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REMOTE SENSING OF THE STRATOSPHERE Vol. I: Background and Requirements

The Mitre Corporation/Metrek Division

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The Capability of Satellite Borne Remote Sensors to Measure Stratospheric Trace Constituents

Volume I: Background and Requirements

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ABSTRACT

This document is Volume I of a three volume report issued as MITRE/METREK Technical Report, MTR-7519. The three volumes cover the following principal subjects:

Volume I contains a synthesis of the results of two previous MITRE/METREK studies [1,2] and an update of the information contained in them. The update was made during the Summer and Fall of 1977. These studies deal with a comprehensive review of stratospheric trace constituent measurement requirements. The scope of the study was restricted to those constituents which fall into the general category of "air pollutants."

Volume II separates stratospheric trace constituent measurement requirements into two somewhat overlapping areas. In the first area, it is assumed that the only problem of interest is ozone; its chemistry chain, environmental effects and measurement requirements. In like manner, in the second area it is assumed that the only problem of interest is stratospheric aerosols; their chemistry, effects and measurement requirements.

Volume III contains material of a supportive nature not considered to be of sufficient importance to be included in the other two volumes. This material is of two types:

- Information and numerical evaluations used in the development of mission evaluations for stratospheric trace constituent measurement.
- Various spatial and temporal distributions for those stratospheric trace species having sufficient measurements available to warrant their presentation.

The reader is advised to note that the results and conclusions presented here are based on the specific combination of remote sensors, Shuttle orbits and analysis values selected to exemplify the technique presented. Although these sensors and orbits are typical, extension of the study to include all available sensors and many orbits, or to another specific small combination could result in different results and conclusions.

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LIST OF CHEMICAL SYMBOLS*

Symbol	Name
A	Argon
Al^{++++}	Aluminum ion
nAl_2O_3	Aluminum oxide aerosol
Br	Atomic bromine
Br^-	Bromide ion aerosol
BrO	Bromine oxide
Ca^{++}	Calcium ion aerosol
CBr_4	Tetrabromomethane (carbon tetrabromide)
$CCl_2{=}CHCl$	Trichloroethylene
CCl_4	Tetrachloromethane (carbon tetrachloride)
$CFCl_2^+$	Dichlorofluoromethane radical
$CFCl_3$	Trichlorofluomethane (F-11)
CF_2Cl^+	Chlorodifluoromethane radical
$CF_2ClCFCl_2$	Trichlorotrifluoroethane (F-113)
CF_2Cl_2	Dichlorodifluoromethane (F-12)
$CHClF_2$	Chlorodifluoromethane (F-22)
$CHCl_2F$	Dichlorofluoromethane
$CHCl_3$	Trichloromethane (chloroform)
$CH_2{:}CHCl$	Vinyl chloride
CH_2Cl_2	Dichloromethane (methyl dichloride)

*Common name given in parentheses where appropriate. Unless specifically stated, species is assumed to be in gaseous state.

LIST OF CHEMICAL SYMBOLS (Continued)

Symbol	Name
CH_2O	Methanal (formaldehyde)
CH_3	Methyl radical
CH_3Br	Bromomethane (methyl bromide)
CH_3CCl_3	Trichloroethane (methyl chloroform)
CH_3Cl	Chloromethane (methyl chloride)
CH_3O	Methyl oxy radical
CH_3O_2	Methyl peroxy radical
$(CH_3)_2S$	Methyl sulfide
CH_4	Methane
CO	Carbon monoxide
COCl	Carbonyl monochloride
COS	Carbonyl sulfide
CO_2	Carbon dioxide
nCO_2	Carbon dioxide in cluster formation; quasi aerosol
CS_2	Carbon disulfide
$C_2H_4Cl_2$	Dichloroethane
C_2H_5Cl	Chloroethane (ethyl chloride)
C_xH_y	Non-methane hydrocarbons (NMHC)
Cl	Atomic chlorine
Cl^-	Chloride ion aerosol
$Cl_2C:CCl_2$	Tetrachloroethene (perchloroethylene)
ClFCO	Fluoroformyl chloride

LIST OF CHEMICAL SYMBOLS (Continued)

Symbol	Name
ClO	Chlorine monoxide
$ClONO_2$	Chlorine nitrate
ClO_2	Chlorine dioxide
ClO_x	"Odd" chlorine
Cu^{++}	Copper ion aerosol
F_2CO	Carbonyl fluoride
Fe^{++} or Fe^{+++}	Iron ion aerosol
H	Atomic hydrogen
HBr	Hydrogen bromide
HCl	Hydrogen chloride
HF	Hydrogen fluoride
HNO_2	Nitrous acid
HNO_3	Nitric acid
$nHNO_3$	Nitric acid aeroso
HO or OH	Hydroxyl
HO_2	Hydroperoxyl
HSO_3^-	Bisulfite radical
H_2	Molecular hydrogen
H_2O	Water vapor
nH_2O	Liquid water or ice (as aerosol or in cluster formation)
H_2O_2	Hydrogen peroxide

Symbol	Name
H_2S	Hydrogen sulfide
H_2SO_4	Sulfuric acid
$H_2SO_4 \cdot nH_2O$	Sulfuric acid aerosol
$H_xC_yO_z$	Unspecified organic compound
I^-	Iodide ion aerosol
K^+	Potassium ion aerosol
M	Unspecified third body
Mg	Magnesium aerosol
Mn^{++} or Mn^{+++}	Manganese ion aerosol
N	Atomic nitrogen
N_2	Molecular nitrogen
nN_2	Molecular nitrogen in cluster formation; quasi aerosol
NH_3	Ammonia
NH_4^+	Ammonium ion
nNH_4^+	Ammonium ion aerosol
$NH_4HSO_4 \cdot nH_2O$	Ammonium bisulfate aerosol
$(NH_4)_2SO_4$	Ammonium sulfate aerosol
$(NH_4)_2S_2O_8$	Ammonium peroxydisulfate aerosol
NO	Nitric oxide
nNO	Nitric oxide in cluster formation; quasi aerosol
NO_2	Nitrogen dioxide

LIST OF CHEMICAL SYMBOLS (Concluded)

Symbol	Name
NO_2^-	Nitrite ion aerosol
NO_3	Nitrogen trioxide
NO_3^-	Nitrate ion aerosol
NO_x	"Odd" nitrogen (nitrogen oxides)
N_2O	Nitrous oxide
N_2O_5	Nitrogen pentoxide
Na^+	Sodium ion aerosol
O	Atomic oxygen, unspecified
$O(^1D)$	Atomic oxygen, excited state ^1D
$O(^3P)$	Atomic oxygen, normal state
$O(^1S)$	Atomic oxygen, excited state ^1S
O_2	Molecular oxygen
$O_2(^1\Delta)$	Molecular oxygen, excited state $^1\Delta$
O_3	Ozone
SF_6	Sulfur hexafluoride
SO_2	Sulfur dioxide
nSO_2	Sulfur dioxide in cluster formation; quasi aerosol
SO_3	Sulfur trioxide
$SO_4^=$	Sulfate ion aerosol
Si^{++++}	Silicon ion aerosol

1.0 INTRODUCTION AND CONCLUSIONS

1.1 General Objectives

In previous work for the NASA/Langley Research Center, MITRE completed two studies in the general area of remote measurement of stratospheric trace constituents [1,2]. In the first of these, an assessment was made of the capabilities of specific NASA remote sensing systems to provide appropriate measurements of stratospheric parameters. This study emphasized roles of the aerosol, the nitrogen oxide/ozone chemistry cycle, and the chlorine/ozone chemistry cycle in the stratosphere. It also evaluated the capabilities of six specific instruments to provide required measurements of stratospheric constituents.

In the second study a more comprehensive view of all stratospheric trace constituents was taken. This included:

- development of a prioritized list of requirements for stratospheric trace constituent measurement.
- a comprehensive summary of present knowledge of stratospheric trace constituents.
- development of a structured constituent/instrument/mission evaluation technique.
- application of the technique to a specific set of instrument/orbit combinations.

Since the completion of the two original studies a need has been recognized to synthesize the previous studies along with additional updated information to produce a single document having the following principal objectives:

- providing the scientific community with a concise view of the current status of knowledge of stratospheric trace constituents and adding to the impetus for frank and in-depth discussions of future measurement requirements.
- providing the instrument development community with an information set which would guide them in selecting design goals for new instrument development based on the combination of scientific needs and instrument capabilities.

This document presents the results of this synthesis and updating. (Additional supporting material to this synthesis is presented in appendix form in Volume III.)

1.2 Approach Taken in This Study

In most areas covered by this study, considerable effort has already been expended by many groups, not only within NASA but also among other government agencies, the private sector and in the two previous MITRE studies. MITRE's principal role in the present study was to integrate 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 subsections summarize the major sections of this report.

1.2.1 The Stratosphere

The purpose of section 2.0 is to provide a readily available short summary of the general characteristics of the stratosphere. The temperature regime and circulation are discussed in terms of the general dynamic processes to illustrate the formation of the unperturbed stratosphere. This leads to a summary of the stratospheric constituents and their role in atmospheric chemistry. This section is intended only as a supporting base of information for understanding the various topics covered later.

1.2.2 Current Status of Stratospheric Measurement Techniques

In section 3.0, the multitude of stratospheric measurements which have been made are divided into two generic categories based on the observation method; contact and remote. Within each general category the measurement techniques are segregated into groups which depend on the chemical, physical or optical technique used. Also discussed is the current status and general characteristics of the various platforms available for support of stratospheric measurements.

1.2.3 User Requirements for Stratospheric Measurements

The role of section 4.0 is to discuss some general features of NASA's interaction with users of stratospheric data and offer two major examples (solar ultraviolet radiation and climate) of pressing atmospheric pollution problems which demand of NASA a careful and effective development program. The emphasis is placed on who uses the data and how they use it in order to develop the specifics of the measurement requirements.

1.2.4 Science Requirements

In section 5.0 the analysis of user needs and general measurement requirements developed in the previous section (4.0) are used in combination with the results of many other recent studies to develop a set of scientific requirements for stratospheric trace constituent measurements. The section includes a discussion of the physical and chemical properties of the stratosphere with particular emphasis on the nitrogen oxide cycle and the chlorine cycle. This material is presented to support the development of the scientific criteria and the prioritized list of stratospheric measurements presented later in the section.

1.2.5 Orbital Influences and Instrument Performance

The first part of section 6.0 presents a general discussion of the interplay of the various generic types of instruments and possible orbits in order to quantify the sampling characteristics. The discussion centers on two topics:

- orbital properties, instrumentation and resulting global coverage, and
- appropriateness of a set of instrument/orbit parameters for monitoring a set of significant stratospheric constituents.

In the later part of the section a number of specific remote sensing instruments that are either operational or under development for stratospheric monitoring are discussed and their performance characteristics tabulated.

1.2.6 Mission Evaluation

Section 7.0 presents the results of the application of a method for the evaluation of various stratospheric species measurement mission and analysis efforts. The method itself was developed during previous MITRE effort [2] and is presented in detail in Appendix A. Much of the supporting data used in these evaluations has been assembled in several of the appendices of Volume III of this report. The evaluations include all possible combinations of three orbits (a 30° Shuttle type, a 56° Shuttle type and a polar sunsynchronous type) with one or more of four remote instruments (LIMS, SAGE, CIMATS/solar occultation and HALOE).

1.3 Conclusions of the Study

All of the material presented in this report may be organized into three main areas for discussion of the results and conclusions:

- Current and projected measurement capability
- Requirements for stratospheric measurements
- Selected instrument/orbit evaluations

Each of these areas is treated separately below.

1.3.1 Current and Projected Measurement Capability

Analysis of the material presented in section 3.0 indicates three key conclusions:

(1) The performance of current remote stratospheric sensors, in some cases, compares quite well with identified measurement requirements. Their ability to measure other species has not been demonstrated. A number of in-situ methods also exist with comparable sensitivity and accuracy but whose measurements are of a limited utility, given their spatial and temporal sampling characteristics.

(2) None of the current, in-situ methods have the capability to satisfy the requirements for global monitoring and the temporal constraints derived from the users needs portion of the study.

(3) Existing, non-remote techniques will continue to play an important role in stratospheric investigations for both corroboration of remotely collected data and in the evolutionary development of future remote sensors.

All of the measurement techniques discussed have their strengths and weaknesses. The in-situ methods are extremely sensitive and accurate but suffer from limited coverage and local contamination problems. Remote sensing techniques offer wide area coverage and relatively long mission lifetimes. Their disadvantages lie in the reduced sensitivity to low concentration levels and the requirements for auxiliary data to invert the integrated path measurements which most utilize. Indeed, the masses of data which must be processed in order to yield the desired information is at least a temporary disadvantage of remote sensing methods. The development of better models and improved data handling techniques is expected to minimize these problems.

The general features of remote sensors of the stratosphere aboard a satellite platform reveal two key features:

(1) nadir-viewing instrumentation provides superior performance in the areas of horizontal resolution and measurement time per orbit

(2) limb-viewing instrumentation provides superior sensitivity, and vertical resolution

In most other areas, the two basic monitoring methods are equally capable. The science requirements include the need for vertical profiles and data of fairly high quality. Limb-viewing instrumentation appears to satisfy these needs but provides limited temporal sampling for solar occultation when certain orbits are used. As a result, instrumentation of the limb emission type represents the optimum choice. In general, this type of instrument has the potential of satisfying scientific requirements for vertical profiles as well as those for spatial and temporal sampling.

Orbital considerations emerge as a key element in the applicability of various sensor systems to specific measurement roles. Sun-synchronous orbits provide optimum coverage for nadir-viewing, thermal source sensors and limb-viewing emission source sensors. High angle non-sunsynchronous orbits are preferred for nadir-viewing reflected solar source or limb-viewing solar occultation sensors, if geographical coverage is to be maximized.

1.3.2 Requirements for Stratospheric Measurements

Material utilized in the selection of requirements for stratospheric monitoring has been derived from the user needs survey as well as the detailed investigation of data needed for a better understanding of stratospheric chemistry. In addition, a review of current measurement methods examined the quality of data currently available for a variety of gases of interest. The proposed accuracy requirements reflect improvements, where required, over current limitations.

In many cases no specific requirements have been expressed for spatial or temporal sampling. In view of the generally infrequent and localized nature of current measurements, any satellite monitoring system will represent an improvement in these categories. It is anticipated that the need will exist for global coverage at a rate which provides data on diurnal and seasonal variations as well as longer term trends.

Measurement requirements for various categories of users and uses have been tabulated in Tables 4-V through 4-XI. Based on these results and numerous other specific studies a prioritized list of properties and species has been developed (Table 5-I). 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 the report application of the evaluation methodology presented indicates clearly 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. Those species which show high priority for satellite missions generally fall into priority groups 2 and 3 and are typically the components of the basic reactions involved in the direct production or depletion of ozone. These species fall into four general categories:

- Pure oxygen - O_x
- Hydrogen Oxides - H, H_2, HO_x
- Nitrogen Oxides - NO_x
- Chlorine Oxides - Cl and ClO_x

As our understanding of the stratosphere matures, various constituents will receive more or less emphasis with respect to sampling and data quality. While this list is presently current, changes should be anticipated, particularly when measurements exceed the current minimum requirements.

It should be noted that these requirements have been generated independently of any instrument considerations. Therefore, this material represents a set of performance goals for contact or remote sensors placed on airborne, orbiting, or terrestrial platforms. In the case of those species not yet measured, airborne measurements should receive considerable attention in order to establish background levels and to corroborate proposed remote sensing techniques.

1.3.3 Selected Instrument/Orbit Evaluations

Section 7.0 presented 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 were evaluated for each species of interest. For 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 sunsynchronous 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 sunsynchronous 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 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 7.1 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 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 compares favorably even to the four-instrument combination 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 THE STRATOSPHERE

The purpose of this section is to acquaint the reader with the stratosphere. The temperature regime and circulation are discussed in terms of the general dynamic processes to illustrate the formation of the unperturbed stratosphere. This leads to a summary of the stratospheric constituents and their role in atmospheric chemistry.

2.1 General Properties

The two major reasons for observing or monitoring the stratosphere 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 ozone (O_3) destruction and aerosol formation, will be summarized below to provide a background for later discussions contained in this report.

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

- troposphere,
- stratosphere and,
- mesosphere.

Averaged over reasonable 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 constant. 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 immediately above the stratopause is the mesophere.

The vertical distribution of temperature in the tropical and the polar zones is shown in Figure 2-1 [3]. The two temperature profiles of Figure 2-1 show substantial differences between polar and tropical regions. An indication of the temperature changes with latitude is illustrated by a series of such profiles.

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

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

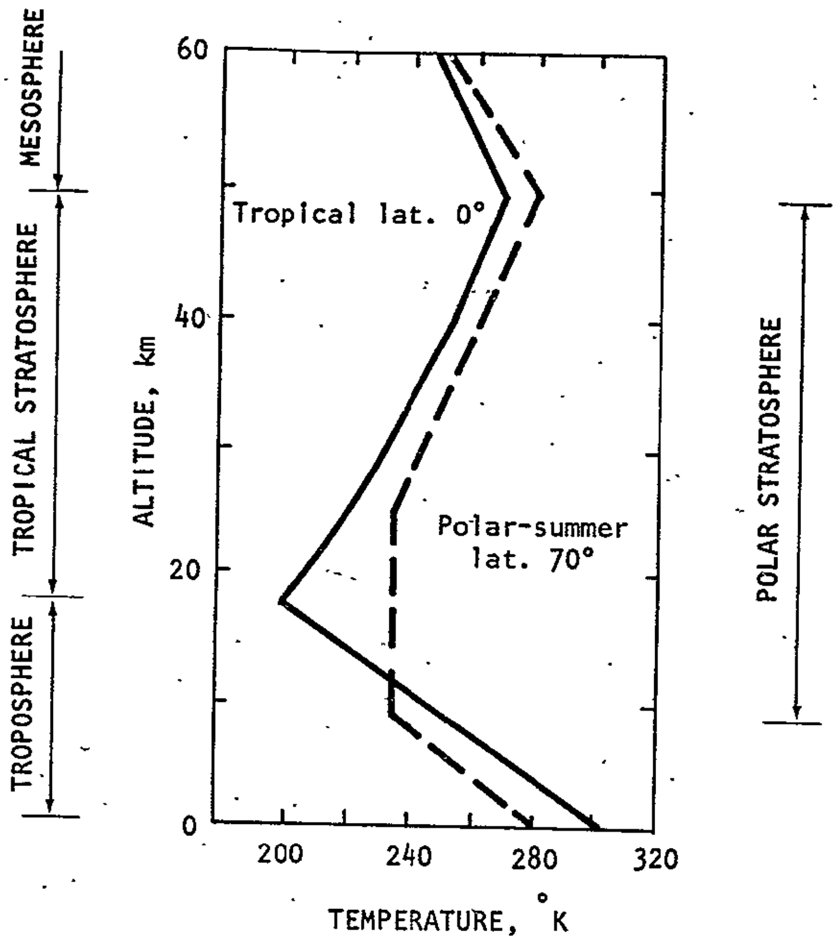

FIGURE 2-1
SAMPLE TEMPERATURE PROFILES IN TROPICAL AND POLAR ZONES [3]
(Troposphere, stratosphere, stratopause, and mesosphere defined in terms of vertical temperature profiles)

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.

2.2 Stratospheric Constituents

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

- major gaseous constituents,
- minor gaseous constituents,
- trace gaseous constituents, and
- aerosols.

The major atmospheric constituents are molecular nitrogen (N_2), O_2, Argon (A), and carbon dioxide (CO_2). 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 [4]. 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, water vapor (H_2O), methane (CH_4), etc., have concentrations of a few parts per million in the stratosphere. Table 2-I summarizes some of the minor constituents at 20 km that are important in stratospheric chemistry. Table 2-II summarizes for some of the important trace gaseous constituents, such as nitric oxide (NO), sulfur dioxide (SO_2), etc., their concentrations at 20 km, their variability, and their role in stratospheric chemistry. These tables are intended as background material only. A complete development of the properties and measurement requirements of stratospheric species is given later, in Section 5.

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.

2.3 Transport Phenomena

Clouds, rain, and thunderstorms are strong evidence for the considerable vertical motion characteristic of the troposphere. In thunderstorms vertical velocities, which are generally 10 cm/sec in normal latitude cyclones and anticyclones, may reach 10 to 20 m/sec.

TABLE 2-I

MINOR STRATOSPHERIC CONSTITUENTS

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 2-II

TRACE STRATOSPHERIC CONSTITUENTS

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	increases up to 40 km; unknown above	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

In the stratosphere, however, the temperature increases with height providing an equilibrium condition. For this reason, the vertical motions rarely exceed a few centimeters per second and are often much smaller. In other words, an air parcel moves up or down more slowly in the stratosphere than it does in the troposphere. This is not true for horizontal motions in the stratosphere which are significantly more rapid than the vertical motions. Typical horizontal wind velocities in the stratosphere are of the order of 1 to 100 m/sec, whereas vertical velocities are in the range of 10^{-4} to 10^{-1} m/sec.

The overall structure of the wind field in the stratosphere has been investigated and shows a complicated latitudinal and seasonal dependence [5,6]. In general, there are some correlations between the meridional (N-S) and vertical wind fields at different times of the year [4]. No correlation seems to exist between the rapid zonal (E-W) circulation and vertical wind data.

