NASA Contractor Report 3557

Technology Needs Assessment of an Atmospheric Observation System for Multidisciplinary Air Quality/Meteorology Missions

Part 2

U. R. Alvarado, M. H. Bortner, R. N. Grenda,
W. F. Brehm, G. G. Frippel, F. Alyea,
H. Kraiman, P. Folder, and L. Krowitz

CONTRACT NAS1-16312
SEPTEMBER 1982

NASA

NASA Contractor Report 3557

Technology Needs Assessment of an Atmospheric Observation System for Multidisciplinary Air Quality/Meteorology Missions

Part 2

U. R. Alvarado, M. H. Bortner, R. N. Grenda,
W. F. Brehm, G. G. Frippel, F. Alyea,
H. Kraiman, and P. Folder
General Electric Company
Philadelphia, Pennsylvania

L. Krowitz
Lowell Krowitz Associates
Philadelphia, Pennsylvania

Prepared for
Langley Research Center
under Contract NAS1-16312

NASA

National Aeronautics
and Space Administration

Scientific and Technical
Information Branch

1982

FOREWORD

The "Technology Needs Assessment of an Atmospheric Observation System" reported in this contractor report for "Multidisciplinary Air Quality/Meteorology Missions" and in a companion report for "Tropospheric Research Missions" (NASA CR 3556, 1982) was funded by NASA's Office of Aeronautics and Space Technology to derive information necessary to guide near-term technology developmental activities in support of NASA's Office of Space Science and Applications long-term Earth environmental observation programs. The benefits of this cooperative effort should, however, extend beyond NASA and manifest themselves in technology developmental programs of other Government agencies, industry and academia.

A broad system approach was used to help assure validity of the technology assessment. This approach started with Earth observational scenarios representative of programs projected beyond the official NASA 5- and 10-year plans--to the decade of the 1990's. Representative measurement needs and missions were defined in terms of corresponding projected generic remote sensing and data management systems along with projected advanced spacecraft with their support subsystems. Technology needs were then assessed for this whole "Atmospheric Observation System." Such technology assessments are usually subject to error from two main sources: (1) the program and mission operational assumptions and projections, and (2) the status, assumptions and projections made regarding the various technologies employed to implement the defined missions. For atmospheric observation systems, however, the results appear to be less sensitive to program projection errors than to technology projection errors. Consequently, NASA selected a large experienced technology-oriented aerospace firm to perform the assessment, and thereby has minimized the errors as much as is practical. The contractor relied primarily on published documents and NASA reviews for program inputs and primarily on company expertise for technology inputs.

The assessment studies show that both the missions dedicated to tropospheric research and the multidisciplinary air quality/ meteorology missions are viable for the 1990's timeframe. They are, however, only representative of real missions which will be defined at a much later date based on the Earth environmental observation program results and potential at that time. Consequently, these reports should be used for technology needs information only and not for Earth observations program information. For program information regarding multidisciplinary air quality/ meteorology missions, the reader should go directly to the cited references.

Lloyd S. Keafer, Jr.
NASA Technical Monitor

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont'd)

TABLE OF CONTENTS (Cont'd)

SECTION 1
INTRODUCTION

This report summarizes the results of the study "Technology Needs Assesment of an Atmospheric Observation System", performed for the NASA Langley Research Center by the General Electric Company, Space Systems Division, under Contract No. NAS-1-16312. Part I of the study dealt with Tropospheric Research Mission and is published as NASA CR-3556.

This volume covers the results of Part II of the study, which deals with multidisciplinary missions. The period of performance for Part II was approximately eight months, commencing May 1981.

The purpose of the study was to define the technology advancements needed to support post 1990 space missions to perform global atmospheric measurements. The study is not meant to define missions or assess science needs, but rather to establish the boundaries of possibilities for technology and assess the technology needs, a process which can only be effected through modeling and planning of potential missions encompassing the mission disciplines, which are:

1. Tropospheric Air Quality
2. Upper Atmospheric Air Quality
3. Weather
4. Severe Storms
5. Air Surface Interface

The latter four disciplines are treated relative to their support of the "core" mission, which deals with upper and lower atmosphere air quality. Although the subject of the study is air quality, it is recognized that those supporting measurements dealing with the physical state and dynamics of the atmosphere are potentially useful to other operational meterological systems by supplying to them complementary or corroborative data.

There are several reasons for the wide scope of the study, encompassing multiple disciplines in a single space-based system. The technology developments that may result from this study should have broad applicability across several disciplines. Another reason is to make the modeled missions upon which the study is based compatible with current trends towards using larger, more complex spacecraft. This in turn permits us to examine the impact of these systems on technology.

From an applications point of view, the multidiscipline approach in the study permits an examination of the potential synergistic benefits of simultaneous measurements of atmospheric quality and meteorological parameters.

Part II covers the following analyses:

1. Review of long-range NASA plans in atmospheric quality to determine knowledge objectives and measurement needs. (Reference Section 3).
2. Determination of the applicability of air quality measurements in the meteorological disciplines. (Reference Section 3).
3. Postulation of generic sensors that would be applicable to the measurement needs. (Reference Section 4).
4. Definition of the sensor characteristics. (Reference Section 4).
5. Synthesis of multidisciplinary space missions and the sensor complement characteristics. (Reference Sections 6 and 7).
6. Atmospheric modeling and determination of optical transmission parameters for various angles relative to the local vertical. (Reference Section 5).
7. Definition of the field-of-view and incidence angle limits of various orbits based on the analysis in 6. (Reference Section 5).
8. Characterization of the relationship between passive sensor sensitivity and sensor design parameters such as optics size, and field of view. (Reference Section 4).
9. Examination of the synergistic benefits of multidisciplinary missions. (Reference Section 6).
10. Definition of the end-to-end data system for a typical multidisciplinary mission. (Reference Section 8).
11. Determination of potential technology drivers in the end-to-end data system. (Reference Section 8).
12. Identification of the advanced technology needs in order to implement the mission in the early 1990's. (Reference Section 9).

Acknowledgement: This study was sponsored by NASA's office of Aeronautics and Space Technology. Overall guidance and technical monitoring of the contract was provided by Lloyd Keafer of the Langley Research Center. Special guidance and meteorology missions was provided by a group at the Goddard Space Flight Center lead by Dr. S. Harvey Melfi.

SECTION 2
SUMMARY OF RESULTS

This section of the report presents a capsule summary of the results of Part II of the Atmospheric Observtion System Study.

The study showed that it could be technologically feasible and scientifically pratical to launch multidisciplinary missions for atmoshperic research and routine observation, in the post 1989 era. Such missions would benefit the pursuit of knowledge of the atmospheric environment, not only from the point of view of air quality, but also weather, climate, severe storms and air surface interface phenomena. The synergistic benefits of concurrent gas and aerosol concentration measurements and meteorological measurements may accelerate the formulation of accurate atmospheric models and thus permit us to understand and control the effects of man's activities upon our important atmoshperic resources. As example of these synergistic benefits are the simultaneous measurement of several gaseous/aerosol species, spectral regions, and viewing geometries, which will enhance the accuracy of interpretation of the chemical reactions..

The technology developments identified by the study were not driven by the fact that may sensors will be accommodated in one spacecraft. This is evidenced by the fact that the size and system suppor trequired by the postulated payloads fall well within the projected capabilities of spacecraft in the early 1990's. Rather, we found that the technology gaps center around the sensing techniques and sensors, as they did in the Part I Study. It is evident that the complexity of such detailed measurements in the upper and lower atmosphere makes may of the measurements difficult relative to obtaining theefrequent global coverage, with the required spatial resolution and accuracy.

A list of the main technology developments that were identified in the study are shown on Table 2-1. Indicated in that Table are the critical items (asterisked numbers) which require prompt attention to ensure that the technology will be attained when it is needed by future environmental satellites for atmospheric observation. It should be pointed out that these technology needs are somewhat independent of the particular type of satellite

Table 2-1. List of Potential Technology Needs for AOS Multidisciplinary Missions

A) <u>NEW MEASUREMENT TECHNIQUES</u>

*1. TECHNIQUES FOR INCREASING VERTICAL RESOLUTION IN TROPOSPHERIC CONCENTRATION MEASUREMENTS.
(e.g. LIMB MEASUREMENTS IN UPPER TROPOSPHERE)

2. MEASUREMENTS OF WIND VECTORS USING LASER HETERODYNE SPECTROMETRY

3. IMPROVED MEASUREMENT OF H_2SO_4, HSO_3, H_2S

4. CORRELATION OF GROUND & SPACE OBSERVATIONS OF THE EFFECTS OF AIRCRAFT ACTIVITY (i.e., O_3, NOx, CO)

5. MEASUREMENT OF PRECIPITATION PARAMETERS

6. SPATIAL CORRELATION OF NADIR AND LIMB DATA

B) <u>PASSIVE SENSORS</u>

*7. PASSIVE MICROWAVE RADIOMETER WITH FIXED, SHAPED REFLECTOR

*8. OPTICS FOR WIDE F.O.V. SENSORS COUPLED WITH MULTISPECTRAL LINEAR ARRAYS

9. 360° - SCAN LIMB SENSORS

10. IMPROVED SOLAR SHIELDING FOR PASSIVE SENSORS

*CRITICAL TECHNOLOGY ITEMS

Table 2-1. List of Potential Technology Needs for AOS Multidisciplinary Missions (Cont'd)

C) <u>ACTIVE SENSORS & SOURCES</u>

*11. LIDAR TECHNIQUES FOR FAINT SPECIES IN THE STRATOSPHERE

12. DOPPLER RADAR FOR PRECIPITATION MEASUREMENTS

13. BI-STATIC LIDAR MEASUREMENTS

14. SUB-MILLIMETER WAVE SOURCES

D) <u>INFORMATION MANAGEMENT</u>

*15. ALGORITHMS FOR AOS LIMB DATA

16. 3-D CORRELATION OF AIR QUALITY AND METEOROLOGICAL PARAMETERS

17. INTERACTIVE AND ADAPTIVE MISSION CONTROL

E) <u>SPACECRAFT & SPACE ASSEMBLY</u>

*18. PRECISE ATTITUDE CONTROL FOR LIMB MEASUREMENTS

19. ASSEMBLY OR DEPLOYMENT OF LARGE PASSIVE MICROWAVE ANTENNA ARRAY

system that will be employed to implement them. For instance, assuming that none of the multidisciplinary atmospheric observation spacecraft postulated here would be implemented within the postulated time frame, the technology needs would still be valid under alternative scenarios. One of these scenarios, for instance, would show advanced versions of the proposed Upper Atmospheric Observation Satellite being complemented by a Lower Atmospheric Research Satellite (LARS), and an effective information management system gathering data from these two satellite systems, research aircraft and advanced versions of current NOAA meteorological satellites. Under alternative scenarios such as this, the technology gaps would still be required to be filled, in most cases, within the relatively short time between now and 1987.

SECTION 3
INFORMATION NEEDS

The problem of air quality has become a major environmental concern and should be aided by investigations based on global measurements from spacecraft. Hence, measurements pertinent to air quality are the major ultimate objectives toward which this study is aimed. That is, this study is aimed toward the assessment of the technology needs for the eventual development of flight missions and their payloads which would provide the best possible measurements for the understanding, quantification, and subsequent improvement of the quality of the earth's atmosphere. It is not intended that this study develop the ultimate "knowledge objectives" as will have to be done for actual flight missions or to determine the best set of instruments, measurements, and flight parameters as will be done for such missions. Rather it is intended that such knowledge objectives, payloads, and missions as considered herein are intended only as representatives and are used only to permit a valid assessment of technology needs.

The objectives which should be pursued by measurements from orbiting spacecraft have been considered in detail by many scientists, committees, workshops, and others in order to furnish information on scientific needs to those involved in planning spacecraft missions. Some of the leading reports on the subject are listed in Table 3-1. These scientific objectives may be categorized in a number of possible ways; however, for the purposes of this study twelve such "Knowledge Objectives" were developed as shown on Table 3-2. There is obvious overlap in some of these objectives, but such can hardly be avoided in such a categorization. Material in references such as those of Table 3-1 was used for the obtention of information from which the knowledge objectives were generated.

3.1 KNOWLEDGE OBJECTIVES DEFINITION

Each of the twelve knowledge objectives in Table 3-2 is made up of a number of parts, each of which is a sub-objective. Answering all of the sub-objectives should provide an answer to that major knowledge objective. The breakdown of sub-objectives is shown in Tables 3-3 through 3-14.

Table 3-1. Documents That Form the Basis for the Knowledge Objectives *

- Upper Atmosphere Research Satellite Science Working Group. (Reference Number 1).
- The Stratosphere; Present and Future. (Reference Number 6).
- National Climate Program Five Year Plan. (Reference Number 7).
- Middle Atmospheric Program Planning Document. (Reference Number 8).
- Atmospheric Chemistry, Problems and Scope. (Reference Number 9).
- Space Remote Sensing of Minor Gaseous and Aerosol Components of the Atmosphere. (Reference Number 10).
- NASA Troposphere Program Plan. (Reference Number 11).

* Full references are given in Section 10.

Table 3-2. Knowledge Objectives

1. Effects of Pollutants on Atmospheric Radiative Transfer.
2. Atmospheric Sulfur Pollution.
3. Atmospheric Carbon Pollution.
4. Global Distribution of Ozone.
5. Effect of Aircraft Activity on the Atmosphere.
6. Effect of Chlorofluoromethane on the Atmosphere.
7. Effect of N_2O on the Atmosphere.
8. Surface-Atmosphere Interaction.
9. Properties and Role of Atmospheric Aerosols.
10. Role of Ions in the Stratosphere.
11. Meteorological Effects on Atmospheric Composition and Radiative Transfer.
12. Effects of Natural and Man-Made Disturbances.

Table 3-3. Knowledge Objective 1

Effect of Pollutants on Atmospheric Radiative Transfer

1. Distribution of Effective Pollutants.
2. Effect of Pollutants on Ozone.
3. Effect of pollutants on Aerosol Size and Distribution.
4. Effect of Aerosol Size and Distribution on pollution.
5. CO_2 Concentration Trend.
6. Role and Effect of Water Vapor and Variations.
7. Variations in Resultant Solar Flux at Surface.
8. Terrestrial Radiation.
9. Effect of Pollutants on Cloud Cover.

Table 3-4. Knowledge Objective 2

Atmospheric Sulfur Pollution

1. S-Source Location and Quantification.
2. Identity and Distribution of S-Containing Species.
3. Photochemistry of S-Containing Species.
4. Formation of S-Containing Aerosols.
5. Loss Processes of S-Containing Species.
6. Interaction with Aerosols.
7. Acid Rain.
8. Troposphere-Stratosphere Transport.

Table 3-5. Knowledge Objective 3

Atmospheric Carbon Pollution

1. CO_2 Concentration Trends.
2. CH_4 Photochemistry.
3. Natural Sources of CO.
4. Anthropogenic Sources of CO.
5. CO Sinks.
6. NMHC Photochemistry.
7. Troposphere-Stratosphere Transport.
8. Cross-Equatorial Flow.

Table 3-6. Knowledge Objective 4

Global Distribution of Ozone

1. Distribution of O_3.
2. Variations in Distribution of O_3.
3. Effect of Pollutants.
4. Photochemistry.
5. Effect on Radiative Transport.
6. Surface Loss of O_3.
7. Troposphere-Stratosphere Transport.
8. Effect of Atmospheric Electricity.

Table 3-7. Knowledge Objective 5

Effect of Aircraft Activity on the Atmosphere

1. Pollutant Distribution from Aircraft - e.g., NOX, HC's, CO.
2. Pollutant Interactions.
3. Pollutant Transport.
4. Effect on Ozone.
5. Effect on Radiative Transfer.
6. Effect on Cloud Cover.

Table 3-8. Knowledge Objective 6

Effect of Chlorofluoromethanes (CFM's) on the Atmosphere

1. Sources of CFM's.
2. Identity and Distribution of CFM's.
3. Sinks of CFM's.
4. Photochemistry of CFM's.
5. Effect on Ozone.
6. Effect on Atmospheric Composition.
7. Troposphere-Stratosphere Transport.

Table 3-9. Knowledge Objective 7

Effect of N_2O on the Atmosphere

1. Natural Sources.
2. Anthropogenic Sources.
3. Sinks.
4. Photochemistry.
5. N_2 Distribution.
6. Troposphere-Stratosphere Transport.
7. Effect on Atmosphere.

Table 3-10. Knowledge Objective 8

Surface-Atmosphere Interchange

1. Ocean as a Source of Minor Atmospheric Constituents.
2. Ocean as a Sink for Minor Atmospheric Constituents.
3. Land as a Source of Minor Atmospheric Constituents.
4. Land as a Sink for Minor Atmospheric Constituents.
5. Vegetation as a Source of Minor Atmospheric Constituents.
6. Vegetation as a Sink for Minor Atmospheric Constituents.
7. Aerosols from the Ocean.
8. Aerosols from the Desert.
9. Role of Wind and Transport.

Table 3-11. Knowledge Objective 9

Properties and Role of Atmospheric Aerosols

1. Size and Distribution of Aerosols.
2. Composition of Aerosols.
3. Interaction with Gaseous Components.
4. Interaction with Precipitation.
5. Formation Mechanisms.
6. Transport.
7. Effect on Radiative Transfer Properties.

Table 3-12. Knowledge Objective 10

Role of Ions in the Stratosphere

1. Identity and Distribution of Ions.
2. Gaseous Interactions.
3. Aerosol Interactions.

Table 3-13. Knowledge Objective 11

Meteorological Effects on Atmospheric Composition and Radiative Transfer

1. Effect of Temperature and Lapse Rate.
2. Water Vapor Interaction.
3. Chemical Effect of Lightning.
4. Effect of Clouds on Radiative Transfer.
5. Vertical Transport.
6. Horizontal Transport.
7. Transport by Wind.
8. Interaction of Precipitation with Atmospheric Species.
9. Removal of Pollutants by Precipitation.
10. Physical Effects of Severe Storms.
11. Field-of-View Effects of Clouds.
12. Surface Temperature and Terrestrial Radiation.
13. Interaction of Pollutants with Water Vapor.

Table 3-14. Knowledge Objective 12

Effect of Natural and Man-Made Disturbances

1. Effect of Gases and Condensed Material from Volcanoes.
2. Transport of Volcanic Material.
3. Atmospheric Interactions of Lightning.
4. Transport in Severe Storms.
5. Chemical Effects of Nuclear Bursts.
6. Radioactivity Introduced by Nuclear Bursts.
7. Effects and Uses of Chemical Releases.
8. Effects on Radiative Transport.

The first knowledge objective concerns the effect of atmospheric pollutants on the transmission, absorption, emission, scattering, reflection, and refraction of radiative flux. Many trace atmospheric species affect radiative transfer.

These include both naturally occurring and anthropogenically introduced species although these are, in general, the same with the anthropogenic effect being one of quantity, in some cases introducing possibly many more times the amount of a trace species than is naturally there. Many of these species affect the amount of radiation reaching the ground which in turn has major effects on both animal and vegetable life[8,14].

Among the species which are most important in their effect on radiative flux are O_3, H_2O, and CO_2[6,8,9,11]. Small decreases in the total amount of ozone in the atmosphere increase the solar flux penetrating the atmosphere, thus potentially increasing the incidence of skin cancer; therefore, there is great interest in the amount of ozone in the atmosphere. Since ozone is closely coupled with the photochemistry of many other trace species in the atmosphere, the distribution of the related species is of interest indirectly through the ozone problem as well as through the direct effect they may have on radiative flux. Some of the species most closely coupled with ozone photochemistry are NO, NO_2, N_2O, OH, HO_2, and Cl[3,8,11].

Aerosols play a major role in radiative transfer[6,11]. They serve to absorb, reflect and refract solar radiation. Their size, number, and distribution are affected by and have an affect on atmospheric trace species. Much of this is not yet understood and it is difficult to be very specific about measurements needed to satisfy such a knowledge requirement until further technological advances are made. However, there is no doubt that aerosols must be characterized in terms of size distribution and in terms of number distribution before their effect on radiation can be predicted with assurance.

In conjunction with measurements of gaseous species and aerosols, as a function of time, altitude, latitude, and longitude, the determination of flux variations with these same parameters is needed.

Knowledge Objective 2 concerns sulfur pollution. This is an industrial pollutant and extensive measurements, mainly ground-based, have been made downwind from industrial sources. There is much less understanding of the ultimate fate of the sulfur thus introduced. Much of the sulfur is introduced as H_2S[6,13] (mainly from natural sources), SO_2 (mainly from industrial sources), and CS_2 and COS (from organic chemical processes). Through a series of steps much of the sulfur ultimately is converted to H_2SO_4[13].

Some reacts with ammonia[11] to form $(NH_4)_2\ SO_4$. These in turn are formed into aerosols. Much of it ultimately comes out as acid rain which causes much interstate and international stress. It is important to follow sulfur emissions for long distances. It is necesssary to determine the chemical status of the sulfur, that is, to know what the distributions of sulfur-containing species are as a function of time and location. In order to understand the chemical conversions, knowledge of the distribution of chemical constituents which react with sulfur-containing species is required. Chief among these are OH, HO_2 and NH_3 together with aerosols which interact probably both chemically and physically with the S-containing species. The characterization and distribution of the aerosols should be known and since the sulfur becomes part of the aerosol, the composition of the aerosol is needed. The occurrence of precipitation should be included in any sulfur-cycle study.

Some sulfur may enter the stratosphere. Some volcanoes introduce H_2S and sulfur in other forms at high altitudes, sometimes even into the stratosphere. Here, as in many other cases to be discussed later, the interchange between the troposphere and the stratosphere must be understood. Measurements for this type of process are difficult to design and must be quite complex. Obviously, well-resolved measurements of sulfur-containing species and aerosols are needed.

In studying troposphere-stratosphere interchange (which is important to many of the knowledge objectives), the use of some species which is photochemically unreactive in this region and which has a usable infrared spectrum has been suggested as being a more feasible technique than temperature profile determination. Methylchloroform, CH_3CCl_3, has been suggested for this purpose.

Knowledge Objective 3 concerns atmospheric carbon pollution. This involves two or three rather distinct problems. One concerns the continual, gradual increase in CO_2 with its resultant effect on radiative flux[1,8]. This is a very gradual change and can be investigated and followed by ground-based measurements.

A second carbon-pollution problem is that of carbon monoxide. The natural sources of CO are not yet understood. This requires an understanding of the atmosphere methane cycle and perhaps other similar cycles[6], as well as determination of CO distribution with time, altitude, latitude (both hemisphere) and longitude, with global coverage. To understand the methane cycle, measurements of CH_4 and, to the extent possible, numerous intermediate species, are needed. Since OH is the most important species for removing CO, it should also be measured. Data on winds, etc., which determine transport are important to the understanding of CO, especially anthropogenic CO.

In addition to methane, other hydrocarbons are significant to atmospheric pollutions. These include the lower alkanes and those alkanes which are present in significant quantities and certain other larger hydrocarbons which may be introduced naturally or anthropogenically. Various terpenes are a prime example of naturally introduced hydrocarbons whose fate is not well known.

Knowledge Objective 4 concerns the distribution of ozone. This obviously overlaps Knowledge Objective 1, but is specific for ozone and extends beyond its effect on radiative transfer. Ozone is of great importance in the stratosphere and its photochemistry involves many other species. Its photodissociation is accomplished by UV radiation. This rate will vary with time of day, time of year, and latitude since the solar flux varies in these ways. Ozone, in turn, affects the solar flux, being a major contributor to its absorption. Ozone, interacts either directly or indirectly, with most of the minor atmospheric species which control many properties of the atmosphere. It reacts directly with OH, HO_2, NO, NO_2, H, O, SO, Cl, ClO, and others including many anthropogenically introduced species. For many it is the fastest destruction mechanism. It is of great importance to know the distribution of ozone as a function of time and of altitude, latitude, and longitude and to understand this distribution so that it can be predicted with reasonable confidence for all conditions.

Several other factors must be considered in conjunction with this. The atmospheric circulation of ozone is very complex. The role of troposphere-stratosphere interchange needs to be quantitatively understood, as does the loss of ozone at the Earth's surface. The possible importance of the well-known creation of ozone by lightning needs to be quantified.

Since the ozone problem is both very complex and very important, it will require an involved program of measurements to satisfy this knowledge objective.

Knowledge Objective 5 concerns the effect of aircraft activity on the atmosphere. Aircraft burning fossil fuels introduce the nitrogen oxides, mainly NO and NO_2; unburned hydrocarbons; carbon monoxide and carbon dioxide, and water. The most important influence is that of NO. It reacts rapidly with ozone by $NO + O_3 \rightarrow NO_2 + O_2$. It is not a one-for-one effect, however, due to the very complex photochemistry of the O_3-NOX system. Various models have predicted various effects on the ozone. It is now generally agreed that there is some reduction in ozone due to the NOX introduced by the aircraft.

In addition to the affect on radiative transfer due to ozone decreases, there are effects on radiation due to the H_2O and CO_2, and to a lesser extent, the various other species introduced. These effects need studying by remote measurements.

Since the aircraft activity is not globally uniform, transport plays an important role in the effect of aircraft-introduced pollutants. The understanding of the transport is a part of this objective.

Knowledge Objective 6 concerns the effect of chlorofluoromethanes (such as freon) on the atmosphere. For several years, chlorofluoromethanes have been a concern to those involved with atmosphere processes. The original CFM's of most interest were CF_2Cl_2, $CFCL_3$, $CHCl_3$, and CCl_4. These and various other CFMs are long-lived in the atmosphere. Most rise through the trosophere and eventually enter the stratosphere. There they are photodissociated and undergo a series of reactions which produce a number of species such as Cl, ClO, HCl, and $ClONO_2$. Some of these react with ozone.

The process Cl + $O_3 \rightarrow ClO + O_2$ appears to be important in reducing the ozone burden in the atmosphere, thus affecting the solar flux penetration. Much of this remains to be quantitatively understood. It remains to determine, for each of a dozen or so CFM's, their distribution, their transport from the troposphere to the stratosphere and within each of these regions, their lifetime in the atmosphere, the photochemical processes they are involved in, including their reactions with and effect on ozone and their reactions wtih nitrogen oxides, their interaction with aerosols, and their overall effect on radiative flux. It is obvious that there needs to be appropriate measurements of the distributions of many CFMs, and of many species with which they interact and of various physical parameters which affect these distributions and processes.

Knowledge Objective 7 concerns the effect of nitrous oxide, N_2O, on the composition of the atmosphere. The processes thought to cause such an effect are the following. Nitrogen-containing fertilizers are responsible for its introduction into the atmosphere. Since it reacts extremely slowly with tropospheric species it has time to be transported into the stratosphere. It is destroyed mostly by reaction with excited oxygen atoms, O('D), which are produced by photodissociation of ozone and are mostly prevalent from the ozone peak to the mesopause. The reaction of N_2O with O('D) has three possible paths, but the principal product is NO. This in turn affects the ozone.

In order to determine whether these processes are really important, and if so, to understand them quantitiatively, it is necessary to determine not only the N_2O distribution but to quantify its sources and sinks. It is necessary to determine the distribution of species with which it reacts and species which it produces by the reactions, and species which are affected by these products. Thus, the distributions of N_2O, O('D), NO, O_3 are related and must be determined. Transport processes, especially those which carry NO into the stratosphere must be understood. Thus, well-resolved measurements around the tropopause are needed. In addition since some N_2O is destroyed by photodissociation and since some probably interacts with aerosols, measurements of solar flux and of aerosol properties and distribution are needed.

Knowledge Objective 8 concerns surface-atmosphere interchange where the surface includes both water and land. This is not as clear-cut as some of the other knowledge objectives. In looking for sources and sinks for specific species, e.g., O_3, N_2O, CH_4, CO, ..., the possibility of sources or sinks for other species may be overlooked. Or by a general survey for all species, sensitivity may be lost. However, important information can be obtained if sources or sinks are located, quantified, and correlated with surface and atmosphere properties. Thus, not only must the species distribution be determined but the properties of the surface must be determined; this includes sea roughness, surface temperature, and surface winds.

Knowledge Objective 9 concerns aerosols in the atmosphere. This is one of the most complex subjects in aeronomy, but the available data are very limited. Most of the available data are on the spatial and size distribution of aerosols with some information on their effect on radiative flux. There is considerable interest in the capabilities of aerosols to remove pollutant species from the atmosphere both by rain-out and by wash-out but needed data on the processes are lacking. Problems such as aerosol formation and growth, the enveloping by aerosols of gaseous species by physical and chemical processes, the chemical composition of aerosols, their chemistry, and their transport need far more information than is currently available. Some of the needed data must be obtained by laboratory and other ground-based studies while some are probably best obtained from space-based measurements. While the greatest importance of aerosols is in the troposphere, their role in the stratosphere is not to be neglected.

In order to determine and understand the atmospheric processes involving aerosols the distribution of the trace chemical species with which they interact must be known. These include various sulfur compounds, ammonia, nitrogen oxides, nitrogen acids, H_2O_2, and, of course, water vapor. Since the interaction of aerosols with ionic species is strong, the identity and distribution of the various positive and negative ions is important. In addition, meteorological affects are very important to aerosol processes and aerosol transport and information on many meteorological parameters is needed.

Knowledge Objective 10 concerns ions in the atmosphere. In the mesophere and above, ions play a major role in determining the chemical composition and their interactions in that region are rather well understood. In the stratosphere, their involvement is less important, but also less well understood. They may well play some key roles, particularly in aerosol formation and other aerosol processes. Thus it is important to determine the ionic composition and concentrations in the stratosphere and to understand the processes by which they interact in this region.

Knowledge Objective 11 concerns meteorological effects on the composition of the atmosphere and on radiative transfer through the atmosphere. It is important to note that this study did not involve any program for obtaining meteorological data for meteorological information (other than to see if the meteorological data obtained to determine the effects on composition and radiative transfer would be a significant addition to available meteorological data used for meteorological purposes).

Many meteorological parameters play a role in atmospheric photochemistry. Among these are temperatures, pressure, precipitation, winds, clouds, lightning, transport and other factors.

Temperature is important in several ways. Surface temperature determines the Earth's radiative emission and albedo; the gas temperature affects many reaction rates; the temperature lapse rate may be correlated with the structure of the atmosphere and, specifically, with the location of the mixing layer, the tropopause and the stratopause. Precipitation interacts both physically and chemically with the atmosphere. It must be characterized in terms of location, type, rate and size distribution in order to understand such interaction. Winds play a major role in the distribution of pollutants in the atmosphere. Both horizontal and vertical components must be known in order to calculate the spread of pollutants and hence their effect. Clouds play an important role in atmospheric processes, in radiative transfer, and in observation capabilities. They interact with gases and other aerosols, they scatter and absorb radiative flux, thus indirectly affecting the chemical composition, and they interfere over wide wave-length ranges with measurements made through the atmosphere. The role of lightning and its interactions with atmospheric composition and other properties is just now being investigated in detail.

General circulation models of the atmosphere require information which is meteorological in nature but is also important to the atmospheric composition and air quality. This includes data on transport, horizontal and vertical mixing in the atmosphere, on atmospheric stratification, mixing layer height, haze dynamics, and related quantities. All parameters associated with energy balance in the atmosphere play a role in atmospheric circulation and composition.

These numerous measurements of meteorological parameters are needed in order to include their important effects in calculations to determine the role of trace species on air quality and radiative transfer.

Knowledge Objective 12 concerns occasional drastic perturbations of the atmosphere which occur due to either natural or man-made events. Among the more drastic natural perturbations are volcanoes and severe storms including lightning, high winds, extreme cloudiness, large temperature differentials, and large precipitation rates. There are few data on the effects of these drastic changes on air quality although they do affect transport, aerosol processes, ozone formation and other atmospheric interactions. Understanding of some of these effects will undoubtedly improve in the next decade and will permit better and more specific recommendations for space-based measurement needs.

Man-made disturbances also drastically affect the atmosphere although such effects are largely temporary. The major short-term effects are in ion and electron densities. Remote measurement capabilities of the variations of these quantities are rather limited with electron densities being the main observable. Of course, long-term increases in radioactivity can be followed.

3.2 MEASUREMENTS

Data to provide useful information for the satisfaction of the Knowledge Objectives requires a series of measurements of the physical and chemical properties of the atmosphere.

They include such things as concentrations of gaseous species (as determined from spectral absorption, etc.), properties of aerosols, physical parameters such as temperature and pressure, cloud properties, radiative flux, wind velocities, and a number of other observable parameters. These observables were specified for each knowledge objective and are listed in Tables 3.2-1 through 3.2-12. As an example of the development of these tables, looking at Table 3-3 (Effect of Pollutants on Atmospheric Radiation Transfer), the second item listed is "effect of pollutants on ozone." In order to satisfy this, it is necessary to know the number density distribution of the pollutants which interact with ozone as well as the distribution of ozone and to know the radiative flux (as a function of wave length and height). For the flux it is necessary to know the flux from all sources (solar, atmospheric, terrestrial) for wavelengths where such are important, but also to be able to include the effect on flux of such things as cloud cover and aerosol. Thus items 1, 2, 3, 6, 8, 10 in Table 3.2-1 are needed to satisfy item 2 of Table 3-3. All items in Table 3.2-1 can be similarily related to those of Table 3-3.

For each of the observable quantities (or groups of the observables), the measurement specifications which are estimated to be needed in order to satisfy the Knowledge Objective are noted in Tables 3.2-13 through 3.2-27. These specifications include spatial resolution and coverage, both horizontal and vertical; temporal resolution and coverage, the range of the variable over which the measurements should be made; and the required accuracy and precision.

It should be re-emphasized that such lists are intended to produce a representative set of measurements in order to assess technology needs and not necessarily to determine the best set of instruments, measurements and flight parameters. From the example given just above, it can be seen that technology requirements should include a knowledge of the chemical and physical interactions of ozone with gaseous and condensed-phase pollutants as well as a capability to determine flux as a function of altitude and wavelength.

The following paragraphs discuss each of these types of specifications in order to aid in the understanding of the data in Tables 3.2-13 through 3.2-26.

Vertical Specifications

Vertical Coverage - In general, coverage of the troposphere, the stratosphere, and the mesophere and above. Since there is much interest in troposphere-stratosphere interchange, some troposphere measurements are extended into the lower stratosphere.

Vertical Resolution - Finest resolution is needed in the troposphere where 1 km resolution is often needed with even finer desired. The troposphere can be divided into three altitude regions - the lowest 300 meters, that from 300 meters to 2 km, and the rest of the troposphere (up to 8 to 18 km depending on latitude, season, etc.). These three regions would be suitable resolution elements if 1 km resolution is not attainable. In the stratosphere, coarser resolution is suitable. A 3 km resolution is usually appropriate except in the lower part of the stratosphere. In higher parts of the atmosphere, still coarser resolution is acceptable.

Horizontal Specifications

In measurements concerning the stratosphere, horizontal coverage and resolution are important. Various applications require resolution from a few km to 1000 km and coverage ranging from small areas to the entire globe.

In measurements applied to stratosphere problems, these considerations are less important. There is more time to mix horizontally so that most questions do not require fine resolution or specific areal or global coverage. Main horizontal variations are latitudinal, especially cross-equatorial.

Temporal Specifications

The frequency of measurements are determined by lifetimes of chemical species and associated parameters. Chemical lifetimes range from fractions of seconds to many years. Times of non-chemical processes are also of importance.

Some of the processes make it impossible to follow the conversion from one species to another. In this case only the steady-state concentrations can be determined. In relatively slow processes, the change in concentrations can be followed if the source varies temporarily.

Some measurements need to be made only a few times while other need many measurements. In some cases diurnal variations are desired, in other cases seasonal variations may be needed, while for still other cases long-term variations are an important question.

Range and Burden

The ranges of species concentrations are those which cover the concentrations (molecules cm^{-3}) where the species are of interest. Since, for remote measurements, spectrally related measurements are of the amount in a total column, the total column density (burden) is given in atmosphere cm (where 1 atm. cm = 2.69×10^{19} molecules cm^{-2} at STP). The highest burden given is for one vertical pass through the atmosphere with nominal concentrations but allowing for increased amounts of pollutants and possible errors in the measurements or estimates of nominal amounts. The lower burden given is usually the amount in one desired resolution element at the upper part of the altitude range of interest.

In some cases this has been limited to the upper 5 km in the stratosphere even though data at higher altitudes is desirable. This was done to limit the burden range.

Models of Levine and of Turco[5] were used where data were needed to establish concentrations. For measurements of parameters other than of species concentrations, the range given is the extremes expected in the locations of interest.

Table 3.2-1. Observables for Knowledge Objective 1

1. O_3 Distribution.
2. NOX Distribution.
3. CFM Distribution.
4. N_2O Distribution.
5. H_2O Distribution.
6. Aerosol Characterization and Distribution.
7. CO_2 Long Term Trend.
8. Radiative Flux (h) - Solar, Terrestrial, Atmospheric.
9. Tropopause Height.
10. Cloud Cover.
11. Albedo.

