrow NO_2 + O_2$$

$$NO_2 + O_3 \longrightarrow NO_3 + O_2$$

Chlorine-oxygen reactions:

$$Cl + O_3 \longrightarrow ClO + O_2$$

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Group 4. This group contains those species considered to be the most important ones in the indirect chemistry chains; that is, those which result in the production or depletion of the major species discussed under Group 3.

Group 5. This group contains those species considered to be involved in a lesser but not unimportant way in the indirect chemistry chains discussed above.

Group 6. This group lists those specific aerosols mentioned in the various references consulted. For the most part their role in the stratospheric aerosol chain is not understood. In fact, the existence of some of the species is only speculative or based on theory.

3.2.2 Species and Properties of Interest

As stated previously, this section presents the list of stratospheric measurements that should be made. The measurements are grouped according to the criteria discussed in Section 3.2.1. These groupings were made by MITRE after analyzing all available references that discuss the importance of the various species. It is interesting to note that after the original groupings were completed a major publication by the National Academy of Sciences[17] was received which provided verification of the MITRE groupings. Table 3-V presents this list along with the major references supporting the selection of the measurement and its placement in the appropriate

TABLE 3-V
PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS

	[13]	[14]	[15]	[16]	[17]	[18]
Group 1A, Direct Measurements of Climatic Change and Ultraviolet Change						
Temperature	x	x	x	x	x	
Solar Irradiance (including UV)	x	x	x	x	x	
Earth Radiance	x		x	x	x	
Group 1B, Species Directly Associated with Changes in Climate and/or Ultraviolet						
Water Vapor, H_2O	x		x	x	x	
Ozone, O_3	x	x	x	x	x	
Aerosols	x	x	x	x		
Carbon Dioxide, CO_2	x		x			
Group 2, Important Species Associated with Two or More Chemistry Chains						
Hydroxyl, OH	x		x	x	x	
Atomic Oxygen, $O(^3P)$	x	x		x		
Atomic Oxygen $O(^1D)$	x	x		x		
Ammonia, NH_3	x			x		
Group 3, Components of the Basic Reactions Involved in the Direct Production or Depletion of the Ozone Concentration						
Nitric Oxide, NO	x	x	x	x	x	
Nitrogen Dioxide, NO_2	x	x	x	x	x	
Atomic Chlorine, Cl	x	x		x		
Hypochlorite, ClO	x	x	x	x		
Hydrogen, H_2	x	x	x		x	
Hydroperoxyl, HO_2	x	x				

TABLE 3-V (CONTINUED)

	[13]	[14]	[15]	[16]	[17]	[18]
Group 4, Components of the Basic Reactions Indirectly Involved in the Production or Depletion of Ozone						
Nitrous Oxide, N_2O	x	x	x	x	x	
Nitrogen Pentoxide, N_2O_5	x	x		x	x	
Nitric Acid Vapor, HNO_3	x	x	x	x	x	
Carbon Monoxide, CO	x	x	x			
Methane, CH_4	x	x	x	x	x	
Hydrogen Chloride, HCl	x	x	x	x		
Trichlorofluoromethane, Freon 11, $CFCl_3$	x	x		x		
Dichlorodifluoromethane, Freon 12, CF_2Cl_2	x	x		x		
Sulfur Dioxide, SO_2	x		x	x		
Group 5, Other Significant Components of the Chemistry Chains						
Hydrogen Sulfide, H_2S				x		
Hydrogen Fluoride, HF		x				
Hydrogen Bromide, HBr		x				
Tetrachloromethane, Carbon Tetrachloride, CCl_4		x				
Chloromethane, Methyl Chloride, CH_3Cl		x				
Dichloromethane, Methylene Chloride, CH_2Cl_2		x				
Trichloromethane, Chloroform, $CHCl_3$		x				
Hydrogen Peroxide, H_2O_2	x		x			
Ammonium Ion, NH_4^+			x			
Methanal, Formaldehyde, CH_2O	x					
Various Organics, $H_xC_yO_z$			x			
Group 6, Specific Aerosols						
Sulfuric Acid, $H_2SO_4 . nH_2O$	x		x			

TABLE 3-V (CONCLUDED)

	[13]	[14]	[15]	[16]	[17]	[18]
Sulfate, SO_4	x		x			x
Sulfur Dioxide (in cluster formation), nSO_2	x		x			
Nitric Acid (as Aerosol), $nHNO_3$	x		x			
Nitrate, NO_3 -	x		x		x	x
Nitrite, NO_2 -			x			x
Nitric Oxide (in cluster formation), nNO	x					
Nitrogen (in cluster formation), nN_2	x					
Ammonium Ion, NH_4 +	x		x			x
Ammonium Sulfate, $(NH_4)_2$ SO_4	x		x			
Ammonium Peroxydisulfate $(NH_4)_2S_2O_8$			x			
Liquid Water or Ice (either as aerosol or in cluster formation) nH_2O	x		x			
Carbon Dioxide (in cluster formation) nCO_2	x					
Aluminum Ion, Al+++			x			
Bromide Ion, Br-	x		x			x
Calcium Ion, CA++			x			x
Chloride Ion, Cl-	x		x			x
Copper Ion, Cu++	x		x			
Iodide Ion, I-	x		x			
Iron Ion, Fe++ or FE+++	x					
Magnesium, Mg			x			x
Manganese Ion, Mm++ or Mm+++	x					
Potassium Ion, K+	x		x			
Silicon Ion, Si++++	x		x			
Sodium Ion, Na+	x		x			x

group. A number of other references, [19-43], were consulted during preparation of the list.

3.3 Properties of the Species of Interest

In this section a summary of the properties of the measurements and species of interest is presented. A generalized summary of the present knowledge of the four dimensional distributions is given along with some of the measurement requirements. The remainder of the section presents typical distributions for various species for which sufficient measurements exist.

3.3.1 Present Knowledge of Distributions and Generalized Measurement Requirements

Table 3-VI summarizes the present knowledge of the four dimensional distributions (latitude, longitude, altitude, and time) of those species and measurements in the prioritized list of desired stratospheric measurements (Section 3.2.2). In addition, the table contains a few of the measurement requirements considered to be pertinent. The distribution information was gathered in general from the same references used to develop the prioritized list of measurements shown in Table 3-V plus various other references. It is not considered necessary to present this information in any detail other than the table summary to satisfy the objectives of this study. The references cited above present these distributions in detail.

GROUP 1	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIUR
1A TEMPERATURE	2°K	C = 3 R = 2	4	WINTER: Cold equator; warm mid-lat; cold pole SUMMER: cold equator; warm high-lat.	High variability	Cold at tropopause; warming up to mesopause	Few measur exist. Cu under inve
1A SOLAR IRRADIANCE (including UV)	5%	C = N.A. R = 3	4	Directly related to solar angle	No variation at top of atmosphere	Relatively constant >45 km; decreases by 90% at 20 km for λ = 305 nm	0 at night at solar n
1A EARTH RADIANCE	5%	C = N.A. R = 3	4	Decreases from solar equator to poles	Varies with temperature, water vapor and clouds	Varies with temperature profile, water vapor and clouds	Maximum at minimum at
1B WATER VAPOR, H_2O	25%	C = 2 R = 2	2	At 18 km altitude: Factor of two higher in tropics than polar regions	Unknown in upper stratosphere; should follow surface weather in lower stratosphere	Between 14 to 28 km; log. decrease of 90% in mixing ratio	No known c
1B OZONE, O_3	Vertical Profile: 10% Total Ozone: 1%	Vertical Profile: C = 3 R = 2 Total Ozone: C = 3 R = 3	4	Total O_3 higher at poles; lower at equator; North Pole > South Pole	10 to 15% variation in total O_3	Partial pressure maximum at 22 km average altitude	Unknown; p small
1B AEROSOLS	10 to 20%	C = 3 R = 3	4	Increase at equator; decrease at poles; largest gradient mid-latitudes	Relatively unknown	Decrease with altitude; maximum at 20 km (sulfate layer); maximum at 50 km (dust layer)	Neglibible

LEGEND:

Desired Accuracy
AVM - Any valid measurement

Present Measurement Capability
C - Contact measurements
R - Remote measurements
0 - No technique exists which is workable for the stratosphere
1 - Techniques under development
2 - Techniques exist but need improvement
3 - Techniques exist and are relatively adequate

Present Knowledge of Distribution

0 - No measurements known
T - Theoretical estimates only
1 - A few measurements taken; distributions not known
2 - A few measurements taken; distributions proposed but may be in error
3 - Enough measurements taken to give a plausible distribution
4 - Four dimensional variations reasonably well measured

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TION		TEMPORAL VARIATION						
L	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
ty	Cold at tropopause; warming up to mesopause	Few measurements exist. Currently under investigation	Varies up to 20°K	Biennial; possible solar cycle	Lower stratosphere varies with surface weather	No preferred launch time	Required	Continuous
top	Relatively constant >45 km; decreases by 90% at 20 km for $\lambda = 305$ nm	0 at night; maximum at solar noon	Directly related to solar angle	11-year sunspot cycle	Sunspots, solar flares	No preferred launch time; maximum daylight coverage	Required	Several decades
mper- apor	Varies with temperature profile, water vapor and clouds	Maximum at midday, minimum at night	Maximum in summer, minimum in winter	Negligible	Negligible	No preferred launch time	Not required	Several decades
er sur- n here	Between 14 to 28 km; log. decrease of 90% in mixing ratio	No known change	Maximum: Late summer; Minimum: Late winter	From 1964 to 1970 steady increase of 25 to 65% in mixing ratio depending on altitude	Probable change in lower stratosphere after thunderstorms	No preferred launch time	Required	Several years
ation	Partial pressure maximum at 22 km average altitude	Unknown; probably small	8 to 10% at equator; 30 to 50% at poles	3% biennial cycle; 11-year sunspot cycle	Weather patterns affect lower stratosphere; possible volcanic effect	No preferred launch time	Required	Several decades
nown	Decrease with altitude; maximum at 20 km (sulfate layer); maximum at 50 km (dust layer)	Neglibible	Inversely proportional to tropopause height; i.e., seasonal	Unknown	Volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

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TABLE 3-VI
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 1 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL
1B CARBON DIOXIDE, CO_2	0.1%	C = 3 R = 2	3	Negligible	Negligible	Negligible	Negligible
GROUP 2							
HYDROXYL, OH	AVM	C = 2 R = 0	T	Unknown	Unknown	Number density increases two orders of magnitude from 10 km to 45 km; decreases above 45 km	Disappears f lower and mi stratosphere night; const upper strato
ATOMIC OXYGEN, $O(^3P)$	AVM	C = 1 R = 0	T	Unknown	Unknown	Mixing ratio increases with altitude by five orders of magnitude from 15 to 50 km	None produce night
ATOMIC OXYGEN, $O(^1D)$	AVM	C = 1 R = 0	T	Unknown	Unknown	Mixing ratio of seven orders of magnitude less than $O(^3P)$; possible maximum at 45 km	None produce night
AMMONIA, NH_3	AVM	C = 0 R = 1	T Estimate 10^{-6} μg/m^3 at 20 km	Theoretically higher over equator than mid-latitudes	Unknown	Theoretically increasing above tropopause to maximum at tropopause plus 8 km; decreasing above	Unknown
GROUP 3							
NITRIC OXIDE, NO	25%	C = 2 R = 2	3	Possible high near equator; secondary maximum at 65°N	Unknown	Mixing ratio increases with altitude	Maximum duri light; rapid crease after
NITROGEN DIOXIDE, NO_2	25%	C = 0 R = 2	2	Only mid-latitude data measured	Unknown	Mixing ratio increases from 0.5 ppbv at 15 km to 3 to 5 ppbv at 30 km; 4.5 ppbv at 40 km	Theoretical increase at decrease in Actual measu shows opposi
ATOMIC CHLORINE, Cl	25%	C = 0 R = 1	T 0.3 to 3 pptv at 30 km	Unknown	Unknown	Unknown	Unknown
HYPOCHLORITE, ClO (Chlorine Monoxide)	25%	C = 0 R = 0	T 30 pptv at 30 km	Unknown	Unknown	Unknown	Unknown

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VERTICAL	TEMPORAL VARIATION DIURNAL	 SEASONAL	 BEYOND ANNUAL	 NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
Negligible	Negligible	Negligible	Unknown	Possible long-term increase	Short-term intermittent. Surveys with no preferred launch	Not required	Several decades, intermittent
Number density increases two orders of magnitude from 10 km to 45 km; decreases above 45 km	Disappears from lower and middle stratosphere at night; constant in upper stratosphere	Unknown	Unknown	Unknown	Short-term, day and night coverage	Required	Short-term
Mixing ratio increases with altitude by five orders of magnitude from 15 to 50 km	None produced at night	Unknown	Unknown	Unknown	Short-term, daylight coverage	Required	Short-term
Mixing ratio of seven orders of magnitude less than $O(^3P)$; possible maximum at 45 km	None produced at night	Unknown	Unknown	Unknown	Short-term, daylight coverage	Required	Short-term
Theoretically increasing above tropopause to maximum at tropopause plus 8 km; decreasing above	Unknown	Unknown	Unknown	Unknown	Short-term, no preferred launch time	Required	Short-term
Mixing ratio increases with altitude	Maximum during daylight; rapid decrease after sunset	Maximum-summer; minimum-winter	Unknown	Unknown	Launch with emphasis on diurnal	Required	One-year minimum
Mixing ratio increases from 0.5 ppbv at 15 km to 3 to 5 ppbv at 30 km; 4.5 ppbv at 40 km	Theoretical increase at night, decrease in daytime. Actual measurement shows opposite	Unknown	Unknown	Unknown	Launch with emphasis on diurnal	Required	One-year minimum
Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

TABLE 3-VI (Continued)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 3 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITIES	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL
HYDROGEN, H_2	AVM	C = 2 R = 0	Vertical Profile = 2 Other data = 0	Unknown	Unknown	Few profiles show increase above tropopause from 0.5 ppmv to maximum of >1.0 ppmv at 28 km, decreasing above	Unknown
HYDROPEROXYL, HO_2	AVM	C = 0 R = 0	T	Unknown	Unknown	Theoretical models show number density increasing above 10 km to a maximum at 20 to 30 km, decreasing above	Unknown
GROUP 4							
NITROUS OXIDE, N_2O	5%	C = 2 R = 2	Mid-latitude vertical profile = 2. Other distributions = 0.	Only mid-latitude data measured	Unknown	Mixing ratio decreases from 0.25 ppmv at 20 km to 0.1 ppm at 30 km, and <0.01 at 45 to 50 km	None
NITROGEN PENTOXIDE, N_2O_5	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Formed at n tributions
NITRIC ACID VAPOR, HNO_3	25%	C = 2 R = 2	3	Springtime data shows low values over equator, maximum values mid to high latitudes; varies by factor of 3	Unknown	Mass mixing ratio shows large gradient at tropopause, increasing to maximum at 20 to 25 km	None or sma
CARBON MONOXIDE, CO	AVM	C = 2 R = 1	1	Unknown	Unknown	Mixing ratios decrease from 0.15 ppmv at tropopause to 0.04 ppmv at 1 km above tropopause, then constant to 30 to 40 km	Unknown
METHANE, CH_4	20%	C = 2 R = 2	1	Unknown	Unknown	Mixing ratios range from 1.5 ppmv at the tropopause to 0.3 ppmv at 50 km	Unknown
HYDROGEN CHLORIDE, HCl	50%	C = 2 R = 1	2	Tendency toward higher values at higher latitudes. No data above 45°N	Unknown	Mixing ratio shows large gradient at tropopause; increasing by an order of magnitude at 18 to 22 km. Values from 22 to 28 km relatively constant	Unknown

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	TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
ew profiles show ncrease above ropopause from 0.5 pmv to maximum of .0 ppmv at 28 km, ecreasing above	Unknown	Unknown	Unknown	Unknown	No preferred l.unch time	Required	Short survey
heoretical models how number density ncreasing above 10 n to a maximum at 0 to 30 km, de- reasing above	Unknown	Unknown	Unknown	Unknown	High frequency of measurement over short time	Required	Short survey
ixing ratio de- reases from 0.25 pmv at 20 km to .1 ppm at 30 km, nd <0.01 at 45 to 0 km	None	Unknown	Unknown	Unknown	Intermittent measurements with no preferred launch time	Required	One-year minimum
nknown	Formed at night, distributions unknown	Unknown	Unknown	Unknown	Launch with emphasis on diurnal	Required	Short survey
ass mixing ratio hows large gradi- nt at tropopause, ncreasing to maxi- um at 20 to 25 km	None or small	Maximum winter, minimum late spring	Unknown	Unknown	No preferred launch time	Required	One-year minimum
ixing ratios de- rease from 0.15 pmv at tropopause o 0.04 ppmv at 1 m above tropopause, hen constant to 30 o 40 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
ixing ratios range rom 1.5 ppmv at he tropopause to .3 ppmv at 50 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
ixing ratio shows arge gradient at ropopause; increas- ng by an order of agnitude at 18 to 2 km. Values from 2 to 28 km rela- ively constant	Unknown	Unknown	Unknown	Unknown; possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

TABLE 3-VI (Continued)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 4 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	
TRICHLOROFLUOROMETHANE, FRECN 11 ($CFCl_3$) (Estimated to correspond to ^{85}Kr distribution in lower stratosphere)	AVM	C = 2 R = 0	2	Maximum in tropical regions, decreasing toward both poles	Unknown; theoretically should follow stratospheric weather patterns	80 to 90 pptv at 15 km, decreasing to 20 to 50 pptv at 20 km	Unkno
DICHLORODIFLUOROMETHANE, FREON 12 (CF_2Cl_2)	AVM	C = 0 R = 0	0	Unknown*	Unknown*	Unknown*	Unkno
SULFUR DIOXIDE, SO_2	AVM	C = 0 R = 1	0	Unknown	Unknown	10^{-6} $\mu g/m^3$ at 20 km	Unkno
GROUP 5							
HYDROGEN SULFIDE, H_2S	AVM	C = 0 R = 0	T Estimated 10^{-7} $\mu g/m^3$ at 20 km	Unknown	Unknown	Unknown, 0.05 ppbv measured in lower troposphere (CIAP)	Unkno
HYDROGEN FLUORIDE, HF	AVM	C = 0 R = 1	0	Unknown	Unknown	Unknown	Unkno
HYDROGEN BROMIDE, HBr	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
TETRACHLOROMETHANE, CARBON TETRACHLORIDE, CCl_4	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
CHLOROMETHANE, METHYL CHLORIDE, CH_3Cl	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
DICHLOROMETHANE, METHYLENE CHLORIDE, CH_2Cl_2	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
TRICHLOROMETHANE, CHLOROFORM, $CHCl_3$	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
HYDROGEN PEROXIDE, H_2O_2	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
AMMONIUM ION, NH_4^+	AVM	C = 0 R = 0	T	Unknown	Unknown	Estimated 0.005 $\mu g/m^3$ at 20 km	Unkno

[*] Theoretically should be proportional to FREON 11 concentrations

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	TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
RTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
90 pptv at 15 creasing to 50 pptv at	Unknown	Maximum shifts near equator in spring toward 20°N in fall. No data for winter and summer.	Unknown; theoretically should follow stratospheric weather patterns	Unknown; theoretically should follow stratospheric weather patterns	Initial missions in winter and summer	Required	Short surveys every few years
n*	Unknown*	Unknown*	Unknown*	Unknown*	No preferred launch time	Required	Short survey to establish F-11/F-12 ratio
g/m^3 at 20	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Required	Short survey
n, 0.05 ppbv ed in lower phere (CIAP)	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
n	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
ated 0.005 at 20 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey

TABLE 3-VI (Continued)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 5 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION		
				LATITUDINAL	LONGITUDINAL	VERTICAL
METHANAL, FORMALDEHYDE, CH_2O, (Mixing ratio upper limit 10^{-8}, based on one marginal measurement)	AVM	C = 0 R = 0	T	Unknown	Unknown	Theoretically number density decreases from $10^8/cm^3$ at 10 km to $4x10^6/cm^3$ at 40 km
VARIOUS ORGANICS, $H_xC_yO_z$	AVM	R = 2 R = 1	0	Unknown	Unknown	Unknown
GROUP 6						
SULFURIC ACID, $H_2SO_4.nH_2O$	AVM	C = 2 R = 0	3	Estimated mixing ratio increases at poles; decreases at equator; higher in Northern Hemisphere. Maximum gradient 30 to 60° N	Unknown	Mixing ratios increase with altitude in 13 to 20 km range. Estimated decrease above 20 km
SULFATE, $SO_4^=$	AVM	C = 2 R = 0	2	Mixing ratio increases at equator; decreases at poles; maximum gradient at 20 to 40°N	Unknown	Mixing ratios increase with altitude in 13 to 20 km range. Estimated decrease above 20 km
SULFUR DIOXIDE, nSO_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown
NITRIC ACID, HNO_3 (As aerosol)	AVM	C = 0 R = 0	0 Estimated to be about 10% as large as H_2SO_4 aerosol	Unknown	Unknown	Unknown
NITRATE, NO_3^-	AVM	C = 2 R = 0	1	Unknown	Unknown	Estimated 0.1 to 0.14 $\mu g/m^3$ at 18 km
NITRITE, NO_2^-	AVM	C = 0 R = 0	0	Unknown	Unknown	At 20 km $NO_2^- + NO_3^-$ averaged for several flights is 0.01 $\mu g/m^3$
NITRIC OXIDE, nNO (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown
NITROGEN, nN_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown
AMMONIUM ION, NH_4^+	AVM	C = 2 R = 0	1	Unknown	Unknown	At 20 km, 0.005 $\mu g/m^3$ (1975 est.). Earlier data shows 0.015 $\mu g/m^3$

FOLDOUT FRAME 1

	TEMPORAL VARIATION						
VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
oretically number sity decreases m $10^8/cm^3$ at 10 to $4x10^6/cm^3$ at km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
nown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
ing ratios in- ase with altitude 13 to 20 km range. imated decrease ve 20 km	Estimated negligible	Estimated inversely proportional to tropopause height	Unknown	After volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
ing ratios in- ase with altitude 13 to 20 km range. imated decrease ve 20 km	Estimated negligible	Estimated inversely proportional to tropopause height	Unknown	After volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
nown	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Required	Short survey
nown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
imated 0.1 to 0.14 $/m^3$ at 18 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
20 km $NO_2^- + NO_3^-$ eraged for several ghts is 0.01 $/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
nown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
nown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
20 km, 0.005 $\mu g/m^3$ 975 est.). Earli- data shows 0.015 $/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

TABLE 3-VI (Continued)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 6 (Continued)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	
AMMONIUM SULFATE, $(NH_4)_2SO_4$	AVM	C = 0 R = 0	0 Existence indicated by only one investigation team	Unknown	Unknown	Unknown	Unkno
AMMONIUM PEROXYDISULFATE, $(NH_4)_2S_2O_8$	AVM	C = 0 R = 0	0 Existence indicated by only one investigation team	Unknown	Unknown	Unknown	Unkno
LIQUID WATER OR ICE, nH_2O (Either aerosol or in cluster formation)	AVM	C = 2 R = 0	1 Most data based on visual cloud observation, no H_2O concentrations	Theoretically high in tropics, low at the poles	Unknown	Theoretically decreasing with altitude	Theor mum l minim
CARBON DIOXIDE, nCO_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
ALUMINUM ION, Al^{+++} $\Sigma(Al+Ca+Mg+Si)$ estimated at 0.05 $\mu g/m^3$ at 20 km altitude	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
BROMIDE ION, Br^-	AVM	C = 2 R = 0	2	At 17 km mass mixing ratio shows minimum at equator, maximum at poles	Unknown	Filter data at 13 to 20 km shows general increase with altitude from $5x10^{-12}g/g$ to $8x10^{-12}g/g$	Unkno
CALCIUM ION, Ca^{++} $\Sigma(Al+Ca+Mg+Si)$ estimated at 0.05 $\mu g/m^3$ at 20 km altitude	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unkno
CHLORIDE ION, Cl^-	AVM	C = 2 R = 0	1	Unknown	Unknown	0.04 $\mu g/m^3$ at 20 km. 0.0028 to 0.0077 $\mu g/m^3$ at 18 km	Unkno
COPPER ION, Cu^{++}	AVM	C = 2 R = 0	1	Unknown	Unknown	Unknown	Unkno
IODIDE ION, I^-	AVM	C = 2 R = 0	1	Unknown	Unknown	Filter data at 16 to 18 km shows 0.08 μg per 25 cm^2 filter and 2 hr. sample	Unkno
IRON, ION, Fe^{++} or Fe^{+++}	AVM	C = 2 R = 0	1	Unknown	Unknown	Estimated <2% of total aerosol	Unkno

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	TEMPORAL VARIATION						
VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
known	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
known	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
eoretically de- easing with titude	Theoretically maximum late afternoon; minimum at night	Maximum summer, mimimum winter	Unknown	Weather patterns affect lower stratosphere	No preferred launch time	Required	One-year minimum
known	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
known	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
lter data at 13 20 km shows gen- al increase with titude from 10^{-12}g/g to 10^{-12}g/g	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
known	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
04 μg/m^3 at 20 . 0.0028 to 0077 μg/m^3 at 18	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
known	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
lter data at 16 18 km shows 0.08 per 25 cm^2 fil- r and 2 hr. sample	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
timated <2% of tal aerosol	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

TABLE 3-VI (Continued)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 6 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			
				LATITUDINAL	LONGITUDINAL	VERTICAL	
MAGNESIUM ION, Mg^{++} $\Sigma(Al+Ca+Mg+Si)$ estimated at 0.05 $\mu g/m^3$ at 20 km altitude	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown
MANGANESE ION, Mn^{++} or Mn^{++++} (Of 35 filter samples 18 showed no Mn; other 17 averaged 0.00114 $\mu g/m^3$ in 15 to 19 km altitude range)	AVM	C = 2 R = 0	1	Unknown	Unknown	Filter data at 15 to 19 km shows 0.001 $\mu g/m^3$	Unknown
POTASSIUM ION, K^+ (Ion detected but quantitative measurement impossible due to low concentration)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown
SILICON ION, Si^{++++} $\Sigma(Al+Ca+Mg+Si)$ estimated at 0.05 $\mu g/m^3$ at 20 km altitude	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown
SODIUM ION, Na^+	AVM	C = 2 R = 0	1	Unknown	Unknown	0.01 $\mu g/m^3$ at 20 km. 0.013 to 0.0056 $\mu g/m^3$	Unknown

	TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
Unknown	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
Filter data at 15 to 19 km shows 0.001 $\mu g/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
Unknown	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
0.01 $\mu g/m^3$ at 20 km. 0.013 to 0.0056 $\mu g/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

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TABLE 3-VI (Concluded)
PRESENT KNOWLEDGE OF DISTRIBUTIONS
AND
GENERALIZED MEASUREMENT REQUIREMENTS

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Explanations of the various columns related to requirements and present knowledge and capability are given below:

Desired Accuracy. Desired accuracy refers to the accuracy of the data given to the user. In most cases this accuracy is given in percent of the reading. In those cases where no present measurements exist any valid measurement would be a reasonable goal. Accuracies shown were assigned by MITRE after analysis of all available reference material.

Present Measurement Capability. These data are presented for contact and remote techniques. Two factors are worthy of note. First, where the entry shows no technique exists, it does not imply that there is absolutely no way to make such a measurement or that no measurement has ever been made. It merely indicates that in the normal progression of stratospheric investigation no measurement capability exists. Second, where adequate techniques are shown to exist, it is not intended as an indication or recommendation that further instrument or technique development is unnecessary.

Present Knowledge of Distribution. There are no stratospheric constituents for which additional measurements would be useless. The entries are given generally in a relative sense; in most cases where the distribution is shown as well measured much more data are needed for a thorough understanding of stratospheric processes.

Requirements for Time of Launch. This requirement refers basically to the time of the year for the launch and not the time of

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day. Generally speaking, time of launch is important only for short missions where complete diurnal and longitudinal coverage would not be possible. It can also be a factor in missions of only a few months' duration if measurements are desired during a certain season of the year. Since the concentrations of many of the species of interest are assumed to be affected by volcanic ash, some missions may have as their objective measurements made before or after large volcanic eruptions. However, since most satellite missions are multipurpose, it is difficult to establish a launch requirement based on unpredictable volcanic activity.

Vertical Profile. Requirements for vertical profile information are stated in one of three ways. If theoretical or actual knowledge of the species distribution indicates a significant vertical variation, then the requirement for vertical profile measurements is noted. If the species is constant with altitude the vertical profile is not required. For those species with unknown distributions, vertical profile measurements are indicated as desirable rather than required.

Duration of Measurement Program. The total length of the basic measurement program given here is based on present knowledge of distributions. In some cases, although the total duration of the program is long, the actual mission requirements may be intermittent at some medium or long interval, depending on the nature of the species.

3.3.2 Specific Distributions

Table 3-VII presents a compilation of the distributions given in this section.

Figures 3-8 through 3-36 show various distributions for those species having sufficient measurements to allow their presentation. References to the principal sources of the information are shown in the caption for each figure. In all cases, the information is intended to show typical rather than precise data. These figures are presented for purposes of mission planning and not necessarily for precise scientific study.

All vertical profiles for gases are presented on identical base charts for interspecies comparisons at a glance. The profiles show both the number density and the volume mixing ratio of each gas. The other distributions shown are presented in the units used in the original references.

3.4 Summary

This section has presented a general background on the physical and chemical properties of the stratosphere and has discussed the development of the scientific criteria for prioritization of measurements for the various species. Background information has been given on both the natural and anthropogenic sources of stratospheric contaminents and the role each plays in the ozone balance and in climatic change.

TABLE 3-VII
SPECIFIC DISTRIBUTIONS INCLUDED IN THIS SECTION

	Vertical	Latitude	Global	Seasonal
H_2O Vapor	x			
O_3	x	x	x	x
Aerosols	x	x		
CO_2	x			
NO	x	x		x
NO_2	x			
H_2	x			
N_2O	x			
HNO_3	x	x		x
CO	x			
CH_4	x			
HCl	x			
Freon 11	x	x		x
Sulfates	x	x		
Bromides	x	x		

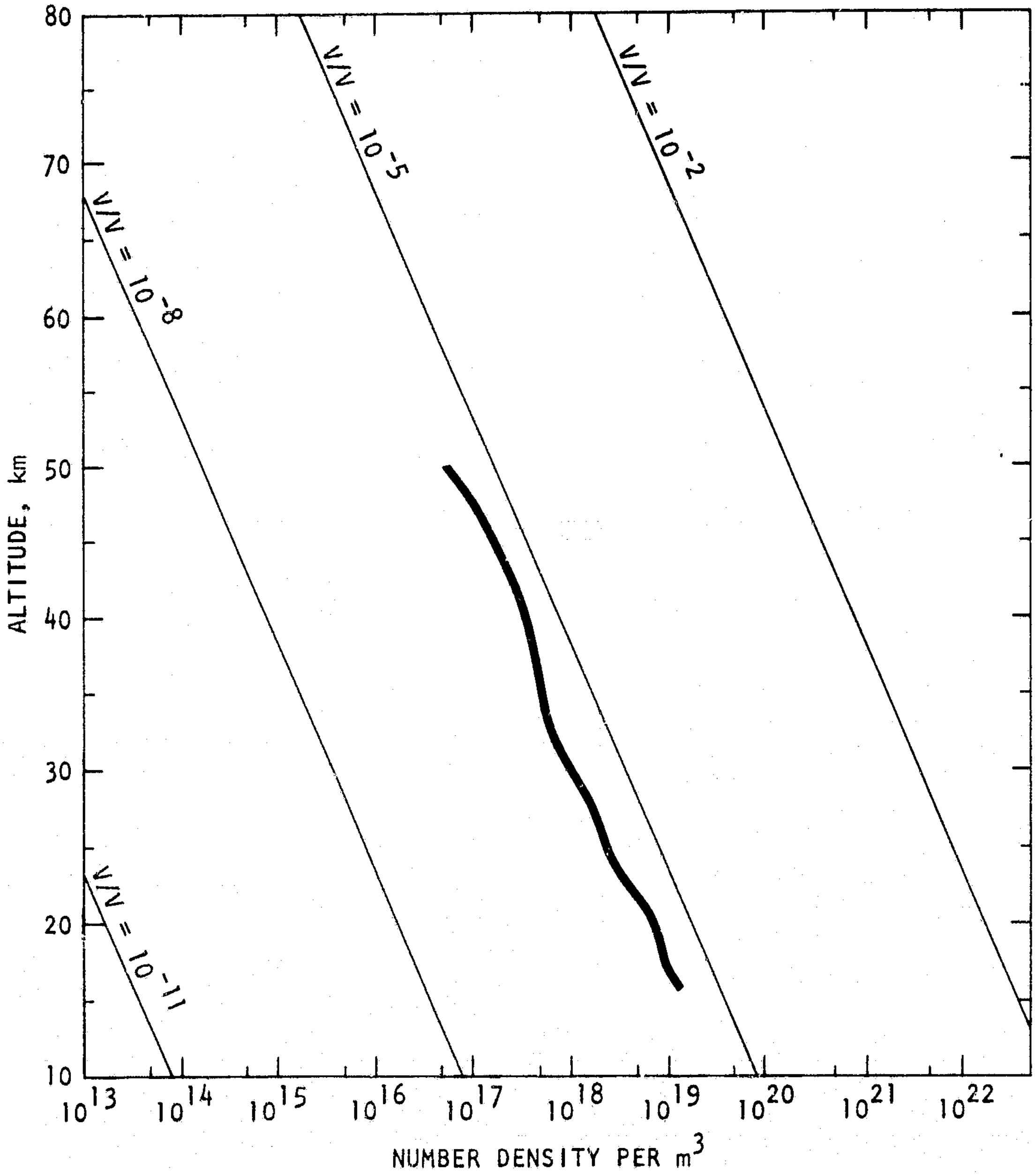

FIGURE 3-8
VERTICAL DISTRIBUTION OF WATER VAPOR,
H_2O, MID-LATITUDE [29,30,31,32]

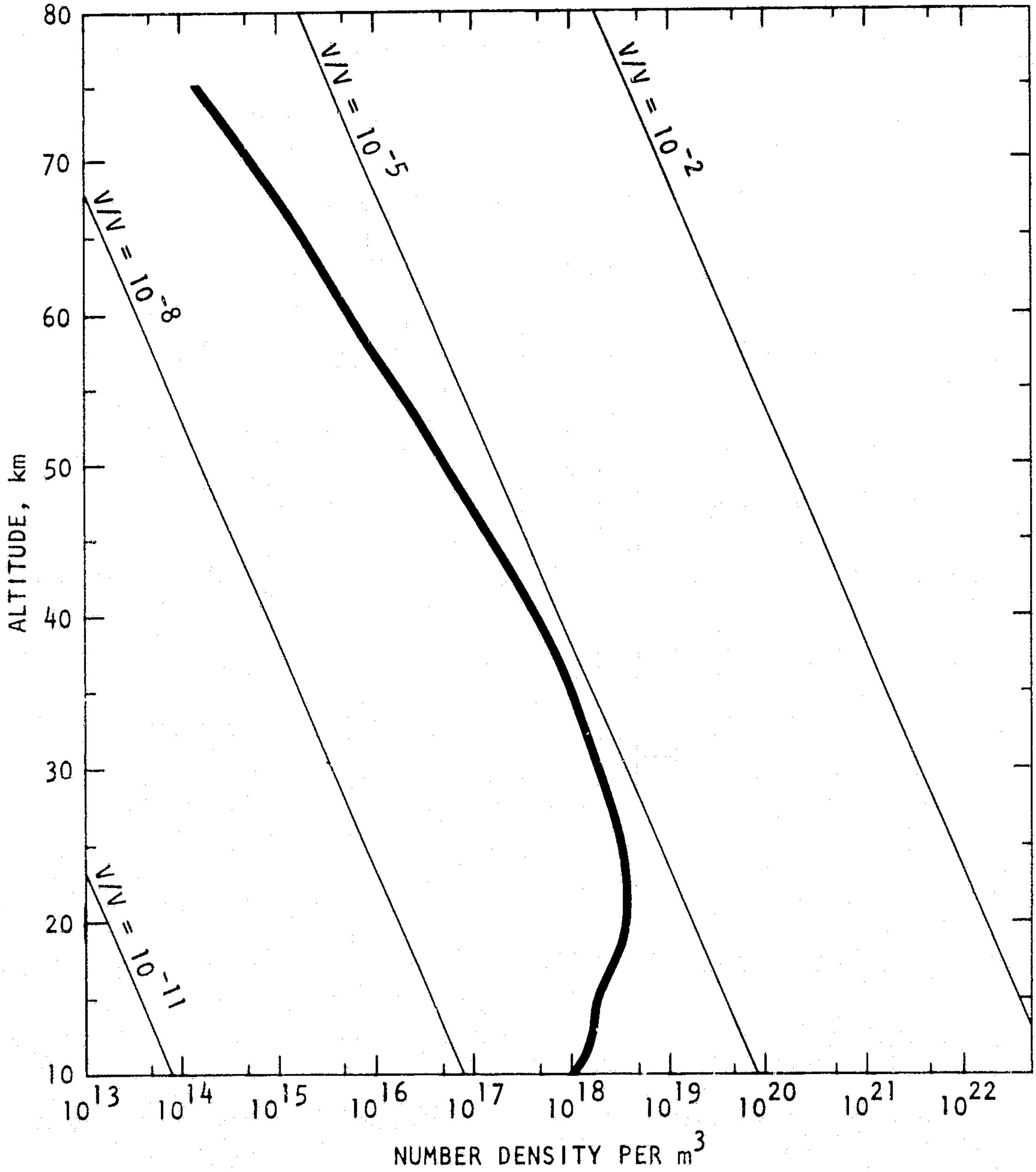

FIGURE 3-9
VERTICAL DISTRIBUTION OF OZONE, O_3
MID-LATITUDE [33]

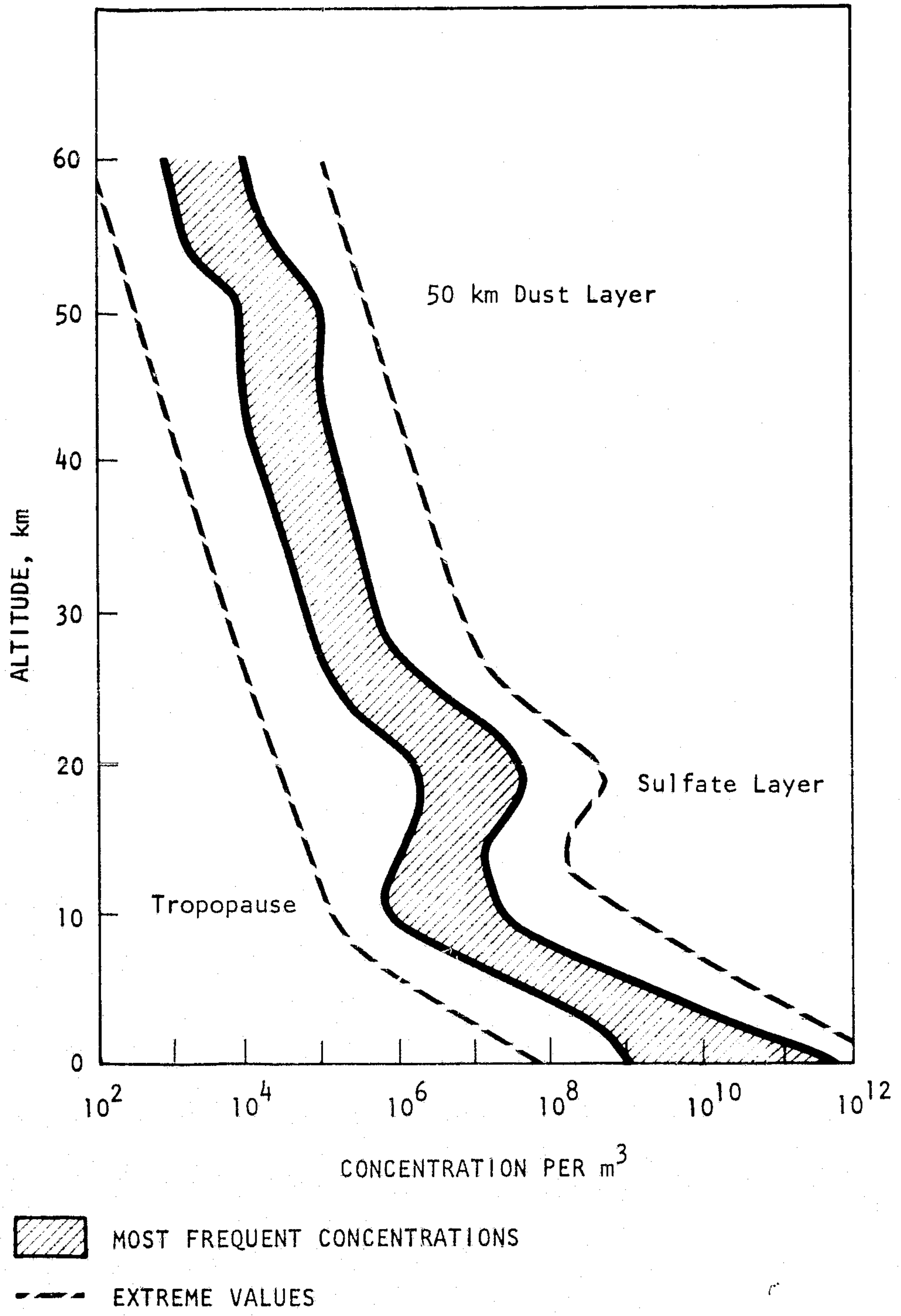

FIGURE 3-10
VERTICAL DISTRIBUTION OF AEROSOLS[18]

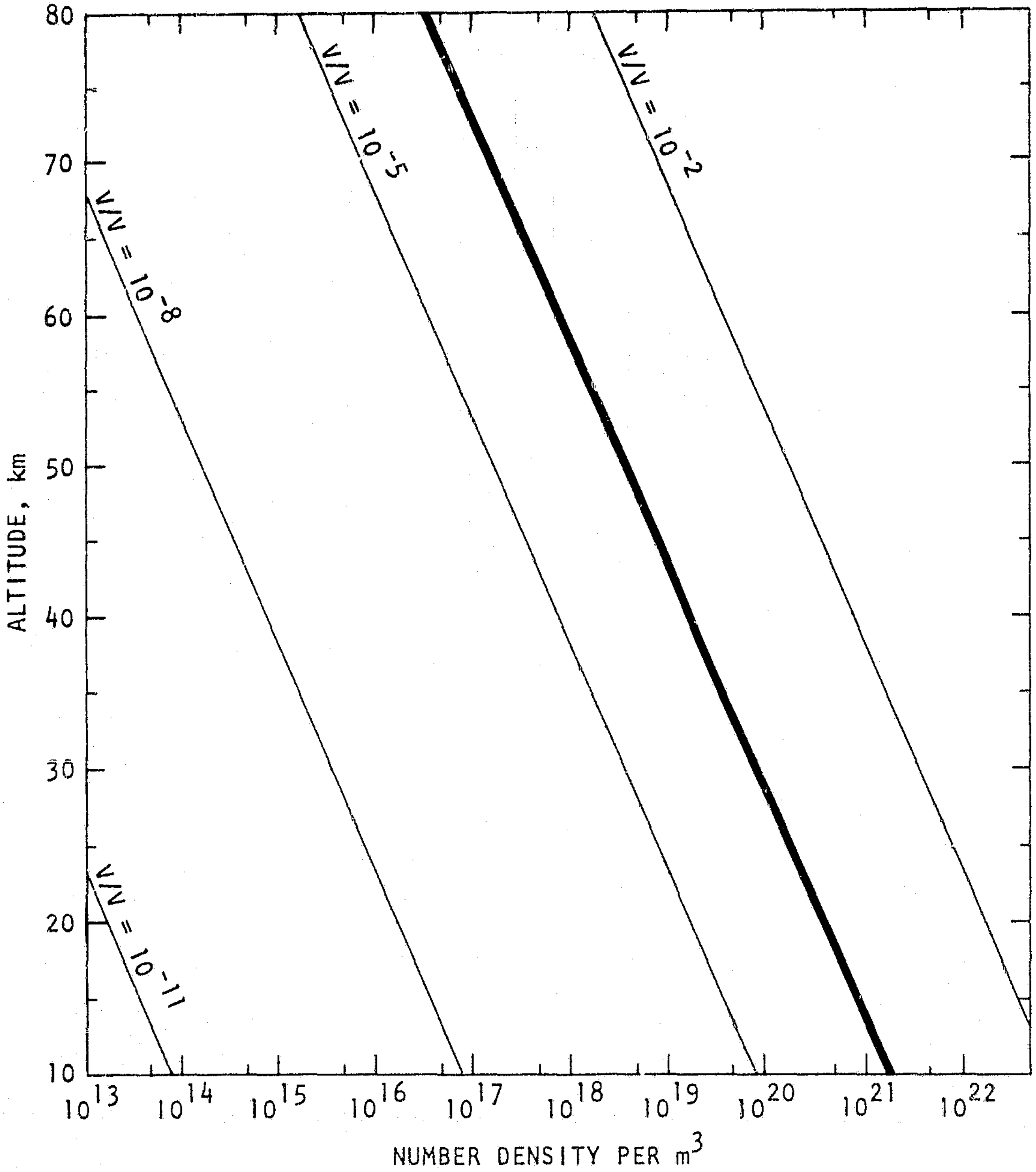

FIGURE 3-11
VERTICAL DISTRIBUTION OF CARBON DIOXIDE, CO_2
ALL LATITUDES, ALL SEASONS [34]

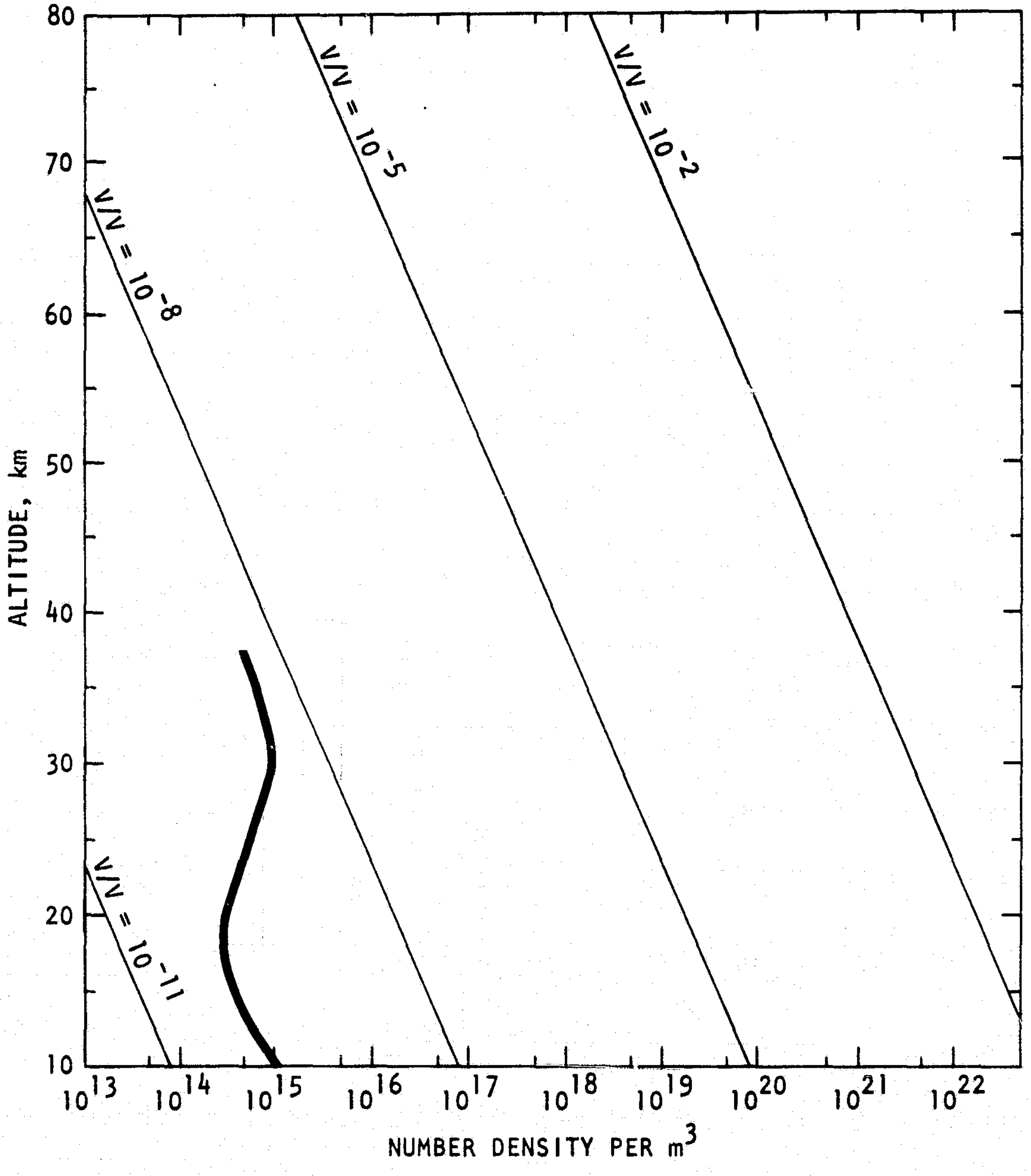

FIGURE 3-12
VERTICAL DISTRIBUTION OF NITRIC OXIDE, NO
MID-LATITUDE[34]