In summary, because of the slow vertical mixing, the contaminants which are introduced into the stratosphere at a particular altitude will remain near that altitude for periods as long as several years [7]. This long residence time allows the contaminants to take part actively in the chemical and radiative processes of the stratosphere. In the case where a contaminant is capable of entering a catalytic process which would lead to the destruction of an important stratospheric constituent such as ozone, the consequences are of great importance and must be thoroughly investigated.

3.0 CURRENT STATUS OF STRATOSPHERIC MEASUREMENTS AND TECHNIQUES

3.1 General Techniques

For the purpose of this study, the multitude of stratospheric measurements which have been performed are divided into two generic categories; contact measurements and remote sensing measurements. Within each general category the experiments are segregated into groups which depend upon the chemical, physical or optical technique used.

3.2 Contact Measurements

Within this category are placed all of those experiments which do not utilize remote sensing techniques. It could have been further subdivided into grab-sample and in-situ techniques, but as the intent is to compare the generic category with that of remote sensing, this further distinction has not been made. Historically, contact measurements have formed the bulk of the empirical data collected on stratospheric constituents and processes. They will continue to be used for local or regional measurement programs and to provide calibration for satellite sensor systems now being developed. The following listing provides a representative cross section of the contact measurements which have been, and are being, made.

3.2.1 Hygrometers

There are two types of hygrometers ~~currently in use~~ for measurements of atmospheric water vapor; the frostpoint hygrometer and the aluminum oxide hygrometer.

In the frostpoint hygrometer a thermoelectric cooler is used to chill a stainless steel mirror to the dew point, the temperature of which is monitored by a platinum resistance element. The onset of condensation is detected by optical sensors using light reflected from the mirror surface.

The aluminum oxide hygrometer consists of an aluminum base, an aluminum oxide layer, and a porous gold film on top of the oxide. The a-c impedance of this device is dependant upon the amount of adsorbed water. Calibration curves relate the output signal to water vapor concentration.

3.2.2 Other Water Vapor Contact Sensors

Several other techniques for contact sensing of water vapor have been investigated. The Office of Naval Research (ONR) has examined the Tritium Water Vapor Sensor substrate [26]. The rate is proportional to the exchange of hydrogen ions from water vapor with the polymer-bound tritium.

NASA/AMES Research Center has investigated a lithium chloride crystal oscillator as a means of determining water vapor concentration [26]. The impedance of the crystal, and thus its frequency of oscillation, is changed by the adsorption of water molecules.

3.2.3 Electrochemical Measurement of Ozone

Most electrochemical techniques utilize variations on the Komhyr cell. This device depends upon the oxidation of potassium iodide by ozone. The reaction produces iodine which, upon conversion to iodide, produces free electrons. The resulting current is directly proportional to the ozone concentration of the gas sample.

3.2.4 Chemiluminescence Measurement of Gases

These devices depend upon the luminescence induced in dyes such as Rhodamine B by the presence of ozone. The luminescence is proportional to the ozone concentration and the flow rate of the gas through the sensor. A photomultiplier is used to monitor the light flux from the excited dye. The device is usually coupled with pressure and temperature sensors when used in a rocket-deployed ozonesonde.

A chemiluminescence technique is also used for detection of nitrogen oxides (NO_x). This variation utilizes the reaction between NO and O_3 to produce an excited state of nitrogen dioxide (NO_2) and O_2. The excited state gives up its energy in the form of a photon which is detected by a photomultiplier tube. For NO_2, a catalytic converter is first employed to reduce NO_2 to NO, and the previous reaction is followed.

3.2.5 Other Nitrogen Oxide Contact Sensors

Other contact techniques have been used for the detection of NO_x. Balloon measurements performed by NASA/Goddard Space Flight Center (GFSC), have used a combination of photoionzation and mass spectroscopy to identify NO and NO_2 [26]. A group at the Illinois Institute of Technology Research Institute has used a cryogenic sampler to detect nitrogen oxides as well as CH_4, carbon monoxide (CO), and molecular hydrogen (H_2) [26]. The technique is usually coupled with electron spin resonance for laboratory identification of the trace species.

3.2.6 Particulate Techniques

Impact filters continue to be the mainstay of the contact measurements of particles in the atmosphere. They are used to collect particles as small as 0.1 μm in radius. The analysis of the samples may take one of many forms, depending upon the species and the preference of the investigator. Among those used are: gamma radiation, X-ray fluorescence, scanning electron microscopy and neutron activation. For smaller particles, Aitken nuclei detectors are utilized by experimenters, e.g., the University of Wyoming [27]. These devices are modifications of cloud chambers, with particle detection being dependent upon vapor condensation.

Table 3-I summarizes these contact techniques.

3.3 Remote Measurements

All current efforts in remote sensing of atmospheric constituents involve either passive or active optical techniques. Active techniques include LIDAR, for aerosol detection, and Raman spectroscopy for other trace constituents. The passive techniques involve either emission or absorption of radiation by the species of concern. Instruments may be either spectrometers or interferometers. Some representative examples are described below.

TABLE 3-I

CONTACT MEASUREMENTS

TECHNIQUE	SPECIES	ABSOLUTE ACCURACY	INTEGRATION TIMES	SENSITIVITY	DYNAMIC RANGE	LIMITATIONS	ADVANTAGES	INVESTIGATORS**
Frostpoint Hygrometer	H_2O Vapor		<1 min.		30(B)*			Mastenbrook-NRL Sissenwine-AFCRL
Aluminum oxide Hygrometer	H_2O Vapor	±50%	30 sec.	±3°C in dew temperature	30(B)	Calibration problems		Hilsenrath-GSFC Goodman-ONR
Tritium Sensor	H_2O Vapor	±10%		0.5 ppb @ 50 mb	20(A/C)			ONR
LiCl Crystal Oscillator	H_2O Vapor			1 ppb	20(A/C)			NASA-ARC
Electro-chemical	O_3	±10%	90 sec.	2 to 3 ppb	30(B)	Response time, pump efficiency	Good vert. resolution <25 km	Kroenig-Minn.
Chemilumin-escent	O_3, NO_x	±20% ±60%	<1 sec.	10 ppb (0 to 1 ppb)	70(R) 20(A/C)	Calibration problems	Fast respones	Hilsenrath-GSFC Popoff-NASA/ARC
Photoion-ization/Mass Spectroscopy	NO_x				30(B)			NASA-GSFC
Cryogenic Sampler	NO_x, CH_4 CO, H_2			1 to 10 ppb	20(A/C)			IITRI
Impact Filters	Particles ≥0.1 μm	±40%			20(A/C)	Paper background, air flow varies		Sedlacek-LASL
Aitken nuclei detector	Particles ≥.003 μm	±10%	10 sec.	0.1 to 10^6 nuclei/cc	30(B)			University of Wyoming

*B: Balloon; A/C: Aircraft; R: Rocket

**NRL - Naval Research Laboratories
AFCRL - Air Force Cambridge Research Laboratories
GFSC - NASA/Goddard Space Flight Center
ONR - Office of Naval Research
NASA-ARC - NASA/Ames Research Center
Minn. - University of Minnesota
IITRI - Illinois Institute of Technology Research Institute

3.3.1 LIDAR

Active laser studies of the atmosphere have been made since 1964. Various groups at NASA have made ground-based measurements while Shuster of National Center for Atmospheric Research (NCAR) has used an airborne version on the NASA Convair 990 [26]. Other investigators have measured the concentration of CO_2, SO_2, and N_2 [29]. While theoretically, the Raman technique offers the advantages of requiring but a single laser wavelength for excitation and unique backscattered frequencies, it is limited, in practice, by its extremely low sensitivity. The scattering cross-section for Raman processes is several orders of magnitude lower than that for Rayleigh scattering.

3.3.2 Radiometers

Radiometers are used to measure the intensity of electromagnetic radiation incident upon a detector. They are, usually, designed to measure over fairly wide spectral regions. This results in relatively simple design criteria but at the price of specificity. Their application to remote sensing is therefore limited, but for the purposes of temperature measurements, they are still widely used. When used in a scanning mode, with the scan perpendicular to the spacecraft heading, the radiometer may produce imagery after suitable processing. This technique is used in the Cloud Imager class of instruments.

3.3.3 Spectrometers

In order to obtain high specificity of atmospheric constituents, greater spectral isolation is required. There are two general classes of spectrometers of interest; nondispersive and dispersive.

Nondispersive spectrometers obtain spectral isolation by the simple means of optical filtering. Some instruments utilize narrow-band interference filters to pass the wavelength or wavelengths of interest for detection and subsequent analysis. Other varieties use a sample of the gas of interest as a filter and perform a correlation between the incident radiation from the scene and that from a reference black body source. Filters may be arranged so as to cover several portions of the spectrum simultaneously, or mounted on a rotating filter wheel which permits sequential viewing of selected spectral regions. Nondispersive spectrometers are sometimes referred to as spectroradiometers.

Dispersive spectrometers may depend upon either refraction or diffraction of the incident radiation. Refractive spectrometers use prisms of various materials to provide the spectral separation of the received energy. Resolving power is limited in prism instruments and the energy throughput is quite low. Diffraction gratings provide greater resolution but still suffer from the relatively low efficiency imposed by the requirement for narrow slit widths on the entrance and exit apertures.

A variation of the nondispersive spectrometer was mentioned above in discussing the gas filter correlation techniques. Similar variations of dispersive spectrometers also exist and should be mentioned. While the conventional dispersive instrument scans the spectral components across a single exit slit, several techniques utilize masks in the exit plane to perform either correlation measurements with a known spectra or to simultaneously measure the contributions of the source at several wavelengths.

3.3.4 Interferometers

In order to view a large spectral interval with high resolution, and greater throughput than that provided by spectrometers, many investigators have turned to the interferometer. Most interferometers used for remote sensing are variations on the Michelson instrument, in which the incident radiation is collimated and passed through a beamsplitter in order to obtain separate path lengths which are eventually recombined. One path contains a movable mirror, or other technique to produce a variation in path length with time. Upon recombination, the resultant intensity shows variations due to the phase difference introduced in one path. These variations in intensity, as a function of displacement of the mirror, produce an interferogram. The interferogram contains all the spectral information of the incident radiation. Mathematical techniques, such as Fourier transformations, may be used to extract the spectrum. One current technique, (CIMATS) [30, 31, 32] compares the interferogram directly with one which contains the spectral information on the constituent of interest rather than transforming it into an optical spectrum.

3.4 Platforms

Stratospheric measurements may be made from balloons, rockets, aircraft, satellites and from the ground. General characteristics of some of the platforms are shown in Table 3-II.

Most of the current measurements of the stratosphere have been made from aircraft platforms. These offer a maximum payload, and significant range and duration. Aircraft may also serve as a test bed for satellite instrumentation in the development stages. Coverage may be made nearly global with the development of unmanned instrument packages, such as that developed for the GASP program, to be installed on commercial Boeing 747 aircraft flying world wide routes.

Rockets are still used extensively for the measurement of atmospheric state variables such as temperature, pressure and wind profiles. They have an obvious altitude advantage over aircraft and are relatively inexpensive to operate. Rockets may be used to delineate the range of measurement capability which may be required for satellite sensors or to provide corroboration of satellite data.

Balloons provide for larger payloads than rockets with the further advantages of extended operating range and measurement time. They provide accurate vertical profiles up to altitudes of 50 km. Like aircraft platforms, balloons may be used for flight tests of developmental satellite systems.

TABLE 3-II

SELECTED CHARACTERISTICS OF SENSING PLATFORMS

PLATFORM	OPERATING ALTITUDE	OPERATING RANGE	OPERATING TIME	MAX. PAYLOAD CAPABILITY
Airplanes	<23 km	4000 km	5 hrs - 8 hrs	<5000 kg
Balloons	0 to 50 km	4000 km	24 hrs - 30 days	2000 kg
Sounding Rockets	0 to 200 km	5 km - 500 km	minutes (can return by parachute)	200 kg
Earth Satellites	200 to 40,000 km	Global	Indefinite	10 kg - 30,000 kg

With the current requirements for global coverage of the stratosphere, there is no platform equal to the satellite. Since the development of the NIMBUS payloads, improved measurements have already been obtained on solar ultraviolet radiation (UV), temperature and ozone. Future NIMBUS systems will measure other trace constituents in the stratosphere on a global scale, for the first time.

3.5 Results and Limitations

All of the measurement techniques discussed have their strengths and weaknesses. The *in situ* methods are extremely sensitive and accurate but suffer from limited coverage and local contamination problems. Remote sensing techniques offer wide area coverage and relatively long mission lifetimes. Their disadvantages lie in the reduced sensitivity to low concentration levels and the requirements for auxiliary data to invert the integrated path measurements which most utilize. Indeed, the masses of data which must be processed in order to yield the desired information is at least a temporary disadvantage of remote sensing methods. The development of better models and improved data handling techniques is expected to minimize these problems.

4.0 USER REQUIREMENTS FOR STRATOSPHERIC MEASUREMENTS

The role of this section is to discuss some general features of NASA interaction with users of stratospheric data and offer the two major examples (UV and climate) of pressing atmospheric pollution problems which demand of NASA a careful and effective program of development. The examples serve to demonstrate the need for an understanding of the overall physical problem in order to provide effective user support.

The approach to user needs must recognize the synergistic relationship between the user community and the technology community. In the next section (5.0), these user needs are integrated into a set of scientific requirements for stratospheric measurements and in later sections (6.0 and 7.0) the capabilities of proposed satellite remote sensing instruments are codified and compared with requirements of the potential user community. Depending on the user, modifications of capabilities may be required for the successful melding of instrument capabilities and user requirements.

The users, the recipients of observed data, have been grouped into three major categories, those concerned with scientific studies (stratospheric physics and chemistry, biological research studies, etc.), monitoring activities (for example, regulatory functions and long-term trend analysis), and predictive modeling (particularly in the climate field).

The totality of users of stratospheric data is potentially limitless. In an attempt to reduce the problem to manageable proportions and still provide sufficient detail to specify user requirements, two specific problems are addressed. The two topics chosen, the climatic and solar ultraviolet radiation (UV)* changes which may result from alteration of the balance of stratospheric constituents is defined to a great extent by the current national and global interest in these two topics. In this way, the information developed can be directly related to any on-going NASA program planning which addresses analysis of these problems. Furthermore, there is an overriding requirement that the development of scientific requirements rely upon an understanding of the physical processes being studied by the users.

In order to separate the two topics as much as possible, the UV study concentrates on users interested in the effects of such changes on the biosphere, while the climate study concentrates on those physical processes which may alter the climate.

The next section discusses the development of user requirements for the UV and climatic change studies. The information presented here is summarized principally from previous MITRE work [1] and exists in much greater detail in that study.

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*Biologists divide the UV spectrum into three wavelength regions: UV-A: 0.32 to 0.4 μm; UV-B: 0.28 to 0.32 μm; UV-C: less than 0.28 μm. Unless specifically stated, the term UV when used in this report refers to all three regions.

4.1 Influences on the Biosphere

Provision of useful data from observations of the upper atmosphere is determined by a consideration of atmospheric influences on human activities and on subjects of human interest. The Climatic Impact Assessment Program (CIAP) [33,34] has examined the cause and effect interactions between human activities and the stratosphere. Because of the wealth of data which this study has produced, this section will focus on the influence of the stratosphere on the biosphere, i.e., the region near earth's surface where life is concentrated.

Most of the solar ultraviolet light (UV) at wavelengths below 0.3 μm is absorbed by stratospheric ozone before it reaches the troposphere. This absorption limits the amount of UV received by the biosphere and produces the stratospheric heating and temperature inversion which, by limiting stratosphere-troposphere mixing, maintains the amount of stratospheric ozone at its present levels. The UV energy absorption and the temperature inversion "ceiling" affect the Earth's climate.

UV at the earth's surface is composed of both direct and scattered sunlight. Galactic UV is negligible and artificially generated UV is not found in the upper atmosphere. Changes in surface UV intensity are due to the solar zenith angle and to variations in the solar source intensity and atmospheric transparency. Although air molecules, aerosols and clouds affect UV transmission, the primary influence is in the amount of ozone present in the stratosphere.

Climate is a complex system depending on many factors other than solar radiation and atmospheric transparency. It is a function of albedo, a snow and ice distribution, of global and regional atmospheric and oceanic physical and chemical properties and motions, and of the vegetation and human activity on the surface. Agricultural and grazing practices, e.g., irrigation or replacement of forest by cropland, and industrial activity can change the climate [35]. In turn, climate influences all forms of life, and inorganic materials as well. An attempt to represent climate in a block diagram would require inputs from everywhere and outputs to everywhere, due to the complexity of the set of phenomena collectively called "climate." In such a situation, the numerous feedback relationships make it difficult to determine the precise relationship of any one element to climate and to separate its effects from those of other phenomena.

For this reason, this section concentrates on UV and its relationship to the biosphere. The relative simplicity of the chain of effects producing surface UV makes it easier to isolate its effects compared to the effects of climate. This simplifies the determination of physical phenomena and the functional relationships involved, or organizations concerned, and of the associated data requirements and use. An initial survey of the effects of UV on the biosphere can then serve as a guide to the treatment of the more complicated area of climatic effects.

In previous MITRE work [1], a four-step procedure was used to identify the data requirements and utilization involved in studies of UV influences on the biosphere:

(1) The first step was identification and tabulation of the important physical and biological effects of UV.

(2) The second step was classification of the physical/biological phenomena through the human activity concerned, rather than by a biological taxonomy. Such classification follows the end use of the information, and is a natural consequence of the preceeding steps, since both information sources and organizations tend to be grouped according to some pattern of end use.

(3) The third step was identification and tabulation of the related human activities and the groups involved.

(4) The final step was identification of the information flow within each category of activity. In the biological fields considered here, research was shown to be an obvious use, but the need for operational monitoring for UV purposes was not demonstrated.

Until the requirement for operational monitoring is established, the UV studies should focus on data requirements for research purposes. Since these studies are generally concerned with living organisms, the focus is usually on surface UV, and direct use of satellite observations may not be required. Typical biological research work involves data from many sources, and assessment of these is part of the final step. While UV may have a major and critical effect on some area of activity, the study of that activity need not involve satellite observation at all. Rather the influence of satellite observations may be in establishing the parameters which indicate that a critical situation may occur. A of the application of the above four step procedure is given in the following subsections.

4.1.1 Biophysical Effects of UV

Photochemistry concerns the effects of radiation, including UV, on matter. Here the interest is in the effects of UV on living matter, and primarily concerned with radiation of wavelengths between 0.28 and 0.32 μm, in the "UV-B" region. Radiation at wavelengths below 0.28 μm is still effectively removed by the atmosphere, even with very reduced levels of stratospheric ozone, and wavelengths longer than 0.32 m are relatively unaffected by ozone. Thus variations in stratospheric ozone produce intensity changes mostly in the shorter UV wavelengths penetrating to the surface, and consequently the following discussion relates primarily to UV-B.

In general, UV is [illegible] to living organisms. The production of vitamin D and its use in insect vision are two of the few known beneficial effects. Reactions of the high-energy UV radiation with organic compounds in the cell usually result in products which are not part of normal cell chemistry. Of the variety of photochemical reactions possible with the complex constituents of living matter, certain important and common effets, involving primarily DNA and proteins, can be mentioned.

Individual UV photochemical reactions lead to physiological response which produce complex and synergistic effects and result in varying sensitivities to UV [36,37]. Sunburn (erythema) and tanning of the human skin by UV stimulation of pigment production are familiar examples of physiological effects [38]. Erythema from abrupt UV-B exposure is not important in itself since changes in UV levels need not have serious consequences for this avoidable problem. However, UV-B and erythema are both related via long-term effects to skin cancer, and increased levels of UV can have serious results. The medical community has been concerned with the problem for years, and recently it has received additional attention under the CIAP program, the NAS Climatic Impact Committee (NAS-CIC) and Council on Environmental Quality Task Force on Inadvertent Modification of the Stratosphere (IMOS) studies [39,40].

Both erythema and skin cancer appear to be produced by, or related to, wavelengths below 0.32 μm, and especially below 0.3 μm, although individual sensitivities vary [41,42,43]. Skin cancer takes two forms. Malignant melanoma, the less common but more virulent and frequently fatal form (median survival time of 7 years), has an annual incidence of new cases in white populations varying from 3×10^{-5} in the northern U.S. to 8×10^{-5} in the southwest. The geographic incidence, the location of lesions on sun-exposed areas, and the striking differences in location and frequency according to sex and life habits (e.g., occurrence on women's legs) clearly relate it to sunlight. Frequency among fair skinned people, compared to darker pigmented groups, strongly suggest UV. While UV is not the sole cause or malignant melanoma, a relationship seems clear [39].

Nonmelanoma skin cancer is the most common of all cancers in humans and is generally grossly underreported. Incidence statistics for older groups of white males range up to 5 x 10^{-3} at lower latitudes, and prevalence among whites of all ages may range up to 0.01 according to some recent estimates.

Evidence clearly links UV to nonmelanoma cancer. While rare among heavily pigmented races, it is more common among albinos of such races. Nonmelanoma cancer occurs chiefly among light pigmented races, especially Celts. Incidence increases with cumulative sunlight exposure, i.e., with increasing age, with lower latitudes, and with outdoor occupations.