Table 3.2-2. Observables for Knowledge Objective 2

1. Sulfur-Compound Identity e.g. H_2S, SO_2, SO_3, CS_2,
2. Sulfur-Compound Distribution COS, HSO_3, H_2SO_4 ...
3. OH Distribution
4. HO_2 Distribution
5. NH_3 Distribution
6. Aerosol Characterization and Distribution
7. Aerosol Composition
8. Precipitation Occurrence
9. Precipitation Composition
10. Tropopause Height
11. Vertical Velocities
12. Intense Convective Activity (Height and Extent)

Table 3.2-3. Observables for Knowledge Objective 3

1. CH_4 Distribution
2. CO Distribution
3. NMHC Distribution, e.g. C_2H_2, C_2H_4, C_2H_6, C_3H_8, Terpenes
4. CH_4 Product Distribution, e.g., CH_2O, CH_3OH, HCOOH...
5. OH Distribution
6. CO_2 Concentration Profiles
7. Solar Flux Profile in Appropriate Spectral Regions
8. Vertical Wind Speed
9. Vertical Profiles of Horizontal Winds
10. Intense Convective Flow

Table 3.2-4. Observables For Knowledge Objective 3

1. O_3 Distribution
2. NO Distribution
3. NO_2 Distribution
4. O Distribution
5. OH Distribution
6. HO_2 Distribution
7. CFM's Distribution
8. T Profile
9. T Surface
10. Solar Flux (h) 310-800 nm
11. Electrical Activity
12. Vertical Velocities

Table 3.2-5. Observables for Knowledge Objective 5

1. O_3 Distribution
2. NO Distribution
3. NO_2 Distribution
4. CO Distribution
5. HC Distribution
6. Aircraft Activity Data
7. Temperature Profiles
8. Cloud Cover
9. Water Vapor
10. Contrails

Table 3.2-6. Observables for Knowledge Objective 6

1. $CFCl_3$ Distribution
2. CF_2Cl_2 Distribution
3. CCl_4 Distribution
4. CHF_2Cl Distribution
5. CH_3Cl Distribution
6. CH_3CCl_3 Distribution
7. OH Distribution
8. ClO Distribution
9. $ClONO_2$ Distribution
10. O_3 Distribution
11. Aerosol Characterization and Distribution
12. Aerosol Composition
13. Solar Flux (h) at appropriate spectral regions
14. Vertical wind velocities
15. Convective Activity

Table 3.2-7. Observables for Knowledge Objective 7

1. N_2O Distribution
2. $O(^1D)$ Distribution
3. O_3 Distribution
4. Aerosol Characterization and Distribution
5. Solar Flux (h, 2)
6. Vertical Velocities
7. Convective Activity

Table 3.2-8. Observables for Knowledge Objective 8

1. Minor Species Distribution as a Function of Surface
2. Minor Species Distribution in Troposphere, e.g., O_3, N_2O, CH_4...
3. Aerosol Characterization and Distribution
4. Dust
5. Sea Surface Roughness
6. Surface Temperature
7. Air Temperature
8. Surface Winds
9. Convective Activity

Table 3.2-9. Observables for Knowledge Objective 9

1. Aerosol Characterization (Number as a Function of Size)
2. Aerosol Composition
3. Aerosol Distribution
4. Identity and Distribution of S-Compounds
5. Identity and Distribution of Nitrogen Oxides and Acids
6. Distribution of NH_3
7. Distribution of H_2O_2
8. Identity and Distribution of Positive and Negative Ions
9. Radiative Transfer Characteristics of Atmosphere
10. Albedo
11. Lapse Rate
12. Convective Activity
13. Vertical Wind Profiles
14. Height of Mixing Layer

Table 3.2-10. Observables for Knowledge Objective 10

1. Distribution of Positive Ions in Stratosphere
2. Distribution of Negative Ions in Stratosphere
3. Distribution of Active Species in Stratosphere (e.g., O, N, NO...)
4. Aerosol Characterization and Charge
5. Aerosol Distribution
6. Radio Propagation

Table 3.2-11. Observables for Knowledge Objective 11

1. Temperature Profile
2. Surface Temperature
3. Winds - Horizontal and Vertical Velocities; Turbulent Intensity
4. Cloud Cover and Distribution
5. Water Vapor Distribution
6. Radiative Flux
7. Precipitation Distribution
8. Lightning
9. Precipitation Composition
10. Severe Storm Distribution and Characterization
11. Albedo

Table 3.2-12. Observables for Knowledge Objective 12

1. Volcanic Particulate Characterization
2. Volcanic Particulate Distribution (with Time)
3. Volcanic Gaseous Compound Identification
4. Volcanic Gaseous Compound Distribution (with Time)
5. Ion Identity and Distribution
6. Radical-Species Distribution
7. Distribution of Lightning
8. Nuclear Burst Location
9. Flux (h, ν)

Table 3.2-13. Ozone Measurement Specifications

Vertical Specifications

Through troposphere and three Km into stratosphere with 1 Km resolution.

Rest of stratosphere and mesophere with three Km resolution.

Horizontal Specifications

Global coverage needed for budget determination with 200 Km resolution. Concentrate on one longitude, 0 to 90° N.

Small selected clean areas of perhaps 500 Km size with 100 Km resolution for studies of surface interaction and layer interchange and for CFM effects in stratosphere.

Study of aircraft activity effects require resolution of the order of 10 Km in appropriate areas.

Temporal Specifications

Weekly measurements lasting one year for most applications.

Daily measurements[1] for two one-month periods.

Monthly measurements for a period of many years.

Range

10" to 10^{13} covers normal range for 0-45 Km and allows for some areas of increased concentration.

Burden of 10^{-2} to 10^{0} atm cm allows for from less than 1/10 to more than three times normal burden for one vertical pass.

Accuracy

5%[1] desirable for budget determination.

10% acceptable for most applications.

Precision should be 2%.

Table 3.2-14. Oxygen - Hydrogen Species Measurement Specifications

Species

O, O ('D)
OH, HO_2, H_2O, H_2O_2

Vertical Specifications

Tropospheric measurements of H_2O, H_2O_2, HO_2 and OH with 1 Km resolution.

Stratosphere measurements of all species with 5 km resolution. Measurements of O and O('D) should be made to as low an altitude as possible.

Horizontal Specifications

Global coverage for tropospheric measurements with 100 km resolution[3].

Stratospheric and mesospheric measurements can be made at selected locations but a thorough latitudinal variation must be included.

Temporal Specifications

For trospheric measurements, a daily measurement is highly desirable[2]. For higher measurements, weekly repetition is suitable[3].

Ranges

	Number Density (mlcl cm^{-3}*)	Burden (atm cm)
O	$1^7 - 2^{11}$	$1^{-5} - 2^{-2}$
O('D)	$1^1 - 1^4$	$1^{-4} - 1^{-8}$
OH	$1^5 - 1^8$	$1^{-8} - 1^{-5}$
HO_2	$1^7 - 1^9$	$1^{-6} - 4^{-2}$
H_2	$1^7 - 1^{13}$	$1^{-3} - 4^0$
H_2O	$1^6 - 1^{18}$	$2^0 - 2^4$
H_2O_2	$1^7 - 1^{12}$	$4^{-6} - 4^{-2}$

Accuracy

Accuracies needed are generally stated in the range of 5[1] to 20[2]%. Water is needed somewhat more grossly with as high as 50%[2] accuracy being sufficient for some purposes. Oxygen atoms, both ground state and excited peak high up in the atmosphere and, therefore, to be useful, these already difficult measurements are needed to high accuracies of the order of 1%. For OH, HO_2, H_2O_2, 10% should be suitable.

* On this table and on subsequent Tables 3.2-14 to 3.2-19 the number density values given as X^y are used to represent X times 10^y (e.g., $1^7 - 2^{11}$ = 1 x 10^7 to 2 x 10^{11}).

Table 3.2-15. Nitrogen Compounds Measurement Specifications

Species

NO, NO_2, N_2O_5, N_2O, HNO_2, HNO_3, NH_3; NO of greatest importance with NO_2, HNO_3, N_2O, NH_3 also of major importance.

Vertical Specifications

Trosphere with 1 km resolution.

Stratosphere with 5 km resolution.

Mesosphere: NO with 5 km resolution.

Horizontal Specifications

As with O_3.

N_2O in selected "clean" area.

NO in one spot continuously (see below) selected for NO source.

Temporal Specifications

Up to 30 km, the $NO \rightarrow NO_2$ conversion is on a scale of minutes. Looking at one area continuously would be the only way to study this. The conversion of NO and NO_2 to HNO_3 requires from a few hours in the troposphere to a few days in the stratosphere. Thus, unless hourly measurements can be made as they could in that same one area, weekly measurements[1] would suffice. Daily measurements[2] would only serve stratosphere.

Weekly measurements sufficient for N_2O and NH_3.

Ranges

	Number Density (mld cm^{-3})	Burden (atm cm)
NO	1^{7} - 2^{10}	4^{-6} - 1^{-3}
NO_2	1^{7} - 5^{9}	4^{-6} - 4^{-4}
N_2O_5	1^{6} - 1^{9}	1^{-7} - 5^{-5}
N_2O	1^{10} - 2^{13}	1^{-3} - 1^{0}
HNO_2	1^{5} - 1^{8}	4^{-9} - 1^{-5}
HNO_3	1^{6} - 5^{10}	4^{-5} - 2^{-2}
NH_3	1^{8} - 5^{10}	4^{-5} - 1^{-2}

Accuracy

Upper atmospheric applications need accuracies of the order of 5%[1] for most species while 20% has been suggested[2] for lower atmosphere needs. Ten percent[3] would seem like a reasonable number. Precisions should be of the order of 2% to have comparative distribution data. N_2O needs high precision though low accuracy.

Table 3.2-16. Carbon Compounds Measurement Specifications

Species

CO, CO_2, CH_4
CH_2O, CH_3OH, HCOOH, C_2H_2, C_2H_4, C_2H_6, C_3H_8, terpenes.

Vertical Specifications

Major species need to be measured through stratosphere and troposphere with CO and CO_2 on through the mesophere. The non-methane hydrocarbons should be measured up to about 20 km while the intermediates in the CH_4 - CO chain should be determined in the stratosphere. A resolution of 1 km over the 0 to 20 km range and of 5 km above should be suitable although a troposphere resolution of 3 km with 0.5 km desired has been suggested[2]. It would be preferable to break the troposphere up into three altitiude ranges (0 - 0.3 km, 0.3 - 5 km, 5 km - top of troposphere).

Horizontal Specifications

Global coverage of tropospheric measurements is needed with 500 km or better[1,2] resolution. Stratosphere measurements need not be global, nor of this resolution.

Temporal Specifications

CO_2 measurements needed only a few times a year[1], but over a very extended time (many years), CO measurements should be obtained weekly[1] and for a few years. Measurements of intermediate products in the methane-to-CO chain are needed only a few times.

Accuracy

CO_2 needed to a 1% accuracy to be useful. The more stable species, such as CO, CH_4 and other hydrocarbons should be obtained to 10% accuracies while the measurements of intermediates would be suitable with 50% accuracy.

Table 3.2-17. Sulfur Compunds Measurement Specifications

Species

H_2S, HS, SO_2, SO_3, H_2SO_4, COS, CS_2
Aerosol and precipitation measurements to be correlated.

Vertical Specifications

Troposphere of greatest importance and should be covered with 1 km[2] resolution.

Stratospheric measurements needed of at least H_2S and SO_2 with 5 km resolution, possible 2 km resolution in the bottom several km of stratosphere.

Horizontal Specifications

Global coverage desirable. Since SO_2 is primarily an antroprogenic product, large metropolitan areas and areas downstream from them are most important. However, H_2S is primarily a natural product and needs global coverage. Both ultimately lead to sulphuric acid (H_2SO_4)[2]. A resolution of 500 km[1,2] is suitable although as fine as 50 km[2] has been suggested.

Temporal Specifications

Unless a selected area containing sources can be continuously covered, weekly can be used although daily[2] would be a little more informative.

Ranges

	Number Density (mld cm^{-3})	Burden (atm cm)
HS		4^{-8} - 4^{-4}
H_2S	1^{6} - 1^{10}	
SO		
SO_2	1^{8} - 1^{12}	4^{-8} - 1^{-3}
SO_3		
HSO_3	1^{6} - 1^{9}	4^{-8} - 1^{-6}
H_2SO_4	1^{7} - 1^{10}	4^{-8} - 4^{-5}
COS	1^{9} - 1^{11}	1^{-6} - 1^{-8}
CS_2	1^{8} - 1^{10}	4^{-7} - 4^{-9}
CH_3SCH_3	1^{8} - 2^{10}	4^{-7} - 4^{-5}

Accuracy

Ten percent accuracy has been suggested[1,2].

Table 3.2-18. CFM's Measurement Specifications

Species

$CHCl_3$, CH_2Cl_2, CH_3Cl, CCl_4
CHF_2Cl, CH_3CCl_3
ClO, $ClONO_2$, HCl

Vertical Specifications

Coverage is needed of the troposphere at 2 km resolution (usual three levels would be better than poorer even resolution[2]) and of stratosphere with 5 km resolution. Stratosphere the more important; measurement of ClO, HCl and $ClONO_2$ needed only in stratosphere. Stable species could be used to locate tropopause.

Horizontal Specifications

Global coverage has been requested[1] but selected areas would seem to be suitable with 500 km resolution[1,2]. In stratosphere, this would be suitable even with poorer resolution.

Temporal Specifications

Weekly measurements should be sufficient[1] with only monthly measurements needed for the more stable, source, molecules[1]. Daily has been requested[2] but is probably unnecessary because of long life times.

Ranges

	Number Density (mlcl cm^{-3})	Burden (atm cm)
$CFCl_3$	1^{10} - 2^{13}	1^{-1} - 2^{0}
CF_2Cl_2	1^{10} - 1^{13}	1^{-1} - 1^{0}
CH_3Cl	1^{7} - 1^{11}	1^{-5} - 1^{-3}
CCl_4	1^{6} - 1^{10}	1^{-6} - 1^{-4}
CHF_2Cl		
CH_3CCl_3	1^{6} - 5^{9}	1^{-6} - 1^{-4}
HCl	1^{8} - 5^{9}	1^{-6} - 1^{-4}
ClO	1^{8} - 5^{9}	1^{-6} - 1^{-4}
$ClONO_2$		

Accuracy

An accuracy of about 10% is generally suggested[1,2] and should be suitable.

Table 3.2-19. Metals and Oxides Measurement Specifications

Species

N_a, M_g, C_u, F_e, Al
N_i, K, L_i
H_g, P_b
NaO, MgO

Vertical Specifications

Heavy metals (Hg, -Pb) in troposphere only with three layers (0-.3, 3-5,5 to top) resolution.

Others in troposphere and stratosphere and mesosphere with 5 km resolution in latter two regions.

Horizontal Specification

Global with 500 km resolution.

Temporal Specification

A few weekly periods with daily measurements and a diurnal variation.

Accuracy

10 parts per trillion suggested[2].

Table 3.2-20. Ions

Species

Individual positive ions
Individual negative ions

Vertical Specifications

From 0 to 100 km with 5 km resolution
From 100 to 200 km with 10 km resolution
From 200 to 400 km with 20 km resolution

Horizontal Specifications

Global coverage with 200 km resolution except around severe storms and other disturbances where 10 km resolution is needed.

Temporal Specifications

Diurnal variations in selected areas for several weekly periods in a year. Hourly measurements.

Range

Troposphere:	Total of $10^1 - 10^3$ with individual ions of $10^0 - 10^3$ cm^{-3}	
Stratosphere:	Total	$10^1 - 10^4$
	Individual	$10^0 - 10^4$
Above Stratopause:	Total	$10^3 - 5 \times 10^6$
	Individual	$10^1 - 3 \times 10^6$

Accuracy

20% in relative number. 40% in total.

Table 3.2-21. Aerosols Measurement Specifications

Size Distribution
Number density (by size)
Composition (including charge)

Note: Most reports merely state aerosols. More specific measurement requests needed. Total mass is not all that is needed.

Composition may require correlated in-situ measurement.

Vertical Specifications

Mainly tropospheric - two or three elements (layers) over troposphere sufficient for most applications although 1 km resolution is ultimately desirable. Sulfur chemistry probably needs 1 km resolution.

Horizontal Specifications

Global coverage for most applications. Resolution of 200 km suitable although as fine as 10[2] has been suggested. Composition measurements may be at selected areas.

Temporal Specifications

Two measurements per day needed. This is more important than complete horizontal coverage. Should extend for a year or more to determine variations and trends.

Range

Size:	10^{-6} to 10^{-2} cm diameter
Number Density:	10^{-1} to 10^5 cm^{-3}
Composition:	Need to differentiate among $S(SO_4)$, $N(NO_3)$, solid particulates, etc. and determine chemical form.

Accuracy

25 to 50% suitable.

Table 3.2-22. Temperatures Measurement Specifications

Measurements should be made at same time and place and resolution as those of species with which temperatures are to be correlated.

Measurements

Temperature profile, T(h)
Surface temperature, Ts (Air at surface)
Cloud-top temperature, T_C

Horizontal Specifications

Global coverage for both T(h) and T_S with 100 km resolution cloud-covered areas with same resolution as cloud cover.

Vertical Specifications

Troposphere with 1 km resolution lapse rate is of primary importance especially in transport and mixing which is the most important way temperature enters into species distribution. At least 1 km resolution for tropopause and stratopause location.

Stratosphere with 5 km resolution. Lapse rate again most important.

Temporal Specifications

Weekly for many applications but daily[1,2] measurements (or more often) may be needed at times.

Range

T(h)	180 - 280 K
Ts	230 - 320 K
Tc	180 - 300 K

Accuracy

1 K suitable for mixing and chemistry.
Ts need to about 0.2 for radiation.

Table 3.2-23. Solar Flux

Measurements to correlate with species measurements:

310 - 360 nm ($\underline{\nu}$,h)
400 - 800 nm ($\overline{\underline{\nu}}$,h)
250nm - 15μ m ($\overline{\underline{\nu}}$,h)

<u>Vertical Specifications</u>

Need measurements as a function of altitude from 0 - 15 km, with 1 km resolution. Higher altitude measurements also desirable. If not attainable other than in-situ, such should be made in appropriate locations with correlations with remote species measurements.

<u>Horizontal Specifications</u>

Global coverage of flux at surface and at high altitude with resolution of 100 km satisfactory. Vertical profile of flux should be obtained at selected regions, selected for variations in atmospheric gases and aerosols.

<u>Temporal Specifications</u>

A few sets of measurements each season of year.

<u>Accuracy</u>

Since percent changes in flux in O_3 region have very significant effects, a 1% accuracy at surface and a 1% precision in profile is needed.

Table 3.2-24. Winds Measurement Specifications

Measurements to be made to correlate with species measurements.

<u>Vertical Specification</u>

Measurements needed with fine resolution (1 km) from ground into stratosphere for study of species transport and layer interchange. Above about 20 km, resolution of order of 5 km acceptable.

<u>Horizontal Specifications</u>

Global coverage with resolution of the order of 100 km with a number of selected areas, chosen by needs of species measurements, with resolution of order of 5 km. Desired resolutions based on resolutions for gaseous species measurements.

Temporal Specifications

Weekly averages are suitable for most data but for study of wind effects on composition probably need minute-by-minute measurements for several hours. Measurements with this repetition rate should be made for a year.

Range

Horizontal winds:	Need to cover entire range of winds which occur. The larger the value of wind speed, the greater the effect in composition and distribution.
Vertical winds:	

Accuracy

25% suitable with 10% precision over a one-day period.

Table 3.2-25. Clouds Measurement Specifications

Measurements should be at same place and time (with same resolutions) as species measurements. Problem of making species measurements with cloud-cover condition remains.

Vertical Specifications

Cloud-top height to 1 km.

Cloud thickness to 1 km, needed to give height at which interactions with atmospheric species occurr.

Horizontal Specifications

Fraction of cloud cover with same coverage and resolution as species measurement.

Global coverage, 100 km resolution satisfactory for most applications. May need some over very limited area with 5 km resolutions.

Temporal Specifications

Nearly coincident with species Measurements.

Daily cloud cover height and thickness would be sufficient for most applications but must be at appropriate time.

Range

Cloud height and thickness throughout range of cloud occurrence.

Cloud cover: 0 - 100%

Accuracy

$\pm$0.5 km in height.

Cloud cover should be in the order of 5%.

Table 3.2-26. Precipitation Measurement Specifications

Measurements should be at same time and place, with same resolution, as those of species with which precipitation is to be correlated (SO_4, NO_3, NOX, etc.).

Measurements

Type
Spatial Distribution
Characterization (Size distribution, composition, charge)

Vertical Specifications

Cover troposphere with 1 km resolution (2 km resolution suitable above 5 km).

Horizontal Specifications

Global coverage with resolution of 200 km. Finer resolution suggested(2) only needed for meteorological applications.

Temporal Specifications

Daily or better has been suggested(2) but actually needed same as species measurements.

Accuracy

Location to 10 km
Amount, rate and size to 25%.

Table 3.2-27. Severe Storms

Measurements of parameters of severe storm activity:

Lightning
Winds, horizontal and vertical, with direction
Precipitation
Coordinate with species measurements

Vertical Specifications

Mainly tropospheric with 1 km resolution. Finer resolution probably advisable in 0-2 km altitude range.

Horizontal Specifications

Selected areas of about 500 km, one or two having high severe storm activity, and one with little. Should have fine resolution for both meteorological and species measurements, perhaps 10 km.

Temporal Specifications

Follow selected areas constantly with one hour resolution for at least three one-month periods in a year.

3.3 APPLICABILITY OF AOS MEASUREMENTS TO METEOROLOGY RELATED DISCIPLINES

Consideration was given concerning the utility of the identified AOS measurements for the "CORE" air quality mission, in each of the meteorological disciplines. This consideration is in consonance with the basic approach for the study, which considers primarily the air quality requirements and their associated meteorological measurements; and secondarily, the potential utility of the AOS in complementing the world-wide meteorological data nets. Section 3.3.1 through 3.3.1.5 discuss these aspects.

Recognizing the NASA's interest in establishing important program interrelationships, the complementary problem was examined, i.e., to what extent could the current operational meteorological satellite systems and the total atmospheric data base, both observed and calculated, that is used for operational weather analysis and forecasting, complement or duplicate measurement to be made by the AOS for the CORE air quality mission. These aspects are presented in Section 3.3.17.1 through 3.3.17.6.

The basis of the analysis is the set of 12 Knowledge Objectives, the principal information requirements of each, an integrated set of observables derived from them and the specifications, as shown in Sections 3.1 and 3.2.

The following paragraphs discuss the applicability of these specified measurements to the problems of operational weather analysis and forecasting, herein termed synoptic meteorology; to climate studies; to mesoscale and/or severe storm analysis and forecasting; and to studies of the atmosphere/surface interface. In addition, the major impacts of these weather and climate problems on the measurement requirements of the AOS are discussed.

3.3.1 OZONE

3.3.1.1 Symoptic Meteorology

The total columnar ozone content and the vertical profile of ozone concentration are not presently used for the radiation calculations in current numerical forecast models. However, they could be incorporated into improved models that may be implemented in the near future. If this were the case, global measurements would be needed on a 2.5^{o} x 2.5^{o} latitude/longitude grid with a vertical resolution of at least 3 km. Furthermore, a commitment would have to be made to provide these global measurements a minimum of twice daily, indefinitely into the future.

3.3.1.2 Climate Studies

The vertical distribution of ozone and its impact on ultraviolet radiation and stratospheric/mesospheric temperature profiles, are an integral part of globe climate and climate change studies. The ozone profile measurements suggested for the AOS are directly applicable to this problem with the exception that daily measurements would be needed with the same specifications suggested for Synoptic Meteorology for an extended number of years.

3.3.1.3 Mesoscale/Severe Storms

Ozone is not recognized as an important factor on the temporal and spatial scales of interest here.

3.3.1.4 Atmosphere/Surface Interface

The interface of the atmosphere with the earth's surface is a major sink for ozone. This is not, however, a meteorological problem but rather one involving air quality. Hence the consideration of these interface processes is included with the air quality knowledge objectives, observables for the knowledge objectives, measurement needs, and mission requirements.

3.3.2 OXYGEN/HYDROGEN SPECIES

3.3.2.1 Synoptic Meteorology

The principal constituent of concern in this group is, of course, water vapor. Tropospheric and stratospheric measurements of water vapor at the horizontal and vertical resolutions proposed would represent a major contribution to the atmospheric data base, but only if observations were made at least twice daily. The accuracy of these measurements would have to be held to 10% or better. It must be emphasized here that if these measurements were made part of an Atmospheric Observation mission, strong consideration should be given to making these measurements at times of day that would augment rather than duplicate those measurements provided by the operational meteorological satellites.

3.3.2.2 Climate Studies

The temporal and spatial distribution of water in all of its states is the heart of the climate problem. The measurements proposed for the AOS would contribute significantly to the data base required. However, once again, measurement accuracies would have to be kept to $\pm 10\%$.

3.3.2.3 Mesoscale/Severe Storm

Tropospheric water vapor data would be very valuable to the mesoscale and severe storm forecast problem. However, the horizontal resolution of the measurements would have to be an order of magnitude better than suggested for the AOS, that is about 10 km. In this case, measurement accuracy would have to be raised to $\pm 5\%$ and the frequency of observation increased to hourly. It would be fair to note, however, that a high resolution moisture data field even once or twice a day would be a valuable input to newly evolving mesoscale numerical forecast models.

3.3.2.4 Atmosphere/Surface Interface

Measurements of the water vapor concentration at the land/air and sea/air interfaces on a global basis even at horizontal resolution of 100 km, once per day, would represent a significant addition to the presently available data base. Because of the importance of water vapor transport to the energy balance of the atmosphere, the AOS missions should provide data which, when used in conjunction with other meteorological data, would greatly assist such programs.

3.3.3 NITROGEN COMPOUNDS

None of the proposed measurements are applicable to any of the weather and climate studies under consideration here.

3.3.4 CARBON COMPOUNDS

3.3.4.1 Synoptic Meteorology

In the operational numerical forecast models, the assumption is made that the concentration of carbon dioxide in the atmosphere is uniform and constant. The time-scale of the change in CO_2 content of the atmosphere is far too long to be of concern to day-to-day weather forecasting.

3.3.4.2 Climate Studies

The long-term change in the carbon dioxide content of the atmosphere and its resulting impact on the earth/atmosphere radiation balance is a central issue in long-term climate change theory. Carbon dioxide is one of the primary absorbers of long wave terrestrial radiation in the atmosphere. Increases in carbon dioxide content of the atmosphere, it is postulated, would result in an enhancement of the atmospheric "greenhouse effect" and hence a potential long-term increase in average temperature. The measurements proposed for the AOS would represent a very definite contribution to the desired global climate data base.

3.3.4.3 Mesoscale/Severe Storms and Atmosphere/Surface Interface

Not applicable.

3.3.5 SULFUR COMPOUNDS

3.3.5.1 Synoptic Meteorology

Not applicable.

3.3.5.2 Climate Studies

Acid rain and its long-term environmental effects has become of increasing concern in local climate studies. Basic to these investigations is the knowledge of the distribution of sulfur compounds in the boundary layer. The data provided by the AOS would be an important augmentation of this data base.

3.3.5.3 Mesoscale/Severe Storms

Data on the distribution of sulfur compounds could conceivably be used in rgional mesoscale forecast models, not from the point of view of contributing to the forecast skill of the model, but rather from the point of view of having the model forecast where and when serious concentrations of sulfur oxides could be anticipated. This would be particularly important near selected metropolitan and industrial areas where acid rain has emerged as a problem. For this purpose, daily observations of the sulfur compounds would have to be provided with a horizontal resolution closer to 50 km.

3.3.5.4 Atmospheric/Surface Interface

Not applicable.

3.3.6 CFM'S

These measurements would not be applicable to any of the weather and climate problems.

3.3.7 METALS AND OXIDES

These measurements would not be applicable to any of the weather and climate problems.

3.3.8 IONS

3.3.8.1 Synoptic Meteorology

Not applicable.

3.3.8.2 Climate Studies

It is conceivable that the long-term variations of the concentration and distribution of ions in the atmosphere could be of consequence in climate change studies. Provision of these data would require a commitment to a long-term global measurement program. The horizontal and vertical resolutions proposed for the AOS would be quite acceptable for this application.

3.3.8.3 Mesoscale/Severe Storms

It is not apparent how the ion measurements proposed for the AOS would be applied in these studies, though it is quite obvious even to the casual observer that electrical fields are very much involved in severe storms. It can only be suggested that if an extensive ion data base were available that some correlation studies would be run to determine their applicability to severe storm forecasting.

3.3.9 AEROSOLS

3.3.9.1 Synoptic Meteorology

The effects of aerosols on the long-wave and short-wave radiation passing through the atmosphere, both incoming and outgoing, could be modeled and included in current global numerical forecasting models. The aerosol measurements proposed for the AOS would provide a firm basis for such modeling; however, a continuing observation program would have to be assured. The resolution and accuracy proposed for the AOS measurements would be satisfactory for this application.

3.3.9.2 Climate Studies

Aerosol distribution and concentration in the atmosphere are very basic and important to climate change studies. Aerosols are a vital element of a widely accepted theory of climate change that relates the vertical distribution of aerosols to atmospheric stability and ultimately to the formation and vanishment of major desert areas. To support these studies, the horizontal resolution of the aerosol measurements would have to be closer to 10 km.

3.3.9.3 Mesoscale/Severe Storm

Although aerosols serve as condensation nuclei in cloud formation and improved measoscale/severe storm models may, in the future, include aerosols, the data from measurements of aerosols made by air quality mission would not be sufficient for such use..

3.3.9.4 Atmosphere/Surface Interface

The ocean being one of the major sources of atmospheric aerosols, it is clear that measurements of aerosol concentration at the sea/air interface would provide an important contribution to the investigation of the rate of production of aerosols at sea/air interface. For these purposes, the proposed horizontal resolution of 200 km would be quite adequate.

3.3.10 TEMPERATURE

3.3.10.1 Synoptic Meteorology

Temperature is one of the basic state variables of the atmosphere, and as such, an integral part of the numerical prediction models. It is, of course, one of the fundamental weather elements of interest in weather forecasts. To the extent any measurement enhances the definition of the atmospheric temperature fields, it is of value in weather analysis and forecasting. The vertical resolution of the measurement proposed for the AOS is acceptable for synoptic meteorology as well. The horizontal resolution of the AOS measurements would also be acceptable for vertical temperature profile measurements. The frequency of observation must be increased to at least twice per day. In designing the Atmospheric Observation System, it would be advantageous if consideration could be given to having the observations made at times that augment the data provided by the operational meteorological satellites, rather than be duplicative of them.

The surface temperature measurements range suggested for the AOS would have to be extended to 190 K to 320 K and the measurement accuracies increased to 0.5 K. Over ocean areas, a measurement accuracy of 0.1 K is required.

3.3.10.2 Climate Studies

Temperature is one of the definitive elements of climate. Part of the definition of the climate of any given region depends on its average variation of temperature. Therefore, to the extent that the AOS observations augment the available atmospheric temperature data base, they are contributing to the definition of climate and its variation.

3.3.10.3 Mesoscale/Severe Storms

The temperature measurement requirements for mesoscale and severe storm forecasting and analysis are even more stringent than for synoptic meteorology; much finer horizontal resolution is required. For vertical temperature profiles, measurements with a 10 km resolution are needed, while for surface and cloud-top temperature measurements, a horizontal resolution of 1 km would be required.

The coverage areas generally need to be about 500 x 500 km surrounding the severe storms or the designated mesoscale feature of concern. However, the problem is that these areas are continuously moving and cannot be anticipated too far ahead of time because of the relatively short lifetime of these phenomena. The temperature measurements need to be made hourly with an accuracy somewhere between 0.5 K and 0.1 K. It should be pointed out, however, that if a detailed, accurate temperature field were provided even once or twice a day, it might serve as a valuable input to a numerical mesoscale forecast model.

3.3.11 SOLAR FLUX

3.3.11.1 Synoptic Meteorology

The solar flux data used in numerical weather prediction are currently derived from a combination of a solar geometry and measurements of the vertical profile of humidity. Direct measurements of the solar flux would certainly enhance the performance of these models. These measurements would have to be made at least twice daily for an indefinite period of time. The proposed horizontal resolution for the solar flux measurements would be fine; the proposed vertical resolution of 5 km would be acceptable.

3.3.11.2 Climate Studies

Solar flux is, once again, a fundamental quantity in climate studies and intimately involved in theories of climate change. The measurement specifications proposed for the AOS are suitable for this application as well. However, at least daily measurements for a very extended period of time would be necessary.

3.3.11.3 Mesoscale/Severe Storms

It is not apparent how this measurement could be applied to this problem.

3.3.11.4 Atmosphere/Surface Interface

Measurement of the solar flux at the earth's surface on a 100 km global grid at least twice daily would significantly enhance these studies. Relatively few data of this type are available on a global basis. Over a few countries, such as the U.S., or at a few research stations, such as the South Pole, some solar flux data at the surface have been compiled. Over the vast majority of the earth's surface, especially the ocean areas, no data presently exist.

3.3.12 WINDS

3.3.12.1 Synoptic Meteorology

The vector winds are one of the basic and critical input parameters of numerical weather prediction models. Any wind measurements that can be provided on a routine twice-daily basis represent a major contribution to the atmospheric data base for operational weather analysis and forecasting. Over the tropics ($\pm 30^0$ latitude) where pressure gradients tend to be quite flat and streamline analysis is used to define the synoptic features, wind data are absolutely essential. In the numerical analysis and forecast models used in the middle latitudes, the wind and pressure fields are used as independent variables and are allowed to mutually adjust each other depending on the scale and depth of the particular circulation features in which simultaneous data may be available. Studies of the U.S. have shown that wind measurements over the eastern Pacific result in substantial improvements of the forecast results over the U.S. However, presently few wind data, aside from those obtained from GOES, are available over the ocean areas. It should be noted that for synoptic analysis purposes, these wind measurements are needed with accuracy of ± 3 mps and $\pm 10^{\circ}$.

3.3.12.2 Climate Studies

The same wind measurements needed for synoptic meteorology if available daily on a full global basis for an indefinite period of time, would represent a major contribution to the available world climate data base and would be most useful in studies of long-term changes in the global circulation and hence, climate.

3.3.12.3 Mesoscale/Severe Storm

Wind data are critically important to mesoscale analysis and forecasting but must be available in even greater spatial and temporal detail. It is suggested that wind measurements for this application would have to be made at a horizontal resolution of 1 km at least four times per day. However, in these cases, the region of concern changes from day-to-day and extends over variable size areas approximately 500 x 500 km in size. It is likely that the planned implementation of a Doppler weather radar network across the U.S. by the end of the decade would obviate the need for these AOS measurements over the U.S.

3.3.12.4 Atmosphere/Surface Interface

If wind shear measurements at the sea/air interface could be made twice daily with a horizontal resolution of 10 km, studies of the momentum exchange between the oceans and the atmosphere would benefit greatly. Such investigations are basic to ocean current studies, to ocean wave and storm research, and to ocean/atmosphere general circulation studies.

3.3.13 CLOUDS

Cloud measurements or observations, with the exception of cloud thickness and ceiling height, would be redundant to those being made today by the variety of meteorological satellites, both U.S. and foreign, in operational use. Improvement in the data on ceiling height is important to meteorological problems as well as to other applications. However, to improve meteorological data to a useful degree would require measurements which would be beyond these suggested for air quality needs. In assessing the technology improvements needed to satisfy the representative air quality missions, consideration was limited to the air quality needs. Better measurements are needed for meteorological purposes and there are probably technology improvements required for such measurements. It may be that improved ceiling height measurements would be helpful to air quality but such assessment is currently very difficult.

3.3.14 CLOUD THICKNESS

3.3.14.1 Synoptic Meteorology

The cloud thickness measurements proposed for the AOS would provide a useful input to the radiation model used in the operational numerical weather prediction models. The same measurements would also be extremely valuable in the meteorological support of private and commercial aircraft operations. The horizontal resolution of these measurements would have to be increased to something between 1 to 5 km, and observations would have to be made at least four times each day.

3.3.14.2 Climate Studies

To the extent that cloud thickness influences the flux of incoming and outgoing radiation, it is of interest in theoretical climate studies. However, as an individual parameter, it is not very important in this application.

3.3.14.3 Mesoscale/Severe Storms

Cloud thickness is a most useful parameter in mesoscale analysis and forecasting, but hourly observations with a horizontal resolution of 1 km would be needed.

3.3.14.4 Atmosphere/Surface Interface

Not applicable.

3.3.15 PRECIPITATION

In relating the precipitation measurements required for the Atmospheric Observation System to those needed in meteorology and climatology, it is important to understand the nature of the observation needed for the AOS. The principal issue of concern here is the extent to which the precipitation serves to "scrub" or remove a given minor constituent from the air as it passes through a region of precipitation. In essentially all cases, whether it be frontal, convective, or orographically induced precipitation, the precipitation area is related to a feature of the circulation pattern through which the air passes. A front might be moving along at 10 to 20 knots while the air, say in the middle troposphere, could be moving relative to the front at 70 to 80 knots. Squall-line thunderstorms can move faster than air through which they propogate ahead of a gravity wave on a stable layer. At the other extreme, orographically induced precipitation will remain fixed with respect to the ground while the air flows through it.

What the atmospheric chemists and air pollution scientists want is to measure the concentration of a gaseous constituent in a given volume of air before it enters an area of precipitation and the concentration of that constituent in the very same volume or parcel of air after it leaves the area of precipitation. The difference could presumably be related to the "precipitation scrubbing" mechanism.

Point concentration measurements do not really reveal this information. If, for example, the concentration of SO_2 were measured over a metropolitan area ahead of a cold front and another measurement made after the cold front passed, the change in SO_2 concentration could not be ascribed to any frontal process, precipitation included, but simply to the fact that the air present "now" has moved in from a different source region. The air moving in could be cleaner or could have a greater SO_2 burden if moving in from a region with a greater concentration of factories. The air that was present ahead of the front could conceivably be hundreds of miles downstream and many thousands of feet above the ground. To understand the role of the precipitation mechanism for the AOS, specific air "parcels" would have to be tracked and measured. Perhaps the approach needed is to continuously chart the three-dimensional distribution of precipitation rate in the atmosphere and to utilize air trajectory analysis to "post facto" determine the time history of gaseous concentrations in moving volumes of air.