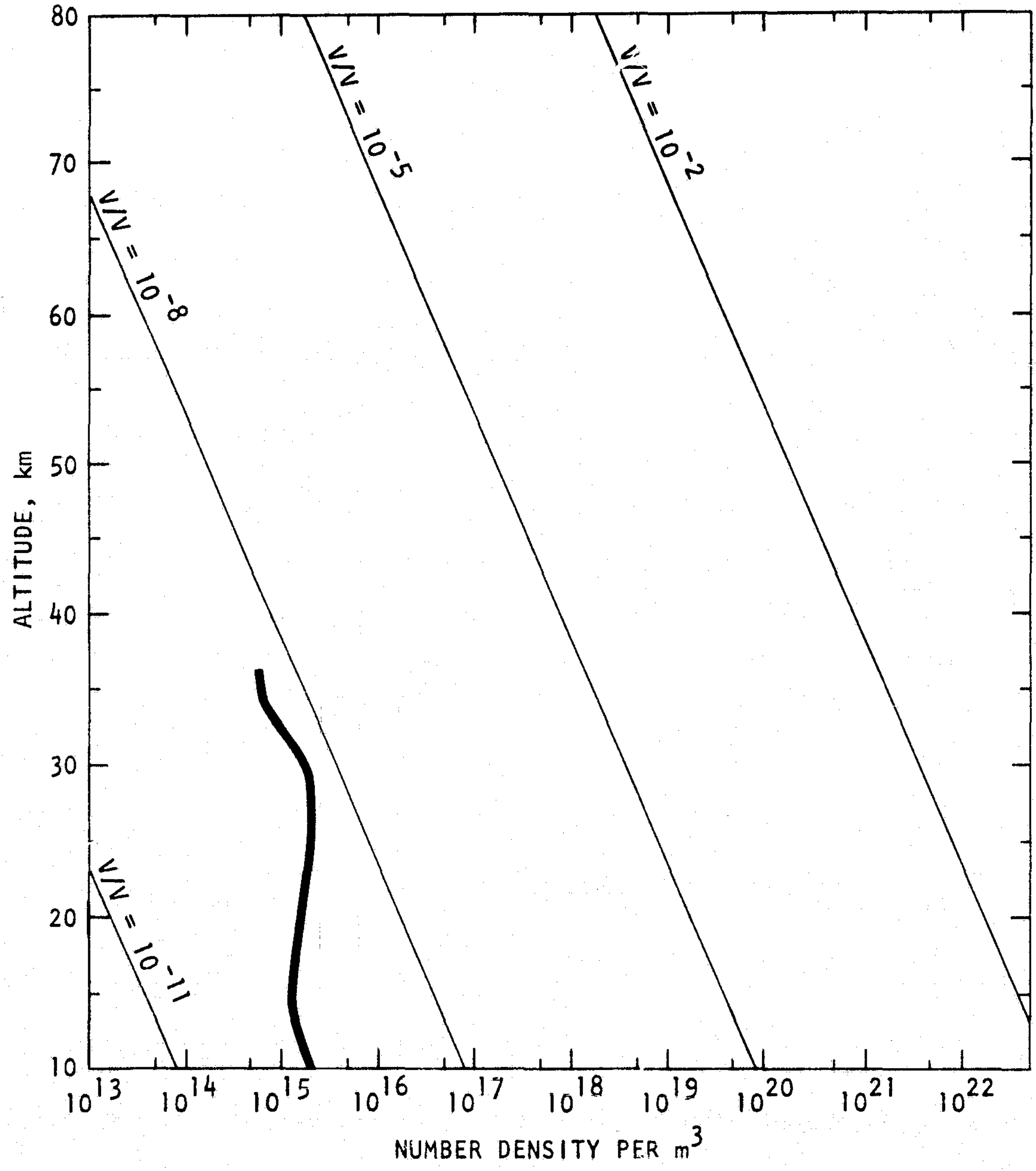

FIGURE 3-13
VERTICAL DISTRIBUTION OF NITROGEN DIOXIDE, NO_2
MID-LATITUDE [34]

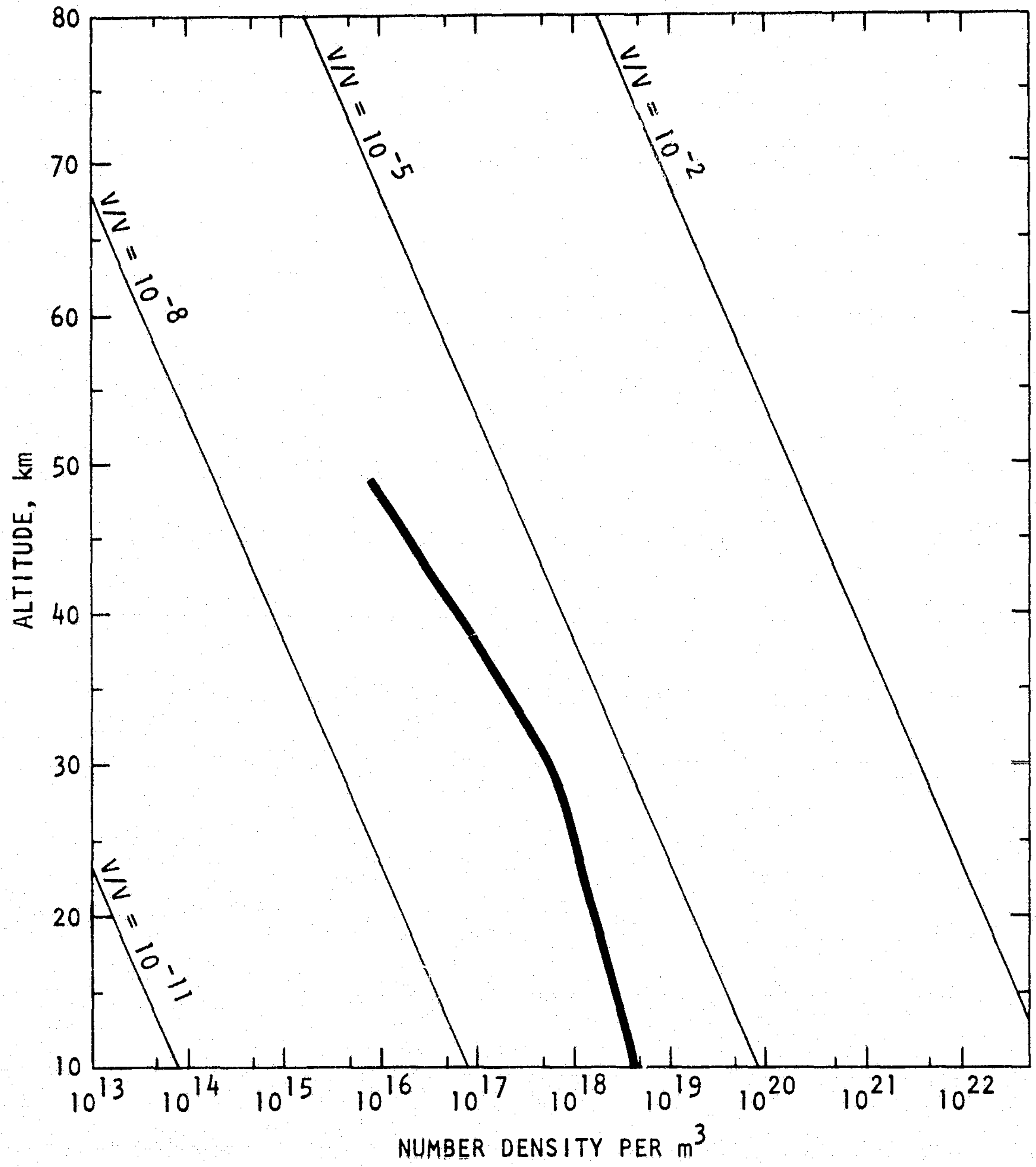

FIGURE 3-14
VERTICAL DISTRIBUTION OF HYDROGEN, H_2
MID-LATITUDE[14]

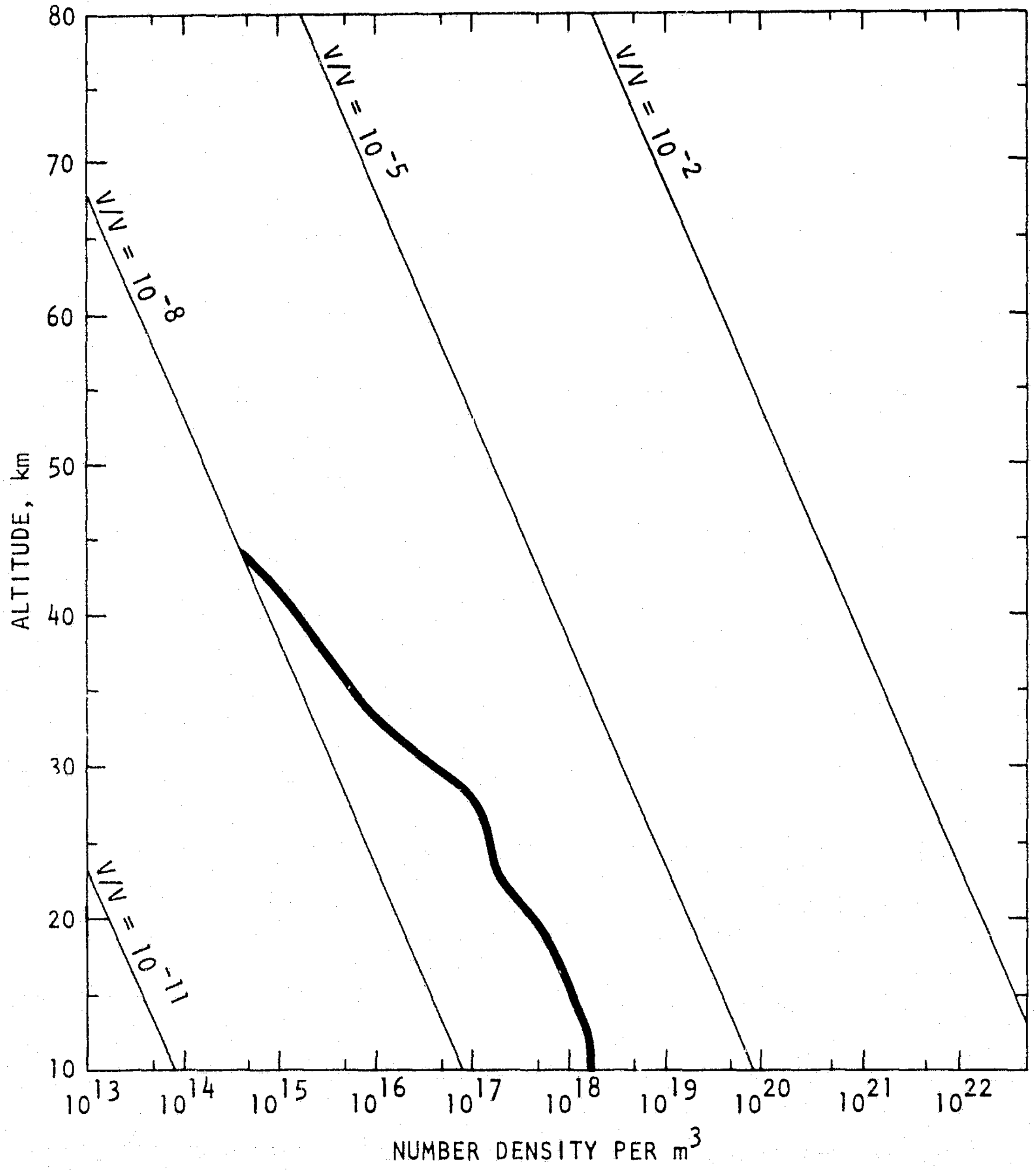

FIGURE 3-15
VERTICAL DISTRIBUTION OF NITROUS OXIDE, N_2O
MID-LATITUDE [35]

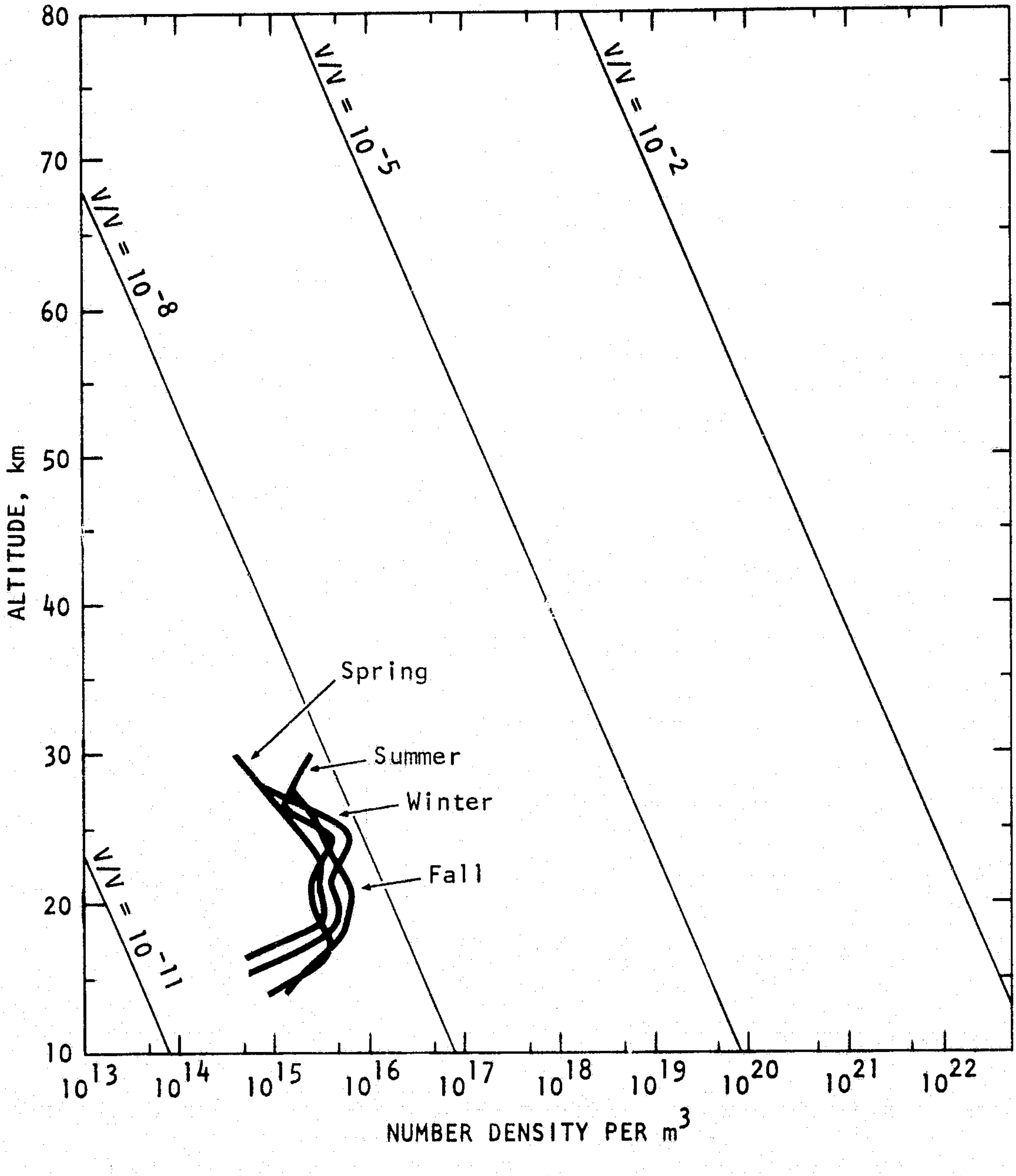

FIGURE 3-16
VERTICAL DISTRIBUTION OF NITRIC ACID, HNO_3
MID-LATITUDE [36]

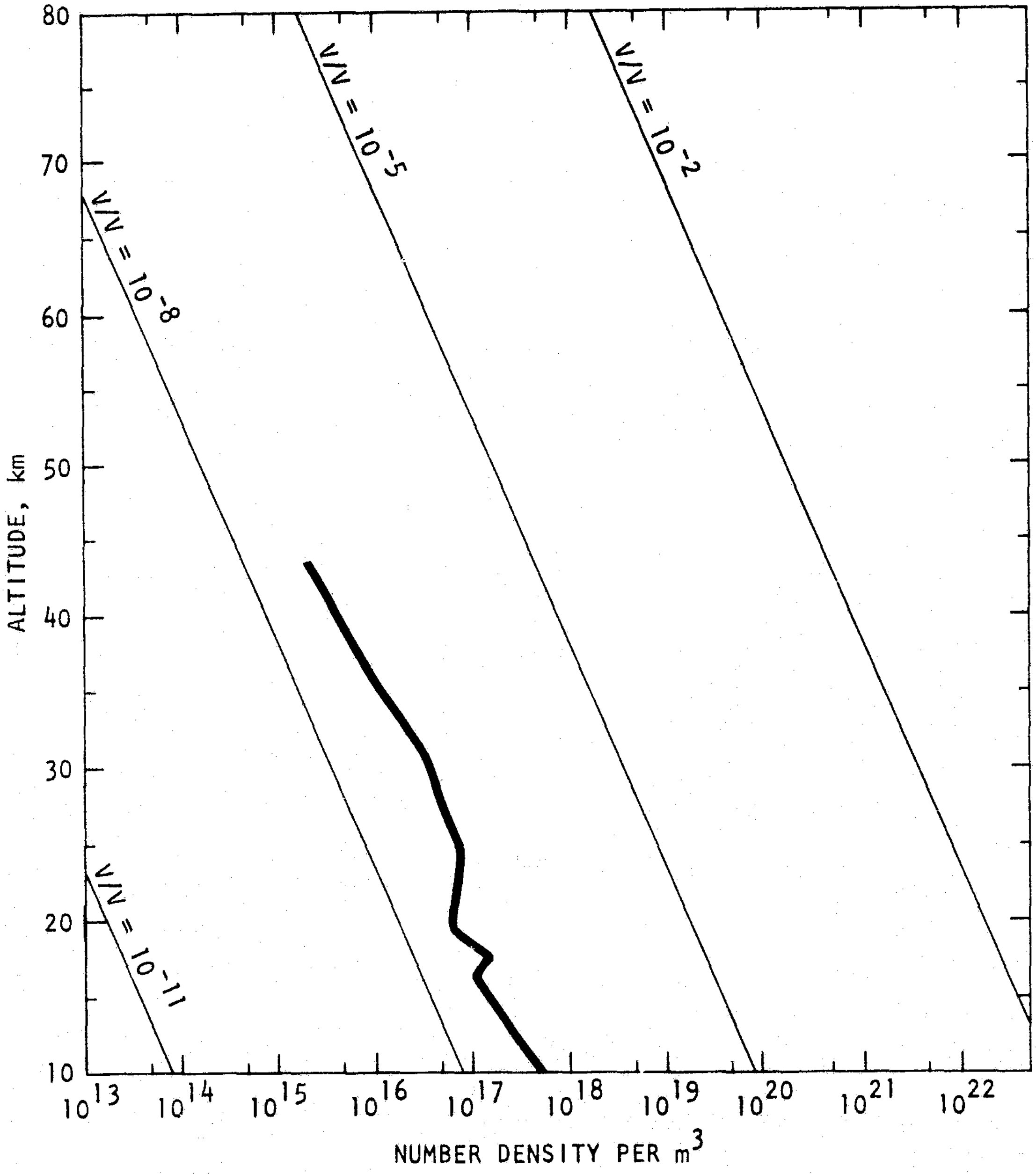

FIGURE 3-17
VERTICAL DISTRIBUTION OF CARBON MONOXIDE, CO
MID-LATITUDE[35]

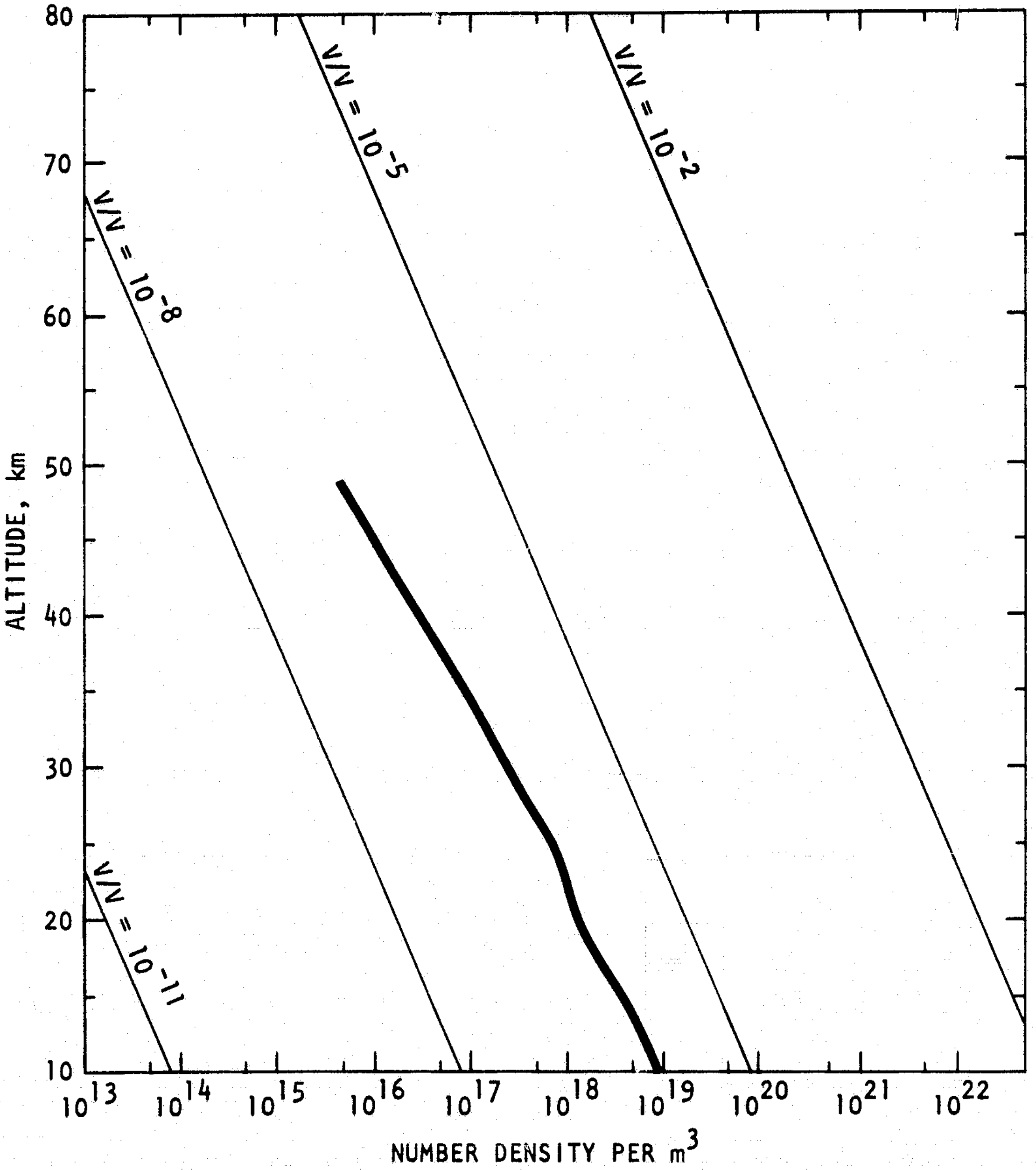

FIGURE 3-18
VERTICAL DISTRIBUTION OF METHANE, CH_4
MID-LATITUDE [35]

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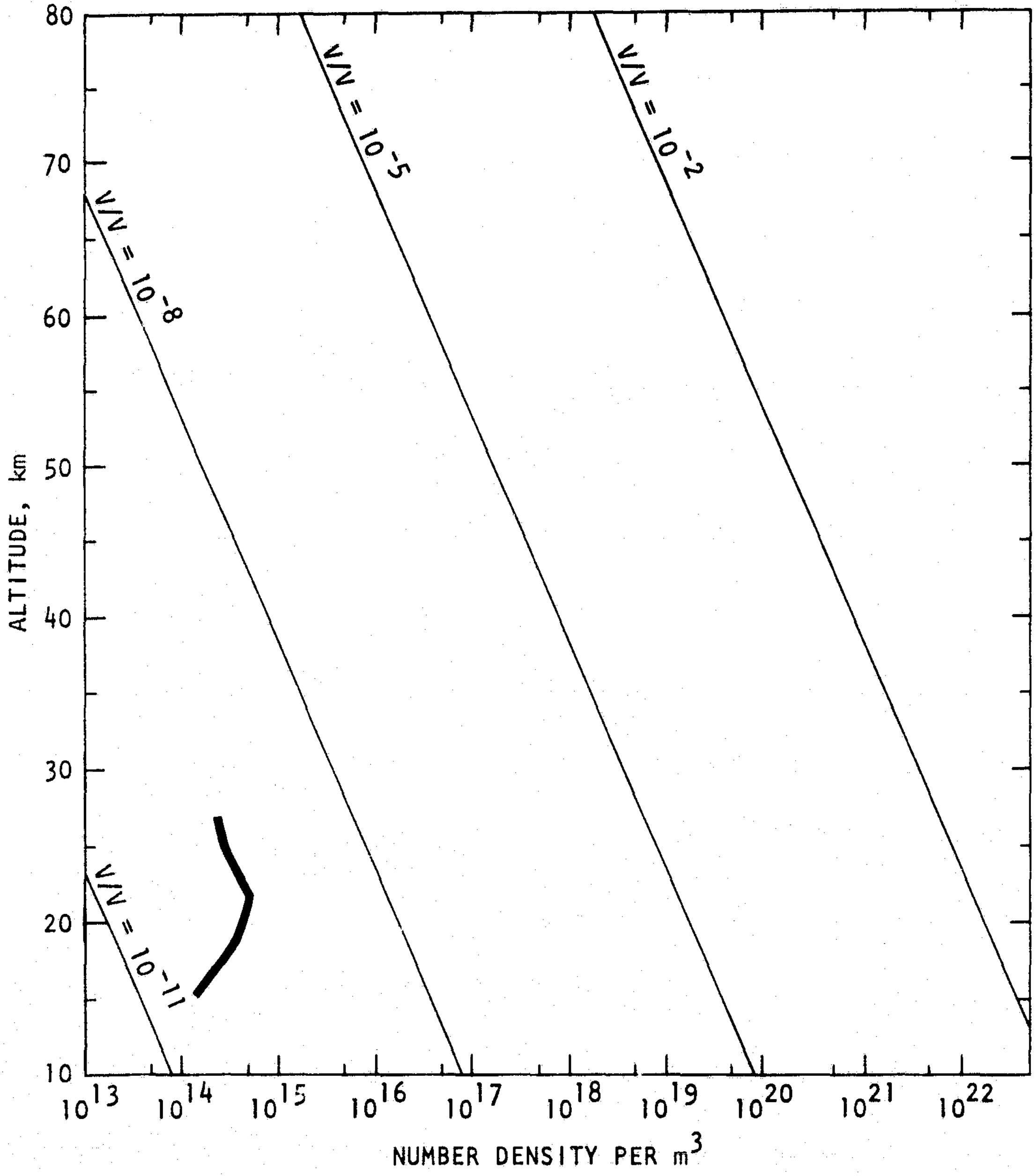

FIGURE 3-19
VERTICAL DISTRIBUTION OF HYDROGEN CHLORIDE, HCL
MID-LATITUDE[15]

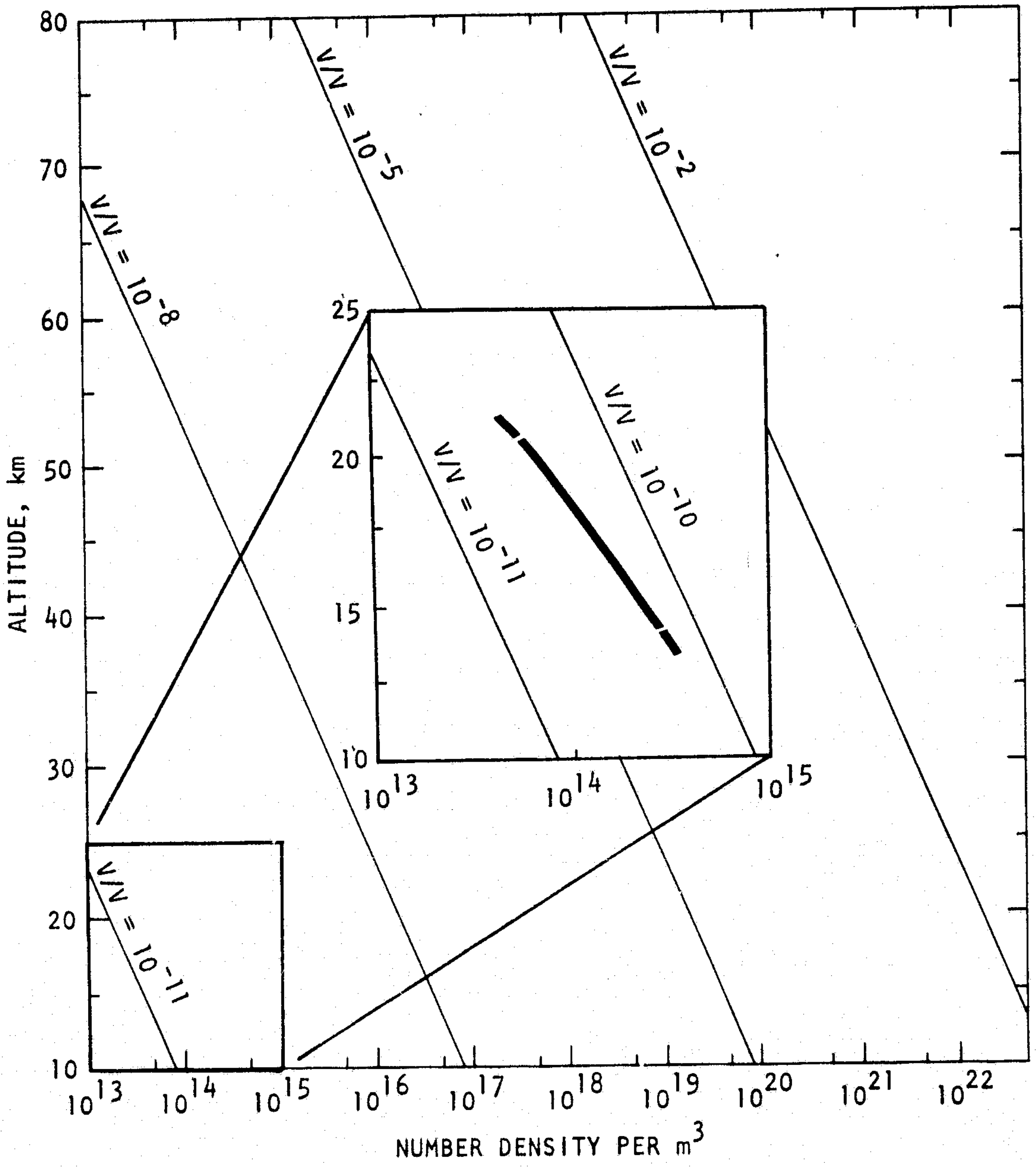

FIGURE 3-20
VERTICAL DISTRIBUTION OF FREON 11, SPRING, EQUATOR [15]

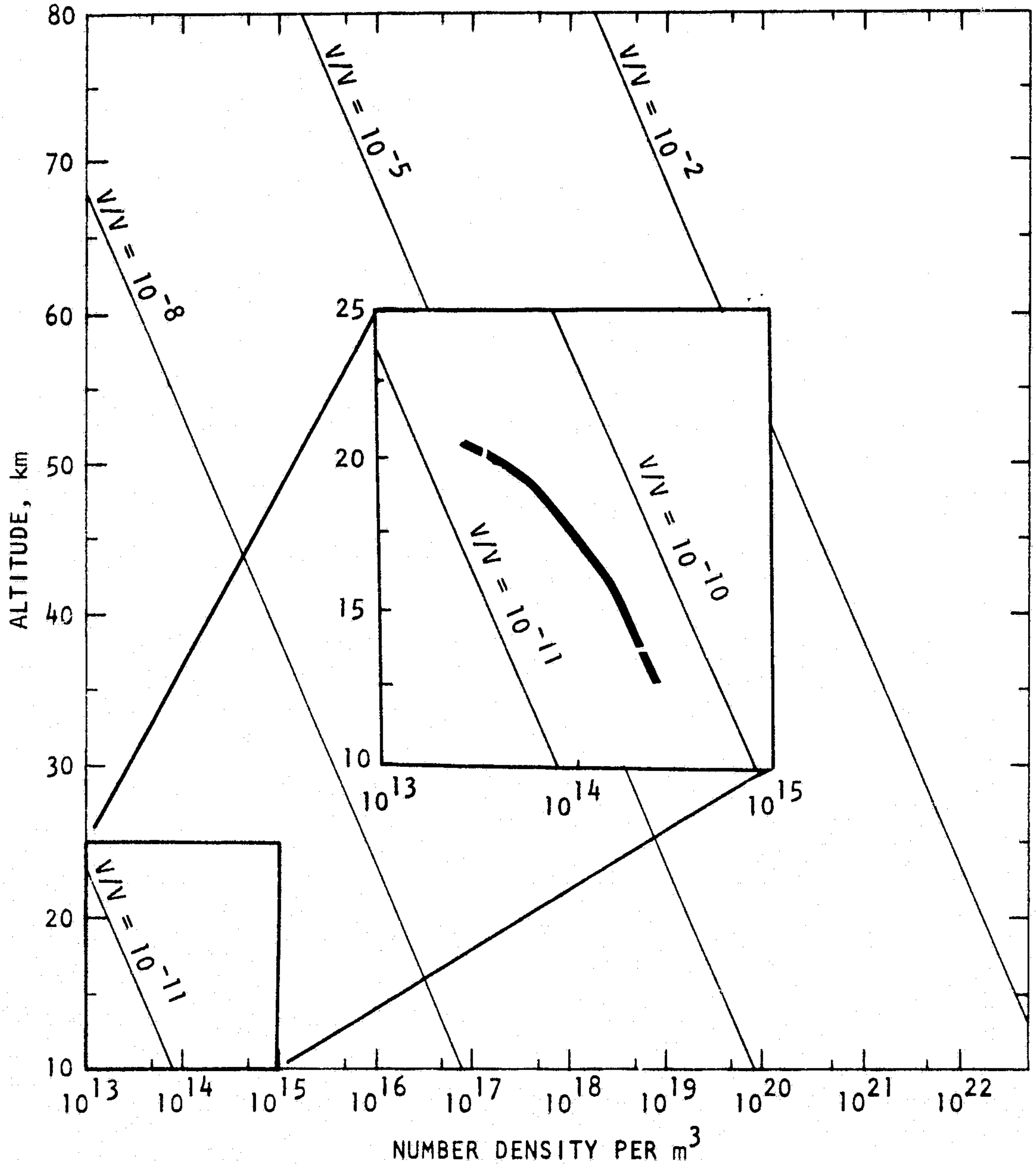

FIGURE 3-21
VERTICAL DISTRIBUTION OF FREON 11, SPRING, MID-LATITUDE[15]

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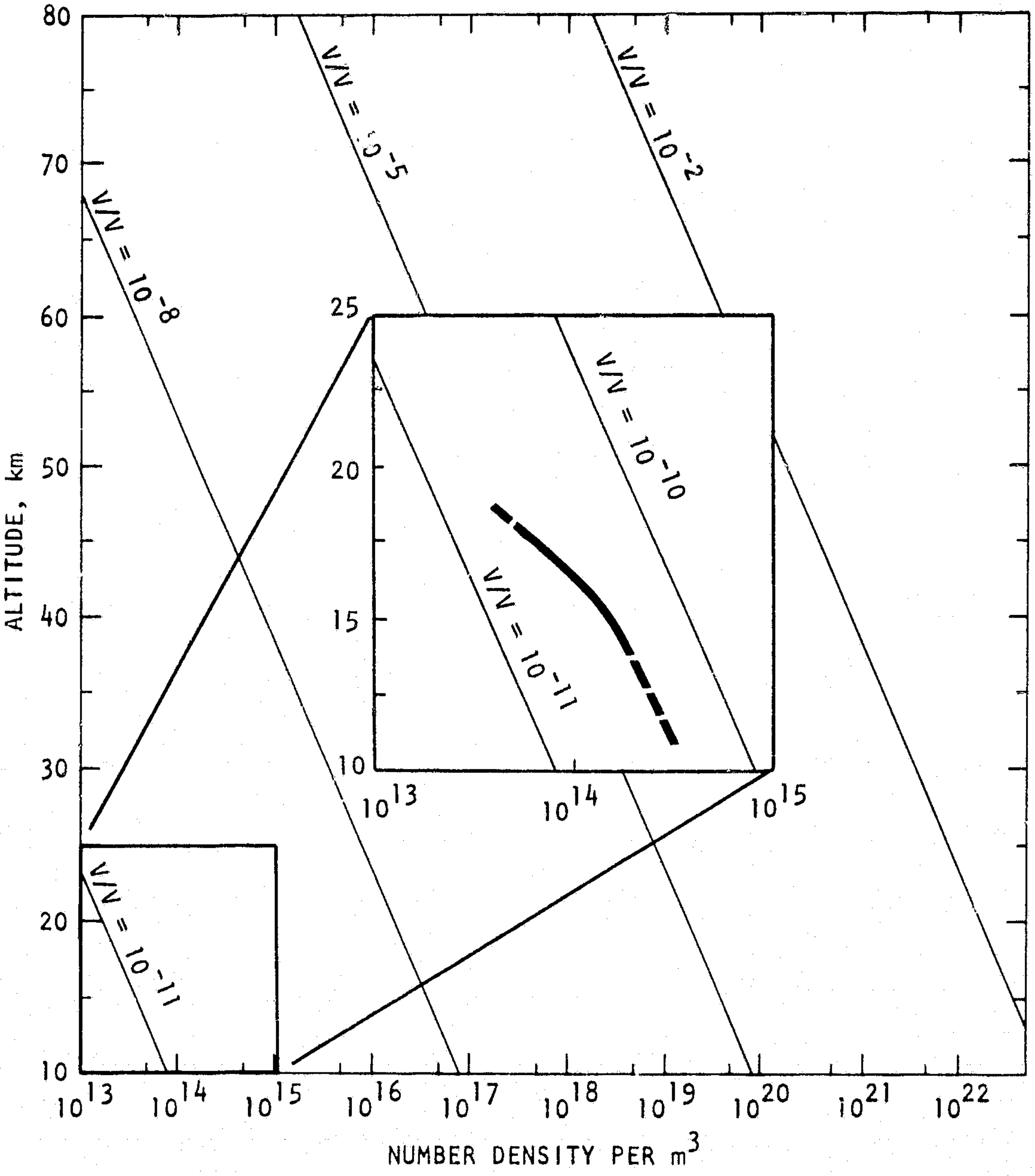

FIGURE 3-22
VERTICAL DISTRIBUTION OF FREON 11, SPRING, 70°N [15]

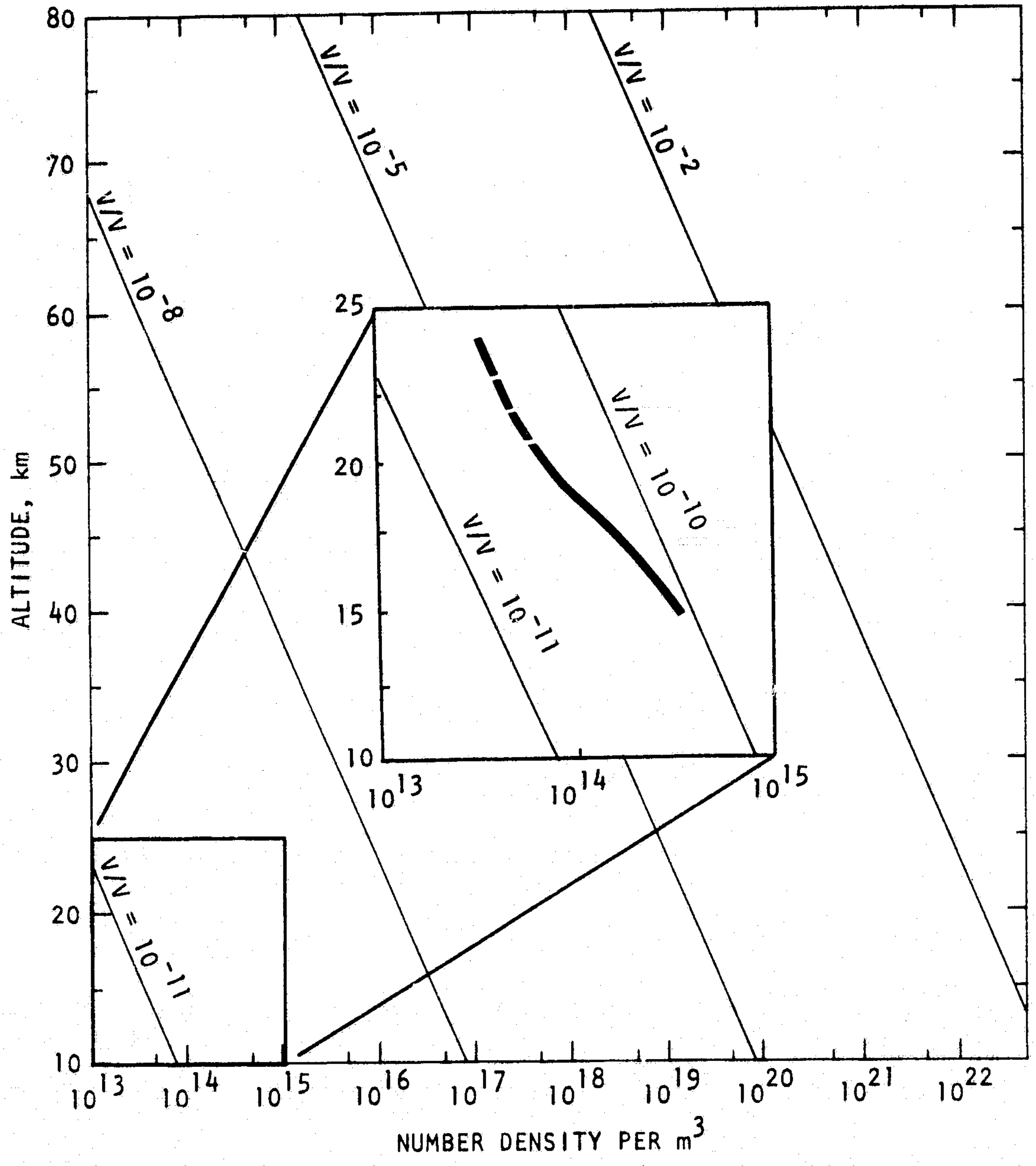

FIGURE 3-23
VERTICAL DISTRIBUTION OF FREON 11, AUTUMN, EQUATOR [15]

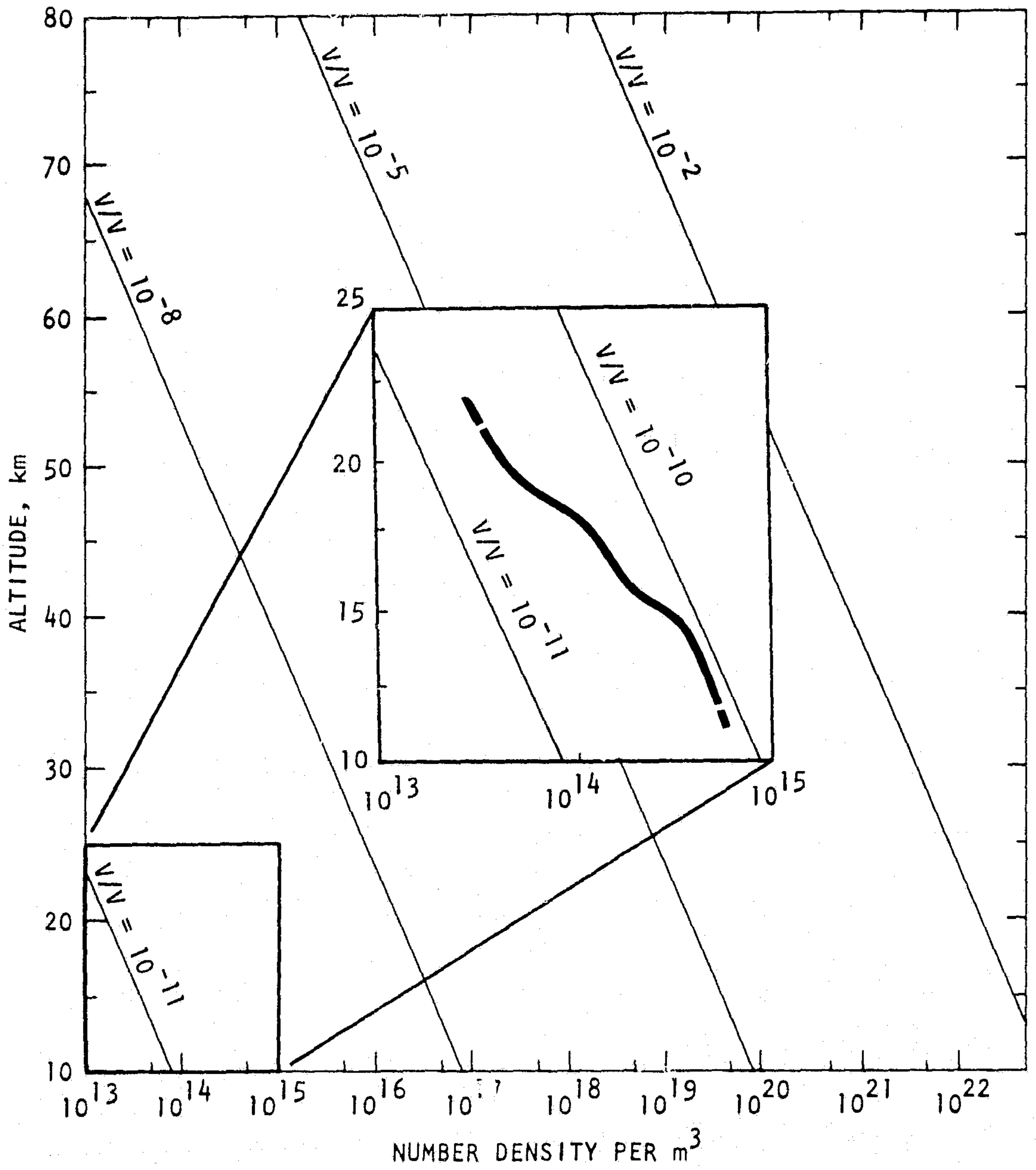

FIGURE 3-24
VERTICAL DISTRIBUTION OF FREON 11, AUTUMN, MID-LATITUDE [15]

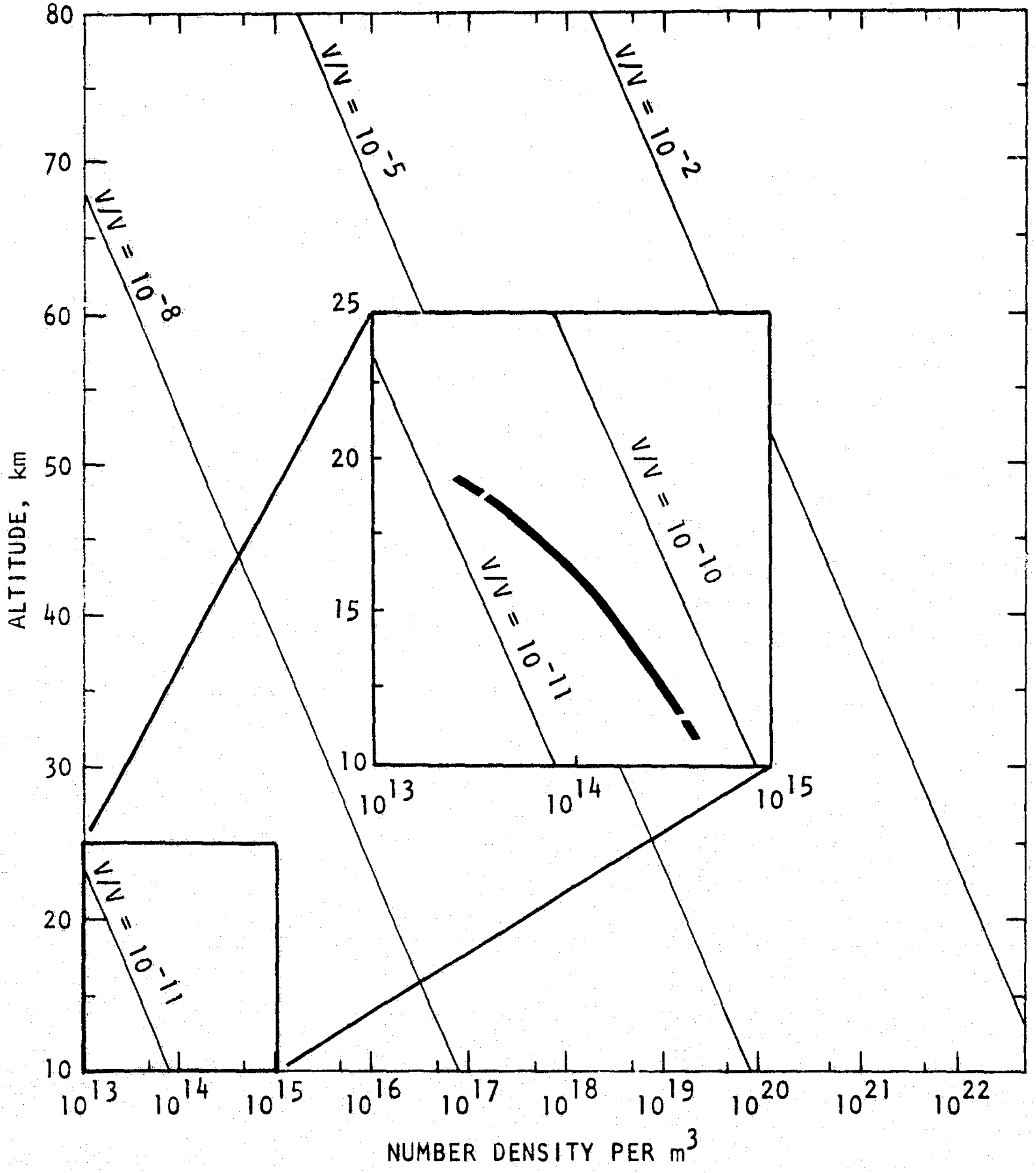

FIGURE 3-25
VERTICAL DISTRIBUTION OF FREON 11, AUTUMN, 70°N [15]