There is little evidence currently relating UV to serious opthalmological problems, although there is some indication of cataract formation from animal experiments [44].

Skin cancer is not limited to man; some light colored animals lacking melanin, are subject to it. Most higher forms of animal life have natural protection against UV such as fur, feathers or thick skin.

Insects can see in the UV range, but relatively little is known about the effects of UV-B. To date, it appears that many insects are not particularly sensitive to UV, although a few may be strongly sensitive [40]. There are indications that fish populations may vary with solar cycles but UV effects are probably on the eggs rather than the adults.

In summary, the major animal problems determined to exist relate mostly to man and domesticated species.

Studies of effects of UV on higher plants have been supported by the CIAP program and conducted principally at the USDA Agricultural Research Service, Beltsville, MD, and at the Universities of Florida and Utah [34].

Plants cannot avoid sunlight and consequently have physiological defense mechanisms, especially photoreactivation [45]. The nonlinear relationships resulting from synergistic effects and from repair systems make the design of experiments and the interpretation of results difficult [39,46]. One cannot make very small, and consequently linear, perturbations in a plant experiment as one does with a mathematical problem. Nature provides her own perturbations, so small artificial perturbations yield undeterminable results unless enormous statistical samples are used.

Thus, the differences resulting from the removal of natural UV-B, which is fairly easily and inexpensively achieved, are not necessarily the negative of those resulting from addition of a like amount of UV-B. Photorepair and synergism imply the need for providing both the correct spectrum of light and correct growing conditions to obtain useful experimental results. This may be difficult and expensive, especially for field tests, whose results frequently differ from those of simpler laboratory tests. Thus, interpretation of results of plant experiments is no easier than predicting the increase in skin cancer corresponding to a certain decrease of stratospheric ozone.

All microorganisms and most small organisms tend to be extremely sensitive to UV because they lack protective coverings. Thus, the importance of such organisms as the basis of major ecosystems must be recognized and their vulnerability considered. Microorganisms make up for their vulnerability by enormous rates of reproduction in favorable conditions.

Statistical prediction in this area is as questionable as in skin cancer or higher plant effects. The major cause of concern is that any periods of change of population not be too destructive. An ecosystem involves interactions between microbiota, plants, insects, and other animals - if all are changing simultaneously it is difficult to predict the eventual mix which will previal.

Studies of ecosystems take time to accomplish. Potentially important problems may conceivably exist, although the probability of their existence currently appears low.

4.1.2 UV Influence on Human Affairs

The preceding section has identified a number of effects of UV on living organisms and on systems of organizations. This was Step 1 of the methodology set forth earlier. The list of phenomena makes it obvious that all humans are affected in some way. Steps 2 and 3 of the methodology examine the types of effects and the human organizations involved, and are followed by consideration of how the flow of information may be related to NASA missions (Step 4).

Table 4-I lists a few types of effects, classified by human interest, generally in a descending order of immediacy or urgency of requirement. Alongside each of the categories of effects is a list of the organized human activities which are involved.

Essentially all of the material on UV effects presented in the previous section is drawn from research publications. The only "operational" uses of UV known are its use by some insects in vision, the production of vitamin D in humans, and the deliberate exposure of the skin by humans to acquire a fashionable suntan.

Research activity in the effects of UV on living organisms are conveniently classified, for the purposes of this report, as basic or applied. Basic research, as defined here, is concerned with understanding the mechanisms of biological and ecological responses to UV, and may thus be considered to be a branch of photobiology, photophysiology, photochemistry, or ecology.

Applied research, as defined here, is concerned with some of the specific applications listed in Table 4-I. It is aimed at the development of methods of solving specific problems, including the development of plant or animal organisms with desired characteristics. The results of applied research are actual or recommended practices in agriculture, medicine, etc.

4.1.3 Organizational Involvement

Organizations are involved in this work either by conducting the research or by sponsoring it. Sponsoring organizations generally

TABLE 4-I

HUMAN ACTIVITIES CONCERNED WITH UV

NATURE OF UV EFFECT	FIELD OF HUMAN ACTIVITY CONCERNED
1. Direct effects on humans.	Medicine: Cancer, opthalmology, dermatology.
2. Effects on other organisms used by humans for food, material, etc.	Agriculture, horticulture, forestry, animal husbandry, fish culture and fisheries, veterinary medicine, water purification.
3. Long-term and indirect effects on: systems of organisms, climate, societal problems and stability, etc.	Ecology, conservation practices, regulatory activity.
4. Effects on cultural interests: leisure resources, species preservation, etc.	Ecology, water purification, preservation, environmental planning.

represent the individuals and groups of people concerned with a problem or an activity, and usually include the Federal Government. NASA's concern lies more closely with the various Federal organizations involved, with which NASA may have to deal.

A tabulation of the Federal executive departments or agencies with a major role in subjects affected by UV is presented in Table 4-II. Federal organizations with only minor or peripheral involvement are not mentioned.

Figures 4-1, 4-2, and 4-3 indicate the major breakdowns in UV research activity according to the various biological categories with basic research shown in the first and applied research in the later two. These figures and the foregoing table are not intended nor claimed to be complete, since they were based upon a limited, selective sampling of the literature. A somewhat more complete listing of organizations, subjects, and principal investigators is given in reference 1. In compiling the material for that reference and the current work, numerous organizations active in medical research and in photobiology are not mentioned at all. The intent is rather to indicate the nature of the overall activities by presenting a representative sample.

4.1.4 Information Flow and Use of Results

Since life is concentrated at or near the Earth's surface, it is subjected only to surface UV, which therefore is the real topic of concern in terms of biological effects. Stratospheric observations

TABLE 4-II
FEDERAL DEPARTMENTS AND AGENCIES WITH MAJOR CONCERN WITH UV

ORGANIZATION	ACTIVITY
1. Department of Agriculture	
1.1 Animal and Plant Health Inspection Service	Operational - animal inspection
1.2 Packers and Stockyards Administration	Operational - effects on food, animals
1.3 Agricultural Research Service	Research - UV effects on plants, farm animals
1.4 Forest Service	Forestry effects
1.5 Soil Conservation Service	Ecological effects
1.6 Cooperative State Research Service	Research by states on above topics
2. Department of Commerce	
National Oceanic and Atmospheric Administration	
2.1 National Weather Service	Operational satellite observations
2.2 National Marine Fisheries Service	Effects on marine fisheries
2.3 National Ocean Survey	Oceanic ecological effects
2.4 Environmental Data Service	Operational data transmission
3. Department of Health, Education, and Welfare	
3.1 Public Health Service	
3.3.1 National Institute of Health	
(i) National Cancer Institute	Human cancer effects
(ii) Nation Eye Institute	Opthalmological effects - human
(iii) National Institute of Arthritis, Metabolic, and Digestive Diseases	Dermatological effects - human
(iv) National Institute of Environmental Health	Environmental effects - human
(v) National Institute of General Medical Science	Basic research-cellular and molecular basis of disease

TABLE 4-II (Continued)

ORGANIZATION	ACTIVITY
3. Department of Health, Education, and Welfare (Continued)	
3.1.2 Food and Drug Administration	
(i) Bureau of Radiological Health	Safety standards, exposure effects and control methodology
(ii) Bureau of Drugs	Synergistic photosensitive effects on humans
(iii) Bureau of Foods	Synergistic photosensitive effects on humans
3.2 Health Resources Administration, National Center for Health Statistics	Providing data to researchers
4. Department of Interior	
4.1 National Park Service/U.S. Fish and Wildlife Service	Ecological effects - sport fisheries, game
4.2 Office of Water Resources and Technology	Ecology - water quality
4.3 Office of Land Use and Water Planning	Ecological effects
4.4 Bureau of Land Management	Ecological effects
4.5 Bureau of Reclamation	Ecological effects
5. State Department	
Assistant Secretary for Oceans and International Environmental and Scientific Affairs	International programs-policies, proposals
6. Department of Transportation	
Assistant Secretary for Systems Division and Technology	
Climatic Impact Assessment Program (e.g.)	Overall research

TABLE 4-II (Concluded)

ORGANIZATION	ACTIVITY
7. Environmental Protection Agency	Potential regulatory aspects
8. National Academies of Science and Engineering	Advisory aspects
9. Smithsonian Institution	
Radiation Biology Laboratory	Basic research

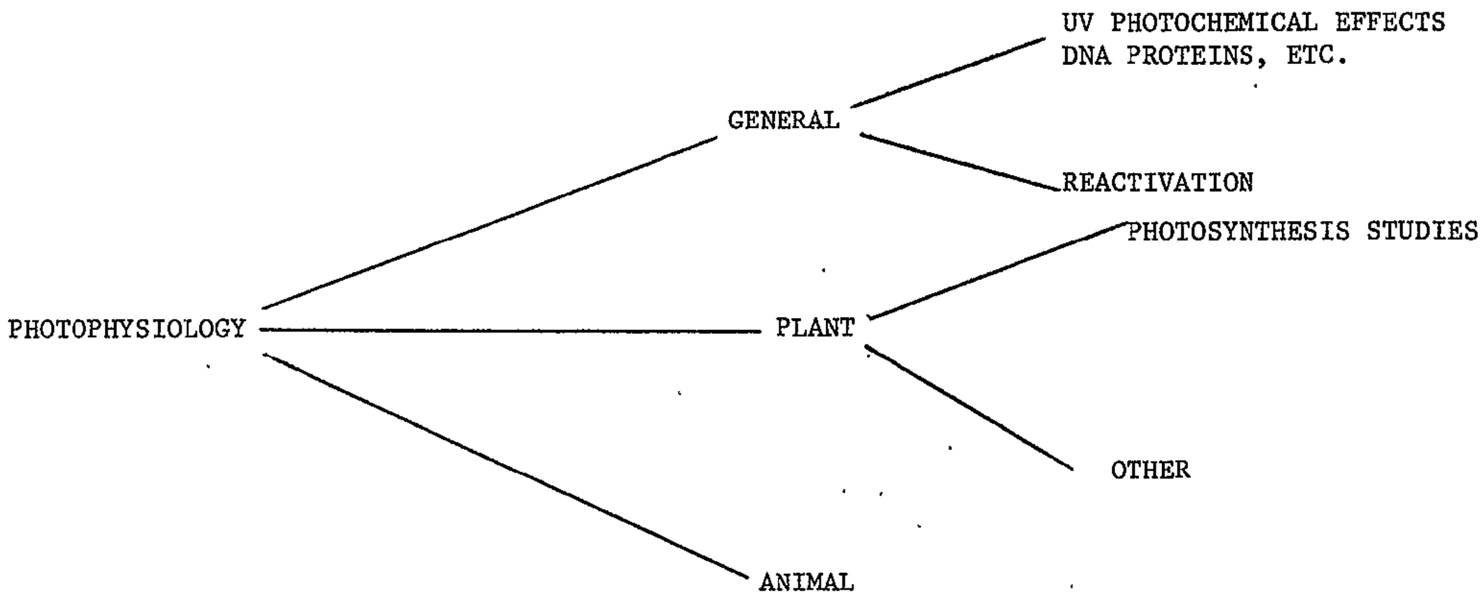

FIGURE 4-1
BASIC RESEARCH ACTIVITY

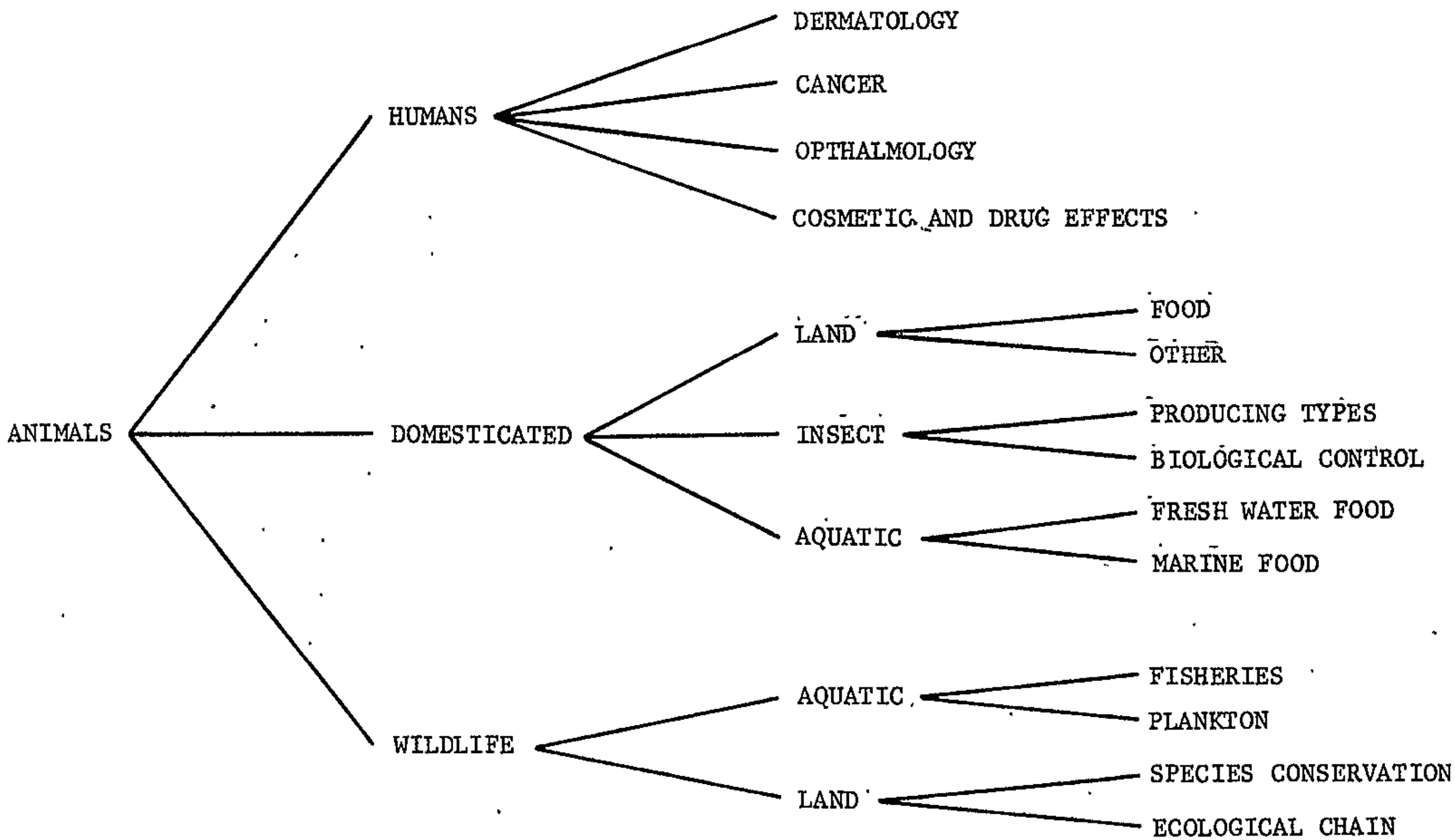

FIGURE 4-2
APPLICATIONS ACTIVITY – ANIMALS

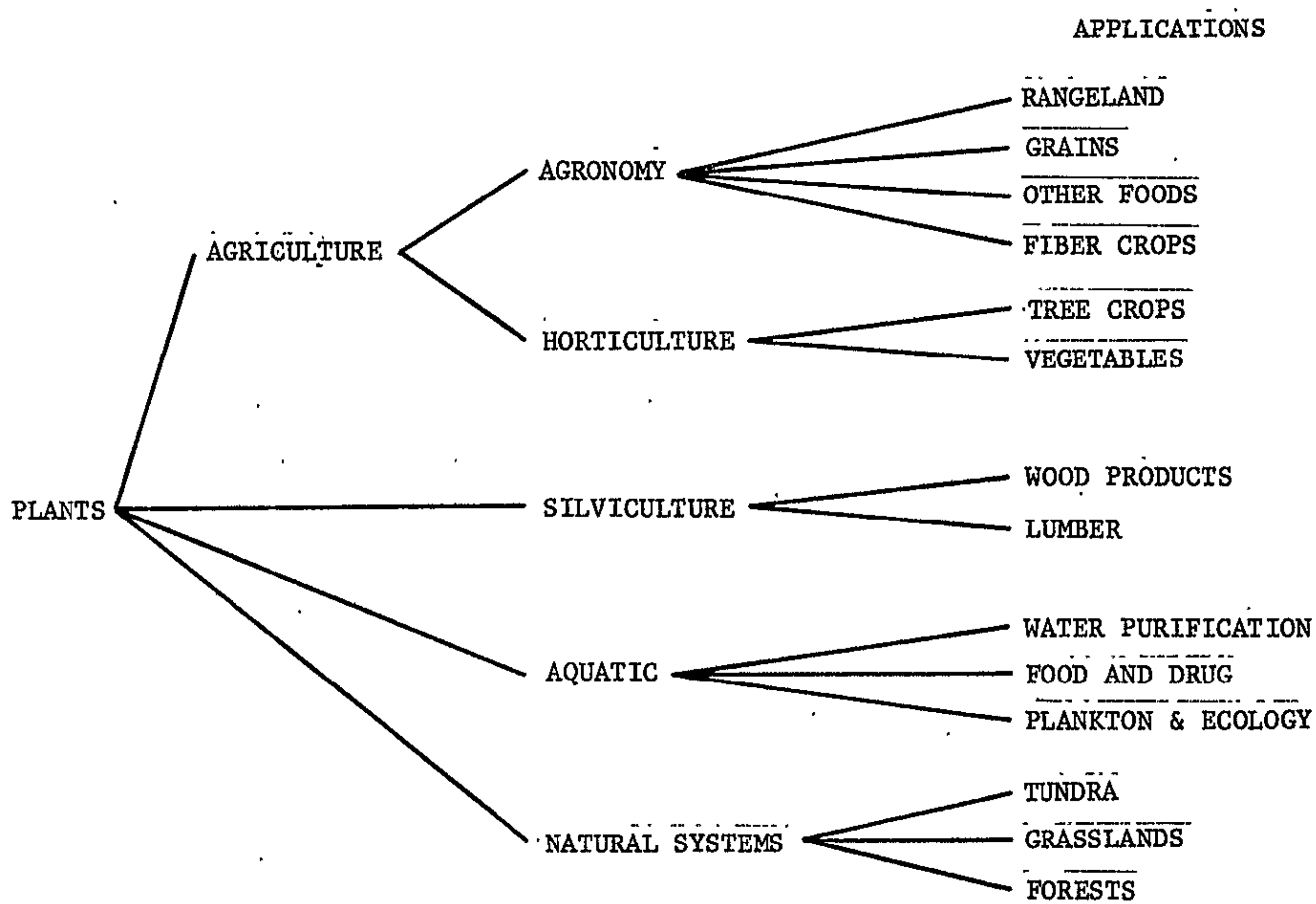

FIGURE 4-3
APPLICATIONS ACTIVITY — PLANTS

are of interest generally only to predict the surface intensities. Thus, research on biological effects is only at best an indirect user of satellite observations, i.e., these researchers are interested only in the long-term predictions which the atmospheric and climatic models can make on the basis of such observations.

At present the only users of surface UV observations, among the community concerned with biological effects, are research workers. Their use is in statistical correlation of surface UV intensity with the incidence of various biological phenomena, and with the recording, and perhaps modification, of surface UV levels during ongoing experiments. They may also be used for correlative purposes. Thus, there are no operational users of UV data as distinct from research users, nor is there now any obvious future operational need for stratospheric UV monitoring for biospheric effects.

Operational surface UV monitoring in the future may be a possibility as one part of a system for the early detection of long-term trends in biological effects, such as skin cancer, and their correlation with UV. However, in light of the large and slow variations in surface UV which normally exist, this would probably only be part of a large statistical survey system, i.e., the "operational" use does not present a real-time requirement in the same sense as weather observation.

Note that the research approach used can affect the data requirements very strongly. For example, the attempt to use statistical methods and modeling techniques to correlate UV with skin cancer, requires much data. A few deterministic experiments with mice, on the other hand, prove that UV can create skin cancer. In fact, the two methods are complementary, for the experimental approach provides no basis for prediction of the increase in cancer to be expected from a given increase in surface UV.

Thus, the large classes of people who are undoubtedly concerned with UV may be termed beneficiaries, rather than direct users, of any UV observations. They are users of the applictions research work in biological effects, since this research work affects their actual practices. The research workers in biological effects are the users of surface observations, and of the predictions furnished by climatic modelers. The last group are potential direct users of both satellite and surface measurements.

4.1.5 Measurement Requirements for UV Studies

It is clear from the material of this section that the predominant interest in the field of UV in the biosphere is in interaction of biological systems with UV. Until recently, little interest had been expressed in the interaction between the UV environment and conditions of the atmosphere. As a result, it appears that this field is dominated by users far removed from the ability to effectively utilize observations which describe the state or variability of those features of the atmosphere which control UV transmission.

There is at the same time considerable interest in measurements which will help clarify the physical and chemical processes which control the UV environment. There is an evident gap between those groups of users. That gap can only be filled by scientists interested in the interdisciplinary study of the coupled system of biosphere and atmosphere.

Specific measurement requirements are not clear, particularly because the largest potential group of users is not specifically interested in the physics or chemistry of the atmosphere but rather the reaction of biological systems to changes in their environment. The most effective method for establishing priorities is as suggested in Section 4.4, where the constituents which play a role in determining the UV transmission of the stratosphere are identified as key subjects of an experimental program. However, some general requirements for support in the field can be developed.