The presumption has to be made here that the AOS has little interest in quantitative or accumulated precipitation at the earth's surface, but really needs to know the distribution of precipitation rate throughout the atmosphere, as well as such physical properties of the precipitation as drop-size or particle-size distributions. These requirements are related to the meteorology/climatology problems of interest here in the following paragraphs.

3.3.15.1 Synoptic Meteorology

Precipitation rate measurements over the range of 0-50 mm per hour would be particularly useful for analysis and forecasting if they were made frequently enough to permit the movement of the precipitation patterns to be tracked so that a time integration of the data could be used to determine precipitation totals at the ground for hourly, six-hourly, and daily periods. These measurements would have to be made at a horizontal resolution of about 10 km.

3.3.15.2 Climate Studies

Precipitation at the ground is a basic climatic element; but short-term precipitation rate data would not particularly assist the climatologist. It is presumed that any contribution of the AOS to synoptic meteorological precipitation data would subsequently become part of the available climate data base.

3.3.15.3 Mesoscale/Severe Storms

Precipitation rate is very much a part of the measurement of severe storm intensity and an essential element in flood and flash flood forecasting. However, these data would have to be very local and very detailed. It is estimated that a horizontal resolution of 1 km would be needed with an observational frequency of at least once per hour. This might have to go as high as four times per hour. Once again, over populated areas, which really are only where these measurements are of any consequence, it's not clear that AOS measurements could compete with ground-based Doppler weather radar observations.

3.3.15.4 Atmosphere/Surface Interface

Precipitation is an important constituent in the mass flux through the air/surface interface; however, it is measurements of accumulated precipitation that would be required. If a useful integration scheme for the precipitation rate observations is developed, these data would be useful in this application.

3.3.16 SUMMARY RELATIVE TO AOS CONTRIBUTION TO METEOROLOGY

The applicability of the proposed AOS observations to problems in weather and climate and the additional requirements that such applications would place on such observations are summarized in Table 3.3.16-1.

3.3.17 UTILITY OF THE AVAILABLE METEOROLOGICAL DATA BASE TO THE AOS

3.3.17.1 Discussion

Routine operational weather analysis and forecasting today is a large, complex, international cooperative operation that involves rather extensive observation and measurement of much of the atmosphere many times each day. The types of measurements made vary from simple instrumentation at thousands of surface weather observation stations around the world and on dozens of buoys to balloon-borne instrumentation that senses the atmosphere routinely up to heights of 30,000 meters at well over 1000 sites. It involves more complex sensors such as microwave radars and a rather sophisticated operational satellite system that currently includes for geostationary spacecraft (two of which belong to the U.S.) and at least two low-altitude spacecraft in near-polar, sun-synchronous orbits. As a consequence, there is compiled daily a rather extensive, though far from perfect, global atmospheric data base. To be sure, even for operational weather forecasting, the data are, as yet, inadequate. There remain many extensive data sparse regions of the globe and many regions of the atmosphere where the array of measurement is not sufficiently dense, made sufficiently often, or made at all. Nonetheless, it would be well in planning and designing the AOS to consider what atmospheric measurements are routinely obtained and the extent to which these data might preclude the need for the measurement being made again by the Atmospheric Observation System. In the following sections, a brief summary is presented, by parameter, of many of the routine operational meteorological observations being taken today.

3.3.17.2 Cloud Observations

Extremely comprehensive observations of the earth's cloud cover have been routinely obtained by the operational meteorological satellites for some time now. The Low Earth-Orbiting (LEO) satellites provide full global observations twice each day in the IR and once a day in the visible spectrum, all at a

Table 3.3.16-1 A: Summary of Applications of AOS Measurements

Observables	Synoptic Meteorology	Climate Studies	Mesoscale/Severe Storms	Atmosphere/Surface Interface
Ozone	Current NWP models do not account for O_3 profile or burden. Requires data on a $2.5^o \times 2.5^o$ lat/long grid with 5 km vertical resolution.	Impact on UV radiation flux and stratosphere temperature profile is a factor in climate change studies. Proposed measurements applicable; needed daily for many years.	Not a factor	N/A
Oxygen/ Hydrogen Species	Proposed measurements a major contribution to atmospheric data base only if made 2X/day with accuracy of $\pm$ 10%. Should be made at times that augment not duplicate meteorological satellite obs.	Temporal and spatial distribution of water in all its states is central to climate problem. Accuracy of $\pm$ 10% required.	Tropospheric water vapor distribution valuable. Observations needed hourly during periods of "active weather" over 500 x 500 km areas. Need horizontal resolution of 10 km and accuracy of $\pm$ 5%	Daily global measurements of water vapor concentration at surface/air interface with horizontal resolution of 100 km would be a significant "first".
Nitrogen Compounds	N O T A P P L I C A B L E			
Carbon Compounds	N/A	Long-term effects of CO_2 is a central issue. Proposed measurements excellent.	N/A	N/A
Sulfur Compounds	N/A	Acid rain is of increasing concern	Could become an element in evolving regional mesoscale forecast models. Need daily measurements at 50 km resolution	N/A
CFM's	N O T A P P L I C A B L E			

Table 3.3.16-1-B: Summary of Applications of AOS Measurements (Cont'd)

Observables	Synoptic Meteorology	Climate Studies	Mesoscale/Severe Storms	Atmosphere/Surface Interface
Metals and Oxides	N O T	A P P L I C A B L E		
Ions	N/A	Long-term changes might be of interest.	Not apparent how to use data, but electrical fields very much involved.	N/A
Aerosols	Effects on incoming and outgoing radiation could be incorporated into NWP models.	Vital element in one theory of climate change; data needed at 10 km resolution.	N/A	Interested in concentration of sea salt nucleii at sea/air interface on a 200 km grid.
Temperature	Observations needed 2X/day at times that augment meteorological satellite data. Proposed vertical resolution is OK; horizontal resolution suitable for profiles. Surface and cloud top temps require 10 km resolution. Need accuracies of 0.5° C over land and 0.1° over oceans.	Proposed measurements would augment available atmospheric data base.	Need hourly obs. with horizontal resolution of 1 km; vertical profiles need horizontal resolution of 10 km. Accuracy: 0.5° C to 0.1° C. Coverage area is 500 x 500 km, but location varies.	Could use surface/air temperature differences to $\pm$ 0.5° K on a 200 to 300 km grid.
Solar Flux	Twice daily measurements for an indefinite period could replace estimates now used in NWP models.	A fundamental quantity in climate studies, but daily measurements needed for an extended period of time.	Not apparent how this measurement could be used.	Solar flux at surface on a 100 km global grid would represent a major contribution.
Winds	Twice daily measurements with accuracy of $\pm$ 3 mps and $\pm$ 10° would be <u>extremely</u> important	Major contributions to available data base.	Need observations 4X/day with horizontal resolution of 1 km. Not likely to compete with doppler radar.	Could use wind shear measurements at sea/air interface on 10 km grid twice per day.

Table 3.3.16-1-C: Summary of Applications of AOS Measurements (Cont'd)

Observables	Synoptic Meteorology	Climate Studies	Mesoscale/Severe Storms	Atmosphere/Surface Interface
Clouds	Any cloud observations with the exception of cloud thickness or ceiling height would be entirely redundant to those being made by operational meteorological satellites today.			
Cloud Thickness	Useful for radiation model and aircraft operations. Need 1 - 5 km resolution obs. 4X/day.	Not of primary importance; effects dealt with in radiation data.	Need hourly data at a 1 km resolution.	N/A
Precipitation	Precipitation rate measurements at 10 km resolution at least 4X/day could be useful. Also need hourly, six hourly, and daily accumulations.	Precipitation is a basic element of climate. Daily amounts on a 200 km grid would be a major contribution.	Need hourly precipitation rate and amount with horizontal resolution of 1 km. Need vertical distribution of precipitation rate. Area of coverage (500 x 500 km) varies from day-to-day.	Dominant factor in mass flux through atmosphere/surface interface. Proposed measurement would be acceptable.

resolution of 3.5 km. Actually, by virtue of the fact that all of these spacecraft are in near-polar sun-synchronous orbits, the polar regions are observed even more frequently.

The LEO spacecraft, while in contact with the Command Data Acquisition (CDA) stations, also provide local area direct readout visible and IR cloud-cover imagery with a resolution of 1.1 km. The area covered is about 1400 n. mi. wide by 2500 n. mi. long. Furthermore, once each orbit this detailed imagery can be obtained from a preselected area of 1400 x 2100 n. mi., stored and subsequently read out to a CDA station.

The Geosynchronous Earth-Orbiting (GEO) satellites provide cloud cover imagery of an area of 6000 n. mi. in diameter centered at the satellite subpoint. Visible and IR images are provided every 30 minutes with a resolution of approximately 1 km in the visible and 8 km in the IR. There are at least four GEO's operating now, including one Japanese spacecraft and one European spacecraft. At times there are five in operation. Thus, fairly good coverage outside of the polar regions is available retrospectively through international data exchange. Of course, coverage of the Western Hemisphere is directly available from NOAA.

The height of the cloud tops visible from satellites, can be fairly well estimated from measurements of the IR radiance in the atmospheric window region (10-12 u). The heights of the tops of low and middle clouds are estimated to about $\pm$0.5 km. The accuracy to which the tops of the high clouds can be measured varies with their emissivity which can range from 0.1, where essentially no determination can be made, to 1.0, where again an accuracy of $\pm$0.5 km could be realized. Most of the time, the high cloud determinations are good to only about $\pm$2 km.

Measurements of the height of the cloud bases, or ceiling height, are made only from ground stations or aircraft. The direct pilot observations are quite good and depend only on the accuracy of their altimeters. Ground-based ceilometer observations are accurate to about $\pm$100 feet, but their horizontal sampling frequency varies quite dramatically over the world. Over the U.S., station density probably averages 300 km.

3.3.17.3 Precipitation

Precipitation observations are made at essentially all surface weather stations and include differentiation of precipitation type. However, the physical characteristics of the precipitation are rarely measured, e.g., drop-size distribution. There is though, a small network of stations in the U.S. at which the acidity of the rainfall is measured.

Radar can frequently differentiate between such forms of precipitation as snow, sleet and rain, especially can the freezing level be clearly seen on radar as the height at which snow is changing into rain.

The distribution and amount of precipitation is sampled by a surface rain gage network that over the U.S. has an average spacing of about 50 km. Elsewhere in the world it is less dense. Precipitation amount is usually measured in either hundredths of an inch or in millimeters. Radar does show the horizontal and vertical distribution of the precipitation, but does not provide good quantitative data. The resolution of the radar measurements are beam width dependent and hence, are a function of distance. It should be noted that digitized radar data are currently available for most of the U.S. on a 22 x 22 n. mi. grid.

3.3.17.4 Temperature

The surface temperature as reported by weather observation stations around the world is commonly the temperature of the air measured at a height of approximately six feet, preferably over grass-covered ground. To accomplish this measurement, thermometers are usually placed in a well ventilated instrument shelter. On the average throughout the U.S., these measurements are available on a 50 km grid, though there are many local mesoscale networks throughout the country as well. The typical accuracy of surface temperature measurements is 0.1 K.

These measurements must be contrasted with the satellite measurements of "surface temperature" which, whether made in the infrared or microwave, are actually the effective radiatiative temperature of the surface somewhat modified by unknown concentrations of water vapor in the surface boundary layer. Some good progress has been made in developing corrections for this low-level water vapor using radiance data from the TOVS (TIROS Operational

Vertical Sounder), so that surface temperatures measured over ocean areas are now accurate to about ± 1 K. The accuracy of surface temperatures over land areas probably averages ± 2 K. It must be emphasized here that under clear skies and dry air conditions, satellite surface temperature measurements can be considerably different from the commonly measured surface air temperature. That is, while temperature measured by satellite-based instruments is that of the surface (and not the air just above the surface), the temperature of the air as commonly measured six feet above the surface may be as much as 10 K higher than the surface. This does not mean that there is an inaccuracy of 10 K but that the surface and the air at the surface may have temperatures which are different by 10 K. Of course, the advantage of the satellite surface temperatures is that they are available locally twice each day, though when based on infrared radiance observations, are only available from cloud-free areas. The resolution of the satellite surface temperature measurements is the same as was described previously for the infrared imagery, i.e., approximately 3.5 km for the LEO global data, 1.1 km for the local data and approximately 8 km for the GEO data.

3.3.17.5 Cloud-Top Temperatures

The cloud-top temperatures are derived from the same satellite radiance measurements as are the cloud-top height measurements mentioned in an earlier section. There are a few commercial aircraft that carry a weather observation package that also provide air temperatures at the height of the cloud-tops, but this observation is not available nearly as frequently as pilot observations of cloud-top height.

3.3.17.6 Vertical Temperature Profiles

Vertical temperature profile measurements are available from two sources; balloon-borne rawinsondes released over the major areas of the earth twice each day, and from satellites, which provide temperature profiles twice each day globally, but not synoptically.

Rawinsonde data are available over the U.S. and Eurasia on about a 500 to 600 km grid. Elsewhere in the world, average station separations are even larger. The coverage that is provided is essentially the inhabited land areas of the earth.

During the hour and a half or so that it takes for the balloon to rise from the surface of the earth to its maximum altitude, the instrument actually drifts a fair distance from the launch site, so that each sounding is actually taken to represent an area of about 200 km on a side. The vertical resolution of the rawin sounding is about 0.2 to 0.3 km. The temperature measurement accuracy is $\pm 1^{\circ}C$.

The satellite vertical temperature soundings nominally are made with a horizontal resolution of about 250 km. The vertical resolution of these measurements is approximately 3 km in the lower troposphere increasing to about 10 km in the stratosphere. The measurement accuracy is about $\pm 1.5^{\circ}$ C. It should also be noted that the TOVS instrument provides moisture values in three layers of the troposphere, as well as total atmospheric ozone.

3.3.17.7 Winds

Surface winds are measured at many surface weather observation stations. A value of 300 km would probably represent a typical separation distance between measurements in the U.S. and Europe. In Asia and elsewhere in the world, separation distances would probably be greater. Winds are commonly measured hourly with an accuracy of about ±2% in speed and $\pm 2^{\circ}$ in wind direction. According to international convention, wind measurements represent one minute average values, but in practice they rarely represent averages of periods of time greater than 10 seconds.

The rawinsonde data also result in vertical wind profiles with about the same horizontal and vertical resolutions as were stated under the temperature profile discussion. It should be noted that the rawinsonde winds are actually layer mean winds that are determined from successive balloon positions as it rises. Winds provided by the balloon sounding have an accuracy of about ±2 meters per second and $\pm 5^{\circ}$ in direction. At the highest levels of the sounding, accuracy is probably reduced to about ±5 meters per second and $\pm 10^{\circ}$ in direction.

3.3.18 INFERENCES CONCERNING THE APPLICABILITY OF AIR QUALITY DATA TO METEOROLOGCIAL PROBLEMS

1. Many of the observations needed to support the Atmospheric Observation System would have value in operational weather analysis and forecasting and in climate studies.

2. The principal impacts of the weather and climate requirements on the specifications for the Atmospheric Observation System relate to the resolution of the observations needed, the frequency with which the observations are made, and the proposed duration of the mission.

3. The most extreme requirements arise from the mesoscale/severe storm problem. The requirements for synoptic meteorology, climate studies, and for the surface/atmosphere interface studies are reasonably compatible with the need of the AOS.

4. To properly correlate many meteorological and AOS measurements, it will be necessary to utilize trajectory analysis to develop the time-motion history of specific volumes or parcels of air.

5. The global atmospheric data base available at the National Meteorological Center that is compiled for daily weather analysis and forecasting could provide important support to the Atmospheric Observation System and could eliminate the need for many supplementary atmospheric measurements.

SECTION 4

GENERIC SENSORS

4.1 APPLICABLE SENSORS

The measurement techniques that are available and projected were considered in terms of their applicability to the multidisciplinary mission goals. The techniques were synthesized into sensor concepts that were candidates for the payload. As in AOS Part I, several factors were considered in the selection of sensors:

1. The ability of the sensor to perform the type of measurement, in theory.
2. The existence of spectral features and general interference-free regions which permit the sensor to perform the measurement.
3. The feasibility of a mode or modes of sensing, e.g., limb, solar occulation, Earth-looking, etc., which will permit the sensor to collect enough signal to perform the measurement.
4. The existence of other factors which include the measurement of particular species or events (e.g., with ultra high resolution) using a specific sensor.

The analysis of these four factors was performed primarily in a qualitative manner; however, existing experimental data and some modeling were used in selected areas. No attempt was made to optimize a unique sensor selection for a given measurement, recognizing that some overlap in measurement capability will be desirable using various techniques. Future detailed analyses by mission planners, investigator teams and instrument designers will permit the refined sensitivity analyses and error budgeting necessary to make precise sensor selections.

The list of applicable sensors is as follows:

Passive Optical Sensors

1. UV/Visible Spectrometer.
2. Cryogenic IR Radiometer/Spectrometer.
3. Gas Filter Radiometer (including nadir viewing and solar occultation).
4. Pressure Modulated Radiometer.
5. Partial Scan Interferometer.

6. Interferometer Spectrometer.

7. Temperature Sounder.

8. Multispectral Linear Array.

Passive Microwave Sensors

9. Passive Microwave Radiometer.

10. Sub-millimeter Wave Radiometer.

Active LIDAR Sensors

11. Laser Heterodyne Spectrometer.

12. LIDAR

These generic sensors and their applicable species and parameter measurements are listed in Table 4.1-1 which also indicates whether the viewing mode for the sensor is limb looking emission, solar occultation through the limb, or nadir and off-nadir viewing. The species and parameters which can most probably be measured as demonstrated by previous measurements with the instruments or by sensitivity computations are listed in the solumn next to the viewing mode. The species and parameters in the column to the far right of the table are possible measurements but with undetermined sensitivity and accuracy.

4.2 PASSIVE OPTICAL SENSORS

4.2.1 UV/VISIBLE SPECTROMETER

This sensor is a high resolution grating spectrometer with spectral response from the ultraviolet into the visible spectral regions. Vertical profiles of the O_3 and NO concentrations may be deduced from observations of the solar flux scattered by the atmospheric molecules in a limb viewing optical path. The same type of instrument could make similar measurements if equipped with a Sun tracker and operated in a solar occultation limb scanning mode. Altitude profiles are obtained by scanning vertically through the limb with a mechanical scanning mirror in the case of the limb scattering measurements.

These O_3 and NO measurements are made during sunlit portions of the orbit and can be coordinated with radiometric measurements made in the thermal infrared portion of the spectrum on a continuous 24 hour basis.

Table 4.1-1. Sensor Vs Measurements

Key

L = Limb
S = Solar Occ.
N = Nadir & Off Nadir

SENSOR	VIEWING MODE	APPLICABLE MEASUREMENTS	
UV/VIS SPECTROMETER	L	O_3, NO	
CRYO. IR RADIOMETER/ SPECTROMETER	L	O_3, CH_4, H_2O, NO, NO_2, HNO_3, CO, CO_2 N_2O, F11, F12, HCL	NH_3, CH_2O, CCL_4, CLO, $CLONO_2$, OH
ADVANCED SOLAR OCCULATION GAS FILTER RAD. (HALOE)	S	NO, CO, CH_4, NH_3, N_2O, COS, F12, HCL, SO_2	CH_3CL
GAS FILTER RAD. (MAPS)	N	N_2O, NH_3, CO, CH_4	SO_2
PRESSURE MODULATED RADIOMETER (PMR)	L	NO, CO, CH_4, N_2O,	WINDS
PARTIAL SCAN.	N	O_3, H_2O, N_2O, NH_3, CO, CO_2, CH_4, HCL	SO_2
INTERFEROMETER	S	O_3, H_2O, NO, NO_2, HNO_3, CO, CO_2, CH_4, N_2O	F11, F12, CH_3CL, CCL_4, COS
INTERFEROMETRIC	N	O_3, H_2O, N_2O, NH_3, CO, CO_2, CH_4	TEMP
SPECTROMETER	S	MOST SPECIES ARE POSSIBLE WITH THIS INSTRUMENT	
TEMPERATURE SOUNDER	N	TEMP. PROFILE	
MULTISPECTRAL LINEAR ARRAY	N	SURFACE TEMPERATURE, CLOUD TOP RADIANCE, CLOUD COVER, GEOGRAPHIC CORRELATION	
PASSIVE MICROWAVE RAD.	N	PRECIPITATION, WATER VAPOR, TEMP. PROFILE	
SUB-MM RADIOMETER	L	CLO, HCL, H_2O, HNO_3, O_3, NO_2, N_2O, NO, CO, SO_2	OH
LIDAR	N	O_3, H_2O, NO_2, N_2O, CO, SO_2, NA, Cloud Tops, Winds, Aerosols	

A number of grating spectrometers of varying resolution have been proposed for UARS (Upper Atmospheric Research Satellite) including the USIS (UV Stratospheric Imaging Spectrometer). The sensor is expected to provide ozone density distribution in the 30 to 90 km altitude range and NO at altitudes above 80 km with 2 km vertical resolution.

The physical characteristics of the sensor, using the USIS as a guide, are tabulated below:

Size:	2.28 m x 0.5 m x 0.5 m
Weight:	130 kg
Power:	50 watts
Data Rate:	3 kbps
IFOV:	0.04^{o} x TBD for 2 km vertical resolution
FOV:	360^{o} azimuth scan

Some technology developments for the improved sensor include the use of linear detector arrays with scanning CCD outputs, at the focal plane of the spectrograph to obtain vertical resolution through the limb instead of using single detectors and mechanically scanning the fore optics through the limb. Since the detector array elements have non-uniform responsivity, the array must be calibrated periodically and the relative and absolute response of each element measured. The detector array must also be pointed accurately at the horizon with an accuracy of about 15 arc seconds, and satellite slew rates would have to be kept to less than 15 arc seconds/second if the 2 km vertical resolution requirement is to be met. A second option would involve the development of a photometer with multispectral linear arrays at the focal plane to make simultaneous measurements at the required spectral bands rather than use the dispersive system employed by the USIS and the Ultraviolet Ozone Spectrometer (UOS). This may require development of more sensitive detector materials than silicon for use in the UV spectral region.

4.2.2 CRYOGENIC INFRARED RADIOMETER/SPECTROMETER

There are a number of species whose stratospheric concentration can be determined by a simple narrow-band radiometric measurement in emission or absorption (i.e., solar occultation). For emission measurements, especially cryogenic cooling of the optics improves sensitivity by decreasing the background noise caused by the sensor. To measure species for which there is significant spectral interference, a higher resolution spectral filtering technique is necessary. The tilt-tuned etalon filter provides a means of producing a narrow-band filter with a spectral width of about 0.25cm. This permits strong target gas emission lines to be measured with optimum signal-to noise in regions of minimal spectral interference. Cryogenic cooling is even more imperative for the higher resolution instrument since the target gas signal is much smaller than collected by the wider band radiometer.

Duplication of cryogenic systems for cooling the optics for two or more sensors is an inefficient use of resources. A coolec optics facility capable of directing the received radiation to one or more sensor systems would be more practical. A beamsplitter with wide spectral response could direct a portion of the energy to each sensor to permit simultaneous measurements over the full spectral range of each sensor. The fore optics would have to be increased to allow for the sharing of the incoming energy and for losses in the beamsplitter and relay optics.

The use of linear arrays at the sensor focal plane would eliminate the need for mechanical scanning to provide vertical profiles through the atmospheric limb.

Determinations of stratospheric concentration profiles of atmospheric minor species by radiometric measurements of limb emission have been carried out by satellite radiometers such as LRIR (Limb Radiance Inversion Radiometer) and LIMS (Limb IR Monitor of the Stratosphere) in the past. These were uncooled sensors whose sensitivity was reduced by background noise due to thermal emission from the sensor. The proposed cryogenic cooling of the sensor optics for these AOS sensors permits sensitivity increases of a factor of 10^4 over that for an uncooled sensor.

<u>Sensor Performance</u>

Based on previous LRIR and LIMS experience and estimated performance of the CULER (Cryogenic Upper Atmospheric Limb Emission Radiometer), ALS (Advanced Limb Scanner), and CLAES (Crogenic Limb Array Etalon Spectrometer) sensors proposed for UARS, the following table shows the expected performance for the AOS IR radiometer/spectrometer.

IR Radiometer

Species	Accuracy	Spatial Resolution(Km)	Altitude Range(Km)
O_3	$\leq$10%	3 x 12 x 500	8-120
CH_4	$\leq$10%	3 x 12 x 500	8-100
H_2O	$\leq$10%	3 x 12 x 500	8-85
NO	$\leq$10%	3 x 12 x 500	8-120
NO_2	$\leq$10%	3 x 12 x 500	8-60
HNO_3	$\leq$10%	3 x 12 x 500	8-60
CO	$\leq$10%	3 x 12 x 500	8-120
CO_2	$\leq$10%	3 x 12 x 500	8-120
N_2O	$\leq$10%	3 x 12 x 500	8-80
F11	$\leq$10%	3 x 12 x 500	8-50
F12	$\leq$10%	3 x 12 x 500	8-50
NH_3	TBD	3 x 12 x 500	TBD
OH	TBD	3 x 12 x 500	$\leq$120
CH_2O	TBD	3 x 12 x 500	TBD
CCL_4	TBD	3 x 12 x 500	TBD

Etalon Spectrometer

Species	Accuracy	Spatial Resolution	Altitude Range
HCL	0.1 ppb	3 x 270 x 500	20 - 50
O_3	1 ppm	3 x 36 x 500	10 - 55
NO	0.4 ppb	3 x 45 x 500	20 - 50
NO_2	0.6 ppb	3 x 54 x 500	20 - 60
N_2O	0.3 ppb	3 x 90 x 500	10 - 60
$CLONO_2$	0.3 ppb	3 x 72 x 500	25 - 35
F11	0.004 ppb	3 x 90 x 500	10 - 25
F12	0.005 ppb	3 x 108 x 500	10 - 35
CLO	0.4 ppb	3 x 90 x 500	30 - 40

The spatial resolution is given as (vertical resolution) x (horizontal resolution perpendicular to the line of sight) x (horizontal resolution along the line of sight).

Principle of Operation

The cryogenically cooled infrared radiometer/spectrometer is a combination of the CULER or ALS on UARS with the etalon spectrometer, CLAES, also proposed for UARS. The concept for the combined instrument is to design fore-optics cooled to cryogenic temperatures, suitable for use by two or more sensors which could benefit from the decreased background emission. The sensor compartment would also be cooled to cryogenic temperatures and contain the individual sensors and necessary beamsplitters and relay optics.

A schematic of the instrument is found in Figure 4.2.2-1.

The new technology required to implement this sensor is in the areas of cryogenics, detectors and filters. Cooling sensors of this size to cryogenic temperatures for long periods of time will require development of both passive radiative and closed cycle cryogenic systems with sufficient capacity to cool optics and structure as well as the detector. Detector arrays for the long wavelength infrared with CCD outputs and high transfer efficiency are being developed for applications of this type.

Development of on-focal plane processing would permit compensation of non-uniform detector responsitivity and offsets. Deposition of different narrow band spectral filters directly onto the rows of detectors in a large rectangular array would permit a multi-channel measurement with a very compact focal plane.

4.2.3 GAS FILTER RADIOMETER

The gas filter sensor, as described in the Part I Final Report, is a trace-gas specific correlation radiometer based on nondispersive infrared technology. Radiation from an external source, which would be thermal radiation from the Earth, reflected solar radiation, or solar radiation passing through the limb atmosphere, passes through the atmosphere and is spectrally altered by the atmospheric species of interest before entering the instrument. The radiation then passes through two cells, one of which is evacuated and the second which contains a sample of the gas of interest. The gas cell forms a spectral filter which is matched specifically to the species of interest. The energy transmitted through the two cells is directed to a detection system where the difference in energy between the two paths is measured. This energy difference can be related to the amount of gas of interest in the atmospheric path. Section 4.2.4 describes the PMR, one variation of the instrument wherein the pressure in the filter is varied.

Gas filter radiometers measure integrated spectral irradiance from the atmosphere within a spectral band which may be on the order of 100 cm^{-1} wide and which contains the contribution from several spectral lines of the species

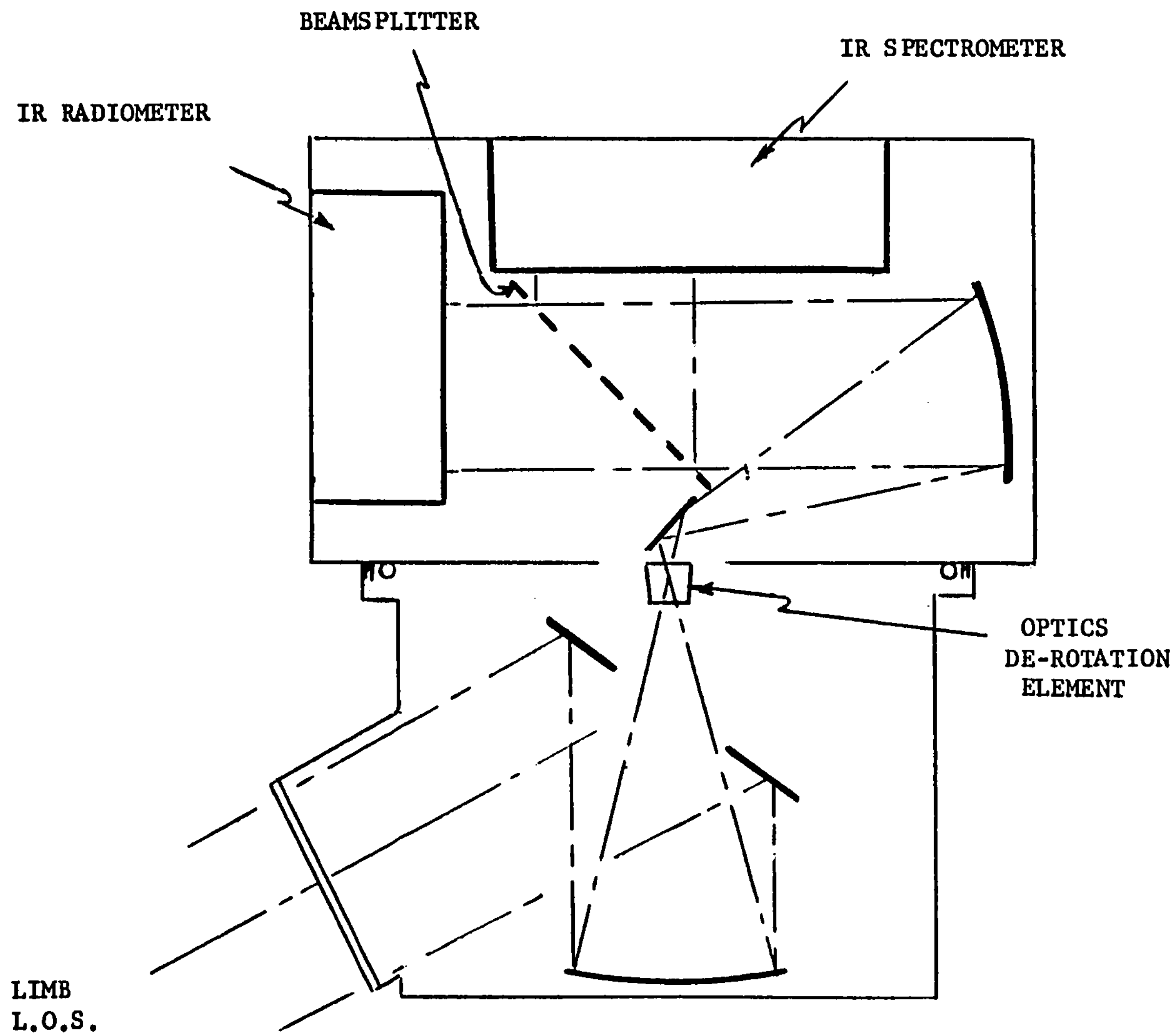


Figure 4.2.2-1. Cryogenic IR Radiometer/Spectrometer

of interest. By varying the pressure of the gas in the optical path, the response of the instrument can be tuned to the radiation from the species within a specified altitude range.

The measurement capabilities of the gas filter radiometer in its nadir mode can be exemplified by its application in the measurement of carbon monoxide at 4.6 microns with a resulting measurement range of 5.4×10^{11} to 6.7×10^{12} molecules/cm^3 with an accuracy of 20%. The horizontal resolution is 150 km with an integration time of 10 seconds. The resolution can be reduced with improved sensitivity and reduced measurement time.

The nadir-viewing gas filter radiometer has the MAPS sensor as its heritage. This instrument is an advanced stage of development, having flown on the second Space Shuttle.

Sensor improvements would include better methods of gas containment in the absorbing cell, better detector cooling, and sensor and optics cooling to improve sensitivity. Improvements in the dual optical beam balancing system to null out offsets would provide increased sensitivity. A wider swath could be achieved by designing the system to accommodate a linear detector array for operation in a push-broom mode.

In general, the performance of nadir viewing passive optical sensors is degraded by surface clutter effects due to variations in surface emissivity and reflectivity. Improvements in sensor design may be negated if the background surface noise effects are not minimized or compensated.

If the gas filter is to be used in a nadir looking mode from geosynchronous altitude, the optical and balancing system would have to be redesigned to accept a large mosiac detector array at the focal plane (about 64 x 64 pixels) operated in a staring mode. This instrument, known as the Geosynchronous Gas Filter Radiometer (GGFR), is shown schematically in Figure 4.2.3-1 (without the added complexity of the calibration and beam balancing sources). The optics consist of a Casegrainian configuration with a Schwartzschild extension, and features a concave focal plane containing two-dimensional array of detectors. The gas cells mount in a turret in front of the detector and can be rotated into position by command or in some preselected sequence. Long integration times of the order of 100 seconds allow the aperture size to

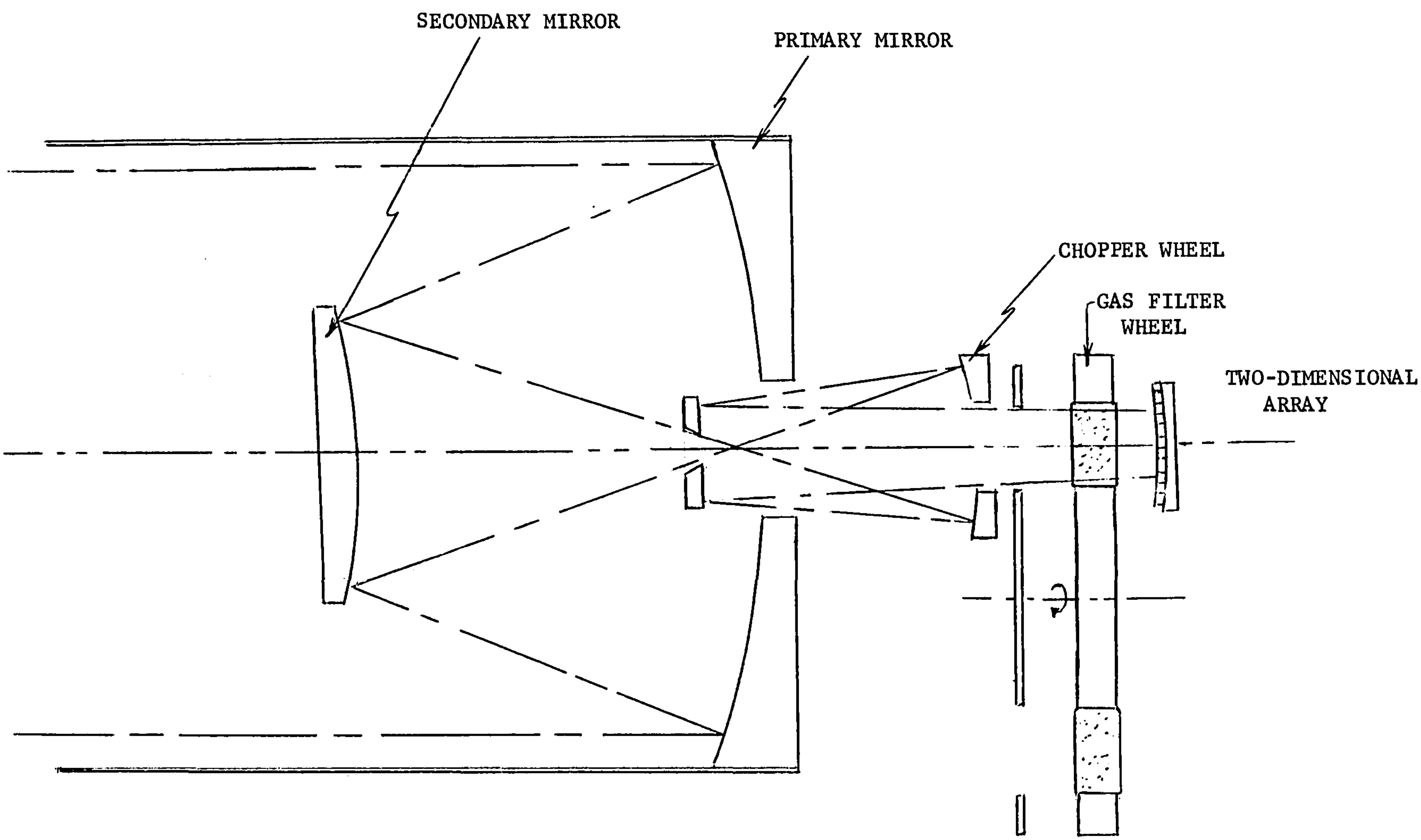


Figure 4.2.3-1. Schematic of Geosynchronous Gas Filter Radiometer (GGFR)

remain manageable. The relationship between the various observational parameters and optics size is discussed in Section 4.2.9.