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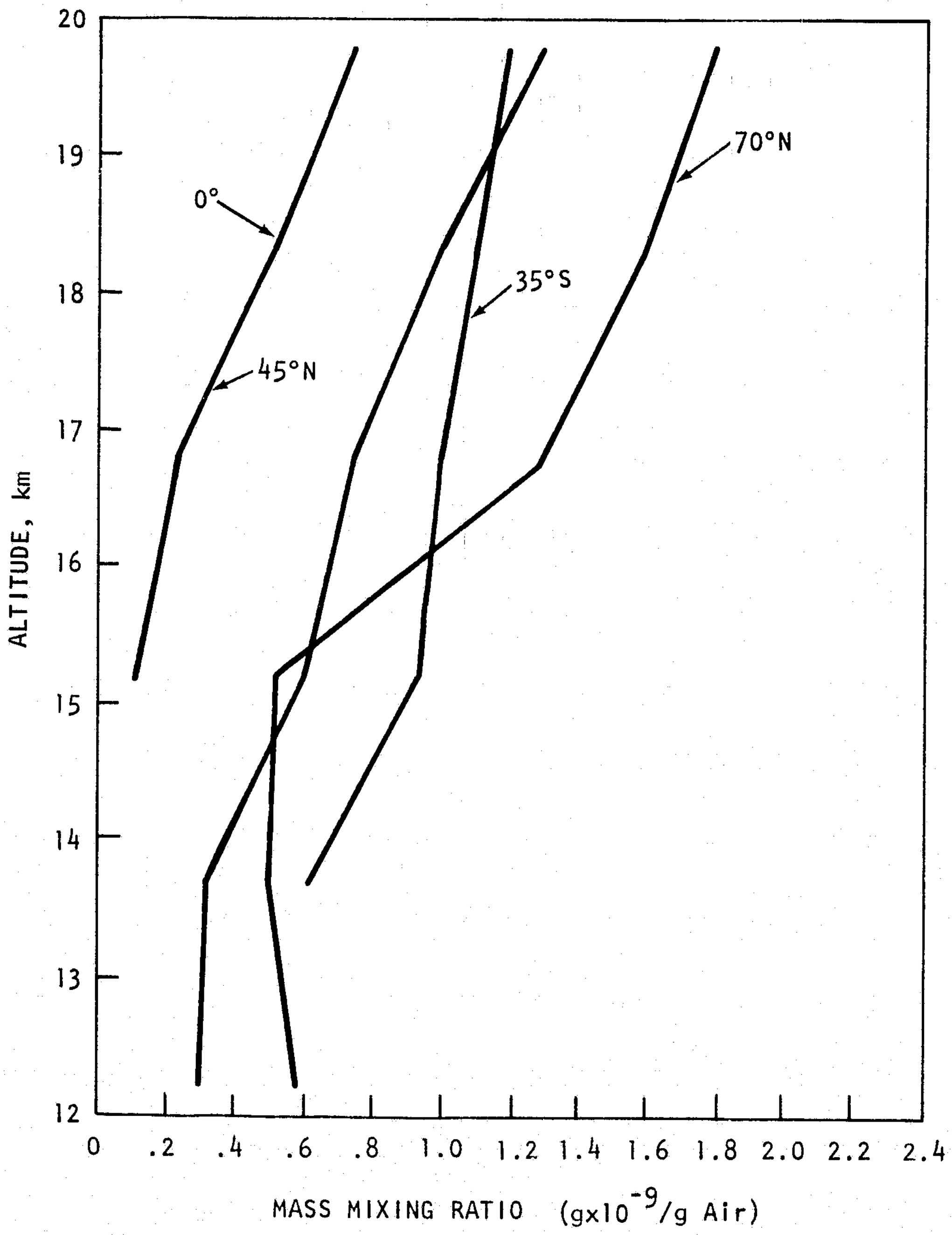


FIGURE 3-26
VERTICAL DISTRIBUTION OF SULFATES [26]

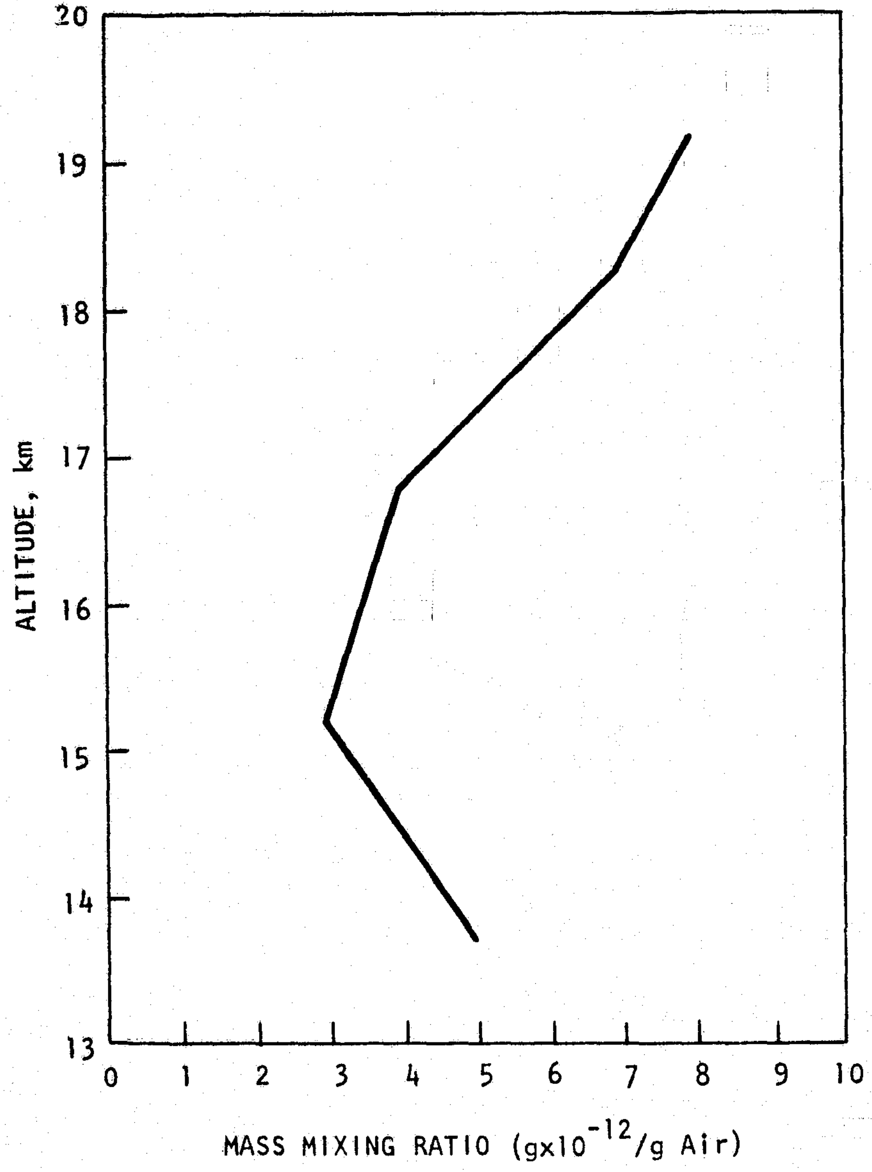
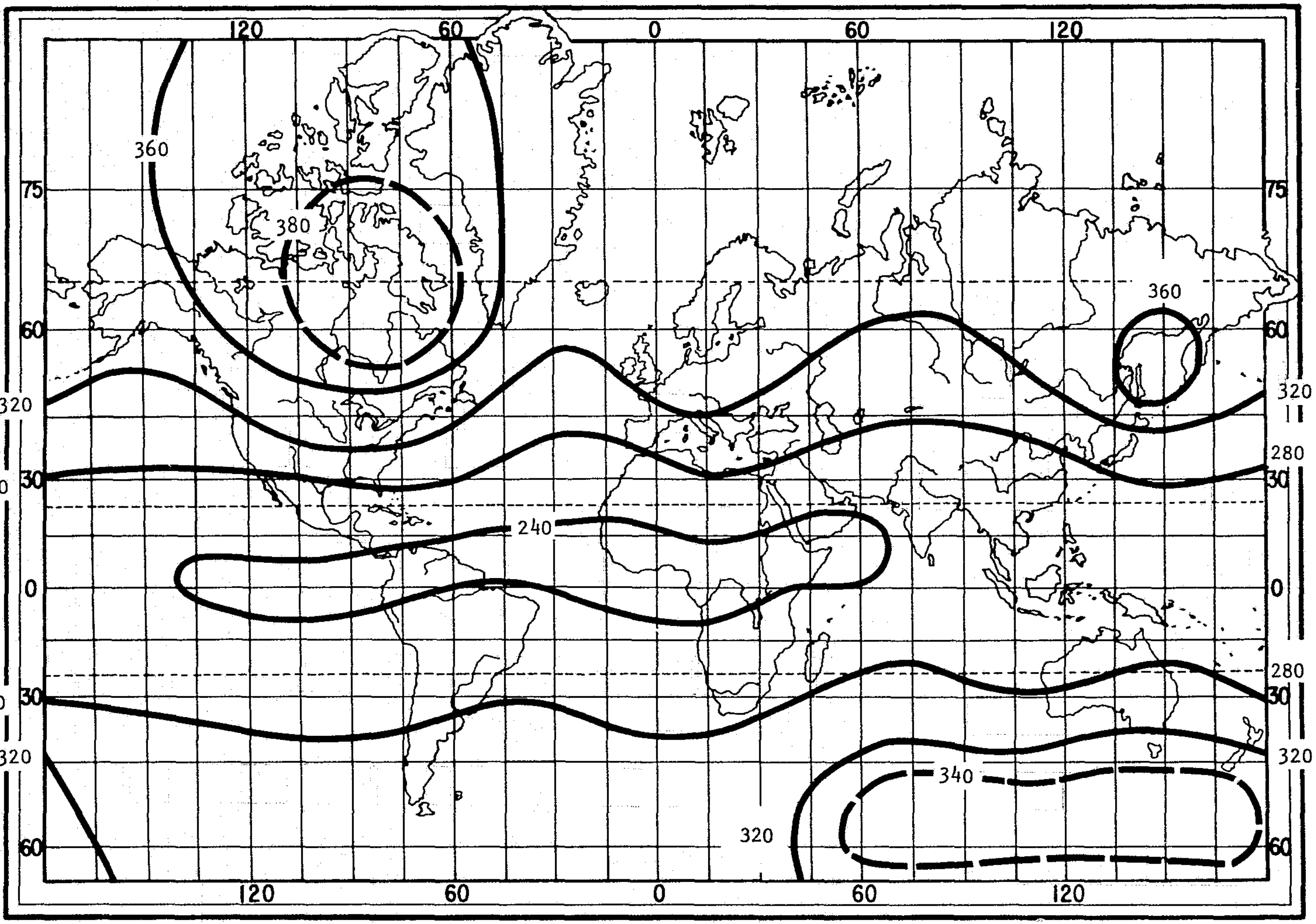
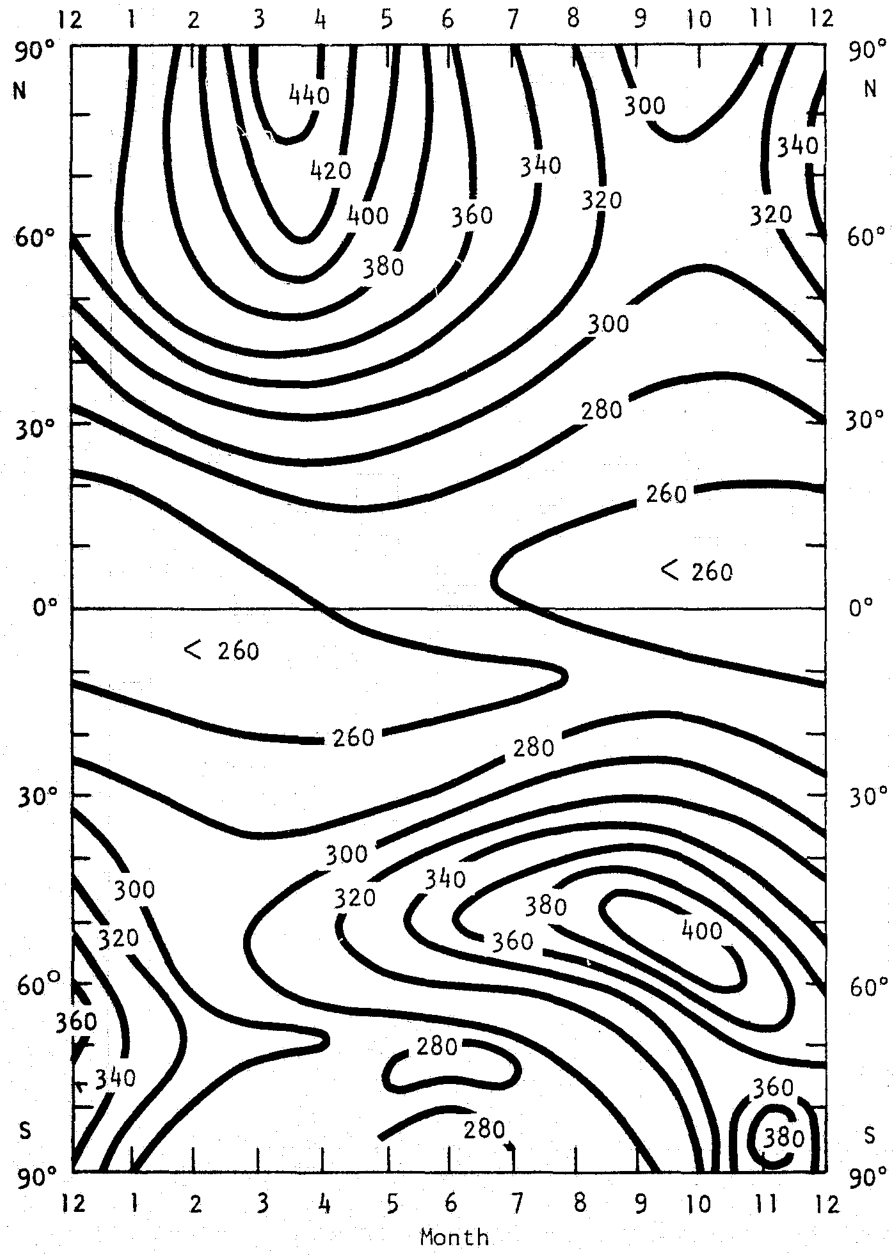


FIGURE 3-27
ESTIMATED MID-LATITUDE VERTICAL PROFILE FOR BROMIDES [25]



(Units: milli atm.-cm.)

FIGURE 3-28
GLOBAL DISTRIBUTION OF TOTAL OZONE[15]



(The numbers are total amounts in the conventional units of 10^{-3} atm-cm STP.)

FIGURE 3-29
WORLDWIDE TOTAL OZONE AS A FUNCTION OF SEASON AND LATITUDE [14]

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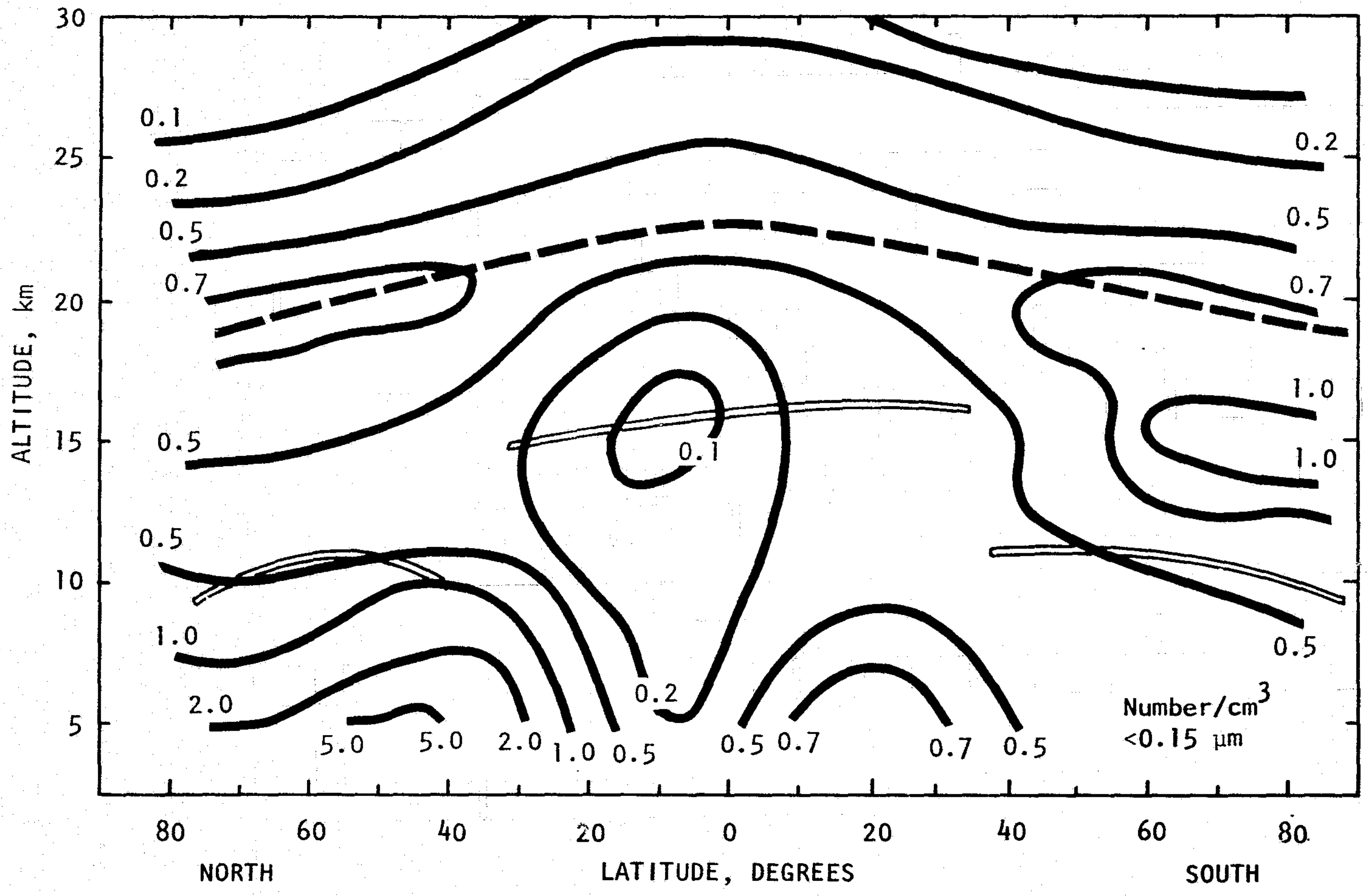

(Solid lines are lines of constant aerosol concentrations [number cm^{-3}]; open lines indicate the altitude of the tropopause.)

FIGURE 3-30
LATITUDINAL DISTRIBUTION OF AEROSOLS[18]

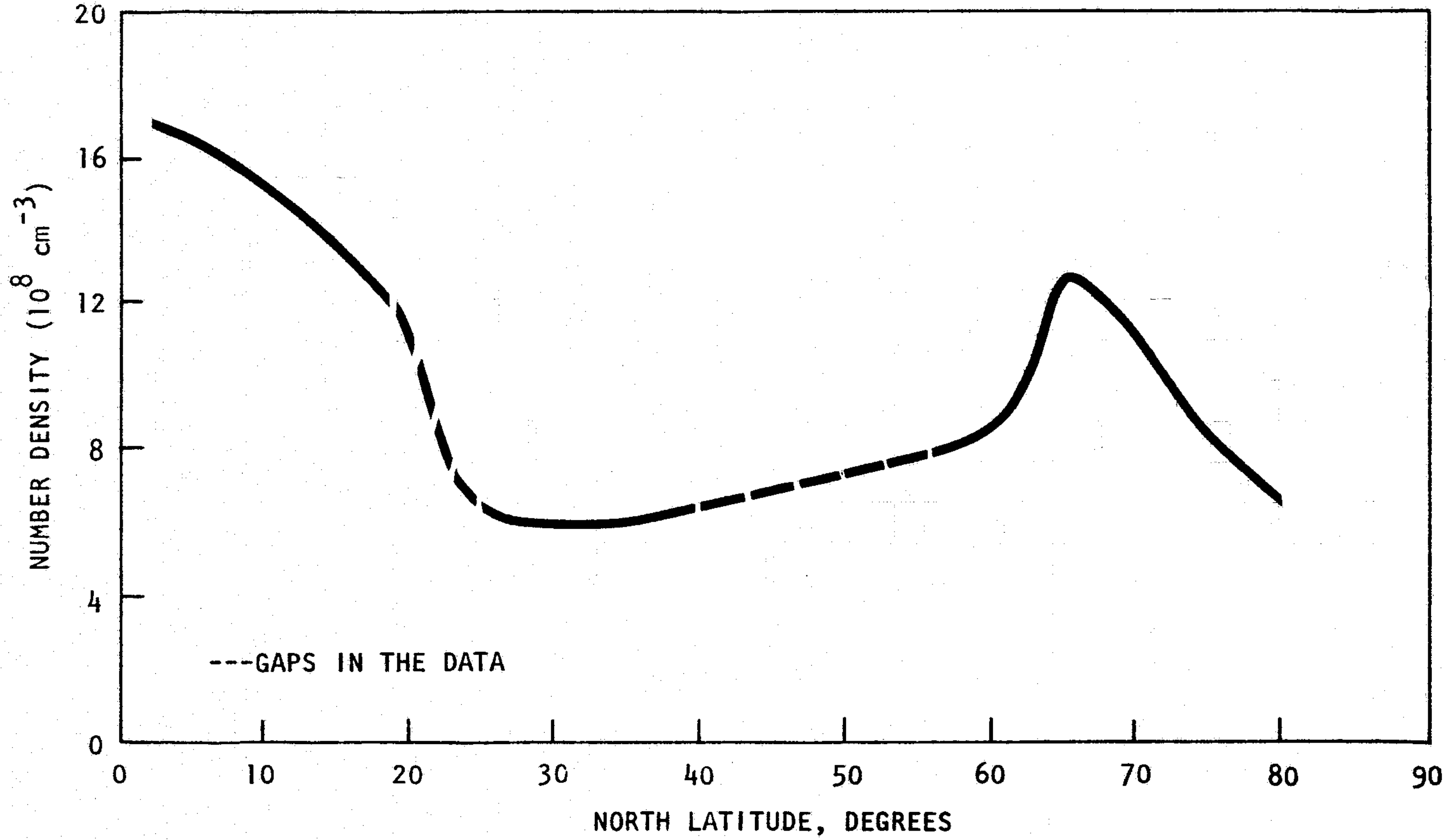

FIGURE 3-31
AVERAGE LATITUDINAL DISTRIBUTION OF NITRIC OXIDE, NO, AT 18.3 km[27]

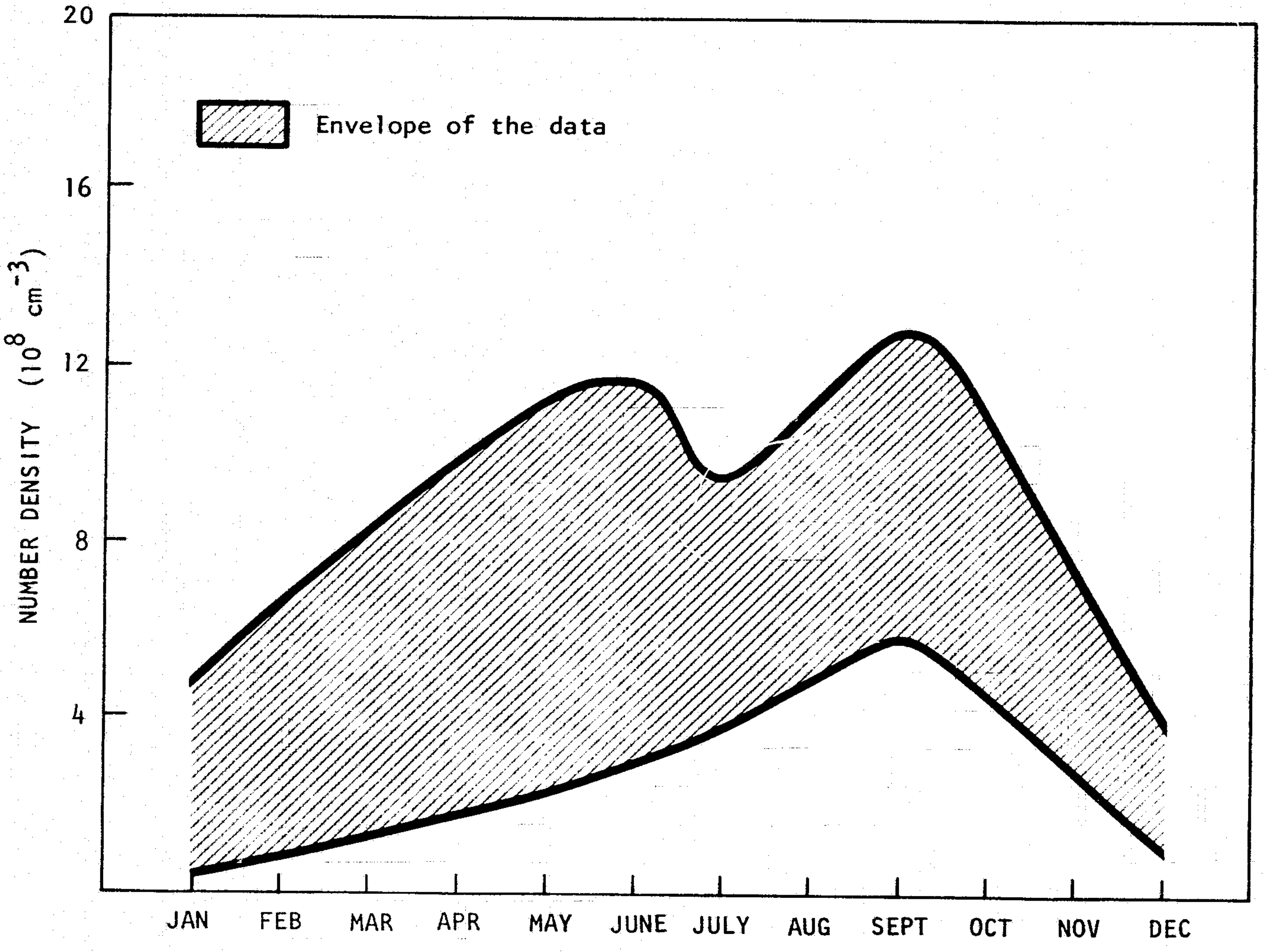

FIGURE 3-32
SEASONAL DISTRIBUTION OF NO AT 21.3 km [27]

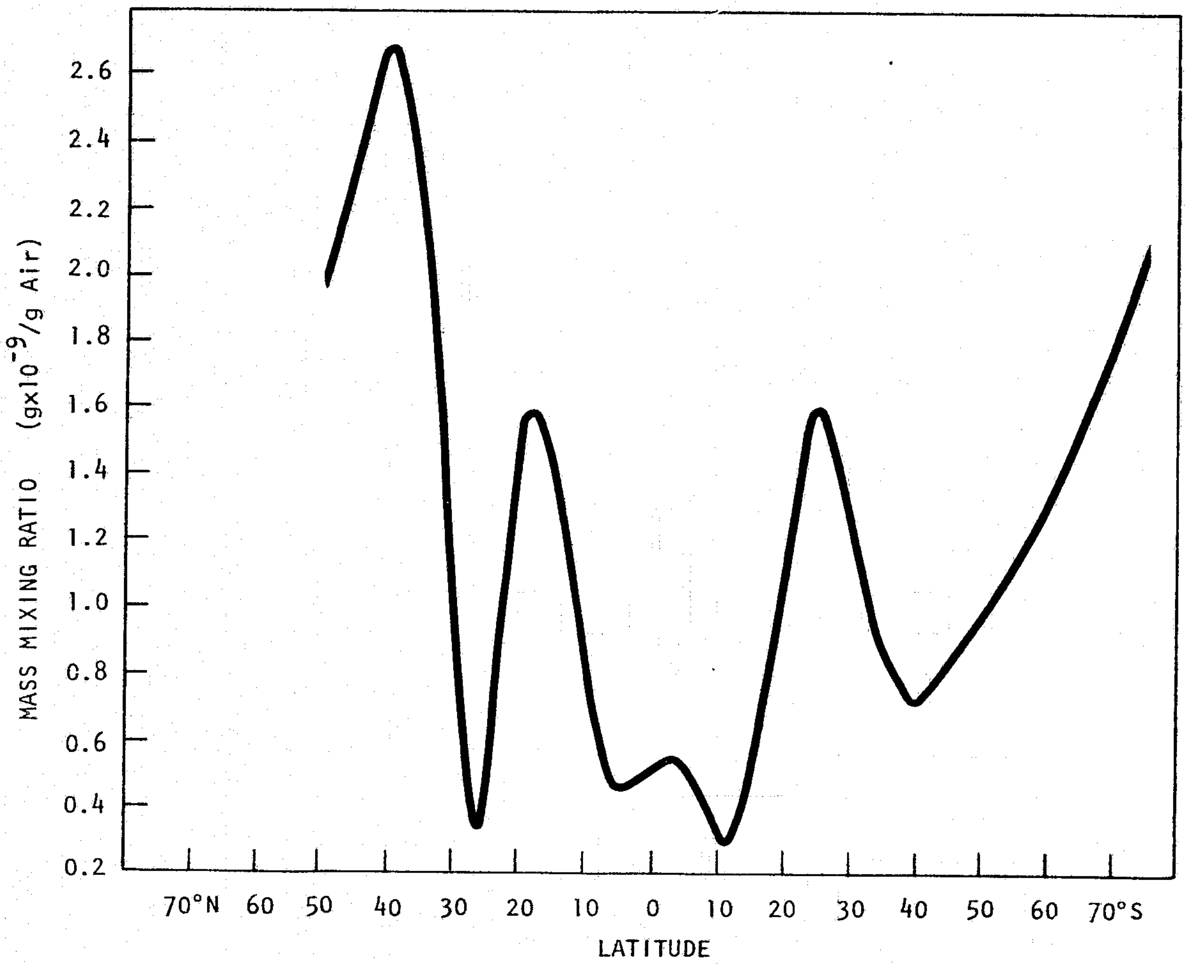

FIGURE 3-33
LATITUDINAL DISTRIBUTION OF HNO_3 VAPOR AT 19 km [26]

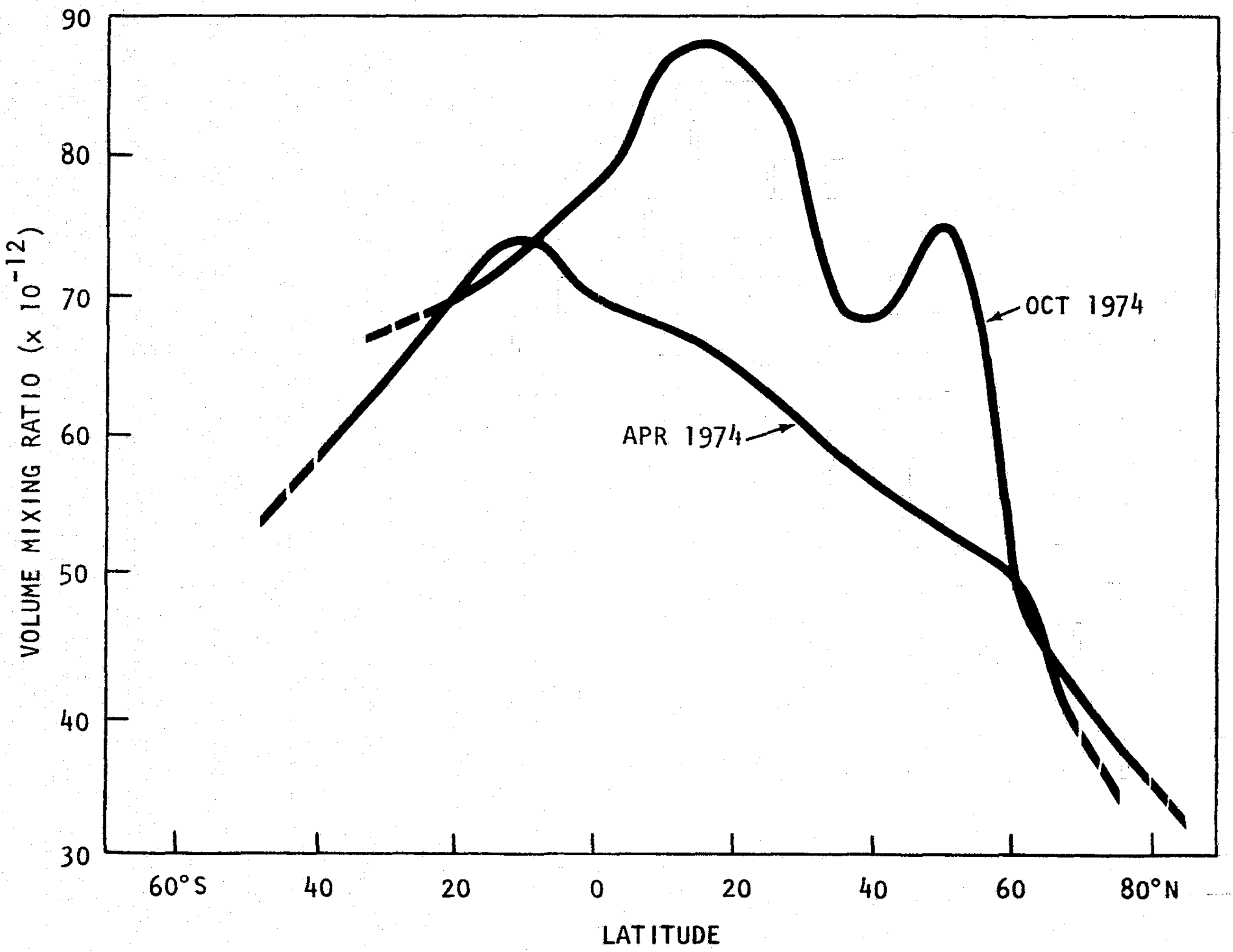

FIGURE 3-34
LATITUDINAL VARIATION OF FREON 11 AT 17 km [28]

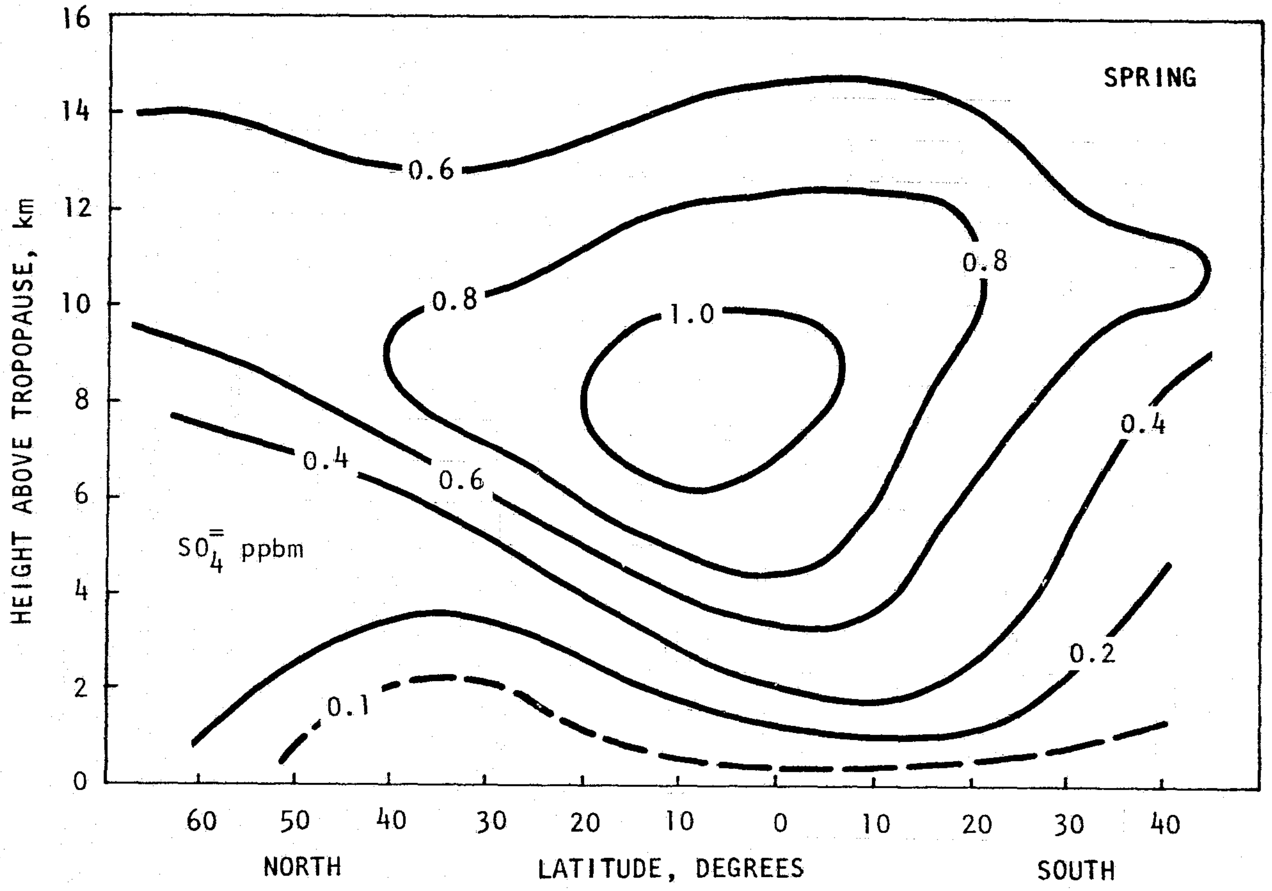

FIGURE 3-35
LATITUDINAL DISTRIBUTION OF SULFATE [18]

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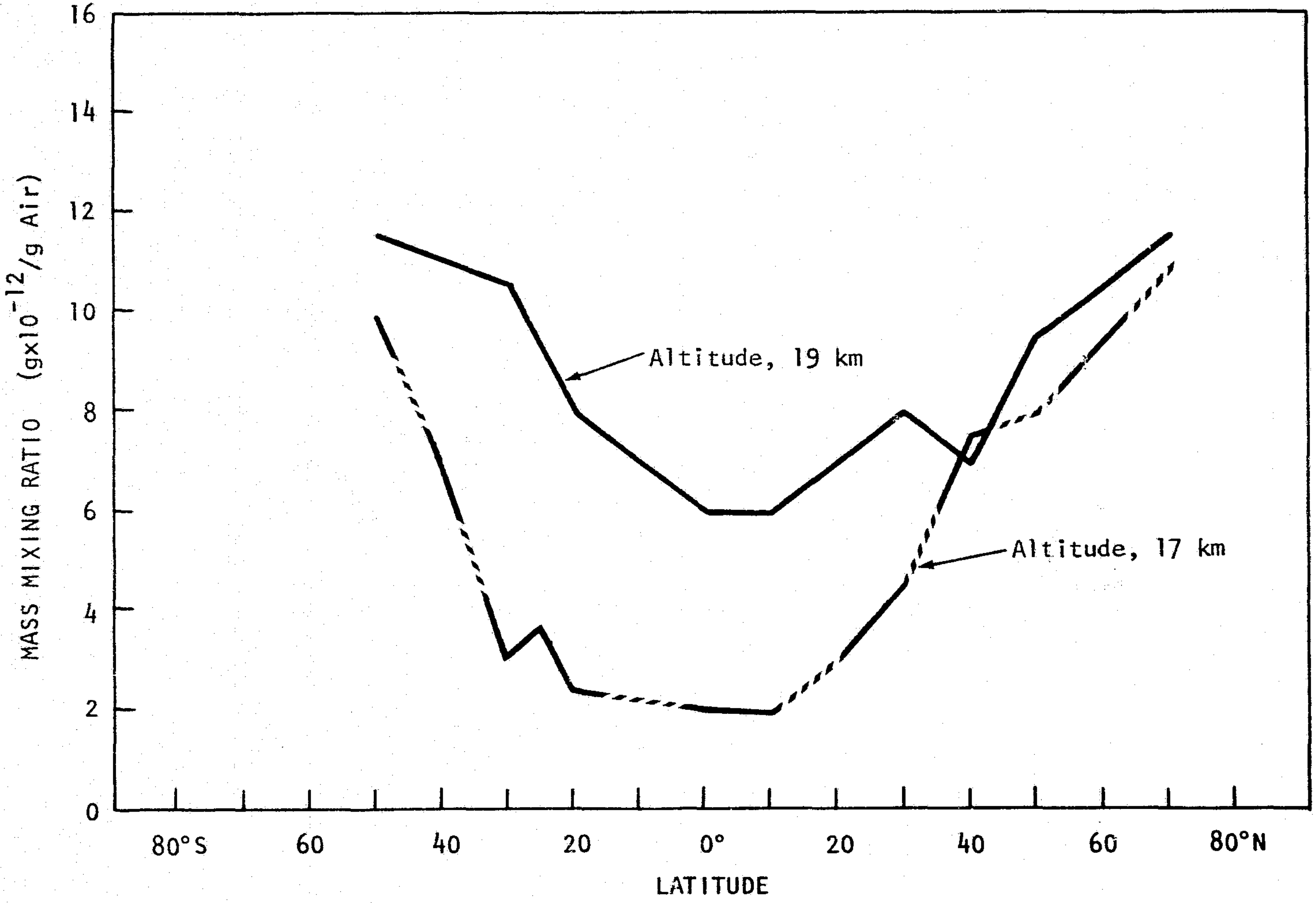

FIGURE 3-36
ESTIMATED LATITUDINAL PROFILES FOR BROMIDES [25]

A prioritization of properties and species has been developed. This prioritization was based principally on the relative role any given property or species plays in either the ozone balance or climatic change. The properties and species identified as having the greatest priority for measurement were

- Stratospheric temperature
- Solar irradiance
- Earth radiance
- Water vapor
- Ozone
- Aerosols
- Carbon dioxide

It must be remembered that this list has been developed on a purely scientific basis, without regard to present knowledge of the distribution or present or potential measurement capability. Later in this report these factors will be integrated into the analysis, and it will be shown that most of the above listed properties and species do not receive the highest priority for planned satellite missions since their distributions are much more understood than most of the other important stratospheric species.

4.0 INSTRUMENT PERFORMANCE

The previous section has indicated the constituents of scientific interest. Many very important species were shown not to be detectable by current remote sensing methods. In this section, those instruments that are either operational or under development and are reported to be capable of measuring one or more of the species of interest are presented. The instruments described are the most advanced of their type at this time.

Table 4-I presents a representative instrument selection for a satellite measurement program. Information contained therein represents the present claimed capabilities of the various sensors for measuring some of the species of interest. Question marks refer to design decisions that have yet to be made with regard to the instrument's final configuration. The remainder of this section will provide capsule descriptions of the instruments appearing in the table.

4.1 LIMS (Limb IR Monitor for the Stratosphere)

This instrument is an evolutionary development of LRIR and LACATE. As a limb scanner, it is capable of providing vertical profiles of the measurable species. It is planned to be used for measurements of CO_2 (used for temperature determination), O_3, H_2O, NO_2 and HNO_3. Operating in the thermal IR region, it has a requirement for cryogenic cooling of its detectors. Vertical scanning, of the few degrees required, will be provided, but the azimuthal view will probably be fixed at about 30° from the orbital plane.

TABLE 4-I
INSTRUMENT CAPABILITY VS. SPECIES

INSTRUMENT	TEMP/ CO_2	O_3	H_2O	Aerosols	Clouds	NO_2	HNO_3	HCl	CH_4	N_2O	NH_3	CO	CH_2O	SO_2
LIMS	S	S	S	–	–	S	S	–	–	–	–	–	–	–
SER	–	S	–	S	–	S(?)	–	–	–	–	–	–	–	–
MAPS	–	–	–	–	–	–	–	–	T(?)	–	T	T	–	T(?)
CIMATS	–	–	S	–	–	S,T	–	–	S,T	S,T	S,T	S,T	T	–
HALOE	–	–	S	–	–	–	–	S	S	–	–	–	–	–
THIR	–	–	T(?)	–	T	–	–	–	–	–	–	–	–	–
BUV-TOMS	–	S	–	–	–	–	–	–	–	–	–	–	–	–
VRPM	–	–	–	T/S	–	–	–	–	–	–	–	–	–	–
APP	–	S	–	S	–	–	–	–	–	–	–	–	–	–

S = Stratosphere
T = Troposphere

4.2 SER (Solar Extinction Radiometer)

SER is an outgrowth of the SAM II and SAGE instruments. It operates in a solar occultation mode using the visible, near-UV, and near-IR portions of the spectrum. The instrument is designed to measure aerosols and O_3, primarily, with either H_2O or NO_2 secondarily. Azimuth scan capability of ± 180° and a vertical scan of ±3° for tracking are provided. Once the sun is acquired, a lock-on mode retains it in the field of view during its transit of the atmosphere.

4.3 CIMATS (Correlation Interferometer for the Measurement of Atmospheric Trace Species)

This sensor is a modification to the COPE instrument which has been flown aboard aircraft and helicopters. It is being considered for the measurement of H_2O, NO_2, CH_4, N_2O, NH_3, CO, and possibly NO, CO_2, SO_2, CH_2O, C_2H_4 and C_2H_6. Operating in the solar IR region (1 to 4 μm), it produces interferograms which are subsequently computer-correlated with interferograms of known species. CIMATS is configured for nadir viewing and requires a solar elevation angle sufficient to provide adequate radiance and a relatively homogeneous field of view for optimum data interpretation.

4.4 MAPS (Measurement of Air Pollution from Satellites)

MAPS is designed to measure CO and NH_3 total burdens in the troposphere. Using differential absorption of IR wavelengths, the instrument will operate in a nadir-viewing mode. Each gas channel will be provided with three optical paths; two will contain a sample of the gas at different partial pressures, and the other will contain an identical evacuated cell. Incoming radiation is alternately passed through the cells and relative ratios of signal strength obtained, which are used to determine the concentrations of the species. Cryogenic cooling for the detectors is required, as is information on vertical temperature distribution, vertical water vapor distribution, and cloud cover.

4.5 HALOE (Halogen Occultation Experiment)

This instrument is, essentially, the MAPS instrument described above in a solar viewing mode. The gas cell complement will be designed for measurements of HCl and, perhaps, HF, CH_4 and H_2O. The limitations are similar to any solar occultation measurement with the additional constraint of the possible effects of doppler shift of the signal through the relatively narrow spectral band pass of the gas cells.

4.6 APP (Atmospheric Physical Properties)

The APP is a new instrument that is being designed to measure aerosols and ozone. Operating in the 0.3 to 1.0 μm region, APP will use solar scattering in, probably, four or five spectral bands in order to obtain size and distribution data on aerosols and ozone concentration.

4.7 VRPM (Visible Radiation Polarization Monitor)

Designed to measure tropospheric aerosols, the VRPM utilizes three or four spectral bands in order to analyze both the polarization and intensity of the incoming radiation. This, in turn, allows the description of aerosol size distribution and concentration. The instrument is locked on to a specific ground target and receives the backscattered radiation from this scene. Tracking of this area is allowed by a ±60° scan about the spacecraft nadir. In common with other scattered radiation sensors, the VRPM requires solar elevation angles of 20° to 80°. In addition, like CIMATS, it requires a relatively homogeneous field of view.

4.8 BUV/TOMS (Backscattered UV/Total Ozone Mapping System)

This instrument is an improved version of the BUV sensor that flew on Nimbus 4. Operating in the 0.16 to 0.40 μm region of the spectrum, BUV/TOMS will measure the flux reflected by the earth's atmosphere. As many as twelve discrete wavelengths may be utilized in order to measure the total ozone burden and to obtain a crude vertical profile of the ozone concentration. Concurrent measurements of the solar flux in the same spectral region will be used to assess the differential absorption due to ozone in the atmosphere. The TOMS component of the system will have a cross-track scan capability of ±48° and will include a silicon photodiode used to detect cloud cover. The presence of clouds or aerosols could cause errors in the instruments' performance.[1]

4.9 Supporting Instrumentation

Many of the above instruments require auxiliary data for the interpretation of their measurements. Most common among these requirements are those for water vapor, cloud cover, and aerosols.

The presence of these constituents may cause errors in the instrument data if uncorrected. Among the supporting instruments available for a Shuttle mission would be:

- THIR - Water vapor and cloud cover
- VTPR - CO_2 and water vapor
- VRPM - Aerosols

Table 4-II presents an operational summary of the instruments described in this section and includes the three supporting instruments.

The inability of current remote sensing technology to provide measurements of some of the more important properties of the atmosphere remains an area of importance. It is hoped that the results of this study will provide guidance in choosing the scientific and engineering goals that will be pursued next. Until sufficient monitoring capability is developed, instrumentation improvements will be a factor in the development of the related atmospheric research programs.