First, it is clear that a topic of primary concern is the intensity and wavelength distribution of ultraviolet radiation at the Earth's surface. Inference of this data from spacecraft measurements provides a unique opportunity to supplement the world-wide network of ground stations and provide more comprehensive coverage in space and time.

Secondary studies would include determination of the variability of radiation features, studies of the influence of polluting gases on the atmospheric transmission in the UV spectrum and data which relates the UV environment to biological variability.

Clearly, further direct NASA contact with those studying the subject will begin the communication cycle so necessary if experiments are to be developed which satisfy these users.

4.2 Influence on Climate

Climate effects are much more pervasive than those defined in the previous section for ultraviolet (UV). In the case of UV, the chain of concern is traceable from the stratosphere directly to the well-defined set of users, both direct and indirect. For climate, the end point of such a consequence chain is much more diffuse. Nearly everyone is concerned, in some degree at least, with climate and the effects of climatic modifications. This interlocking relationships with all human affairs gives climate a more profound influence upon terrestrial life than that attributed to the UV chain.

These considerations dictate a different approach than that taken in the UV section. In this section, the user community will be restricted to the primary users of remotely sensed data, with the tacit understanding that the ultimate users are omnipresent. For purposes of discussing the general areas of climate study, the primary user community will be divided into two categories, modeling (including physical processes) and monitoring. The interests and requirements of each category will be discussed separately, although there is considerable overlap in both interests and activities between the two groups.

4.2.1 Modeling and Studies of Physical Processes

The total system which comprises the Earth's climate is extremely complex and highly interrelated. With the attendant risk of over-simplification, it is usually desirable to separate the system into various components. These components result not only from the different spatial regimes which help to define them but, also, from the differing techniques of observation involved in the description of their characteristic processes.

By considering the processes rather than the spatial location, it will be easier to visualize the interactions and other effects which will be treated in subsequent sections. The major processes to be considered are: radiation, cloud, surface and atmospheric. Each will be defined below.

4.2.1.1 Radiation Processes. The most fundamental driving force for Earth's climate is solar irradiance. While the effects of this external energy may be modified by surface and atmospheric effects, it remains the single most important element in the entire climatic system. For purposes of climate modeling, the most useful inputs are the boundary fluxes and the internal sources and sinks of the atmosphere. Solar radiation, in all spectral bands, provides the major input to the system, while scattering and reradiation provide the primary outputs. All of these parameters are amenable to measurement from satellite platforms.

4.2.1.2 Cloud Processes. Clouds influence the terrestrial climate in several distinct ways:

- By reflection, absorption and emission of solar and terrestrial radiation;
- By the redistribution of heat and momentum through condensation and evaporative processes; and
- By the ground-atmosphere coupling provided by precipitation.

The modeling community is interested in the areal and temporal variations in cloud types and coverage. The interactions of radiation, local turbulence, large-scale circulation and microphysical processes need to be investigated further.

4.2.1.3 Surface Processes [47]. The interaction with the Earth's land areas produce profound atmospheric effects with climatic implications. One of the more basic aspects is found in the surface albedo, which may range from 0.1 to 0.9 for land areas. Other parameters of interest are the surface topography, land use and distributions of moisture. These directly affect the transfer of momentum and energy from the atmosphere as well as the surface emissivity.

The world's oceans represent the largest component of thermal and mechanical inertia on the Earth's surface. This is due to their high heat capacity and the long time constants found in the oceanic circulation processes. Most of the interactions of the air-sea boundary are determined by the temperature of the sea surface itself. Very little data is available on ocean parameters and their time and space variability. Vertical and horizontal movements of warm and cold water masses impact upon local climate directly and through the air-sea interface, influence atmospheric processes on a much larger scale.

Ice cover, both sea and terrestrial, exerts a large influence upon the Earth's climatic system. Seasonal variations in snow cover and sea ice are extremely large and alter the surface-atmosphere interface as well as the albedo. In the case of sea ice, changes also are produced in the sea surface conditions and in the upper ocean layers. From the hydrological standpoint, ice sheets of Greenland and Antarctica alone, contain 80 percent of the Earth's fresh water supply. Although any changes in these ice sheets occur on time scales of the order of 10^5 years, their presence impacts directly on models of the short-term climatic variability.

4.2.1.4 <u>Atmospheric Processes</u> [47,48]. With the exception of cloud processes, which are described separately, atmospheric processes may be conveniently grouped into the generic headings of gases and aerosols. As examples of the gases of primary concern, carbon dioxide, ozone and freons will be described in this section. In subsequent paragraphs, other species will be described which may impact either directly upon the climate system or upon other gases and aerosols.

Carbon dioxide (CO_2) has a relatively high and spatially constant concentration in the Earth's atmosphere, on the order of 320 ppm.

This concentration has been rising with man's increased burning of fossil fuels and is expected to increase another 20 percent by 2000 A.D. The major concern with increasing CO_2 levels is in its ability to absorb infrared radiation and thereby influence the Earth's heat budget and climate. The effects of high levels of CO_2 upon the biosphere is also a matter of increasing concern since some studies have indicated that the ability of the oceans and land plants to take up CO_2 is decreasing as the ambient levels increase.

Ozone has a highly variable concentration in the atmosphere. Section 4.2 has addressed the effects of ozone depletion on the biosphere. There is a climatic effect attributable to ozone as well. It provides the principal mechanism for radiative heating of the stratosphere. This heating results from the absorption, by ozone, of solar radiation, mainly in the ultraviolet region of the spectrum. The stratospheric heating determines the relative stability as well as the dynamic behavior of the stratosphere and, thus, the interactions with the troposphere where most climatic processes occur. Much more information is required on the natural spatial and temporal variability of ozone in the stratosphere before meaningful predictions can be made on the effects of manmade pollutants.

An example of trace gases which may impact indirectly upon the climatic system is found in the freon family of chemicals. Primary concern with freons is centered in their deleterious effects upon the stratospheric ozone and the subsequent effects of increased UV-B radiation on the biosphere. More recent interest in the photochemical reactions in which freons take part is centered in the potential climatic effects of ozone depletion. The direct impact of ozone absorption on the warming of the stratosphere and troposphere was mentioned above. A recent article [49] considers the infrared absorption by the chlorofluorocarbons themselves and concludes that this mechanism may enhance the greenhouse effect with a concomitant impact upon the climate chain.

Atmospheric aerosols are the result of both natural and antropological processes. While aerosols are found in both the troposphere and stratosphere, the sources are thought to be different in most cases. Complex homogeneous and heterogeneous chemical reactions are the source of most aerosols. Some direct injection does occur in both altitude regimes. Volcanic eruptions may increase the background stratospheric aerosol level by as much as a factor of 50 in the case of major eruptions [50]. These perturbed levels may remain for periods of 3 to 5 years. In the case of the troposphere, direct injection is attributable to sea spray and mineral dust particles. Most aerosols, however, in both the troposphere and stratosphere, are the result of gas to particle conversion. Major gases involved in these reactions are SO_2, NH_3, NO_2 and hydrocarbons, from either natural or manmade sources [47]. The density and size distribution is a strong function of relative humidity as they depend upon the absorption of water for their growth. The effects of aerosols on the climate are twofold: changes in the radiation budget through their scattering and absorptive properties, and providing condensation nuclei for cloud formation.

4.2.2 Climatic Monitoring Programs [51]

In late 1961, the National Academy of Sciences proposed the establishment of several international programs in atmospheric science. These recommendations were subsequently adopted by the United Nations General Assembly and form the basis for the present international programs administered by the World Meteorological Organization (WMO) in consultation with the International Council of Scientific Unions (ICSU). The first result of these proposals was the creation of the World Weather Watch (WWW) with the required regional weather service centers and the necessary telecommunications system to link them together in a world-wide network. In 1967 WMO and ICSU agreed to co-sponsor a Global Atmospheric Research Program (GARP), and created the Joint Organizing Committee (JOC) to define and direct all efforts within the GARP.

The Federal Committee for Meteorological Services and Supporting Systems approved the plan for U.S. participation in GARP in 1970 and assigned planning responsibility to NASA. Goddard Space Flight Center (GSFC) was delegated this responsibility by NASA Headquarters at the same time.

4.2.2.1 Current Status [47,52]. Many of the current efforts were originally instituted as weather programs. Since climate may be considered as the historical statistics of weather, the variables are similar and weather data is the major input to climatological data banks.

Data from operational satellite systems is assembled by NOAA's National Environmental Satellite Service (NESS) and becomes available to the atmospheric research community. Satellite data will increase in both importance and volume in the years ahead. They will provide man's first global view of the Earth's climate system.

Within the framework of GARP, several regional observational programs have already been performed. The GARP Atlantic Tropical Experiment (GATE) has had a short data collection phase in 1973 and a 3 month long observation period in 1974. The Air-Mass Transformation Experiment (AMTEX) has completed three phases, one each year from 1973-1975. The Polar Experiment (POLEX) has been underway since 1973 and will continue into mid-1978. The Monsoon Experiment (MONEX) has had two collection periods to date, 1973 and 1975. At least one more MONEX is planned for mid-1977. The Complex Atmospheric Energetics Experiment (CAENEX) ran from 1973 through early 1976.

4.2.2.2 Planned Programs [47,51,52]. The next major international program planned for this time is the First GARP Global Experiment (FGGE). Scheduled for 1977-1978, this will utilize the expanded facilities of the World Weather Watch, five geostationary satellites, two polar orbiting satellites, a combination of dedicated ships and carrier ballons, buoys and constant level balloons, and special automatic ground stations. FGGE represents the first major attempt at global coverage for an extended time period. The Global Experiment has four major objectives:

(1) Obtain better understanding of atmospheric motion for the development of more realistic models for extended range forecasting, general circulation studies and climate.

(2) Assess the ultimate limit of predictability of weather systems.

(3) Develop more powerful methods for assimilation of meteorological observations and, in particular, for using nonsynchronous data as a basis for predicting the large-scale motion.

(4) Design an optimum composite meteorological observing system for routine numerical weather prediction of the larger-scale features of the general circulation.

The timing of FGGE is such that both MONEX and POLEX will overlap with the Global Experiment. This will allow a study of model capabilities to simulate the start of the southwest Asian monsoon in the case of MONEX, and increased data coverage in the polar regions with POLEX.

As a result of the Global Experiment, it is felt that most of the requirements for a permanent global monitoring capability will have been identified. Such a monitoring system could become a reality in the 1980's. The U.S. involvement in FGGE will be major.

Overall GARP coordination has been assigned to NOAA, preliminary planning for FGGE is the responsibility of NASA, while NSF is responsible for university support of all GARP-related activities. NASA is also planning and managing the Data Systems Test (DST) for the Global Experiment.

While FGGE represents a major phase of the United States climatic effort for the next several years, there will continue to be purely domestic programs. NASA has a continuing satellite development program planned through the 1980 time frame. Examples of satellites which will have climatic or meteorological capability are TIROS-N, NIMBUS-G, SEASAT, and SAGE. NASA will continue to develop instruments and platforms for satellite missions while NOAA will assume operational control of monitoring capabilities subsequent to launch.

4.2.3 Climatic Data User Categories and Their Requirements

In order to present an overview of the data requirements of the climatological community, an analysis was designed to reflect particular uses and categories of users who might be important in a number of areas relating to experiment definition [1]. Sources of information for this analysis included previous experience obtained during evaluation of the Earth Energy Experiment [53] study, field interviews and comprehensive literature survey.

Three basic branches of climatological data utilization were addressed:

- Climate modelers - whose goal is long-term prediction of global atmospheric and oceanic circulation as well as the statistics of variation of climatic variables.

- Atmospheric physicists - whose goal is a clearer understanding of the physical and chemical processes occurring in the atmosphere including the effects of changes in atmospheric constituents and albedo as a result of pollution, land use and other anthropogenic activity.

- Monitoring - for climatological archive development.

It should be clear that improvements in models and validation of their results will rely on results produced by the last two categories of users. An overlap in research areas is common.

Governmental interest and awareness of the need to study and monitor potential climatic change has been increasing even to the extent that congressional action is underway [121] to provide direct support to climatic related activities. At the same time major agencies of the government are formulating plans for agency involvement in these climatic activities. NASA [122] has published a proposal for climatic programs supported by satellite and other space activities. In addition the Energy Research and Development Agency is undertaking a program of study of climate/energy problems.

4.2.3.1 Modelers. Within the modeling community, further distinctions can be drawn. There are two major groups engaged in the development of a capability for predicting the time evolution or time averaged statistics of future climates. The groups include climate modelers who utilize general circulation models and those who have developed global one- or two-dimensional models of climate. Each of the modeling groups has its own specific requirements. The tables shown later in Section 4.4 present a summary of the general measurement requirements as derived from the analysis. Of course, the requirements expressed are by no means unique to any individual group but rather represent the requirements of the community as a whole.

4.2.3.2 Physical and Statistical Studies. In order to satisfy the needs of this user group, a slightly different approach must be taken. Two major categories of experiments can be defined which support work of this type. Simply because climate and its variation is the topic of interest, it is clear that long-term and uninterrupted data represents one of the goals. Historically, this data has been provided by a number of individual sensing stations reporting on a periodic basis. The utilization of more advanced techniques, including satellite-based remote observations, will allow the measure of several additional parameters on a global, synoptic basis. Among these data are the solar constant, albedo, long and shortwave fluxes, cloud patterns, trace gases and vertical profiles of temperature and humidity.

In addition to the requirement for long-term data, it is clear that an ideal measurement program would also provide data of high absolute accuracy with a spatial and temporal sampling rate which at least compares with the typical averaging intervals of climate models, such as 30 day averages and 5° x 5° surface grid (for model validation).

Experiments of this type, which are characterized by the GATE experiment, need not be as long as the monitoring role discussed above nor need they provide the same level of coverage.

In summary, this group will require, for a number of different applications, experiments which range widely in spatial, temporal and radiometric requirements.

4.2.3.3 Monitoring. Clearly, the requirement in this area is to provide reliable, long-term calibrated data which can be used to initialize and carry out a program of observation of features of the climate which are observable from space. As mentioned elsewhere in the report, spacecraft probably should not be expected to perform this role without assistance from the many ground-based observing stations which have been in use for many years and have provided the information available to date. The unique feature of spacecraft which will justify their utilization is their ability to make global observations at a high rate and to measure features not observable from Earth.

As discussed in Section 4.4, the requirements for the types of experiments will include virtually anything which can be observed. While the sampling rate and spatial resolution requirements cannot be clearly stated, the general unavailability of global data sets will guarantee the use of any archive which offers such quality.

4.2.3.4 User Needs Conclusions. Summarized below are the results of the various sources of information and relationship of them to the specific goal of the study. The comments represent MITRE's interpretation of the various user requirements.

- Some of the numerical measurement requirements expressed by the users are merely best informed opinions. To date, little sensitivity analysis has been reported in the modeling community with the exception of solar constant, aerosols and CO_2. Other features, particularly those related to radiation climatology remain to be studied in order that model-specific measurement requirements can be expressed. While it is not clear how well the various requirements expressed represent what will be found in a detailed analysis, a number of these contacted felt that discrepancies could result. A related result is that it is almost universally felt that a minimum of 3-4 years will be required for the completion of the required sensitivity studies or for the completion of the model development so that such studies can be performed.

- The wide variation in the user goals has guaranteed that no one experiment represents a unique or essential part of the program. This is particularly appropriate in the case of radiation climatology which retains a level of importance which is quite high. While there is scientific interest in an experiment of that type due to pervasive features of radiation in climatology, only the users specifically interested in understanding the role of radiation in the climate feel that this experiment is of unique value. The value of the experiment is most limited in the case of the modelers who face considerable problems with the parameterization of complex systems such as clouds, although the information could be of value in those cases where the model predicts the radiation field and data is needed for validation rather than initialization. However, many other climate features emerge as being utilized as representative of climate and its variability. In fact, for the use of those who study the physical and statistical features of the climate, it is clear that the largest number of experiments possible are required.

- For optimum support of the global climate models, the measurements will have to be long-running but will not require the high absolute radiometric accuracy demanded by the general circulation models. In fact, due to the methods of model "tuning," trends in the data would be sufficient to be of value to the global models. The use of the data in the service of the GCM's, however, will generally require highly detailed experiments of relatively short duration (approximately 1 year) which include measurements of a number of interactive features of the climate (temperature and cloudiness, radiation properties and albedo, etc.), on a scale which is at least regional. These models will also be well served by the short-term experiments of the GARP type which can provide details unavailable from space but which are complemented by spacecraft measurements.

- Based on current usage, the demands of the modeling community on the quality and completeness of the data archive is the highest of any user community.

- The data archive already extracted from spacecraft measurements has been used by only a limited number of scientists mostly in the areas of physical processes and validation of model output. Further exploitation of those older archives could be of value.

- Experiments of the type discussed will have application under any conditions just because they add to the store of information which describes the climate and its variability. However, NASA should not expect the results of any single experiment alone to have a significant impact on the quality of the models currently under development. In fact, it is hard to imagine any single experiment, regardless of length or data quality, heavily impacting the capabilities of the predictive models. The limitations they face at this time go deeper than the quality of the initialization or validation data.

- The current use of radiation climatology, especially that obtained from space, has been to validate the results of model predictions, initialization of particular features of the models, and generation of parametric relationships for model development. The majority of the data appears to have been used for model validation although examples of each type of use can be found.

4.3 Specific User Measurement Requirements

The previous sections have had as their goal the identification of users, their general uses of data and their general measurement requirements if they exist. This section seeks to summarize all that has been learned concerning the specific numerical measurement requirements which must be met in atmospheric observation so as to serve the wide variety of interested users. The data presented in this section includes that data which was obtainable from interested users and MITRE's opinion as to other measurement requirements.

A major source of particular requirements is meetings and conferences held to address these issues. Over the last few years, a number of such conferences and meetings have been held, including the participation of a number of interested organizations, related to the assessment and prediction of climate and its relation to atmospheric properties. As a result of a survey of these conferences, a list of their requirements has been organized into Tables 4-III and 4-IV. In addition, requirements of specific experiments (like the GARP, GATE and FGGE) have been included.

Inspection of the tables indicates the considerable detail of the identified measurement requirements. Similar detail cannot be developed in the case of UV effects. However, because of the intimate link between atmospheric properties and the UV environment of the biosphere, the data presented in the tables represents a reasonable set of requirements for monitoring for eventual changes in climate or UV.

The preceding discussion and tables represent an amalgamation of the user requirements from the scientific and monitoring communities as represented by interviews and in the literature. With the present pace of stratospheric investigation, it should not be surprising to find additional species achieving requirement status. Therefore, it is prudent to assess the status periodically.

TABLE 4-III

GENERAL MEASUREMENT REQUIREMENTS OF GLOBAL CLIMATE MODELS

	Radiation Transfer (longwave, shortwave, solar)	Physical Cloud Features (height, type albedo, global distribution)	Atmospheric Features (temperature, wind, humidity)	Land Features (temperature albedo)	Trace Constituents (gases, aerosols)	Ocean Features (surface temperature, circulation)	Cryosphere (ice and snow cover)
Duration	In excess of 3 years →	→	→	→	→	→	→
Time	← Start within 3 to 4 years →	Radiation properties needed in future					
Spatial Resolution	Regional of little interest. Global averages required.	Global average. Multiple layer resolution may be required.	Zonal average of 500 mb temperature. Profile desirable of humidity and temperature.	Zonal	Aerosols on a regional scale. Water vapor one year average.	Zonal	Zonal
Temporal Resolution	← Yearly average →				Decade average for gases other than water vapor		
Radiometric Resolution	High resolution not required	High resolution not required	Moderate	Trends more important than absolute measurement	Moderate	Desirable	Desirable
Coverage	Global →	→	→	→	→	→	→
Importance	Desirable but not a complete experiment	Cloud top temperature and albedo highly desirable for model validation	Moderate interest	Moderate	Moderate	Desirable	Desirable
Use	Parameterization	Parameterization	Parameterization	Parameterization	Parameterization sensitivity studies	Parameterization sensitivity studies	Parameterization

TABLE 4-IV

GENERAL MEASUREMENT REQUIREMENTS FOR A GENERAL CIRCULATION MODEL
(including coupled models)

	Radiation Transfer (longwave, shortwave, solar)	Physical Cloud Features (height, type albedo, global distribution)	Atmospheric Features (temperature, wind, humidity)	Land Features (temperature albedo)	Trace Constituents (gases, aerosols)	Ocean Features (surface temperature, circulation)	Cryosphere (ice and snow cover)
Duration	← 1 year →						
Time	← Begin in 3 to 4 years →						
Spatial Resolution	Regional with equator-pole variation	Cloud top height and cloud distribution	Profiles	Regional	Regional	Regional	Regional
Temporal Resolution	5 to 15 days	5 days	5 days	5 days	5 to 15 days	5 days	5 to 15 days
Radiometric Resolution	High	High	High	Moderate	Moderate	Moderate-high	Moderate
Coverage	Global →						
Importance	Highly desirable	Highly desirable	Desirable, especially winds	Desirable	Low, except ozone	Highly desirable	Desirable, especially ice cover and snow cover
Use	Parameterization validation	Validation	Initialization parameterization validation	Parameterization validation	Parameterization validation	Parameterization validation	Parameterization validation

In addition to the requirements defined above for domestic research requirements, the WMO-ICSU has developed a set of requirements for the GARP. Some of the more pertinent of these are given in the following tables. Tables 4-V and 4-VI represent the preliminary requirements for model validation and monitoring definition. Tables 4-VII through 4-X address the tentative measurement requirements for a long-term monitoring program as now envisioned. Results from FGGE and other programs will undoubtedly modify some of these stated requirements. The final table, 4-XI, presents the opinions of experts in climatic effects.