The solar occultation gas filter system is patterned after the HALOE sensor. This is mounted on a gimbal system which accurately tracks the Sun at Sunrise and Sunset.

Improvements in the HALOE sensor would be primarily concerned with improving the signal balancing techniques to provide higher sensitivity, and in developing gas cells for the containment of reactive gas species.

The physical characteristics of the solar occultation gas filter sensors is tabulated below:

Size:	3.85 inch diameter x 33.8 inch height
Weight:	188 lbs.
Power:	96 watts peak, 65 watts average
Data Rate:	4300 bits/sec.

4.2.4 PRESSURE MODULATED RADIOMETER

The Pressure Modulated Radiometer (PMR) is a version of the generic class of gas filter correlation radiometers. These radiometers discriminate the emission or absorption due to chosen spectral lines of gas species of interest from the background radiation levels, by using matched spectral filters composed of gas cells containing the gas of interest in the optical line of sight. In the PMR type of sensor, shown schematically in Figure 4.2.4-1, the spectral characteristics of the gas cell filter are varied by modulating the pressure of the gas in the filter cell. This varies the amount of the absorption and the shapes of the absorption lines of the gas in the cell. For stratospheric measurements, the gas pressures are low enough so that the temperature modulation effects caused by the rapid modulation of the gas in the cell can be compensated by signal offset adjustments. The PMR is able to make limb emission measurements in the stratosphere for a number of gas species, among them NO, CO, CH_4 and N_2O. Zonal wind measurements with the PMR are possible since the atmospheric gas spectrum is doppler shifted with respect to the spacecraft gas cell spectrum due to both spacecraft motion and wind effects. An azimuth scan at a rate which provides image motion

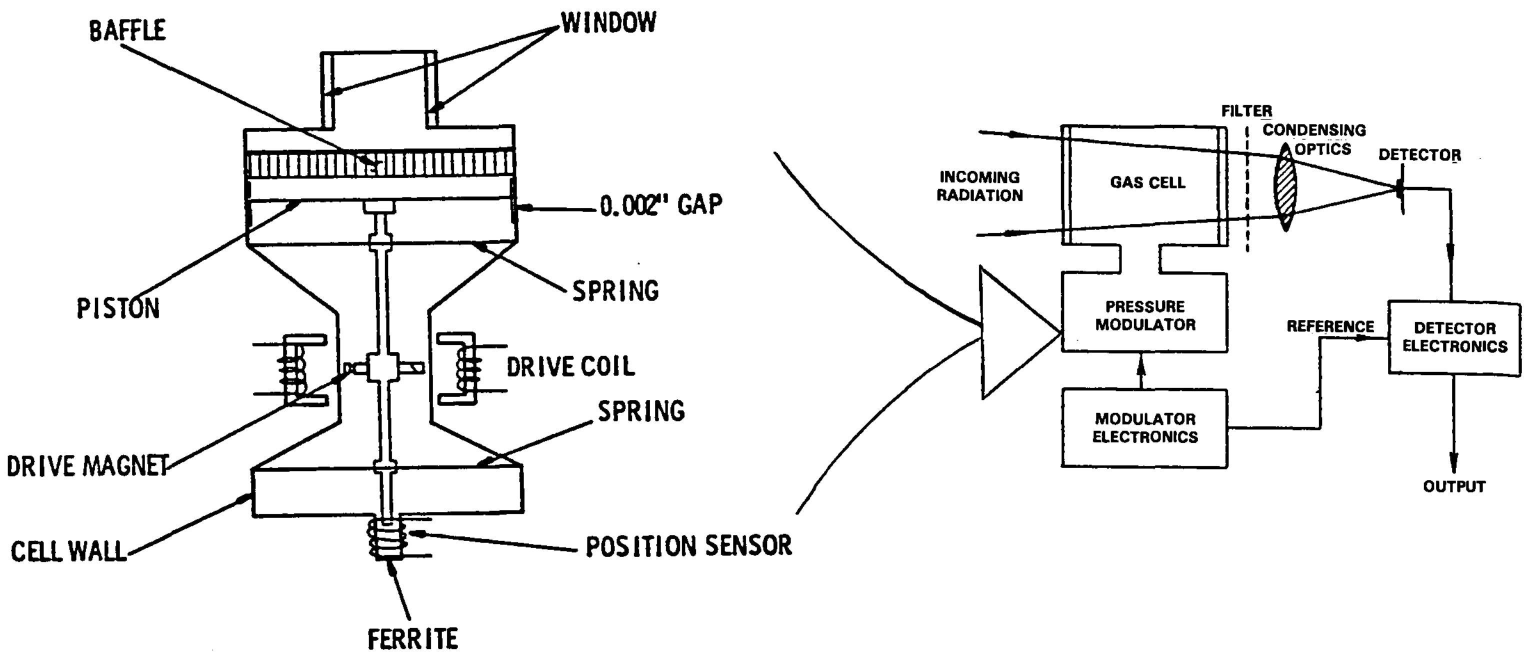


Figure 4.2.4-1. PMR Schematic

compensation at the tangent point will produce a signal which has a maximum at some azimuth angle nearly normal to the flight direction. At this angle, the combined effects of the spacecraft velocity, the Earth's rotation and the wind component along the line of sight sum to zero. If the velocity and altitude of the spacecraft are known with sufficient accuracy throughout the azimuth scan sequence, the zonal wind component can be deduced.

The PMR sensor is based on a number of previous sensors which were flown on various Nimbus spacecraft, i.e., the Selective Chopper Radiometer (SCR), the Pressure Modulator Radiometer (PMR) and the Stratospheric and Mesospheric Sounder (SAMS). An improved version of the SAMS, i.e., ISAMS, has been proposed for UARS.

The measurement capabilities of the PMR sensor are listed below for both the PMR channels and the radiometric channels which are included as part of the sensor:

Measurement	Altitude Range(Km)	Accuracy
CO	15 - 60	10%
NO	15 - 60	10%
CH_4	15 - 60	10%
N_2O	15 - 60	10%
H_2O	15 - 100	10%
Temperature	15 - 80	1^oK
Wind	15 - 60	10 m/sec.

The sensor physical characteristics are tabulated below:

Size:	x (85 cm) y (92 cm) z (64 cm)
Weight:	70 kg
Power:	100 watts average, 120 watts peak
Data Rate:	530 bps

Pointing:

	Azimuth	Elevation
FOV	$+15^{\circ}$	$+7^{\circ}$
IFOV	$\pm 0.5^{\circ}$	$\pm 0.1^{\circ}$
Pointing Direction	$+90^{\circ}$	-21°
Attitude Accuracy	$\pm 0.01^{\circ}$	0.05°
Stability	0.01°/6 min.	0.0003°/sec.

Sensor performance could be improved by the use of a linear detector array to define the vertical profile through the limb rather than using mechanical scanning. However, this would require investigation of whether the optics could be redesigned to accept the larger field of view necessary, and would increase the problem of calibrating the detector array. An increase in sensitivity and extension of the measurement range to higher altitudes would be possible with cooling of the sensor and optics to some lower temperature. However, the PMR is extremely sensitive to temperature, and the temperature to which it could be cooled would have to be carefully investigated. With more elaborate Sun shielding the sensor could possibly be used in a 360 degree azimuth scan mode. If the problems associated with the temperature effects due to high gas cell pressures could be overcome, then the PMR would be able to probe into the traposphere.

4.2.5 PARTIAL SCAN INTERFEROMETER

As described in the AOS Part I Report, the partial scan interferometer is a variation of the basic Michelson interferometer in which the spectrum of the incident radiation is not recovered from the interferogram because the total interferogram is not measured or recorded. Essentially, all the information on any given species (i.e., all the effect of that species on the interferogram) occurs over a small part of the interferogram, therefore, only that range of interferogram path difference needs to be scanned. The operation of the partial scan (or correlation) interferometer involves the treatment of the interferogram data directly within the instrument, to obtain data on the species concentrations or total vertical burden; this is in contrast with the use of the spectrum obtained by the Fourier transform of the total interferogram. In such an instrument, the concept of spectral resolution loses its meaning since the spectrum is not recovered from the measurement.

The optical configuration of the instrument is essentially that of the simple Michelson interferometers. The change in optical path difference over limited range can be accomplished by the back and forth rotation of a plate of refractive material placed in one arm of the interferometer. A similar interferogram scan can be achieved by fixing the compensator plate and moving one of the mirrors back and forth over a limited range.

The partial scan interferometer is similar to the gas filter radiometer in that it measures the integrated spectral irradiance for a spectral band containing several lines of the species of interest, but the measurement is made in the interferogram-path-difference regime rather than in the spectral domain. Discrimination between the species of interest and the interferent species is performed mathematically and by selecting the interferogram region which minimizes interferent effects. It is expected that the sensitivity of the partial scan interferometer would be similar to that of the gas filter radiometer.

Concerning the measuring capabilities of the sensor, the sensitivity of the partial scan interferometer has been computed for nadir viewing application to carbon monoxide at 2.3 microns. The resulting measurement is a total burden measurement in the vertical column down to the earth's surface. The sensor has a burden range of 2×10^2 to 1×10^4 parts per million meter with an accuracy of 20%. The horizontal resolution is 40 km for a 1 second integration time.

The partial scan interferometer is also useful for making limb measurements in the solar occultation mode. In this mode it would have to be equipped with a Sun tracker system. The estimated sensitivities for a number of gases relative to a CO measurement at 2.3 microns are listed in Table 4.2.5-1 for various interferogram delay regions, showing how the sensitivity can be greatly increased by selecting the proper delay region. It is important to be able to vary the delay of the partial scan sensor if optimum performance is to be achieved for a large number of gases.

Table 4.2.5-1. Estimated Sensitivities of the Partial-Scan Interferometer in the Solar Looking Mode Relative to CO (CO = 0.04 atm-cm)

Specie	Filter Center Frequency		Delay Range	Minimum Detectable Burden (atm-cm x 0.04)
	cm^{-1}	(um)	mm	
CH_4	4280	(2.34)	5.5 - 6.4	5
			All other	2
CO	4280	(2.34)	2.3 - 3.5	1
			5.6 - 6.3	
			7.4 - 9.4	
CO_2	4835	(2.07)	5.0 - 6.0	2
			6.0 - 8.0	125
			All other	1250
H_2O	3465	(2.89)	All	1250
NH_3	4500	(2.22)	2.6 - 4.0	5
			6.3 - 7.5	10
N_2O	3465	(2.89)	3.0 - 3.6	5
			8.5 - 9.7	.5
NO*	1900	(5.26)	2.8 - 3.7	.2
			5.8 - 7.0	.08
			9.0 - 9.5	.08
NO_2*	1630	(6.13)	0.5 - 4.0	.06
SO_2*	1370	(7.30)	2.0	.03
			2.5 - 4.0	.2
			4.5 - 5.7	.2
			8.0 - 9.5	.3
C_2H_4*	2988	(3.35)	1.0 - 4.0	.5
			4.5 - 5.5	.2
			6.0 - 8.5	.5
C_2H_6	2988	(3.35)	1.0 - 4.0	.02
			5.0 - 7.5	.008
			7.5 - 9.2	.02

Detector with a D = 3 x 10^{10} cm $Hz^{1/2}$ w^{-1}; all other species assume detector with a D* = 10^{11} cm $Hz^{1/2}$ w^{-1}.

The basic partial scan sensor has the following physical characteristics:

Size:	0.8 x 0.5 x 0.5 meters
Weight:	85 kg
Power:	150 watts
Data Rate:	3 kbps
IFOV:	2^{o} to 7^{o} for nadir viewing; 1.0 mr for solar occultation

The utility of a partial scan interferometer would be enhanced by the development of the capability to scan more than one optical path region of the interferogram either on command on in some preprogrammed sequence. In the AOS application, this capability will permit the measurement of several species with maximized signial-to-noise ratio, since most species will exhibit maximum signal at different interferogram delays. As with the interferometric spectrometer discussed above, the partial scan interferometer would benefit from the development of automatic optical alignment systems for the interferometer mirrors. Improved data inversion algorithms will be required for the various species measured with the partial scan interferometer. Inputs to this algorithm would include not only the Fourier transform of the partial scan interferometer, but perhaps other ancillary information such as temperature, profile, or ground temperature and emission characteristics.

A technology gap is foreseen in this development due to the lack of a specific development program for the foreseeable future.

4.2.6 INTERFEROMETER SPECTROMETER

This spectrometer measures the spectral radiance of the upwelling atmospheric radiation with very high resolution and over wide spectral bands. Although there are many possible optical configurations, basically they all employ a Michelson interferometer. The incident radiation is divided by a beamsplitter into two approximately equal components. After reflection from the movable and fixed mirrors, the two beams recombine and interfere with each other with a phase difference which depends on the optical path difference between the two beams. The recombined beam is focussed on the detector and the signal, called the interferogram, is recorded as a function of the optical path difference between the two beams. The spectrum of the incident radiation is reconstructed by a computer and is the Fourier transform of the interferogram.

The interferometer, or Fourier Spectrometer permits the measurement of spectral radiance of the atmosphere with high spectral resolution over very wide spectral bands within the infrared spectral region (typically 2-14 micrometers). For this reason it constitutes a useful spectral survey instrument.

The interferometer spectrometer has capabilities which are similar to those of the laser heterodyne spectrometer in that it provides a high enough spectral resolution to define the individual spectral line shapes.

The resolution is sufficient to permit species concentration measurements when the signal-to-noise ratio is sufficiently high. The sensitivity requirements in a nadir-looking mode would necessitate active cooling of the sensor detector and fore-optics.

The interferometer spectrometer has the advantage over heterodyne systems in that its technology will probably be available sooner for nadir viewing measurements. The disadvantage is that the data rates generated by the sensor are very large compared with species dedicated sensors; also the large spectral interval may require relatively long integration times for faint species, thus degrading spatial resolution.

The sensor has the potential for measuring most of the stratospheric trace species of interest in the limb-viewing solar-occultation mode. A single cryogenically cooled instrument could be used in a number of modes.

1. Limb emission for stratospheric measurements.
2. Nadir emission for tropospheric measurements.
3. Solar occultation (if solar heat load could be minimized).

The sensor capabilities in the solar-occultation mode are shown in Table 4.2.6-1 which indicates the predicted spectral signal-to-noise ratio for the ATMOS sensor operating with an interferogram scan time of one second and a spectral resolution of 0.02 cm^{-1}.

Table 4.2.6-1. Predicted Spectral S/N Ratio For ATMOS

(T=1s, $\Delta\sigma$=0.02cm^{-1})

Filter Band	Spectral Interval cm^{-1}	SPECTRUM SENSITIVITY (SNR$_\sigma$) 1 mr FOV	2 mr FOV	4 mr FOV
1	625 - 1200	45	120	300/1
2	1100 - 2000	60	145	*
3	1580 - 3400	55	130	*
4	3100 - 4700	85	195	*
5	625 - 750	25	70	175/1
	& 2000 - 2500	80	220	*
6	625 - 3600	55	125	*

* OBLIQUITY LIMITED

* From Morse, Paul G., "Progress Report of the ATMOS Sensor: Design Description and Development Status", AIAA Conference: Sensor Systems for the 80's, December 1980.

The sensor characteristics (based on the JPL ATMOS sensor) are:

Size:	108 cm L x 89 cm W x 113 cm H
Weight:	243 kg
Power:	193 watts (average)
Data Rate:	16 Mbps

The principal technology requirement for the Interferometric Spectrometer is high spectral resolution and signal-to-noise ratios. For passive sensing of the troposphere with an interfermetric spectrometer, the high spectral resolution is necessary to separate the spectral features of the gas species from those of the interfering species. The high resolution is also necessary for determination of spectral line shape which may be used to compare vertical concentration profiles of atmospheric constituents. The current development of flight instrumentation includes an interferometer with 0.02 cm^{-1} resolution in a solar occultation mode. For the tropospheric application, a nadir-looking instrument is required with a resolution of 0.01 cm^{-1}. One of the technical challenges is the development of automated optical alignment systems for the interferometer in order to prevent degradation of system performance during the life of the mission. Another technical challenge will be to develop a larger instrument with larger aperture, also the capability for cooling the sensor and detector fore-optics for higher sensitivity.

The current state-of-the-art is typified by the JPL ATMOS Sensor, which is scheduled to fly on Spacelab in a solar occultation mode. There are no current plans for a cryogenically cooled, nadir-looking instrument. The technology projection for this generic instrument is for continued improvement in the resolution and signal-to-noise ratio but operating in a limb mode. Unless there is significant impetus concerning the tropospheric research, it is not foreseen that a nadir-looking instrument will be developed during this decade. Other precursors to the AOS Generic Sensor are the MARK II Interferometer, the IRIS Voyager Sensor, and the HIRIS Sensor for sounding rockets.

4.2.7 TEMPERATURE SOUNDER

The purpose of this sensor is to measure the vertical temperature profile of the atmosphere and to provide correlation data on moisture profile. Two optical approaches are considered for this measurement: use of a relatively wide-band instrument of conventional design and use of a very high resolution Laser Heterodyne Spectrometer.

4.2.7.1 Conventional Optical Sounds

The instrument is similar to the sounder described in the AOS Part 1 Final Report for the troposphere, but tailored to measurements of tropospheric and stratospheric temperature. The salient features of this instrument are:

1. Seventeen channels ranging from 0.7 microns to 15 microns.
2. Total field-of-view (102°) compatible with other earth-looking sensors in AOS, such as the Gas-Filter Radiometer, Partial-Scan Interferometer, Interferometric Spectrometer and Multispectral Linear Array.
3. Instantaneous field-of-view of 1.2°, which yields a footprint of 25 km x 25 km from an altitude of 700 km.
4. Electronic scanning of 17 detector arrays operating in the push-broom mode, in place of a mechanical scanner.

The heritage of this sensor is founded on the High Resolution Infrared Radiation Sounder (HIRS). In addition, the experience gained in the Visible and IR Spin Scan Radiometer and the advanced version, the VAS will be factored into the designs.

The projected characteristics of the instrument are as follows:

Size:	25 x 60 x 45 cm
Weight:	40 km
Power:	50 watts
Data Rate:	1 kbps

4.2.7.2 Laser Heterodyne Spectrometer (LHS)

Extremely high resolution spectrometry can be accomplished with the LHS, which measures upwilling radiation from the Earth's surface and emission from the atmosphere. Representative spectral resolution is 0.001 cm^{-1}, while the sensitivity is nearly quantum noise limited. Sensitivity figures for concentration measurements of minor atmospheric species were presented in AOS Part I Report, Section 3.3.4. These characteristics are useful in discriminating among interfering signals, and discerning the fine structure in upper atmospheric spectral lines.

The instrument consists of a heterodyne detector with a tuneable laser local oscillator. The signal is collected by the primary reflective optics, and focussed on the detector by the secondary mirror. A beam splitter in the light path serves to mix the signal entering the detector with the laser beam. The LHS is particularly suited to applications where fine spectral detail is needed over a spectral band the width of which depends upon the range of tuneability of the laser local oscillator.

4.2.8 WIDE-SWATH MULTISPECTRAL LINEAR ARRAY

This instrument serves four basic observational needs in AOS:

1. Measure Earth-surface temperature for use in conjunction with air-surface interface investigations, radiance calibrations for Earth-looking sensors, and radioactive transfer calculations.
2. Measure cloud top radiance, and percent cloud cover; detect the presence of thin clouds.
3. Provide polarization data to satisfy the three Stokes parameters needed to determine aerosol burden.
4. Provide geographic correlation with the three dimensional data from other sensors.

The initial specifications for this instrument, corresponding to the 700 km altitude of Mission #1 (see Section 6), for the purpose of this study, are as follows:

Instantaneous Field of View:	0.23^{o} (5 x 5 km pixel)
Swath Width:	1927 km (from 700 km orbit) or 102 degrees
Number of resolution elements per swath:	385 (275 elements/sec.)

Channel No.	Wave Length (Microns)	Radiance Input (MW/CM^2,S.R. Micron	Polarization Filter
1	0.5	3.5	None
2	0.5	3.5	90°
3	0.5	3.5	45°
4	0.65	1.5	None
5	0.75	5.5	None
6	0.75	5.5	90°
7	0.75	5.5	45°
8	1.0	6.0	None
9	1.0	6.0	90°
10	1.0	6.0	45°
11	11.5	(270°K)	None

4.2.9 SCALING OF PASSIVE SENSOR OPTICS FOR VARIOUS ALTITUDES

4.2.9.1 Aperture of a Gas Filter Radiometer for Use From Geosynchronous Orbit

In order to determine the feasibility of using a passive sensor such as the gas filter radiometer in a nadir viewing mode from geosynchronous orbit, the results of atmospheric radiative transfer calculations reported in Section 5.1 were utilized. The computations provided the signal contribution for individual lines of a uniformly mixed gas species over a wide range of line strengths. For a given gas burden in the path the signal and fractional signals in the band are proportional to the line strength, when the absorption and emission are weak. In this case, the signal and fractional signal (or signal modulated by the gas filter) are also proportional to the product of line strength and total burden.

The measurement signal-to-noise ratio is related to the instrument parameters and the target source radiance by the expression.

$$\frac{S}{N} = \frac{\pi}{4} \frac{D\theta}{F} \Delta N \ \tau_o \ D^* \quad \text{for a 1 second integration time}$$

D = diameter of the aperture

0 = field of view

F = optics f/number

τ_o = system transmittance

ΔN = incremental source radiance due to the target gas

D^* = system specific detectivity

The expression may be rearranged to compute the aperture size D, as a function of the other parameters

$$D = \frac{4F}{\pi \theta} \left(\frac{S}{N}\right) \times \frac{1}{\Delta N \; \tau_0 \; D^*}$$

The radiative transfer calculations in Section 5.1 provided the values of ΔN vs. $S_{\ell\mu}$, the line strength per molecule, for a uniformly mixed species with a mixing ratio of 0.1 ppm. This is approximately the value for carbon monoxide in a non-urban environment. These values are shown in Figure 4.2.9.1-1 The same calculations provided the fractional absorption by the line in the selected spectral band as a function of line strength. Figure 4.2.9.1-2 indicates these values of fractional signal modulation vs. line strength.

Using CO as the example for the calculation of sensor aperture, the total line strength for the first 15 lines of the P-branch at 4.6 um is 86.804 cm^{-2} - atm^{-1}. This gives an average value of $S_{\ell\mu}$ of 2.15×10^{-19} cm^{-2} - atm^{-1} per molecule. The value of ΔN for $S_{\ell\mu} = 2.15 \times 10^{-19}$ is 2.8×10^{-8} watts/cm^2 - ster per line, or 15 times greater if the signal from all 15 lines is integrated.

It is also assumed that a minimum signal to noise of 10 is necessary to make a useful measurement. The other parameters used in the calculation of D are the following:

D^* = 6×10 cm - $Hz^{1/2}$ - $watt^{-1}$

τ = 0.1

F = 2.0

θ = $200/36000 = 5.56 \times 10^{-3}$ radian

For this case D is computed to be 0.1817 cm for $S_{\ell\mu} = 2.15 \times 10^{-19}$ and a one second integration time. This value of D is inversely proportional to $S_{\ell\mu}$. D is plotted as a function of $S_{\ell\mu}$ in Figure 4.2.9.1-3 for a one

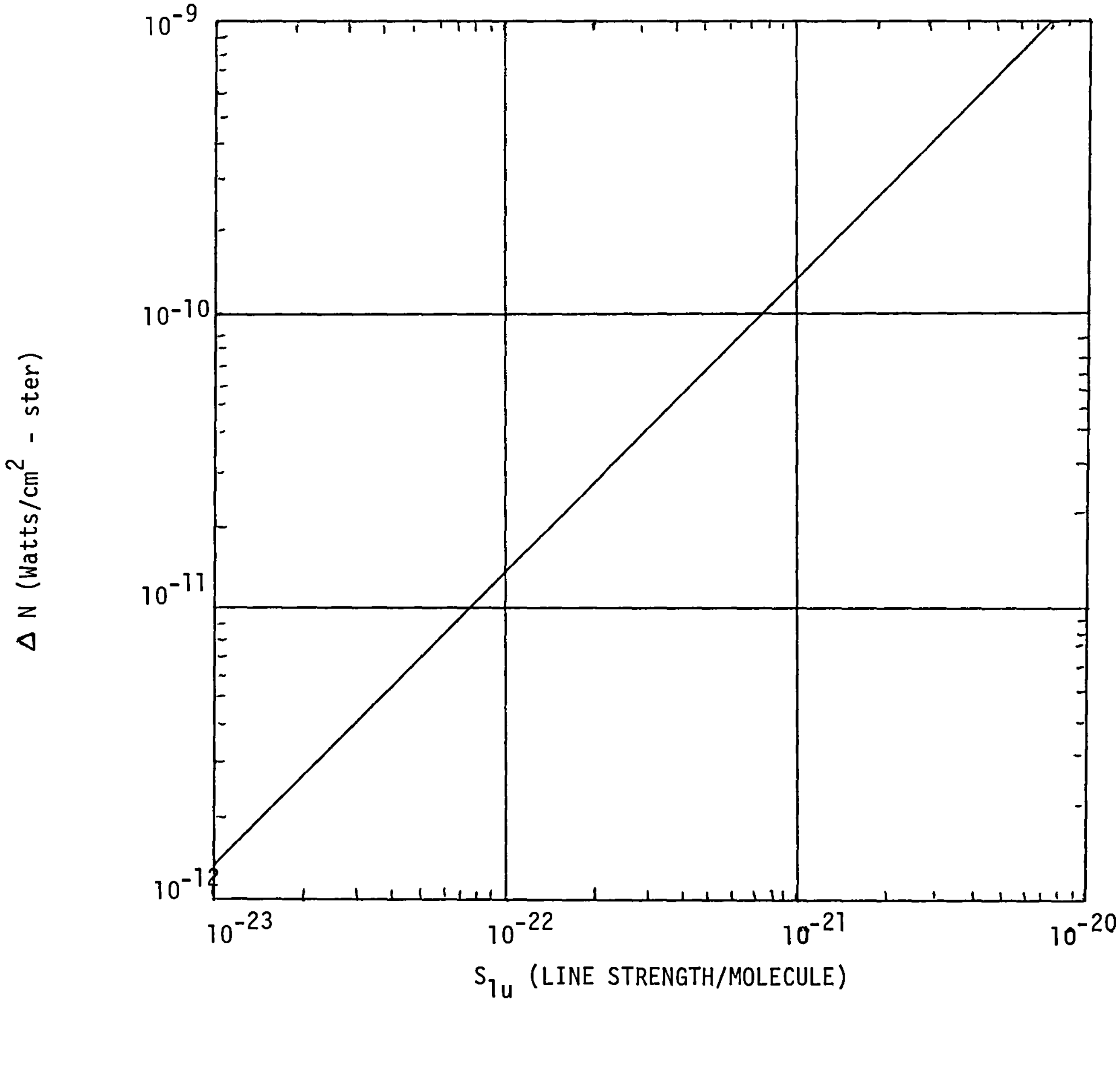


Figure 4.2.9.1-1. Incremental Source Radiance for a Uniformly Mixed Species as a Function of Line Strength

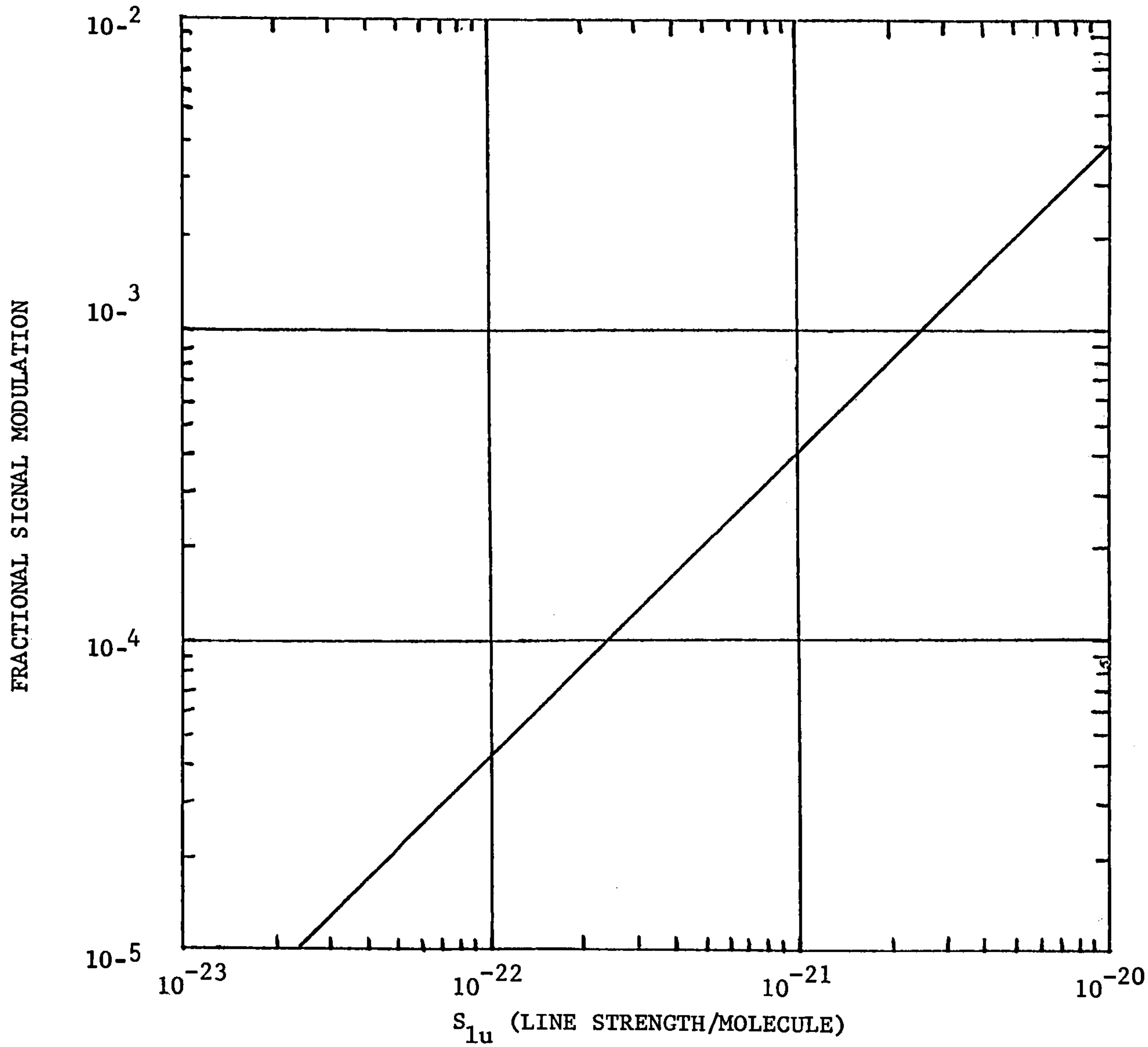


Figure 4.2.9.1-2. Fractional Signal Modulation Vs. Spectral Line Strength

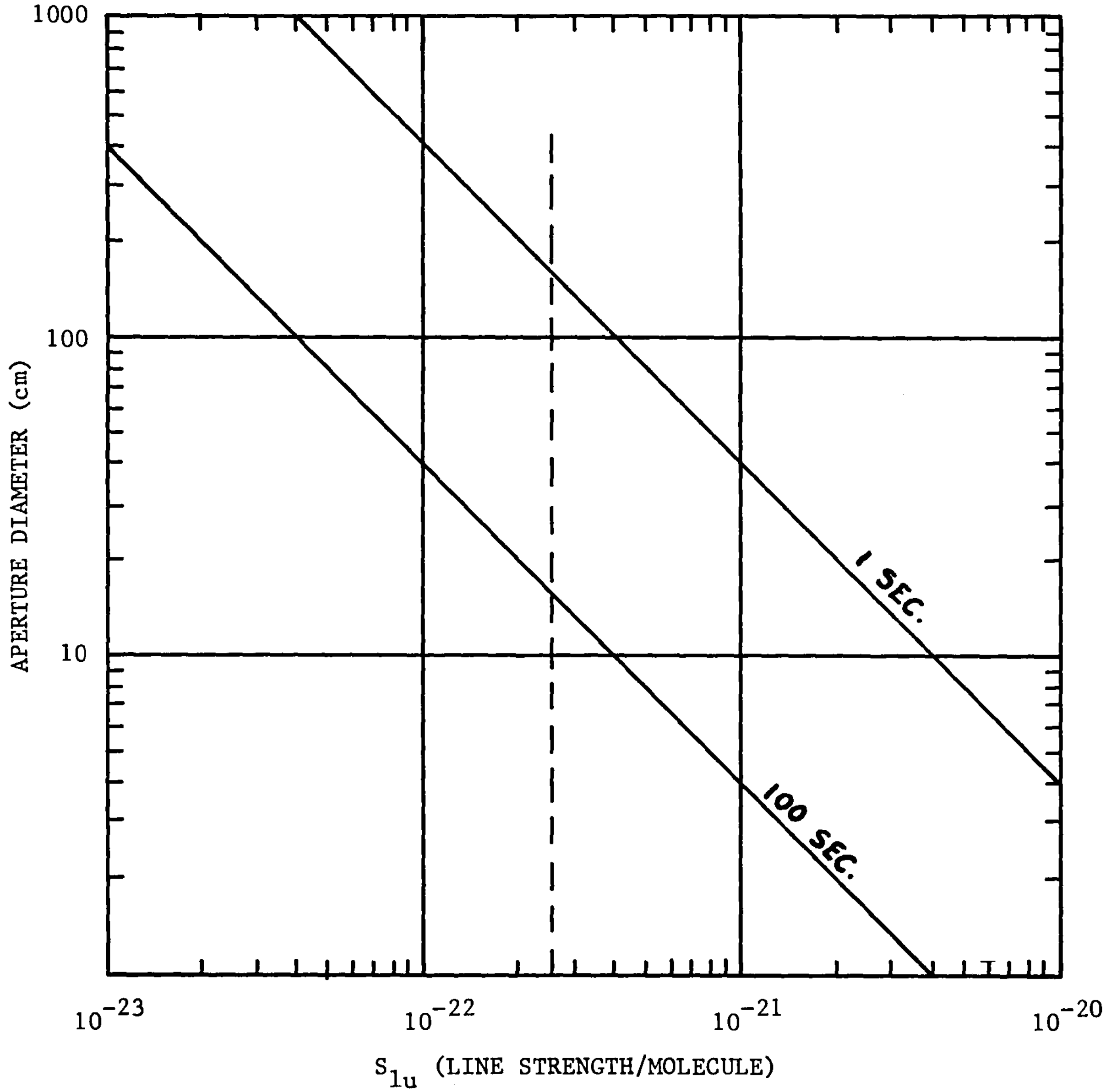


Figure 4.2.9.1-3. Aperture Relationship for Geosynchronous Mission

second integration time and for a 100 second integration time which decreases the value of D by a factor of 10.

Figure 4.2.9.1-3 indicates that more sensitivity can be gained by increasing the sensor aperture. In practice there are other instrumental factors, and error sources which limit the ultimate sensitivity. One consideration in defining the optics size is the stability of the optical path balancing system. The incident pollutant signal which the gas filter is modulating is a small fraction of the total radiation within the spectral band. This fractional signal modulation is plotted in Figure 4.2.9.1-2 as a function of the parameter $S_{\ell\mu}$ for a gas like CO with a constant mixing ratio of 0.1 ppm. If it is assumed that signal balancing techniques will improve to one part in 10^5 from the current value of one part in 10^4, then an estimate of the sensitivity can be made. For a S/N ratio of 10 based on the balancing noise, the signal modulation must be greater than one part in 10^4. This means that the value of $S_{\ell\mu}$ must be greater than 2.65×10^{-22} as shown in Figure 4.2.9.1-2. For these weak signals the fractional modulation does not very if the product of $S_{\ell\mu}$ and total burden remains the same. As a result, the total burden which corresponds to a fractional signal modulation of one part in 10^4 is given by

$$\text{CO min} = \frac{2.65 \times 10^{-22}}{2.15 \times 10^{-19}} \times 0.1$$

$$= 1.23 \times 10^{-4} \text{ atm-cm}$$

This value defines the limiting sensitivity for the system based on optical balancing system stability and is independent of the collection aperture size to achieve this limiting sensitivity with a one second integration time would require an aperture of 150 cm.

It should be noted that the calculations have assumed that the gas filter is 100% efficient, and only one nominal atmospheric model has been considered. If the effects of spectral interferents and other atmospheric models were considered, then the required size would be increased. The aperture size can be decreased by increasing the integration time, but the ultimate measurement sensitivity is not determined by the aperture size alone. This is governed by factors such as the stability of the beam balancing, and uncertainty in the atmospheric and spectral parameters which are involved in the data inversion process.

4.2.9.2 SCALING OF LIMB SENSOR APERTURE WITH ORBITAL ALTITUDE

The signal to noise ratio for a limb looking sensor at a given satellite altitude is expressed by:

$$\frac{S}{N} = \frac{Ad \ \Delta \ N \ \ To}{4 \ F \ ^2 NEP}$$

where A_d = detector area (cm^2)

ΔN = incremental radiance of the target species

T_o = optics transmission

NEP = system noise equivalent power

F = optical system F/number

If the sensor has a rectangular field of view given by 0_v radians in the vertical direction and 0_4 radians in the horizontal direction, then the detector area, A_d is given by:

$$A_d = D^2 F^2 \theta_v \theta_h$$

where D = optics diameter.