TABLE 4-II
INSTRUMENT SUMMARY

INSTRUMENT	SPECIES	MODE	WAVELENGTH (μm)	BAND/CHANNELS	AZIMUTH SCAN	VERTICAL SCAN	COMMENTS
LIMS	CO_2, O_3, H_2O, NO_2, HNO_3	Limb Emission	6 to 20	5 to 8	No (fixed at 30° from heading line)	Yes	Modification of LRIR, LACATE
SER	Aerosols, O_3 and either H_2O, NO_2	Solar Occultation	0.3 to 1.1	5	Tracking	No	Modification of SAM II, SAGE
CIMATS	H_2O, NO_2, CH_4, N_2O, NH, CO, CH_2O	Solar Occultation	2.0 to 3.5	Probably 2 or 3	No: may be fixed as LIMS	N/A	Modification of COPE
MAPS	CO, NH_3	Nadir - Differential Absorption	4.6 (CO) and 11.2 (NH_3)	2	No	N/A	
THIR	H_2O Cloud cover	Nadir - Thermal	6.5 to 7.0 and 10.5 to 12.5	2	Cross-track	N/A	
VTPR	CO_2, H_2O	Nadir - Thermal	6 to 15 and 19	8: 6 for CO_2 2 for H_2O	Cross-track	N/A	
HALOE	HCl - Primary HF, CH_4, H_2O	Solar Occultation - Differential Absorption	2.4 to 6.0	4	Tracking	No	MAPS in a solar occultation mode
APP	Aerosols, O_3	Solar Scattering	0.3 to 1.0	Probably 4 to 5	Some	N/A	
VRPM	Aerosols (TROPO)	Nadir - Solar Reflected - Polarization	0.4 to 1.0	3 or 4	± 60° about Nadir lock-on	N/A	
BUV/TOMS	O_3	Nadir - Solar Reflected	BUV: 0.16 to 0.40 TOMS: 0.31 to 0.38	2	BUV: No TOMS: ± 48° Cross-track	N/A	

5.0 ORBIT CONSIDERATIONS

5.1 Altitude Effects

From the standpoint of orbital dynamics, the effects of altitude are most pronounced on the period of the orbit of the satellite. From the point of view of the instrument designer, the altitude is directly related to the width of the ground swath for nadir viewing instruments, assuming a constant field of view. This consideration affects both areal coverage and horizontal resolution. For particular applications, such as the Shuttle sortie missions and sun-synchronous orbits, other considerations become important.

The Shuttle's relatively low orbital altitudes affect the degree to which effluents are removed from the Shuttle area. This is discussed more fully in Appendix A. In the case of sun-synchronous orbits, the altitude and inclination angle are directly related as shown in Figure 5-1.

5.2 Temporal Coverage

The requirements for data sampling are as diverse as the constituents themselves. While some users may feel the necessity for diurnal sampling at a given latitude and longitude, others would be content with seasonal sampling. These requirements are most restrictive in the case of solar occultation measurements from sun-synchronous orbits. Based upon the time of nodal crossing, the revisit rate may be as infrequent as two to four per year, in the case of sun-synchronous orbits. While the use of low inclination orbits may increase the

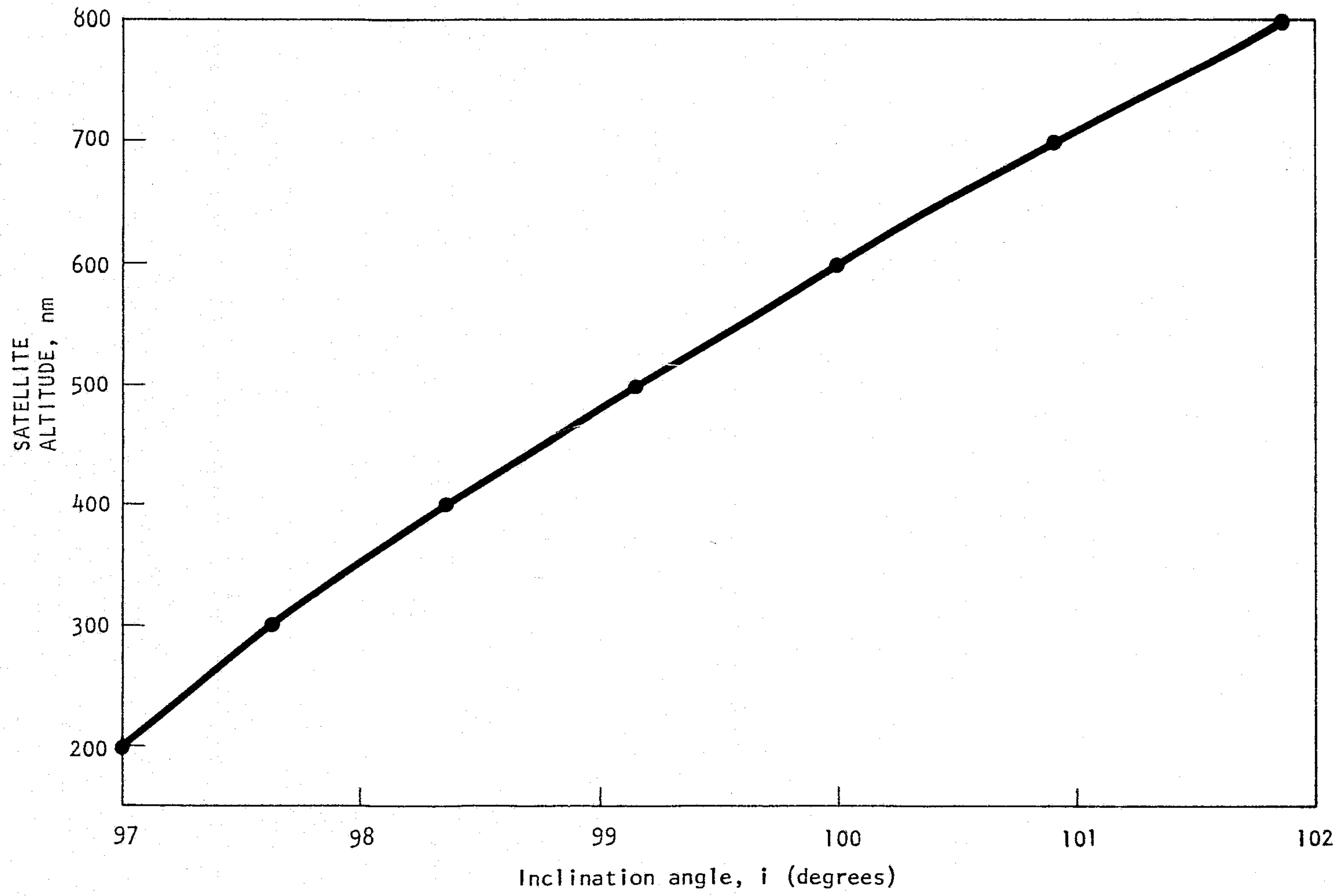

FIGURE 5-1
ALTITUDE vs. INCLINATION ANGLE FOR SUN-SYNCHRONOUS ORBITS

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sampling rate for solar occultation measurements, it does so at the expense of high-latitude coverage.

At the other extreme is the case of nadir-viewing thermal instrumentation. In this case the temporal coverage is not so critical. As the following figures indicate, repeat cycles of five days may be easily chosen within the constraints of inclination angle and altitude given for early Shuttle missions.

Between these two extremes is the limb-viewing case which utilizes thermal emission. This technique offers the advantages of large coverage areas and, hence, more frequent revisit times and the direct measurement of vertical profiles.

5.3 Areas Covered

As mentioned above, the areal coverage is directly related to satellite altitude and instrument field of view. It is also dependent upon the degree of cross-track scanning available, if any. For the orbits investigated, a 45° azimuth scan capability is seen to provide at least a 40 percent overlap in coverage on successive orbits. For earth-viewing applications, this would give global coverage within the latitudinal limits imposed by the inclination angle. In the case of limb-viewing instruments, this would imply near-global coverage within a repeat cycle, as well as higher latitudinal coverage than is available to nadir-viewing instruments in the same orbit.

For the case of reflected solar instruments, the solar elevation angle is an important factor. A family of figures in this section will present the limitations imposed by various sun elevation angle requirements.

5.4 Diurnal and Seasonal Coverage

Many species of interest in the stratosphere depend upon photochemical reactions for creation and/or destruction. For these species, the intensity of sunlight is an important variable and the concentration measurements must take it into account. One way of doing this, of course, is to make diurnal measurements of a species to determine the effects of illumination upon the concentration.

When the species concentration may depend upon both radiant intensity and ambient temperatures, seasonal measurements may be in order. These measurements also show variations that may result from seasonal variations in the height of the tropopause and stratospheric motions.

For the orbits considered in this section, diurnal and seasonal coverage is obtained on some latitude bands as a function of time from launch. In order to obtain diurnal coverage of a particular geographic area, either specialized stationary orbits or a multi-satellite network would be required. Neither of these cases is considered in this report. It is felt that diurnal or seasonal coverage in a zonal sense is sufficient for most constituents at this time.

5.5 Analysis of Selected Orbits

Several sun-synchronous and inclined orbits were examined in the course of this study. The sun-synchronous orbits were 97.4° and 99° with altitudes of 500 km and 958 km, respectively. The inclined orbits were 30° and 56° with altitudes of 547 km and 565 km, respectively. These were selected by NASA for reasons of repeat cycle and ETR launch site constraints.

A complete analysis would consider the technical specifications of given sensor systems in conjunction with the orbit. These factors are more fully considered in Section 6.0, where atmospheric constituents, sensors, and a given orbit are all used as inputs to the payload selection. Only generic sensors are considered in this section. In the case of nadir-viewing instruments, two operational modes are considered: thermal sensing and reflected solar devices. The latter are strongly influenced by solar elevation angle and the coverage is reduced by requirements for higher elevation angles.

For 30° inclined orbits Figure 5-2 shows the effects on latitude of the requirement for solar elevation angles of ≥10°, ≥30°, and ≥45°. Figure 5-3 presents the latitude coverage of 56° inclined orbit with the same minimum solar elevation requirements.

In the case of sun-synchronous orbits, the latitude coverage is a function of both the minimum required solar elevation angle and the local time of equatorial crossing on the ascending pass. Figure 5-4 indicates the coverage obtained with a noon crossing for the same solar elevation angles and an altitude of 500 km. Figure 5-5 treats

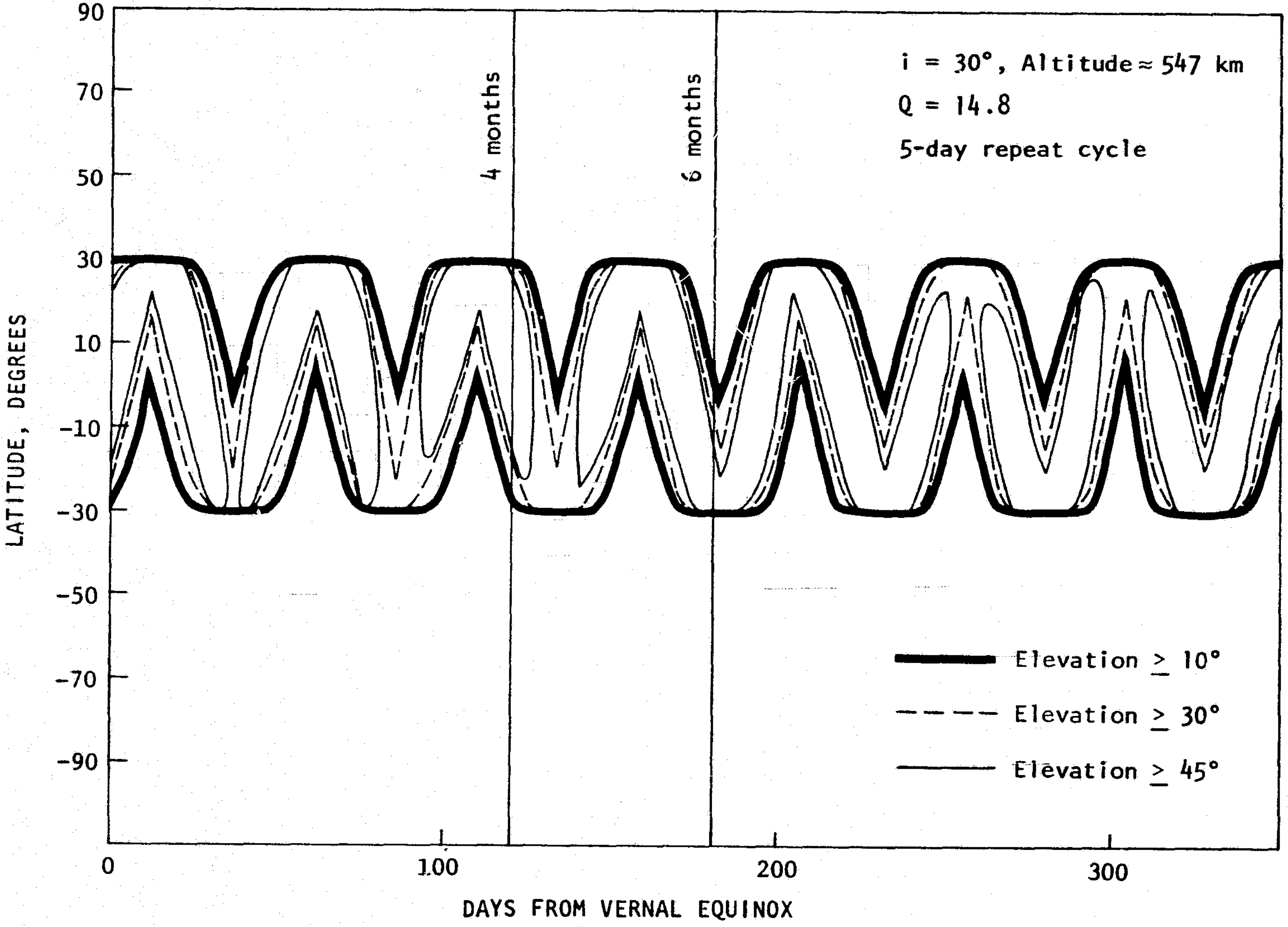

FIGURE 5-2
LATITUDE COVERAGE FOR 30° ORBIT

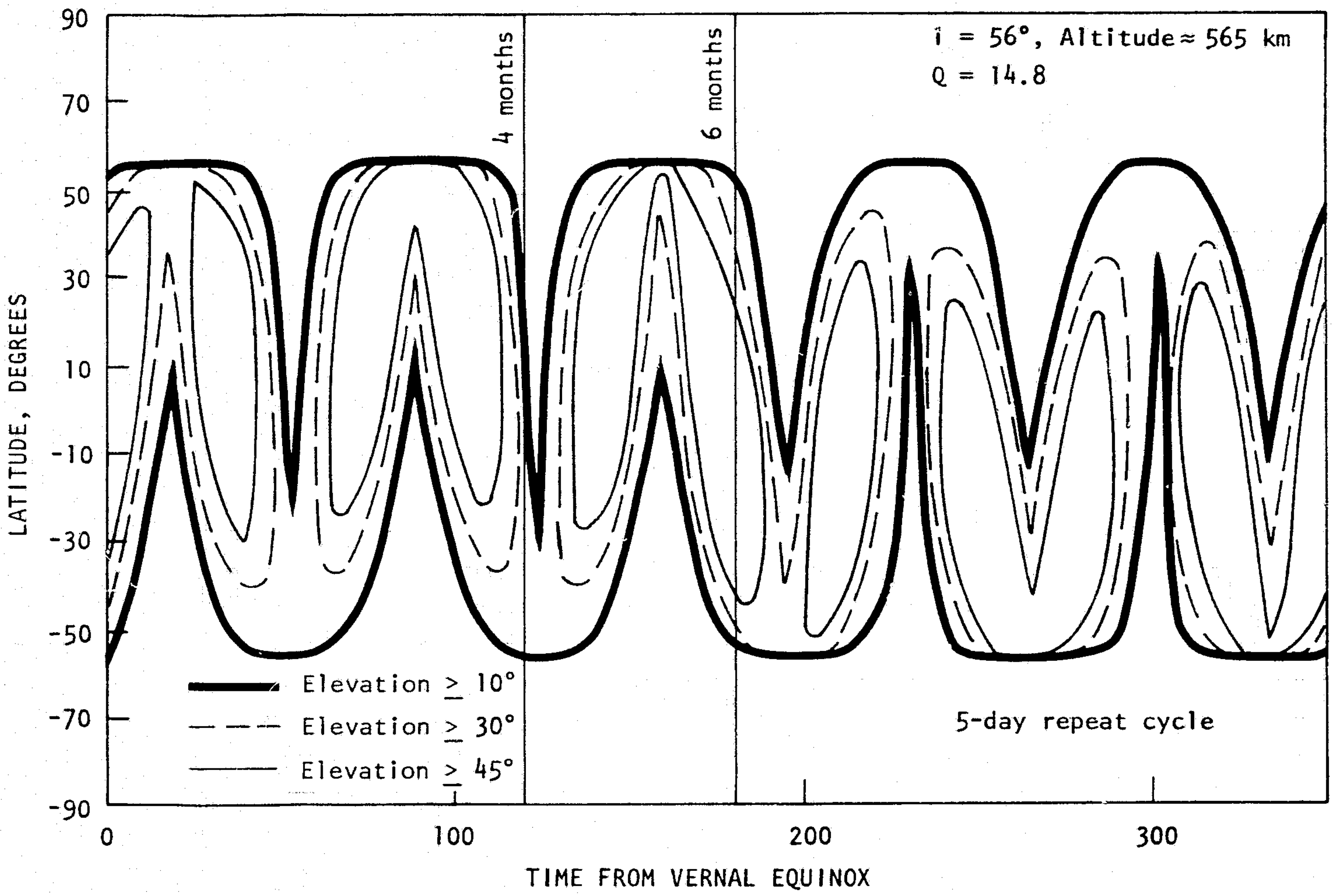

FIGURE 5-3
LATITUDE COVERAGE FOR 56° ORBIT

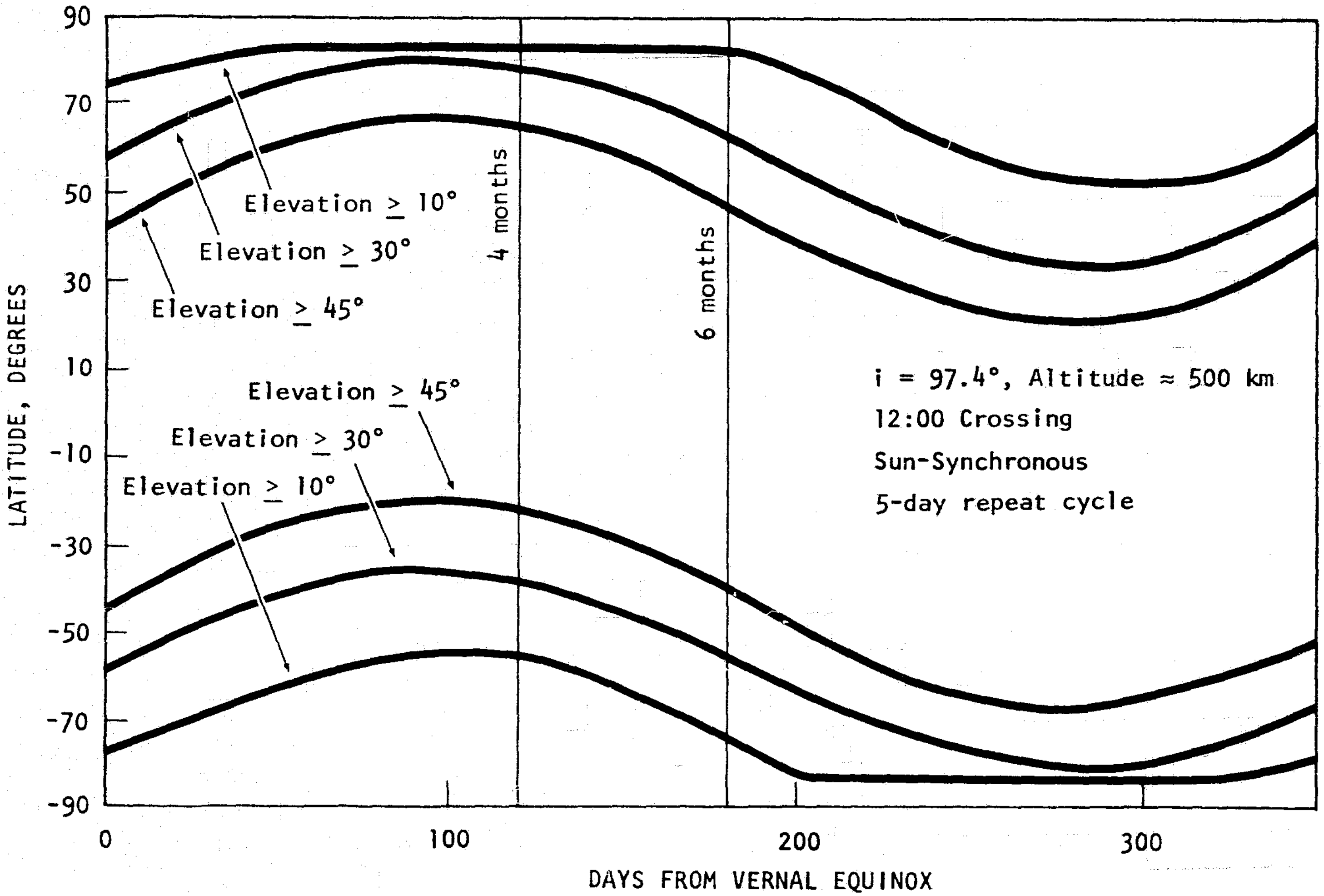

FIGURE 5-4
LATITUDE COVERAGE AS A FUNCTION OF MINIMUM SOLAR ELEVATION ANGLE LOW SUN-SYNCHRONOUS ORBIT, NOON CROSSING

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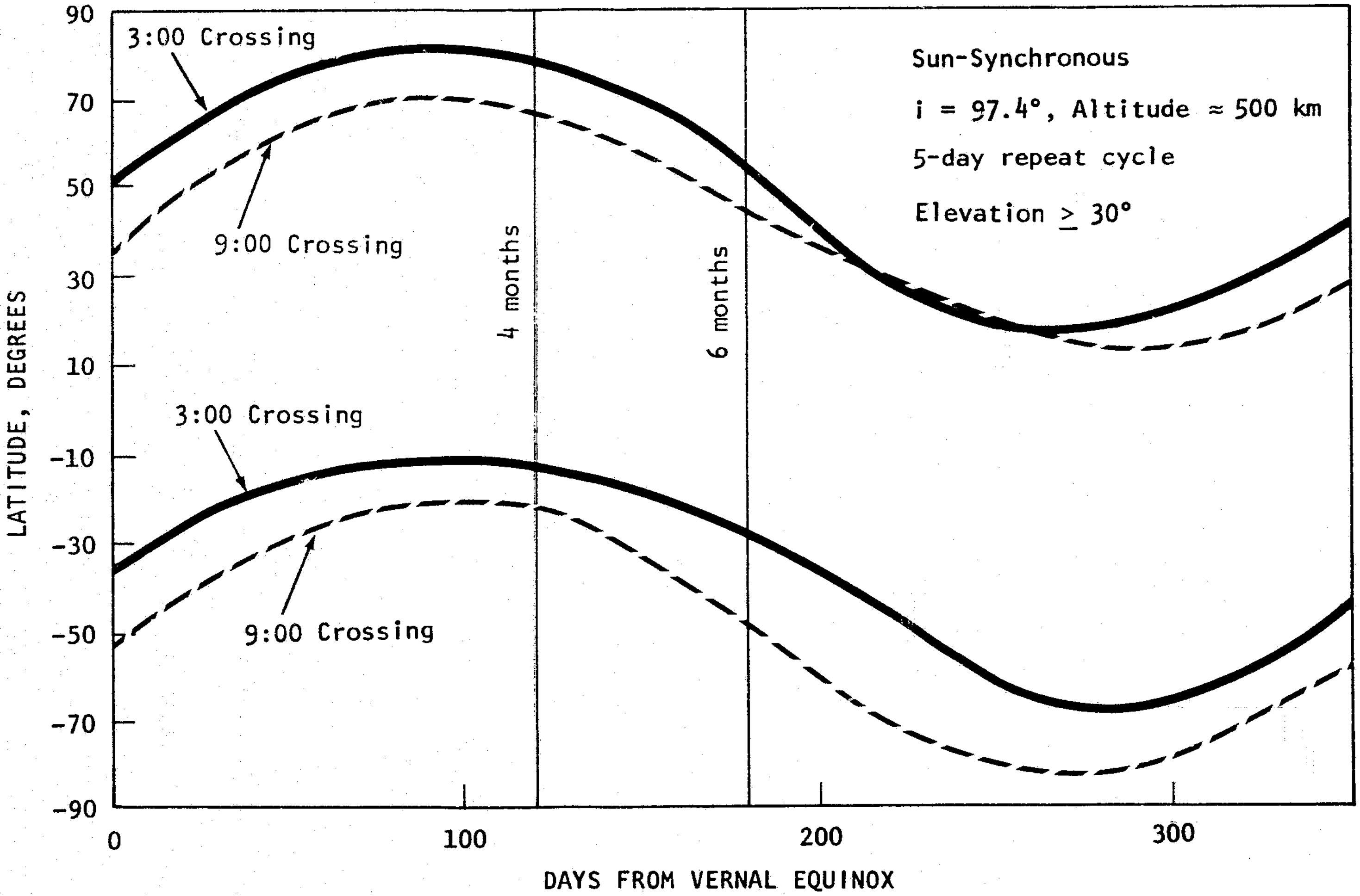

FIGURE 5-5
LATITUDE COVERAGE FOR MINIMUM SOLAR ELEVATION ANGLE OF 30°
LOW SUN-SYNCHRONOUS ORBIT, 9 AM AND 3 PM CROSSINGS

the same sun-synchronous orbit and shows the effects of crossing time with the requirement for a solar elevation angle of greater than or equal to 30°. Figures 5-6 and 5-7 present the same information for a sun-synchronous orbit with an altitude of 960 km.

The ground tracks for nadir-viewing instruments utilizing thermal sensing are shown in Figure 5-8 to Figure 5-11 for each of the four orbits. These same figures also indicate the degree of over-sampling of the polar regions that could occur with sun-synchronous orbits.

For the case of solar occultation instruments, the latitude of the tangent point of sunrise and sunset is of interest. Figure 5-12 illustrates the tangent latitude of both sunrise and sunset as a function of time from launch. It should be noted that, due to orbital precessions, relative to the sun, there are periods when the data points are solely in one hemisphere or the other. Figures 5-13 through 5-15 present the same information for the 56° orbit and the two sun-synchronous orbits, respectively. The latter two figures (Figures 5-14 and 5-15) illustrate the limitations in latitudinal coverage intrinsic to a solar occultation experiment on a sun-synchronous satellite.

It can be concluded then that, while certain orbital limitations can be identified in a straightforward manner, such as those that occur in using occultation instruments, the careful selection of orbit parameters will be generally required. The data of this

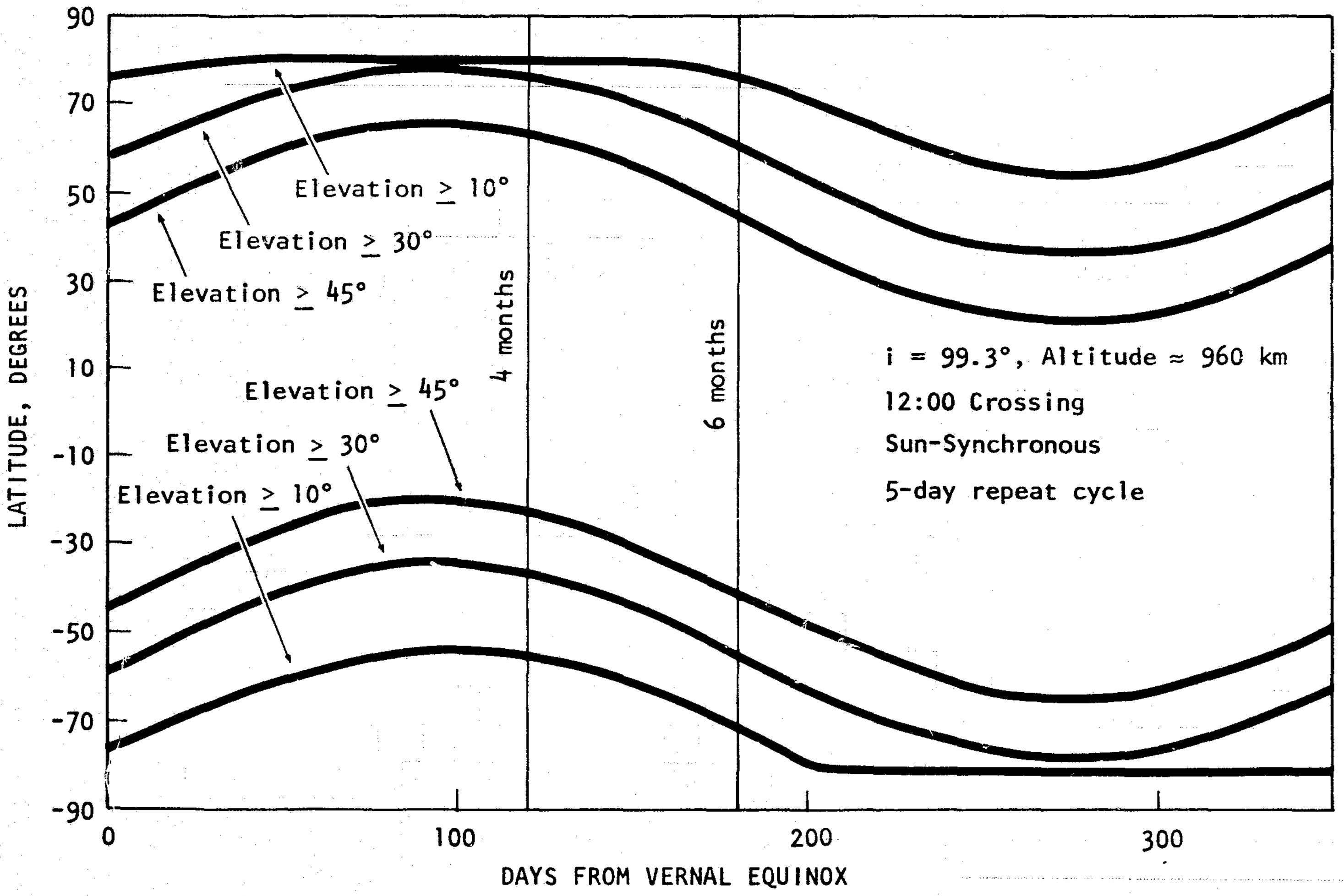

FIGURE 5-6
LATITUDE COVERAGE AS A FUNCTION OF MINIMUM SOLAR ELEVATION ANGLE, HIGH SUN-SYNCHRONOUS ORBIT, NOON CROSSING

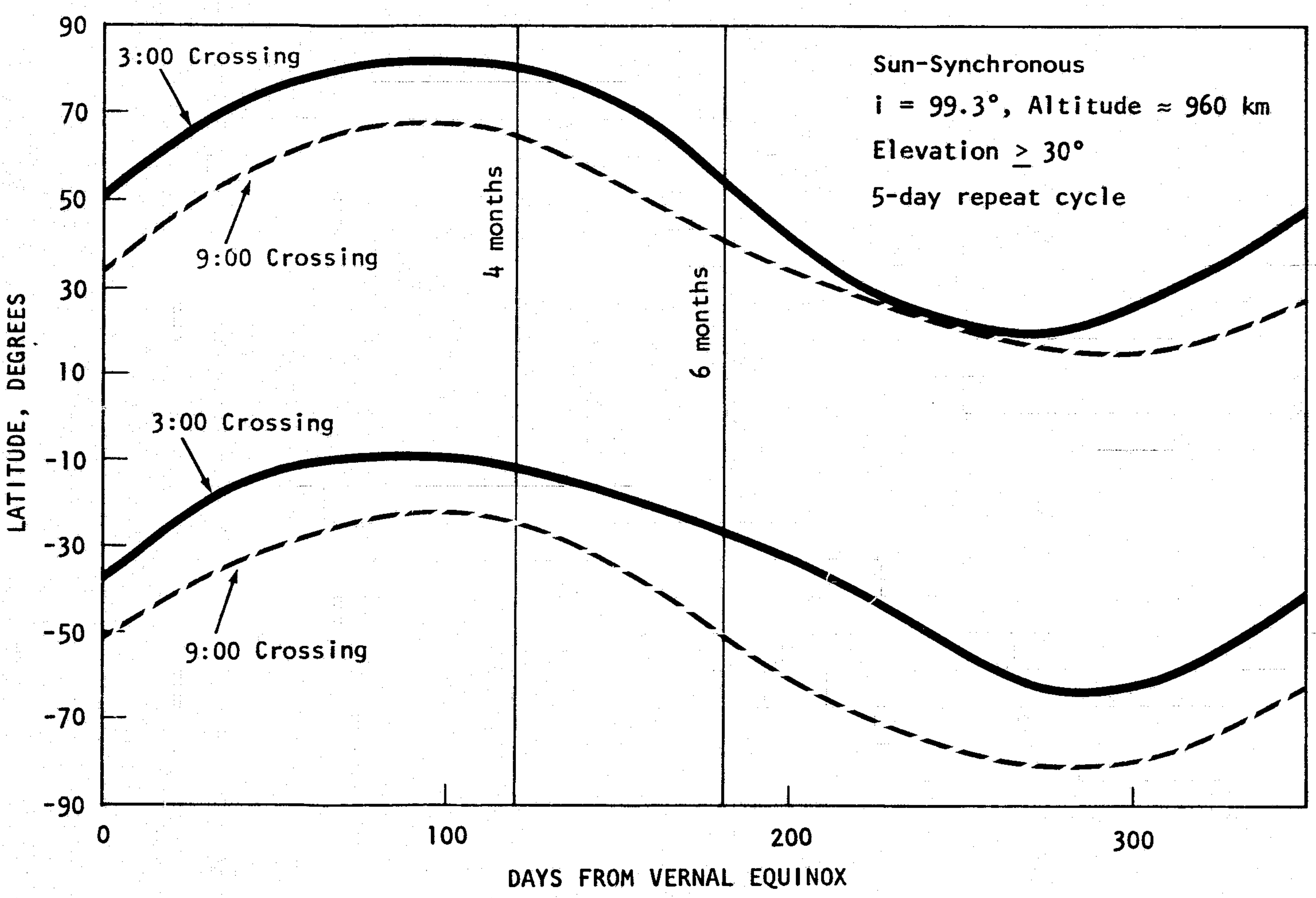

FIGURE 5-7
LATITUDE COVER FOR MINIMUM SOLAR ELEVATION ANGLE OF 30°
HIGH SUN-SYNCHRONOUS ORBIT, 9 AM AND 3 PM CROSSINGS

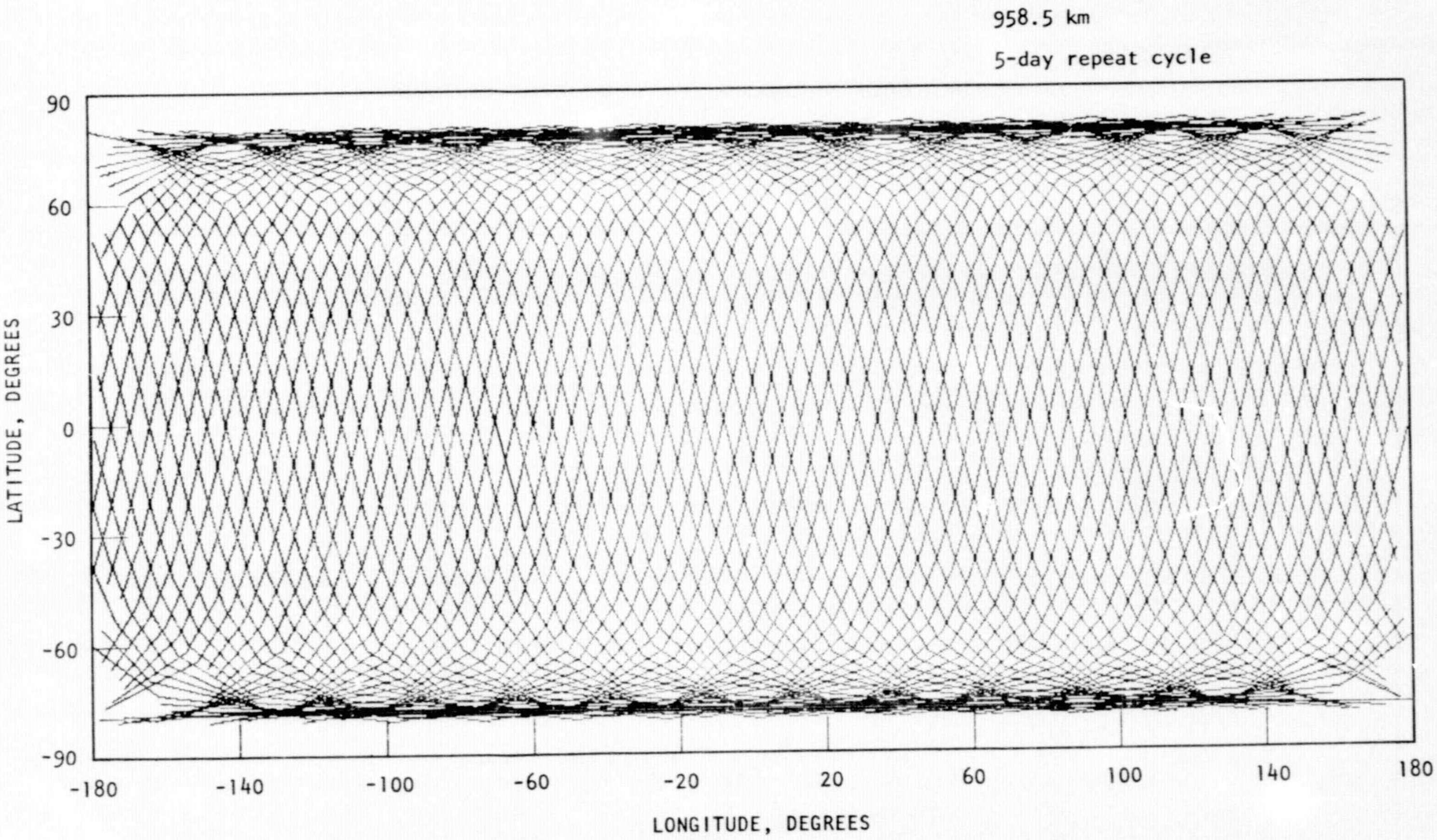

FIGURE 5-8
GROUND TRACK FOR HIGH SUN-SYNCHRONOUS ORBIT

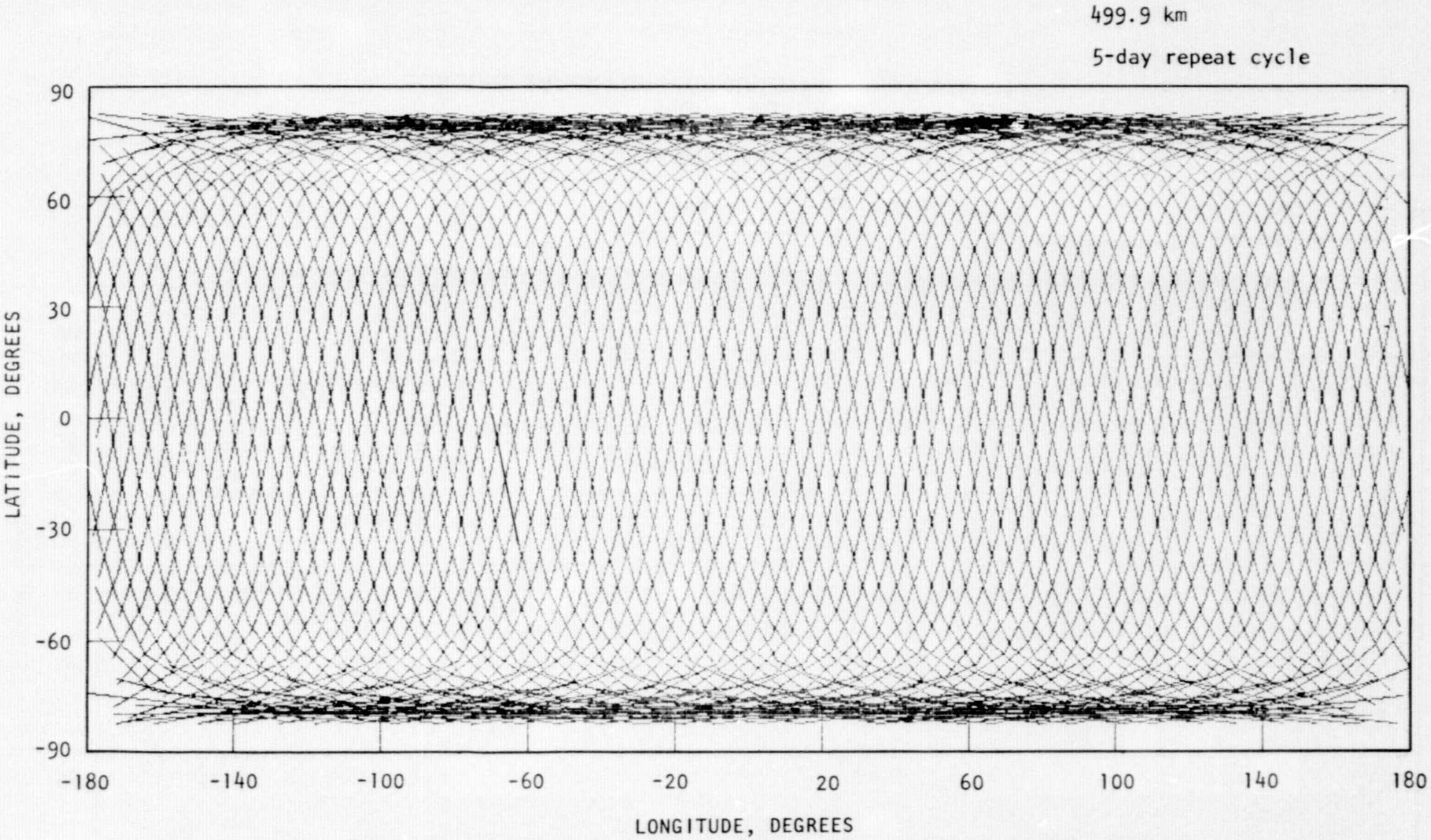

FIGURE 5-9
GROUND TRACK FOR LOW SUN-SYNCHRONOUS ORBIT

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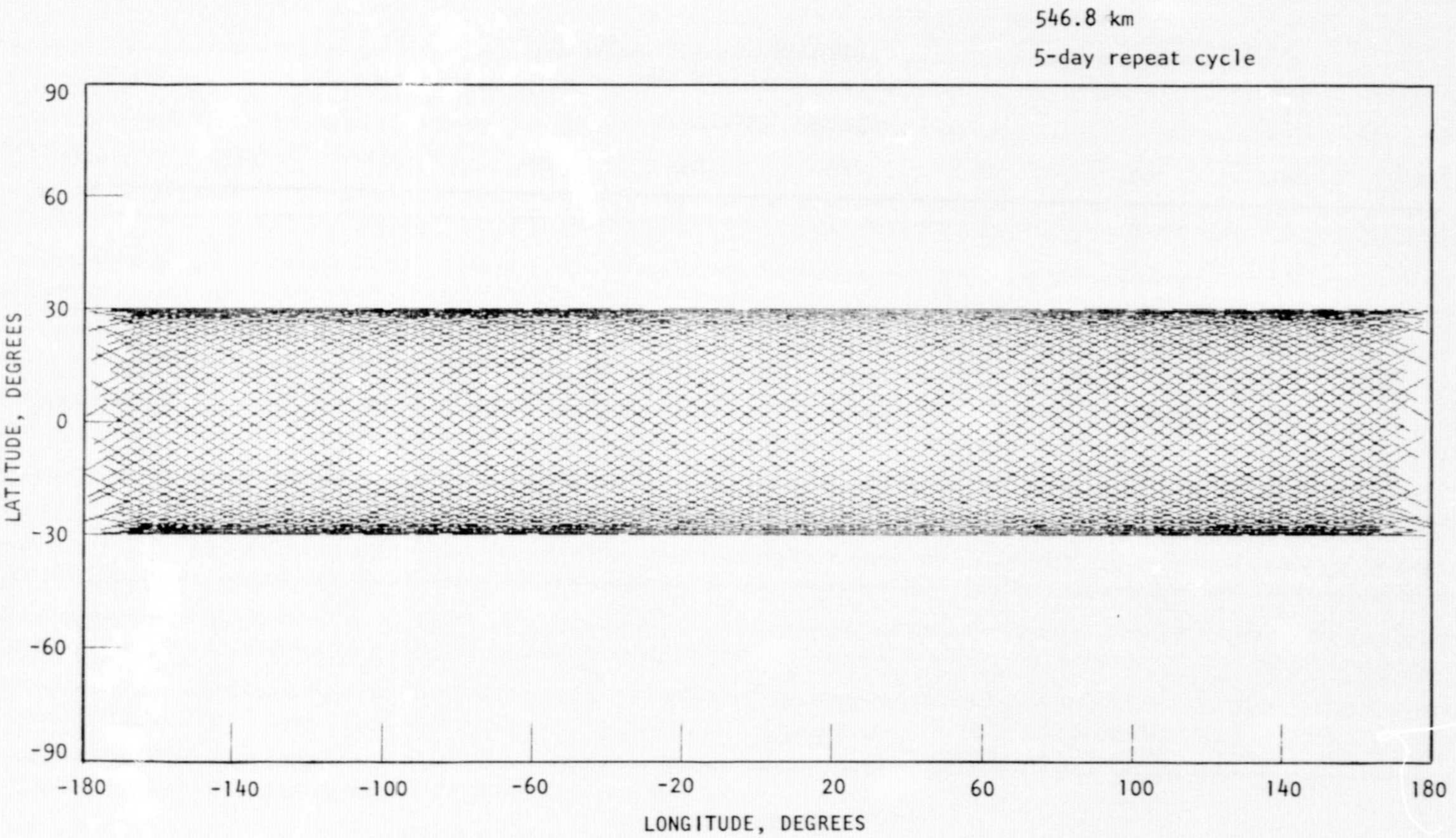