In addition to the measurement requirements expressed by the various user meetings, measurement requirements have been developed by evaluating the constituents which play a major role in the chemistry of the stratosphere. The importance of any one constituent varies somewhat, depending upon the potential user, from absolutely necessary to desirable. An effort has been made to harmonize these requirements and place them in context with the proposed application.

TABLE 4-V

OBSERVATIONS REQUIRED FOR VALIDATION OF CLIMATE MODELS[47]

	VARIABLE	ACCURACY (1σ) Desired	ACCURACY (1σ) Useful	TIME RESOLUTION
1.	Net radiation budget at top of atmosphere (solar and terrestrial)	2 Wm^{-2}	15 Wm^{-2}	5 days
2.	Clouds: horizontal distribution of clouds and measure of diurnal variation	5% amount 1°C cloud top temp.		5 days
3.a)	Sea surface temperature	0.5°C	1.5°C	5 days
b)	Heat content of upper layer (200 m)	1 kcal cm^{-2}	3 kcal cm^{-2}	5 days
4.a)	Snow (100 km resolution)	Presence/Absence		5 days
b)	Sea ice (50 km r[illegible])	Presence/Absence		5 days
5.	Surface albedo	0.01	0.03	5 days
6.a)	Precipitation over land	1 mm/day	3 mm/day	5 days
b)	Precipitation over sea*	1 mm/day	4 levels of discrimination	5 days
7.	Soil moisture*	10% of local field capacity	2 levels of discrimination	5 days
8.	Runoff(river basin)	10%		15-30 days
9.	Land surface temperature and relative humidity (over land)	1°C 10%		5 days
10.	Ozone Profile (2 km vertical resolution)	0.5 ppm		5 days
11.	Wind stress over ocean	0.1 dyne cm^{-2}	0.4 dyne cm^{-2}	5 days

*The tentative specification of useful accuracy for precipitation and soil moisture cannot be used for critical quantitative checking of heat and hydrological budgets, but could be useful for qualitative evaluation.

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TABLE 4-VI

DATA REQUIREMENTS FOR FGGE[47]

BASIC PARAMETERS		HORIZONTAL RESOLUTION (km)	VERTICAL RESOLUTION		ACCURACY	FREQUENCY*
			TROPOSPHERE	STRATOSPHERE		
Mid and High Latitudes	Temperature	500	4 Levels	3 Levels	± 1°K	1/day
	Wind	500	4 Levels	3 Levels	± 2m/sec	1/day
	Relative Humidity	500	2 Degrees of Freedom		± 30%	1/day
	Sea-Surface Temperature	500			± 1°K	3 day avg.
	Pressure	500			± 0.3%	1/day
Tropics**	Wind	500	4 Levels	3 Levels	± 2m/sec	1/day
	Temperature	500	4 Levels	3 Levels	± 1°K	1/day
	Relative Humidity	500	2 Degrees of Freedom		± 30%	1/day
	Sea-Surface Temperature	500			± 1°K	3 day avg.

Additional Parameters:

- Cloud, Snow and Ice Cover
- Precipitation Area and Intensity
- Soil Moisture
- Earth Radiation Budget
- Sea Temperature/Currents
- Oceanic Variables in the Upper Mixed Layers
- Aerosols
- Stratospheric Constituents

*2 Per Day Would Be Highly Desirable for All Parameters Except Sea-Surface Temperature.

**Data Requirements for the Tropics are Currently Being Reexamined

TABLE 4-VII

TENTATIVE SPECIFICATION OF GLOBAL OBSERVATION OF GASES AND PARTICULATES [47]

Variable	Space Resolution	Time Resolution	Accuracy (1σ) of Determination	Period	Additional remarks, Observing Technique, Etc.
1. Water vapor	500 km	1 per day	1 per day	FGGE	
2. CO_2	2 to 4 baseline stations and 10 additional regional stations	15 days	± 0.1 ppm	FGGE-limited number of stations and post-FGGE	Chemical analysis of air sample
3. Ozone distribution	500 km - 2 km vertical resolution	1 day	± 0.5 ppm	FGGE	Backscatter UV spectrophotometry by NIMBUS-G
3a Total Ozone	Existing WMO network	1 day	1 to 5%†	FGGE	Ground-based optical measurements (preferably Dobson spectrophotometer)
3b Ozone Profile	10 stations distributed over the globe	1 week	± 1 ppm	FGGE	Ozonesonde profile measurement
4. Tropospheric Aerosols	WMO baseline air-chemistry stations	1 day	5%	FGGE	Aerosol analysis of air sample
5. Atmospheric Turbidity	WMO baseline stations	1 week	1%†	FGGE	Need to measure direct and diffuse radiation separetly
6. Stratospheric Aerosols	2 to 4 baseline stations	1 day	5%	FGGE	Lidar. Sunlight polarization

† relative accuracy

TABLE 4-VIII

AEROSOL PROCESSES-SUMMARY OF TENTATIVE OBSERVATIONAL REQUIREMENTS [47]

I. STUDY OF PROCESSES

a) Radiative effects of aerosols.

Required aerosol parameter for troposphere and stratosphere	Observational requirement and accuracy
Size distribution $\frac{dn}{dr}$ in cm^{-4} STP	5%
Vertical profile of size distribution	5% Required vertical resolution generally 0.5 to 1.0 kilometer
Real refractive index of bulk material n	1% over the range $1.0 \leq n < 2$
Imaginary part of the refractive index k	10% over the range $0.001 < k < 0.1$
Bulk density δ of aerosol particles, in g cm^{-3}	5% over the range $1.0 \leq \delta < 3.0$
Solubility of aerosol particles and/or growth characteristic with relative humidity	Use of 3 to 4 typical growth curves
For necessary data to calculate energy balance of the atmosphere	
b) Aerosol cloud interaction	Cannot be specified at this time.

II. MONITORING

Variables to be monitored	Space Resolution	Time Resolution	Accuracy
1) Total number concentration 2) Concentration of optically important particles 3) Total mass concentration 4) Concentration of gaseous precursors	about 20 baseline stations distributed over the globe	daily	5%

TABLE 4-IX

TENTATIVE SPECIFICATION OF LONG-TERM MONITORING REQUIREMENTS FOR RADIATION BALANCE COMPONENTS[47]

VARIABLE	ACCURACY (DESIRED)	ACCURACY (USEFUL)	TIME RESOLUTION
1. Solar irradiance (top of atmosphere) (reproduction accuracy required)	2 WM^{-2}	10 WM^{-2}	3-6 months
2. Net radiation budget (top of atmosphere) solar and terrestrial, 10^4-10^5 km^2	2 WM^{-2}	15 WM^{-2}	15 days
3. Clouds		*	*
4. Snow and sea-ice (10^4 km^2)	Presence/Absence		5-15 days
5. Carbon dioxide (2-4 baseline stations, 10 regional stations)	0.1 ppm		15 days
6. Ozone profile (latitudinal distribution, 2 km vertical resolution)	0.5 ppm		10-30 days

*Will be specified as more is learned of the radiative properties of clouds.

TABLE 4-X

TENTATIVE SPECIFICATION OF GLOBAL OBSERVATION REQUIREMENTS
FOR
VERIFICATION OF OCEAN MODELS

QUANTITY	SPACE SCALE*	TIME SCALE	ACCURACY (1 σ) (DESIRED)	(USEFUL)	PERIOD
Surface temperature	200 km	5-10 days	0.5°C	1.5°C	FGGE
Heat content upper layer**	200 km	5-10 days	1.0 kcal cm^{-2}	3.0 kcal cm^{-2}	—
Surface stress	200 km	5-10 days	0.1 dyne cm^{-2}	0.4 dynes cm^{-2}	—
Sea level	200 km	5-10 days	2 cm	10 cm	—
Ice cover	200 km	5-10 days	—	—	—

* The space scale is defined as a distance L, where a representative sample for a region LxL is desired. Extra resolution required in special regions.

** Measurements by drifting buoys, ships of opportunity.

TABLE 4-XI
TRACE SPECIES MEASUREMENT REQUIREMENTS FOR CLIMATE

CONSTITUENT	VERTICAL RESOLUTION km	ACCURACY	FREQUENCY	SPATIAL RESOLUTION km	COVERAGE	MEASUREMENT REQUIRED WITHOUT SPECIFICATION	REMARKS
O_3	*2[47]	Profile 10%[57] 0.5 ppm[47] Total 1-1.5%[47] 1%[57]	1 day average[47] and after volcanoes 30 day average[47] high rate not required[47]	100[47] high resolution not required[47]	global[47,57]		satellite monitoring considered especially appropriate[47]
CO_2	*	0.5 ppm[57]			global[57]	[4]	not expected from satellite measurements[47] attractive[35]
NO		ppb range[35] 10 ppb[40]			lower stratosphere[35,56] global[56,57]	[47,4]	
NO_2	*	ppb range[35] 10 ppb[57]			lower stratosphere[35,56] global[56,57]	[47,4]	
HNO_3	*	1 ppb[57]			global[57]	[47,4]	
H_2O		50 ppb			global[57]		
H_2O	*	1 ppm[35] profile 0.5 ppm[57] total 20%[57]	[illegible]	local or regional[47] latitudinal[35]	lower stratosphere[35,56] global[56,57]	[47,4]	expected from NIMBUS-F and G[47]
CO	*	10 ppb[57]	sporadically[47]		upper stratosphere[35] global[57]	[47,4]	
Fluorocarbon		<0.001 ppb[57]					
H_2						[47]	
SO_2		ppb range[35] 0.5 ppb[57]	A.V.E.[47] [illegible]		lower stratosphere[35,56] global[56,57]	[47,4]	
ClO_x			A.V.E.[47] [illegible][47]			[47]	
Particulates		0.01-0.1 μm[47]	A.V.E.[47]		global[35,56,57] lower stratosphere[35,56]		optical properties[35] distribution[56]
Aerosols	profiles desired[47]		A.V.E.[47]		large as possible in both hemispheres[47] [illegible]	[4]	SO_2 mixing ratio[47], particle size [47] spacecraft monitoring attractive but ground-based preferable[47]
N_2O	*	50 ppb[57] 5%[47]	occasionally[57]			[47]	
NMHC		ppb range[35]			lower stratosphere[35,56] global[56]		
Methane	*	0.2 ppm[57]			lower stratosphere[35,56] global[56,57]	[47,4]	
HCl, ClO_x, OH						[4]	

* - simultaneous vertical profiles[35]
A.V.E. - after volcanic eruptions

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5.0 SCIENCE REQUIREMENTS

A number of recent major study groups (CIAP, GARP, etc.) and many smaller ones have addressed the general question of man's interaction with and impact on the stratosphere. Further considerable interest has developed recently concerning the effects of the stratosphere (and its constituents) on man's environment--particularly weather, climate and the radiation environment. In the previous section (4.0) the results of many of these efforts were used to analyze user needs and present general measurement requirements. In this section the results of these efforts are summarized and used to develop a set of scientific requirements for stratospheric trace constituent measurements.

5.1 Background

5.1.1 Physical and Chemical Properties of the Stratosphere

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 many current stratospheric mathematical models is shown in Figure 5-1.

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 nitrous oxide (N_2O) is formed on the ground

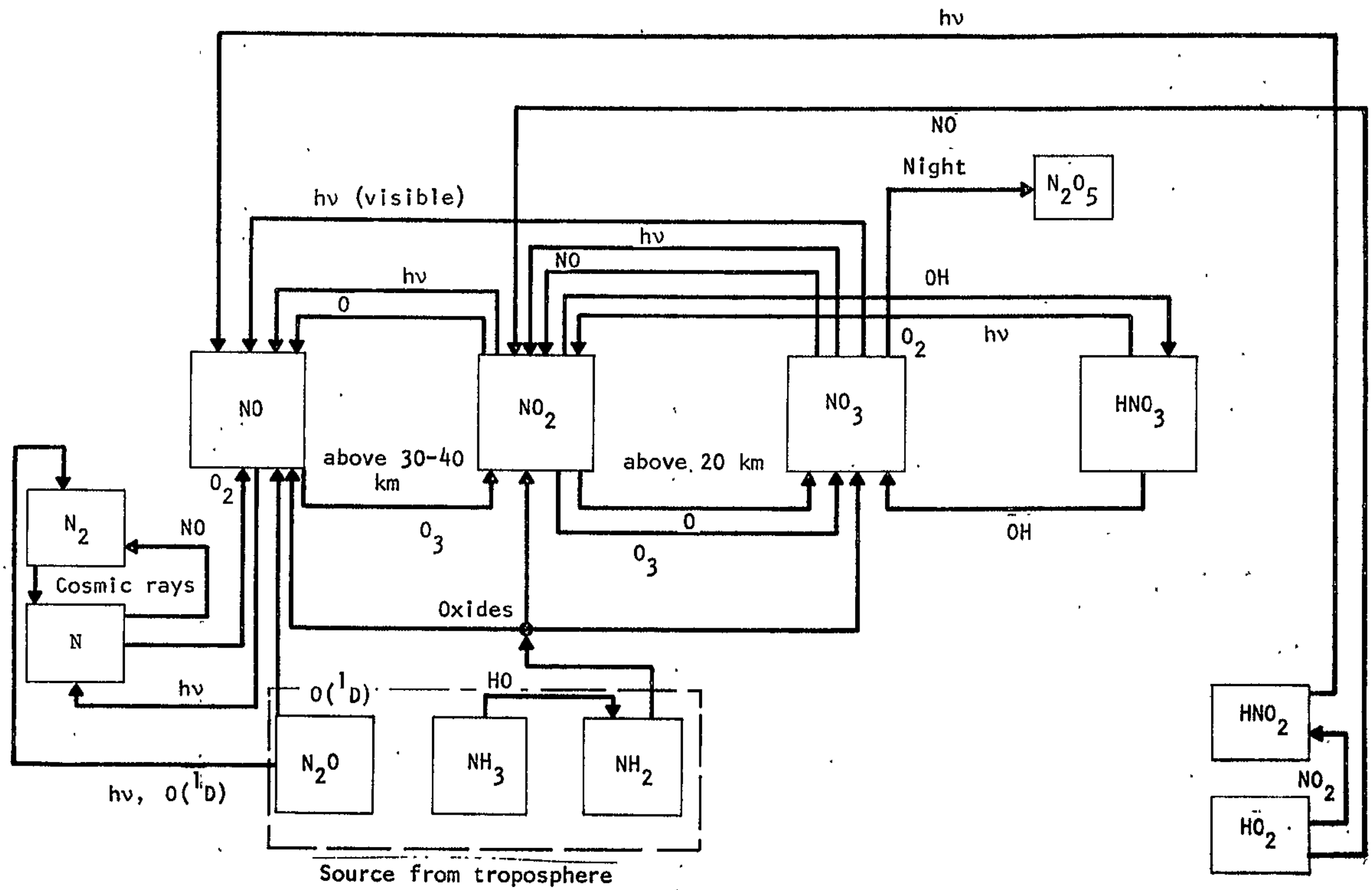

FIGURE 5-1
COMPLETE NITROGEN CYCLE USED IN CURRENT MATHEMATICAL MODELS

through biological processes and diffuses upward. Once NO is formed, a photochemical steady state is established between NO and nitrogen dioxide (NO_2). The reactions involved are:

$$NO + O_3 \rightarrow NO_2 + O_2, \quad (2)$$

$$NO_2 + O \rightarrow NO + O_2, \text{ and} \quad (3)$$

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

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

$$NO + HO_2 + M \rightarrow HNO_3 + M \quad (5)$$

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

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

which may possibly proceed through heterogeneous reactions involving ambient sulfate droplets or particles. HNO_2, and especially nitric acid (HNO_3), 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 hydrogen chloride (HCl) [58]. HCl can produce free chlorine which can, in turn, interact catalytically with O_3. A simplified diagram shows the interaction mechanisms, Figure 5-2.

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

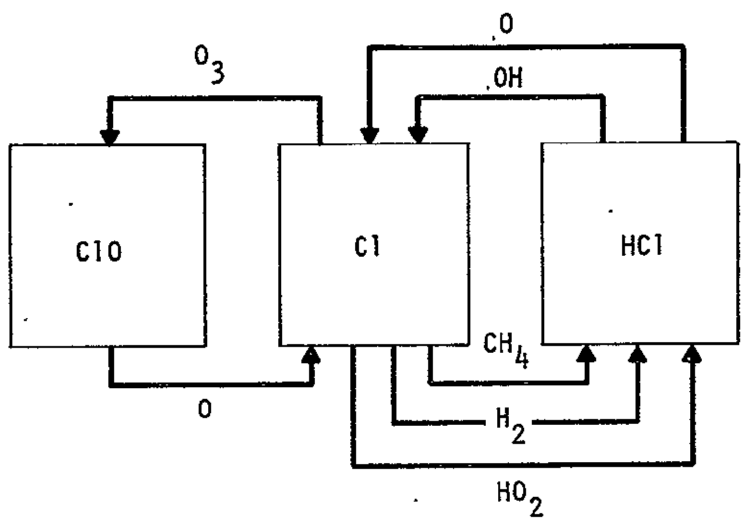

FIGURE 5-2
BASIC CHLORINE CYCLE

stratospheric chemistry [59]. 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. 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.

5.1.2 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, three 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 Space Shuttle, the engine effluent of concern is HCl. Hydrogen chloride acts as a catalyst to NO_x, thereby reducing the ozone. The aluminum oxide (Al_2O_3) 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 (0.19 to 0.225 μm) 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 in the stratosphere. The extensive use of bromine fumigants in agriculture could be a significant source. This usage combined with widespread application of nitrogen fertilizers forms the third possible large source of pollutants.

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 [60]. 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 (0.28-0.32 μm) 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 [39]. 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 belong to two chains. These chains are the UV chain and the climate chain.

5.1.3 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_x, CO_2, and H_2O, whose role and impact are fairly well understood, and aerosols, whose effects are not so well understood [47].

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, 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. Considerable ultraviolet radiation is 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. In addition to the absorption of solar radiation, the constituents 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.

5.2 Development of Scientific Criteria

The scientific criteria developed for stratospheric pollution measurements must have as their basis 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.

5.2.1 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 in a major way with both ozone and aerosol 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:

$$O_3 + h\nu\ (\lambda : 0.45\text{–}0.675\ \mu m) \longrightarrow O + O_2$$

$$O_3 + h\nu\ (\lambda : 0.31\text{–}0.34\ \mu m) \longrightarrow O_2 + O(^3P)$$

$O_3 + h\nu(\lambda < 0.31\mu m) \longrightarrow O(^1D) + O_2$

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

$O_3 + O \longrightarrow O_2 + O_2$

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:

$Cl + O_3 \longrightarrow ClO + O_2$

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.

5.2.2 Species and Properties of Interest

As stated previously, this section presents the list of stratospheric measurements that should be made or would be of interest. The measurements are grouped according to the criteria discussed in Section 5.2.1. These groupings were made after analyzing all available references that discuss the importance of the various species. Table 5-I presents this list along with the major references supporting the selection of the measurement and its placement in the appropriate group. A number of other references [49, 57-61, 74-103, 113-120] were consulted during preparation of the list.

5.3 Properties of the Species of Interest

In this section a summary of the properties of the measurements and species of interest is presented. Table 5-II 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 5.2.2). 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 5-I 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.