The angular fields-of-view may be related to the spatial fields-of-view by the relations.

$$0_v = \frac{\Delta V}{R} \qquad \text{radians}$$

and $$0_h = \frac{\Delta H}{R} \qquad \text{radians}$$

where ΔV, ΔH are the vertical and horizontal resolution elements respectively, expressed in kilometers and R is the range in kilometers from the satellite to the limb.

The NEP is given by:

$$NEP = \frac{\sqrt{A_d \Delta f}}{D^*} \quad \text{watts}$$

where Δf = electrical bandwidth, Hz

D^* = system specific detectivity, cm $-Hz^{1/2}$watt

Substituting all these expressions in the equation for S/N ratio, the expression for S/N becomes:

$$\frac{S}{N} = \frac{\pi}{4} \frac{D\sqrt{\Delta V \Delta H}}{F \quad R} \Delta N \, To \, D^*$$

If it is required to maintain the same S/N ratio, and all parameters except D and R are constant, then:

$$\frac{S}{N} \sim \frac{D}{R}$$

and D must be increased in proportion to R if the signal to noise ratio is to remain constant.

4.3 PASSIVE MICROWAVE SENSORS

4.3.1 PASSIVE MICROWAVE RADIOMETER

The primary measurement for this instrument is precipitation, particularly in connection with investigations of rain as a removal agent in the acid rain problem. Two frequencies have been selected for measuring precipitation: 37 GHz for heavy precipitation and 94 GHz for light precipitation. Two additional channels have been added: 21 GHz to measure water vapor profile and 60 GHz for all-weather temperature sounding. The three measurements precipitation, water vapor and vertical temperature profile-are highly relevant to meteorlogical investigations and routine operational monitoring.

The preliminary specifications include the provision that the microwave antennas should be fixed or non-rotating, to prevent the vibratory perturbations associated with large, mechanically scanned radiometers.

For the lowest frequency band, 15 km (and for the other frequency bands, 10 km) resolution is desirable. In order to provide small enough revisit intervals, which is mandatory for accurate meterological observations, relatively large swaths, S, and large cross-track orbit observation angles, in the order of $\pm 50^{o}$ to $\pm 54^{o}$ are necessary. Two different orbit heights, H, which meet these requirements will be considered in the following: (1) H = 700 km orbit height with S = 1927 km swath width, and (2) H = 2500 km orbit height with S = 6120 km swath width, corresponding to Missions 1 and 4. The rationale for these selections is given in Sections 5 and 6.

The microwave antenna problem in principle can be solved by either a scanning phased array or by a feed-array optics combination. The phased array for the given requirements needs a very large number of elements, far beyond the state of-the-art. The feed array with a properly compensated optics, like a dual shaped reflector system, on the other hand, requires a relatively complex reflector system but utilizes the minimum possible number of radiating elements in a linear feed array.

In the following, the feed array dual shaped reflector optics concept will be discussed in some detail.

Antenna System Configuration for Case 1 (H = 700 km, S = 1927 km)

Figure 4.3-1 shows a typical geometry of a dual shaped reflector optics, using an offset-fed paraboloid, a shaped subreflector and a curved surface for the radiating elements in the feed array. For the given example, the scanning is provided in the plane of the paraboloid offset, which may be desirable for certain spacecraft applications. In other applications, the scan can be accomplished in the symmetry plane of the system (perpendicular to the plane of Figure 4.3-1). In those cases, one scan-dependent dimension of the subreflector is slightly smaller than for the offset fed plane scan case. The dimension of the subreflector in the plane perpendicular to the scan plane for both applications is about half than the scan plane dimension. Projection of the subreflector contour to a plane perpendicular to its normal at its center point is approximately an ellipse with a 2:1 aspect ratio. The geometry of optics in Figure 4.3-2 is a derivative of Figure 4.3-1 and it is designed in such a way that the absolute peak to peak scan angle (which determines the swath width for an individual element) $2\theta_M = 16.75^{o}$. While it is possible to design slightly larger absolute scan angles, around $2\theta_M = 20^{o}$, the

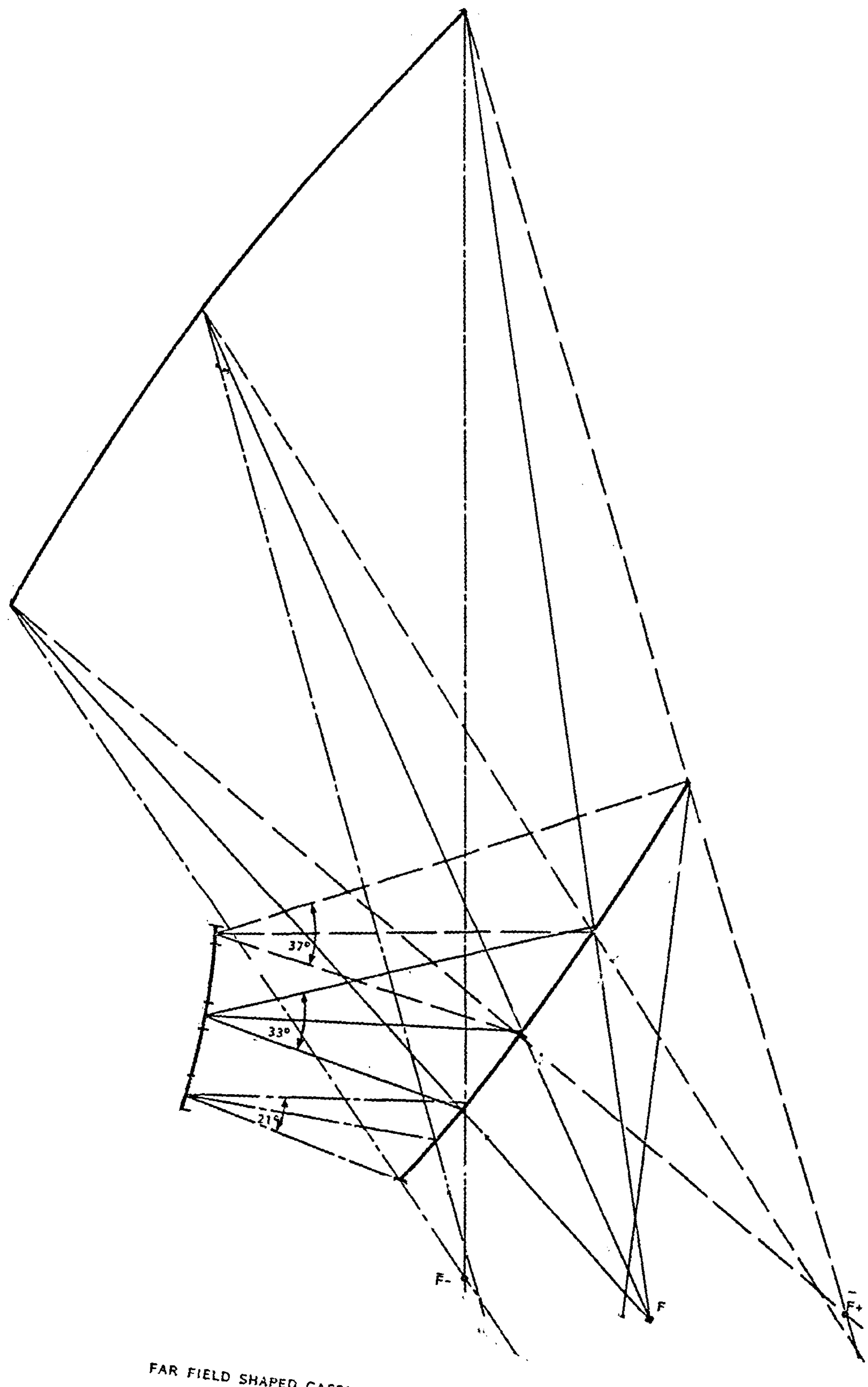


Figure 4.3-1. Example for Far Field Shaped Cassegrainian Optics

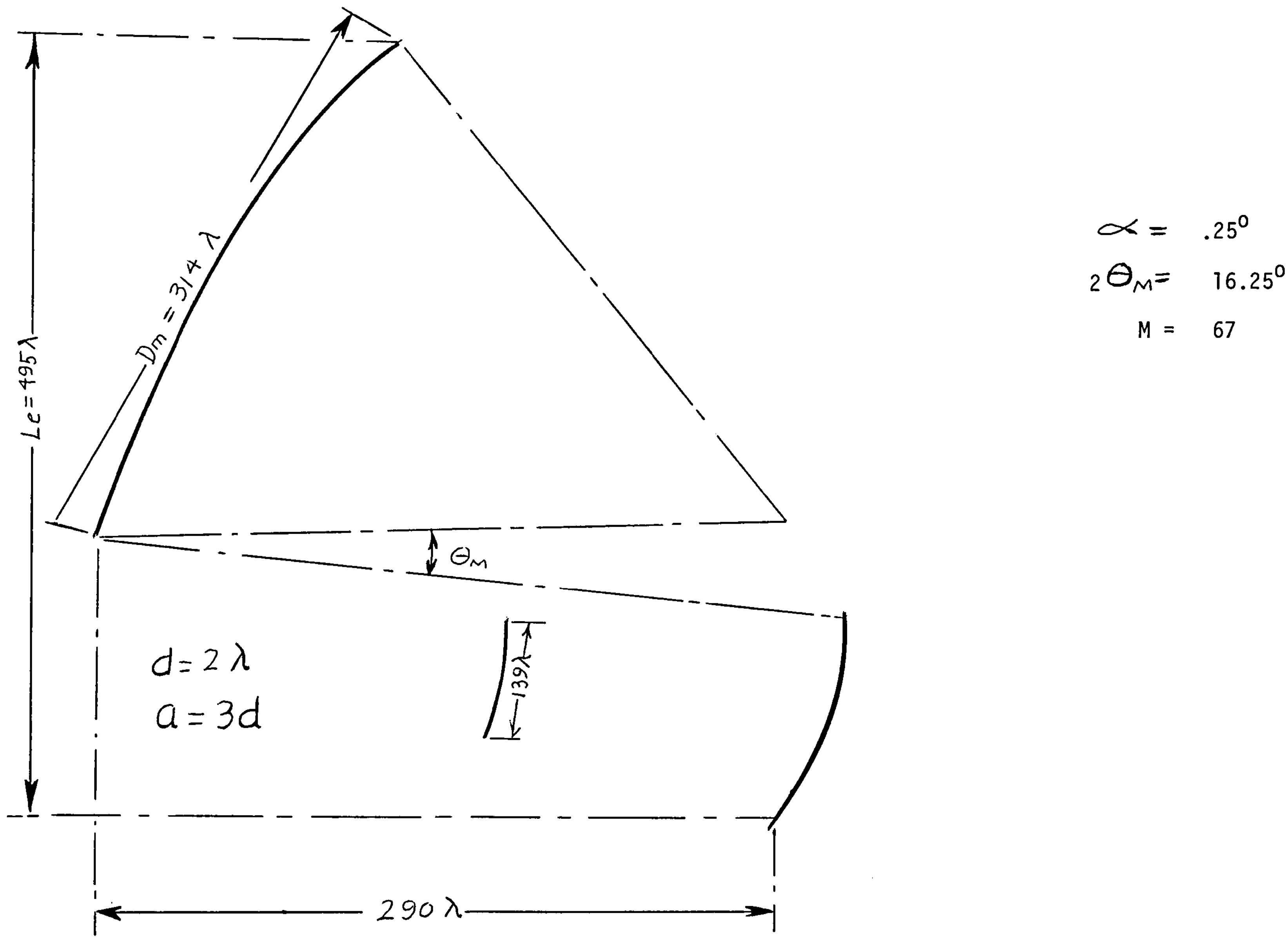


Figure 4.3-1A. Typical Shaped Dual Reflector Optics With 2 Θ_M Scan Range, α = 0.25°

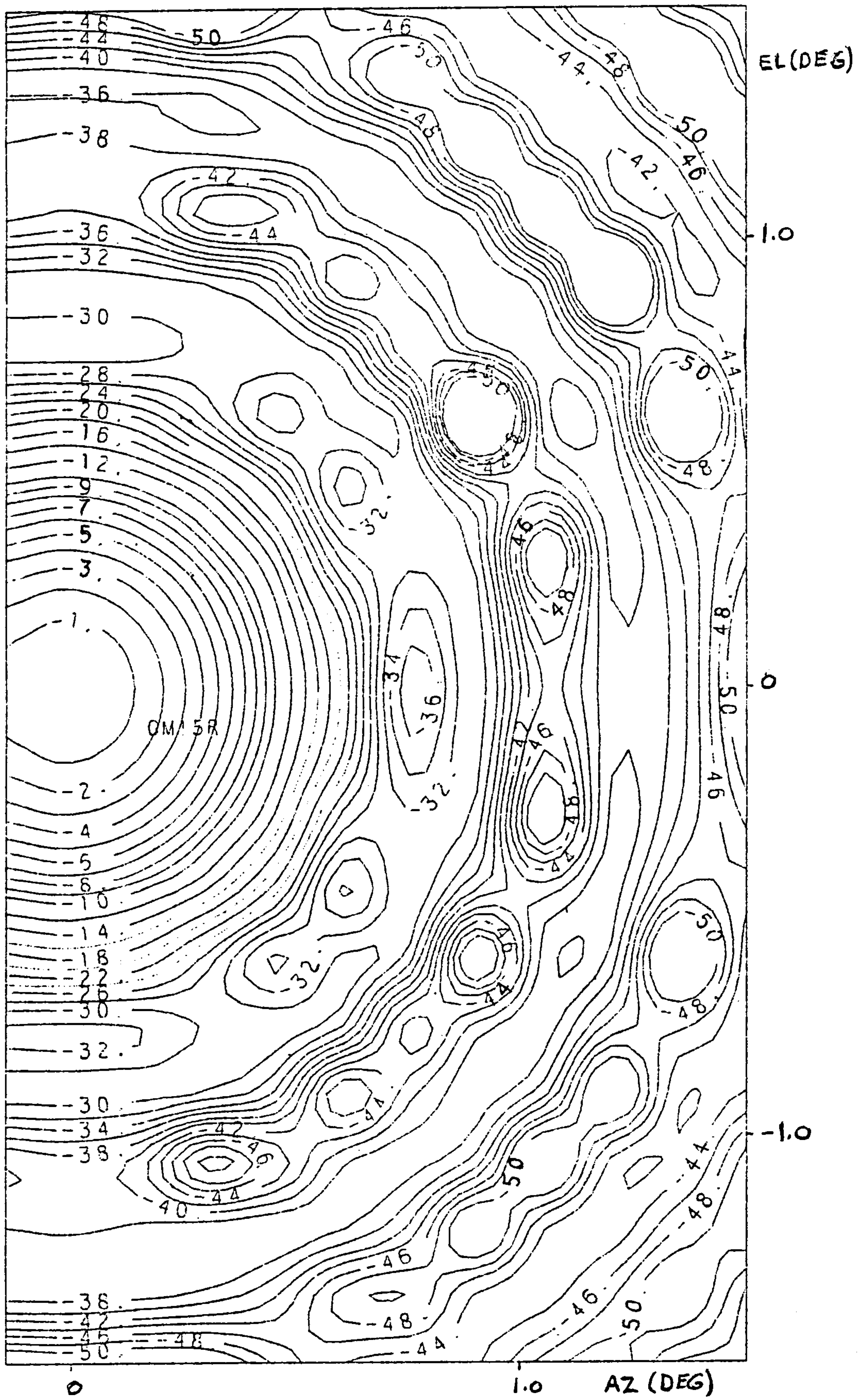


Figure 4.3-2. Secondary Gain Contour With 21 dB Edge Taper At Scan Angle Where Optics Generated Phase Error is 0.

scan plane subreflector width reaches the width of the main reflector and it is impractical to design larger scan angles with two reflector systems. In the A.O.S. initial design for the radiometer the absolute scan angles will be restricted to $2\theta_M = 18^0$ or $\theta_M = \pm 9^0$, thus making it possible to attain 108^0 swath width with the use of 6 individual radiometer elements.

If the beam center to beam center positions during scan is $.25^0$, then 67 beam positions (cells) will be required, $(16.75^0/.25)$. The cell diameter, is generally not identical to the 3 dB beamwidth, which varies with frequency and beam position.

Table 4.3-1 shows the most important dimensions of the optics for a reference, $\alpha = .25^0$ cell size. In Table 4.3-1, D is the diameter of the main reflector aperture, which is also the maximum dimension of the physical reflector in the plane perpendicular to the scan, D_m is the maximum dimension of the main reflector in the plane of scan and L_ℓ is the lateral dimension of the resultant optics.

Table 4.3-1. Most Important Characteristics of the Dual Reflector Optics for $\alpha = .25^0$, $2\theta_M = 16.75^0$

f GHz	cm	Dcm	D_m cm	D_m 1cm	L_ℓ cm	θ_{30}
22.5	1.333		418.8			.36
37	.8108	219.7	254.7	254.7	401.7	.25
60	.5	135.5	157.1	157.1	247.7	.25
94	.3191		1003.3			.20

The operation of the optics given in Figures 4.3-1 and 4.3-1A and Table 4.3-1 is fairly simple. For an unscanned received plane wave the main reflector illuminates the center part of the subreflector in the scan plane and all of it in the perpendicular to scan plane. This part of the subreflector is shaped in such a way that it focuses all the received power to a single focal point in the middle of the feed arc. In order to assure an aperture taper about 21 dB the feed horn must have a diameter of about $a = 6\lambda$. This in turn assures a first sidelobe level about 30 dB down and a second sidelobe about 36 dB down. (See Figure 4.3-2.) As the beam is scanned to $\theta_1 \angle \theta_M$ and

$\theta_2 < \theta_M$ in the $\pm$ angular scan range the illuminated part of the subreflector shifts outward from the unscanned case to the point that it does not overlap the originally illuminated section. Thus it is feasible to design the subreflector shapes for these positions independently from the shape of the center position and achieve two additional perfect focal points on the feed arc, on either side of the original focal point. Since no scan-dependent phase error is generated in these locations the performance of the associated beams is nearly the same as for the unscanned beam. The worst performance will occur at scan limits and between the optimum angle positions (at approximately $\pm$ 3^0 and $\pm$ 8.37^0). However, even with a single radiation element per beam, fairly low sidelobes are achievable in these locations and these sidelobes levels can be further improved if seven element clusters of horns with proper compensating illumination is used in the vicinity of these angles.

In order to achieve the required $\alpha = .25^0$ the radiating elements (horns) must be $d = 2\lambda$ from each other in the direction of scan. Since the feed diameter is 6λ this requires the staggering of the horns in the direction of flight, yielding a total of three rows of horns.

Table 4.3-1 indicates that the desired D_m value varies more than 1:4 ratio for the various frequency bands. Such large variation cannot be practically compensated by feed illumination to produce the desired resolution. However, two separate antennas are required: the 22.5 GHz, 37 GHz band (1:1.64 ratio)can be combined in one antenna and the 60 GHz, 94 GHz band (1:1.57 ratio) can be combined into another antenna. This results in two antenna systems for the four frequency bands, and with the selected main reflector maximum dimension, D_m yields proper ratios for the 0_3 angles of the different frequency bands (0_{31}: 0_{32}: 0_{33}: 0_{34} = 1.44:1:1:.8).

On the basis of the above considerations Figure 4.3-3 shows the subdivision of the total half-scan range into three zones, served by three separate optics. Each zone is 18^0 wide. They provide 227.4 km and 454.9 km wide observation strips, adding up to a total of 2 x 963.5 = 1927 km swath width. In each zone an antenna described in Figure 4.3-1 is used, except the scan plane is chosen in the symmetry plane. The dimension of the main reflector is smallest for zone 1 and largest for zone 3 in order to keep the resolution approximately

Dimensions in CM

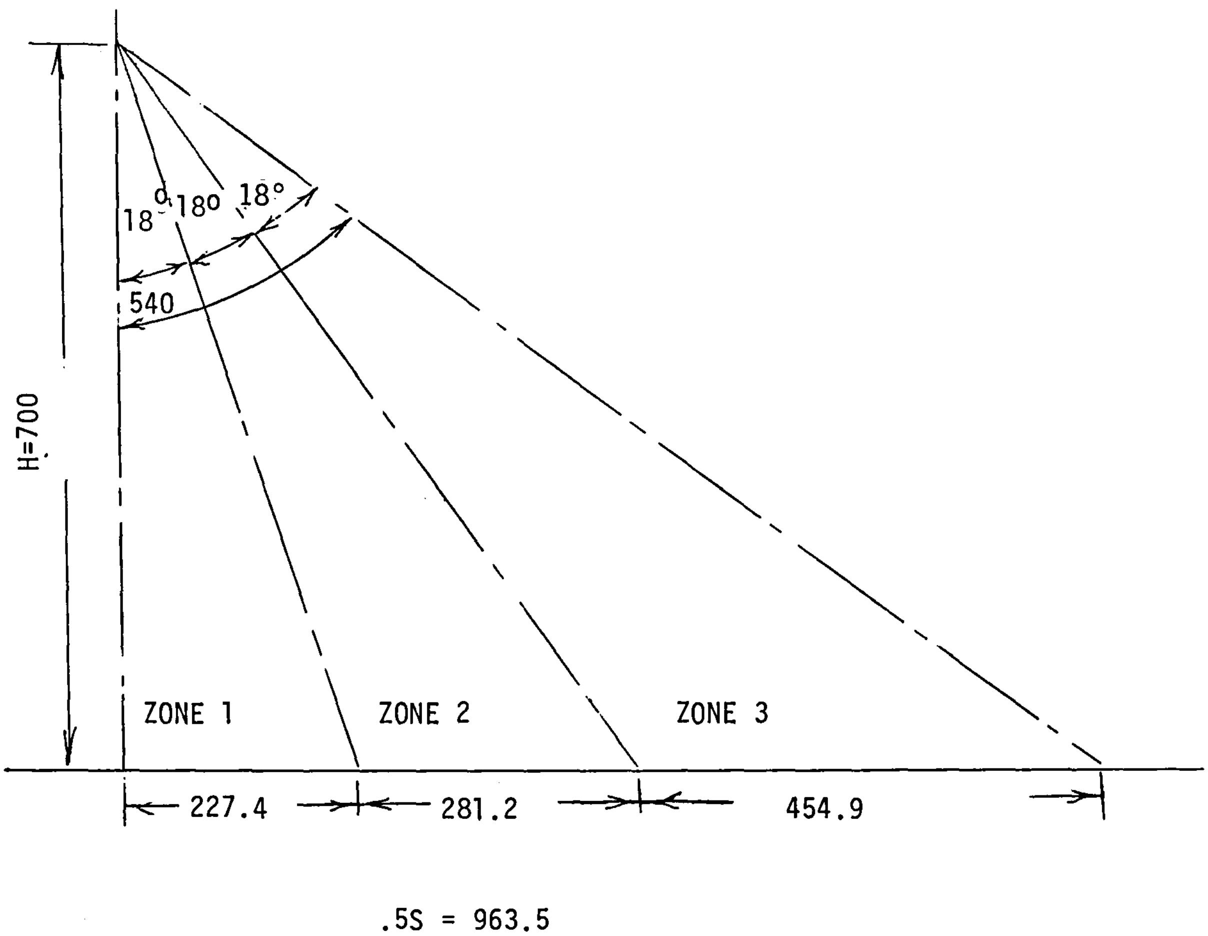


Figure 4.3-3. Subdivision of The Elevation Range Into 3 Zones for Case 1 System Configuration

independent of scan. Table 4.3-2 gives the characteristics of the antenna system, which uses a total of 12 optics to cover the 6 zones and 4 bands in an "optics array" configuration.

Table 4.3-2. Main Characteristics of the Overall Antenna System for H = 700 km, S = 1927 km, 4 Frequency Bands

	Zone 1	Zone 2	Zone 3	Zone 4
D_1 cm	64.1	82.3	137.3	567.4
D_2	39.5	50.7	84.7	349.9
M	21	27	45	186
$a v^o$	.857	.666	.400	

Table 4.3-2, D_1 is the aperture diameter of the main reflector for the 22.5 GHz/37 GHz bands and D_2 is the aperture diameter of the main reflector for the 60/94 GHz bands. M is the number of feeds for the corresponding zones. In the simplest case this is also the number of horns. The last column in Table 4.3-2 shows the total combined width of the optics system in the plane of scan and the total number of horns. The actual width of the optics system is only 467.4 cm because the far out antennas are tilted outward. Thus, the overall system width is approximately compatible with the STS envelope without deployment.

Figure 4.3-4 shows the concept of the overall configuration. Table 4.3-3 shows the achievable average resolutions with the above described system.

Table 4.3-3. Average Resolution of the Case 1 System

($_f$GHz)	x (km) Δ x
22.5	14.92
37	10.36
60	10.36
94	8.29

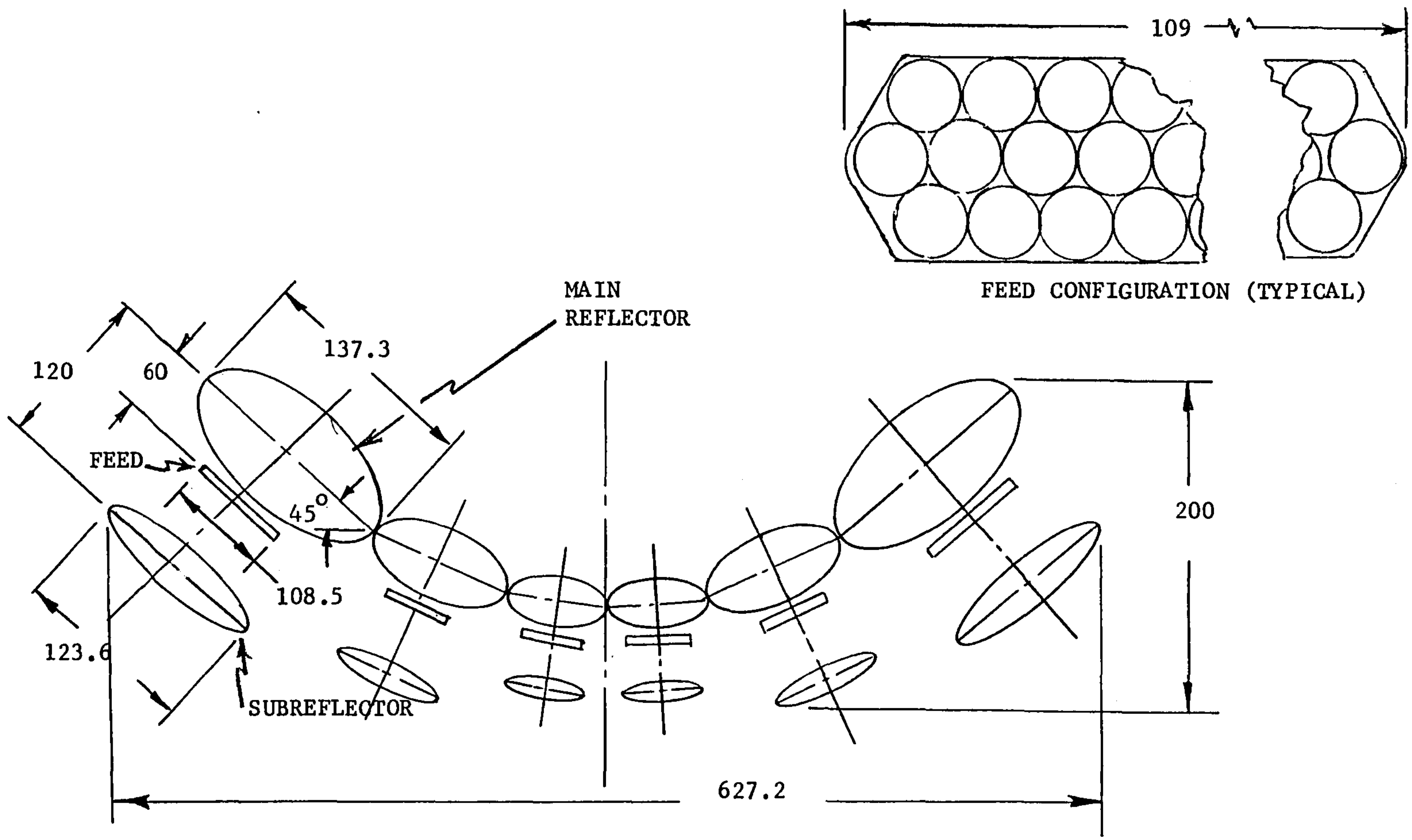


Figure 4.3-4. Mission I AOS Passive Microwave Radiometer Configuration

Antenna System Configuration for Case 2 (H = 2500 km, S = 6120 km)
The principles given in Section 2 can be easily extended to a system, which is operated at 2500 km orbit height. Table 4.3-4 gives the main characteristics, Table 4.3-5 the achievable average resolution and Figure 6 the overall configuration.

Table 4.3-4. Main Characteristics of the Overall Antenna System for H = 2500 km, S = 6120 km, 4 Frequency Bands

	Zone 1	Zone 2	Zone 3	Zone 4
D_1 cm	219.7	262.3	393.5	1751
D_2 cm	135.5	161.8	242.7	1080
M	67	80	120	534
α_{av} °	.250	.209	.139	

Table 4.3-5. Average Resolution of the Case 2 System

f GHz	km Δx
22.5	16.21
37	11.26
60	11.26
94	9.00

This system requires a total of 14.42 m width for the optics system and 11.62 m dimension in the direction of flight. While the width of the system may be compatible with the length of the STS cargo bay the flight direction dimension is not. The reduction of this dimension will require a single degree freedom gimbal on the main reflectors.

The following main development requirements can be recognized for the implementation of the above described concepts:

1. Shaped dual reflector optics geometry optimization. Definition of the surfaces must be developed on the basis of some geometrical optical aberration criteria.

2. Multimode radiating elements and/or cluster of these elements must be developed for the selected optics configurations.

3. Construction and thermal control of reflector surfaces up to about 4 m diameters and rms surface accuracies of $\lambda/80$ will be needed. Most difficult implemention is for the Case 2, Zone 3 reflector at 94 GHz. Here the wavelength is .3191 λ = .1256 in. The $\lambda/80$ criteria gives 1.57 mill, rms surface accuracy for a 242.7 cm = 95.55 in. diameter main reflector. This results in a $D/\Delta = 6.09 \times 10^4$ diameter to rms surface accuracy ratio. The subreflector surface accuracy generally has to be about a factor of 2 better than for the main reflector, which results for this case .79 mill rms requirement and $D_S/\Delta \sim 4 \times 10^4$. For this case the D/Δ ratio is 3 to 4 times larger.

4. For Case 2 a main reflector gimbal technology is required which has a range of approximately 90^o and a final position accuracy of approximately $.2^o$.

4.3.2 SUB-MILLIMETER WAVE RADIOMETER

This instrument is similar to the sub-millimeter instrument described in the AOS Part I Final Report. It is also similar to the laser heterodyne spectrometer, but uses a sub-millimeter source which is pumped by a CO_2 laser. The incoming radiation is heterodyned with the sub-millimeter signal to produce a high resolution measurement of important trace species in the upper atmosphere. The sensor is capable of operating on three channels simultaneously, out of a total of nine selectable channels, as follows:

O_3	96 and 184.37 GHz
OH	1.8 THz
CO	115.27 GHz
CEO	204.3 GHz
N_2O	251 GHz
H_2O_2	204.5 GHz
NO	150 GHz
SO_2	70 GHz

An important feature of this instrument is the addition of the OH channel which is useful in solving some of the knowledge objectives related to an understanding of the photochemistry of the stratosphere and ozone destruction processes. The OH channel has its heritage in the 163 micron heterodyne radiometer being developed by H.M. and T.L. Boyd in the Jet Propulsion Laboratory. A CO_2-pumped methanol laser is used to produce a local oscillator signal near one of the transition frequencies of OH. One of the key components of this channel is the photoconductive frequency mixer consisting of a strained germanium crystal, doped with gallium.

The physical characteristics of the instrument are as follows:

Size of electronics module:	71 x 56 x 56 cm
Size of Antennas:	160 cm max. dia. (2 antennas)
Weight:	250 Kg

The demands on the satellite system are:

Power (Average):	Less than 100 watts
Data Rate:	Approximately 5 Kilobits/sec.

4.4 ACTIVE OPTICAL (LIDAR) SENSORS

This section postulates the use of a Lidar Sensor for upper and lower atmospheric measurements of typical trace species such as 03, NO, NO_2, N_2O, CO, CO_2, Na, as well as cloud top heights from low Earth Orbit. The information was calculated based on a receiver effective area of one M^2 and a requirement to provide data during daylight as well as night. The calculations are further based on obtaining a unity signal to noise ratio in the worst case including day Earth background and at look angles of up to 60^0 from the nadir. The analysis takes as its point of departure the data generated for the Atmospheric Lidar Study in reference no. 16. The calculation results are summarized in Table 4.4.1. Additional more detailed descriptions are given in the following paragraphs. These techniques are all used from a low Earth Orbit since there are no techniques which can be postulated for making these measurements from intermediate (i.e., 2000 - 10,000 km) or synchronous Orbit in the 1990 time frame.

The following sub-sections provide an assessment of the Lidar measurements of the aforementioned typical trace species.

4.4.1 OZONE

Two techniques are possible for measurement Ozone in the Earth's upper atmosphere from low Earth orbit. These are the differential range techniques in the ultraviolet and DIAL measurements in the infra-red and in the ultraviolet.

Table 4.4-1. Summary of Lidar Measurements From Low Earth Orbit

SPECIE	METHOD	(NM)	LASER TYPE	TRANS. EN.(J)	RCVR AREA (M^2)	FOV (MR)	RANGE CELL (KM)	RCVR BANDPASS	DETECTOR	ALT RANGE (KM)	MAX OF NADIR RANGE
O_3	DIFFER. RANGE	280 to 300	EXIMER OR DYE	10	1	0.1	1	3.3x 10-3	PHOTON COUNT	0-40	60^o
O_3	DIAL	9454.7 9452.2	CO_2	100	1	0.01	1	$7.5x10^{-4}$	HETERODYNE	0-40	60^o
NO	RES. FLUOR.	215	EXCIMER	10	1	0.01	1	$4.4x10^{-3}$	PHOT COUNT	70-150	60^o
NO_2	UV DIAL	450.0 448.1	DYE	12	1	0.01	1	$2.2x10^{-3}$	PHOT COUNT	-	60^o
N_2O	IR DIAL	4504.9 4502.4	CO2 x2	1	1	0.01	1	$7.5x10^{-4}$	HETERODYNE	-	60^o
CO	IR DIAL	4657.5 4658.7	CO2 x2	100	1	0.01	1	$7.5x10^{-4}$	HETERODYNE	-	60^o
SO_2	UV DIAL	306.53 305.56		100	1	0.01	1	$7.5x10^{-3}$	PHOT COUNT	-	60^o
WINDS	ELASTIC SCATT.	11193.3	CO2	10	1	0.01 SCANNING	1	$5x10^{-3}$	HETERODYNE	0-20	60^o
CLOUD TOPS	ELASTIC SCATT.	ANY	ANY	0.1	1	0.1	0.1	$7x10^{-3}$	PHOT COUNT	0-10	60^o
Na	RES FLUOR	589.9	DYE	1	1	0.1	1	$1.7x10^{-5}$	PHOT COUNT	20-80	60^o

In general the UV measurement techniques are to be preferred since the return signal for ozone measurements is primarily aerosol backscattering in the infrared, which falls off much more rapidly with increasing altitude than the return signal in the UV, which is primarily backscattering from atmospheric gases.The most promising wavelengths for ozone dial measurement in the UV are in the 305 to 310 nm range, which are just on the edge of the ozone absorption band. Differential range measurements can be made over a wider wavelength region of 280 nm to 300 nm. Refer to Table 4.4.1-1.

The ultraviolet differential range technique offers the most promise in the 1990 time period from the standpoint of laser energy requirements. This laser will be a dye or an excimer laser in the wavelength band between 280 and 300 nm. The laser output energy required is 10 joules with a pulse length which ranges from nanoseconds to a few microseconds in order to obtain one kilometer resolution. The average power required by the laser depends, of course, on the laser repetition rate, but at the postulated 15 Hz the average input power level will be 1500 watts for an excimer laser and 15,000 watts for a dye laser.

Table 4.4.1-1. Ozone Measurement Primary System Parameters

Ozone Measurement	Primary System Parameters
Measurement Type	Differential Range or Dial
Laser Type	Dye or Excimer (Prefered)
Wavelength (nm)	280 to 300 nm (differential range) 305 to 310 nm (DIAL)
Energy	10 J per pulse
Pulse Width	Nanoseconds to few microseconds
Pulse Rate	15 PPS
Average Laser Power (W)	150 W
Average Input Power (W)	1500 W (excimer) to 15000 W (dye)
Optics Size Receive Transmit	1 m^2 effective area 15 to 30 cm. Dia.
Receiver	Photomultiplier
Technology Required	Space Qualified Excimer Laser at Required Energy Level

Integration of 1000 pulse pairs would provide a sensitivity limitation of 8 PPD for O_3 at low altitudes.

4.4.2 OXIDES OF NITROGEN (NO_x)

The Oxides of Nitrogen which can be detected by lidar are NO, NO_2, and N_2O.

Nitric Oxide (NO)

Altitude profiles at a single wavelength can be obtained from NO by resonant scattering or fluorescence techniques at the resonnance line of the NO γ-Band at $\sim$ 215 nm. Of the three oxides on nitrogen mentioned, NO is the most difficult to measure since the exciting laser linewidth must be very small (less than 0.0005 nm) and centered exactly on the NO line. The accuracy of the measurement of NO has been calculated at 20% in the 70 to 150 km altitude range for three km range cell lengths and integration times of 125 pulses. At lower altitudes the accuracy becomes lower or the integration times become larger. The system parameters are given in Table 4.4.2-1 for the measurement of NO, NO_2, and N_2O.