FIGURE 5-10
GROUND TRACK FOR 30° ORBIT

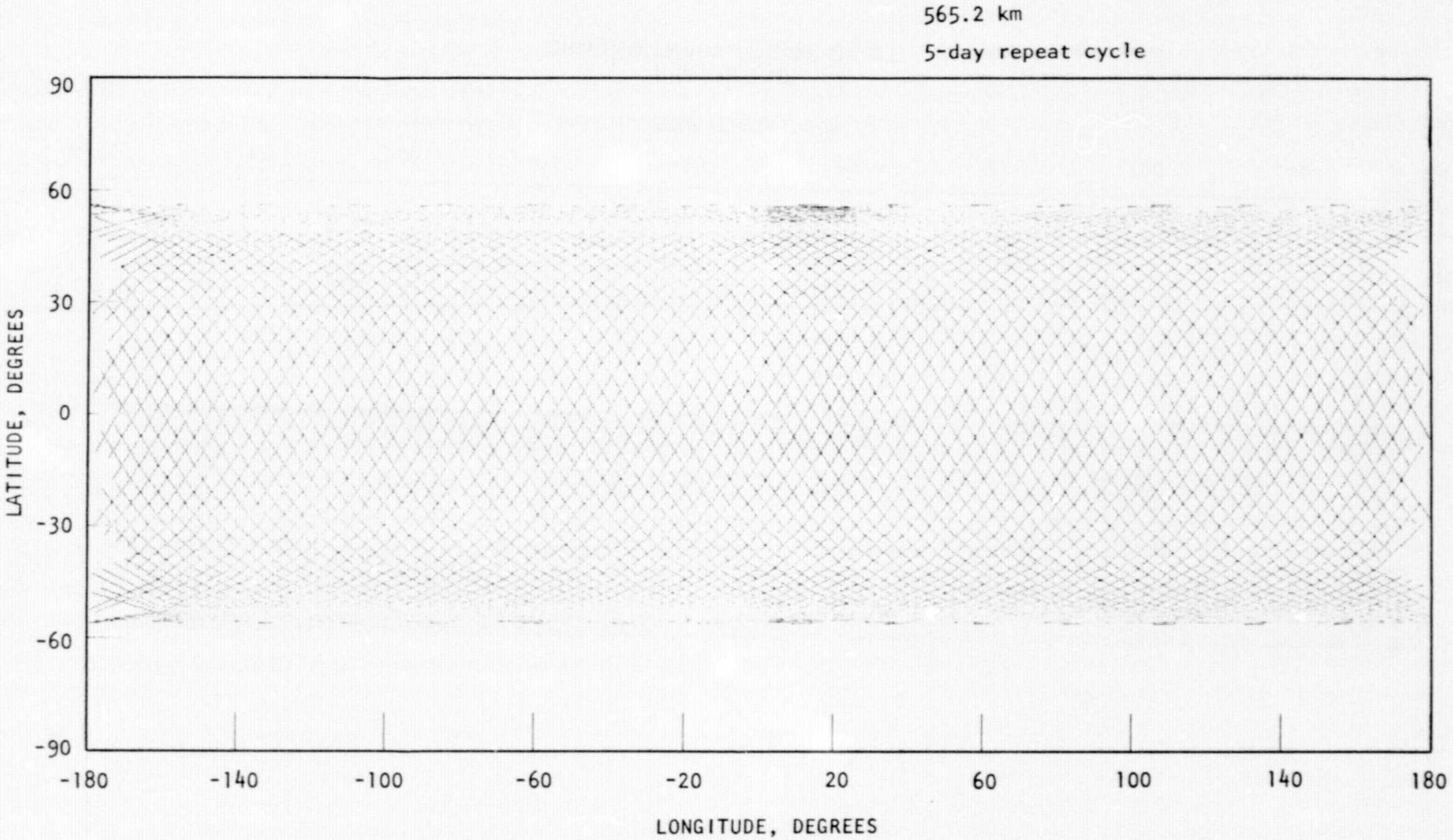

FIGURE 5-11
GROUND TRACK FOR 56° ORBIT

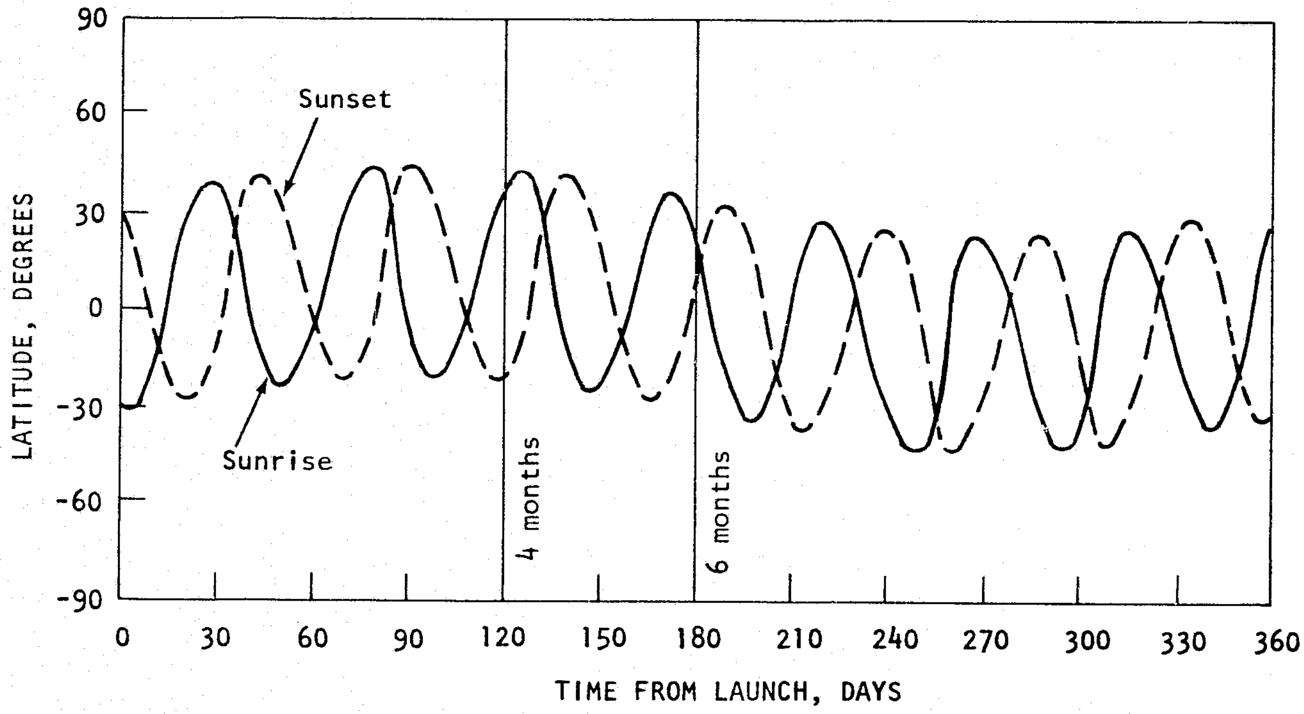

FIGURE 5-12
LATITUDE COVERAGE FOR SOLAR OCCULTATION SENSOR, 30° ORBIT

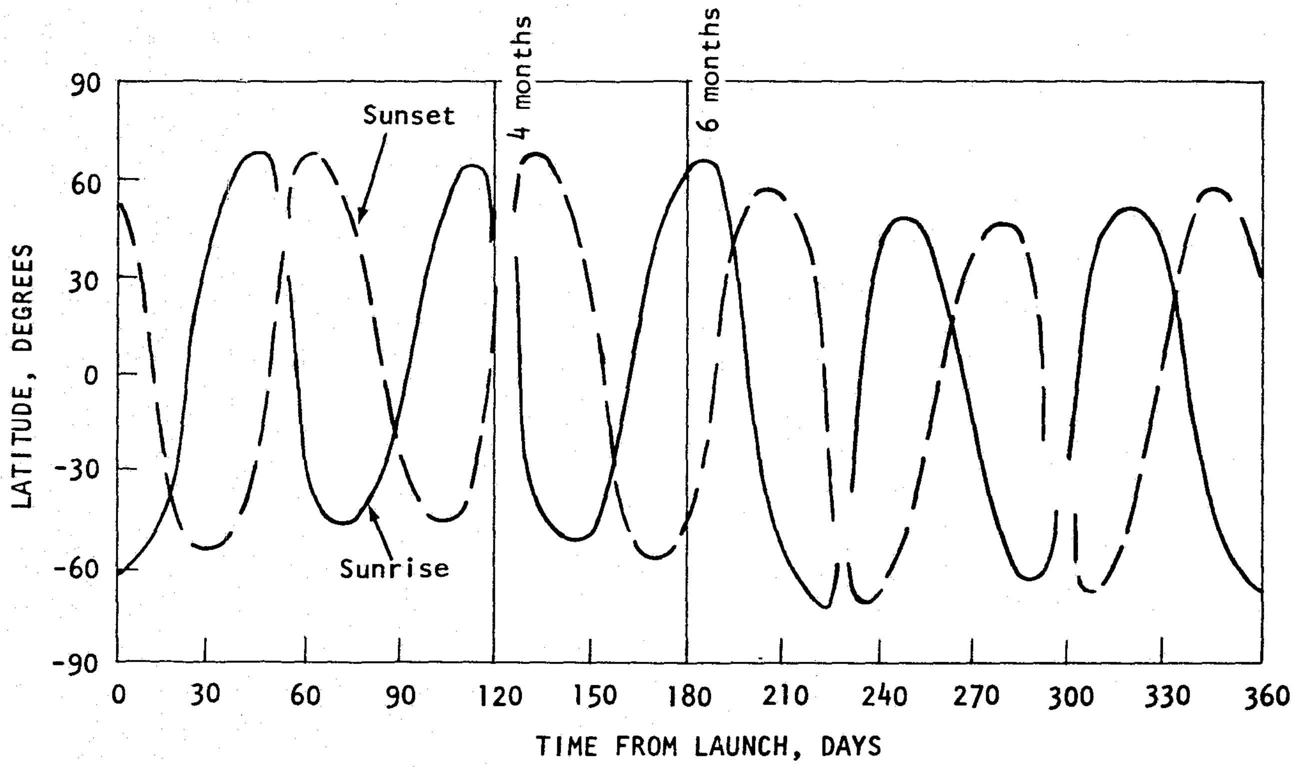

FIGURE 5-13
LATITUDE COVERAGE FOR SOLAR OCCULTATION SENSOR, 56° ORBIT

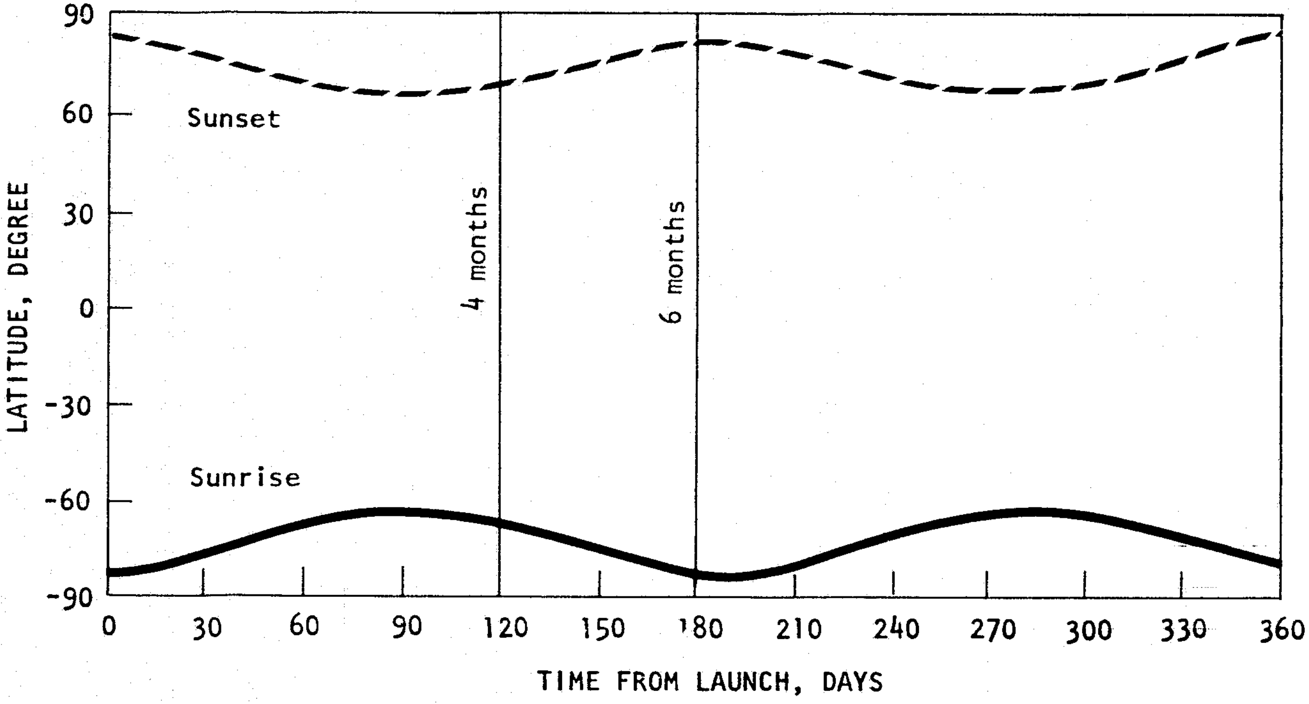

FIGURE 5-14
LATITUDE COVERAGE FOR SOLAR OCCULTATION SENSOR,
LOW SUN-SYNCHRONOUS ORBIT

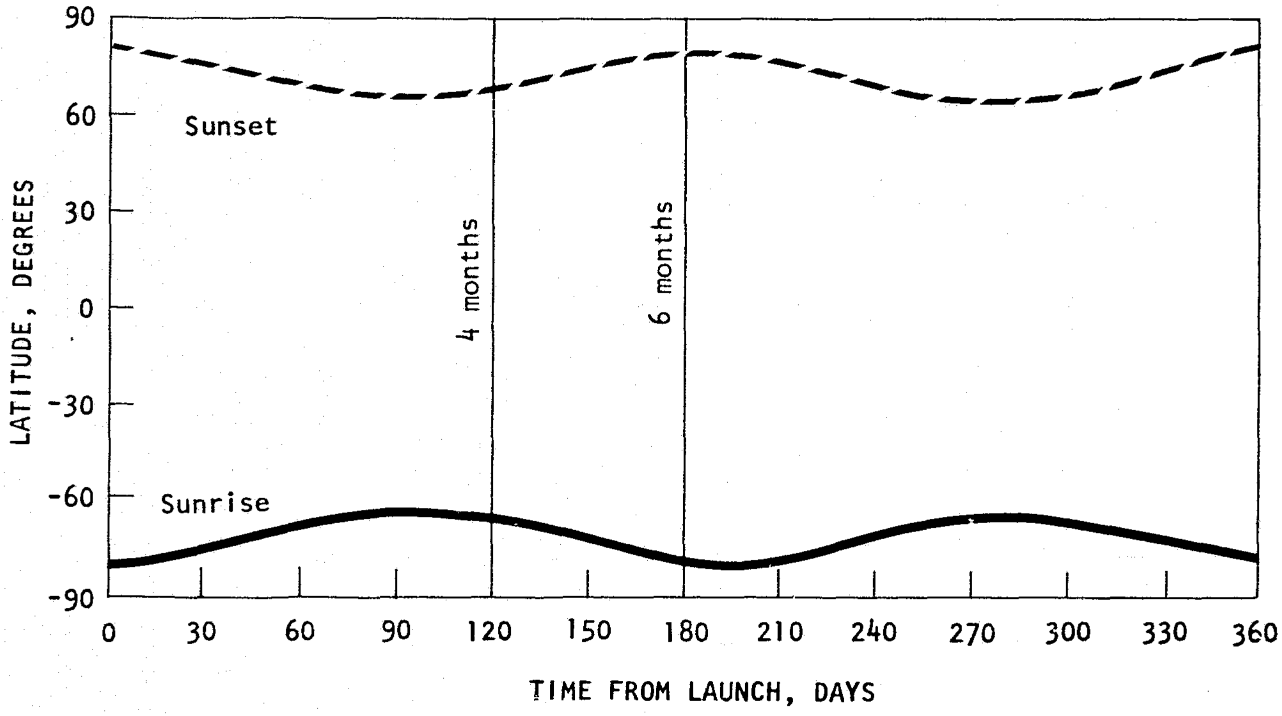

FIGURE 5-15
LATITUDE COVERAGE FOR SOLAR OCCULTATION SENSOR, HIGH SUN-SYNCHRONOUS ORBIT

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section are utilized in Section 6 to evaluate the effectiveness of various orbit/instrument combinations in producing results of scientific value.

6.0 PAYLOAD SELECTION

6.1 Mission Evaluation Methodology

In order to properly determine how well any selected stratospheric species measurement mission improves on present knowledge of the characteristics and spatial/temporal distribution of the species, a method is presented that evaluates a selected mission in terms of the present status of stratospheric knowledge of the species of interest and the required level of knowledge (as expressed by the scientific user community). The method has also been inverted and used to select the mission that is most effective.

The selection of an optimum mission involves not only the evaluation of orbital characteristics but also the selection of those species to be measured that provide the optimum incremental improvement from present knowledge to required knowledge. Thus, two factors are involved:

(1) Prioritization of pollutants based on a combination of present knowledge and required knowledge.

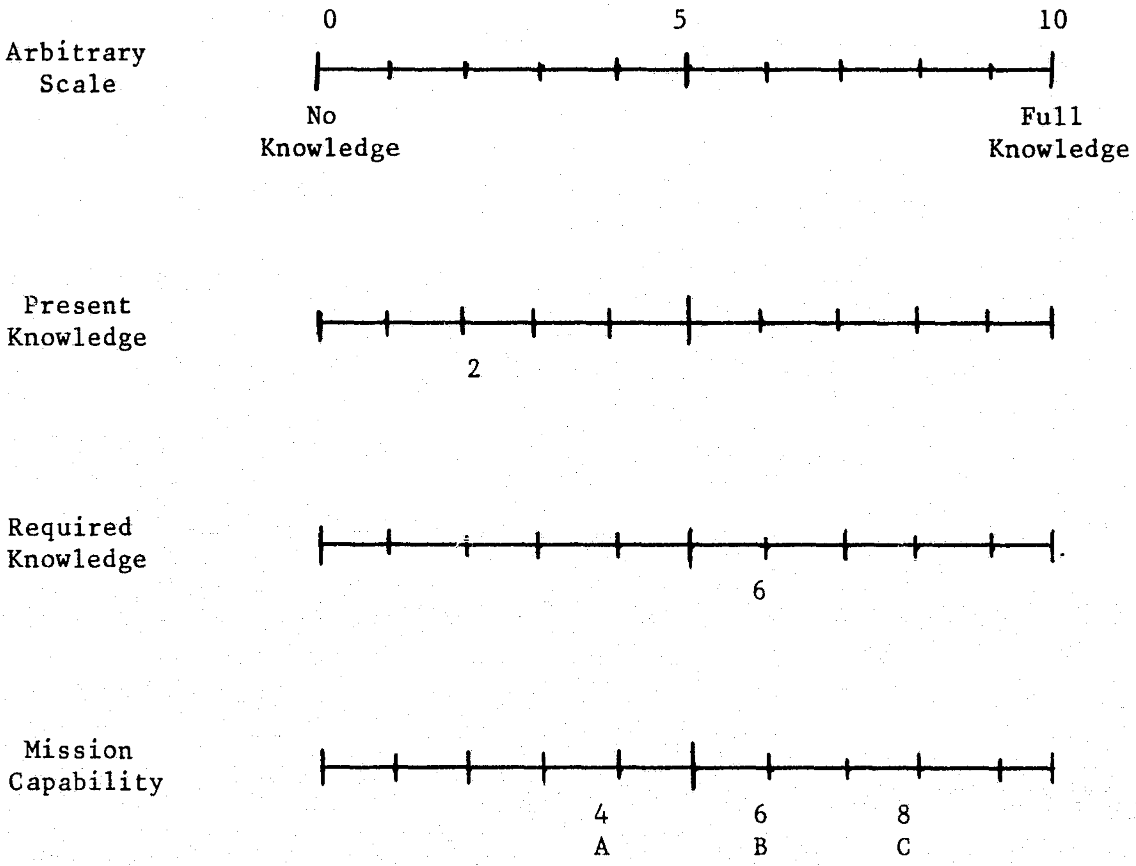
(2) Selection of the "optimum" mission (orbit plus instrument) based on present measurement knowledge and required knowledge.

The following sections will be limited to a discussion of the "optimum" mission selection for a single species. The prioritization of species based on requirements was discussed in Section 3.2. Incorporation of these priorities into the evaluation methodology will be discussed later.

This evaluation technique can be applied specifically to orbit evaluation, instrument evaluation, or both by selection of the appropriate parameters.

6.1.1 Approach to the Ranking and Evaluation

For each stratosphere species of interest one may assign a ranking or value in terms of an arbitrary scale of, say, 0 to 10 based on a comparison of either: (1) the present knowledge of the species distribution, (2) the required knowledge of the species distribution, or (3) the projected measurement capability of a specific mission with the total possible four-dimensional knowledge. For a typical species this may be exemplified as follows:



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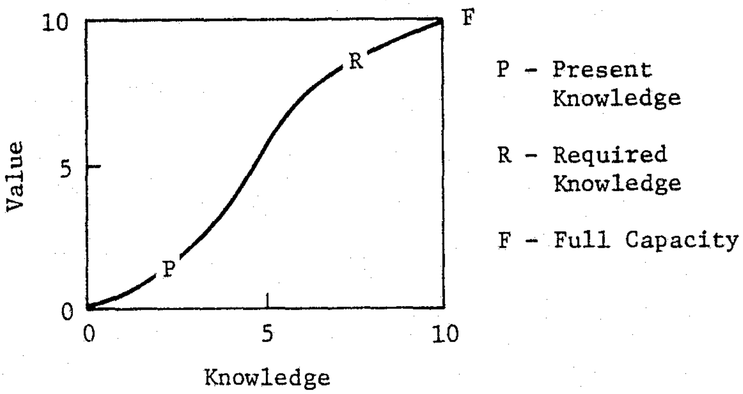
The key to assessing the value of a particular mission lies in comparing the mission capability with the incremental improvement between present knowledge and required knowledge. In the example illustrated above, the present level of knowledge has been given an arbitrary rating of 2 and the required knowledge an arbitrary rating of 6. It is important to note that the required knowledge level is not always set at the maximum. This may be for two reasons. On the one hand, a full capability of 10 may provide the user with much more data than he needs or could ever make use of. On the other hand, the present level of knowledge may be so low that the user would require only a small increase in knowledge to achieve a significant improvement in understanding the chemistry and distribution of the pollutant. Requirements should be set at the level that best equals the capability of the user community to assimilate the data measured.

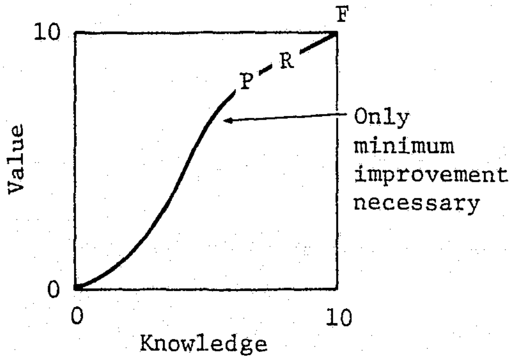
Thus, in the given example, the critical area for gain lies between the present knowledge and the required knowledge. Therefore, system C is not automatically much better than system B. However, each (B and C) is significantly better than system A.

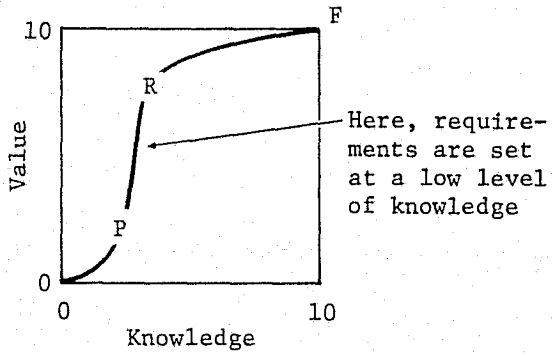
In order to indicate this in a more powerful way, the ranking scheme may be presented in a slightly different manner:



Here we see a sharp rise in value between present and required knowledge and little gain thereafter. Present knowledge is assigned a value at or near zero and required knowledge is assigned a value approaching 10 but allowing some small value for additional knowledge up to full.

In other cases the present knowledge may be such that it commands a high value in relation to full capability leaving little room for improvement. Conversely, the current requirements may be such that they can be fulfilled with only a minimum additional capability.





This type of evaluation has been used previously in a variety of system evaluations[44-48]. These reports give the details of the application of the method to both real cases and illustrative examples. The evaluation method makes use of value judgments of experts, either individually or by consensus, to provide information where "hard" data are unavailable. The objective is to make use of as much information as is available to the system. Much of this information is derived from the experience of experts associated with the system being evaluated. It is the objective of the evaluation to extract this information and check for its validity and utility. Critical areas can be identified where further gathering of information would be most effective. The success of the method depends on two critical factors:

- Availability of expert opinions or facts on the subject either directly or through adequate documentation.
- A thorough understanding of the structure and utilization of the evaluation procedure.

A logical sequence of steps in the application of the evaluation method is shown in Figure 6-1. The first step is to identify the appropriate evaluation parameters. These parameters when measured will provide the information needed to describe and adequately evaluate the candidate species, instruments, and orbits. The selection of the parameters must be made independent of any particular knowledge of instruments or orbits.

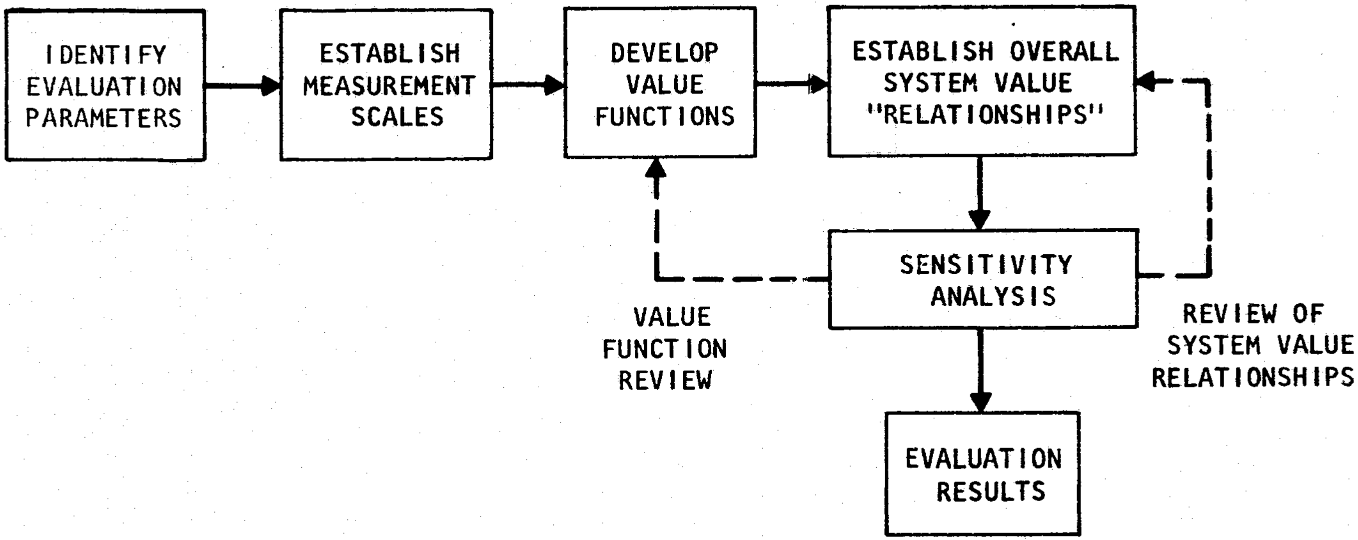


FIGURE 6-1
EVALUATION TECHNIQUE DEVELOPMENT AND VALIDATION

Once the parameters are identified, measurement scales must be established for each parameter. The ranges of the technical parameter measurement values can be based either on established facts (which are generally unavailable) or expert judgments. The analytical formulation of the technique begins with the development of the value functions. The value function and its graphic representation, the value judgment curve, are the basic inputs of the method. The value function relates points on the parameter measurement scale to a value scale that ranges between zero for no value to the user and some arbitrary positive number for maximum value to the user. (Ten was selected as maximum in this study.)

The first step in developing a typical value judgment function is to establish the maximum and minimum points for each of the evaluation parameters. Additional points between the parameter maximum and minimum points are defined and each assigned a value to the user. Identification of all break points is very valuable in this procedure. These points are then plotted on a value judgment scale to indicate the nature of the actual relationship. In most cases the judgment curves should have the following characteristics,

- Smooth variation over the entire range
- Zero slope at the origin
- An asymptotic approach to zero or the maximum for large values of the parameters
- Flexibility so that special cases are easily incorporated

These characteristics are best represented by the family of hyperbolic tangent curves characterized by the scale factors α and n. Then,

$$V = \tanh(\alpha x^{n}) \qquad \text{or} \qquad V = 1-\tanh(\alpha x^{n})$$

where, V = value to the user; x = parameter value; α determines at what point a change in parameter value begins to have a significant effect on the value to the user and n determines the slope of the change. In order for value to user to increase with increasing parameter change n must be greater than 1. While the hyperbolic tangent curve is used in most cases, it should be noted that other types of value functions can be used. These may in some cases be step functions or binary functions.

The next phase in the formulation of the technique is to develop the overall system value relationship. This is accomplished by establishing the relative importance of each of the parameters through weighting functions. The initial step in developing these functions is to designate each parameter as a factor or a term. A parameter is designated as a factor if it is of such paramount importance that if the value to the user is zero for that parameter, the entire system is considered valueless. If a parameter is not of the same level of criticality as a factor, it is designated a term. A term is related to the other parameters through an additive relationship.

The second step in establishing the relative importance of the performance parameters is to assign weights to each parameter designated

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a term; where the sum of these weights is equal to unity. Various methods can be used to assign the weights. For example, the Delphi technique developed by the RAND Corporation has been used to reach a consensus within a group of experts as to the weights which should be assigned. Another method is to assign an initial set of weights and evaluate them against candidate species whose characteristics and relative importance are known. Refinement of the weights is then made based on the results. However, there is <u>no substitute</u> for the participation of experts in the field, either actually or by proxy.

The relationship among all parameters, including terms and factors, is then established, taking the general form of the following equation:

$$V = \prod_{j=1}^{n} \left(F_j \ (x_j) \right) \sum_{i=1}^{m} \left(A_i G_i \ (x_i) \right)$$

where $$\sum_{i=1}^{n} A_i = 1$$

V = value

A_i = weight

F_i = value function (factor)

G_i = value function (term)

x_i = parameter measurement

This equation is termed a value set and can be used to evaluate for example all candidate instruments and/or orbits for a single stratospheric species.

A total system value can be calculated by combining all the individual value sets for the various species into one equation such as,

$$\text{Total System Value} = V_1 V_2 \left(W_3 V_3 + \bullet\bullet\bullet \quad + W_8 V_8 \right)$$

where

V_1, V_2 are individual value sets which are factors

$V_3 \bullet\bullet\bullet\ V_8$ are individual value sets which are terms

$W_3 \bullet\bullet\bullet\ W_8$ are term weighting functions where $W_3 + \bullet\bullet\bullet + W_8 = 1$

A sensitivity analysis can be performed on all value sets and value functions if desired. The analysis should indicate which evaluation parameters are most critical to the system value. In addition this analysis may also indicate if the various weighting functions or value set algorithms should be modified.

This technique is of high utility for decision making. However, it is a tool for use in decision making and not a decision maker itself. The ultimate decisions should be made by the experts in the field who have benefitted from the logical presentation of available information by means of this structured technique.

6.1.2 Application of the Method to Stratospheric Species Measurement

The evaluation method discussed in the previous section was used in the development of the evaluation techniques applied to stratospheric species measurement. However, two basic changes were made in its present application:

(1) Incremental values were used in place of smoothly varying value functions

(2) Two-dimensional value functions were used for each measurement parameter

The first change was indicated by the minimal amount of information available about most species of interest. The second change was made because the quality and quantity of the various measurements were considered to be an important part of the value function development. In a sense, these may be considered as weighting factors on each measurement parameter. In the actual application, these were combined into a common parameter called the data status.

The parameters considered to be of sufficient importance to be included in stratospheric species mission analysis are:

- Latitude coverage
- Duration of the mission or measurement program
- Diurnal coverage
- Launch date
- Vertical coverage

- Vertical resolution, and
- Longitude coverage

Each of the above parameters must be analyzed and values assigned to the various performance levels from zero to full capability. The measurement scales selected for each parameter are shown in Figures 6-2 through 6-5.

For each matrix shown, values must be selected for each incremental improvement from no capability for both the parameter and the status of the data up to full capability for both. The general approach is first to determine the level of present knowledge and the required level of knowledge for each species. These levels are then assigned appropriate values from 0 to 10 and the levels beyond and in between these levels are given other appropriate values based upon the present and required knowledge. For example, for the case of latitude coverage for nitric acid vapor, it is known from Section 2.5 and supporting information that nitric acid has been measured in the stratosphere over various latitudes that cover approximately 120°. However, the quantity of data available is very small. Thus the value matrix for nitric acid versus latitude becomes:

Nitric acid vapor, HNO_3

DATA STATUS		None	60	120	180
	Good				R 10
	Med				
	Sparse			P	
	None	0			

LATITUDE BAND COVERED

Latitude Coverage -

DATA STATUS		None	60°	120°	180°
	Good				10
	Med				
	Sparse				
	None	0			

LATITUDE BAND COVERED*

*Includes nadir coverage plus any additional coverage due to orientation of instrument.

Duration of Measurement Program -

DATA STATUS		None	Short Survey	One Year Plus	Decades
	Good				10
	Med				
	Sparse				
	None	0			

DURATION OF MEASUREMENT PROGRAM

FIGURE 6-2
PARAMETERIZATION OF LATITUDE COVERAGE AND PROGRAM DURATION

Diurnal Coverage -

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good						10
Med						
Sparse						
None	0					

DIURNAL COVERAGE*

*Based on both orbit and instrument capability.

Launch Date or Beginning of Experiment -

DATA STATUS	270°	180°	90°	None or DNA
Good				10
Med				
Sparse				
None	0			

SEASONAL PHASE DEVIATION*

* 90° - Launch is one season prior to desired season
180° - Launch is two seasons prior to desired season
270° - Launch is three seasons prior to desired season
DNA - Launch time not important therefore does not apply

FIGURE 6-3
PARAMETERIZATION OF DIURNAL COVERAGE AND TIME OF LAUNCH

Vertical Coverage -

		None	<10%	50%	100%
DATA STATUS	Good				10
	Med				
	Sparse				
	None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Resolution -

		None	<1	1	10	>40
DATA STATUS	Good					10
	Med					
	Sparse					
	None	0				

NUMBER OF DATA POINTS OBTAINED*

*Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

FIGURE 6-4
PARAMETERIZATION OF VERTICAL COVERAGE AND VERTICAL RESOLUTION

Longitude Coverage -

DATA STATUS		None	0-90°	90°-180°	180°-360°
	Good				10
	Med				
	Sparse				
	None	0			

LONGITUDE BAND COVERED*

---

*It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore mission capability is automatically raised from present knowledge to full capability.

FIGURE 6-5
PARAMETERIZATION OF LONGITUDINAL COVERAGE

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where the P indicates the present knowledge. Since nitric acid vapor is considered to be one of the very important members of the NO_x chemistry chain, requirements (R) have been set at full capability. Values from 0 to 10 are then assigned to each of the matrix areas yielding:

Nitric acid vapor, HNO_3

DATA STATUS	None	60	120	180
Good		6	9	R 10
Med		4	8	9
Sparse		2	P 5	7
None	0			

LATITUDE BAND COVERED

These value matrices were prepared for all species prioritized into Groups 1 and 2 plus those in Groups 3 and 4 for which satellite-borne remote sensing instruments either exist or are under development. The matrices are shown in Appendix C.

6.1.3 Weighting Factors

In order to determine the extent (in terms of value) to which each orbit and/or instrument under consideration raises the present knowledge of the species distribution up to or beyond the required knowledge, the capability of the mission for each parameter (i.e., latitude coverage, vertical coverage, etc.) must be known. The values corresponding to the capabilities for each parameter are then combined into the value set for each species which provides a measure of how the entire orbit/instrument improves on present knowledge and how it compares with other orbit/instrument missions. However, as indicated in Section 6.1.1, simple combination of such values assumes that all of the parameters are of equal importance. This is definitely not true. For any given species some of the parameters are of much greater interest to the user community than others. Thus weighting factors must be assigned for each measurement parameter. For example, in general the latitudinal distribution of stratospheric species is considered to be more important than the longitudinal distribution. Thus, it is more valuable to measure the latitudinal distribution before the longitudinal distribution if both cannot be measured simultaneously. However, if the latitudinal distribution is already well known then the primary value lies in extending knowledge to include the longitudinal distribution.

For most stratospheric species distributions the desirable progression from "no knowledge" to "full knowledge" would be:

(1) No data

(2) a. Fixed point data exist (one latitude, longitude, altitude, and time.)

  b. Fixed point column burden data exist (one latitude, longitude, and time.)

(3) Fixed point vertical profile

(4) Latitude coverage

(5) Seasonal coverage*

(6) Diurnal coverage*

(7) Longitude coverage

(8) Long time coverage (years or decades)

Thus weighting factors must be assigned to each parameter for each species based on present and required knowledge and the logical progression of desired knowledge given above. High weights should be given to those parameters that would yield the best improvement from present to required knowledge and smaller weights to the other parameters.

The various values for each parameter (adjusted by the weighting functions) are combined to yield the total value for the mission under study. Each mission value is then compared with the value of the present knowledge and the required knowledge. The mission that provides the largest improvement from present knowledge to required knowledge should be considered the "optimum" system. If any mission achieves a value beyond the required knowledge level, the mission value should be truncated at the required knowledge level since this is the goal for each pollutant. However, if several missions achieve approximately equal values then this additional benefit should be acknowledged.

In some cases the mission may show only a small improvement over present knowledge or in fact none at all. Thus, the incremental

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* For a few specific species diurnal coverage may be more important than seasonal coverage and possibly latitude coverage.

gain in value over the value of present knowledge would be zero. However, this in no way implies that the entire mission under evaluation has no value at all. At the present state of the art of remote sensing of the stratosphere any successful mission would have value in terms of engineering, technological, and scientific advances. The value derived from the present evaluation only indicates that the mission would not significantly advance our knowledge of the mean stratospheric distribution of the species measured. For this reason, no mission will be given an absolute zero in the actual application of this method. Such cases will be indicated as less than one.

In order to evaluate a multiple pollutant or multiple instrument mission the value of each individual orbit/instrument is added to give the total value. In the case where several instruments measure the same pollutant the highest capability for each parameter is used to determine the contributing value. However, in the case of a multi-species mission, simple addition of the individual species values assumes that all are of equal importance. As was discussed in Section 3.2 and again at the beginning of this section, the species have been prioritized. These priorities must be taken into account when comparing the values of different species. This is accomplished by applying weighting factors. These factors have been assigned to the different species groups as follows:

Group 1a - Direct measurements of climatic change and ultraviolet change	1.0

Group 1b	- Species directly associated with changes in climate and/or ultraviolet	1.0
Group 2	- Important species associated with two or more chemistry chains	0.9
Group 3	- Components of the basic reactions involved in the direct production or depletion of ozone	0.9
Group 4	- Components of the basic reactions indirectly involved in the production or depletion of ozone	0.8
Group 5	- Other significant components of the chemistry chains	0.6
Group 6	- Specific aerosols	0.6

The rationale for selecting these factors is as follows. On a scale of 0 to 1 a factor of 1 was given to Groups 1a and 1b since no distinction in importance could be identified. Group 2 rates almost as high due to the fact that the species are involved in more than one major chemistry chain. The Group 3 species are considered to be primary from both the NO_x and Cl chemistry chains. All of these species are directly related to the ozone generation and destruction reactions. Thus, the weighting remains high. Group 4 species are considered to be secondary in the sense that they are primarily involved in the production of the primary species listed in Group 3. The Groups 5 and 6 species, although very important in stratospheric chemistry, cannot be considered as important as the species in the previous groups. In the actual evaluation an initial set of weights was postulated. This set was exercised against a small set of species for which relative importance was known with some confidence. From this the final revised set of weights was determined.

The combined values for present and required knowledge for all pollutants for which value matrices were generated are given in Appendix C. The combined values also include the parameter weighting functions and the rationale for the selection of each. It should be mentioned that, for the particular stratospheric species and missions considered here, all final values are rounded off to the nearest integer since this is considered to be the maximum preciseness that can be justified by the accuracy of the input values.

6.2 Evaluation of Specific Missions

A number of missions and instruments were selected for evaluation using the methodology discussed in Section 6.1 and the values shown in Appendix C. The missions evaluated were:

- A Shuttle-type mission with a 30° inclination and a four- to six-month duration.
- A Shuttle-type mission with a 56° inclination and a four- to six-month duration.
- A polar-type mission with a one- to two-year duration.

Several instruments under development were evaluated for each of these missions. The instruments evaluated are shown in Table 6-I along with the generic type of each and the species that were evaluated.

Tables 6-II through 6-XVI show the results of these evaluations for each species/instrument/mission combination. Included with

TABLE 6-I
STRATOSPHERIC INSTRUMENTS AND SPECIES EVALUATED

Name	Generic Type	Species
LIMS	Limb scanning	CO_2 O_3 H_2O NO_2 HNO_3
SAGE	Solar occultation	O_3 Aerosols
CIMATS	Solar occultation	H_2O CH_4 N_2O NH_3 CO
HALOE	Solar occultation	H_2O HCl CH_4

TABLE 6-II
EVALUATION OF CARBON DIOXIDE, CO_2, LIMS WITH 80° AZIMUTH SCAN

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	0.1	8	0.8	9	0.8	5 90°	0.5	8 140°	0.8	10 170°	1.0
Duration of Program	0.3	8	2.4	8	2.4	5 4-6 mos	1.5	5 4-6 mos	1.5	7 1-2 yrs	2.1
Diurnal Coverage	0.1	8	0.8	8	0.8	10 Full	1.0	10 Full	1.0	9 Part D&N	1.0
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	0.2	10	2.0	10	2.0	10 Full	2.0	10 Full	2.0	10 Full	2.0
Vertical Profile Resolution	0.2	8	1.6	9	1.8	10 <1Km	2.0	10 <1Km	2.0	10 <1Km	2.0
Longitude	0.1	8	0.8	8	0.8	10 Full	1.0	10 Full	1.0	10 Full	1.0
	1.0		8.4		8.6		8.0		8.3		9.1
Total Value			8		9		8		8		9
Incremental Gain Over Present					<1		<1		<1		1

LEGEND:
V = Value
V x WF = Value x weighting factor

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TABLE 6-III
EVALUATION OF OZONE, LIMS WITH 80° AZIMUTH SCAN

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.25	10	2.5	10	2.5	5 90°	1.25	6 140°	1.5	10 170°	2.5
Duration of Program	.25	7	1.75	10	2.5	4 4-6 mos	1.0	4 4-6 mos	1.0	6 1-2 yrs	1.5
Diurnal Coverage	.15	2	.3	8	1.2	10 Full	1.5	10 Full	1.5	8 Part D&N	1.2
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.1	7	.7	10	1	10 Full	1.0	10 Full	1.0	10 Full	1.0
Vertical Profile Resolution	.15	5	.75	10	1.5	10 <1Km	1.5	10 <1Km	1.5	10 <1Km	1.5
Longitude	.1	10	1	10	1	10 Full	1.0	10 Full	1.0	10 Full	1.0
	1.0		7.0		9.7		7.25		7.5		8.7
Total Value			7		10		7		8		9
Incremental Gain Over Present					3		<1		1		2

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-IV
EVALUATION OF OZONE, SAGE, SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.25	10	2.5	10	2.5	4 90° sparse at extremes	1.0	7 150° sparse at extremes	1.75	0	0 5
Duration of Program	.25	7	1.75	10	2.5	4 4-6 mos	1.0	4 4-6 mos	1.0	6 1-2 yrs	1.5
Diurnal Coverage	.15	2	.3	8	1.2	2 Part Day 2 points	0.3	2 Part Day 2 points	0.3	2 Part Day 2 points	0.3
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.1	7	.7	10	1	10 Full	1.0	10 Full	1.0	10 Full	1.0
Vertical Profile Resolution	.15	5	.75	10	1.5	7 ~10 points	1.05	7 ~10 points	1.05	7 ~10 points	1.05
Longitude	.1	10	1	10	1	10 Full	1.0	10 Full	1.0	10 Full	1.0
	1.0		7.0		9.7		5.35		6.1		4.85
Total Value			7		10		5		6		5
Incremental Gain Over Present					3		<1		<1		<1

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-V
EVALUATION OF WATER VAPOR, H_2O, CIMATS SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.3	6	1.8	9	2.7	6 90° sparse at extremes	1.8	8 150° sparse at extremes	2.4	0	0 5°
Duration of Program	.2	5	1.0	9	1.8	6 4-6 mos	1.2	6 4-6 mos	1.2	9 1-2 yrs	1.8
Diurnal Coverage	.1	7	0.7	8	0.8	2 Part Day 2 points	0.2	2 Part Day 2 points	0.2	2 Part Day 2 points	0.2
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	5	0.75	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	7	1.05	10	1.5	5 ~20 points	0.75	5 ~20 points	0.75	5 ~20 points	0.75
Longitude	.1	0	0	8	0.8	10 Full	0.1	10 Full	0.1	10 Full	0.1
	1.0		5.3		9.1		5.55		6.15		4.35
Total Value			5		9		6		6		4
Incremental Gain Over Present					4		1		1		<1

LEGEND:
V = Value
V x WF = Value x weighting factor

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TABLE 6-VI
EVALUATION OF WATER VAPOR, H_2O, HALOE SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.3	6	1.8	9	2.7	6 90° sparse at extremes	1.8	8 150° sparse at extremes	2.4	0	0 5°
Duration of Program	.2	5	1.0	9	1.8	6 4-6 mos	1.2	6 4-6 mos	1.2	9 1-2 yrs	1.8
Diurnal Coverage	.1	7	0.7	8	0.8	2 Part Day 2 points	0.2	2 Part Day 2 points	0.2	2 Part Day 2 points	0.2
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	5	0.75	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	7	1.05	10	1.5	5 2 km	0.75	5 2 km	0.75	5 2 km	0.75
Longitude	.1	0	0	8	0.8	10 Full	0.1	10 Full	0.1	10 Full	0.1
	1.0		5.3		9.1		5.55		6.15		4.35
Total Value			5		9		6		6		4
Incremental Gain Over Present					4		1		1		<1

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-VII
EVALUATION OF WATER VAPOR, H_2O, LIMS WITH 80° AZIMUTH SCAN

Parameter	WF 0-1	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.3	6	1.8	9	2.7	7 90°	2.1	9 140°	2.7	10 170	3.0
Duration of Program	.2	5	1.0	9	1.8	6 4-6 mos	1.2	6 4-6 mos	1.2	9 1-2 yrs	1.8
Diurnal Coverage	.1	7	0.7	8	0.8	10 Full	1.0	10 Full	1.0	9 Part D&N	0.9
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	5	0.75	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	7	1.05	10	1.5	10 <1Km	1.5	10 <1Km	1.5	10 <1Km	1.5
Longitude	.1	0	0	8	0.8	10 Full	1.0	10 Full	1.0	10 Full	1.0
	1.0		5.3		9.1		8.3		8.9		9.7
Total Value			5		9		8		9		10
Incremental Gain Over Present					4		3		4		5

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-VIII
EVALUATION OF AEROSOLS, SAGE SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.15	9	1.35	10	1.5	4 90° sparse at extremes	0.6	7 150° sparse at extremes	1.05	0	0 5
Duration of Program	.15	8	1.2	9	1.35	7 4-6 mos	1.05	7 4-6 mos	1.05	9 1-2 yrs	1.35
Diurnal Coverage	.05	9	0.45	9	0.45	6 Part Day 2 points	.3	6 Part Day 2 points	.3	6 Part Day 2 points	.3
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.25	8	2.0	10	2.5	10 Full	2.5	10 Full	2.5	10 Full	2.5
Vertical Profile Resolution	.15	7	1.05	10	1.5	7 ~10 points	1.05	7 ~10 points	1.05	7 ~10 points	1.05
Longitude	.25	6	1.5	10	2.5	10 Full	2.5	10 Full	2.5	10 Full	2.5
	1.0		7.55		9.8		8.00		8.45		7.7
Total Value			8		10		8		8		8
Incremental Gain Over Present					2		<1		<1		<1

LEGEND:
V = Value
V x WF = Value x weighting factor

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TABLE 6-IX
EVALUATION OF AMMONIA, NH_3, CIMATS SOLAR OCCULTATION

Parameter	WF	Present		Required		Shuttle		Shuttle		Sun-Sync	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.2	0	0	7	1.4	7 90° sparse at extremes	1.4	8 150° sparse at extremes	1.6	0	0 ~5°
Duration of Program	.1	0	0	6	0.6	8 4-6 mos	0.8	8 4-6 mos	0.8	9 1-2 yrs	0.9
Diurnal Coverage	.15	0	0	6	0.9	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.25	0	0	7	1.75	10 Full	2.5	10 Full	2.5	10 Full	2.5
Vertical Profile Resolution	.25	0	0	7	1.75	9 ~20 points	2.25	9 ~20 points	2.25	9 ~20 points	2.25
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		0		6.8		8.05		8.25		6.75
Total Value			0		7		8		8		7
Incremental Gain Over Present					7		8		8		7

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-X
EVALUATION OF NITROGEN DIOXIDE, NO_2, LIMS WITH 80 ° AZIMUTH SCAN

Parameter	WF 0-1	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.15	4	.6	10	1.5	7 90°	1.05	9 140°	1.35	10 170°	1.5
Duration of Program	.15	5	.75	9	1.35	7 4-6 mos	1.05	7 4-6 mos	1.05	9 1-2 yrs	1.35
Diurnal Coverage	.35	5	1.75	9	3.15	10 Full	3.5	10 Full	3.5	8 Part D&N	2.8
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	4	0.6	10	1.5	10 ≲ 1Km	1.5	10 ≲1Km	1.5	10 ≲1Km	1.5
Longitude	.05	0	0	8	0.4	10 Full	.5	10 Full	.5	10 Full	.5
	1.0		4.6		9.4		9.1		9.4		9.15
Total Value			5		9		9		9		9
Incremental Gain Over Present					4		4		4		4

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-XI
EVALUATION OF NITRIC ACID VAPOR, NHO_3, LIMS WITH 80° AZIMUTH SCAN

Parameter	WF 0-1	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.3	5	1.9	10	3.0	7 90°	2.1	9 140°	2.7	10 170°	3.0
Duration of Program	.25	3	.75	9	2.25	7 4-6 mos	1.75	7 4-6 mos	1.75	9 1-2 yrs	2.25
Diurnal Coverage	.1	7	.7	8	.8	10 Full	1.0	10 Full	1.0	8 Part D&N	0.8
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	7	1.05	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.1	8	.8	10	1.0	10 ≲1Km	1.0	10 ≲1Km	1.0	10 ≲1Km	1.5
Longitude	.1	0	0	8	.8	10 Full	1.0	10 Full	1.0	10 Full	1.0
	1.0		4.8		9.35		8.35		8.95		9.55
Total Value			5		9		8		9		10
Incremental Gain Over Present					4		3		4		5

LEGEND:
V = Value
V x WF = Value x weighting factor
D & N = Day & Night

TABLE 6-XII
EVALUATION OF HYDROGEN CHLORIDE GAS, HCl, HALOE SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.35	4	1.4	9	3.15	6 90° sparse at extremes	2.1	8 150° sparse at extremes	2.8	0	0 5°
Duration of Program	.1	5	.5	8	.8	8 4-6 mos	0.8	8 4-6 mos	0.8	9 1-2 yrs	0.8
Diurnal Coverage	.1	0	0	7	.7	3 Part Day 2 points	0.3	3 Part Day 2 points	0.3	3 Part Day 2 points	0.3
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.2	6	1.2	9	1.8	9 10-40Km	1.8	9 10-40Km	1.8	9 10-40Km	1.8
Vertical Profile Resolution	.2	7	1.4	9	1.8	9 2Km	1.8	9 2Km	1.8	9 2Km	1.8
Longitude	.05	0	0	8	.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		4.5		8.65		7.35		8.0		5.2
Total Value			5		9		7		8		5
Incremental Gain Over Present					4		2		3		<1

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-XIII
EVALUATION OF METHANE, CH_4, CIMATS SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.4	0	0	8	3.2	7 90° sparse at extremes	2.8	8 150° sparse at extremes	3.2	0	0 5°
Duration of Program	.1	0	0	6	0.6	8 4-6 mos	0.8	8 4-6 mos	0.8	9 1-2 yrs	0.9
Diurnal Coverage	.15	0	0	6	0.9	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	8	1.2	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	3	0.45	9	1.35	9 ~20 points	1.35	9 ~20 points	1.35	9 ~20 points	1.35
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		1.35		7.65		7.55		7.95		4.85
Total Value			1		8		8		8		5
Incremental Gain Over Present					7		7		7		4

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-XIV
EVALUATION OF METHANE, CH_4, HALOE SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
		V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.4	0	0	8	3.2	7 90° sparse at extremes	2.8	8 150° sparse at extremes	3.2	0	0 ~5
Duration of Program	.1	0	0	6	0.6	8 4-6 mos	0.8	8 4-6 mos	0.8	9 1-2 yrs	0.9
Diurnal Coverage	.15	0	0	6	0.9	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	8	1.2	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	3	0.45	9	1.35	9 2Km	1.35	9 2Km	1.35	9 2Km	1.35
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		1.35		7.65		7.55		7.95		4.35
Total Value			1		8		8		8		5
Incremental Gain Over Present					7		7		7		4

LEGEND:
V = Value
V x WF = Value x weighting factor

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TABLE 6-XV
EVALUATION OF NITROUS OXIDE, N_2O, CIMATS SOLAR OCCULTATION

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Capability V	Required Capability VXWF	Shuttle 30° V	Shuttle 30° VXWF	Shuttle 56° V	Shuttle 56° VXWF	Sun-Sync Noon V	Sun-Sync Noon VXWF
Latitude	.25	4	1.0	10	2.5	7 90° sparse at extremes	1.75	9 150° sparse at extremes	2.25	0 ~5°	0
Duration of Program	.15	5	0.75	9	1.35	7 4-6 mos	1.05	7 4-6 mos	1.05	9 1-2 yrs	1.35
Diurnal Coverage	.1	8	0.8	8	0.8	1 Part Day 2 points	0.1	1 Part Day 2 points	0.1	1 Part Day 2 points	0.1
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	10	1.5	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	4	0.6	10	1.5	9 ~20 points	1.35	9 ~20 points	1.35	9 ~20 points	1.35
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		4.05		8.05		6.25		6.75		4.8
Total Value			4		8		6		7		5
Incremental Gain Over Present					4		2		3		1

LEGEND:
V = Value
V x WF = Value x weighting factor

TABLE 6-XVI
EVALUATION OF CARBON MONOXIDE, CO, CIMATS SOLAR OCCULTATION

	WF	Present Knowledge		Required Capability		Shuttle 30°		Shuttle 56°		Sun-Sync Noon	
Parameter	0-1	V	VXWF	V	VXWF	V	VXWF	V	VXWF	V	VXWF
Latitude	.4	0	0	8	3.2	7 90° sparse at extremes	2.8	8 150° sparse at extremes	3.2	0	0 ~5°
Duration of Program	.1	0	0	6	0.6	8 4-6 mos	0.8	8 4-6 mos	0.8	9 1-2 yrs	0.9
Diurnal Coverage	.15	0	0	6	0.9	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6	4 Part Day 2 points	0.6
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	5	.75	9	1.35	10 Full	1.5	10 Full	1.5	10 Full	1.5
Vertical Profile Resolution	.15	3	.45	9	1.35	9 ~ 20 points	1.35	9 ~20 points	1.35	9 ~20 points	1.35
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		1.2		7.8		7.55		7.95		4.85
Total Value			1		8		8		8		5
Incremental Gain Over Present					7		7		7		4

LEGEND:
V = Value
V x WF = Value x weighting factor

each parameter value is the performance used to determine the value. The results have been weighted by the weighting factors for the various pollutant groups.