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
<u>GROUP 1A</u>, DIRECT MEASUREMENTS OF CLIMATIC CHANGE AND ULTRAVIOLET CHANGE														
Temperature	✓	✓	✓	✓	✓	✓				✓		✓	✓	✓
Solar Irradiance (including UV)	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Earth Radiance	✓	✓	✓		✓	✓				✓			✓	
<u>GROUP 1B</u>, SPECIES DIRECTLY ASSOCIATED WITH CHANGES IN CLIMATE AND/OR ULTRAVIOLET														
Water Vapor, H_2O	✓	✓	✓		✓	✓	✓		✓	✓		✓	✓	✓
Ozone, O_3	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Aerosols		✓	✓	✓	✓	✓	✓					✓	✓	✓
Carbon Dioxide, CO_2	✓	✓	✓					✓		✓		✓	✓	✓

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 2, IMPORTANT SPECIES ASSOCIATED WITH TWO OR MORE CHEMISTRY CHAINS														
Hydroxyl, HO	√	√	√		√	√	√	√	√	√		√	√	√
Atomic Oxygen, $O(^3P)$	√		√	√	√	√	√	√	√	√		√	√	√
Atomic Oxygen, $O(^1D)$	√		√	√	√	√	√	√	√	√		√	√	√
Ammonia, NH_3			√		√	√	√					√		

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
<u>GROUP 3</u>, COMPONENTS OF THE BASIC REACTIONS INVOLVED IN THE DIRECT PRODUCTION OR DEPLETION OF THE OZONE CONCENTRATION														
Nitric Oxide, NO	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Nitrogen Dioxide, NO_2	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Atomic Chlorine, Cl	✓		✓	✓	✓			✓	✓	✓		✓	✓	✓
Chlorine Monoxide, ClO	✓	✓	✓	✓	✓	✓		✓	✓	✓		✓	✓	✓
Hydrogen, H_2 or H	✓	✓	✓	✓		✓		✓	✓	✓		✓		✓
Hydroperoxyl, HO_2	✓		✓	✓		✓	✓	✓	✓	✓		✓		✓

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 4, MAJOR COMPONENTS OF THE BASIC REACTIONS INDIRECTLY INVOLVED IN THE PRODUCTION OR DEPLETION OF OZONE														
Nitrous Oxide, N_2O	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Nitrogen Pentoxide, N_2O_5	✓		✓	✓	✓	✓		✓					✓	✓
Nitric Acid Vapor, HNO_3	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Chlorine Nitrate, $ClONO_2$								✓	✓			✓		✓
Carbon Monoxide, CO		✓	✓	✓		✓				✓		✓	✓	✓
Methane, CH_4	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓	✓	✓	✓
Hydrogen Chloride Gas, HCl	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓
Trichlorofluoromethane, F-11, $CFCl_3$	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓
Dichlorodifluoromethane, F-12, CF_2Cl_2	✓	✓	✓	✓	✓			✓	✓	✓		✓	✓	✓
Sulfur Dioxide, SO_2	✓		✓		✓	✓	✓					✓	✓	

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
<u>GROUP 5</u>, OTHER SIGNIFICANT COMPONENTS OF THE CHEMISTRY CHAINS														
Tetrachloromethane, CCl_4 (Carbon Tetrachloride)	✓			✓				✓	✓	✓		✓		✓
Chloromethane, CH_3Cl (Methyl Chloride)				✓										
Dichloromethane, CH_2Cl_2 (Methyl Dichloride)				✓										
Trichloromethane, $CHCl_3$ (Chloroform)				✓										
Methanal, CH_2O (Formaldehyde)			✓											
Chlorodifluoromethane, F-22, $CHClF_2$								✓	✓					
Dichlorofluoromethane, F-21, $CHCl_2F$								✓						
Bromomethane, CH_3Br (Methyl Bromide)	✓							✓	✓	✓		✓		
Trichloroethylene, $CCl_2 = CHCl$									✓	✓				✓
Methylchloroform, CH_3CCl_3									✓	✓				✓
Trichlorotrifluoroethane, F-113, $CF_2ClCFCl_2$									✓					
Carbonyl Fluoride, F_2CO									✓	✓		✓		✓

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 5 (Continued)														
Fluoroformyl Chloride, ClFCO									✓	✓				✓
Tetrabromomethane, CBr_4 (Carbon Tetrabromide)	✓													
Methyl Peroxy Radical, CH_3O_2	✓													
Methyl Oxy Radical, CH_3O	✓													
Chlorodifluoromethane Radical, CF_2Cl^+	✓									✓				
Dichlorofluoromethane Radical, $CFCl_2^+$										✓				
Chlorine Dioxide, ClO_2	✓													
Methyl Sulfide, $(CH_3)_2S$												✓		
Carbonyl Sulfide, COS														✓
Carbon Disulfide, CS_2														✓
Dichloroethane, $C_2H_4Cl_2$														✓
Ethyl Chloride, C_2H_5Cl														✓
Carbonyl Monochloride, COCl														✓

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 5 (Continued)														
Tetrachloroethene, $Cl_2C:CCl_2$ (Perchloroethylene)														✓
Vinyl Chloride, $CH_2:CHCl$														✓
Hydrogen Sulfide, H_2S					✓	✓	✓					✓		
Hydrogen Fluoride, HF				✓					✓	✓		✓	✓	✓
Hydrogen Bromide, HBr				✓								✓		✓
Hydrogen Peroxide, H_2O_2	✓	✓	✓			✓		✓				✓		✓
Ammonium Ion, NH_4^+		✓				✓	✓							
Sulfur Hexafluoride, SF_6									✓	✓				✓
Sulfur Trioxide, SO_3	✓						✓					✓		
Bisulfite Radical, HSO_3^-							✓					✓		
Nitrogen Trioxide, NO_3	✓					✓						✓	✓	
Bromine Oxide, BrO												✓		✓
Atomic Bromine, Br												✓		✓

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 5 (Concluded)														
Atomic Oxygen, $O(^1S)$														✓
Oxygen, $O_2(^1\Delta)$														✓
Non-Methane Hydrocarbons, C_xH_y												✓		
Various Organics, $H_xC_yO_z$	✓													

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Continued)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 6, SPECIFIC AEROSOLS														
Aluminum Oxide Aerosol, nAl_2O_3	✓											✓		
Sulfuric Acid Aerosol, $H_2SO_4 \cdot nH_2O$	✓	✓	✓			✓	✓					✓		
Sulfate, $SO_4^{=}$	✓	✓	✓			✓	✓							
Sulfur Dioxide (in cluster formation), nSO_2		✓	✓											
Nitric Acid Aerosol, $nHNO_3$		✓	✓											
Nitrate, NO_3^-		✓	✓			✓	✓							
Nitrite, NO_2^-		✓					✓							
Nitric Oxide (in cluster formation), nNO			✓											
Nitrogen (in cluster formation), nN_2			✓											
Ammonium Ion Aerosol, nNH_4^+		✓	✓			✓	✓							
Ammonium Sulfate, $(NH_4)_2 SO_4$		✓	✓			✓	✓					✓		
Ammonium Peroxydisulfate, $(NH_4)_2 S_2O_8$			✓			✓								
Liquid Water or Ice (as aerosol or in cluster formation), nH_2O	✓	✓	✓											

TABLE 5-I

PRIORITIZED LIST OF DESIRED STRATOSPHERIC MEASUREMENTS
(Concluded)

NAME OF SPECIES/PROPERTY AND SYMBOL	MAJOR REFERENCES WHERE CITED													
	39	40	62	63	64	65	66	67	68	69	70	71	72	73
GROUP 6 (Concluded)														
Carbon Dioxide (in cluster formation), nCO_2			√											
Aluminum Ion, Al^{+++}		√												
Bromide Ion, Br^{-}		√	√				√							
Calcium Ion, Ca^{++}		√					√							
Chloride Ion, Cl^{-}		√	√				√							
Copper Ion, Cu^{++}		√	√											
Iodide Ion, I^{-}		√	√											
Iron Ion, Fe^{++} or Fe^{+++}			√											
Magnesium, Mg		√												
Manganese Ion, Mn^{++} or Mn^{+++}			√											
Potassium Ion, K^{+}		√	√											
Silicon Ion, Si^{++++}		√	√											
Sodium Ion, Na^{+}		√	√				√							

Explanations of the various columns in Table 5-II 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 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 some species with unknown distributions, vertical profile measurements are indicated as desired 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.

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GROUP 1	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
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 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
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; 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
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 midday, minimum at night	Maximum in summer, minimum in winter	Negligible	Unknown	No preferred launch time	Not required	Several decades
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 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
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; 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
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)	Negligible	Inversely proportional to tropopause height; i.e., seasonal	Unknown	Volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

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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TABLE 5-II
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

GROUP 1 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
1B CARBON DIOXIDE, CO_2	0.1%	C = 3 R = 2	3	Negligible	Negligible	Negligible	Negligible	Negligible	Unknown	Possible long-term increase	Short-term intermittent. Surveys with no preferred launch.	Not required	Several decades, intermittent
GROUP 2													
HYDROXYL, OH	AVM	C = 2 R = 0	2	Unknown	Unknown	Number density increases from 10 km to 45 km; constant 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
ATOMIC OXYGEN, $O(^3P)$	AVM	C = 1 R = 0	2	Unknown	Unknown	Mixing ratio increases with altitude by more than one order of magnitude from 25 to 45 km	None produced at night	Unknown	Unknown	Unknown	Short-term, daylight coverage	Required	Short-term
ATOMIC OXYGEN, $O(^1D)$	AVM	C = 1 R = 0	1	Unknown	Unknown	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
AMMONIA, NH_3	AVM	C = 0 R = 1	1 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	Unknown	Unknown	Unknown	Short-term, no preferred launch time	Required	Short-term
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 during daylight; rapid decrease after sunset	Maximum-summer; minimum-winter	Unknown	Unknown	Launch with emphasis on diurnal	Required	One-year minimum
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 night, decrease in daytime. Actual measurement shows opposite	Unknown	Unknown	Unknown	Launch with emphasis on diurnal	Required	One-year minimum
ATOMIC CHLORINE, Cl	25%	C = 0 R = 1	1 0.3 to 3 pptv at 30 km	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
HYPOCHLORITE, ClO (Chlorine Monoxide)	25%	C = 0 R = 0	1 30 pptv at 30 km	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

TABLE 5-II (CONTINUED)
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 3 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITIES	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION: LATITUDINAL	SPATIAL VARIATION: LONGITUDINAL	SPATIAL VARIATION: VERTICAL	TEMPORAL VARIATION: DIURNAL	TEMPORAL VARIATION: SEASONAL	TEMPORAL VARIATION: BEYOND ANNUAL	TEMPORAL VARIATION: NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
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	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
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	Unknown	Unknown	Unknown	High frequency of measurement over short time	Required	Short survey
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 ppmv at 30 km, and <0.01 ppmv at 45 to 50 km	None	Unknown	Unknown	Unknown	Intermittent measurements with no preferred launch time	Required	One-year minimum
NITROGEN PENTOXIDE, N_2O_5	AVM	C = 0, R = 0	0	Unknown	Unknown	Unknown	Formed at night, distributions unknown	Unknown	Unknown	Unknown	Launch with emphasis on diurnal	Required	Short survey
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 small	Maximum winter, minimum late spring	Unknown	Unknown	No preferred launch time	Required	One-year minimum
CHLORINE NITRATE, $ClONO_2$	AVM	C = 2, R = 0	T	Unknown	Unknown	Mixing ratio shows maximum of .75 ppbv at 25 km, decreasing above and below	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
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 a few km above tropopause, then constant to 39 to 40 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
METHANE, CH_4	20%	C = 2, R = 2	2	Unknown	Unknown	Mixing ratios range from 1.5 ppmv at the tropopause to 0.3 ppmv at 50 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
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 30 km relatively constant or possibly decreasing	Unknown	Unknown	Unknown	Unknown; possibly after volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum

TABLE 5-II (CONTINUED)
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 4 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
TRICHLOROFLUOROMETHANE, FREON 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 10 pptv at 30 km	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
DICHLORODIFLUOROMETHANE, FREON 12 (CF_2Cl_2)	AVM	C = 0 R = 0	1	Unknown*	Unknown*	200 pptv at 15 km decreasing to 50 pptv at 30 km	Unknown*	Unknown*	Unknown*	Unknown*	No preferred launch time	Required	Short survey to establish F-11/F-12 ratio
SULFUR DIOXIDE, SO_2	AVM	C = 0 R = 1	0	Unknown	Unknown	10^{-6} $\mu g/m^3$ at 20 km	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Required	Short survey
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)	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
HYDROGEN FLUORIDE, HF	AVM	C = 0 R = 1	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Desired	Short survey
HYDROGEN BROMIDE, HBr	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
TETRACHLOROMETHANE, CARBON TETRACHLORIDE, CCl_4	AVM	C = 0 R = 0	1	Unknown	Unknown	0.1 ppbv at 15 km decreasing above	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
CHLOROMETHANE, METHYL CHLORIDE, CH_3Cl	AVM	C = 0 R = 0	1	Unknown	Unknown	.75 ppbv at 15 km decreasing above	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
DICHLOROMETHANE, METHYLENE CHLORIDE, CH_2Cl_2	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
TRICHLOROMETHANE, CHLOROFORM, $CHCl_3$	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
HYDROGEN PEROXIDE, H_2O_2	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
AMMONIUM ION, NH_4^+	AVM	C = 0 R = 0	T	Unknown	Unknown	Estimated 0.005 $\mu g/m^3$ at 20 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey

*Theoretically should be proportional to FREON 11 concentrations

TABLE 5-II (CONTINUED)
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

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GROUP 5 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
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	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
VARIOUS ORGANICS, $H_xC_yO_z$	AVM	R = 2 R = 1	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
GROUP 6 (Aerosols)													
SULFURIC ACID, $H_2SO_4 \cdot nH_2O$	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	Estimated negligible	Estimated inversely proportional to tropopause height	Unknown	After volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
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	Estimated negligible	Estimated inversely proportional to tropopause height	Unknown	After volcanic activity	No preferred launch time, except after volcanic activity	Required	One-year minimum
SULFUR DIOXIDE, nSO_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Possibly after volcanic activity	After volcanic activity	Required	Short survey
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	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
NITRATE, NO_3^-	AVM	C = 2 R = 0	1	Unknown	Unknown	Estimated 0.1 to 0.14 $\mu g/m^3$ at 18 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
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 $\mu g/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
NITRIC OXIDE, nNO (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
NITROGEN, nN_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
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 $\mu g/m^3$	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

GROUP 6. (Continued)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION			TEMPORAL VARIATION				REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
				LATITUDINAL	LONGITUDINAL	VERTICAL	DIURNAL	SEASONAL	BEYOND ANNUAL	NON-SPECIFIC			
AMMONIUM SULFATE, $(NH_4)_2SO_4$	AVM	C = 0 R = 0	0 Existence indicated by only one investigation team	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
AMMONIUM PEROXYDISULFATE, $(NH_4)_2S_2O_8$	AVM	C = 0 R = 0	0 Existence indicated by only one investigation team	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
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	Theoretically maximum late afternoon; minimum at night	Maximum summer, minimum winter	Unknown	Weather patterns affect lower stratosphere	No preferred launch time	Required	One-year minimum
CARBON DIOXIDE, nCO_2 (In cluster formation)	AVM	C = 0 R = 0	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Desired	Short survey
ALUMINUM ION, Al^{+++} Σ(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	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
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 5×10^{-12}g/g to 8×10^{-12}g/g	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
CALCIUM ION, Ca^{++} Σ(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	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
CHLORIDE ION, Cl^-	AVM	C = 2 R = 0	1	Unknown	Unknown	0.54 $\mu g/m^3$ at 20 km. 0.0028 to 0.0077 $\mu g/m^3$ at 18 km	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
COPPER ION, Cu^{++}	AVM	C = 2 R = 0	1	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
IODIDE ION, I^-	AVM	C = 2 R = 0	1	Unknown	Unknown	Filter data at 16 to 18 km shows 0.05 μg per 25 cm^2 filter and 2 hr. sample	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
IRON, ION, Fe^{++} or Fe^{+++}	AVM	C = 2 R = 0	1	Unknown	Unknown	Estimated <2% of total aerosol	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

TABLE 5-II (CONTINUED)
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

5.4 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.

A prioritization of properties and species has been developed. This prioritization was based principally on the relative role any given property or species pays 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 purely on the needs of the scientific community 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.

GROUP 6 (Concluded)	DESIRED ACCURACY	PRESENT MEASUREMENT CAPABILITY	PRESENT KNOWLEDGE OF DISTRIBUTION	SPATIAL VARIATION: LATITUDINAL	SPATIAL VARIATION: LONGITUDINAL	SPATIAL VARIATION: VERTICAL	TEMPORAL VARIATION: DIURNAL	TEMPORAL VARIATION: SEASONAL	TEMPORAL VARIATION: BEYOND ANNUAL	TEMPORAL VARIATION: NON-SPECIFIC	REQUIREMENTS FOR TIME OF LAUNCH	VERTICAL PROFILE	DURATION OF MEASUREMENT PROGRAM
MAGNESIUM ION, Mg^{++} Σ(Al+Ca+Mg+Si) estimated at 0.05 μg/m^3 at 20 km altitude	AVM	C = Q R = Q	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
MANGANESE ION, Mn^{++} or Mn^{++++} (Of 35 filter samples, 18 showed no Mn; other 17 averaged 0.00114 μg/m^3 in 15 to 19 km altitude range)	AVM	C = Z R = Q	1	Unknown	Unknown	Filter data at 15 to 19 km shows 0.001 μg/m^3	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
POTASSIUM ION, K^{+} (Ion detected but quantitative measurement impossible due to low concentration)	AVM	C = Q R = Q	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey
SILICON ION, Si^{++++} Σ(Al+Ca+Mg+Si) estimated at 0.05 μg/m^3 at 20 km altitude	AVM	C = Q R = Q	0	Unknown	Unknown	Unknown	Unknown	Unknown	Unknown	Probable increase after volcanic activity	Before and after volcanic activity	Required	Short survey
SODIUM ION, Na^{+}	AVM	C = Z R = Q	1	Unknown	Unknown	0.01 μg/m^3 at 20 km, 0.013 to 0.0056 μg/m^3	Unknown	Unknown	Unknown	Unknown	No preferred launch time	Required	Short survey

TABLE 5-II (CONCLUDED)
PRESENT KNOWLEDGE OF STRATOSPHERIC DISTRIBUTIONS AND GENERALIZED MEASUREMENT REQUIREMENTS

6.0 ORBITAL INFLUENCES AND INSTRUMENT PERFORMANCE

6.1 Orbital Influences

As in any spacecraft mission, compromises must be made in the selection of the orbit based on the ideal coverage and available instrumentation. Monitoring of the stratosphere is no exception. Maximum spatial and temporal sampling is required because of the generally scant information on the global distribution and time variance of the various stratospheric constituents. These requirements are discussed in Sections 4.0 and 5.0 where a common feature is the requirement for global coverage.

A general set of instrument/orbit criteria has been derived from other sections of the report. As expected these criteria include requirements for:

- diurnal sampling,
- the largest possible latitude coverage,
- frequent periods when the various types of instrumentation can monitor the same region for corroboration of data quality, and
- seasonal sampling.

This section is devoted to the interplay of the various generic types of instruments and possible orbits in order to quantify the sampling characteristics. The discussion will center about two topics:

(1) properties of the orbit, instrumentation, and resulting coverage of the globe, and

(2) appropriateness of a set of instrument/orbit parameters for monitoring a set of significant stratospheric constitutents.

Some topics which will be utilized in the evaluation of a monitoring system include properties of the orbit, influences of the solar position as a function of position in the orbit, and season of the year. The influence of mean cloud cover, day/night performance, and the spatial distribution of selected stratospheric constituents will be discussed.

6.1.1 Orbit Parameters

A number of potential orbits have been considered. For example, a typical sunsynchronous orbit provides morning equatorial crossing and high inclination circular orbits. Typical orbital parameters are found in Table 6-I. Similar parameters are used in the subsequent sections to determine the latitudes over which occultation and nadir measurements can be made, and to identify any operational limitations.

6.1.2 Instrument Operation

The performance of the remote sensors being considered in this document is greatly influenced by the selection of the spacecraft orbit. The position of the Sun, with respect to the spacecraft for a variety of orbital and seasonal conditions is important in determining global coverage. Table 6-II compiles the basic requirements for each generic type of sensor system. Each of the four cases depicted in Table 6-II will be discussed in this section.

TABLE 6-I

TYPICAL ORBIT PARAMETERS UTILIZED IN THE ANALYSIS
(representing a sunsynchronous, high inclination, circular orbit).

PROPERTY	VALUE	UNITS
Equatorial Crossing Time	0900	hours
Altitude	958	km
Period	104.3	minutes
Westward displacement per orbit	26.1	° of longitude
Orbits per day	13.8	-
Inclination	99.3	°
Precession Rate	0.986	°/day relative to Earth
	0.0	°/Day relative to Sun

TABLE 6-II

SENSOR REQUIREMENTS ON SOLAR POSITION DURING MEASUREMENT IN ORBIT

	Solar Source	Reflected Solar Source	Thermal
Limb (Occultation)	Sun must appear in stratospheric limb	–	Sun must not appear in FOV
Nadir	–	Local elevation angle must be large enought to provide adequate radiance	Sun not required

6.1.2.1 Limb - Solar Source (Occultation). Limb instrumentation utilizing the Sun as a radiation source has a large potential for monitoring the stratosphere. The resulting high signal-to-noise ratio and sensitivity are ideal performance criteria. However, instrumentation of this type is limited to a short measurement period per orbit (0.5 - 3 minutes for both the sunrise and sunset) as well as to the location of measurements which are concentrated in relatively narrow latitude bands.

Figure 6-1 illustrates the experiment configuration. The tangent point is some distance from the spacecraft and produces a measurement made through a large segment of the stratosphere. By definition, the tangent point, which moves about 21 km during a given sunrise or sunset, is called the data point.