Table 4.4.2-1. NO_x Measurement Primary System Parameters

NO_x Measurement	NO	NO_2	N_2O
Measurement Type	Res. Fluor	UV Dial	IR Dial
Laser Type	Excimer	Dye or Excimer	Optical Parametric Osc.
Wavelength (nm)	215 nm	450 nm 448.1 nm	4502.4 nm 4504.9 nm
Energy (J)	10	12	1
Pulse Width	ns to microsec.	ns to microsec.	ns to microsec.
Pulse Rate (Hz)	15	15	15
Average Laser Power (W)	150	150	150
Average Input Power (W)	1500	1500	1500
Optics Size Receive Transmit	$1m^2$ 30 cm	$1m^2$ 15 cm	$1m^2$ shares same optic
Receiver	Photomultiplier	Two Photomultipliers	Two Heterodyne Receivers
Technology Required	Note 1	Note 2	Note 3

Notes

1. Excimer laser with very narrow linewidth (less than 0.0005 nm) and tight wavelength coutrol.

2. Excimer or dye laser with tight wavelength control.

3. Space qualified heterodyne system, and doubled CO_2 laser.

(All lasers must be space qualified where none now exist in this energy regime).

Nitrogen Dioxide (NO_2)

Nitrogen dioxide is detected in the visible spectrum by dial techniques with lines at 450 nm and 448.1 nm. These wavelengths are chosen since they give the maximum differential absorption in the visible spectrum. Despite this, the total differential absorption is quite low since the absorption coefficient for NO_2 is low and the rural population density of NO_2 is small. Even with the low absorption coefficient, calculations of the performance level indicate that the integration of 1000 pulse pairs would provide a detection capability of 1 PPB at near ground level. The primary system parameters are given in Table 4.4.2-1.

Nitrous Oxide (N_2O)

The measurement of N_2O is best accomplished by DIAL techniques in the atmospheric window near 5 micrometers. At wavelengths of 4.5049 micrometers and 4.5024 micrometers, obtainable from an optical parametric oscillator driven by a doubled CO2 laser or a Nd:yag laser. Even with modest laser energies ($\sim$ 1 joule) the system will measure to one half the modeled concentration of N_2O up to altitudes of 5 km with the integration of only 100 pulse pairs. The primary system parameters are given in Table 4.4.2-1.

4.4.3 CARBON MONIXIDE (CO)

The detection of CO in the atmosphere from low Earth orbit is performed with IR DIAL measurements at two wavelengths, 4.6575 micrometers and 4.6587 micrometers. The laser used is postulated to be an optical parametric oscillator driven by a double CO_2 laser or a nd:yag laser. The main problem with the measurement of CO is the effects of interferring species primarily water vapour and N_2O whose absorption lines overlay or nearly overlay the CO absorption lines. It is estimated that with a 100 joule laser with heterodyne detection, the minimum detectable limit of CO molecules would be approximately one tenth of the assumed distribution at near ground level. The primary system parameters are given in Table 4.4.3-1 for the measurement of CO.

4.4.4 SULFUR DIOXIDE (SO_2)

The measurement of SO_2 is probably the most difficult of the measurements postulated. The reasons for this are twofold. First the differential attenuation available, even with the best choice of lines, is quite low. Second, the suitable absorption lines available are 306.53 nm and 305.56 nm, which are obscured by an interferring specie, ozone, large systematic errors caused by the interferring specie require a large laser energy to give barely acceptable results. Calculations indicate that the detectable limit for SO_2 measurement with the parameters given would be about 2 PPB which would allow SO_2 measurement down to approximately 5 km altitude. The primary system parameters for SO_2 measurement are given in Table 4.4.4-1.

Table 4.4.3-1. CO Measurement Primary System Parameters

CO Measurement	Primary System Parameters
Measurement Type	IR Dial
Laser Type	Optical Parametric Osc. Doubled CO_2 or nd:yag Pumped
Wavelength (nm)	4.6575 and 4.6587 micrometers
Energy (J)	100 J
Pulse Width	6 msec.
Pulse Rate	15 Hz
Average Laser Power (W)	1500 W
Average Input Power (W)	15000 W
Optics Size	1 m^2 Transmit and Receive Share Optic
Receiver	Dual Heterodyne
Technology Required	Optical Parametric Oscillator Space Qualified Hetrodyne System

Table 4.4.4-1. SO_2 Measurement Primary System Parameters

SO_2 Measurement	Primary System Parameters
Measurement Type	UV Dial
Laser Type	Dye or Exicmer
Wavelength (nm)	306.53 and 305.56 nm
Energy (J)	100 J
Pulse Width	15 Hz
Pulse Rate	15 Hz
Average Laser Power (W)	1500 Watts
Average Input Power (W)	(Not Available)
Optics Size Receive Transmit	1 m^2 30 cm. Dia.
Receiver	Two Photomultipliers
Technology Required	Very High Energy Near UV Lasers

4.4.5 CLOUD TOPS

The measurement of the altitude of Cloud Tops above the local terrain is the easiest of all the Lidar measurements to make. The measurement is made simply by examining the elastic scattering signal from a single channel of dial or from any other measurement where a ground return is visible. Most of the experiments described in this report will give good ground returns and cloud returns even through milti-layer cloud formations. Tests with ground lasers have shown that even with modest energies and small receiver apertures that cloud boundaries are easily identified. THe cloud boundaries are, of course, soft, in that the cloud has no sharp edge. Different wavelengths will give different values for cloud boundaries, with the UV giving the highest values because of the effects of enhanced scattering from smaller droplets. It appears that the optimum wavelength for cloud detection lies between the red and the green regions of the visible spectrum.

4.4.6 SODIUM (N_a)

The measurement of sodium atoms in the atmosphere is done by exciting the atoms at their resonance wavelength of 589.9 nm and observing the fluorescence. This, measurement has been accomplished from the ground with modest laser energies and very good results. It is postulated that with a laser energy of 1 joule and a collector of 1 m^2 sodium atoms could be detected to relatively low altitudes. This same technique can be used for the detection of lithium atoms at 670.3 am and potassium atoms at 766.5 nm. The primary parameters of this system are given in Table 4.4.6-1.

Table 4.4.6-1. Sodium Atom Measurement Primary System Parameters

Sodium Atom Measurement	Primary System Parameters
Measurement type	Photon counting Res. Flourescence
Laser Type	Dye
Wavelength (AM)	589.9 nm
Energy (J)	1
Pulse Width	Less than 6 msec.
Pulse Rate	15 Hz
Average Laser Power	15 w
Average Input Power	1500 w
Optics Size Receive Transmit	1 m^2 15 cm. Dia.
Receiver	Single Photomultiplexer
Technology Required	1 Joule Dye Laser Space Qualified

SECTION 5

ANALYSES OF INCIDENCE ANGLES, SPECTRAL RADIANCE AND ORBITS

The transition from the selection of generic/sensors to mission definitions required an intermediate step to analyze the effects of geometric constraints and atmospheric transmissivity parameters upon the selection of orbit and instrument fields of view. This section presents the results of two analyses:

1. Determination of optical signal characteristics of earth-reflected or emitted radiance, versus incidence angle (i.e., angle between local vertical and the line-of-sight at the intersection of the l.o.s. with the earth's surface).

2. Determination of spatial coverage and "diurnal" coverage as a function of orbit and instrument field-of-view (Diurnal coverage refers to the spatial-temporal constraints for viewing large areas of the world at different local times in the diurnal cycle).

The data are presented in parametric form, rather than being tailored to specific orbits and viewing geometries, to permit wide use of the data by scientists and mission planners in future atmospheric investigations.

5.1 OPTICAL RADIANCE AT VARIOUS VIEWING ANGLES*

Calculations of radiation emerging from the atmosphere of the earth have been performed in order to evaluate signal levels, parametrically, for various satellite orbits and viewing geometries. The model selected for the numerical work is an extension of that developed in Reference 32 and relies on the single line approximation. This simplification computes radiative transfer for a single atmospheric line and neglects the effects of adjacent ones. Overlapping calculations for single lines can be performed rapidly such that a number of parametric variations are possible. Multiple-line programs such as LOWTRAN 5 were used to a limited extent, in verifying the single-line data.

The monochromatic radiative transfer equation for the absorption, emission and scattering of photons along a ray is given (Reference 33) by:

*Viewing angle uses local vertical of the observable as the reference, thus it is the same as "incidence angle" which is used in subsequent discussions concerning geometry at various orbits.

$$\frac{dI_\nu}{dS} = \epsilon_\nu - I_\nu \; a_\nu \qquad \text{EQ. 1}$$

where:

I_ν = spectral intensity (watts/cm^3-ster-cm^{-1})

S = distance along ray (cm)

ϵ_ν = spectral emission coefficient (watts/cm^2-ster-cm^{-1}), a function of S

a_ν = spectral absorption coefficient (cm^{-1}), a function of S

For the conditions of interest to the present study, solar energy is attenuated as it penetrates to the surface of the earth. At this point, it is reflected assuming a Lambertian surface and the total intensity is increased by earthshine. The resulting flux is then further attenuated by the atmosphere until the satellite is reached. Atmospheric emission increases photon flux at each point on the ray and is directly additive on a differential basis as shown by Equation 1.

The formal solution to the radiative transfer equation can be written:

$$I_\nu = \rho_\nu \left[I_{0,\nu} \exp\left(-\int_0^{z_1} a_\nu \, dS''\right) + \int_0^{z_1} \epsilon_\nu \exp\left(\int_{S'}^{z_1} a_\nu \, dS''\right) dS' \right]$$

$$+ I_{e,\nu} \exp\left(-\int_0^{z} a_\nu \, dx''\right) + \int_0^{z} \epsilon_\nu \exp\left(-\int_{x'}^{z} a_\nu \, dx''\right) dx' \qquad \text{EQ. 2}$$

where:

$I_{0,\nu}$ = solar flux (watts/cm^2 - ster-cm^{-1})

$I_{e,\nu}$ = earthshine (watts/cm^2 - ster-cm^{-1})

ρ_ν = earth reflection coefficient

Integration of Equation 2 along the path of the ray from the sun to the earth to the satellite is then performed numerically given values of ϵ_ν and a_ν as a function of attitude at a constant wave number. In order to obtain the spectral line profile, Equation 2 is solved first at the line center. The wavenumber is then incremented by 0.001 cm^{-1} and the calculation is repeated until the entire line profile is established within the wavenumber interval of interest (usually selected as the midpoint between adjacent lines). Because high resolution is not necessary in the line wings, the wavenumber increment of 0.001 cm^{-1} is doubled every other step.

The spectral absorption and emission coefficients are computed using models for atmospheric pressure and temperature, species and aerosol number density and aerosol size distribution. These have been taken directly from LOWTRAN 3b (Reference 34). The spectral absorption coefficient is composed of the sum of the terms, namely

$$a_\nu = a_{M,\nu} + a_{A,\nu} + a_{S,\nu}$$

where:

$a_{M,\nu}$ = Absorption due to molecules

$a_{A,\nu}$ = Absorption due to aerosols

$a_{S,\nu}$ = Scattering by moleculer and aerosols

The absorption coefficient for a molecular line is given (Reference 32) by:

$$a_{M,\nu} = \phi_\nu \; S_{\ell u} \; e^{hcE_1/k\left(\frac{1}{\bar{T}} - \frac{1}{T}\right)} \frac{\left[1 - e^{-hc\nu/kT}\right]}{\left[1 - e^{-hc\nu/k\bar{T}}\right]} \frac{\bar{Q}}{Q} \frac{n_t}{\bar{n}_t}$$

where:

S_{1u} = line strength (cm^{-2} -atm^{-1})

$hc\nu/k$ = energy per transition (^oK)

T = temperature (^oK)

n_t = total number density of absorbing species

Q = partition function

ϕ = Voight profile function ($1/cm^{-1}$)

E_1 = lower state energy (cm^{-1})

and the bars over any quantity represent evaluation at the reference conditions where S_{1u} was measured. Thus, in addition to atmospheric parameters, computation of molecular absorption requires specification of S_{1u} and ϕ_ν .

Aerosol absorption and molecular and aerosol scattering are functions of atmospheric conditions under study. For purposes of the present work, these radiation attenuation functions were taken directly from LOWTRAN 3b without modification.

The emission coefficient is computed from the absorption coefficient and the black body function using the equation.

$$\epsilon_{\nu} = B_{\nu}\ (T)\ (a_{M,\nu} + a_{A,\nu})$$

where:

B_{ν} (T) = BLACK BODY FUNCTION

In this approximation, multiple scattering is neglected and all scattered photons are lost.

The computer program described in detail in Reference 32 was modified for the present work to include aerosol absorption and scattering and molecular scattering as outlined by the above equations. All other details of the code were left unchanged. Input requirements for the calculations are summarized in Table 5.1-1 and selected species distributions taken from Reference 4 shown in Figure 5.1-1. In this latter case, one of the three mixing ratio profiles shown on the figure can be selected as representative for most of the species of interest to the present study.

"Results of a typical line calculation are presented in Figure 5.1-2. At the line center (corresponding to zero on the abscissa) the line should be black due to high absorption, however, there is a peak due to emission from the upper atmosphere. As the wavenumber increases from the line center, the portion of the line that is measured has decreasing amounts of absorption, and therefore the sensor sees deeper into the atmosphere. The decrease in intensity exhibited by the curve in Region A is due to the decrease in temperature in deeper regions of the upper atmosphere. The minimum of the curve in Region B corresponds with the volume of the atmosphere near the tropopause. Finally, in the line wings (Region C), absorption by the line decreases and the sensor views increasing temperatures at deeper regions of the troposphere, until it sees the ground itself.

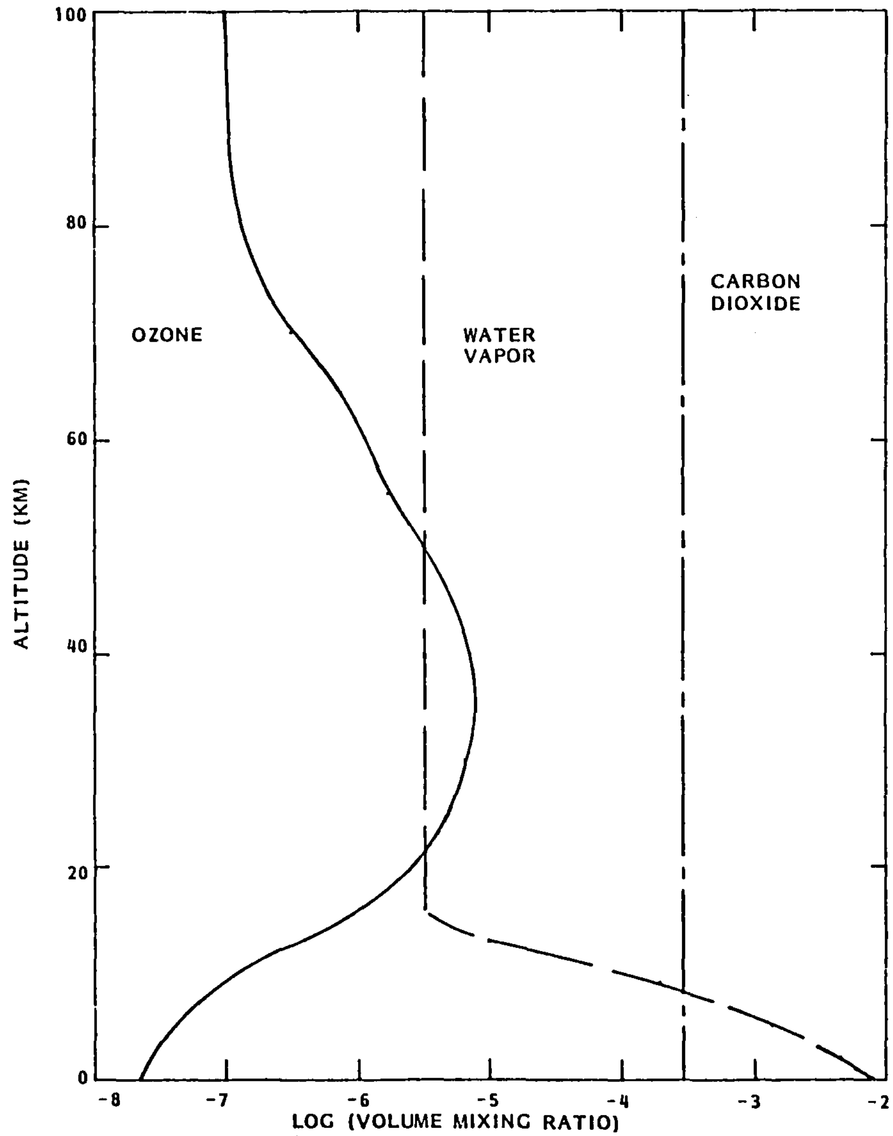


Figure 5.1-1. Atmospheric Mixing Ratio Profiles

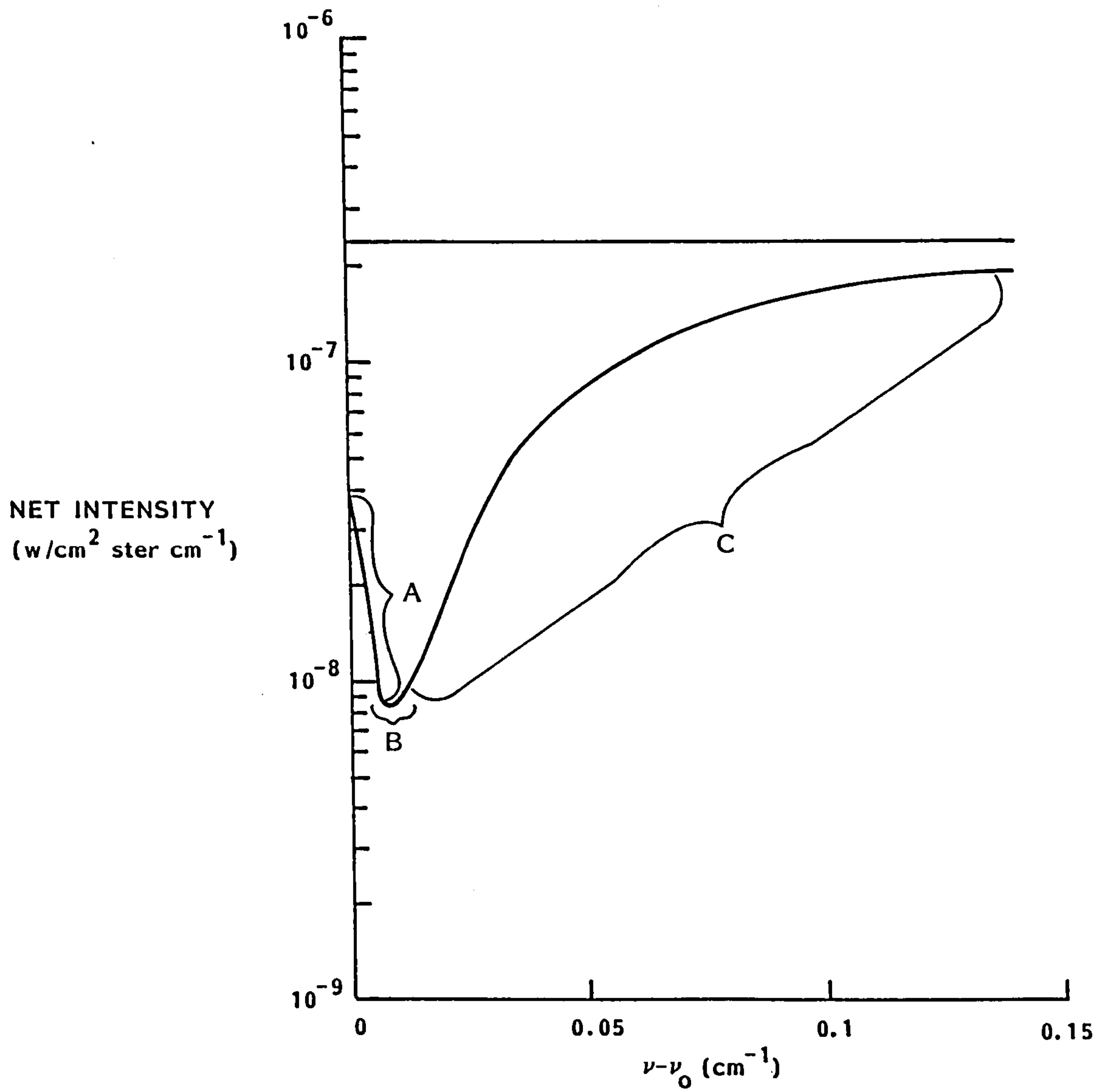


Figure 5.1-2. Line Profile Showing Emission Peak at Center
(Satellite Viewing Angle = 0°)

Table 5.1-1. Input Parametric for Calculation of Atmospheric Spectra

Parameter	Symbol	Value
Atmospheric Model	-	Midlatitude Summer
Aerosol Model	-	Rural
Species Distribution Model	-	Variable
Line Strength	$S_{\ell u}$	Variable
Wavenumber	ν	1000, 2000, 5000 cm^{-1}
Lorentz Width	-	$6 \times 10^{-2} cm^{-1}$
Line Spacing	-	3.5 cm^{-1}
Lower State Energy	E_{ℓ}	1000 cm^{-1}
Solar Zenith Angle	-	0^{o}
Satellite Nadir Viewing Angle	-	Variable from 0^{o} to 90^{o}
Ground Reflectivity	ρ_{ν}	0.2
Visibility		23 km
Ground emissivity		1.0
Ground Temperature		298 K

Figure 5.1-3 presents the upwelling radiance due to thermal emission and/or reflected sunlight from the atmosphere as a function of satellite viewing angle computed for the case of no molecular absorption. In this instance, all attenuation is caused by scattering and aerosol absorption. At 5 and 10 microns the curves are nearly flat which shows that scattering and aerosol absorption are nearly negligible and will not effect instrument design at these wavelengths for the atmospheric models considered. However, at 2 microns the continuum drops severely above about 60^{o}. This is caused by the decrease in reflection coefficient of the earth (assumed Lambertian) with increasing angle. A similar decrease can be anticipated when the solar zenith angle is greater than 60^{o}. Thus, instrument design problems can be expected in the solar infra-red for satellite orbits which require either viewing angles or solar zenith angles greater than 60^{o}.

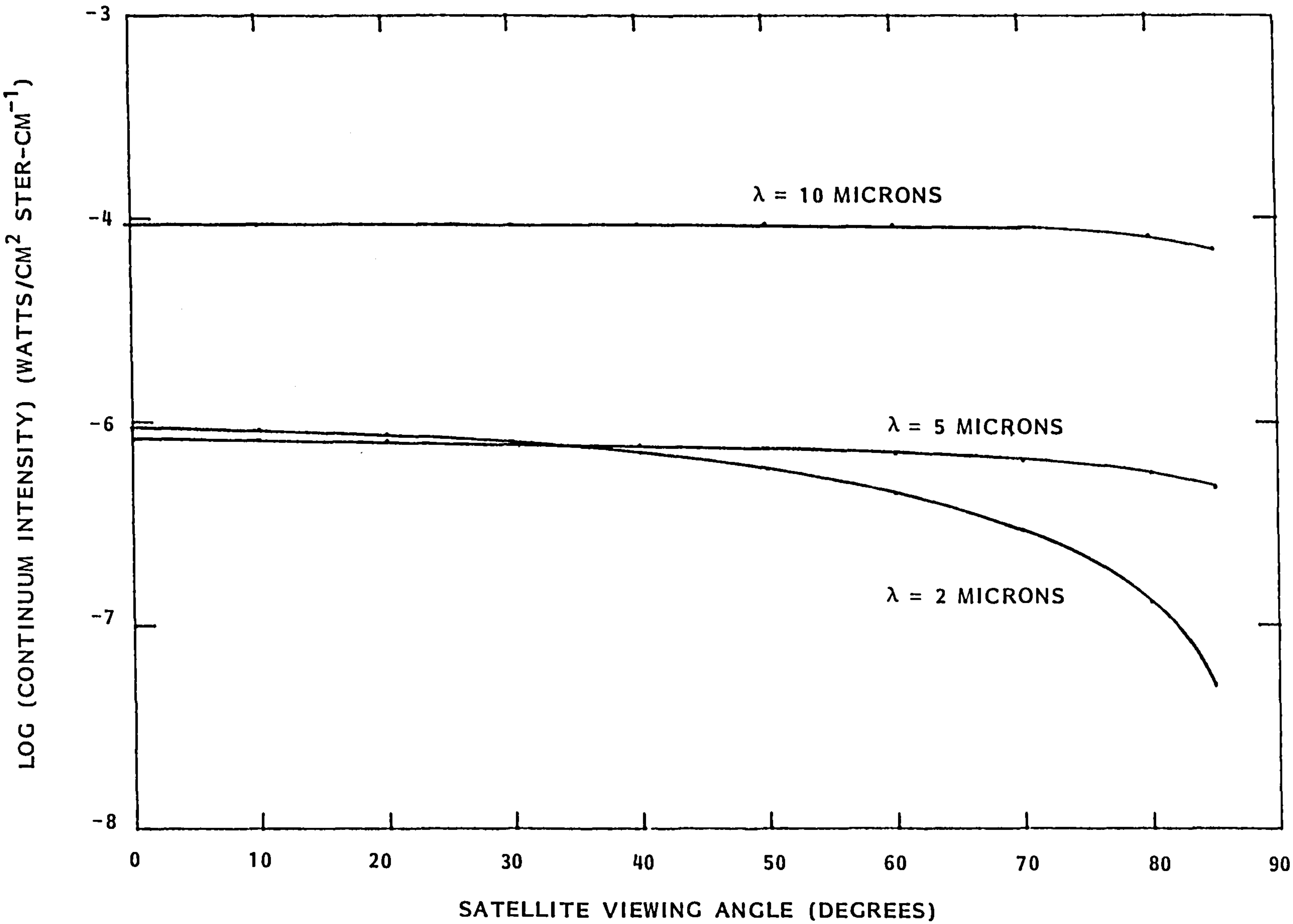


Figure 5.1-3. Variation of Continuum Intensity With Viewing Angle

A series of calculations have been performed to evaluate molecular absorption, parametrically, as a function of satellite viewing angle, wavenumber and atmospheric species distribution. Typical program output is shown in Table 5.1-2 where I_0 is defined as the intensity at 1.75 wavenumbers. The integrated radiation* at the top of the printout is defined by:

$$\int_0^{1.75} \left[\frac{I_0 - I}{I_0} \right] d\nu$$

and represents the net number of photons removed by atmospheric attenuation. The significance of this quantity is that it is relatable (approximately) to the signal which a satellite borne instrument would observe.

Figures 5.1-4 to 5.1-12 present plots of the integrated absorption (defined above) as a function of satellite viewing angle parametically with the line strength atmospheric burden product for the nine cases considered (three species concentration profiles and three wavelengths) where the atmospheric burden is defined as the integral of the species concentration (see Figure 5.1-4) over altitude and is given in Table 5.1-3. In general, the results cover all ranges of species concentration which are measurable by optical techniques because the integrated absorption is varied from the case of a nearly black line to that where the line becomes undetectable. Thus, Figures 5.1-4 to 12 can be regarded as design curves which can be interpolated, and/or otherwise processed as required to define appropriate signals for optical atmosphere sounding instrumentation. In other words, the trends in integrated absorption as a function of satellite viewing angle observed in Figures 5.1-4 to 5.1-12 are expected to apply for all passive optical instruments considered in the present study between 2 and 10 microns.

Table 5.1-3. Atmospheric Burdens

Profile	Atmospheric Burden (cm atm)
CO	8.0×10^{-2}
O_3	2.3×10^{-2}
H_2O	4.1×10^{3}

*Also called integrated absorption

Table 5.1-2. Typical Output from The Calculations of Atmospheric Radiations Transfer

INTEGRATED RADIATION = 2.7181E-02

WAVENUMBER	INTENSITY	I/I0	I0-I/I0	WAVENUMBER	INTENSITY	I/I0	I0-I/I0
0.0000E-01	2.0527E-07	2.6728E-01	7.3272E-01	1.0000E-03	1.9836E-07	2.5828E-01	7.4172E-01
2.0000E-03	1.7544E-07	2.2844E-01	7.7156E-01	4.0000E-03	9.5925E-08	1.2491E-01	8.7509E-01
6.0000E-03	1.1150E-07	1.4519E-01	8.5481E-01	1.0000E-02	2.7217E-07	3.5439E-01	6.4561E-01
1.4000E-02	3.9670E-07	5.1655E-01	4.8345E-01	2.2000E-02	5.4242E-07	7.0629E-01	2.9371E-01
3.0000E-02	6.1683E-07	8.0318E-01	1.9682E-01	4.6000E-02	6.8657E-07	8.9398E-01	1.0602E-01
6.2000E-02	7.1747E-07	9.3423E-01	6.5772E-02	9.4000E-02	7.4334E-07	9.6791E-01	3.2093E-02
1.2600E-01	7.5363E-07	9.8131E-01	1.8695E-02	1.9000E-01	7.6142E-07	9.9146E-01	8.5437E-03
2.5400E-01	7.6426E-07	9.9515E-01	4.8493E-03	3.8200E-01	7.6632E-07	9.9784E-01	2.1611E-03
5.1000E-01	7.6705E-07	9.9878E-01	1.2220E-03	7.6600E-01	7.6757E-07	9.9946E-01	5.3884E-04
1.0220E+00	7.6775E-07	9.9969E-01	3.0569E-04	1.3860E+00	7.6787E-07	9.9985E-01	1.4692E-04
1.7500E+00	7.6798E-07	1.0000E+00	0.0000E-01	0.0000E-01	0.0000E-01	0.0000E-01	1.0000E+00