In Table 6-XVII the incremental gains have been summarized to show the totals for each instrument/orbit/species combination. It is obvious that those combinations showing the highest gains exhibit two prominent characteristics,

- The instrument measures a larger number of species;
- Most of the species measured represent those for which little data now exist; this allows large incremental gains for any successful measurement.

The incremental gain totals for each instrument/orbit combination are summarized in Table 6-XVIII.

6.3 Evaluation of Multiple Species or Instrument Missions

Table 6-XIX shows the summary of incremental gains resulting when various combinations of two, three, or four instruments are flown on the same mission. These values are obtained by adding the individual contributions of each species/instrument except in those cases where two or more instruments measure the same species. In this latter case, the value is determined by using the best value for each parameter among the instruments involved.

Not surprisingly, the results indicate that those missions that contain the most sensors score the highest. On more limited missions, those sensors that claim to measure the most species score higher than those designed for more special-purpose applications.

TABLE 6-XVII
SUMMARY OF INCREMENTAL GAINS FOR EACH SPECIES/INSTRUMENT/ORBIT COMBINATION

Species	Priority Group	Weighting Factor	Instrument	Weighted Required Gain	Weighted Incremental Gain		
					30° orbit	56° orbit	Polar orbit
CO_2	1	1	LIMS	<1	<1	<1	1
O_3	1	1	LIMS	3	<1	1	2
	1	1	SAGE	3	<1	<1	<1
H_2O	1	1	CIMATS	4	1	1	<1
	1	1	HALOE	4	1	1	<1
	1	1	LIMS	4	3	4	5
Aerosols	1	1	SAGE	2	<1	<1	<1
NH_3	2	0.9	CIMATS	6	7	7	6
NO_2	3	0.9	LIMS	4	4	4	4
HNO_3	4	0.8	LIMS	3	2	3	4
HCl	4	0.8	HALOE	3	2	2	<1
CH_4	4	0.8	CIMATS	6	6	6	3
	4	0.8	HALOE	6	6	6	3
N_2O	4	0.8	CIMATS	3	2	2	<1
CO	4	0.8	CIMATS	6	6	6	3
				$\sum = 41$			

TABLE 6-XVIII
SUMMARY OF INCREMENTAL GAINS FOR EACH INSTRUMANT/ORBIT COMBINATION

Instrument	Species Measured	Weighted Required Gain	30° orbit	56° orbit	Polar orbit
LIMS	CO_2, O_3, H_2O, NO_2, HNO_3	14-15*	9-10*	12-13*	16
SAGE	O_3, Aerosols	5	<1	<1	<1
CIMATS (solar occultation)	H_2O, NH_3, CH_4, N_2O, CO	25	22	22	12-13*
HALOE	H_2O, HCl, CH_4	13	9	9	3-4*

*Uncertainty due to use of values of <1.

TABLE 6-XIX
SUMMARY OF INCREMENTAL GAINS RESULTING FROM VARIOUS INSTRUMENT COMBINATIONS

Instruments	Species Measured	Weighted Required Gain	30° Orbit	56° Orbit	Polar Orbit
FOUR INSTRUMENTS LIMS, SAGE, CIMATS, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols, NH_3, CH_4, N_2O, CO, HCl	40-41*	33-34*	36	29
THREE INSTRUMENTS LIMS, CIMATS, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3 NH_3, CH_4, N_2O, CO, HCl	38-39*	33	35-36*	28-29*
LIMS, SAGE, CIMATS	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols, NH_3, CH_4, N_2O CO	37-38*	31-32*	34	28-29*
SAGE, CIMATS, HALOE	O_3, Aerosols, H_2O, NH_3, CH_4, N_2O, CO, HCl	33	25	25	14-15*
LIMS, SAGE, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols, HCl, CH_4	25-26*	18-19*	21	19-20*

*Uncertainty due to use of values of <1

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TABLE 6-XIX (Concluded)
SUMMARY OF INCREMENTAL GAINS RESULTING FROM VARIOUS INSTRUMENT COMBINATIONS

Instruments	Species Measured	Weighted Required Gain	30° Orbit	56° Orbit	Polar Orbit
TWO INSTRUMENTS					
LIMS, CIMATS	CO_2, O_3, H_2O, NO_2, HNO_3, NH_3, CH_4, N_2O, CO	35-36*	31	33-34*	28
CIMATS, HALOE	H_2O, NH_3, CH_4, N_2O, CO, HCl	28	24	24	13-14*
SAGE, CIMATS	O_3, Aerosols, H_2O, NH_3, CH_4, N_2O, CO	30	23	23	14
LIMS, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3, HCl, CH_4	23-24*	18	20-21*	19
LIMS, SAGE	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols	16-17*	10-11*	13	16
SAGE, HALOE	O_3, Aerosols, H_2O, HCl, CH_4	18	10	10	5

*Uncertainty due to use of values <1

6.4 Summary

This section has developed and applied a method for the evaluation of various stratospheric species measurement missions. Four principles were held central in the development of the method. Thus development was focused on adaptability, simplicity, repeatability, and completeness including allowance for the use of expert value judgments as part of the evaluation process.

Adaptability is a necessary condition for a usable technique since a wide variety of candidate instruments and orbits could be considered for stratospheric missions. In addition, adaptability concerns the availability of information necessary to make development decisions. In the early stages of most programs, complete technical information is seldom, if ever, available. Yet decisions must be made. Therefore, this decision-assisting technique must be adaptable to any stage of the process and be designed so that as new and better technical data become available it can easily be incorporated into the technique.

Simplicity is the essence of reliability and understanding. A simple system is likely to be a reliable system. This also holds true for decision systems. Therefore, each part of the evaluation technique should be visible and the interrelationship of the parts easily understood.

The results must be repeatable, therefore the technique should rely on engineering measurements to the maximum extent possible. However, since it is rarely possible to get firm data in the early stages of most programs, the technique results should allow for the measurement of uncertainty associated with estimates. The decision-maker must know these uncertainties and how they could affect the decision.

Finally, the technique must be complete. The obvious measurable technical characteristics of the system under evaluation must be considered. However, important factors of value judgment must be considered in the absence of objective criteria. The decision-assisting technique must be able to utilize these subjective criteria effectively if the technique is to be complete.

Such a method was developed here. This method rank-ordered candidate systems in terms of an abstract set of value criteria. The basic comparison was straightforward and matched system performance against some value to the user of the system in order to obtain a numerical value versus performance. Thus, the results are relative and not absolute.

Inspection of the actual results reemphasizes some previous intuitive knowledge and also presents some new concepts. In the former category are such results as:

- The more individual species and/or instruments involved the greater the value
- Solar occultation-type instruments give poor global coverage in polar orbits
- Limb-looking instruments give excellent global coverage in polar orbits

The principal conclusion in the later category is that the highest potential for gain in value lies in the measurement of those species in Groups 2, 3, or 4 which play very important roles in stratospheric processes but whose characteristics and spatial/temporal distributions are poorly known. These factors consistently place instruments such as LIMS and CIMATS considerably higher in all instrument/orbit combinations evaluated.

APPENDIX A

EFFECTS OF SHUTTLE ENVIRONMENT ON REMOTE OBSERVATION OF THE ATMOSPHERE

APPENDIX A

EFFECTS OF SHUTTLE ENVIRONMENT ON REMOTE OBSERVATION OF THE ATMOSPHERE

A-1.0 INTRODUCTION

A number of features of the spacecraft platform have an important impact on the performance of electromagnetic sensors. Table A-I summarizes the various factors, with their effects and control. Many of these will have effect on the various sensors to be used aboard Shuttle and have been addressed in detail in terms of determination of environmental standards [49, 50, 51].

In addition to impacts on sensors, other spacecraft systems such as solar cell panels, thermal control paints, and attitude control startracking facilities may be affected.

It is the intention of this Appendix to address one particular aspect of the Shuttle environment; namely, the impact of the spacecraft environment on instruments designed to make remote measurement of the earth's atmospheric composition. This issue is of particular importance for these instruments, for they are designed to be most sensitive to those very materials that may exist in the spacecraft vicinity.

This discussion concentrates on the possible detrimental features of an atmosphere of particles and gases near the spacecraft (A-2.0), sources of such pollutants and their measurement (A-3.0), preventive measures (A-4.0), and a summarization of standards, their applicability to the instruments of interest, and the probable Shuttle-induced atmosphere (A-5.0).

TABLE A-1
ENVIRONMENTAL FACTORS AFFECTING SENSOR OPERATION[49]

ENVIRONMENTAL FACTOR	PARAMETERS INVOLVED	EFFECTS	COUNTERMEASURE	REMAINING LIMITS
Average temperature	Linear dimensions	Shifts in focus, cross-track mapping error	Material selection of mirrors, barrels, sensor assembly	$\Delta T = 100°C$ (focus shifts) $\Delta T = 100°C$ (array expansion)
	Refractive index	Focus shift, image degradation	Restriction in glass selection	$\Delta T = 50°C$ (reflector) 5°C (refractor)
Temperature cycles and gradients	(As above)	Dynamic focal shifts, alignment errors, image degradation	Conducting barrel, insulating jacket (As above)	$\Delta T = 20°C$
Shock and vibrations pre-launch and launch	Linear dimensions	Alignment errors	Construction and mounting, favors concentric system	Mechanical design
Attitude control	Imagery, mapping accuracy	Image smear, mapping errors	Attitude stabilization	0.06 degree/sec
Vacuum	Outgassing phenomena	Degrading by optical surface films	Avoid outgassing sources inside optics/sensor structure	Restricted selection of sensor bonding materials and cabling
Micrometeorites	Scattering coefficient of outermost optical surface	Surface erosion	Continuous pointing at nearby Earth	Effect largely suppressed (life>10 years)
Atomic particles	(As above) Boron glass lattice spectral transmission	Surface sputtering, lattice damage formation of color centers, changes in spectral transmission in bands 1 and 2	(As above) (As above) (Cerium-stabilized glasses)	(As above) (As above) Restrictions in optical design
Hard radiation	(As above)	(As above)	Shielding (aided by down-looking orientation)	None

A-2.0 MECHANISMS OF PERFORMANCE DEGRADATION

The sensors under consideration in this study (see Section A-3.0) are generally sensitive to radiation in the range from 0.4 to 11.0 μm. They are designed to exhibit maximum sensitivity to trace gases of importance in atmospheric studies. The environment of these instruments must therefore be carefully controlled so as to limit the various degrading effects that can be produced.

The major effects can be classified into the following groups:

a) Scattering (both particulate and molecular)

b) Absorption

c) Thermal emission

d) Surface contamination by deposition

In each case the atmosphere of the spacecraft can be characterized by the spatial and temporal distribution of the material, its physical characteristics (type of gas, size of particles), and its impact on each of the above features of the propagation of radiation to and into the instrument.

Since the instruments under consideration do not image the distribution of pollutants within their field of view, a feature most affected by scattering and surface contamination, the major concern is that wavelength selective scattering, absorption, or emission may take place, thereby altering the performance capabilities of the sensors. The following paragraphs summarize briefly the processes involved in the degradation of data resulting from the factors noted above. In the first three topics, the assumption is made that the effects are a result of materials in the Shuttle-induced atmosphere and the residual earth atmosphere (which is a function of altitude). Deposition effects are discussed separately.

A-2.1 Scattering

In the case of pure scattering (that is, where no simultaneous absorption occurs), changes in the radiation reaching the instrument include reduced radiance from the target due to the scattering of radiation away from the instrument, time-varying radiation background due to motion of the scatterers through the field of view, and increased radiance from sources outside the field of view (particularly the thermal emission from the spacecraft) as a result of sidescatter and backscatter. In each of these cases it is assumed that no deposition of scatterers onto optical surfaces has occurred but that an atmosphere of such materials (both molecular and particulate) exists within the field of view of the instrument.

Each of these effects may also be wavelength-dependent because of the variation of scattering properties as a function of the size parameter (ratio of scatterer size to radiation wavelength). Sensitivity of the instrumentation to each of these scattering effects will also be a function of the optical and electronic properties of the system, particularly field of view and response time.

The physical process of radiation scattering can best be described after comparing the scatterer size and the wavelength of the radiation.

Three ranges of the size parameter are important [53]. They are:

a) Rayleigh scattering (β=scatterer radius/wavelength < 0.08);

b) Mie scattering ($0.08 < \beta < 3$); and

c) Nonselective scattering ($\beta > 3$)

Rayleigh scattering is characterized by wavelength dependence which varies as N/λ^4; that is, scattering becomes more pronounced for shorter wavelength components and as the number of scatterers increases. The result is that for small β, scattering varies strongly with wavelength and can be produced by molecular components of the spacecraft environment.

For the case of Mie scattering, the variation of scattering with wavelength approaches zero but still varies linearly with the number of scatterers. It is within this range (when $\beta \sim 1$) that scattering efficiency is maximized.

Nonselective scattering shows little wavelength dependence and can, for practical purposes, be described by the Mie scattering calculations. It results from at least three physical processes, including reflection, diffraction, and refraction.

Clearly then, it is important, due to the range of instrumentation being considered, that the number of scatterers (both molecular and particulate) be carefully controlled. It is particularly important that the number of scatterers in the range of sensitivity of the instrumentation (normally 5 μm) be carefully controlled. It would also be advantageous to control the temporal variability of the concentration and size distribution of the scatterers. Standards for such control in the Shuttle environment are discussed in Section A-5.0.

A-2.2. Absorption

Absorption may occur due to two processes in the generally narrow sensitivity bands of the instrumentation. First, molecules of the specie to be detected may actually be a component of the spacecraft atmosphere. Associated band and/or line absorption would then result. Second, components with absorption bands in the range from 0.4 to 11μm could also affect the measurements. Important species in this regard are H_2O, CO_2, CH_4, N_2O, and O_3 [54].

The likelihood of overlapping absorption lines between species being detected and those in the local atmosphere will be unique to each instrument due to the choice of absorption lines or bands. Only a detailed study can reveal particular problem areas.

The importance of absorption by these species will be a function of the instrument characteristics. In particular, the correlation devices (including filter and interferometer) will generally be less susceptible to degradation since they rely on features of the line absorption distributed over a broad (relative to line width) portion of the spectrum.

As in the case of scattering, movement of absorbers through the field of view will cause time-dependent errors. Control of this variability will allow calibration which can identify the magnitude of the effect.

A-2.3 Thermal Emission

Materials in the atmosphere around the Shuttle may produce an indirect effect from radiation sources by absorbing energy and reradiating at a longer (thermal) wavelength. This process would then create radiance associated with the scene of interest. This will be a more important problem on the sunlit side of the orbit where reflections of sunlight from the spacecraft and the earth as well as direct solar irradiation of the materials would case them to warm and reradiate.

In addition to the spatial distribution of these absorbers within the field of view, their temporal variability will be important since a nearly constant background can be identified using a suitable calibration procedure, whereas a time dependent background will be more difficult to evaluate.

In those cases where the re-emission is within the visible band, it may be more appropriate to refer to the process as fluorescence.

A-2.4 Surface Contamination by Deposition

The importance of optical surface contamination is basically described by scattering and absorption. The physical features of these mechanisms have been described. A unique feature of this problem is, however, the cumulative nature of the process. This is particularly important for cryogenically cooled detectors and other system elements. As in the other cases discussed, time variability of the effect should be minimized. In this case it is clear that the inherent time dependence of accumulation cannot be avoided.

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Furthermore, spatial variability in the accumulation can be expected.

Then there are a number of key features that determine the importance of surface contamination: length of the mission, magnitude and composition of the ambient atmosphere, temperature of the elements of concern, and effectiveness of protective measures.

The materials expected to accumulate on surface (both cooled and uncooled) are low-vapor-pressure high-molecular-weight materials, since contaminants adhere more readily to those surfaces that have a temperature lower than the contaminant's condensation temperature [55].

A-2.5 Importance for Infrared Instrumentation

The general conclusion [49, p.4] reached is that due to all of the effects described, infrared instrumentation will be the most susceptible of any payload component and will therefore require the most careful environmental control. The three specific features leading to that conclusion are: (1) the use of infrared wavelengths where scattering and absorption by the induced atmosphere may be large, (2) the common requirement for cryogenically cooled detectors and optical components, and (3) the instrument designs that are most effective at detecting trace gases.

It is in this regard that calibration procedures are most important. The most effective method will be to utilize an external source, such as the sun or stars, for calibration so that all contaminants (those deposited as well as those in the operating field of view) can be detected. Internal calibrations may also become contaminated and thereby lose their effectiveness.

A-3.0 SOURCES AND TYPES OF POLLUTANTS IN THE SHUTTLE ENVIRONMENT

The atmosphere around the Shuttle will come from two sources: the contribution from the Orbiter and its payload and the ambient atmosphere of the earth. The Shuttle-induced atmosphere of particulates and molecules will be continously supplemented by the sources described below. Depletion of the induced atmosphere will result from drag imposed by the ambient atmosphere. The result is likely to be a near-steady-state environment [56, p.4]. Figure A-1 illustrates the Shuttle, a payload (in this case Spacelab), an appropriate coordinate system and some major contaminant sources.

A-3.1 Sources

In addition to the ambient atmosphere of the earth, which is of course a function of altitude, the Shuttle Orbiter and its payload are a source of pollutant gases and particles. In this section we will address only those features of the Shuttle environment that are likely to occur in orbit, which is where measurements will be made.

The sources of most importance [55] include:

> Outgassing: contribution to the environment by molecular emission which results from the material bulk characteristics and is long-term in nature. Further, the rate is a function of ambient pressure, surface temperature, area exposed, and material type. In the case of Skylab, the majority of the deposition observed was the result of outgassing [49]. Due to the similarity between the altitude and inclination of the Skylab and Shuttle orbits, as well as the probable similarity in the surface temperatures, deposition rates due to outgassing can be expected to be similar. During Skylab the average outgassing rate was 200 g/day [49].
>
> Offgassing: contribution from volatiles which are absorbed or adsorbed by a material. Rapid evaporation of these components occurs after exposure to vacuum. A nominal period for the decay of this process is 100 hours [49].

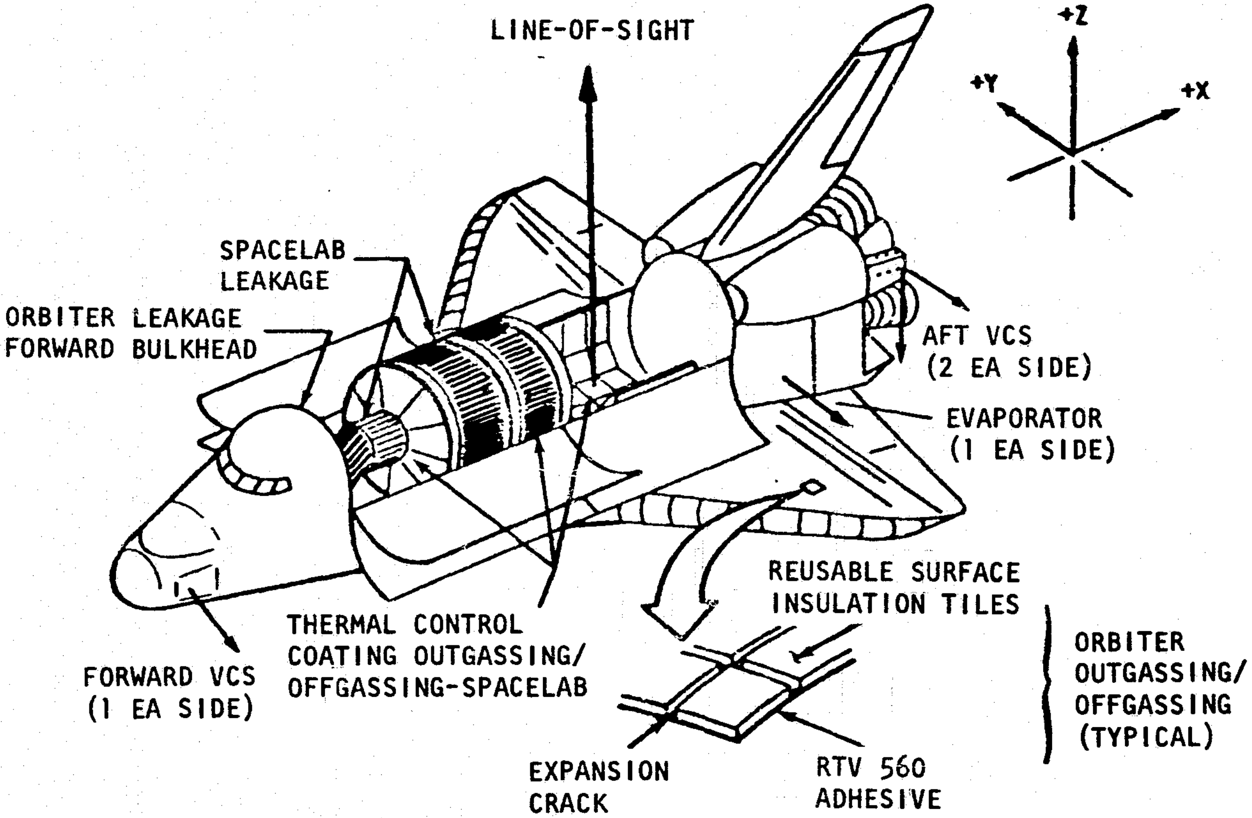

FIGURE A-1
MAJOR SHUTTLE ORBITER/SPACELAB
CONTAMINATION SOURCE LOCATIONS AND GEOMETRY [56]

Cabin leakage: contribution by leakage from habitated areas. The components of the atmosphere of the cabin will include gases for breathing, internal material offgassing and outgassing, friction erosion, and evaporation of liquids. Larger particles wil be prevented from leaving the cabin due to the microscopic size of the leakage paths as well the filters in the life support systems. The losses from the Skylab cabin (which operated at 3.5 psi) amounted to 1.4 kg/day with a gaseous composition of: oxygen (63 percent), nitrogen (27 percent), carbon dioxide (7 percent), and water vapor (3 percent]. The estimated losses for Shuttle (operating at 14.7 psi) amounted to 3.2 kg/day [49].

Leaks from other sources: contribution from losses in pressurized hydraulic and gas lines outside of the inhabited areas.

Vernier control subsystem 25 lb. thrusters (VCS): contribution from products of attitude control subsystem.

Supplemental flash evaporation vents (SFEV): water vapor produced by the fuel cells, which will be ejected periodically.

Returned flux: contribution to the atmosphere around Shuttle from materials or gases reflected by the ambient atmosphere (and therefore a sensitive function of altitude). Other factors important in the rate of returned flux are molecular size and weight of emitted contaminants, their velocity, density, and molecular size of ambient atmosphere, altitude, temperature of Shuttle Orbiter and payload surfaces, source location, and rate. This is likely to be a more significant problem on Shuttle than on Skylab due to the lower orbital altitudes anticipated in early missions.

Mass loss: contribution from particulate matter produced by the decomposition of surfaces due to exposure to sunlight, high velocity particles, or erosion. This topic does not include outgassing, which is molecular in nature, or erosion within inhabited areas.

Evaluation of several of these sources has indicated that the Shuttle Orbiter will contribute 22 percent of the outgassing, 6 percent of the offgassing, and 90 percent of the habitation leakage [56, p.3]. The remainder will be contributed by the Spacelab, the example payload utilized in Reference 56.

Some general features of the sources have been assembled into Table A-II, which summarizes the location, temporal characteristics, flow rate, components, and other features.

A-3.2 Types of Contaminants Induced by Shuttle and Its Payload

As noted in Table A-II, a wide variety of constituents will be found in the Shuttle environment. Among those will be several that can be identified as having a detrimetal effect on the operation of remote sensors of the atmosphere. As noted in Section A-2.2, both H_2O and CO_2 have absorption bands that could overlap with those absorption lines or bands being utilized in the detection techniques. Furthermore, a number of species of interest in atmospheric physics will also be present in the induced atmosphere, most notably CO, NO, and OH which will be produced by the VCS. In addition to the gases cited, particles will also comprise part of the Shuttle-induced atmosphere.

Due to complex spatial and temporal variability of these materials, it will be difficult to make a specific determination of the impact of the induced environment on instrument operation. However, Section A-4.0 proposes some preventive measures and Section A-5.0 discusses the probable performance limitations that may result.

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TABLE A-II
SHUTTLE ORBITER/SPACELAB CARRIER CONTAMINATION SOURCES SUMMARY(56)

	MAJOR SOURCES	MODELED LOCATION	DURATION/ FREQUENCY	FLOWRATE	MAJOR CONSTITUENTS	PLUME SHAPE FUNCTION	MOST PROBABLE VELOCITY	SIZE PARAMETER
SHUTTLE ORBITER	OUTGASSING	All external Shuttle Orbiter surfaces	Continuous	$5.0\ e^{(T-100)/29} \times 10^{-10}\ g/cm^2/sec$	Hydrocarbon chain fragments, RTVs, etc.	$\cos\theta / r^2$	$12.9\sqrt{T(°K)}$ m/sec	Molecular average M=100 (assumed)
	OFFGASSING	All external Shuttle Orbiter surfaces	Continuous (Decreases for approx. first 100 hrs on orbit)	$\left[3.87\ e^{-0.14t} + 3.0\ e^{-.055t}\right] \times e^{(T-100)/29} \times 10^{-9}\ g/cm^2/sec$	Water, light gases, volatiles	$\cos\theta / r^2$	$30.4\sqrt{T(°K)}$ m/sec	Molecular average M=18 (assumed)
	EVAPORATOR* (2)	X=1392 (see Fig. A-1) facing ± Y	As required	13.6 kg/hr total	Water	$\cos^6(1.01\theta)/r^2$ $0° \le \theta \le 36.8°$ $\frac{e^{-.0773(\theta-36.8°)}}{r^2}$ $36.8° < \theta \le 148°$	1012 m/sec	Molecular M=18
	CABIN ATMOSPHERE LEAKAGE	Payload bay fwd bulkhead (see Figure A-1)	Continuous	3.18 kg/day	O_2 – 23% N_2 – 75% CO_2 – 1% H_2O – 1%	$\cos\theta / r^2$	$2220\sqrt{\frac{T}{M}}$ m/sec	Molecular average M=29
	VERNIER CONTROL SYSTEM ENGINES (VCS)**	-Z aft only (see Figure A-1)	As required	40.8 g/min	H_2O-29.5% H-.056% N_2 -41.9% NO-.09% H_2 -1.6% O-.02% CO -17.4% OH-.48% CO_2-8.9% O_2-.04%	$\left(\cos\frac{\pi}{2}\cdot\frac{\theta}{\theta_t}\right)^{8.65} \times r^{-2}$ $0° \le \theta \le 40°$ $r^{-2} \times e^{-0467(\theta-40°)}$ $40° < \theta \le 140°$ $r^{-2} \times e^{-4.67}$ $140° < \theta \le 180°$	3505 m/sec	Molecular average M=20.7
SPACELAB CARRIER	OUTGASSING	All external Spacelab surfaces	Continuous	$1.0\ e^{(T-100)/29} \times 10^{-8}\ g/cm^2/sec$	Hydrocarbon chain fragments, RTVs, etc.	$\cos\theta / r^2$	$12.9\sqrt{T(°K)}$ m/sec	Molecular average M=100 (assumed)
	OFFGASSING	All external Spacelab surfaces	Continuous (Decreases for approx. first 100 hrs on orbit)	$\left[3.87\ e^{-.14t} + 3.0\ e^{-.055t}\right] \times e^{(T-100)/29} \times 10^{-7}\ g/cm^2/sec$	Water, light gases volatiles	$\cos\theta / r^2$	$30.4\sqrt{T(°K)}$ m/sec	Molecular average M=18 (assumed)
	CABIN ATMOSPHERE LEAKAGE	Pressurized module/tunnel surfaces (see Figure A-1)	Continuous	1.35 kg/day	O_2 – 23% N_2 – 75% CO_2 – 1% H_2O – 1%	$\cos\theta / r^2$	$2220\sqrt{\frac{T}{M}}$ m/sec	Molecular average M=29

* Plume reflections off of structural surfaces (e.g. wings, payload bay doors) are equivalent to a source equal to the plume. Impingement rate with a $\cos\theta / r^2$ distribution and a velocity of $30.4\sqrt{T}$ m/sec from the surface where T=surface temp. (°K).

** VCS plume reflections off of structural surfaces are assumed to have a rate equal to the plume impingement rate with a $\cos\theta / r^2$ distribution and a velocity equal to $129\sqrt{\frac{T}{M}}$ m/sec where T=surface temp. (°K).

M = Molecular weight
T = Temperature (°C unless noted)
t = Time (In hours) of vacuum exposure
θ = Angle (degrees) off surface normal or plume centerline
r = Distance (cm) from emitter to receiver

In any case, each instrument and its characteristics should be compared with the proposed Standards (Section A-5.1) so that probable performance may be assessed. In such analysis, the possibility of influence by those gases mentioned above should be addressed.

A-3.3 Probable Atmosphere

In order to specifically identify the probable Shuttle environment, an example has been made of Shuttle Mission-6, which will have an inclination of 56° and a nominal altitude of 570 km. It is the intent of this section to identify, insofar as possible, the spatial and temporal variability around the Shuttle as well as to provide some detail on the concentration and number of contaminants of interest (see Section A-3.2).

The ambient atmosphere at 570 km is dominated [56, p.6] by atomic oxygen ($\sim$ 90 percent by mass). Other components include O_2 (0.2 percent), N_2 (5 percent), He (0.5 percent), and H (0.005 percent). The total atmospheric density amounts to approximately $6 \times 10^{-16} gm/cm^3$. It should be pointed out that the ambient atmosphere may vary over several orders of magnitude due to solar activity and position along the orbit.

Figures A-2 through A-6 illustrate the spatial variability of each of five major sources of Shuttle-induced contamination (in terms of density). While the spatial variability is of importance, it should be noted that outgassing and offgassing will be continuous sources, particularly for short missions. In addition, leakage

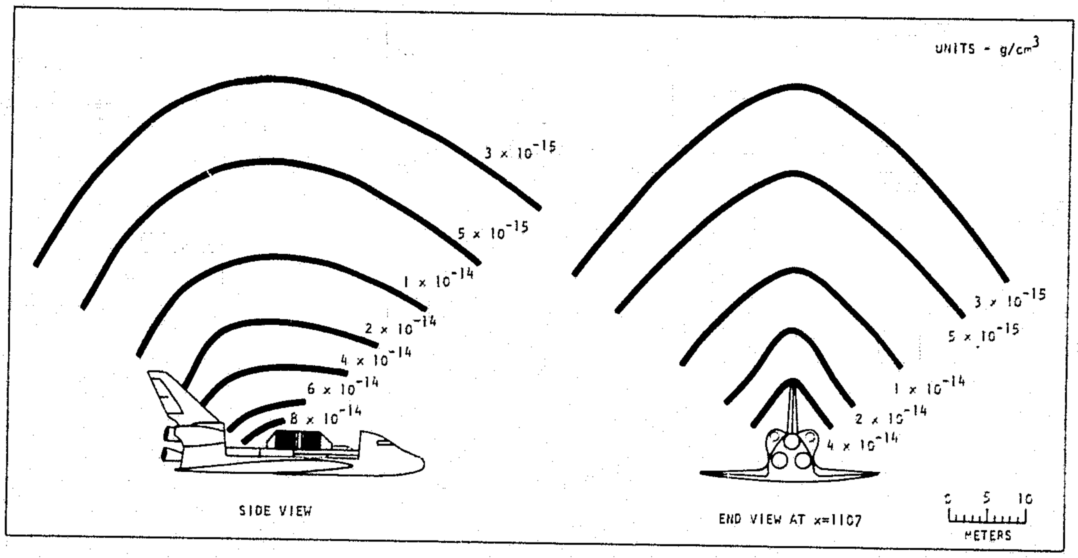

FIGURE A-2
OUTGASSING ISODENSITY CONTOURS (56)

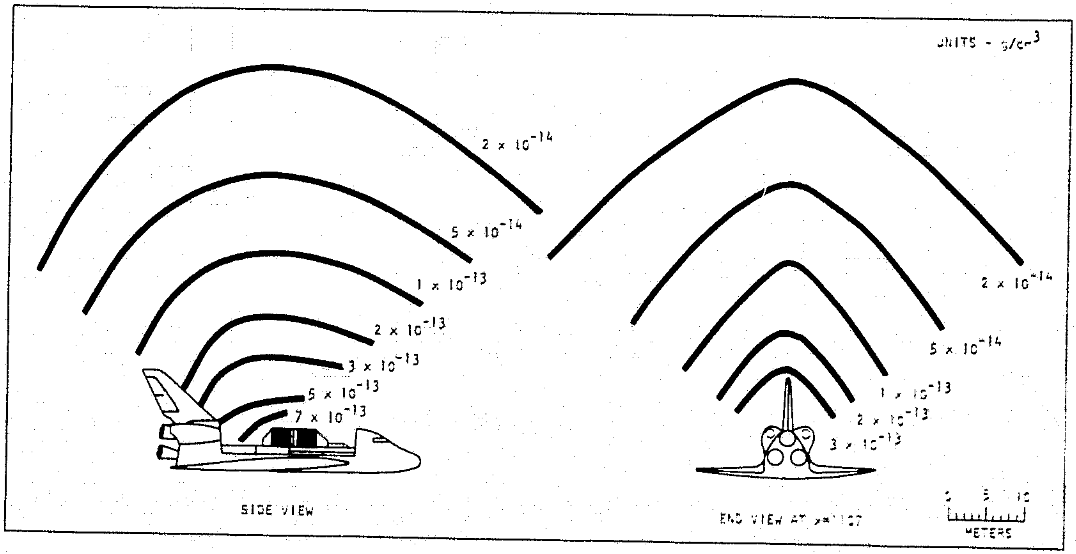

FIGURE A-3
OFFGASSING ISODENSITY CONTOURS [56]

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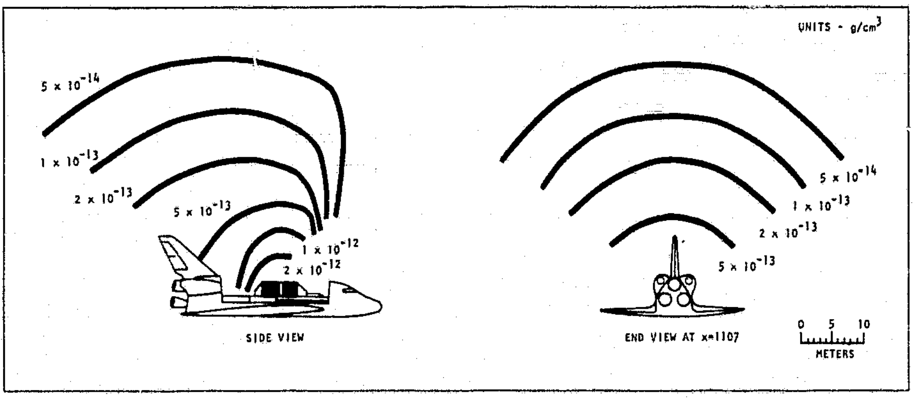

FIGURE A-4
LEAKAGE ISODENSITY CONTOURS(56)

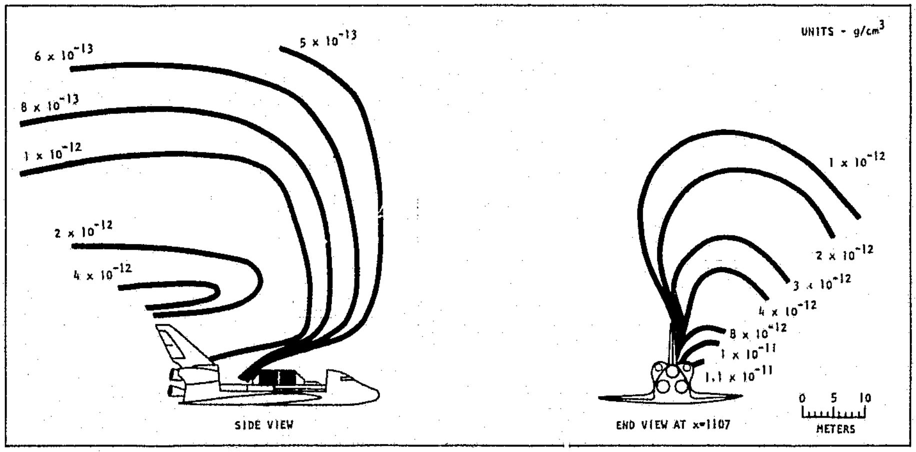

FIGURE A-5
-Z AFT VCS 25 lb. THRUST ENGINE ISODENSITY CONTOURS

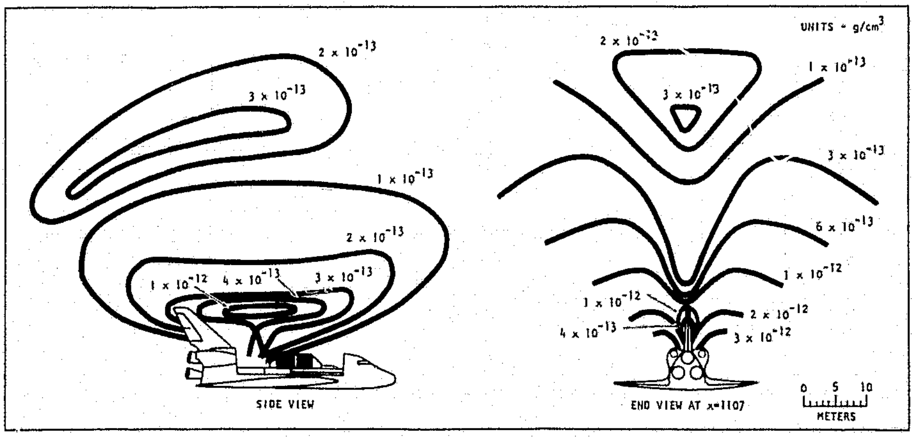

FIGURE A-6
SUPPLEMENTAL FLASH EVAPORATOR ISODENSITY CONTOURS

will also be a constant source of contamination. However, the VCS sources will occur only during engine firing. The importance of this source is then determined by the duration of the engine firing (probably no more than a few seconds) and the frequency, which is a function of the mission requirements. The SFEV will be in operation on the average of 60 percent of on-orbit time [49, p. 44].

Interpretation of the importance of the contours of the figures is made difficult by a lack of knowledge of the type and amount of the contributing constituents (except in the case of SFEV, which is entirely water vapor). Considering our incomplete knowledge of these topics we must be satisfied to identify possible components (see Table A-II) and the total column burden attributable to each type of source. In this way an upper bound can be established that determines if further analysis is required. That is, by assuming that each source is composed solely of gases that are to be monitored, a worst case analysis can be performed on the column burden associated with Shuttle.

Table A-III depicts the probable total molecular column burden associated with Shuttle. The size parameter estimations of Table A-II were utilized to convert mass density to molecular column burden. In each data entry, the extremes in the column burden are indicated, the data having been calculated for various lines of sight and β angles (defined as the angle between the orbit plane and the earth-sun

TABLE A-III
MAXIMUM AND MINIMUM MOLECULAR COLUMN BURDEN INDUCED BY SHUTTLE ORBITER AND PAYLOAD [49]

SOURCE	COMPONENTS AND MOLECULAR WEIGHT (AVE.)	SHUTTLE-INDUCED MOLECULAR COLUMN BURDEN	NOTES
Outgassing	Hydrocarbons RTV, etc M = 100	$4.6\text{x}10^{9} - 6.3\text{x}10^{11}\ \frac{\text{molecules}}{\text{cm}^2}$	
Offgassing	water, light gases, volatiles M = 18	$1.1\text{x}10^{11} - 1.5\text{x}10^{13}$	
Leakage	O_2, N_2, CO_2, H_2O, M = 29	$4.2\text{x}10^{11} - 3.5\text{x}10^{13}$	
Evaporator	H_2O M = 18	$1.8\text{x}10^{11} - 2\text{x}10^{14}$	
VCS (all sources)	See Table A-2 M = 20.7	$1.2\text{x}10^{12} - 7.3\text{x}10^{14}$	
All sources	-	$2.2\text{x}10^{13} - 3.1\text{x}10^{13}$	VCS and evaporator off
		$4.8\text{x}10^{11} - 9.1\text{x}10^{12*}$	β= 73°-offgassing rate after 10 hours of exposure-line of sight along axis-*polar molecules

line). Since it is not clearly known at this time in which attitude the orbiter may be oriented during observation of the earth's atmosphere, the entire range of burdens has been provided.

In addition to the gases that contribute to the environment, particles will also be present. As noted earlier, infrared instrumentation will be most susceptible to these materials, particularly those resulting from thermal emission.

Using Skylab data as a guide, we can expect 16 particles per second of sizes in excess of 25 μm to be emitted [49, p.92]. The dwell time of these particles within the instrument field of view will be a function of the field of view, trajectory of the particle, and its velocity, size, shape, and orbital altitude. Since the particle's acceleration is a function of atmospheric drag, higher altitude orbits produce longer dwell times.

A-3.4 Measurements Proposed for Shuttle

The performance of the Shuttle as a clean platform for scientific instrumentation will be monitored by a number of instruments. Such monitoring will occur during the six orbiter flight tests and the first two Spacelab flights [50, p. 10] in order to determine if Shuttle environmental standards have been met. Further, the detail of the monitoring is to be sufficient to indicate sources so that control can be implemented for those flights on which sensitive payloads will be carried.

During flight the following measurements will be made:

a) Molecular column density

b) Background spectral intensity from UV to IR

c) Particle size and velocity distribution

d) Molecular deposition on an ambient surface

e) Molecular deposition on a cryogenic surface

f) Molecular return flux as a function of species

g) Particulate deposition on surfaces

h) Degradation of optical surfaces

The data quality should be sufficient to identify violation of the standards described in Section A-5.0 [50, p. 10].

In addition, early flights of Spacelab will be assessed for a number of possible contamination problems, including contamination induced during deployment and retrieval of spacecraft; particles and gas environment associated with various flight operations in order to determine mean environment as well as confidence limits on variations; and particle and gas environment within the Spacelab.

In addition to the monitoring proposed for the six Orbiter flight tests and the first two Spacelab flights, measurements have been proposed for each subsequent flight that guarantee an adequate knowledge of the payload environment. It should be anticipated that some of the instrumentation under consideration will require monitoring requirements more stringent and/or complete than those discussed in Reference 55. Some initial information on the instrumentation to be used has been developed.

A number of features of the Shuttle environment are to be measured with the following instruments [51]:

- Induced Environment Contamination Monitor
- Orbiter Development Flight Instrumentation
- Spacelab Verification Flight Instrumentation

The last device will monitor temperature, pressure, humidity, dew-point, condensibles, particle content, and trace contaminants in the payload bay during ascent, descent, and all ground operations. In orbit it will measure deposition rate (including H_20 on cryogenic surfaces), production rate and velocity of particulates, and re-evaporation of condensibles as a function of temperature.

A number of measurement instruments were utilized aboard Skylab to make measurements of this type [57]. The key experiments were the distribution of 248 material samples of 21 different types outside of the orbital workshop for contamination studies (later analyzed for contamination and surface degradation); quartz crystal microbalance for measurement of mass deposition rate, particularly when the balance is on the cold side of the spacecraft (and subsequent mass loss during exposure to sunlight); and a photometer for the determination of light scattering in the vicinity of the spacecraft (related information was obtained from the coronograph)[55,58].

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A-4.0 PREVENTIVE MEASURES

Each of the problem areas outlined in the earlier sections can be dealt with to at least some degree by the implementation of various methods of material selection, surface preparation, orbit activity, etc. It is the purpose of Table A-IV to summarize problem areas and identify correction or protection methods.

Included in the table are some general engineering and operational methods to help control the gaseous and particulate environment of the Orbiter and its payload. Some other features related to control and instrument protection are listed below:

- As noted in Table A-II, the VCS engines and evaporators are the two major sources of pollutant emissions. For that reason, judicious placement of these sources will be of value in controlling the induced atmosphere. In fact, it is quite likely that VCS operation will preclude use of atmospheric remote sensors due to the high column densities and the fact that the gases emitted include some to be measured by the instrumentation.

- Unnecessary venting of wastes should be strictly avoided, by storage until mission completion. Storage of water produced by fuel cells and resulting control of the emissions from the evaporator should be utilized during measurement periods.

- To minimize the impact of the unavoidable presence of sources of scattering (particularly particles), optical instrumentation should be well baffled and covered when possible. Experience with the sun calibration mirror on Landsat 1 and 2 indicates that care in handling and selection of a suitable protective cover prior to launch is an effective method of controlling contamination [58, 59].

- Considerable attention should be paid to control of the unique particle and gas emission from the Orbiter payload, including free-flying satellites.

- Use of free drift to avoid required use of the VCS engines would be a particularly effective control method considering

TABLE A-IV
ENVIRONMENTAL CONTROL METHODS

SOURCE OF POLLUTANT	CONTROLS	REMARKS
Ambient Atmosphere	Select highest altitude possible.	Ambient atmosphere will vary with season and position in orbit.
VCS	Minimize use during measurements. Design for minimum return flux. Select optimum placement. Select alternative control system utilizing cold gas or magnetic torque.	Alternative methods impose weight disadvantage.
Evaporator	Select optimum location. Control operations during measurements.	
Outgassing	Select materials carefully, particularly within optical devices. Avoid direct irradiation by sunlight of optical components.	Reduced by an order of magnitude while in shadow. Rates should be established.
Offgassing	Use care in surface selection and preparation. Rotate orbiter to heat all surfaces to encourage high rate. Keep bay doors open during heating.	Decreases with exposure to vacuum of space as a function of time. Rates should be established.
Returned Flux	Utilize highest altitude possible.	
Leakage	Unavoidable.	Expected to increase as vehicle is used for several missions.
Launch and Deployment Residues	Keep sensitive instrumentation enclosed. Rotate orbiter to heat surfaces to encourage offgassing. Sensitive payloads individually sealed. Pressurize sensitive payloads during launch.	Effective storage will be required including cargo doors, vent systems, etc.
Ground Atmosphere	Proper storage and integration environment.	
Particulates	Material selection/preparation. High quality ground environmental control.	Controls difficult due to abrasion of parts, absorption of particles during launch, deterioration of surfaces from multiple launches/reentrys. Residence time increases with altitude.

the magnitude of this source and its composition (H_2O), which may adversely affect the infrared radiation sensors under consideration. In addition, selection of alternative thrusters using inert cold gases (N_2 or He) has been suggested along with magnetic torqueing. There are some weight disadvantages associated with these methods, however, [51] and experiments that will be adversely affected by the VCS may have to operate while the Orbiter is in a drift (uncontrolled altitude) mode.

- On-orbit activities, such as slow rotation of the Orbiter in order to expose all surfaces to sunlight, will encourage off-gassing and reduce the time required for this source to be reduced in importance [59][60].
- Effective storage of instrumentation will be required to minimize contamination from the atmosphere and launch/deployment gases. Pressurized storage until orbital deployment is preferred.
- Monitoring of the spacecraft environment, particularly during measurement periods, will be of vital importance in assessing the importance of anomolous and normal environments. The selection of monitoring instrumentation and its placement should be carefully analyzed.
- Avoidance of the use of cryogenics until absolutely required and the environment is acceptable will help minimize deposition on these critical cooled surfaces.
- Materials and their preparation should be carefully chosen.
- Location and design of any and all exhaust ports (including gases and liquids) should be carefully developed. During the selection of port location, considerable attention should be given to the combination of Orbiter altitude and preferred line-of-sight of the instrumentation.
- Preparation of methods of control should be mission-specific due to the importance of altitude (on ambient atmosphere and return flux), inclination (duration of solar exposure), and mission (attitude of Orbiter).
- Free-flying payloads should be deployed with full consideration given to the location of VCS engines.