An important computation is the determination of the latitudes covered (defined by the data points) as a function of the season. Since it takes approximately five days for the spacecraft (with an orbit similar to that in Table 6-I) to repeat coverage of a given ground point, the orbit to orbit variations in latitude can be ignored. However the small changes in latitude coverage for each succeeding orbit result in large seasonal changes which must be taken into account when computing maximum and minimum latitude coverage for the different seasons. For sunsynchronous orbits, the designed precession rate of the satellite orbit plane guarantees

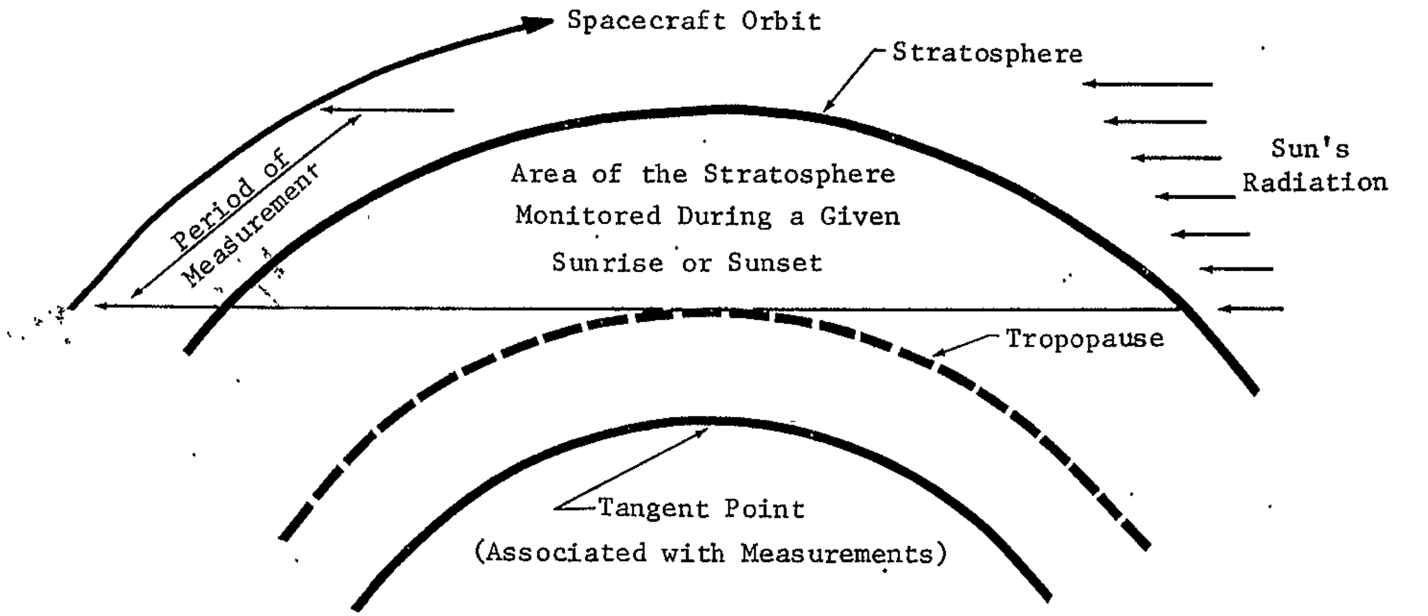

FIGURE 6-1
EXPERIMENTAL CONFIGURATION DURING SOLAR OCCULTATION EXPERIMENT

that a constant angle exists between the plane of the orbit and the Earth-Sun line.

The latitude coverage is defined by determining the tangent point, which is the intercept of the Earth with the satellite-Sun line. Calculations of this type have been performed for a variety of sunsynchronous and other orbits. A typical set of results of the coverage obtained are depicted in Figures 6-2 and 6-3, for sunsynchronous and non-sunsynchronous orbits, respectively.

Data of this type make it clear that limb instruments in sunsynchronous orbits using the Sun as a radiation source have several disadvantages:

- the range of latitude sampled is quite restricted,
- each latitude is seen a maximum of only four times per year (90 days apart),
- the measurement period is quite short (on the order of minutes),
- no diurnal sampling of various latitudes,
- no seasonal sampling of various latitudes, and
- each data point represents the integral of the observed constituent along a substantial path thereby providing limited spatial resolution.

Use of non-sunsynchronous orbits avoids the first two limitations, thereby more nearly satisfying the requirements for near-global coverage. However, the interpretation of the data, in order to obtain the desired spatial resolution, demands considerable attention.

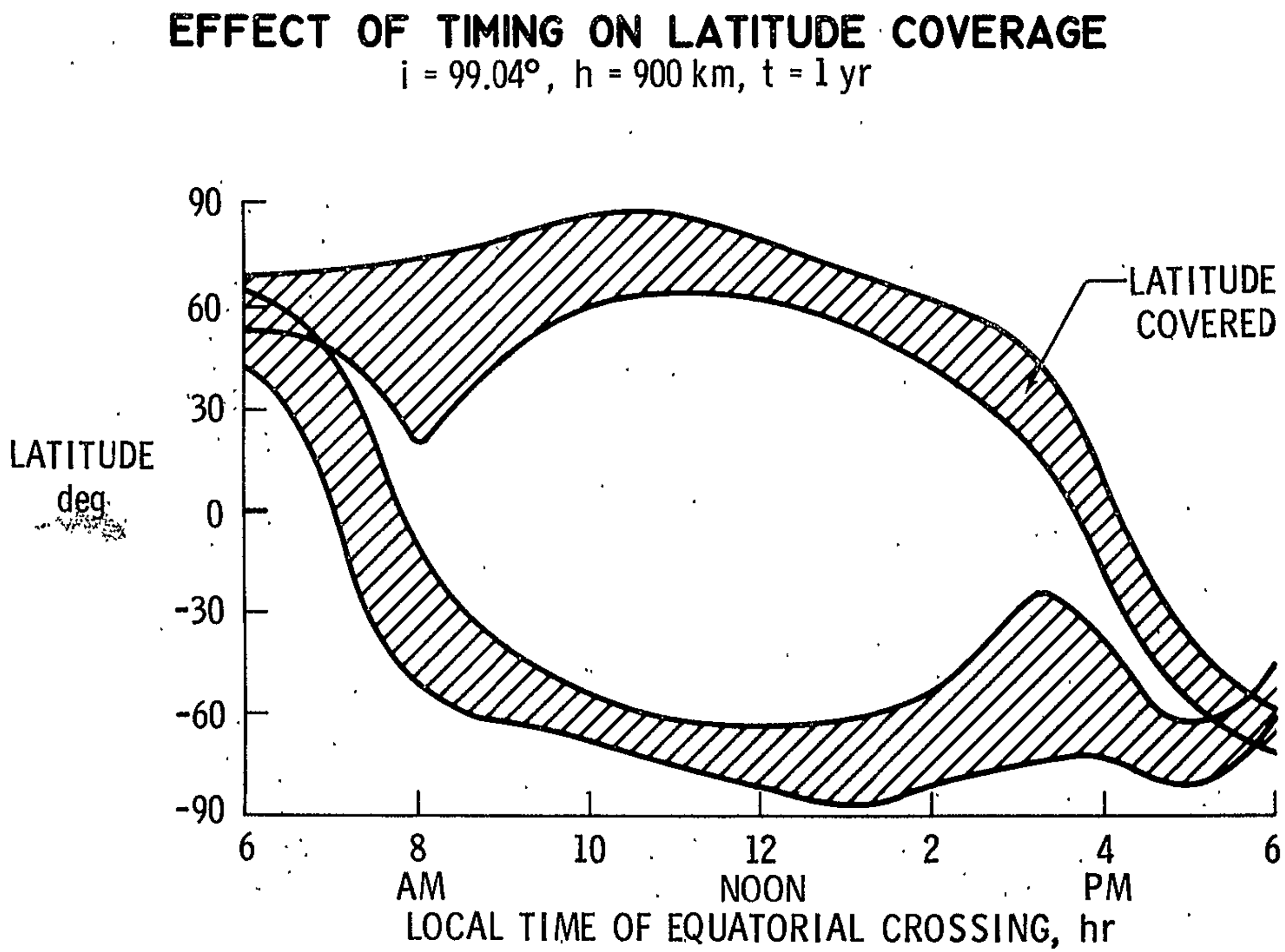

FIGURE 6-2
LATITUDE COVERAGE OF SOLAR OCCULTATION INSTRUMENTATION IN TYPICAL SUN-SYNCHRONOUS ORBITS [103]

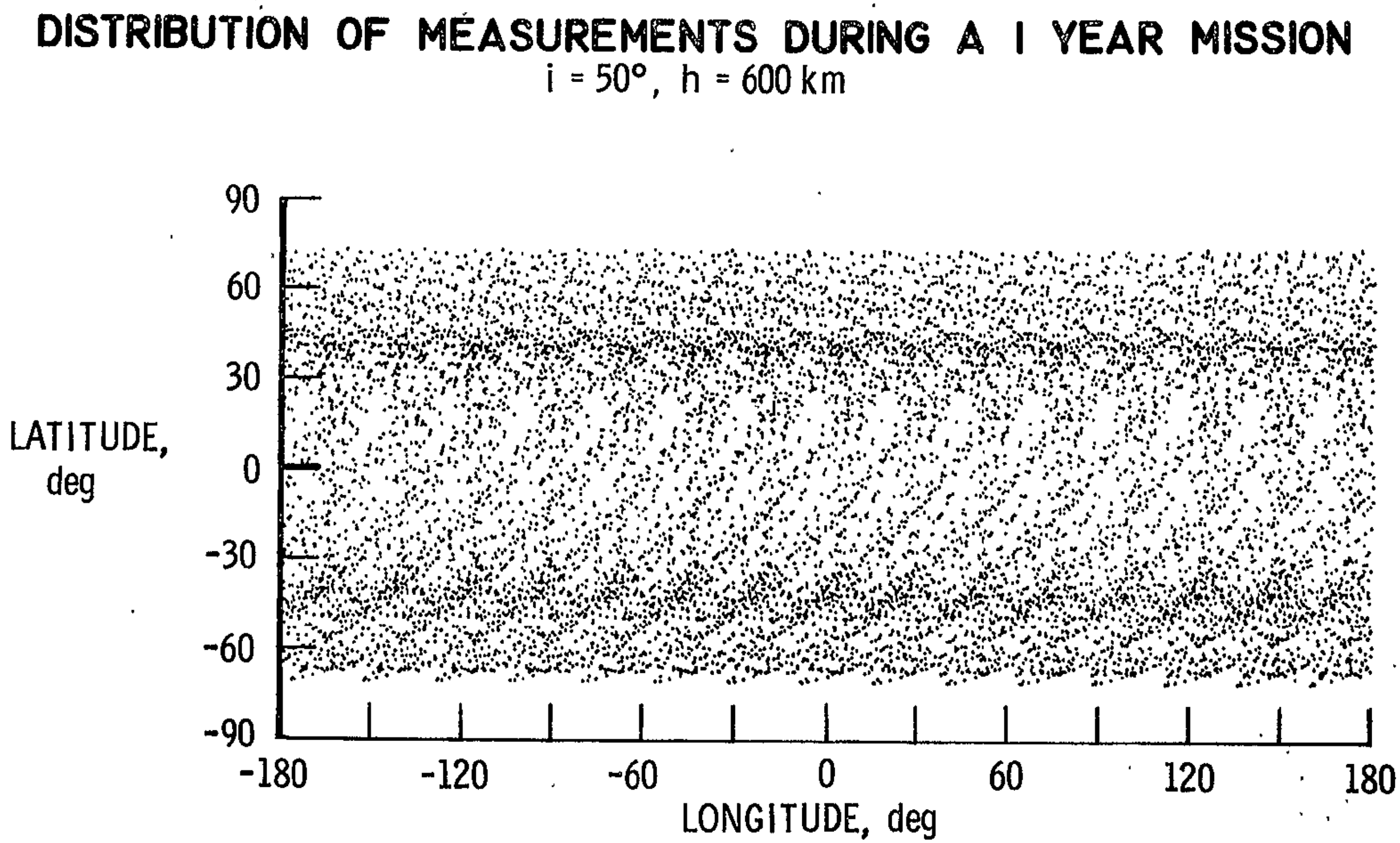

FIGURE 6-3
SAMPLING CHARACTERISTICS OF SOLAR OCCULTATION INSTRUMENTATION IN A NONSUN-SYNCHRONOUS ORBIT. EACH DOT REPRESENTS A DATA POINT [103]

6.1.2.2 Reflected Solar Source. Nadir-looking sensors, which rely on reflected solar radiation, are limited in their operation to those areas where the local solar zenith angle is sufficiently small to provide adequate radiance. Consequently, latitude coverage, as a function of season, is limited. An example of this limitation follows for a nominal solar zenith angle of 45°, the latitudes covered as a function of season of the year and time of the descending node, are illustrated in Figure 6-4 for three equatorial crossing times.

Clearly, such coverage provides monitoring of the Northern Hemisphere during the summer periods and the Southern Hemisphere between September 21 and March 21. The value of such coverage has yet to be determined, but several points can be made:

- latitude coverage is maximized in each hemisphere only once per year,
- seasonal variations in each hemisphere cannot be monitored,
- the equatorial regions (approximately 10°N to 10° S) can be monitored almost continuously for orbits with descending nodes between 9:30 and noon, and
- maximum coverage is obtained for 12:00 noon orbits allowing continuous monitoring for latitudes from 23.5° N to 23.5° S.

The results indicate that nadir-reflected solar instrumentation has a quite limited geographic coverage under the given conditions. Improved performance can be expected if elevation angles of

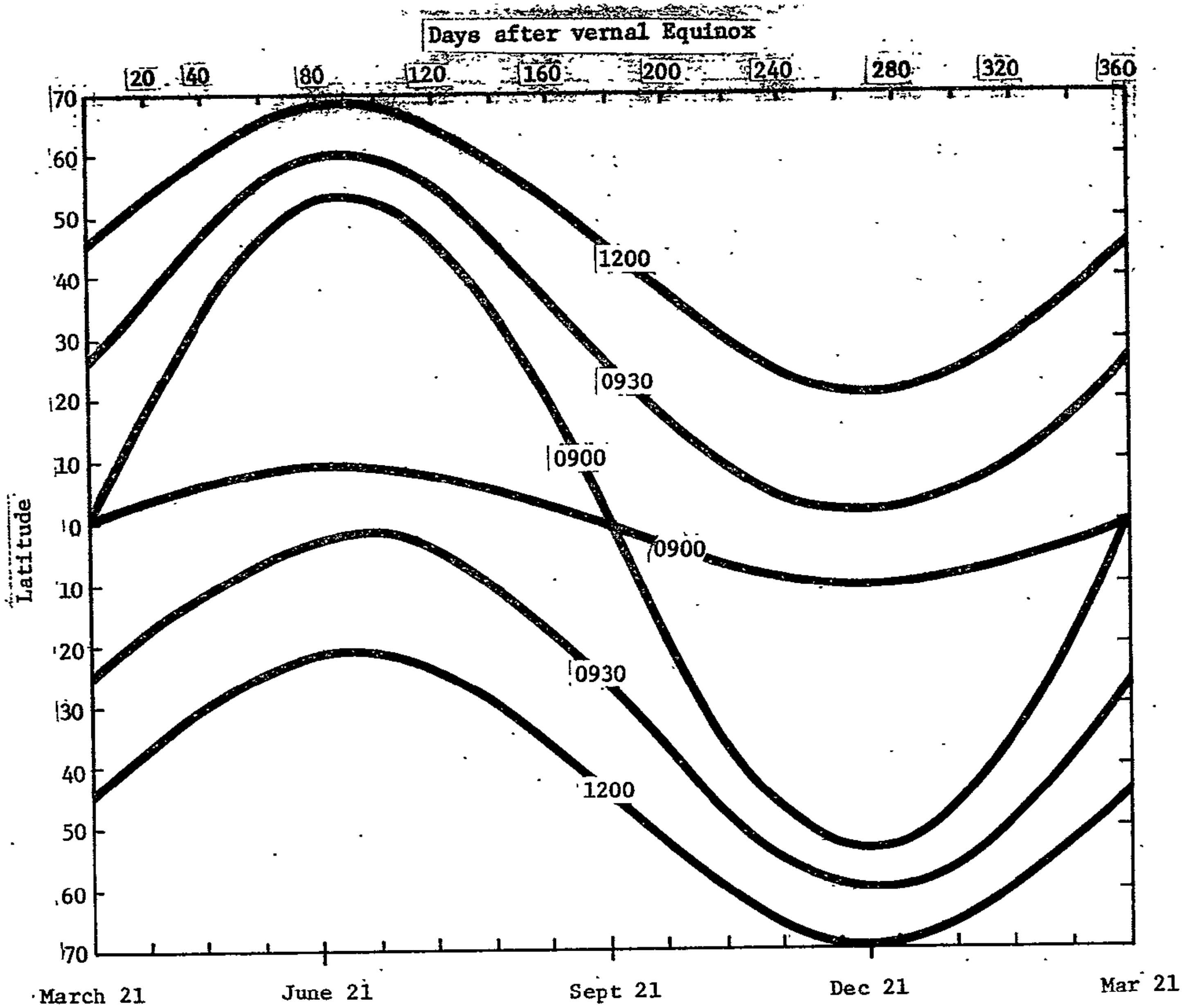

FIGURE 6-4

LATITUDES FOR WHICH THE SOLAR ELEVATION ANGLE EXCEEDS 45° AS A FUNCTION OF SEASON AND TIME OF THE DESCENDING NODE. AREAS COVERED ARE BOUNDED BY THE APPROPRIATE CURVES less than 45° can be used. The selection of a non-sunsynchronous orbit would improve the coverage to some extent although the dominant feature remains the variation of the Sun's position throughout the year.

The occurrence of cloud cover over the globe, as well as instruments relying upon ocean radiation as a source, also limit sensitivity. Significant limitations in the operation of near-infrared instrumentation can be anticipated under these conditions, thus further reducing the area coverage.

6.1.2.3 Nadir-Thermal Source. The operation of nadir-thermal emission instrumentation is not influenced by the Sun's position, with the possible exception that specular reflection of sunlight cannot be directly incident on the receiver. In general, nadir-thermal instruments can be expected to provide day/night, global coverage and can provide frequently sampled data utilizing both sunsynchronous and non-sunsynchronous orbits.

6.1.2.4 Limb-Emissions Source. As in the case of the nadir-thermal instrumentation, the position of the Sun is only critical for the limb-emissions instrument insofar as it does not appear in the field of view of the receiver. Therefore, no significant demands are made on sensor orientation or orbital characteristics. However, the selection of an early morning (6-8 a.m.) sunsynchronous orbit allows effective diurnal sampling.

6.1.3 Coverage Requirements

As discussed in some detail earlier, many of the constituents of the stratosphere require a global observation in order to adequately determine their concentration, seasonal, and latitudinal variations.

These requirements impose several demands on the orbits chosen and, based on the work appearing earlier in this section, one may conclude that no measurement method/orbit combination can satisfy all of the coverage requirements. A review of Section 6.1.2 reveals that both diurnal and seasonal sampling cannot be provided by either the solar occultation or nadir-reflected solar instrumentation in sunsynchronous orbits due to their demand on the relative position of the Sun (which, of course, is a seasonal factor). The thermal emission instrumentation (described in Sections 6.1.2.3 and 6.1.2.4) are superior in terms of their coverage capability although their sensitivity may be lower.

The conclusion is that, based on the classes of instrumentation identified in Sections 6.1.2.1 and 6.1.2.4, coverage requirements from a sunsynchronous orbit are met sufficiently well to monitor the detailed temporal and spatial variations of stratospheric constituents only in the cases of nadir thermal and limb-emission instruments. The selection of a non-sunsynchronous orbit will improve the coverage of the solar occultation class of instruments, but will not provide polar coverage. In order to obtain the temporal sampling rates demanded by some constituents, it may be necessary to use multiple satellite systems.

6.2 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.

Table 6-III 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.

6.2.1 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

TABLE 6-III

INSTRUMENT CAPABILITY VS. SPECIES [30]

INSTRUMENT	TEMP/ CO_2	O_3	H_2O	Aerosols	Clouds	NO_2	HNO_3	HCl	CH_4	N_2O	NH_3	CO	SO_2	HF	NO	CF_2Cl_2
LIMS	S	S	S	–	–	S	S	–	–	–	–	–	–	–	–	–
SER	–	S	S(?)	S	–	S(?)	–	–	–	–	–	–	–	–	–	–
TRW/MAPS	–	–	–	–	–	–	–	–	–	–	–	T	–	–	–	–
CIMATS	–	–	S(?)	–	–	–	–	–	S,T(?)	S,T(?)	S	S,T	T	–	–	–
HALOE	–	–	–	–	–	–	–	S	S	–	–	–	–	S	S	–
THIR	–	–	T(?)	–	T	–	–	–	–	–	–	–	–	–	–	–
BUV-TOMS	–	S	–	–	–	–	–	–	–	–	–	–	–	–	–	–
VRPM	–	–	–	S,T	–	–	–	–	–	–	–	–	–	–	–	–
APP	–	S	–	S	–	–	–	–	–	–	–	–	–	–	–	–

S = Stratosphere
T = Troposphere

the few degrees required, will be provided, but the azimuthal view will probably be fixed at about 30° from the orbital plane.

6.2.2 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 $\pm$ 180° and a vertical scan of $\pm$ 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.

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

This sensor is a next generation to the COPE instrument which has been flown aboard aircraft and helicopters. Based on the Michaelson principle, it produces interferograms which are subsequently computer-correlated with interferograms of known species. CIMATS may be configured for nadir viewing or solar occultation.

The current model is constructed for nadir viewing only using two channels, one in a solar IR band (2-2.5 μm) and the other in a thermal IR Band (4-9 μm). The solar IR channel will be used for measurement of CH_4, N_2O, NH_3, CO and possibly H_2O. The thermal IR channel will be used for measurement of CO and SO_2 with the possible later addition of CH_4 and N_2O. When nadir viewing in the solar IR band it requires a solar elevation angle sufficient to provide adequate radiance and a relatively homogeneous field of view for optimum data interpretation. In the nadir mode measurements will be made primarily of the tropospheric column burden.