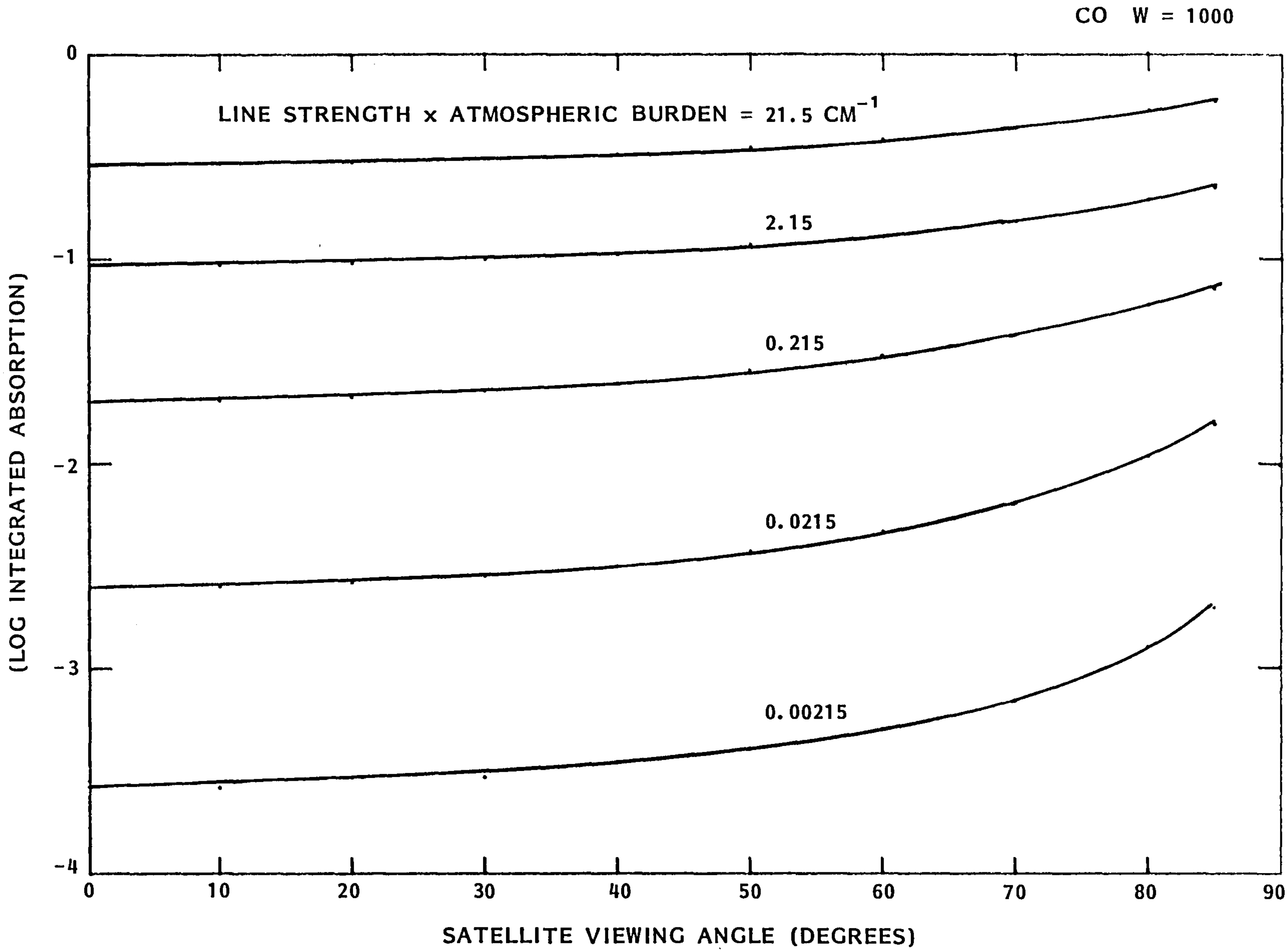


Figure 5.1-4. Integrated Absorption as a Function of Satellite Viewing Angle

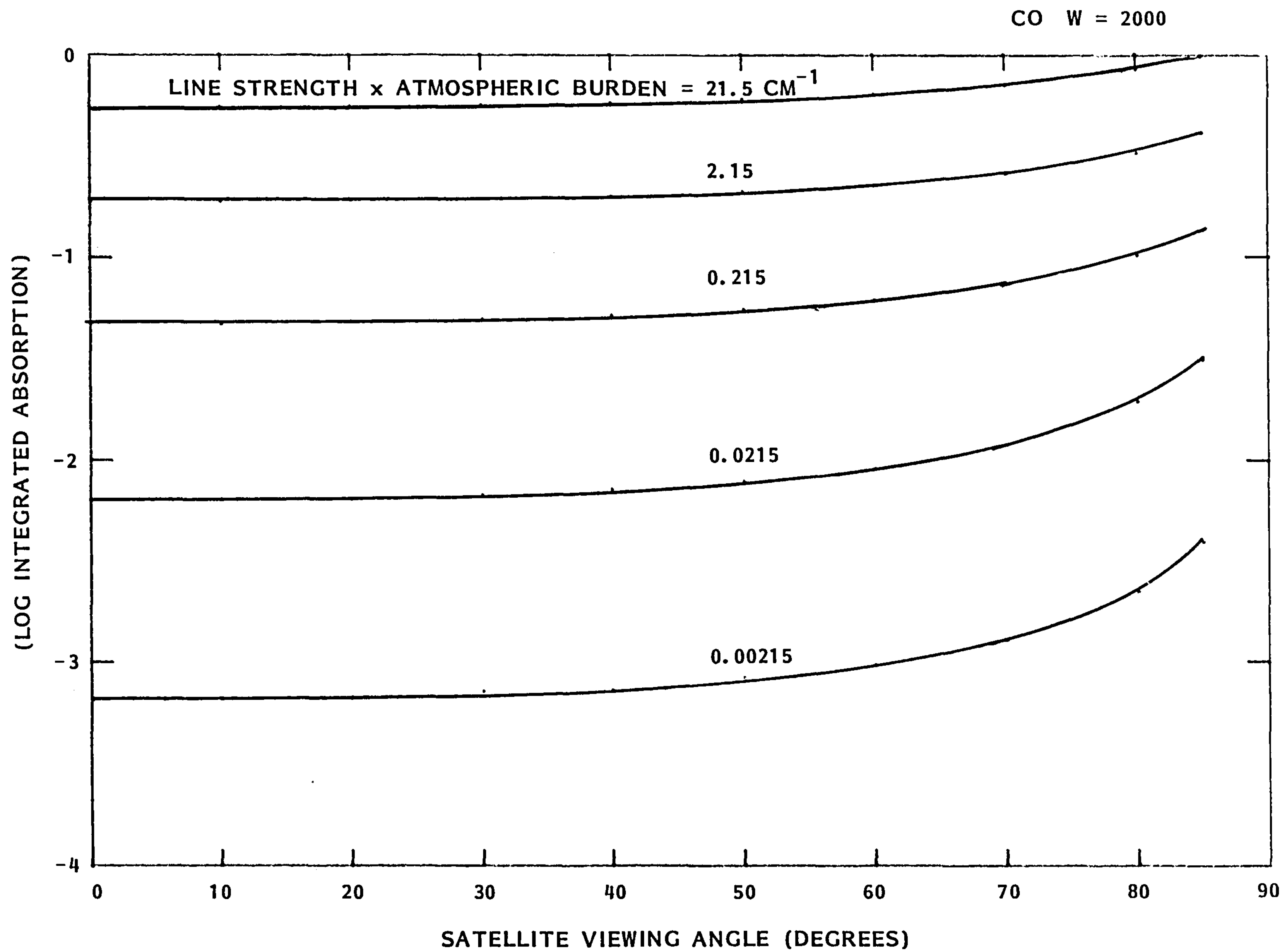


Figure 5.1-5. Integrated Absorption as a Function of Satellite Viewing Angle

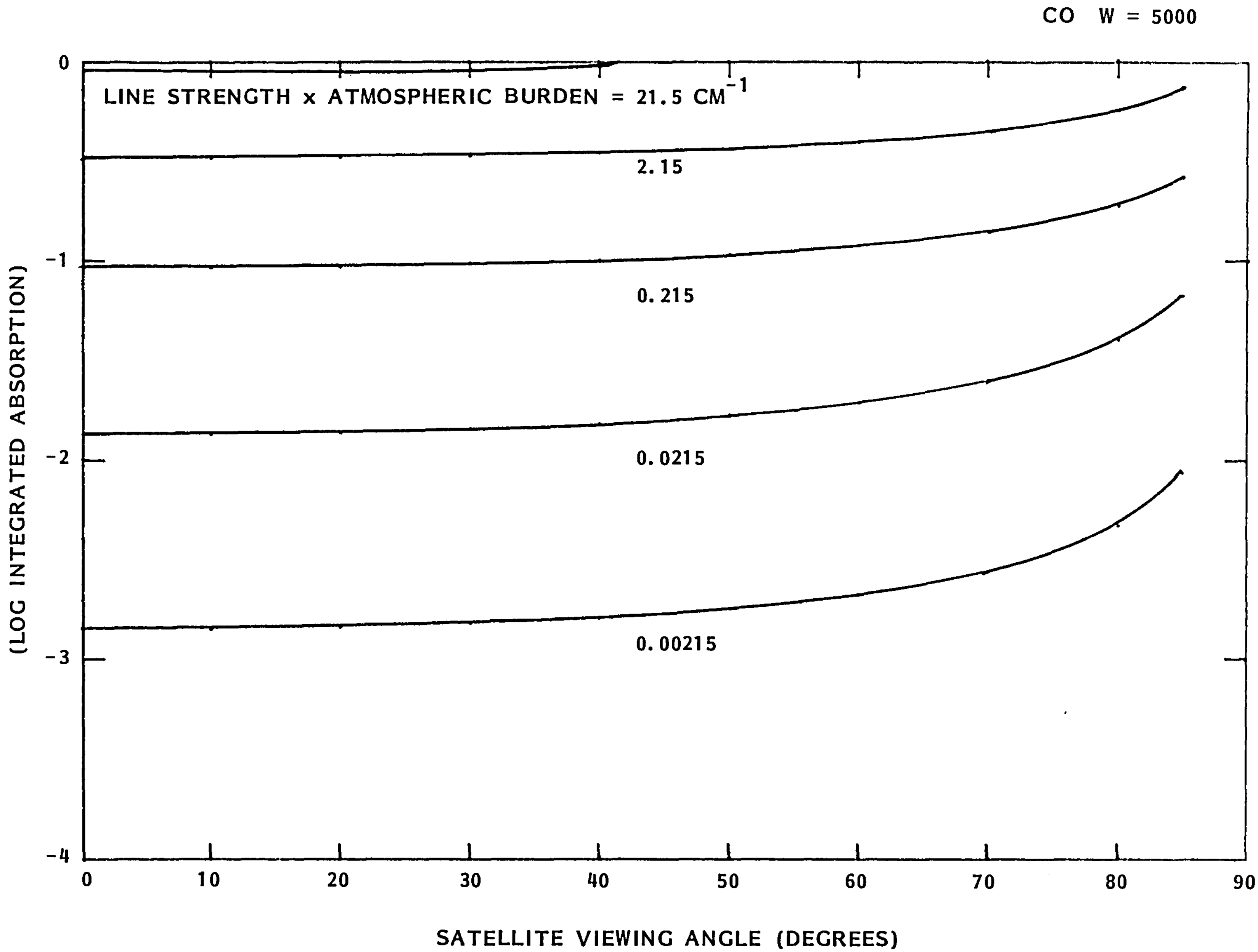


Figure 5.1-6. Integrated Absorption as a Function of Satellite Viewing Angle

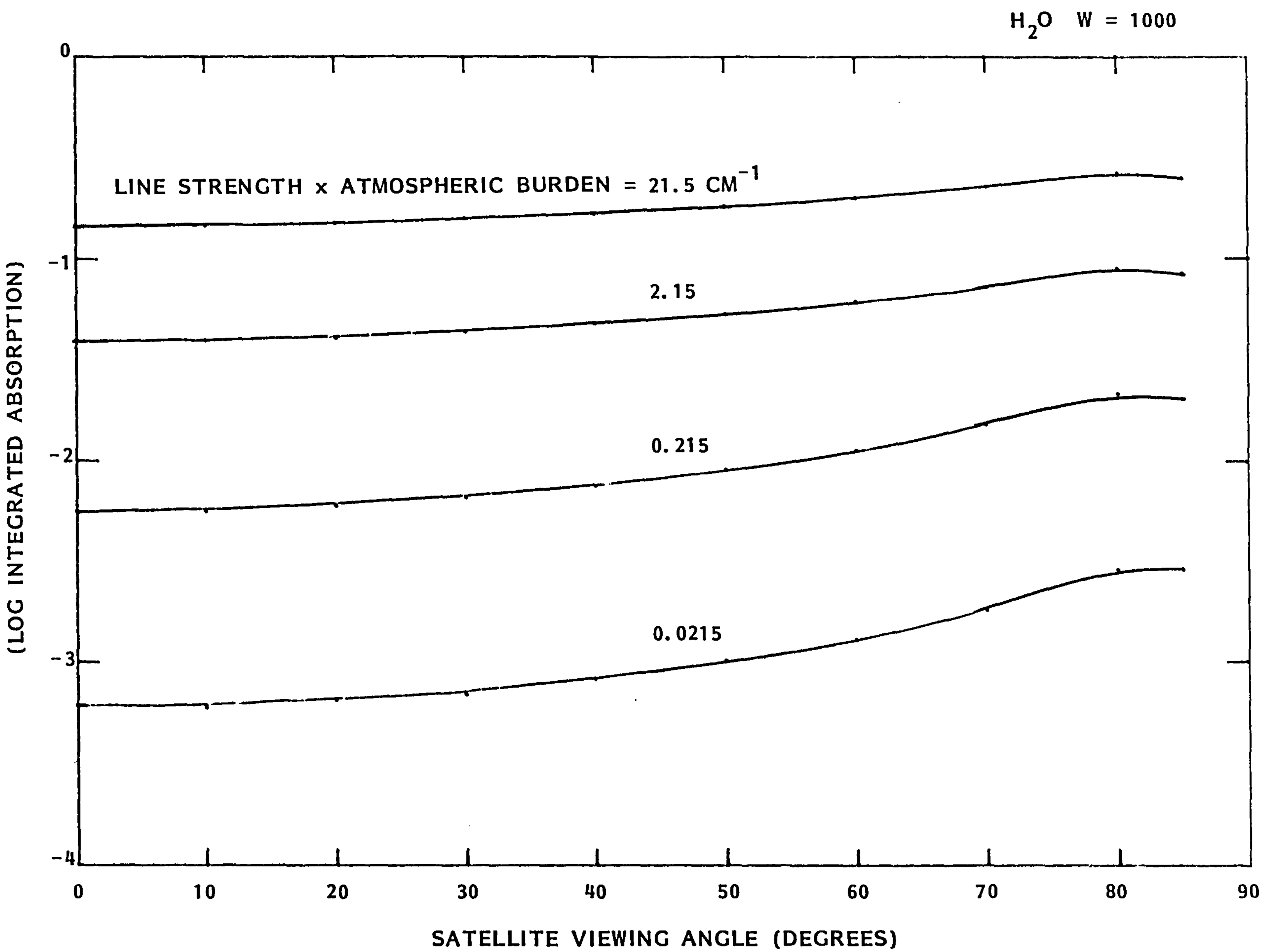


Figure 5.1-7. Integrated Absorption as a Function of Satellite Viewing Angle

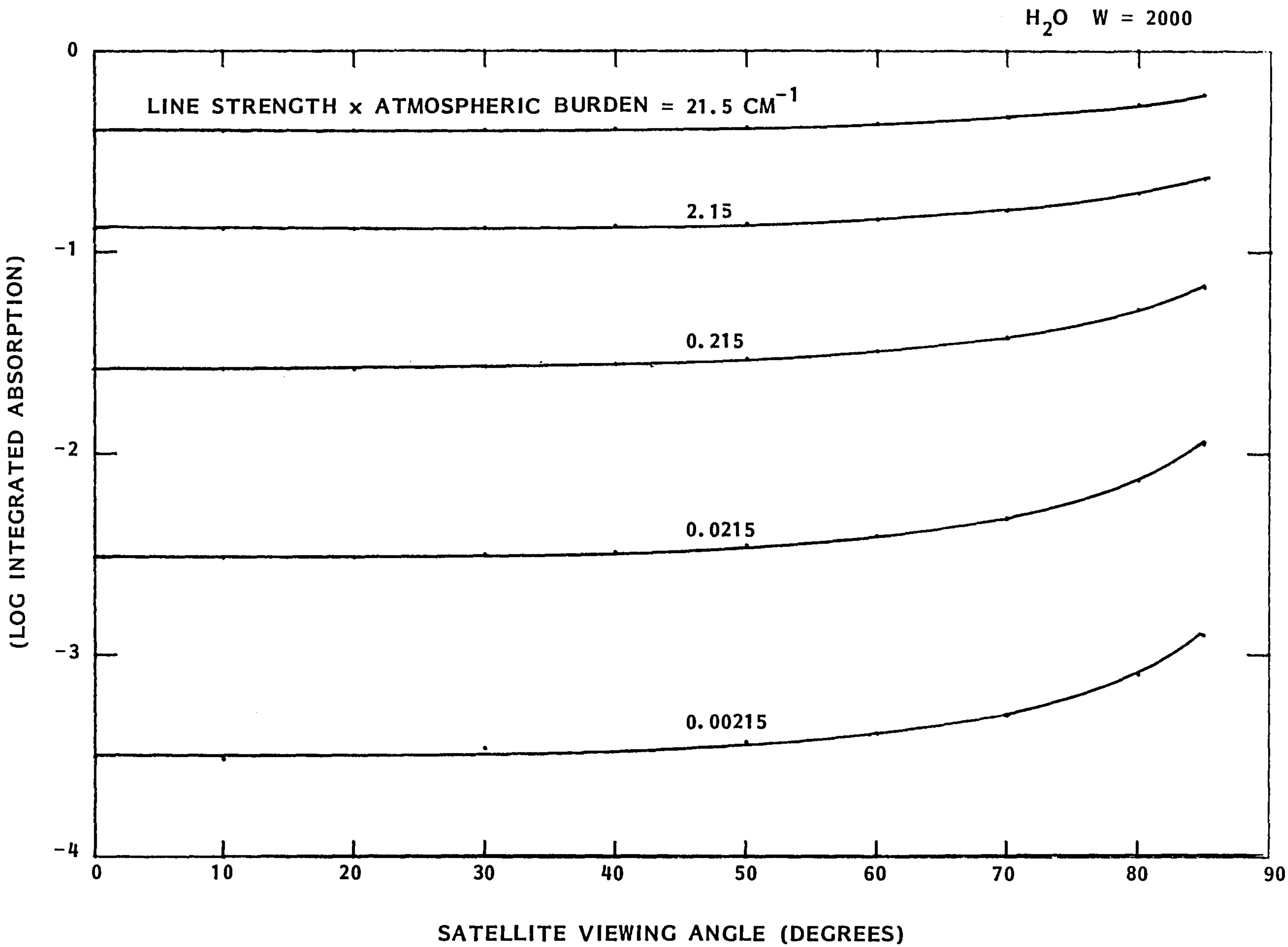


Figure 5.1-8. Integrated Absorption as a Function of Satellite Viewing Angle

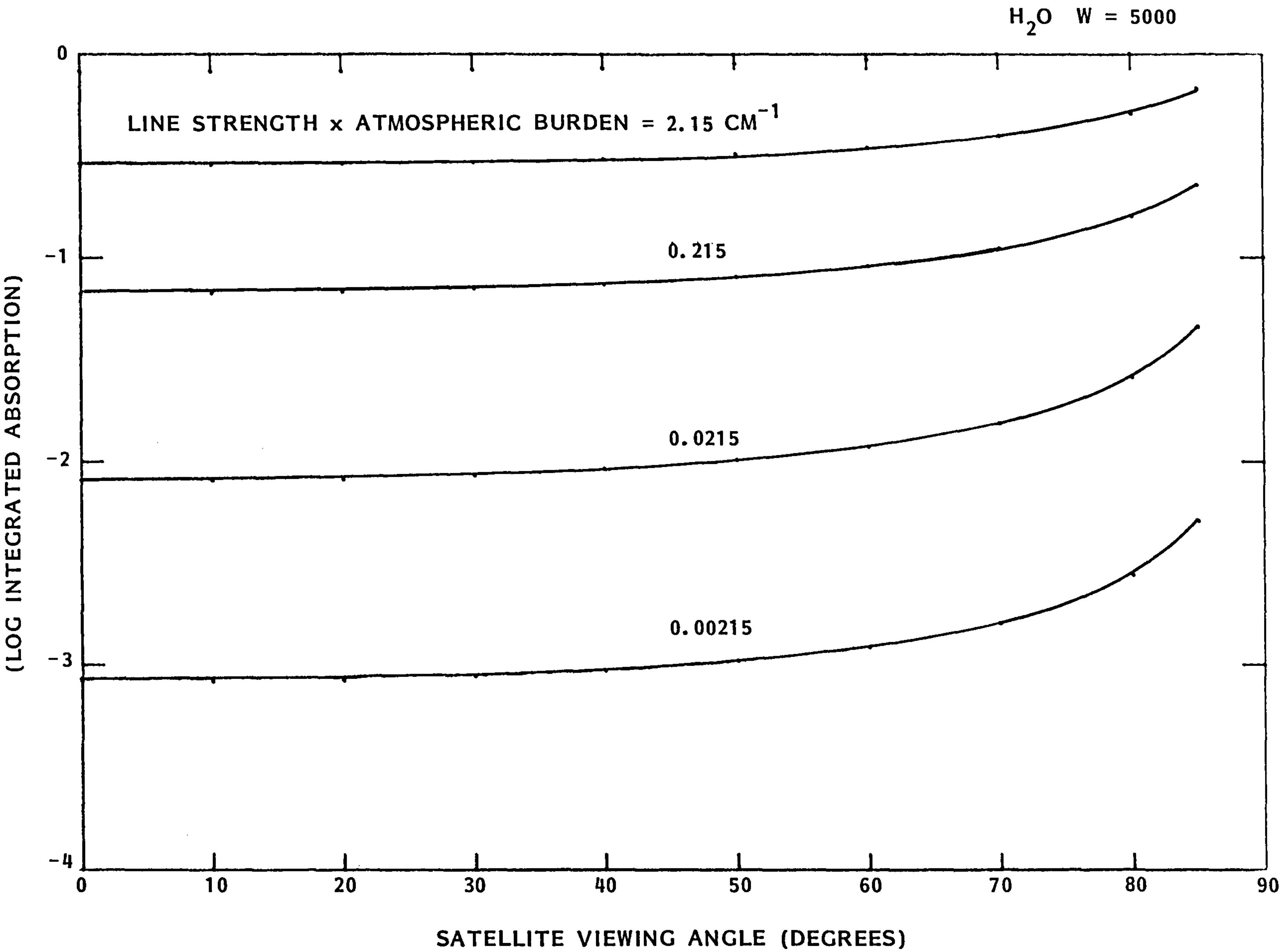


Figure 5.1-9. Integrated Absorption as a Function of Satellite Viewing Angle

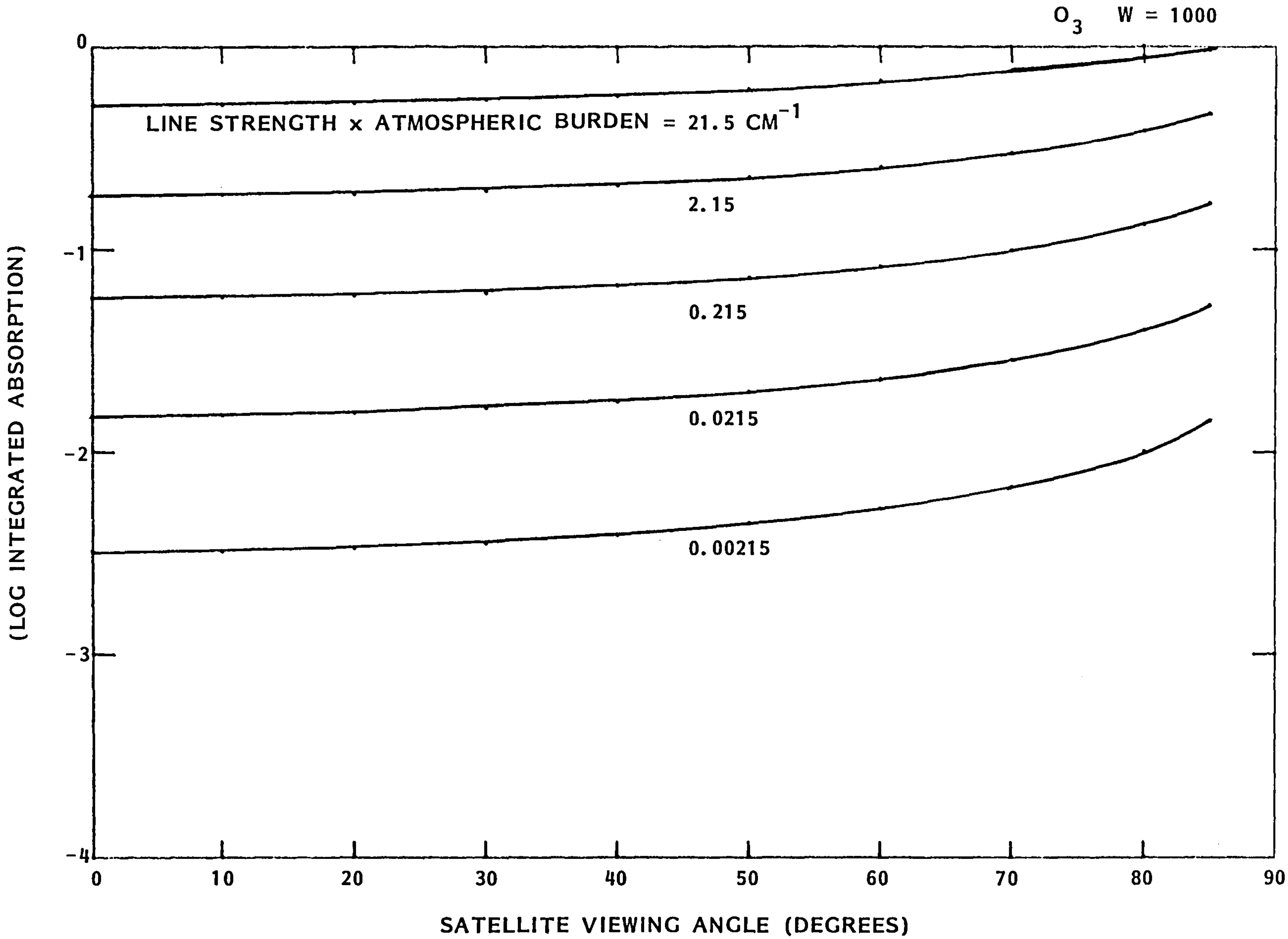


Figure 5.1-10. Integrated Absorption as a Function of Satellite Viewing Angle

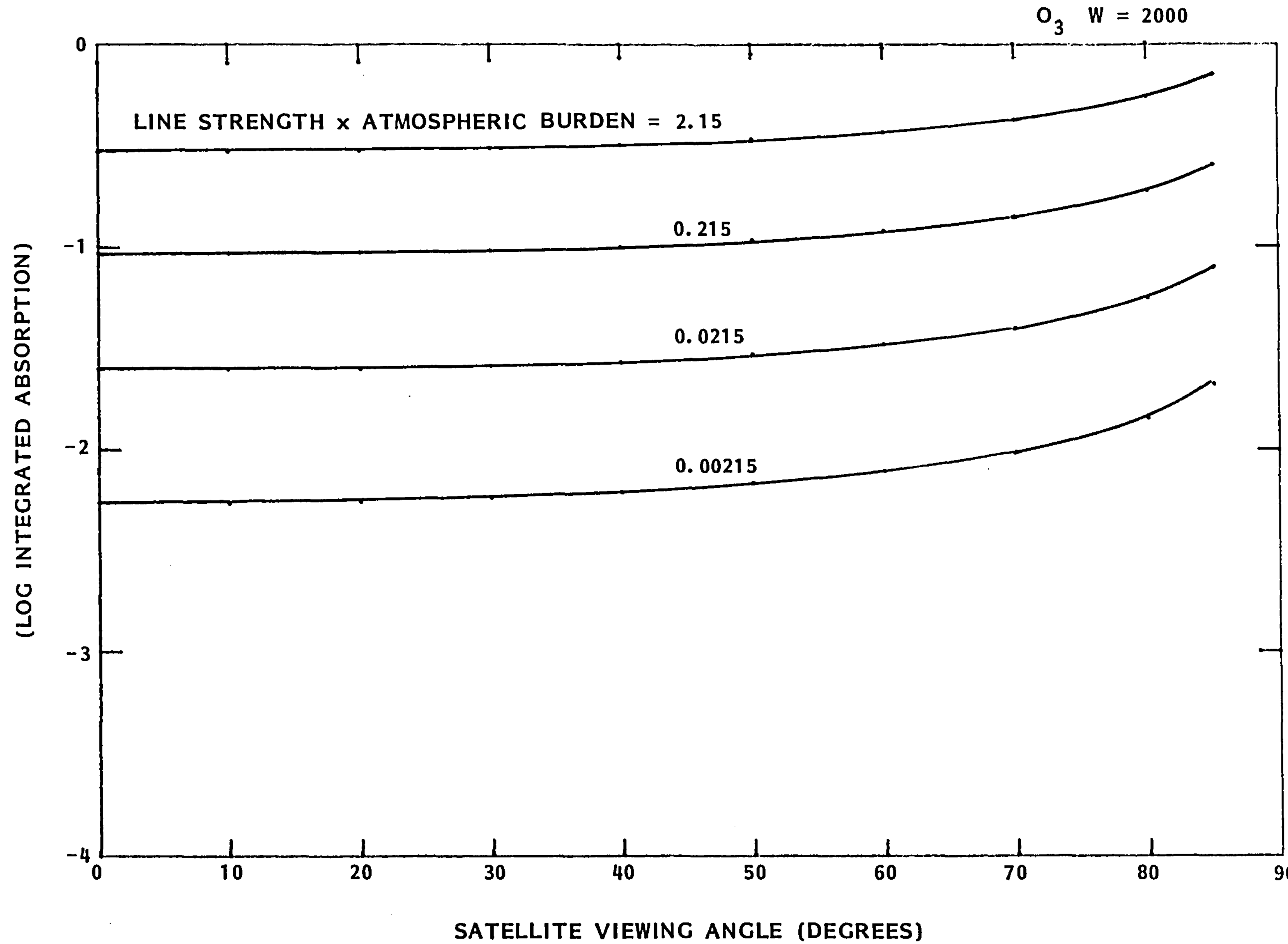


Figure 5.1-11. Integrated Absorption as a Function of Satellite Viewing Angle

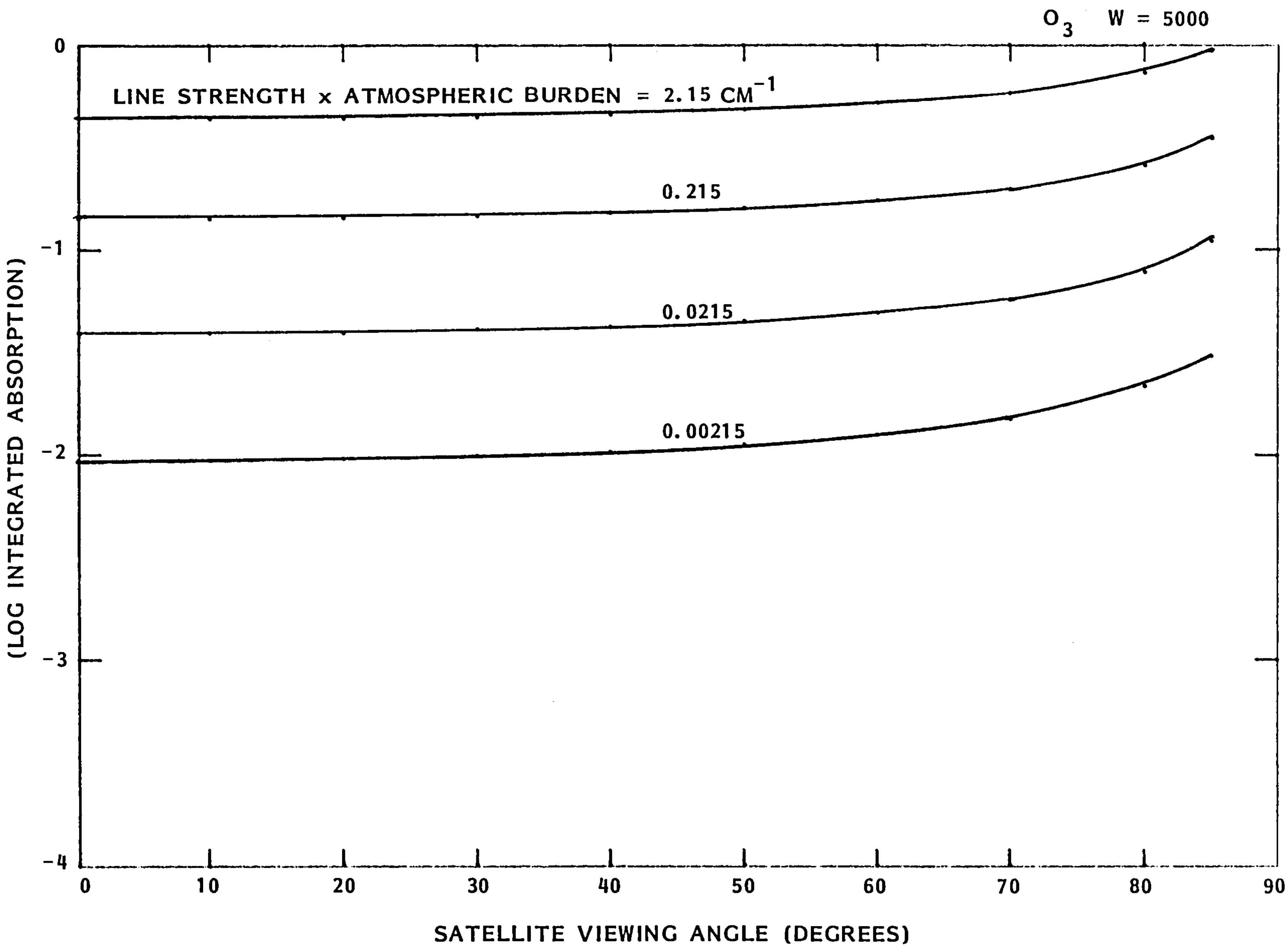


Figure 5.1-12. Integrated Absorption as a Function of Satellite Viewing Angle

The general conclusion to be drawn from the figures is that the effect of satellite viewing angle on reflected or emitted signal is second order for angles below about 70^o. Above 70^o the signal level increases, but the footprint is greatly distorted, as discussed in Section 5.2.3. The effect of cloud obscuration has not been fully analyzed, however, the probability of clouds blocking the signal is greater at large incidence angles.

5.2 SPATIAL RELATIONSHIPS

A parameter of significant importance to the scientific community is the coverage (revisit) frequency and extent of spatial coverage obtainable for specific geographic locations from sensors located on spacecraft at different attitudes. As discussed earlier, higher orbit attitudes can provide greater spatial coverage which, when combined with then inherently longer duration periods, will greatly influence the coverage frequency attainable at various latitude regions. As orbit attitudes are increased, the coverage frequency will naturally decrease at the equatorial and polar regions for purely equatorial and polar orbits, respectively; however, up to certain attitudes the coverage frequency will increase in the intermediate latitude regions for polar and inclined orbits. It will be shown that spacecraft with wide swath width sensors which are placed at intermediate orbit attitudes (from 1500 km to 2500 km) and at high inclination angles, such that pole-to-pole coverage is obtained on a single orbit, will provide maximum average latitudinal coverage frequencies on a global scale.

5.2.1 EQUATORIAL COVERAGE FREQUENCY

An initial investigation was made to evaluate the coverage frequency capability at the equator for wide swath width sensors which, when combined with the orbit inclination angles, in order to provide pole-to-pole coverage. The swath widths under consideration were constrained by the maximum allowable incidence angle between the sensor Line-of-Sight (LOS) and the local vertical at the Earth tangent point. Based on the results of the analysis of optical radiance at various viewing angles, as discussed in Paragraph 5.2 above, the incidence angles selected for this analysis are 50^o, 60^o, 70^o and 90^o. The 50^o to 70^o angles are considered a representative range of practical limits for a push-broom focal plane array sensor, whereas the 90^o angle is applicable for an all azimuth limb sensor. The corresponding minimum orbital inclinations that provide global (pole-to-pole) coverage are 83.6, 81.3 and 77.8 degrees for 50, 60, and 70 degrees incidence angles, from 700 km altitude.

Extent of spatial coverage at the equator is shown in Figure 5.2.1-1 as a function of orbit altitude, for various incidence angle. Expected average daily coverage frequency of longitudinal points located along the equator are indicated by the dashed lines. As an example, for sensors capable of making measurements up to an incidence angle of 70^0, an average coverage frequency of 2 and 4 times per day can be obtained at attitudes of about 700 km and 4000 km, respectively.

It should be pointed out that the average daily coverage frequencies in these analyses do not include the effects of launch direction. The average coverage frequency values are expressed simply as equal to two times the full swath width coverage along the equator divided by the Earth rotation angle during one full orbit period. To correct for launch direction, the average coverage frequency must be multiplied by the factor of 1 plus or minus the cosine of the orbit inclination angle divided by the number of spacecraft orbits per day, with the sign determined by (+) for retrograde orbits and (-) for posigrade orbits. For the example given in the preceding paragraph, the average coverage frequencies based on launch direction would be modified by the multiplication factors of $1\pm.014$ and $1\pm.070$ for the 700 km and 4000 km orbits, respectively. In general, the average coverage frequency values will not be greatly affected by launch direction for the altitudes and inclination angles of the orbits considered as attractive candidates for scientific missions employing wide swath width sensors. An alternative presentation of the data shown in Figure 5.2.1-1 is provided in Figure 5.2.1-2 which, for simplicity purposes, excludes the longitudinal coverage angle at the equator. The sensitivity of the daily coverage frequency to incidence angle and altitude is evident from the curve data in Figure 5.2.1-2 which favors higher altitude regimes; however, final attitude selection should be based on coverage frequencies over the primary latitude regions of interest to the science community. Coverage frequency performance over all latitude regions is provided in the following discussion.

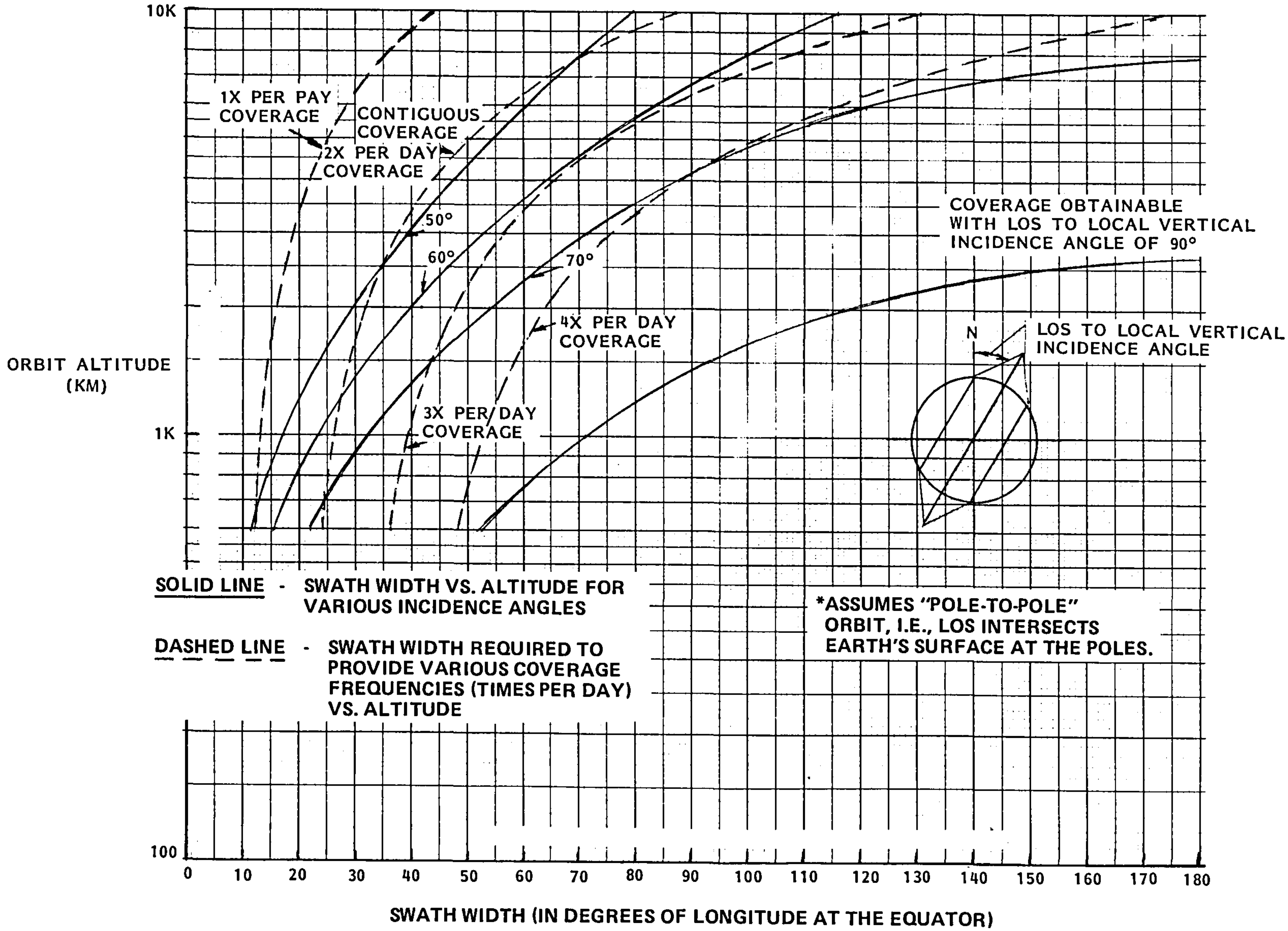


Figure 5.2.1-1. Equatorial Spatial Coverage* for Various Incidence Angles

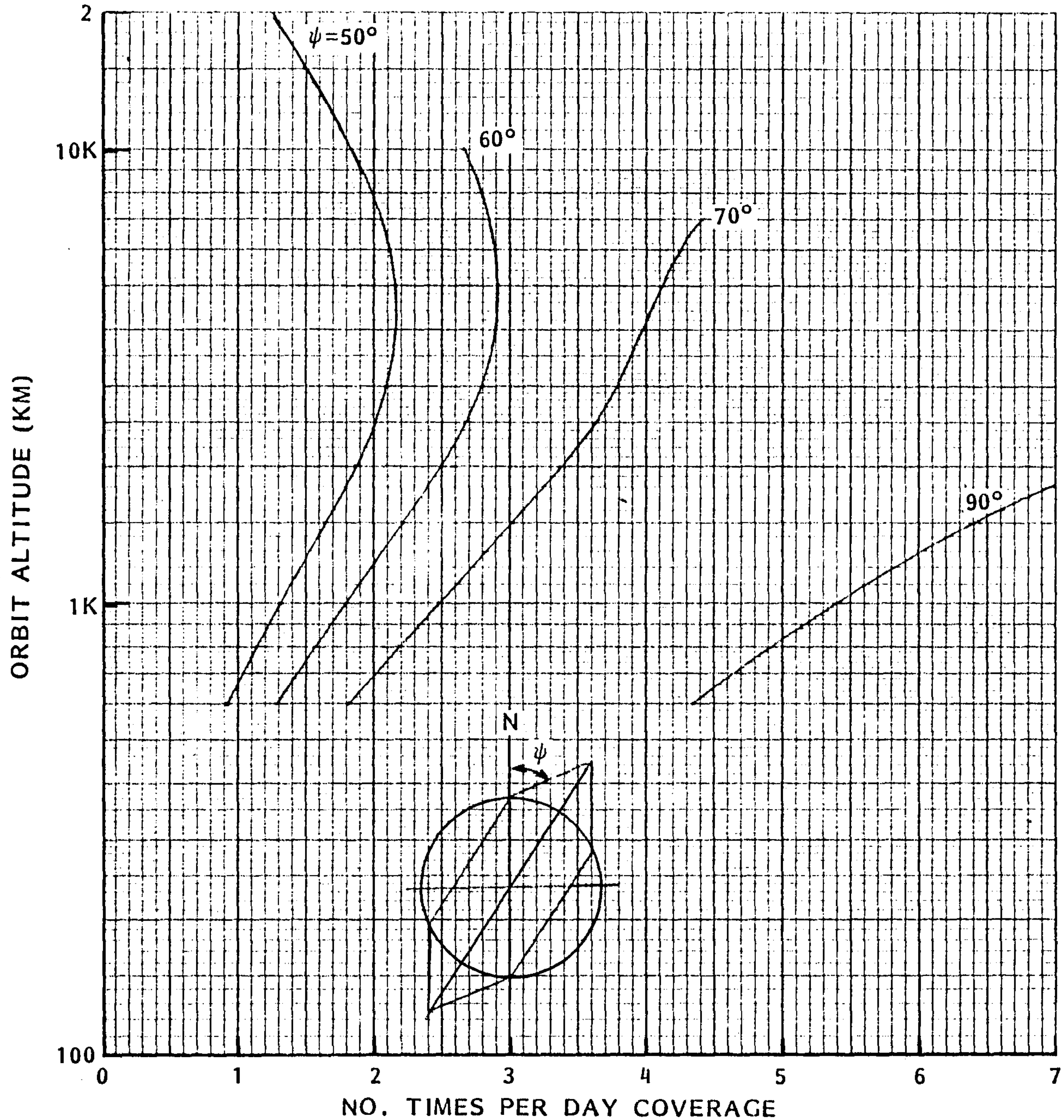


Figure 5.2.1-2. Coverage Frequency (At the Equator)

GLOBAL COVERAGE FREQUENCY

Coverage frequency data was developed for all latitudes between the equator and the pole for selected altitudes and orbit inclination angles. The data was analyzed primarily for the 70^{o} incidence angle (55^{o} orbital inclination at 700 km altitude) conditions; however, some additional data at other incidence angles was investigated for comparative purposes. Altitudes selected to examine the variations in coverage frequency over latitude regions between the equator and the poles include 700 km, 1500 km, 2500 km, 5000 km, and 10,000 km. The four primary inclination angle conditions which were selected at each orbit altitude were 0^{o}, 45^{o}, 60^{o} and 90^{o}. Similar coverage frequencies were analyzed for altitudes of 1500 km, 2500 km, and 5000 km. Coverage frequencies versus latitudes from 0 to 90 degrees at various altitudes (700-10,000 km) is shown in Figure 5.2.1-3. This is a valuable plot for selecting orbits for global coverage. For instance, with respect to those measurements in AOS requiring coverage from four to six times per day, the 2500 and 5000 km orbits look attractive to provide "pole to pole" coverage.