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- All operations should be deferred until the Orbiter environment has reached satisfactory levels.
- Periodic warmup and bakeout of gases trapped on cryogenically cooled surfaces.
- While not a preventive measure, calibration on a regular basis during periods of operation will guarantee knowledge of environmental impacts and allow accurate coordination of monitoring data and atmospheric measurements.

The material discussed above has been assembled into Table A-V, which summarizes protective methods that can be utilized and the problem areas where they are most effective, independent of the source of the contamination.

TABLE A-V
ENVIRONMENTAL CONTROL AND INSTRUMENT PROTECTION MATRIX

Dot (●) indicates that control or protection can be obtained

ENVIRONMENTAL CONTROL PROTECTION

Problem Area	Control Flash Evaporator	Avoid Use of VCS	Location of Ports	Control Waste Emissions	Material Selection*	Solar Radiation Exposure Control*	Periodic Warmup	Restrict Use of Cryogenics	Shuttering and Effective Storage	Baffling
Optical Surface Deposition	●	●	●	●	● ●	●	●		●	
Gaseous Cloud Absorption	●	●	●	●	●					
Particulate Cloud Scattering	●	●	●	●	●	●				●
Cryogenic Surface Deposition	●	●	●	●	● ●		●	●	●	
Gaseous Cloud Scattering	●	●	●	●	●	●				●
Thermal Emission of Gases	●	●	●	●	●	●				●
Thermal Emission of Particules	●	●	●	●	●	●				●

*Dots in left side of column apply to environmental control; those on right apply to protection

A-5.0 STANDARDS AND PROBABLE PERFORMANCE

A-5.1 Standards

A number of groups have reviewed requirements for the Shuttle Orbiter and payload environment [49,50,51,61,62,63]. The performance criteria suggested are summarized in Table A-VI in as much detail as possible. It should be noted that, in these recommendations, no specific reference is made to control during missions that will include atmospheric remote sensors. Because of the use of the infrared spectrum by many of these instruments, the use of cryogenic cooling of detectors and other components, and the significant sensitivity of the instruments to small concentrations of gases, the standards expressed should be considered only as preliminary. It is recommended that standards specific to atmospheric remote sensors be included in any further development of requirements for environmental control.

Furthermore, some assumptions have been made by MITRE concerning the adequacy of these standards to guarantee satisfactory instrument performance:

- That proper fabrication and installation procedures have been utilized so as to guarantee the cleanest possible initial conditions
- That launch and orbit setup activities have minimal impact on the instrument environment
- That all possible precautions are taken to ensure the cleanest possible working environment for the instrumentation on-orbit (see Section A-4.0).

TABLE A-VI
PERFORMANCE CRITERIA FROM VARIOUS SOURCES

	REFERENCE				
	49**	61	50*	62	NOTES
Particles ($\#cm^{-2}S^{-1}$)					
>10µm	$<10^{-4}$	$<10^{-4}$	–	<1 in 4 arc-minute half-angle FOV per orbit within 1 km.	
>5µm	–	–	–	<1 per orbit in $1.5x10^{-5}$ sr FOV and none for 90% of operational period	
Gas (molecule-cm^{-2})					
H_2O and other polar molecules	$<10^{10}-10^{12}$	$<10^{10}-10^{12}$	–	$<10^{12}$	
$H_2O + CO_2$	–	–	10^{11}	–	
$O_2 + N_2$	–	–	10^{13}	–	
Other	–	–	10^{10}	–	
Other Factors					
Return flux (molecules $cm^{-2}S^{-1}$)	$<10^{12}$	$<10^{12}$	–	$<10^{12}$	
VCS fuel expended (kg/day)	<20	<20	–	–	
Waste dump	None	None	–	–	
Deposition ($gm\ cm^{-2}$)	–	–	$<10^{-5}$ in 30 days @ 300°K in 2π sr FOV $<10^{-7}$ in 30 days @ 300°K in 0.1 sr FOV @ 400 km $<10^{-5}$ in 30 days @ 20°K in 0.1 sr FOV @ 400 km	<1% absorption	
Background spectral intensity (5-30µm)					*Violations are permitted provided they are controllable (related to dumps, etc.) and do not persist for more than 10% of the operational time and do not occur more than once in 30 minutes.
Spatial variation ($WM^{-2}sr^{-1}nm^{-1}(°)^{-1}$)	–	–	$1.1x10^{-13}$	–	
Temporal variation ($WM^{-2}sr^{-1}nm^{-1}S^{-1}$)	–	–	$5.5x10^{-14}$	–	
Magnitude ($WM^{-2}sr^{-1}nm^{-1}$)					
1µm	–	–	$1x10^{-10}$	–	**Derived from REFERENCE 61
5µm	–	–	$7x10^{-12}$	–	
10µm	–	–	$1x10^{-11}$	–	
30µm	–	–	$1x10^{-11}$	–	

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- That operational recommendations for payload protection as defined in [50] are utilized

A-5.2 Expected Performance

As noted earlier, an atmospheric burden of up to 10^{13} molecules/cm^2 will be produced by the ambient atmosphere and Orbiter/payload combination. Furthermore, the possible composition of the atmosphere is not clear, but it will certainly comprise components that will produce:

- Band or line absorption by constituents not of direct importance (such as H_2O or CO_2)
- Band or line absorption by constituents to be measured in the earth's atmosphere
- Scattering by molecular or particulate components

Because of the uncertainty in relative importance of each of the cited impacts, for each different instrument design, a general evaluation must suffice. The evaluation assumes that the instruments fall into five classes (see Table A-VII) and that in each case the response of the instrument is directly proportional to the number of pollutant molecules to which it is sensitive, in its field of view.* This approach does not include the possible corruption of the data by scattering at the instrument wavelength or by inadvertent absorption by absorption lines or bands associated with constituents other than the one of interest.

---

*The instruments may include a number of specific types referenced elsewhere in this report which fall into these categories.

TABLE A-VII
INSTRUMENT CLASSES AND SOME OPERATING FEATURES

INSTRUMENT TYPE	RADIATION SOURCE	OPERATION	NOMINAL FIELD-OF-VIEW (radians)
1) Occultation	Sun	Absorption	0.001
2) Limb emission	Thermal emission of gas	Emission	0.1
3) Backscatter	Solar	Selective reflection	0.1
4) Nadir thermal	Thermal emission	Gas emission or absorption	0.1
5) Nadir reflected solar	Sun	Absorption	0.1

In view of the lack of more specific information about the importance of the various effects cited, it may be sufficient to make a worst-case analysis which assumes that all molecules along a given field of view are of the specie to be measured in the earth's atmosphere. There is little chance that any component of the Orbiter atmosphere will absorb, scatter, or emit with the strength of the pollutant of interest at the wavelength at which the instrument operates. Furthermore, because each particular instrument may have a different sensitivity, a normalized measure of the importance of the spacecraft environment can be developed by computing the number of pollutant molecules in the field of view contributed by the spacecraft and by the earth's atmosphere. Clearly this impact will be a function of instrument field of view, viewing orientation, and the vertical and horizontal distribution of the pollutant.

It should be pointed out that it may be possible that this method does not represent a worst case. This would certainly be true if a particularly weak line were chosen for study and some other component of the spacecraft environment had a coincident line or band absorption of a larger mgnitude. It is not likely that such a 'parasitic' absorber would be H_2O or CO_2 since instrument designers avoid lines adversely affected by these two important components of the earth's atmosphere.

It should also be noted that the assumption that all molecules in the spacecraft environment are of the same species to be measured in the atmosphere is a crude representation of the facts. The next most sophisticated approach would attempt to define the fractional components (as identified in Table A-II) in the spacecraft environment. The next level of development would be to investigate the spectroscopy of each of the components and relate their cumulative features to the particular properties of each instrument, particularly wavelength of operation and operating technique. Such additional studies are beyond the scope of this appendix but should be considered for future analysis particularly in the case of those instruments that attempt to measure very low concentrations of trace gases in the earth's atmosphere (for example, occultation and limb scan instruments viewing the top of the atmosphere). In such cases the spacecraft environment will heavily impact the measurements, and a more detailed analysis is required.

The fact that the environmental standards are expressed in terms of a column-burden (molecules/cm^2) and that the instruments detect gases over a larger field of view requires some interpretation to perform the analysis discussed above. The relative impact (R) of the spacecraft environment is

$$R = \frac{\text{Spacecraft environment contribution to number of detected molecules of interest}}{\text{Total number of molecules of interest in field of view contributed by earth's atmosphere}} \cdot \quad (1)$$

In terms of a conical field of view and pollutant with horizontal and vertical variability, the value of R is

$$R = \frac{\int \rho' \, d\theta \, d\phi \, dr}{\int \rho \, dr \, d\theta \, d\phi} \tag{2}$$

where r, θ and ϕ are spherical coordinates,

and $\int \rho \, dr$ is the column burden of pollutant in the earth's atmosphere (and is, of course, a function of θ and ϕ and $\int \rho' dr$ is the column burden of pollutant in the spacecraft environment.

This worst-case analysis can be extended if three assumptions are made:

1) That the concentration of pollution around the spacecraft is uniform and is characterized by a column burden in any direction of 10^{13} molecules/cm^2, and the entire pollution cloud is comprised of the gas to be measured in the earth's atmosphere

2) The distribution of the gas of interest within the field of view is uniform except for a vertical variability in the earth's atmosphere. Data on vertical profiles have been derived from Reference 64.

3) The field of view of the sensor forms a cone.

Under these conditions, R can be expressed as

$$R = \frac{10^{13} \int d\theta \, d\phi}{\int \rho \, dr \, d\phi \, d\theta} = \frac{10^{13} \int d\theta}{\int \rho \, dr \, d\theta} \tag{3}$$

If the field of view is limited to 0.1 radians, an approximation can be made that removes the angular dependence and produces

$$R \approx \frac{10^{13}}{\int \rho \, dr} \tag{4}$$

Table A-VIII presents data obtained for values of R for each instrument type and a number of gases of interest. Limb measurements are evaluated at two altitudes, 10 km and 40 km. The data on column burdens in the atmosphere was obtained from vertical profiles [6, 64] and suitably integrated. For horizontal integrations (for limb-scan and occultation measurements) suitable allowance was made for the variation in concentration along the path of observation. The range of altitudes used in the integration are indicated below:

NO	10-37 km
CO	10-45 km
N_2O	10-30 km
CH_4	10-50 km
NO_2	10-30 km
HNO_3	10-38 km
O_3	10-50 km
OH	10-50 km

Unfortunately, little data on these gases exist for altitudes above those given. This lack of information is in fact one of the motivations for the experiments suggested in this document. However, these conditions impose yet another level of uncertainty on the analysis presented. It should be pointed out, however, that a worst-case analysis is still produced since any components of the atmosphere not included in the analysis would, if included, produce an improved performance rating since the spacecraft environment would

TABLE A-VIII
IMPACT OF SPACECRAFT ENVIRONMENT ON REMOTE OBSERVATION OF SELECTED COMPONENTS OF THE EARTH'S ATMOSPHERE

Data is unitless as defined in Equation 1

		GASES							
		NO	CO	N_2O	CH_4	NO_2	HNO_3	O_3	OH
Occultation**	10 km	2.6×10^{-4}*	9.5×10^{-7}	2.5×10^{-7}*	7.4×10^{-8}	7.4×10^{-8}*	6.5×10^{-5}*	5.2×10^{-8}	7.9×10^{-2}
	40 km	9.3×10^{-4}*	1.4×10^{-4}	2.8×10^{-3}*	2.8×10^{-5}	1.4×10^{-4}*	1.9×10^{-1}*	9.3×10^{-7}	3.5×10^{-2}
Limb**	10 km	2.6×10^{-4}*	9.5×10^{-7}	2.5×10^{-7}*	7.4×10^{-8}	7.4×10^{-8}*	6.5×10^{-5}*	5.2×10^{-8}	7.9×10^{-2}
	40 km	9.3×10^{-4}*	1.4×10^{-4}	2.8×10^{-3}*	2.8×10^{-5}	1.4×10^{-4}*	1.9×10^{-1}*	9.3×10^{-7}	3.5×10^{-2}
Nadir Solar		2.7×10^{-3}*	1.4×10^{-5}	4.1×10^{-6}*	1.0×10^{-6}	6.3×10^{-4}*	1.0×10^{-3}*	4.6×10^{-7}	4.3×10^{-1}
Nadir Thermal		5.4×10^{-3}*	2.8×10^{-5}	8.3×10^{-6}*	2.1×10^{-6}	1.3×10^{-3}*	2.0×10^{-3}	9.3×10^{-7}	8.6×10^{-1}
Backscatter		2.7×10^{-3}*	1.4×10^{-5}	4.1×10^{-6}*	1.0×10^{-6}	6.3×10^{-4}*	1.0×10^{-3}*	4.6×10^{-7}	4.3×10^{-1}

*Profile partially estimated
**Altitudes are for tangent point of FOV

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represent a smaller fraction of the total number of pollutant molecules seen.

The nadir-solar (reflected radiation) case was computed assuming that the sun is in the zenith position, so that the radiation makes two passes through the atmosphere. In the backscatter case, it is assumed that the radiation is predominatly scattered from altitudes down to 25 km.

The table indicates those instrument/gas combinations for which the worst-case analysis indicates that a problem may exist. As noted earlier, a number of assumptions have been utilized in the analysis. The more complete analysis should review those assumptions, assess their importance, and evaluate the possible influence of the spacecraft environment.

Those combinations appearing as potential problem areas have been defined as those for which the fractional contribution of the spacecraft environment exceeds 0.5 percent of the earth's contribution (few instruments can claim to make measurements of this accuracy or sensitivity).

As expected, the areas of concern are concentrated into those instrument/gas combinations that are characterized by limb-scanning or occultation and low atmospheric concentration. Specifically, they are

Nadir thermal - NO, OH
Occultation - HNO_3 (40 km), OH (10 km & 40 km)
Limb emission - HNO_3 (40 km), OH (10 km & 40 km)
Nadir solar - OH
Backscatter - OH

It should be remembered that the instrument/gas combinations cited as potential problem areas were developed from a worst-case analysis that utilized a number of simplifying assumptions. Among those assumptions was that the spacecraft environment contributed a column burden of 1×10^{13} molecules/cm^2 of each of the molecules selected for study. An investigation of Table A-II indicates that of the molecules cited as potential problems (HNO_3, NO and OH), both NO and OH are produced by the VCS system. No source of HNO_3 has been identified.

Clearly, further analysis, including a more sophisticated evaluation of the probable spacecraft environment, will be required to establish the magnitude of the problems implied by this analysis.

A-6.0 CONCLUDING REMARKS AND RECOMMENDATIONS

This appendix has performed an initial evaluation of the impact of spacecraft-induced contamination on remote sensors of the earth's atmosphere. In addition to identifying the methods by which such contamination degrades instrument performance, an evaluation has been performed of the features of the induced contamination expected from the Space Shuttle and its payload(s). From these topics has been derived a series of preventive measures designed to control contamination, induce its departure, and protect instrumentation from the influence of the constituents that are unavoidable. The analysis of key problem areas completes the study and naturally leads into recommendations for additional tasks, particularly related to the assumptions utilized in the analysis. Particular recommendations for further analysis include the following:

- Improvement of the catalogue of probable components of spacecraft environment and a quantitative analysis of their four-dimensional variability.
- Analysis of the type performed in Section A-5.2 with inclusion of a model of the scattering environment (both particulate and molecular).
- Analysis of the probable band absorption in the spacecraft environment resulting from the contaminants cited in Table A-II (particularly CO_2 and H_2O).
- Analysis of the probable line absorption in the spacecraft environment resulting from the contaminants cited in Table A-II.
- Use of the studies already recommended to evaluate the performance of particular instruments taking specific note of the instrument operating principles, field of view, operational characteristics, wavelength(s) utilized, sensitivity, etc.

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- Evaluate the potential benefits to be gained from use of the preventive measures discussed in Section A-4.0.
- Evaluate effectiveness of various calibration techniques for minimizing degrading aspects of contamination.

APPENDIX B

THE SIZE DISTRIBUTION AND COMPOSITION OF STRATOSPHERIC AEROSOLS

APPENDIX B

SIZE DISTRIBUTION AND COMPOSITION OF STRATOSPHERIC AEROSOLS

B-1.0 BACKGROUND

An aerosol may be defined as a solid or liquid particle in a gaseous medium, in this case air. Stratospheric aerosols are those residing above the tropopause and below the mesopause. Aerosols range in size from clusters of a few molecules to particles (or droplets) of about 20 μm radius. The lifetime of aerosols smaller than 0.005 μm radius is very short because they quickly become attached to larger aerosols. The lifetime and travel distance of aerosols larger than 20 μm radius is limited because gravity causes them to settle out. Therefore, the size range of atmospheric aerosols is generally between 0.005 and 20 μm radius. However, the upper size range of stratospheric aerosols is limited to about 5 μm radius because the larger particles readily diffuse down through the tropopause.

The concentration of aerosols in the troposphere decreases with increasing height until, at the tropopause, it is on the order of a few per cubic centimeter. The stratospheric aerosol population is on the order of 0.001 to 0.01 particles per cubic centimeter but may vary in concentration by several orders of magnitude depending upon several exterior events (such as volcanic activity). The regular decrease in concentration of aerosol with height through the troposphere and stratosphere implies that at least the majority (by number) of stratospheric particles originate in the troposphere - entering the stratosphere through the mixing process. More recently studies of stratospheric aerosols have indicated that two size regimes, either in different layers or in the same layer, exist in the lower stratosphere. This phenomenon seems quite reasonable when it is considered that the smaller particles-those aerosols smaller than 0.1 μm in radius called Aitken nuclei--probably diffuse up from terrestrial sources, whereas the Junge, or sulfate, layer aerosols probably are formed in the lower stratosphere by chemical reactions.

B-2.0 WORLDWIDE AEROSOL DISTRIBUTION

Recent concern for the potential modification of the stratosphere by chemical and particulate pollutants has resulted in a considerable increase in studies to define the structure and composition of the stratosphere. The vertical and latitudinal aerosol distributions are presented to provide a general description of the stratospheric aerosol structure.

B-2.1 Vertical Distribution of Aerosols

The vertical concentration of aerosols is subject to considerable variation in time and space. Therefore, for the purpose of this Appendix it is appropriate only to bracket the magnitude of the concentrations as a function of altitude.

The general decrease in concentration with height, regardless of size, is depicted in Figure B-1. The most frequent concentration values are indicated by the area between the two solid curves; the dashed curves enclose the extreme values. The population of aerosols at ground level is on the order of 10^4 to 10^5 per cm^3. The concentration at the tropopause has decreased to the order of a few per cm^3. The regular decrease in concentration above the tropopause suggests that at least the majority of stratospheric aerosols originate in the troposphere, entering the stratosphere via the mixing process.

The increase in concentration at an altitude of about 20 km, known as the Junge, or sulfate, layer, has been the subject of considerable study in recent years. These aerosols appear to be formed by the

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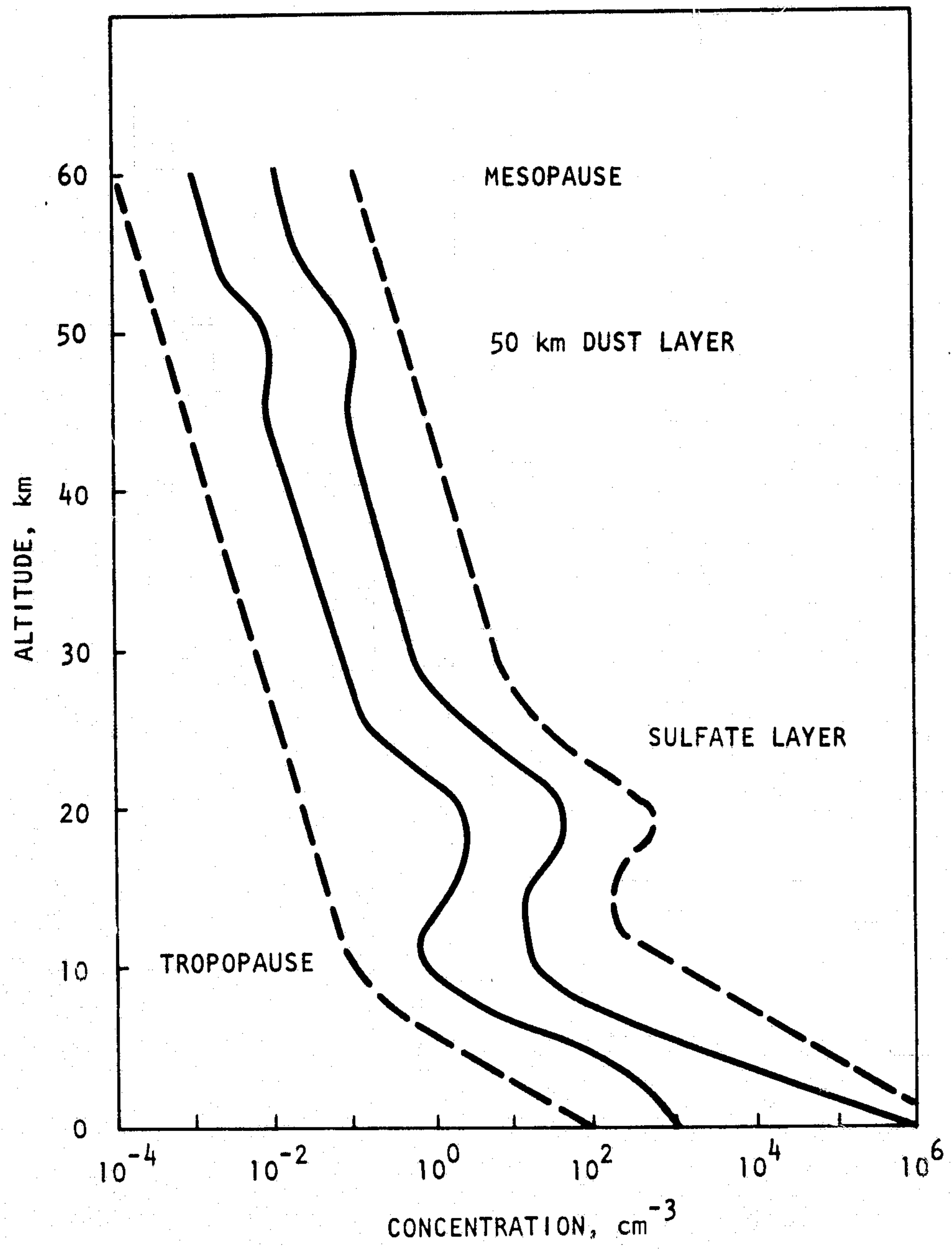

FIGURE B-1
VERTICAL DISTRIBUTION OF AEROSOLS

oxidation of H_2S or SO_2 in situ and will be discussed in greater detail in a later section. The population of aerosols in the Junge layer is on the order of 0.1 per cm^3 and can vary by a factor of three both in space and over short periods of time (order of days and weeks). However, the concentration can increase by as much as a factor of 10 to 100 after a volcanic eruption.

After reviewing several years of data for the Climatic Impact Assessment Program (CIAP), Hoffman and Rosen [65] have shown that there are significant seasonal changes in aerosol concentrations in the lower stratosphere. The concentration of aerosols tends to decrease with time and the size distribution shifts toward smaller sizes--until another volcano erupts. They also found evidence that two size regimes exist, either at slightly different altitudes or within the same layer. This seems quite plausible considering that the smaller sizes are probably Aitken nuclei mixed upward from the troposphere, whereas the larger particles are formed in situ evolving into the sulfate layer.

At altitudes above the sulfate layer, i.e., between 30 and 60 kilometers up to the mesopause, the aerosols decrease regularly with altitude to the order of about 0.002 to 0.003 per cm^3. The only exception is the sporadic observation of the "50 kilometer dust layer." The concentration of aerosols in this layer is thought to be only a factor of two, at most, above the ambient. The aerosols in the upper stratosphere are thought to emanate from the troposphere and/or are of extraterrestrial origin. In any event, the aerosols are quite sparse and represent a negligible optical attentuation.

Clouds, which are composed of either liquid or solid water aerosols, are very rare above the tropopause because of the general lack of sufficient moisture. (Thunderstorm clouds that penetrate the tropopause carry their own moisture with them.) However, the occasional observations of nacreous clouds, generally called mother-of-pearl clouds because of their iridescent appearance, can be considered an exception that cannot be overlooked. These clouds are observed over the North Atlantic and Scandinavian countries in the winter between 25 and 30 kilometers in altitude. According to Cadle [66] the mother-of-pearl clouds probably consist of ice crystals in concentrations of a few particles per cm^3. Junge [67] notes that these clouds could be composed of either super-cooled water droplets or ice spheres. He observed that the mother-of-pearl clouds generally appear during weather conditions that lead to exceptionally low stratospheric temperatures. Mason [68] suggests that these clouds form in much the same manner as lenticular clouds, only at greater heights.

The second type of high-altitude clouds, the noctilucent clouds, are observed during the summer over polar regions at an altitude of about 80 kilometers. It has been speculated that these clouds are composed of dust particles, possibly from an extraterrestrial source, and are associated with the temperature inversion at the mesopause.

Of the three hypotheses listed by Cadle [66], one proposes that noctilucent clouds are composed of ice particles condensed on non-volatile solid particles, which is supported by samples collected with rocket-borne instrumentation. The sample cloud particles contained quantities of iron and nickel, suggesting an extraterrestrial source, and were coated with ice when in situ. Between 10^2 and 10^3 more particles were collected when the noctilucent cloud was present than when it was absent. The particles varied in size from 0.05 to 5 μm in diameter and had an effective (optical) mean radius of 0.10 to 0.15 μm.

B-2.2 Latitudinal Distribution of Aerosols

Global aerosol measurement programs have been initiated in recent years to provide the beginning of baseline data relative to latitudinal (and longitudinal) distribution of aerosols. Hoffman, et al. [69] made over 70 balloon flights in cooperation with Laby of the University of Melbourne, at eleven sites ranging from Barrow, Alaska, to Panama, and from Longreach, Australia, to the South Pole. They used a balloon-borne visible photometer which electronically tabulated the number of aerosols larger than 0.15 μm radius.

During the late winter and early spring of 1973, Fernald et al. [70] probed the stratosphere with an airborne dye laser operating at a wavelength of 585 nm. Flights were flown from point to point (for example, Fairbanks to Honolulu and Honolulu to the equator, etc.) such that the semihemisphere from 0° to 150° West and from the

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equator to 85° North was traversed. The data published consisted of plots of the scattering ratio as a function of altitude (from 12 to 31 km) and the latitude/longitude along the flight path. In order to evolve a partial "aerosol atlas" from these data one must convert the scattering ratio into aerosol concentrations as a function of position, a virtuous task that has not yet been attempted.

The data of Hoffman et al. [69] are plotted in terms of the absolute mixing ratio as a function of latitude and altitude. By melding two diagrams (and converting to the number of aerosols per cubic centimeter), it is possible to construct a general diagram displaying the major features of the aerosol concentration as a function of altitude and latitude. The result is shown in Figure B-2. The double lines represent the tropopause, and the dashed curve indicates the location of the maximum concentration of stratospheric aerosols, which is usually identified by the preponderance of sulfate aerosols. Hoffman et al. [71] remarked that the similarity in the northern and southern hemispheric stratospheric aerosol concentrations and size distributions suggests that the source is independent of human activity. The slight variations shown in Figure B-2 must then be attributed to seasonal changes. Short-term increases from volcanic activity are first manifested by the ash cloud, followed by sulfate aerosol formation that subsequently spreads out along constant pressure levels during dissipation.

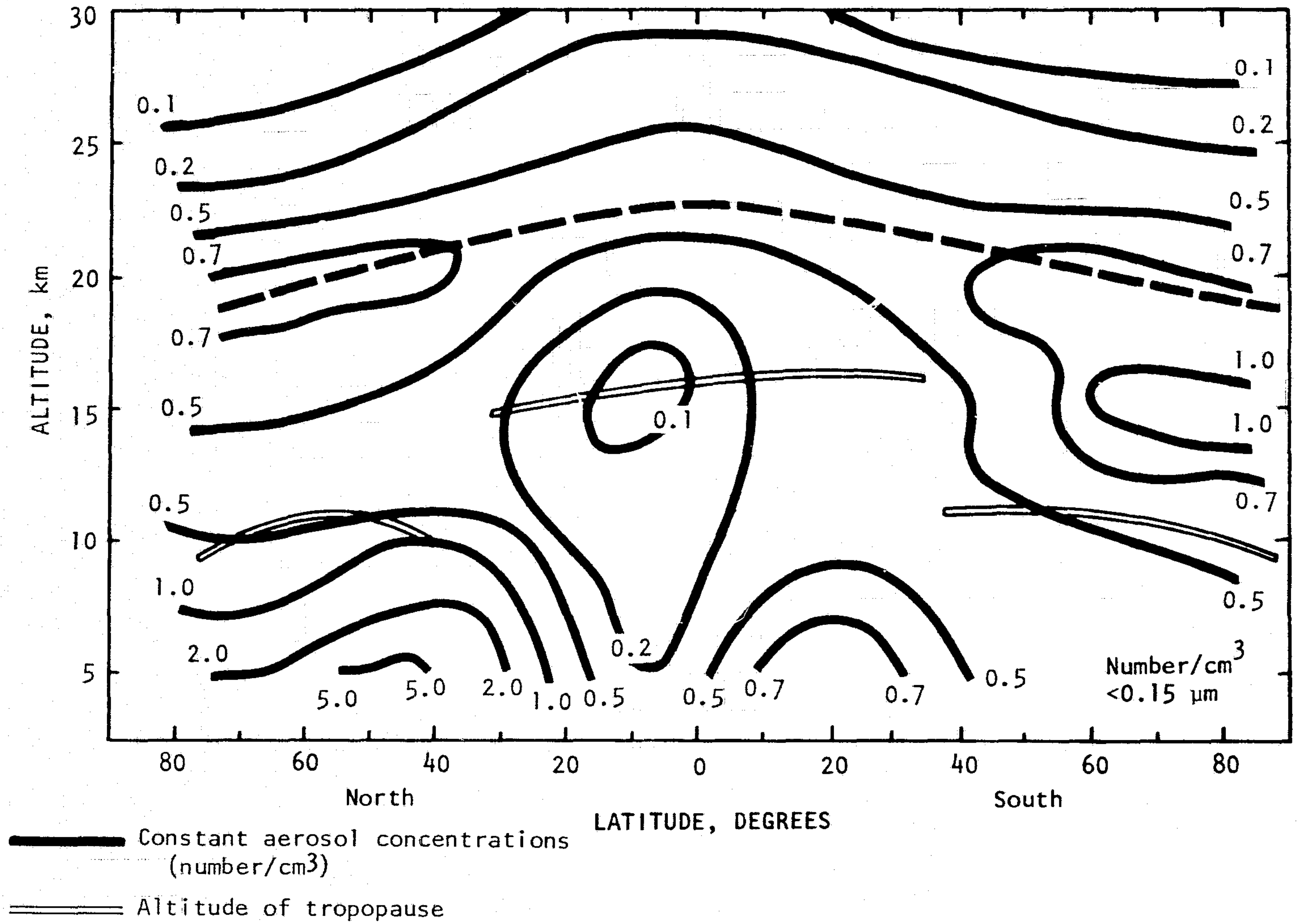

FIGURE B-2
LATITUDINAL DISTRIBUTION OF AEROSOLS [69]

B-3.0 AEROSOL-SIZE DISTRIBUTIONS

The best and most useful technical representation of aerosol size distribution characteristics was first formulated by Junge [72]. Following his nomenclature, an aerosol size distribution may be represented as:

$$\frac{dN}{d(\log r)} = Cr^{-\alpha}, \qquad (1)$$

where dN is the fraction of aerosols in the size range dr. The constant C is related to the concentration and α, which generally varies between 2 and 4, is a characteristic of the aerosol distribution.

Junge et al. [73] extended their aerosol studies to the stratosphere and summarized their results as model distributions indicating possible sources. This model is shown in Figure B-3. Particles smaller than 0.01 μm radius have a very short lifetime because they readily combine by coagulation to form larger particles. Aerosols smaller than 0.1 μm radius, called Aitken nuclei, originate in the troposphere. The concentration of these particles decreases rapidly with height.

Aerosols in the size range from 0.1 to 1.0 μm radius have a maximum concentration in the lower stratosphere; that is, between 6 and 10 kilometers above the tropopause. These hydroscopic submicrometer-size particles are mainly composed of sulfates. Junge et al. [73] hypothesized that these aerosols are formed by the oxidation of H_2S and SO_2 introduced into the stratosphere from terrestrial sources.

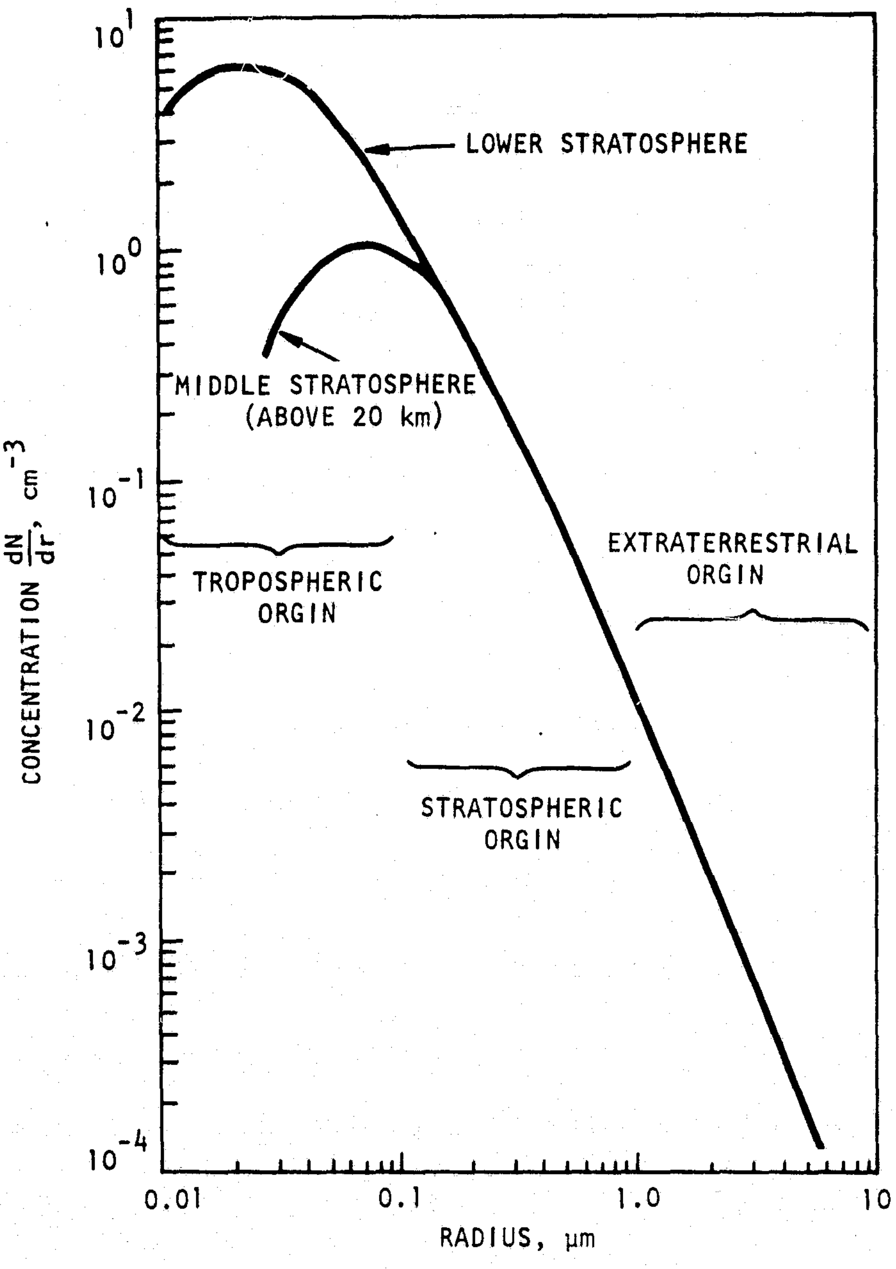

FIGURE B-3
JUNGE AEROSOL MODEL[73]

After growth by condensation ceases, the aerosols continue to grow by coagulation until they ultimately reach sizes that are removed from the stratosphere by sedimentation.

Particles larger than 1.0 μm are few because they readily settle out through the tropopause. According to Cadle [66], these particles are of an extraterrestrial origin, are mainly composed of Fe and Ni, and are probably the residue of zodiacal dust after interaction with the earth's atmosphere. The size of zodiacal dust particles in space ranges from a few tenths to several hundred μm radius. However, when the larger particles, with a small area to mass ratio, enter the stratosphere at high velocities they melt because their mass tends to maintain high velocity. Because particles smaller than approximately 5 μm radius have a large area to mass ratio they enter the stratosphere at lower velocities and tend to maintain their identity slowly settling into the troposphere. The population of extraterrestrial particles is difficult to measure because it is about three orders of magnitude less than that of aerosols originating in the stratosphere. Conversely, tropospheric particles larger than 1 μm radius cannot penetrate the tropopause by normal circulation process. The exception, of course, is the penetration of volcanic particles or those entrained by nuclear detonations.

The aerosol distributions depicted in Figure B-3 illustrate many of the physical characteristics of the stratospheric aerosols. The size-distribution model for the lower stratospheric particles includes

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aerosols originating in the troposphere, i.e., Aitken nuclei, plus aerosols generated in the stratosphere and the remnants of a few particles from space. When measured size distributions are plotted with this curve the data form families of curves, less regular in shape than the model and varying in concentration by a factor of about ±5.

The slope, α, in Equation 1, is approximately 2 for sizes between 0.1 and 1.0 μm. For aerosols larger than 1.0 μm radius, values of α approaching 3 are more appropriate. These slopes are derived from measured aerosol-size distributions presented by Junge et al. [73].

The model size distribution labeled "middle stratosphere" (Figure B-3) includes the sulfate layer, which is a perturbation on the regular decrease in concentration of aerosols with increased height. However, the increase in concentration is not reflected in Junge's model for the middle stratosphere. When Junge formulated this model he undoubtedly was not fully aware of the significance of the sulfate layer nor of its variability in concentration. Much of the data employed to specify the coordinates of this curve were observed prior to the Agung eruption, which made a major contribution to the sulfate layer aerosols. It has recently been demonstrated that volcanic activity is one of the major contributors to the sulfate layer, thereby resulting in some variability in the magnitude of the "middle stratosphere" model.

Several studies of stratospheric aerosols have been sponsored by the Department of Transportation's Climatic Impact Assessment Program (CIAP). These studies have provided additional vertical concentration profiles of aerosols in the middle stratosphere, as well as information on the variability of concentration as a function of altitude and seasons. In many cases, in situ sampling has also resulted in chemical composition data. However, there is a paucity of aerosol-size-distribution measurements beyond the simple specification of the sulfate layer nor of its variability in concentration. Much of the data employed to specify the coordinates of this curve were observed prior to the Agung eruption, which made a major contribution to the sulfate layer aerosols. It has recently been demonstrated that volcanic activity is one of the major contributors to the sulfate layer, thereby resulting in some variability in the magnitude of the "middle stratosphere" model.

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The distribution presented by Friend [74] with its larger concentration seems anomalous when compared with the measurements of Junge et al. [73] and Kondratyev et al. [75]. However, because the sampling was made just after a volcanic eruption these data may represent an upper boundary concentration, in which case the distribution becomes very important. (This is the proper subject of future study.)

It appears that, in Junge et al. [73], the normal aerosol composition of the stratosphere is represented. Kondratyev et al. [75] remarked that discrepancies between the microphysical and optical data found in infrared solar measurements could be explained if "giant particles" with radii greater than 1 μm existed in the turbid medium. They summarized their particle size distribution measurements, sampled with polyvinyl chloride filters and impactors from 1966 to 1969, into three altitude layers: 10-17 km, 17-24 km, and 24 km. Their tabulated data are plotted in Figure B-4.

The left curve in Figure B-4 is for the 10-17 km aerosol layer. The experimental data may be represented by the equations:

for $0.2 \leq r \leq 2.0$ μm

$$\frac{dN}{d\,(\log r)} = 0.02\, r^{-2} \qquad (1a)$$

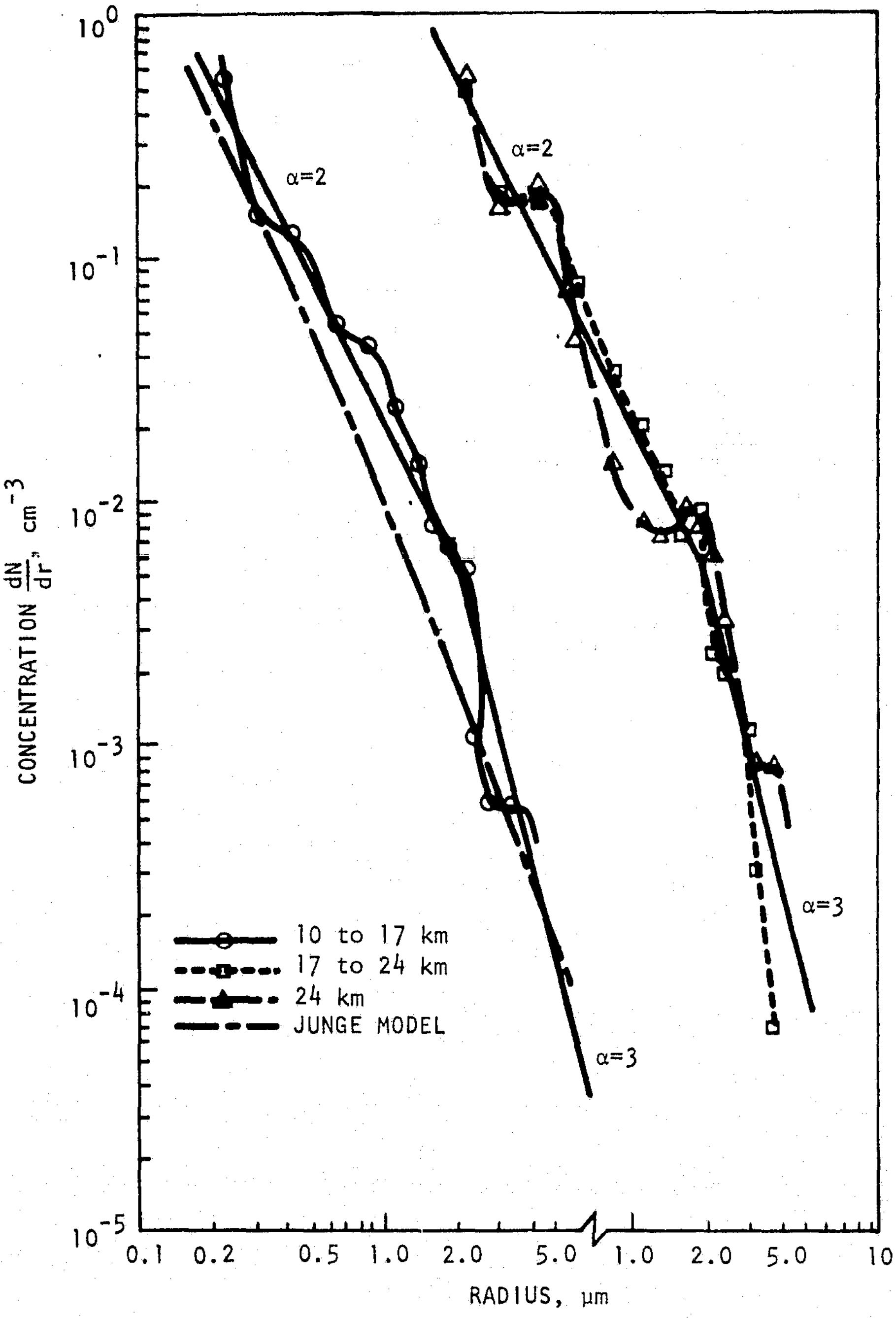

FIGURE B-4
MEASURED AEROSOL SIZE DISTRIBUTIONS[75]

for $2.0 \leq r \leq 5.0$ µm

$$\frac{dN}{d\,(\log r)} = 0.09\ r^{-4} \tag{1b}$$

The dashed curve plotted with these data is the Junge model (shown in Figure B-1), which can be approximated in the size range $0.2 \leq r \leq 5.0$ µm by the equation

$$\frac{dN}{d\,(\log r)} = 0.0096\ r^{-2.5} \tag{1c}$$

The deviations in the data of Kondratyev et al. [75] from the Junge model could imply that some of the data used by Kondratyev et al. in the 10-17 kilometer layer was from the sulfate layer. Following this line of reasoning it may be noted that the maximum peaks of concentration occuring at radii of 0.3 to 0.5 and 1.7 to 2.3 µm provided evidence of droplet growth by condensation [77] and that the deviation of the shape of the size distribution from the Junge model represents the contribution of the sulfate aerosols superimposed on the natural (Aitken nuclei-type) background.

Based on the above discussion it appears reasonable to summarize these speculations by proposing a family of stratospheric aerosol-size distributions. These are illustrated in Figure B-5.

The aerosol distribution model representing the lower stratosphere is that formulate by Junge et al. [73]. It shows the characteristic

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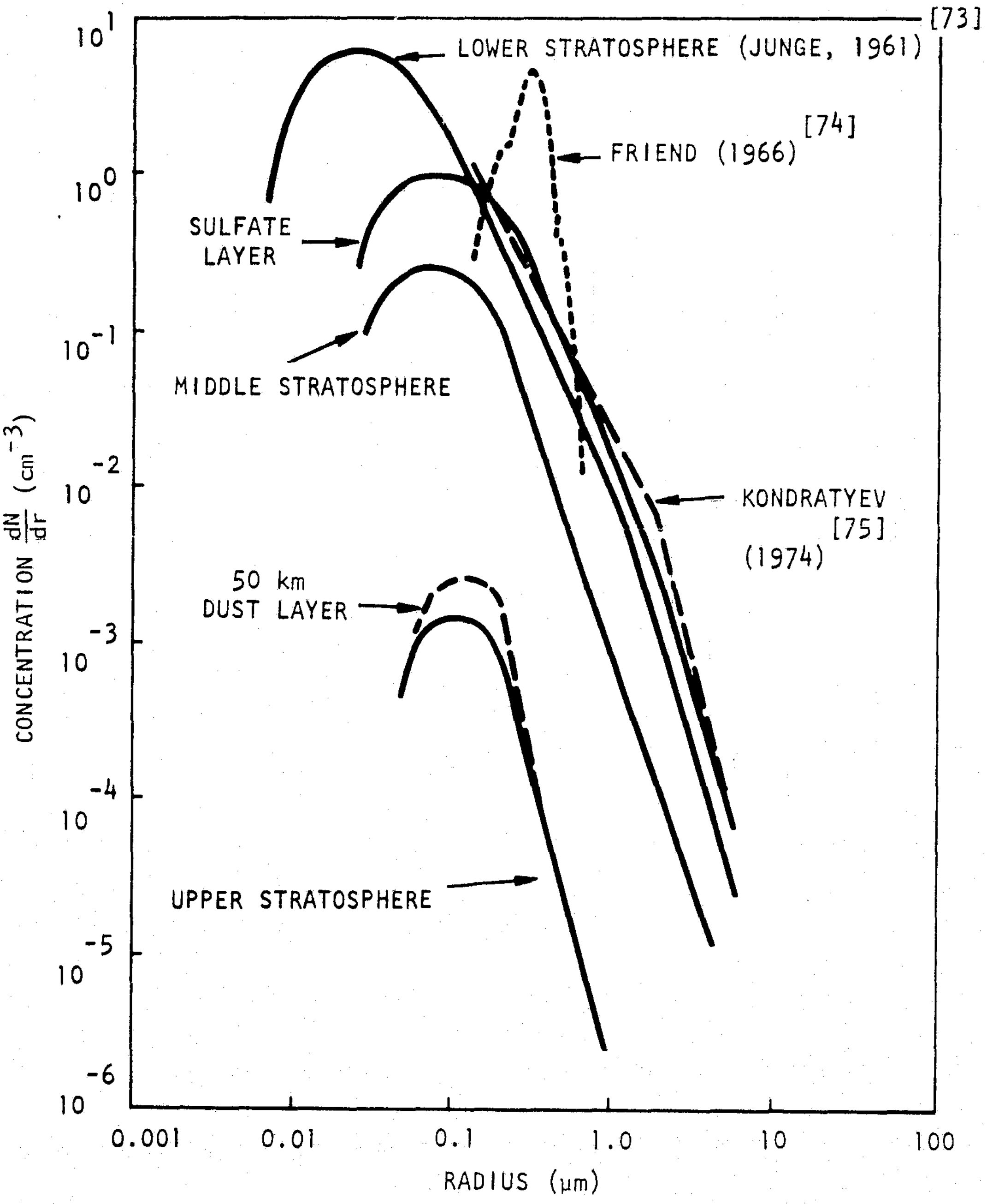

FIGURE B-5
PROPOSED STRATOSPHERIC AEROSOL-SIZE DISTRIBUTION MODEL

Aitken nuclei for sizes less than 0.1 μm radius. The distribution of aerosols with radii between 0.1 and 2.0 μm and with radii larger than 2.0 μm (but generally limited to about 5.0 μm due to lack of measurements) may be represented by:

$$\frac{dN}{d\,(\log r)} = 0.013 \quad r^{-2} \tag{1d}$$

and

$$\frac{dN}{d\,(\log r)} = 0.028 \quad r^{-3} \tag{1e}$$

respectively.

The middle stratospheric aerosol distribution model is fabricated from that presented by Junge et al. [73] but displaced downward to reflect the decrease in concentration with increased altitude. It may be represented by Equation 1 for aerosols with radii larger than 0.2 μm:

$$\frac{dN}{d\,(\log r)} = 8.5 \times 10^{-4} \; r^{-3} \tag{1f}$$

Above the sulfate layer, the concentration of aerosols decreases in a fairly regular manner in accord with the decrease in air density.