If a solar occultation model is constructed possible species to be measured include CH_4, N_2O, NH_3, CO and H_2O. In this mode the primary measurement will be stratospheric.

6.2.4 MAPS (Measurements of Air Pollution from Satellites)

MAPS (TRW version) is configured to measure CO total burdens in the troposphere. Instrument design also allows for future measurement of CH_4 and NH_3. 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.

6.2.5 HALOE (Halogen Occultation Experiment)

This instrument is, essentially, the MAPS instrument described above in a solar occultation mode. The gas cell complement is currently designed for measurements of HF, CH_4, HCl, and NO with filter cells and CO_2, H_2O, O_3 and CF_2Cl_2 (Freon-12) by direct radiometric measurement. The limitations are similar to any solar occultation radiometric 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.

6.2.6 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.

6.2.7 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.

6.2.8 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 instrument's performance.

6.2.9 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 erors 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 and water vapor
- VRPM - Aerosols

Table 6-IV presents an operational summary of the instruments described in this section and includes the three supporting instruments.

TABLE 6-IV

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, CH_4, N_2O, NH_3, CO	Solar Occultation	2.0 to 3.5	Probably 2 or 3	No: May be fixed as LIMS	N/A	Modification of COPE
CIMATS	CO, CH_4, NH_3, N_2O, SO_2	Nadir-Solar Reflected and Thermal	2.0 to 3.5 and 4.0 to 9.0	2	No	N/A	Modification of COPE
MAPS	CO	Nadir - Differential Absorption	4.6	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	HF, CH_4, HCl, NO	Solar Occultation - Differential Absorption	2.4 to 6.0	4	Tracking	No	MAPS in a solar occultation mode
HALOE	CO_2, H_2O, O_3, CF_2Cl_2	Limb Emission	6 to 20	Probably 4	No	Yes	Similar to LACATE
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	

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.

7.0 MISSION EVALUATIONS

This section presents the results of the application of a method for the evaluation of various stratospheric species measurement missions. The method was developed previously [2] and is presented in detail in Appendix A. The current application differs from the one already reported in two aspects:

- Input data to the method has been updated to reflect the latest knowledge on distributions of stratospheric trace species
- Remote sensor characteristics have been updated to reflect the current status of development of the instruments evaluated

7.1 Evaluation of Specific Missions

A number of missions and instruments were selected for evaluation using the methodology discussed above and presented in Appendix A. 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 7-I along with the generic type of each and the species that were evaluated.

Tables 7-II through 7-XVII show the results of these evaluations for each species/instrument/mission combination. Included with

TABLE 7-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	HF CH_4 HCl NO

TABLE 7-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
VXWF = Value x weighting factor

TABLE 7-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
VXWF = Value x weighting factor

TABLE 7-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
VXWF = Value x weighting factor

TABLE 7-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	1.8	8	2.4	0	0
						90° sparse at extremes		150° sparse at extremes			5°
Duration of Program	.2	5	1.0	9	1.8	6	1.2	6	1.2	9	1.8
						4-6 mos		4-6 mos		1-2 yrs	
Diurnal Coverage	.1	7	0.7	8	0.8	2	0.2	2	0.2	2	0.2
						Part Day 2 points		Part Day 2 points		Part Day 2 points	
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	5	0.75	10	1.5	10	1.5	10	1.5	10	1.5
						Full		Full		Full	
Vertical Profile Resolution	.15	7	1.05	10	1.5	5	0.75	5	0.75	5	0.75
						~20 points		~20 points		~20 points	
Longitude	.1	0	0	8	0.8	10	0.1	10	0.1	10	0.1
						Full		Full		Full	
	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
VXWF = Value x weighting factor

TABLE 7-VI

EVALUATION OF WATER VAPOR, H_2O, 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	.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
VXWF = Value x weighting factor

TABLE 7-VII

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
VXWF = Value x weighting factor

TABLE 7-VIII

EVALUATION OF AMMONIA, NH_3, CIMATS SOLAR OCCULTATION

Parameter	WF	Present V	Present VXWF	Required V	Required VXWF	Shuttle V	Shuttle VXWF	Shuttle V	Shuttle VXWF	Sun-Sync V	Sun-Sync VXWF
Latitude	.2	0	0	7	1.4	7 90° sparse at extremes	1.4	8 150° sparse at extremes	1.6	0 ~5°	0
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
VXWF = Value x weighting factor

TABLE 7-IX

EVALUATION OF NITROGEN DIOXIDE, NO_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	.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 $\lesssim$1Km	1.5	10 $\lesssim$1Km	1.5	10 $\lesssim$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
VXWF = Value x weighting factor

TABLE 7-X

EVALUATION OF NITRIC ACID VAPOR, NHO_3, 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	.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
VXWF = Value x weighting factor
D & N = Day & Night

TABLE 7-XI

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 (5°)	0
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
VXWF = Value x weighting factor

TABLE 7-XII

EVALUATION OF METHANE, CH_4, 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	.4	0	0	8	3.2	7	2.8 90° sparse at extremes	8	3.2 150° sparse at extremes	0	0 5°
Duration of Program	.1	0	0	6	0.6	8	0.8 4-6 mos	8	0.8 4-6 mos	9	0.9 1-2 yrs
Diurnal Coverage	.15	0	0	6	0.9	4	0.6 Part Day 2 points	4	0.6 Part Day 2 points	4	0.6 Part Day 2 points
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.15	6	0.9	8	1.2	10	1.5 Full	10	1.5 Full	10	1.5 Full
Vertical Profile Resolution	.15	3	0.45	9	1.35	9	1.35 ~20 points	9	1.35 ~20 points	9	1.35 ~20 points
Longitude	.05	0	0	8	0.4	10	0.5 Full	10	0.5 Full	10	0.5 Full
	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
VXWF = Value x weighting factor

TABLE 7-XIII

EVALUATION OF METHANE, CH_4, 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	.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		4.85
Total Value			1		8		8		8		5
Incremental Gain Over Present					7		7		7		4

LEGEND:
V = Value
VXWF = Value x weighting factor

TABLE 7-XIV

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
VXWF = Value x weighting factor

TABLE 7-XV

EVALUATION OF CARBON MONOXIDE, CO, 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	.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
VXWF = Value x weighting factor

TABLE 7-XVI

EVALUATION OF HYDROGEN FLUORIDE, HF, 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	.2	0	0	7	1.4	7 90° sparse at extremes	1.4	8 150° sparse at extremes	1.6	0 $\sim$5°	0
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 2Km	2.25	9 2Km	2.25	9 2Km	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
VXWF = Value x weighting factor

TABLE 7-XVII

EVALUATION OF NITRIC OXIDE, NO, 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	.25	4	1.0	10	2.5	6 90° sparse at extremes	1.5	9 150° sparse at extremes	2.25	0	0 ∿5°
Duration of Program	.2	8	1.6	9	1.8	5 4-6 mos	1.0	5 4-6 mos	1.0	9 1-2 yrs	1.8
Diurnal Coverage	.3	5	1.5	9	2.7	3 Part Day 2 points	0.9	3 Part Day 2 points	0.9	3 Part Day 2 points	0.9
Launch Time	0	10	0	10	0	10	0	10	0	10	0
Vertical Profile Coverage	.1	7	0.7	10	1.0	10 Full	1.0	10 Full	1.0	10 Full	1.0
Vertical Profile Resolution	.1	7	0.7	10	1.0	8 2Km	0.8	8 2Km	0.8	8 2Km	0.8
Longitude	.05	0	0	8	0.4	10 Full	0.5	10 Full	0.5	10 Full	0.5
	1.0		5.5		9.4		5.7		6.5		5.0
Total Value			6		9		6		7		5
Incremental Gain Over Present					3		<1		1		<1

LEGEND:
V = Value
VXWF = Value x weighting factor

each parameter value for the three missions is the performance used to determine the value. The values (V) shown in each table for present, required and mission capability are taken from the value matrices presented in Volume III of this report. The values represent the relative value on a scale of 0 to 10 (low to high) for the stated performance where 0 indicates no capability and 10 indicates perfect capability. The weighting functions show the value of one parameter relative to the others under study. The product of the value and its corresponding weighting function (VXWF) yields the desired weighted value for each parameter. The sum of the weighted values for each parameter yields the total relative value for each pollutant (see Appendix A for full explanation).

In Table 7-XVIII the incremental gains have been summarized to show the totals for each instrument/orbit/species combination. The results have been weighted by the weighting factors for the various pollutant groups. These weights adjust the individual pollutant values to account for the different priority groups into which they were placed in Section 5.2 (Table 5-I).

The incremental gain totals for each instrument/orbit combination are summarized in Table 7-XIX. 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.

TABLE 7-XVIII

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	LIMS	4	3	4	5
Aerosols	1	1	SAGE	2	<1	<1	<1
NH_3	2	0.9	CIMATS	6	7	7	6
NO	3	0.9	HALOE	3	<1	1	<1
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
HF	5	0.6	HALOE	4	5	5	4

$\sum = 47\text{-}48^*$

*Uncertainty due to use of values <1. Total equals sum of best values for each pollutant.

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TABLE 7-XIX

SUMMARY OF INCREMENTAL GAINS FOR EACH INSTRUMENT/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	HCl, CH_4, NO, HF	16	13-14*	14	7-8*

*Uncertainty due to use of values of <1.

7.2 Evaluation of Multiple Species or Instrument Missions

Table 7-XX 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.

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

TABLE 7-XX

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, NO, HF	47-48*	38-39*	42	32-33*
THREE INSTRUMENTS					
LIMS, CIMATS, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3 NH_3, CH_4, N_2O, CO, HCl, NO, HF	45-46*	38-39*	41-42*	32-33*
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, NO HF	40	30-31*	31	18-19*
LIMS, SAGE, HALOE	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols, HCl, CH_4, NO, HF	32-33*	23-24*	27	23-24*

*Uncertainty due to use of values of <1

TABLE XX (Concluded)

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, NO, HF	35	29-30*	30	17-18*
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, NO, HF	30-31*	23-24*	26-27*	23-24*
LIMS, SAGE	CO_2, O_3, H_2O, NO_2, HNO_3, Aerosols	16-17*	10-11*	13	16
SAGE, HALOE	O_3, Aerosols, HCl, CH_4, NO, HF	21	14-15*	15	9

*Uncertainty due to use of values <1

such as LIMS, CIMATS and HALOE considerably higher in all instrument/ orbit combinations evaluated.

APPENDIX A

MISSION EVALUATION METHODOLOGY

A.1 INTRODUCTION

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.

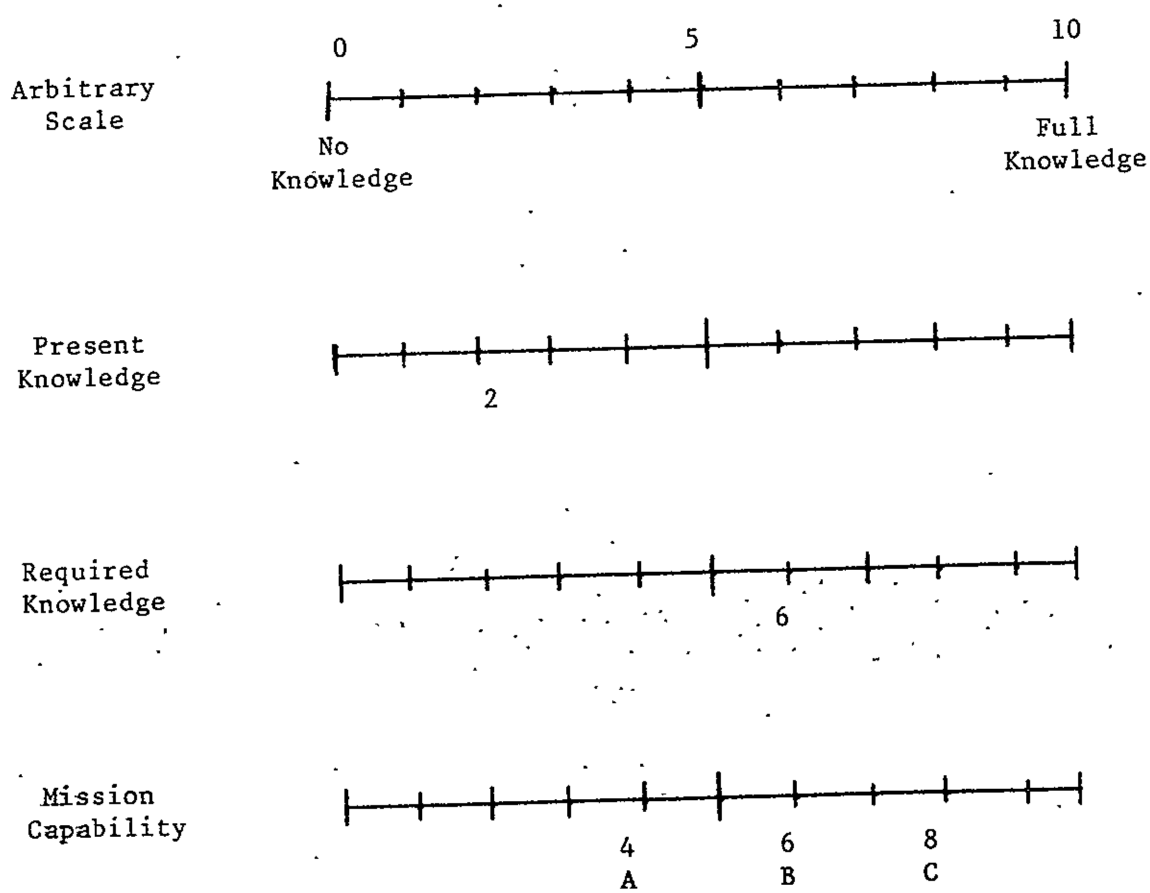
The following sections will be limited to a discussion of the "optimum" mission selection for a single species. The prioritization of species based on requirements was discussed in Section 5.2. Incorporation of these priorities into the evaluation methodology will be discussed later.

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

A.2 DEVELOPMENT OF THE METHOD

A.2.1 Approach to the Ranking and Evaluation

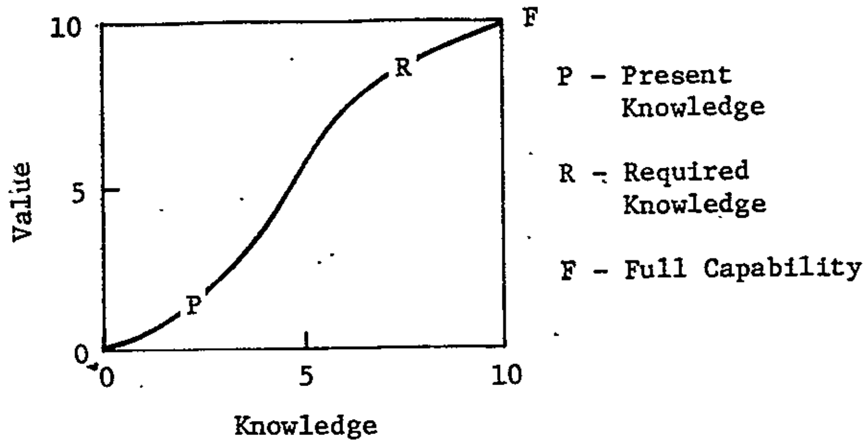
For each stratosphere species of interest one may assign a ranking or value in terms of an arbitrary scale of, say, 0 to 10 based on a comparison of either: (1) the present knowledge of the species distribution, (2) the required knowledge of the species distribution, or (3) the projected measurement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



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.

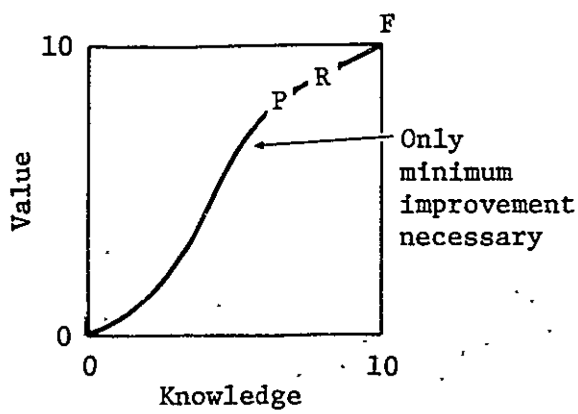
Thus, in the given example, the critical area for gain lies between the present knowledge and the required knowledge. Therefore, system C is not automatically much better than system B. However, each (B and C) is significantly better than system A.

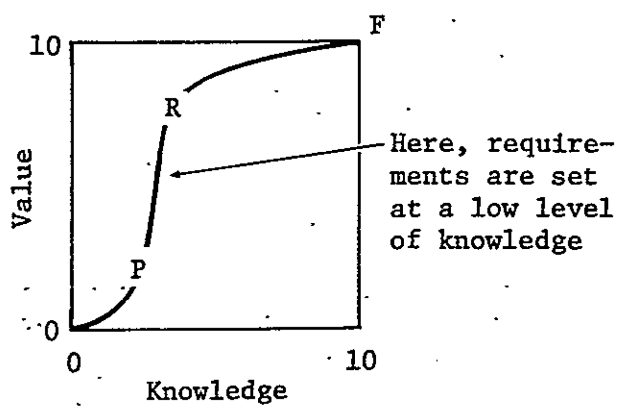
In order to indicate this in a more powerful way, the ranking scheme may be presented in a slightly different manner:



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[108-112]. 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 A-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.

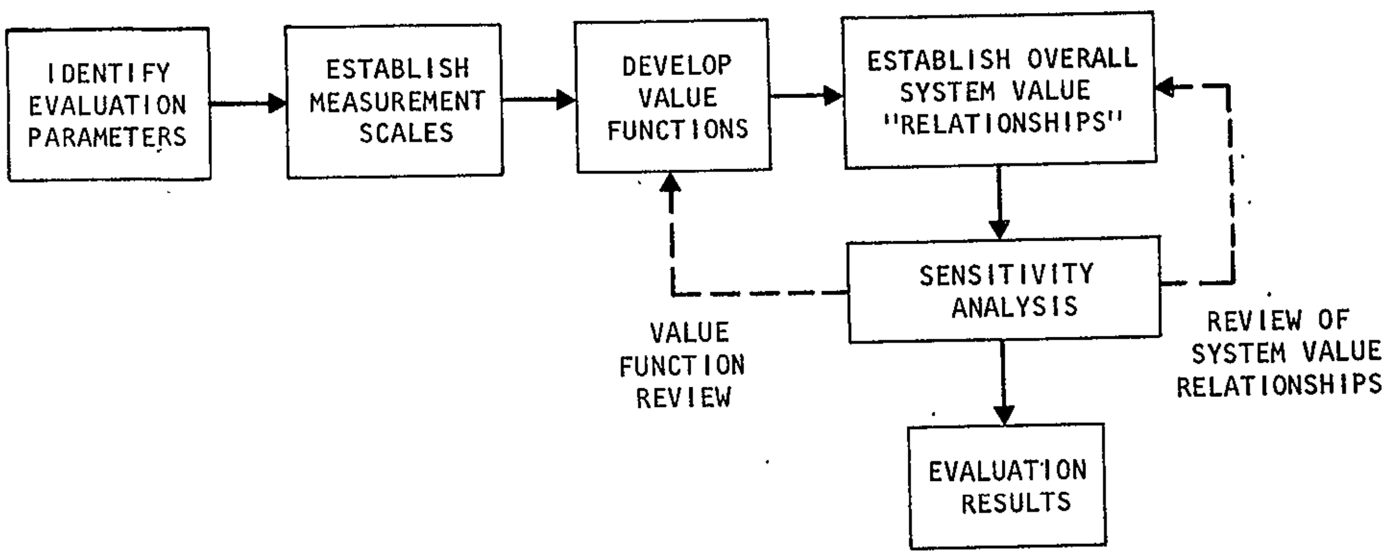


FIGURE A-1
EVALUATION TECHNIQUE DEVELOPMENT AND VALIDATION

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,

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

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 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_j = value function (factor)

G_i = value function (term)

x_i, x_j = 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,

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

where

V_1, V_2 are individual value sets which are factors

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

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

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 benefited from the logical presentation of available information by means of this structured technique.

A.2.2 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 A-2 through A-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 5.3 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					
	Good				10
	Med				
	Sparse				
	None	0			
		None	60°	120°	180°

LATITUDE BAND COVERED*

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

Duration of Measurement Program -

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

DURATION OF MEASUREMENT PROGRAM

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

Vertical Coverage -

DATA STATUS

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

STRATOSPHERIC VERTICAL COVERAGE

Vertical Resolution -

DATA STATUS

	None	<1	1	10	>40
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 A-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 A-5
PARAMETERIZATION OF LONGITUDINAL COVERAGE

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 presented in Volume III of this report.

A.2.3 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 A.2.1, 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

* 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 5.2 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 ultra-violet	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 Volume III of this report. 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.

APPENDIX B

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NOTE: For the convenience of the user, the same set of references is presented in Volumes I, II and III of this report. Therefore, in any one volume, all references are not cited in the text.

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