The possible existence of a high-altitude scattering layer was first indicated by astronauts who observed a light blue band between two deep bands above the limb of the sunset-darkened earth. Cunnold et al. [78] inferred the existence of a dust layer at 50 kilometers altitude from the data of Volz and Goody [78]. Similarly, zenith skylight from rocket flights indicates the existence of a scattering layer at 52 km [80]. Because the concentration of particles in the upper stratosphere is so small, evidence of the existence of a scattering layer has been sporadic and inconclusive. However, Cunnold et al. [78] estimated from photometric measurements that the extinction function is of the same order of magnitude as that for molecular scatterers at this altitude and that this layer appears to be quite variable in time and space. Cunnold et al. [78] derived their estimates by assuming a value of 1.72 times the molecular scattering extinction at a wavelength of 0.55 μm. When a size distribution parameter of $\alpha = 7$ [81] was used, a very narrow aerosol-size distribution resulted. Based on their analysis of their photometric data, Cunnold et al. [78] postulated the existence of an aerosol layer at 50 kilometers.

Kondratyev et al. [75] refers several times to an aerosol layer at 48 kilometers and speculates that it originated from condensation of volcanic gases and water vapor.

Considering these comments and the estimates of Junge and Manson [82] that zodiacal or cosmic dust concentrations are about three orders of magnitude less than stratospheric aerosols at 20 kilometers, a probable upper stratospheric model can be sketched (Figure B-5). This may be approximated by the equation:

$$\frac{dN}{d\ (\log r)} = 2 \times 10^{-6}\ r^{-4} \qquad (1g)$$

The dashed curve labeled "50 kilometer dust layer" is a factor of almost two more in concentration but has a slope (α) of approximately 5--a compromise between Elliott's [81] and Junge and Manson's [82] value.

B-4.0 AEROSOL SAMPLING BY COLLECTION

The Junge aerosol model(s) evolved from many in situ measurements made with impactors over a period of years prior to 1963. Junge et al. [74] calculated that their impactors had a 100 percent collection efficiency over the size range of 0.1 to 1 μm radius. They also performed chemical/spectrographic analyses of the impacted aerosols and reported them to be composed predominately of sulfuric acid droplets with small amounts of ammonia sulfate, silicates, and numerous other trace elements.

Soon after the violent volcanic eruption of Gunung Agung in Bali in 1963, measured concentrations of stratospheric particles increased by 10 to 50 times those reported by Junge et al. [74]. Large amounts of particulate material and sulfur dioxide were injected into the stratosphere where, by oxidation and hydration, they form dilute sulfuric acid droplets. There is some uncertainty about the actual increase in the concentration after 1963 because the more recent particle collections were made with fiber filters that indicated considerably higher sulfate concentrations. The difference in observed concentrations may be partly the result of differences in collection efficiencies.

Cadle et al. [83] collected stratospheric aerosols with IPC filters. These filters, initially fabricated by the Institute of Paper Chemistry, are composed of cellulose fibers impregnated with dibutoxyethylpthalate. In an effort to resolve the uncertainty between the two collecting techniques they simultaneously exposed an impactor (essentially the same as Junge's) with their filters during a five-hour flight. The conclusion reached was that either both impactors have a much lower collecting efficiency for stratospheric aerosols in the 0.1 to 1 μm radius size range than assumed by Junge et al. [73] or the size distribution of particles has greatly changed; that is, a larger percentage of mass is now being associated with particles less than 0.1 μm radius, (Aitken particles). (The filters appear to be more efficient collectors of Aitken particles than are impactors.) If the impactors' collection efficiencies are greatly reduced from that assumed, there is still a significant increase in aerosol concentrations since the early 1960s, which seems real and probably has resulted from volcanic activity.

Cadle et al. [83] also commented that they had observed ammonium ions on the filter paper, indicating that some of the stratospheric sulfate could be present as ammonium salts. The amount collected between 18 and 19 kilometers was chemically equivalent to less than six percent of the stratospheric sulfate concentration. This leads to the question of the chemical composition of stratospheric aerosols.

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B-5.0 AEROSOL CHEMICAL COMPOSITION

The chemical composition of stratospheric aerosols has been the subject of considerable theoretical and experimental investigation during the last few years. Although it is generally agreed that Aitken nuclei, aerosols less than 0.1 μm radius, are of terrestrial origin, their composition, quoting Junge, is "essentially unknown" [84]. Friend [85] speculated that the Aitken nuclei can be accounted for by the following process: SO_2 is oxidized by O-atoms in a three-body reaction with H_2O to give SO_3. This in turn forms H_2SO_4, which can rapidly collect water molecules to form a hydrated embryonic nucleus of sulfuric acid.

Stratospheric aerosols larger than 0.1 μm are generally accepted to be of stratospheric origin. Junge et al. [73] found high quantities of sulfur, most likely a sulfate, in the aerosols collected at the 18 to 20 kilometer level, which has become known as the Junge, or sulfate layer. Junge postulated that these sulfate aerosols are probably formed by oxidation of H_2S and/or perhaps some SO_2, both of which are present in the troposphere. The sulfates enter the stratosphere at the equator, where the H_2S and SO_2 are oxidized by ozone or intense ultraviolet radiation.

Cadle and Powers [86] suggested a three-body reaction of SO_2 with atomic oxygen:

$$SO_2 + O + M \longrightarrow SO_3 + M \qquad (2)$$

where M is the third body in the atmosphere that serves to carry off excess heat. Two other possible chemical systems of interest are:

$$SO_2 \quad + \quad h\nu \quad (2400\text{-}3400\ \mathring{A}) \longrightarrow SO_2^* \qquad (3)$$

where the asterisk denotes an excited electronic state for the sulfur dioxide; and

$$SO_2^* \quad + \quad HO_2 \longrightarrow SO_3 \quad + \quad OH \qquad (4)$$

The speculations and observations of many investigators of stratospheric aerosols guided the laboratory study of Friend et al. [87]. They performed a series of experiments to determine the most propitious combination of atmospheric trace gases for the formation and growth of stratospheric aerosols. Their work may be summarized as follows:

Experiments were carried out in a reaction vessel to which was attached both in condensation nuclei counter and a "dust" counter. Provision was made for irradiating gases with ultraviolet light in the reaction chamber. The gases used were air, nitrogen, water vapor, sulfur dioxide, ammonia, and ozone. Each experiment was run for a maximum of five hours unless the desired reaction--the production of condensation nuclei and/or larger aerosols--occurred earlier.

As a result of Friend et al. [87], the laboratory experiments of the following chemical mechanism was proposed for the formation of stratospheric aerosols. Ozone, which is plentiful above the tropopause, is disassociated by ultraviolet radiation:

$$O_3 + h\nu\ (\lambda\, 2000\text{-}3000,\ 4500\text{-}6500\ \mathring{A}) \longrightarrow O_2 + O \qquad (5)$$

Then $$SO_2 + O + M \longrightarrow SO_3 + M \qquad (6)$$

$$SO_3 + H_2O \longrightarrow H_2SO_4 \qquad (7)$$

$$H_2SO_4 + nH_2O \longrightarrow H_2SO_4 \cdot nH_2O. \qquad (8)$$

The entity $H_2SO_4 \cdot nH_2O$ is thought of as embryonic nuclei (acid embryo), which probably are not cloud condensation nuclei because they may not be capable of growth with the simple addition of water molecules.

It was suggested that these nuclei consist of hydrated sulfuric acid and that photo-oxidation of SO_2 in the lower stratosphere leads to the same type of nuclei found in the natural population of condensation nuclei with $r < 0.1\ \mu m$. Initially, the embryo would be formed quite rapidly following the creation of SO_3.

The number of water molecules n associated with each sulfuric acid molecule is not known but is considered to be greater than ten, i.e., $n > 10$. Coagulation of the acid embryos will produce a size frequency distribution decreasing with radius and extending to large particles ($r > 0.1\ \mu m$). It should also be noted that the coagulation

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of the acid embryos, soil minerals, and organic particles may alter their properties and make the embryos effective condensation nuclei. The interaction of the sulfuric acid with these particles may make them more wettable and capable of growth to cloud aerosol sizes.

The introduction of ammonia into an atmosphere of SO_2, H_2O, and air in the reaction vessel with unfiltered light or ultraviolet light of wavelengths from 2500 to 3200 Å results in the production of a

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The interaction of the sulfuric acid with these particles may make them more wettable and capable of growth to cloud aerosol sizes.

The introduction of ammonia into an atmosphere of SO_2, H_2O, and air in the reaction vessel with unfiltered light or ultraviolet light of wavelengths from 2500 to 3200 Å results in the production of a large number of condensation nuclei and larger particles. These particles appear as colorless, hydroscopic crystals thought to be composed of ammonium sulfate and/or ammonium bisulfate or possibly ammonium persulfate. This reaction occurs at stratospheric temperatures as well as at room temperatures.

The same reaction does not occur in the dark nor with radiation in the 2500 to 4000 Å wavelength band. This observation is interpreted to mean that if the additional compounds of NH_3 and SO_2 [$NH_3 \cdot SO_2$ and $(NH_3)_2 \cdot SO_2$] were formed they did not lead to ammonium sulfate, and that the addition of NH_3 and SO_2 are not precursors to the formation of ammonium sulfate in the stratosphere.

Therefore, the following chemical reactions were proposed by Friend et al. (1973) [87]. After the formation of the acid embryos, $H_2SO_4 \cdot n\ H_2O$, then

$$NH_3 + H_2SO_4 \cdot n\ H_2O \rightarrow NH_4^+\ HSO_4^- \cdot n\ H_2O \qquad (9)$$

$$NH_3 + NH_4^+\ HSO_4^- \cdot n\ H_2O \rightarrow 2NH_4^+\ SO_4^= \cdot n\ H_2O \qquad (10)$$

which are embryos of salt solution or salt embryos. They provide the medium in which rapid catalytic oxidation of SO_2 occurs, thereby resulting in:

$$2SO_2 + 2H_2O + O_2 \xrightarrow[NH_4^+]{\text{salt embryo}} 2H_2SO_4 \qquad \text{(solution)} \qquad (11)$$

The rate-determining step is the oxidation of bisulfite, HSO_3^- to $SO_4^=$, in solution. Ammonium ions "catalyze" the reaction by keeping the pH high so the SO_2 may enter the solution to form HSO_3^-. NH_3 gas is needed to neutralize the acid formed with the salt embryos. This produces NH_4^+, which buffers the solution. The reaction will continue until either NH_3 or SO_2 is depleted. After the NH_3 becomes depleted, continued oxidation overcomes the buffering by NH_4^+, and eventually the low pH prevents further absorption of SO_2 by the particles.

Based on the above rationale, the following model for the formation of stratospheric aerosols was proposed by Friend et al. [87]. The three main processes are:

(1) Photolysis of O_3 produces O atoms which oxidize SO_2 to form acid embryos consisting of sulfuric acid and water;

(2) The acid embryos are neutralized by NH_3 to form salt embryos; and

(3) SO_2 forms $SO_4^=$ by rapid catalytic oxidation in the embryonic solution in which NH_4^+ acts as the catalyst.

Growth of the embryos to larger particles continues as long as NH_3 is available to neutralize the acid or as long as SO_2 can be supplied to the particles.

Chemical reactions represented by Equations 5 through 8 produce acid embryos, which through coagulation form a smooth size distribution of sulfuric acid-water aerosols ranging from embryo sizes to

Chemical reactions represented by Equations 5 through 8 produce acid embryos, which through coagulation form a smooth size distribution of sulfuric acid-water aerosols ranging from embryo sizes to

aerosols with radii greater than 0.1 μm. This may well be the Aitken or condensation nuclei measured by Junge et al. [73] and Junge and Manson [82].

The chemical reactions represented by Equations 9 through 11 involving the catalytic oxidation of SO_2 in the presence of NH_3 produce larger particles (i.e., $r > 0.1$ μm), the size and composition of which are determined by the availability of SO_2, NH_3, and H_2O. However, H_2O is not considered a limiting constituent because it exists in concentrations several orders of magnitude greater than might be expected for NH_3 or SO_2.

Specific results of this study may be summarized as follows:

(1) The quantum yield for homogeneous oxidation of SO_4 with irradiation in the first excited band is less than 1.0×10^{-9}.

(2) The addition of NH_3 and SO_2, if present, are not precursors to the formation of ammonium sulfate in the atmosphere.

(3) Aitken nuclei are formed by oxidation of SO_2 by O atoms with traces of water vapor.

(4) The addition of NH_3 to SO_2 and O atoms results in rapid production of Aitken nuclei and larger particles, probably ammonium sulfate.

(5) Irradiation of air with water vapor and trace organic gases at wavelengths < 2500 Å produces Aitken nuclei.

The above formulation of Friend et al. [87] explains many of the observed optical phenomena and experimental results of aerosol sampling, with the possible exception of the existence of ammonium persulfate particles reported by Friend [85]. More complicated chemistry, involving such radicals as OH and HO_2, may be required. Recently, Harrison and Larson [88] have proposed another scheme involving the homogeneous oxidation by OH, or possibly the heterogeneous oxidation by O_3 to form the sulfate aerosols resulting in the Junge layer. Oxidation of SO_2 by O atoms, NO_3, or HO_2 is considered to be too slow.

The Harrison and Larson [88] reaction is a termolecular recombination by the hydroxyl radicals.

$$HO + SO_2 + M \longrightarrow HSO_3 + M \qquad (12)$$

which assumes that an unspecified faster process abstracts the hydrogen, either before or during hydration. Based on transport, diffusion, and process rates, the chemical reaction of Equation 12 predicts a sulfate profile as a function of height above the tropopause such that the peak concentration is approximately equal to that measured and within one kilometer of the measured peak altitude.

B-6.0 SUMMARY

The state of our knowledge may be summarized as the ability to characterize the stratospheric aerosol-size distribution in only a very general manner (see Figure B-5). The size distribution is based on a few in situ measurements and theoretical growth concepts. The composition of the aerosols is also known only in a general manner, again based on a few in situ samples. Cadle [88] has summarized the chemical composition in terms of a model for aerosols at 20 kilometers altitude. This is given in Table B-I.

The gaseous constituents that participate in aerosol formation are listed in Table B-II. The manner in which they participate, based on the laboratory experiments of Friend et al. [87], is shown diagramatically in Figure B-6.

Assuming that it is important to monitor/predict the concentration of stratospheric aerosols, it should be sufficient to be primarily concerned with the sulfate layer because it represents the major mass of stratospheric aerosols. It is not sufficient to monitor the sulfate layer from the ground (although lidar provides useful, limited, relative data regarding the concentration of aerosols), and in situ sampling, whether by balloon or aircraft-borne instruments, is limited to periodic observations. Photometric instrumentation of the type described by Cunnold et al. [78] and/or the family of radiometers proposed by SAGE II and NIMBUS G can observe the sulfate layer from above. It is sufficient to observe five or six narrow

TABLE B-I
MODEL CHEMICAL COMPOSITION OF STRATOSPHERIC AEROSOLS AT 20 KM [89]

Substance	Concentration in Air $\mu g/m^3$ (ambient)	Observed Concentration Range $\mu g/m^3$ (ambient)
Sulfate	0.6	0.01 - 4*
Basalt**	0.05	0 - 0.7
NH_4^+	0.005	0 - 0.01
NO_3^-***	0	0
NO_2^-	0	0
Na	0.01	0.001 - 0.05
Cl	0.04	0.002 - 0.09
Br	0.002	0 - 0.003
Total	0.71	0.1 - 1

*Agung maximum concentration

**All components of Basalt, e.g., Al, Ca, Mg.

***Particulate NO_3^- as contrasted with HNO_3 vapor

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TABLE B-II
GASEOUS CONSTITUENTS PARTICIPATING IN AEROSOL FORMATION AT 20 KM

Species	Concentration
SO_2	10^{-6} μg/m^3
H_2S	10^{-7} μg/m^3
O	4 x 10^1 μg/m^3
H_2O	1 mg/m^3 (Extremely Variable)
NH_3	10^{-6} μg/m^3

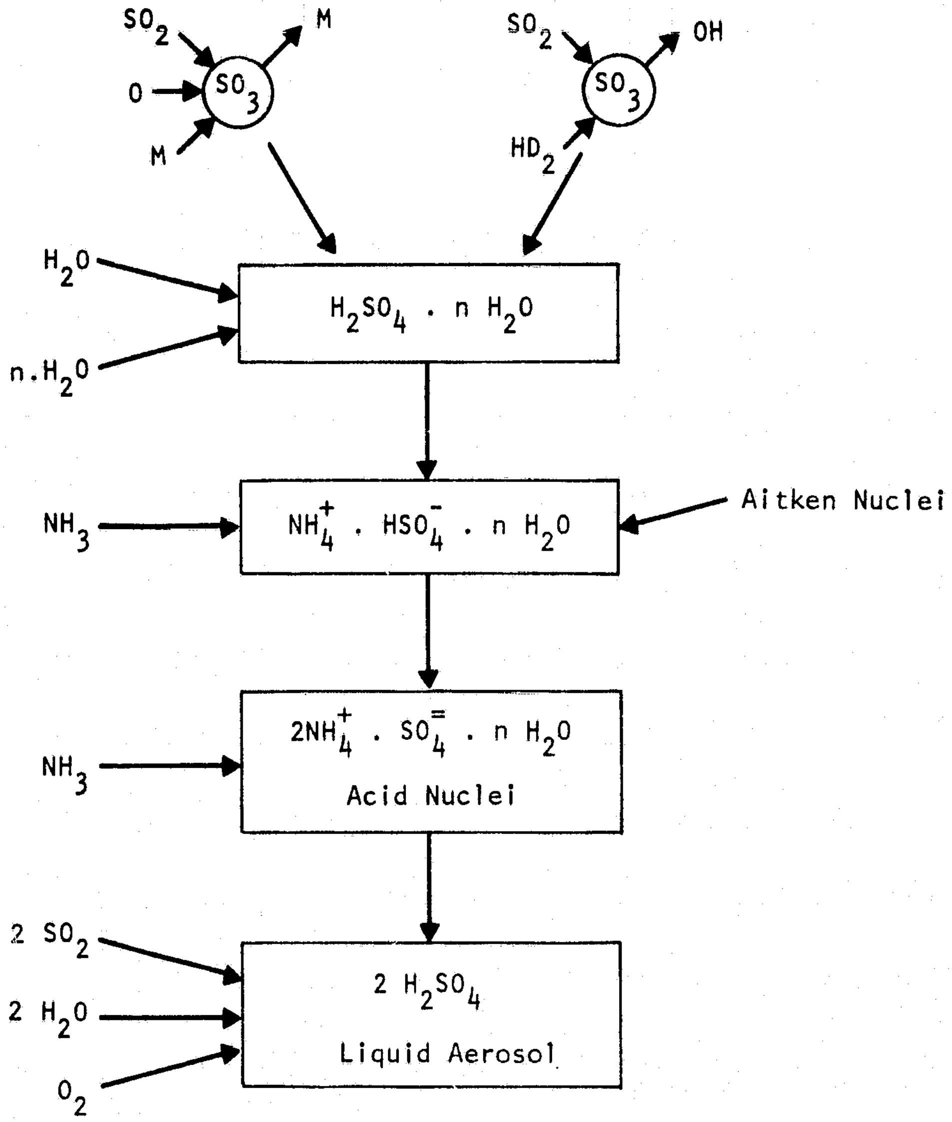

FIGURE B-6
SUMMARY OF JUNGE LAYER AEROSOL FORMATION

wavelength bands, preferably in the visible and near infrared, to snythesize an aerosol size distribution.

Based on the chemical process presumed to produce and stimulate growth of stratospheric aerosols, a satellite-borne infrared radiometer can observe the concentration of appropriate gases. Again, a satellite platform is appropriate because continuous monitoring of stratospheric gases from ground level is inhibited by the intervening higher concentration of tropospheric gases and aerosols.

Besides a general lack of knowledge regarding the concentration of stratospheric SO_2 and NH_3, there are uncertainties in the estimates of atomic oxygen and OH. Further study is required to determine the number of water molecules associated with Equations 9 and 10, i.e., $H_2SO_4 \cdot n\ H_2O$. Therefore, the following constituents should be monitored for stratospheric aerosol formation in the sulfate layer: O, O_2, O_3, OH, SO_2, H_2O, NH_3, and/or their species.

The concentration and diurnal and vertical variations of ozone are fairly well known. Water vapor appears to be plentiful, on the order of 1 to 4 mg/m^3, and therefore is not considered a limiting factor to aerosol formation and growth. But SO_2 and NH_4^+ are not known to within an order of magnitude. These two constituents are thought to occur in quantities of 3×10^{-7} $\mu g/m^3$ and 1×10^{-6} $\mu g/m^3$, respectively. These gases are presumed to be important because, according to the model of Friend et al. [87], the depletion of either one will halt the production of sulfate aerosols. Conversely, an excess of both could lead to an increase in the population of aerosols in the sulfate layer with the subsequent effect on the earth's heat budget.

APPENDIX C

INFORMATION SETS USED IN THE EVALUATION

This appendix presents the two basic information sets used in the evaluation of the individual stratosphere pollutants. The first set consists of the value matrices for all species contained in groups 1 and 2 of the prioritized list of pollutants plus the matrices for all those group 3 and 4 pollutants for which satellite-borne remote-sensing instruments either exist or are under development.

The second information set gives the evaluations of the various species for present knowledge and required knowledge. Also shown are the weighting functions for the various performance parameters along with the rationale for selecting these weightings.

Water Vapor, H_2O

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		6	8	10
Med		5	7	R 9
Sparse		2	P 6	7
None	0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		3	9	10
Med		2	7	R 9
Sparse		1	P 5	7
None	0			

DURATION

REPRODUCIBILITY OF THE
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Water Vapor, H_2O

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		3	5	7	9	10
Med		2	4	6	8	9
Sparse		1	2	3	P 7	R 8
None	0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Water Vapor, H_2O

Time of Launch or Beginning of Experiment

DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				
		270°	180°	90°	None or DNA

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.

180° - Launch is two seasons prior to desired season.

270° - Launch is three seasons prior to desired season.

DNA - Launch time is not important

Water Vapor, H_2O

Vertical Profile: Coverage

DATA STATUS		None	<10%	50%	100%
DATA	Good		3	7	R 10
STATUS	Med		2	6	9
	Sparse		1	P 5	7
	None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS		None	<1	1	10	>40
DATA	Good		0	3	5	R 10
STATUS	Med		0	2	4	9
	Sparse		0	1	3	P 7
	None	0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Ozone, O_3

Latitude Coverage

		None	60°	120°	180°
DATA	Good		4	6	P R 10
STATUS	Med		3	5	9
	Sparse		2	4	8
	None	0			

LATITUDE BAND COVERED

Duration of Measurement Program

		None	Short Survey	One Year Plus	Decades
DATA	Good		2	6	R 10
STATUS	Med		2	5	P 7
	Sparse		1	4	6
	None	0			

DURATION

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Ozone, O_3

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good			5	6	9	10
Med			4	5	R 8	9
Sparse			P 2	3	6	7
None	0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		3	5	P R 10
Med		2	4	9
Sparse		1	3	6
None				

LONGITUDE BAND COVERED

Ozone, O_3

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.

DNA - Launch time is not important

Ozone, O_3

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		2	7	R 10
Med		1	6	8
Sparse		0	5	P 7
None				

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		0	3	7	R 10
Med		0	2	5	7
Sparse		0	1	3	P 5
None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Aerosols

Latitude Coverage

		None	60°	120°	180°
DATA	Good		4	6	R 10
STATUS	Med		3	5	P 9
	Sparse		2	4	5
	None				

LATITUDE BAND COVERED

Duration of Measurement Program

		None	Short Survey	One Year Plus	Decades
DATA	Good		5	R 9	10
STATUS	Med		3	P 8	9
	Sparse		1	5	7
	None				

DURATION

Aerosols

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		8	8	8	9	10
Med		7	7	7	P R 9	9
Sparse		6	6	6	8	8
None						

TEMPEAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	R 10
Med		7	8	9
Sparse		P 6	7	8
None				

LONGITUDE BAND COVERED

Aerosols

Time of Launch or Beginning of Experiment

DATA STATUS		270°	180°	90°	None or DNA
	Good				DNA 10
	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

possible launch after volcanic activity; however, first launch has no requirement for this

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.

DNA - Launch time is not important

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Aerosols

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		2	7	R 10
Med		1	6	P 8
Sparse		0	5	7
None				

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		0	2	7	R 10
Med		0	1	5	P 7
Sparse		0	0	2	4
None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Carbon Dioxide, CO_2

Latitude Coverage

DATA STATUS		None	60°	120°	180°
	Good		3	7	10
	Med		2	5	9
	Sparse		1	2	P R 8
	None	0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS		None	Short Survey	One Year Plus	Decades
	Good		3	7	10
	Med		2	5	9
	Sparse		1	3	P R 8
	None	0			

DURATION

Carbon Dioxide, CO_2

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		2	3	4	9	10
Med		1	2	3	8	9
Sparse		0	1	2	P R 8	8
None	0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		3	7	10
Med		2	5	9
Sparse		1	2	P R 8
None	0			

LONGITUDE BAND COVERED

Carbon Dioxide, CO_2

Time of Launch or Beginning of Experiment

		270°	180°	90°	None or DNA
DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Carbon Dioxide, CO_2

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		2	5	P R 10
Med		1	3	9
Sparse		0	1	8
None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		0	6	R 9	10
Med		0	4	8	9
Sparse		0	2	7	P 8
None	0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Hydroxyl, OH

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		8	9	10
Med		7	R 8	9
Sparse		6	7	8
None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		8	9	10
Med		R 7	8	9
Sparse		5	7	8
None	P 0			

DURATION

Hydroxyl, OH

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		1	4	5	9	10
Med		1	4	5	R 8	9
Sparse		1	3	4	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

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180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Hydroxyl, OH

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		4	8	10
Med		3	R 7	9
Sparse		2	6	7
None	P 0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		2	3	8	10
Med		1	2	R 7	9
Sparse		1	2	5	7
None	P 0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Latitude Coverage

DATA STATUS		None	60°	120°	180°
DATA	Good		8	9	10
STATUS	Med		7	8	R 9
	Sparse		6	7	8
	None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS		None	Short Survey	One Year Plus	Decades
DATA	Good		8	9	10
STATUS	Med		R 7	8	9
	Sparse		5	7	8
	None	P 0			

DURATION

Atomic Oxygen, O(^{3}P)

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		1	4	5	9	10
Med		1	4	5	8	R 9
Sparse		1	3	4	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Atomic Oxygen, O(^{3}P)

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

REPRODUCIBILITY OF THE
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Atomic Oxygen, O(^{3}P)

Vertical Profile: Coverage

DATA STATUS		None	<10%	50%	100%
DATA	Good		4	5	10
STATUS	Med		3	4	R 9
	Sparse		2	3	7
	None	P 0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS		None	<1	1	10	>40
DATA	Good		2	3	6	10
STATUS	Med		1	2	5	R 9
	Sparse		1	2	4	6
	None	P 0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Atomic Oxygen, $O(^1D)$

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		8	9	10
Med		7	8	R 9
Sparse		6	7	8
None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		8	9	10
Med		R 7	8	9
Sparse		5	7	8
None	P 0			

DURATION

Atomic Oxygen, O(^{1}D)

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		1	4	5	9	10
Med		1	4	5	8	R 9
Sparse		1	3	4	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Atomic Oxygen, $O(^1D)$

Time of Launch or Beginning of Experiment

DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				
		270°	180°	90°	None or DNA

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Atomic Oxygen, O(^{1}D)

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		4	5	10
Med		3	4	R 9
Sparse		2	3	7
None	P 0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		2	3	6	10
Med		1	2	5	R 9
Sparse		1	2	4	6
None	P 0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Ammonia, NH_3

Latitude Coverage

DATA	Good		8	9	10
STATUS	Med		7	8	9
	Sparse		6	R 7	8
	None	P 0			
		None	60°	120°	180°

LATITUDE BAND COVERED

Duration of Measurement Program

DATA	Good		8	9	10
STATUS	Med		7	8	9
	Sparse		R 6	7	8
	None	P 0			
		None	Short Survey	One Year Plus	Decades

DURATION

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Ammonia, NH_3

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		3	7	8	9	10
Med		2	R 6	7	8	9
Sparse		1	4	6	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Ammonia, NH_3

Time of Launch or Beginning of Experiment

DATA STATUS		270°	180°	90°	None or DNA
	Good				DNA 10
	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Ammonia, NH_3

Vertical Profile: Coverage

DATA	Good		4	8	10
STATUS	Med		3	R 7	9
	Sparse		2	6	7
	None	P 0			
		None	<10%	50%	100%

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA	Good		2	3	8	10
STATUS	Med		1	2	R 7	9
	Sparse		1	2	5	7
	None	P 0				
		None	<1	1	10	>40

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Nitric Oxide, NO

Latitude Coverage

		None	60°	120°	180°
DATA	Good		6	9	R 10
STATUS	Med		5	8	9
	Sparse		P 4	6	8
	None	0			

LATITUDE BAND COVERED

Duration of Measurement Program

		None	Short Survey	One Year Plus	Decades
DATA	Good		5	R 9	10
STATUS	Med		2	P 8	9
	Sparse		0	2	8
	None				

DURATION

Nitric Oxide, NO

Orbit Diurnal Coverage

DATA STATUS		None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
	Good		2	3	6	9	10
	Med		1	2	5	8	R 9
	Sparse		0	1	4	P 5	8
	None						

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS		None	0-90°	90°-180°	180°-360°
	Good		8	9	10
	Med		7	8	9
	Sparse		6	7	R 8
	None	P 0			

LONGITUDE BAND COVERED

Nitric Oxide, NO

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

REPRODUCIBILITY OF TH
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Nitric Oxide, NO

Vertical Profile: Coverage

DATA	Good		2	8	R 10
STATUS	Med		1	P 7	9
	Sparse		0	3	8
	None				
		None	<10%	50%	100%

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA	Good		0	2	8	R 10
STATUS	Med		0	1	P 7	9
	Sparse		0	0	0	6
	None					
		None	<1	1	10	>40

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Nitrogen Dioxide, NO_2

Latitude Coverage

DATA STATUS					
	Good		6	9	R 10
	Med		5	8	9
	Sparse		P 4	6	8
	None				
		None	60°	120°	180°

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS					
	Good		6	R 9	10
	Med		6	8	9
	Sparse		P 5	7	8
	None				
		None	Short Survey	One Year Plus	Decades

DURATION

Nitrogen Dioxide, NO_2

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		2	3	6	9	10
Med		1	2	5	8	R 9
Sparse		0	1	4	P 5	8
None						

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	F 0			

LONGITUDE BAND COVERED

Nitrogen Dioxide, NO_2

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

REPRODUCIBILITY OF THE
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Nitrogen Dioxide, NO_2

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		2	8	R 10
Med		1	7	9
Sparse		0	P 6	8
None				

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		0	2	8	R 10
Med		0	1	7	9
Sparse		0	0	P 4	6
None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		6	8	10
Med		5	7	9
Sparse		4	6	R 8
None		P 0		

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		7	9	10
Med		6	R 8	10
Sparse		5	7	9
None	P			

DURATION

Atomic Chlorine, Cl

Orbit Diurnal Coverage

		None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
DATA	Good		2	5	7	9	10
STATUS	Med		1	4	6	8	10
	Sparse		0	3	5	R 7	9
	None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

		None	0-90°	90°-180°	180°-360°
DATA	Good		8	9	10
STATUS	Med		7	8	9
	Sparse		6	7	R 8
	None	P 0			

LONGITUDE BAND COVERED

Atomic Chlorine, Cl

Time of Launch or Beginning of Experiment

DATA STATUS		270°	180°	90°	None or DNA
DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

possible launch after volcanic activity; however first launch has no requirement for this

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

REPRODUCIBILITY OF THE
ORIGINAL PAGE IS POOR

Atomic Chlorine, Cl

Vertical Profile: Coverage

		None	<10%	50%	100%
DATA	Good		5	9	10
STATUS	Med		4	R 8	9
	Sparse		3	7	8
	None	P 0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

		None	<1	1	10	>40
DATA	Good		0	3	9	10
STATUS	Med		0	2	R 8	9
	Sparse		0	1	7	8
	None	P 0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Latitude Coverage

DATA STATUS		None	60°	120°	180°
	Good		6	8	10
	Med		5	7	9
	Sparse		4	6	R 8
	None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS		None	Short Survey	One Year Plus	Decades
	Good		7	9	10
	Med		6	R 8	10
	Sparse		5	7	9
	None	P 0			

DURATION

Hypochlorite, ClO

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		2	5	7	9	10
Med		1	4	6	8	10
Sparse		0	3	5	R 7	9
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Hypochlorite, ClO

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

possible launch after volcanic activity; however first launch has no requirement for this

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Hypochlorite, ClO

Vertical Profile: Coverage

DATA STATUS		None	<10%	50%	100%
	Good		5	9	10
	Med		4	R 8	9
	Sparse		3	7	8
	None	P 0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS		None	<1	1	10	>40
	Good		0	3	9	10
	Med		0	2	R 8	9
	Sparse		0	1	7	8
	None	P 0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Nitrous Oxide, N_2O

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		6	9	R 10
Med		5	8	9
Sparse		P 4	6	8
None				

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		6	R 9	10
Med		6	8	9
Sparse		P 5	7	8
None				

DURATION

REPRODUCIBILITY OF THE
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Nitrous Oxide, N_2O

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		2	3	6	9	10
Med		1	2	4	9	10
Sparse		0	1	4	P R 8	9
None						

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Nitrous Oxide, N_2O

Time of Launch or Beginning of Experiment

		270°	180°	90°	None or DNA
DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Nitrous Oxide, N_2O

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		2	8	R 10
Med		1	7	9
Sparse		0	P 6	8
None				

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		0	2	8	R 10
Med		0	1	7	9
Sparse		0	0	P 4	6
None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Nitric Acid Vapor, HNO_3

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		6	9	R 10
Med		4	8	9
Sparse		2	P 5	7
None				

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		5	R 9	10
Med		4	7	9
Sparse		3	P 3	7
None	0			

DURATION

Nitric Acid Vapor, HNO_3

Orbit Diurnal Coverage

		None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
DATA	Good				7	9	10
STATUS	Med				7	R 8	9
	Sparse					P 7	8
	None						

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

		None	0-90°	90°-180°	180°-360°
DATA	Good		6	8	10
STATUS	Med		5	7	9
	Sparse		4	6	R 8
	None	P 0			

LONGITUDE BAND COVERED

Nitric Acid Vapor, HNO_3

Time of Launch or Beginning of Experiment

DATA STATUS	270°	180°	90°	None or DNA
Good				DNA 10
Med				
Sparse				
None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

REPRODUCIBILITY OF THE
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Nitric Acid Vapor, HNO_3

Vertical Profile: Coverage

		None	<10%	50%	100%
DATA	Good			8	R 10
STATUS	Med			P 7	9
	Sparse				
	None				

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

		None	<1	1	10	>40
DATA	Good				9	R 10
STATUS	Med				P 8	9
	Sparse					
	None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Carbon Monoxide, CO

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		8	9	10
Med		7	8	9
Sparse		R 6	7	8
None	P 0			

DURATION

Carbon Monoxide, CO

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		3	7	8	9	10
Med		2	R 6	7	8	9
Sparse		1	4	6	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Carbon Monoxide, CO

Time of Launch or Beginning of Experiment

		270°	180°	90°	None or DNA
DATA	Good				DNA 10
STATUS	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Carbon Monoxide, CO

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		4	8	10
Med		3	7	R 9
Sparse		2	P 5	6
None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		2	3	8	10
Med		1	2	7	R 9
Sparse		0	1	P 3	7
None	0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Methane, CH_4

Latitude Coverage

DATA STATUS	None	60°	120°	180°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LATITUDE BAND COVERED

Duration of Measurement Program

DATA STATUS	None	Short Survey	One Year Plus	Decades
Good		8	9	10
Med		7	8	9
Sparse		R 6	7	8
None	P 0			

DURATION

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Methane, CH_4

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		3	7	8	9	10
Med		2	R 6	7	8	9
Sparse		1	4	6	7	8
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0-90°	90°-180°	180°-360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Methane, CH_4

Time of Launch or Beginning of Experiment

DATA STATUS		270°	180°	90°	None or DNA
	Good				DNA 10
	Med				
	Sparse				
	None				

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Methane, CH_4

Vertical Profile: Coverage

DATA STATUS	None	<10%	50%	100%
Good		4	8	10
Med		3	7	P 8
Sparse		2	5	P 6
None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS	None	<1	1	10	>40
Good		2	3	8	10
Med		1	2	7	R 9
Sparse		0	1	P 3	7
None	0				

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Hydrogen Chloride, HCl

Latitude Coverage

DATA	Good		6	8	10
STATUS	Med		5	7	R 7
	Sparse		P 4	6	8
	None				
		None	60°	120°	180°

LATITUDE BAND COVERED

Duration of Measurement Program

DATA	Good		7	9	10
STATUS	Med		6	R 8	10
	Sparse		P 5	7	9
	None				
		None	Short Survey	One Year Plus	Decades

DURATION

REPRODUCIBILITY OF TH
ORIGINAL PAGE IS POOR

Hydrogen Chloride, HCl

Orbit Diurnal Coverage

DATA STATUS	None	Fixed Time	Partial Day	Full Day	Partial Day and Night	Full Diurnal
Good		2	5	7	9	10
Med		1	4	6	8	10
Sparse		0	3	5	R 7	9
None	P 0					

TEMPORAL COVERAGE

Longitude Coverage - It is assumed that all orbits being considered for stratospheric pollution missions automatically provide good longitudinal coverage. Therefore, mission capability is automatically raised from present coverage to full capability.

DATA STATUS	None	0–90°	90°–180°	180°–360°
Good		8	9	10
Med		7	8	9
Sparse		6	7	R 8
None	P 0			

LONGITUDE BAND COVERED

Hydrogen Chloride, HCl

Time of Launch or Beginning of Experiment

DATA STATUS		270°	180°	90°	None or DNA
	Good				DNA 10
	Med				
	Sparse				
	None				

possible launch after volcanic activity; however, first launch has no requirement for this

SEASONAL PHASE DEVIATION*

* e.g., 90° - Launch is one season prior to desired season.
180° - Launch is two seasons prior to desired season.
270° - Launch is three seasons prior to desired season.
DNA - Launch time is not important

Hydrogen Chloride, HCl

Vertical Profile: Coverage

DATA STATUS		None	<10%	50%	100%
DATA	Good		5	8	10
STATUS	Med		4	7	R 9
	Sparse		3	P 6	8
	None	0			

STRATOSPHERIC VERTICAL COVERAGE

Vertical Profile: Number of Data Points (Resolution)

DATA STATUS		None	<1	1	10	>40
DATA	Good		0	3	9	10
STATUS	Med		0	2	8	R 9
	Sparse		0	1	P 7	8
	None					

NUMBER OF DATA POINTS OBTAINED

Note: <1 data point refers to column density through entire atmosphere which provides only part of a stratospheric data point.

Evaluation of Water Vapor, H_2O

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.3	6	1.8	9	2.7
Duration of Program	.2	5	1.0	9	1.8
Diurnal Coverage	.1	7	0.7	8	0.8
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	5	0.75	10	1.5
Vertical Profile Resolution	.15	7	1.05	10	1.5
Longitude	.1	0	0	8	0.8
	1.0		5.3		9.1
Rounded Off Total		5		9	

Rationale for weighting functions:
All parameters known to some extent. Increased knownedge of Latitudinal and Vertical profiles desirable. Diurnal change considered to be negligible.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Ozone

	WF 0-1	Present Knowledge		Required Knowledge	
Parameter		V	VXWF	V	VXWF
Latitude	.25	10	2.5	10	2.5
Duration of Program	.25	7	1.75	10	2.5
Diurnal Coverage	.15	2	.3	8	1.2
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.1	7	.7	10	1
Vertical Profile Resolution	.15	5	.75	10	1.5
Longitude	.1	10	1	10	1
	1.0		7.0		9.7
Rounded Off Total		7		10	

Rationale for weighting functions:

Latitude coverage very important due to desirability of polar zone measurements.

Total ozone has to be measured for several decades.

Diurnal coverage: Ozone shows little diurnal change extensive measurement not warranted.

Vertical profiles rather well understood some improvement desirable.

Longitudinal distribution of total ozone reasonably well measured.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Aerosols

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.15	9	1.35	10	1.5
Duration of Program	.15	8	1.2	9	1.35
Diurnal Coverage	.05	9	0.45	9	0.45
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.25	8	2.0	10	2.5
Vertical Profile Pesolution	.15	7	1.05	10	1.5
Longitude	.25	6	1.5	10	2.5
	1.0		7.55		9.8
Rounded Off Total		8		10	

Rationale for weighting functions:
Latitude already well covered
Measurements taken over many year period.
Diurnal change small and negligible.
Launch time unimportant except for volcanic activity.
Vertical coverage: More data needed in upper stratosphere current data resolution acceptable.
Longitudinal coverage needs improvement.

Note: SAM II is scheduled for NIMBUS G, 1 Km resolution, polar orbit (aerosols)

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

REPRODUCIBILITY OF THE ORIGINAL PAGE IS POOR

Evaluation of Carbon Dioxide, CO_2

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	0.1	8	0.8	8	0.8
Duration of Program	0.3	8	2.4	8	2.4
Diurnal Coverage	0.1	8	0.8	8	0.8
Launch Time	0	10	0	10	0
Vertical Profile Coverage	0.2	10	2.0	10	2.0
Vertical Profile Resolution	0.2	8	1.6	9	1.8
Longitude	0.1	8	0.8	8	0.8
	1.0		8.4		8.6
Rounded Off Total		8		9	

Rationale for weighting functions:

CO_2 distributions are nearly constant except for long-term buildup. Vertical profile needs some additional verification particularly at higher altitudes.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Hydroxyl, OH

	WF 0-1	Present Knowledge		Required Knowledge	
Parameter		V	VXWF	V	VXWF
Latitude	.15	0	0	8	1.2
Duration of Program	.1	0	0	7	.7
Diurnal Coverage	.3	0	0	8	2.4
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.2	0	0	7	1.4
Vertical Profile Resolution	.2	0	0	7	1.4
Longitude	.05	0	0	8	0.4
	1.0		0		7.5
Rounded Off Total		0		8	

Rationale for weighting functions:

Primary requirements at present are for initial measurements of hydroxyl stressing vertical profile and diurnal change. Theoretical models indicate a strong diurnal change.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Atomic Oxygen, O(^{3}P)

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.15	0	0	9	1.35
Duration of Program	.1	0	0	7	0.7
Diurnal Coverage	.3	0	0	9	2.7
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.2	0	0	9	1.8
Vertical Profile Resolution	.2	0	0	9	1.8
Longitude	.05	0	0	8	0.4
	1.0		0		8.75
Rounded Off Total			0		9

Rationale for weighting functions:
Primary requirements at present are for initial measurements of atomic oxygen stressing vertical profile and diurnal change.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Atomic Oxygen, $O(^1D)$

Parameter	WF 0-1	Present Knowledge V	 VXWF	Required Knowledge V	 VXWF
Latitude	.15	0	0	9	1.35
Duration of Program	.1	0	0	7	0.7
Diurnal Coverage	.3	0	0	9	2.7
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.2	0	0	9	1.8
Vertical Profile Resolution	.2	0	0	9	1.8
Longitude	.05	0	0	8	0.4
	1.0		0		8.75
Rounded Off Total		0		9	

Rationale for weighting functions:

Primary requirements at present are for initial measurements of atomic oxygen stressing vertical profile and diurnal change.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

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Evaluation of Ammonia, NH_3

Parameter	WF 0-1	Present Knowledge		Required Knowledge	
		V	VXWF	V	VXWF
Latitude	.2	0	0	7	1.4
Duration of Program	.1	0	0	6	0.6
Diurnal Coverage	.15	0	0	6	0.9
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.25	0	0	7	1.75
Vertical Profile Resolution	.25	0	0	7	1.75
Longitude	.05	0	0	8	0.4
	1.0		0		6.8
Rounded Off Total		0		7	

Rationale for weighting functions:

Primary requirements at present are for initial measurements of ammonia stressing vertical profile.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Nitric Oxide, NO

	WF	Present Knowledge		Required Knowledge	
Parameter	0-1	V	VXWF	V	VXWF
Latitude	.25	4	1.0	10	2.5
Duration of Program	.2	8	1.6	9	1.8
Diurnal Coverage	.3	5	1.5	9	2.7
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.1	7	0.7	10	1.0
Vertical Profile Resolution	.1	7	0.7	10	1.0
Longitude	.05	0	0	8	0.4
	1.0		5.5		9.4
Rounded Off Total			6		9

Rationale for weighting functions:

Vertical profile has been measured to some extent. Most important need lies in understanding diurnal change. Also important are the latitudinal and seasonal changes. Theoretically diurnal and seasonal changes are large.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Nitrogen Dioxide, NO_2

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.15	4	.6	10	1.5
Duration of Program	.15	5	.75	9	1.35
Diurnal Coverage	.35	5	1.75	9	3.15
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	10	1.5
Vertical Profile Resolution	.15	4	0.6	10	1.5
Longitude	.05	0	0	8	0.4
	1.0		4.6		9.4
Rounded Off Total		5		9	

Rationale for weighting functions:
Critical need lies in diurnal measurements to clarify contradiction between theoretical and measured diurnal changes. Also needed are better vertical profiles, latitudinal and seasonal changes.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Atomic Chlorine, Cl

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.2	0	0	8	1.6
Duration of Program	.1	0	0	8	.8
Diurnal Coverage	.35	0	0	7	2.45
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	0	0	8	1.2
Vertical Profile Resolution	.15	0	0	8	1.2
Longitude	.05	0	0	8	.4
	1.0		0		7.65
Rounded Off Total		0		8	

Rationale for weighting functions:

No measurements of stratospheric atomic Cl exist. Since atomic Cl is formed by various UV reactions and atomic Cl reacts almost immediately with O_3 diurnal variation is very important. Other important initial measurements are vertical profile and latitudinal distribution.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

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Evaluation of Hypochlorite, ClO (Chlorine Monoxide)

	WF	Present Knowledge		Required Knowledge	
Parameter	0-1	V	VXWF	V	VXWF
Latitude	.2	0	0	8	1.6
Duration of Program	.1	0	0	8	0.8
Diurnal Coverage	.35	0	0	7	2.45
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	0	0	8	1.2
Vertical Profile Resolution	.15	0	0	8	1.2
Longitude	.05	0	0	8	0.4
	1.0		4.8		9.35
Rounded Off Total			5		9

Rationale for weighting functions:

No measurements of stratospheric ClO exist. Reactions of ClO are closely linked to atomic Cl reactions. Also ClO photodissociates in presence of UV. Diurnal change important. Therefore, same weighting functions as Atomic Cl are used.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Nitrous Oxide, N_2O

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.25	4	1.0	10	2.5
Duration of Program	.15	5	0.75	9	1.35
Diurnal Coverage	.1	8	0.8	8	0.8
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	10	1.5
Vertical Profile Resolution	.15	4	0.6	10	1.5
Longitude	.05	0	0	8	0.4
	1.0		4.05		8.05
Rounded Off Total		4		8	

Rationale for weighting functions:
Very few measurements exist. Primary need is for increased vertical profile data and latitudinal distributions. Theoretically there is no diurnal change.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Nitric Acid Vapor, HNO_3

	WF 0-1	Present Knowledge		Required Knowledge	
Parameter		V	VXWF	V	VXWF
Latitude	.3	5	1.5	10	3.0
Duration of Program	.25	3	.75	9	2.25
Diurnal Coverage	.1	7	.7	8	.8
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	7	1.05	10	1.5
Vertical Profile Resolution	.1	8	.8	10	1.0
Longitude	.1	0	0	8	.8
	1.0		4.8		9.35
Rounded Off Total		5		9	

Rationale for weighting functions:

Latitudinal variations and seasonal variations are large and require additional measurement. Vertical profile should be extended to top of stratosphere. Diurnal variation appears to be small.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Carbon Monoxide, CO

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.4	0	0	8	3.2
Duration of Program	.1	0	0	6	0.6
Diurnal Coverage	.15	0	0	6	0.9
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	5	.75	9	1.35
Vertical Profile Resolution	.15	3	.45	9	1.35
Longitude	.05	0	0	8	0.4
	1.0		1.2		7.8
Rounded Off Total			1		8

Rationale for weighting functions:

Distribution mostly unknown except for a few vertical profiles. Additional vertical profiles and latitudinal measurements of first priority.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

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Evaluation of Methane, CH_4

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.4	0	0	8	3.2
Duration of Program	.1	0	0	6	0.6
Diurnal Coverage	.15	0	0	6	0.9
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	8	1.2
Vertical Profile Resolution	.15	3	0.45	9	1.35
Longitude	.05	0	0	8	0.4
	1.0		1.35		7.65
Rounded Off Total			1		8

Rationale for weighting functions:

Distribution mostly unknown except for a few vertical profiles. Additional vertical profiles and latitudinal measurements of first priority.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

Evaluation of Hydrogen Chloride Gas, HCl

Parameter	WF 0-1	Present Knowledge V	Present Knowledge VXWF	Required Knowledge V	Required Knowledge VXWF
Latitude	.35	4	1.4	9	3.15
Duration of Program	.1	5	.5	8	.8
Diurnal Coverage	.1	0	0	7	.7
Launch Time	0	10	0	10	0
Vertical Profile Coverage	.2	6	1.2	9	1.8
Vertical Profile Resolution	.2	7	1.4	9	1.8
Longitude	.05	0	0	8	.4
	1.0		4.5		8.65
Rounded Off Total		5		9	

Rationale for weighting functions:

Very few measurements of stratospheric HCl exist. Basic need is for better and more extensive measurements of the vertical and latitudinal profiles. Since the reaction rates for the basic HCl formation and decomposition reactions are at least an order of magnitude slower than the rates for the principal Cl and ClO reactions, diurnal changes in HCl should be small.

Legend: WF = Weighting Function
V = Value to user taken from value matrices
VXWF = Product of V and WF

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