5.2.2 DIURNAL COVERAGE

Upper atmospheric parameters are often susceptible to the solar incidence angle or local time at the time of measurement, for the particular season of the year. Gathering the data at the same time of the day for all measurements would not be adequate since they would not factor in the effects of this "diurnal" variability. In proposed satellites such as UARS (Upper Atmospheric Research Satillite), the specified orbits insure a suitable period of less than N days elapses for a complete diurnal cycle. Our analysis examines diurnal coverage not only at the equator but also at the various latitudes. In Figure 5.2.2-1, coverage contours are provided as a function of local time and applicable latitudes encompassed by several sensor swath widths, as determined from their Line-of-Sight (LOS) to the local vertical incidence angle. Since these orbits are based on pole-to-pole coverage, 12 hours in the polar regions are inherently covered by the sensor LOS's. As swath widths increase (by going to higher incidence angles) more local hours are acquired within the lower latitude regions. Increased swath widths have a twofold effect, i.e., they reduce the number of remaining local time hours which need to be accumulated for full durinal coverage at the equator and, their corresponding lower orbit inclination angles reduce the number of days

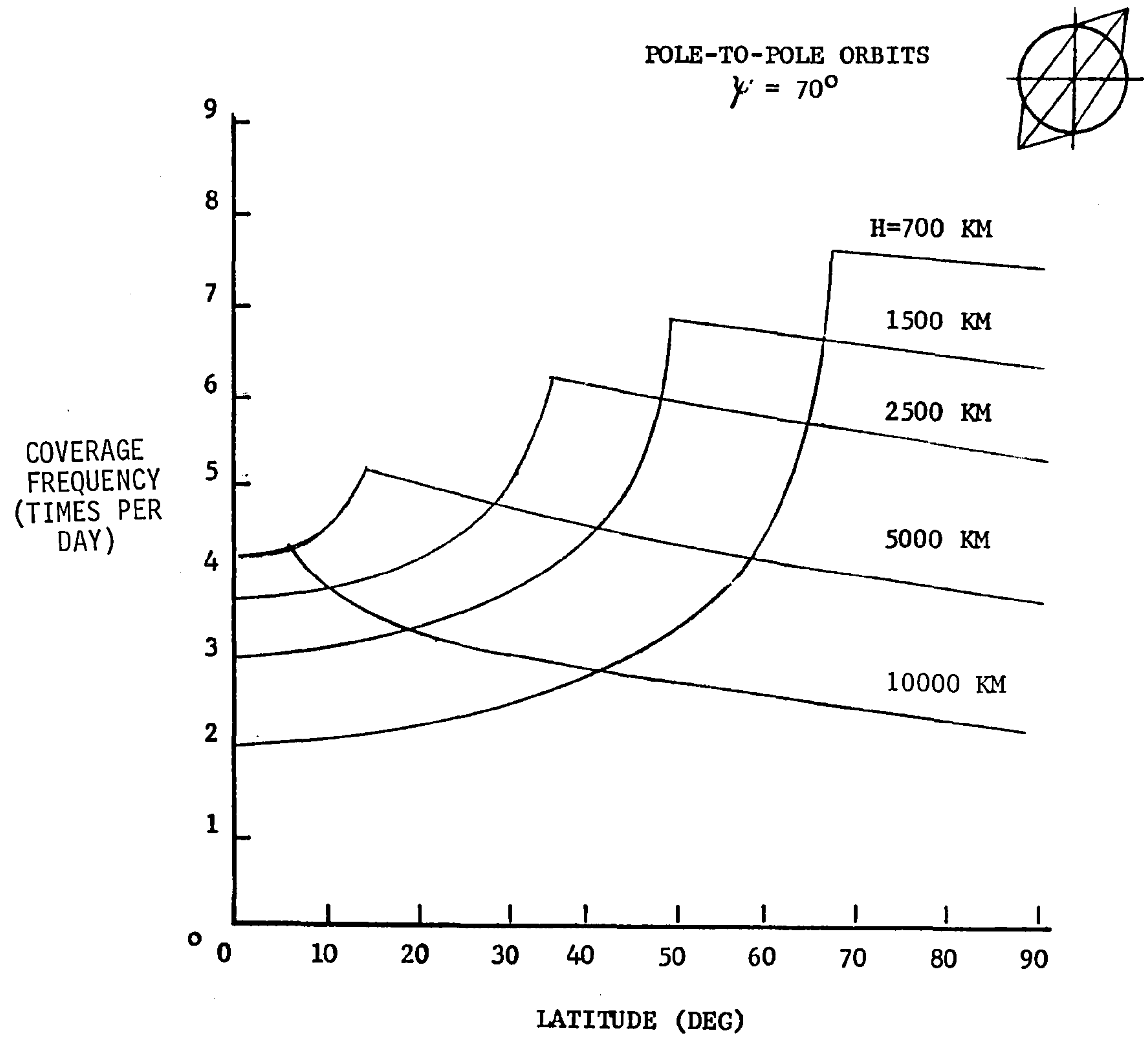


Figure 5.2.1-3. Comparison of Coverage Frequencies for Various Altitudes

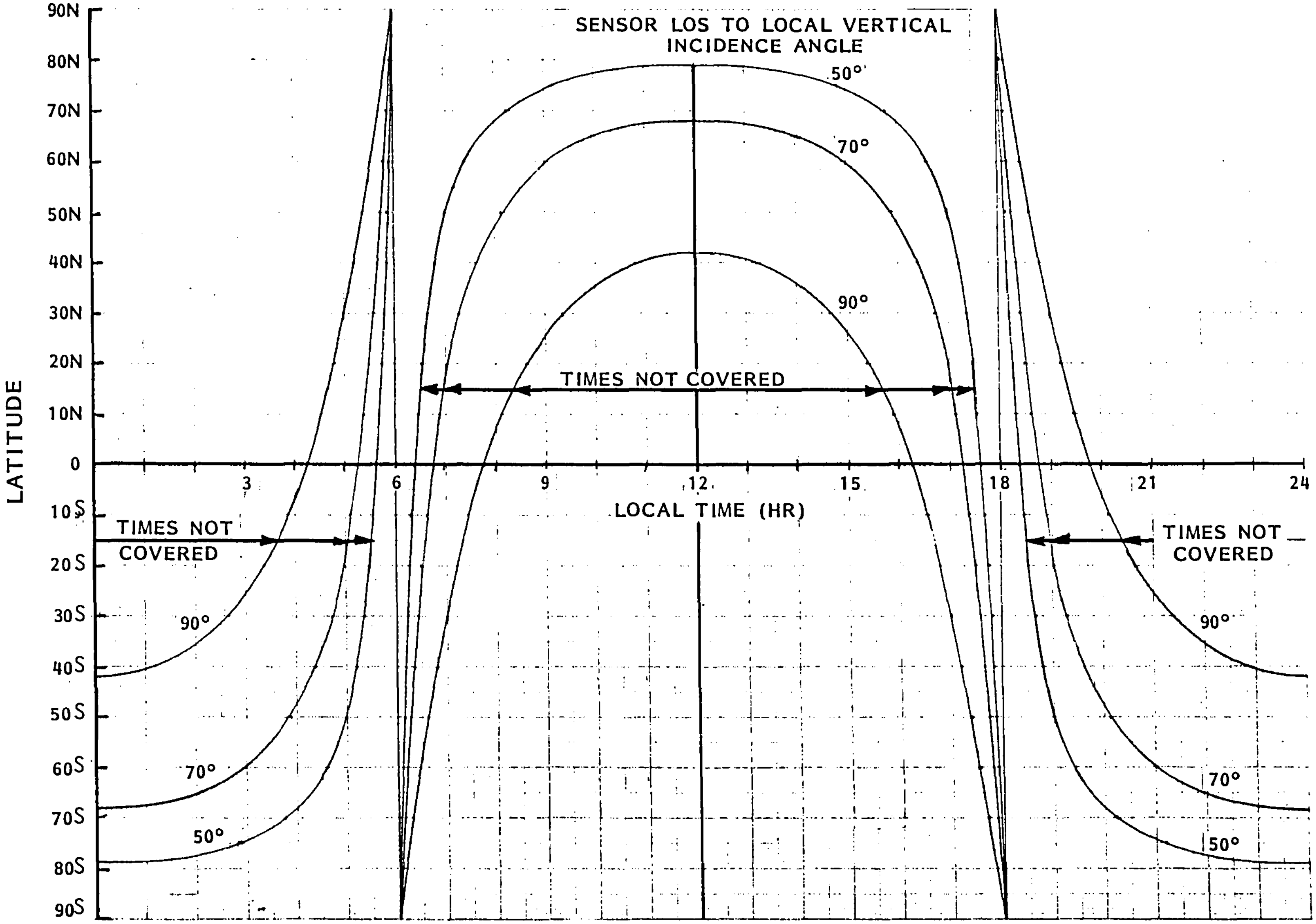


Figure 5.2.2-1. Off-Nadir Sensor Local Time Coverage (H = 600 KM)

required to complete coverage at the polar regions due to their higher precision rate orbits.

Figure 5.2.2-2 provides data relative to the number of days required to complete durinal coverage at the equatorial and polar regions. The impact of reduced incidence angles on the duration for complete diurnal coverage is evident from the data within this figure. As the data indicates, polar region coverage is best obtained with relatively low orbits (800 to 1500 km), whereas equatorial region coverage is satisfied best at higher orbits ($\geqslant$2500 km).

Figure 5.2.2-3 for an orbit altitude of 600 km, provides data relative to the impact of lower inclinations and resulting loss of polar coverage on the days required to complete diurnal coverage. The data is based primarily on a LOS to local vertical incidence angle of 70^0, and shows that significant reduction can be obtained in the number of days to complete diurnal coverage at the lower latitudes if a non-coverage region at the pole can be tolerated. Included in the figure is data (dashed lines) corresponding to a limb sensor ($\psi=90^0$) which can view the poles and an off-nadir sensor ($\psi=70^0$) with the same orbit inclination angle for this case. The polar region not covered by the off-nadir sensor can be acquired with the limb sensor.

The data in Figure 5.2.2-4, for an orbit altitude of 2500 km, is very similar to that provided in the figure for an orbit altitude of 600 km. The primary differences in diurnal coverage capability between the two altitudes are that a shorter duration to complete diurnal coverage is obtained at the lower latitudes for the 2500 km orbit; however, at the expense of longer durations at the higher latitude regions. The crossover latitude points occur at about 40^0 with the limb sensor ($\psi=90^0$), and at about 20^0 for the off-nadir sensor ($\psi=70^0$) with the same orbit inclination angle

A generalized plot has been included (Figure 5.2.2-5) that establishes the type of diurnal coverage afforded by any combination of altitudes and inclinations.

5.2.3 EFFECT OF INCIDENCE ANGLE ON THE SHAPE OF THE VOLUMETRIC RESOLUTION ELEMENT

Surface data measured at incidence angles that are off-nadir will not have the same shape of footprint as those obtained at nadir. This distortion applies

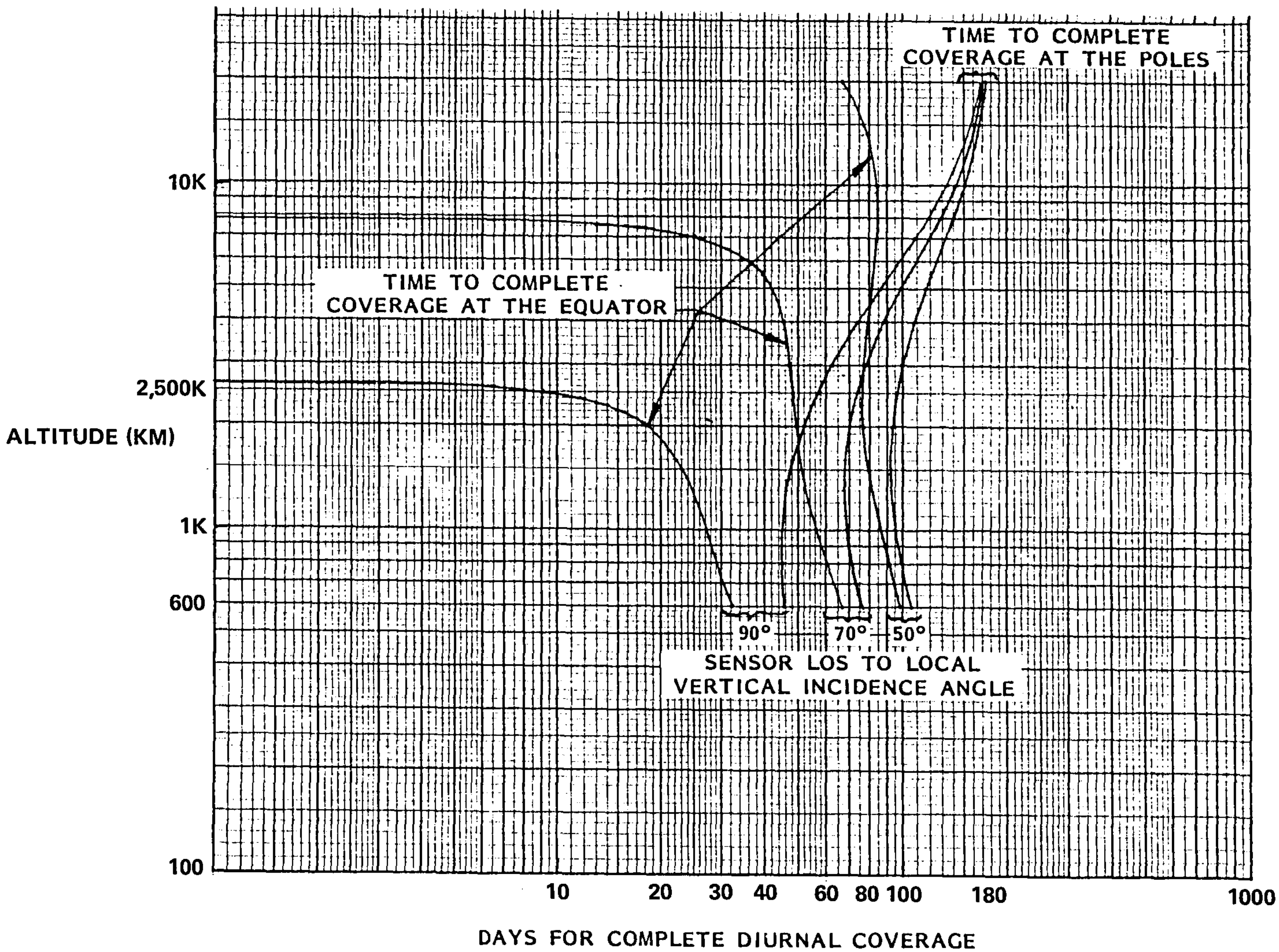


Figure 5.2.2-2. Time Required for Complete Diurnal Coverage

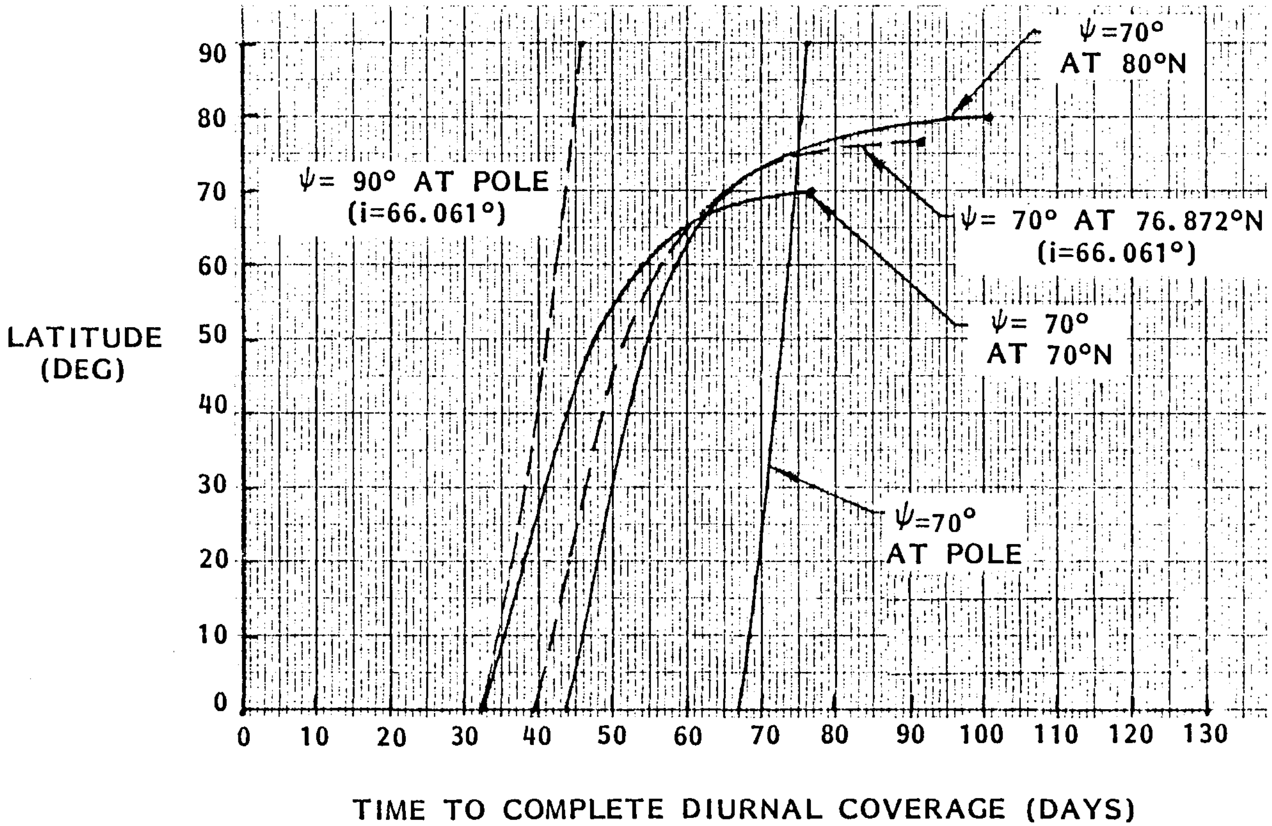


Figure 5.2.2-3. Latitudinal Diurnal Coverage Capability
(600 Km Orbital Altitude)

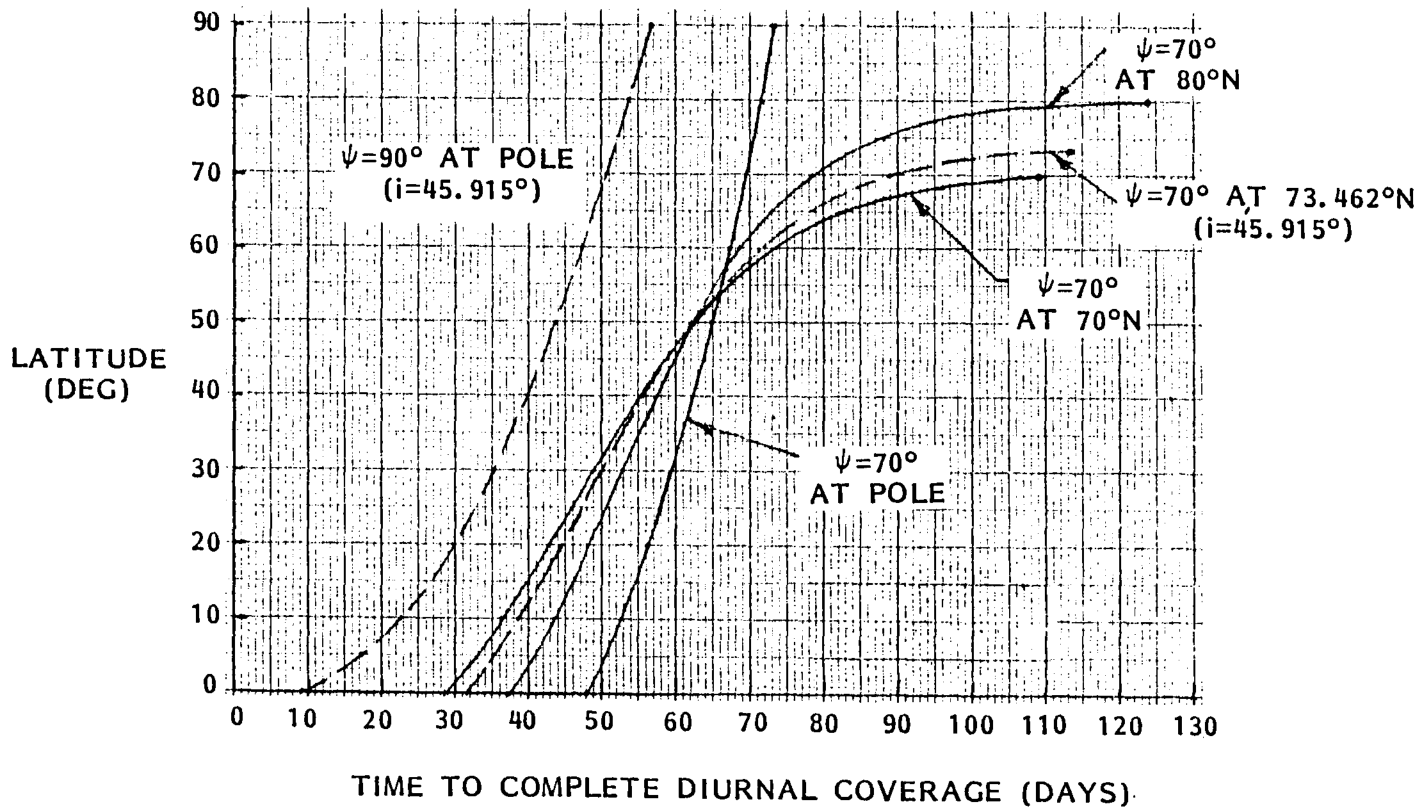


Figure 5.2.2-4. Latitudinal Diurnal Coverage Capability
(2500 Km Orbital Altitude)

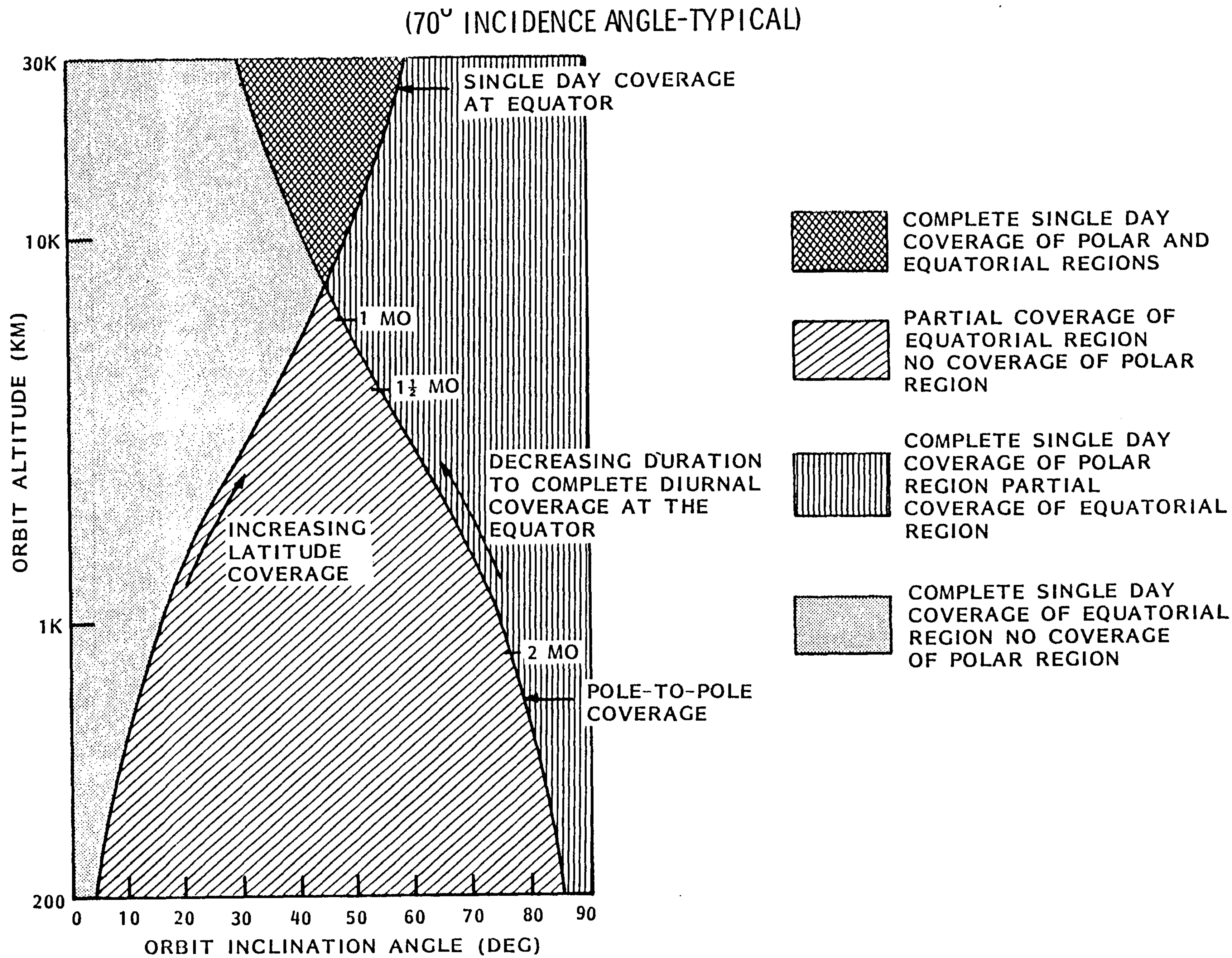


Figure 5.2.2-5. Off-Nadir Diurnal Coverage Orbits

to any atmospheric layer, as well as the earth's surface. In addition, the local vertical through the center of any volumetric resolution element will be displaced from other local verticals on the same off-nadir line of sight.

Figure 5.2.3-1 shows these two spatial distortions that take place in off-nadir observations of the atmosphere: (1) enlargement of the volumetric element at each atmospheric layer, and (2) displacement of the center of each volumetric element in the atmosphere at different altitudes.

The plot on the left quantifies the enlargement of the footprint in terms of the ratio (L/d) which shows how much larger the footprint is at a given incidence angle as compared with its size at nadir. Up to around 50^{o} the effect is small, and beyond the knee of the curve at 70^{0} it takes off rapidly.

The curve on the right shows the relationship between displacement (as a function of the altitude difference (H) between the atmospheric layers being measured, and incidence angle. This type of displacement must be corrected for during data processing, so that the atmospheric profile data can be presented along the Earth's radii. One reason for avoiding very large incidence angles (say around 80^{0}) is the error in registration of resolution elements, due to the uncertainty in attitude knowledge.

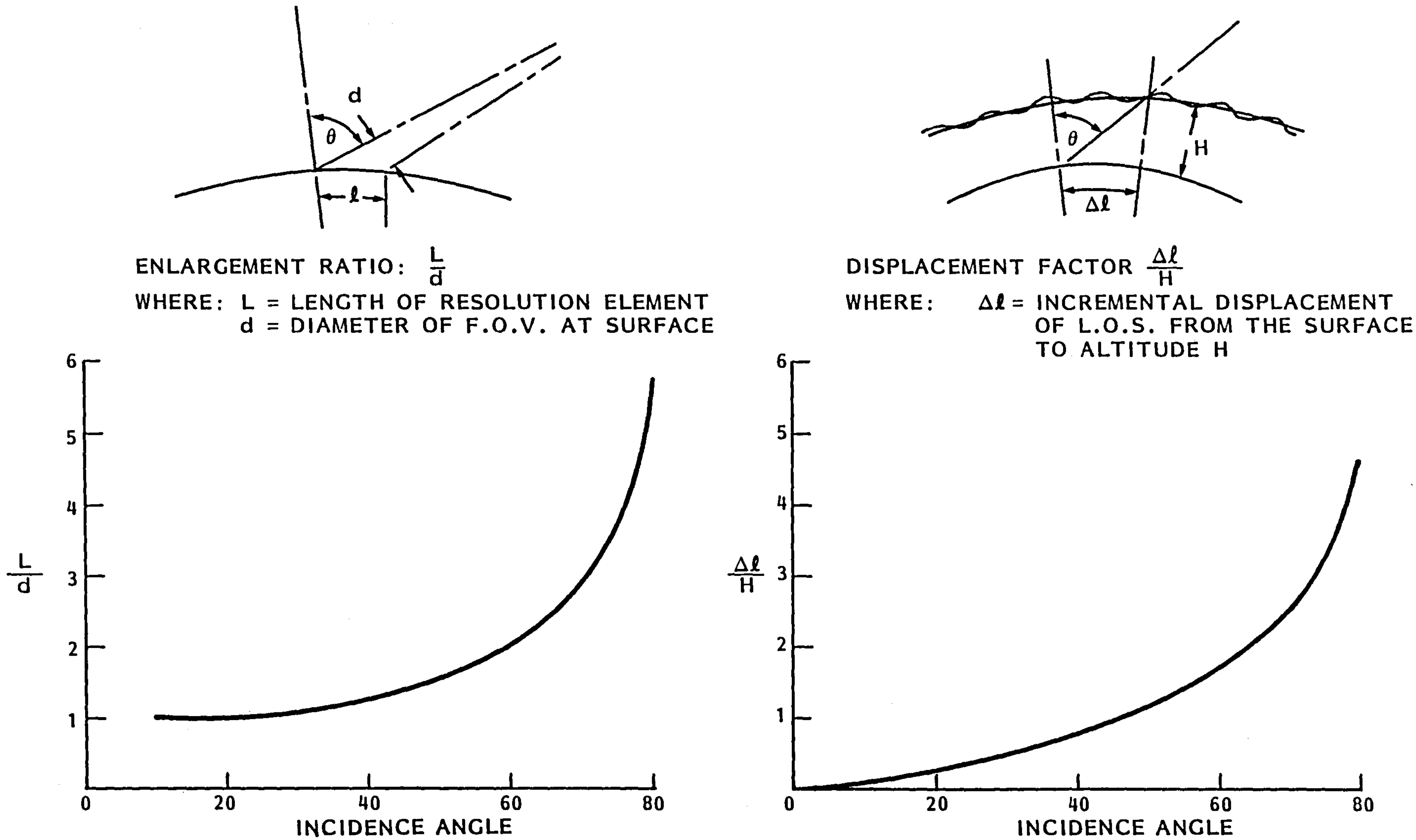


Figure 5.2.3-1. Effect of Incidence Angle on Horizontal Resolution and Ground Projection of Resolution Elements

SECTION 6
PROJECTED MISSIONS

The multidisciplinary nature of the AOS mission implies that as many of the measurements as possible are to be made by each mission. (Within the context of this study, a mission is defined as a single flight operation of a multi-year duration orbital system with a full complement of sensors.) It is also assumed that many measurements would be performed simultaneously or concurrently, rather than subdividing the mission into many investigational phases running serially. However, all the measurements cannot be performed in a single flight mission, due to the following constraints:

1. Spatial-temporal coverage requirements driving towards more than a single orbit.
2. Technological limitations which tend to spread the needed capability over a period of time. These limitations suggest a series of missions which use increasing levels of technology.

Synergism

Consideration was given to the synergistic benefits of simultaneous measurements from the same spacecraft. In the measurements discussed in Section 3, there are a number of examples of synergism. The following paragraphs describe some of the salient examples.

The measurement of cloud-top height and the simultaneous measurement of total burden (in nadir mode) of gaseous species provide data on vertical distribution of the gaseous species.

Two simultaneous measurements which are both affected by a gaseous species, may permit the accurate determination of that species by one of the measurements so that its effect on the other measurement may be cancelled through subtraction, during the data interpretation phase.

The simultaneous measurement of two gaseous species whose concentrations are interrelated may permit a more accurate analysis of the atmospheric chemistry of these species than that obtained by individual measurements, or measurements at different times. Examples of this are O_3 and NO, CO and OH, of N_2O and O('D). This is not necessarily limited to gaseous species. Aerosols would fit in some examples as would various meteorological parameters. The simultaneous measurement of aerosols and certain gaseous species, such as sulfur-containing compounds, HNO_3 or other nitrogen-containing compounds, would contribute more to understanding the aerosol formation and growth processes than would individual measurements. Along with those measurements, the measurement of rainfall characteristics would provide data for the understanding of acid rain.

The measurement of the same gaseous species in both limb and nadir modes, such that the data obtained are at least centered over the same area, and are collected within the same or successive orbital passes, could give some insight into three-dimensional distribution.

Certain data which are suggested as needs for the air quality modeling and understanding, would be helpful to meteorological models. Future meteorological models may include ozone data which could be provided by suggested measurements. Surface aerosol data will be useful to the meteorologist. Some of the suggested meteorological parameters (i.e., winds, temperature profiles) would provide complementary data under conditions not now available from operational meteorological satellites.

Operational Use

Consideration in the mission analysis was given to the operational vs. developmental use of data. Developmental use aims to satisfy knowledge objectives stated in Section 3.1, wheras operational use supports decision-making functions.

Most of the data obtained would be used in a developmental manner. That is, it would be used to further understand the interactions which take place in the atmosphere, to heat and improve the models of the atmosphere and to establish a data bank of atmospheric parameters. However, some of the data may be useful in a more direct way in an operational system. Such applicable measurements would not, in general, be predictable but the system could provide for direct communication of the data to the appropriate operating system. Examples of this might be:

1. The detection of an unexpected source of pollutant material, together with the appropriate meteorological data to predict its movement.

2. Detection of pollution episodes prior to their discovery by other existing systems of detection.

3. Use of meteorological data in prediction codes. Possible use of ozone data in meteorological prediction codes.

4. Detection and prediction of acid rain.

List of Missions

Four missions were synthesized as a hypothetical model that would serve as a basis for the technology assessment. The missions are as follows:

Mission		Approximate Timeframe
#1	L.E.O. Mission using Passive Sensors	1990
#2	Geosynchronous Mission using Passive Sensors	1992
#3	L.E.O. Mission using Active (LIDAR) and Passive Optical Sensors	1994
Alternate:		
#4	Intermediate Altitude Orbit Mission using Passive Optical and Microwave Sensors	1990-1992

Mission No. 1 constitutes the earliest full-up mission that is projected for the next decade. Its constraints are mainly technological, since it will be limited to passive sensors. Mission No. 3 might be a mid-1990's mission employing the active sensors which will make better vertical resolution possible in some of the trace gas concentration measurements.

Mission No. 2 concentrates on dynamic atmospheric measurements requiring high frequency of observation. This mission uses a geosynchronous orbit, which permits continuous observations of large portions of the earth's atmosphere. Its vantage point at the geosynchronous orbit is highly advantageous for meteorological observations, as well as concentration measurements of fast-reacting gases; however, it was the disadvantage that the orbit is not suitable for limb measurements over large areas which constitute the major source of data for upper atmospheric measurement using passive sensors.

An alternate mission to Mission No. 1 or 2 is the 2500 km altitude mission designated as No. 4. This flight would be very similar to No. 1, but requires an intermediate altitude orbit to permit better spatial and diurnal coverage as determined from the analysis described in Section 5.2. Mission #2 provides excellent repeat coverage for a large portion of the earth but requires approximately 90 days for complete global coverage, while Mission 4 provides approximately four measurements per day, globally.

The following are the summary specifications for the four missions.

6.1 MISSION SPECIFICATION - MISSION NO. 1

Mission Name: Low Earth Orbit Mission with Passive Sensors

Mission Objectives: The objective of this mission relate to the acquisition of knowledge in the following areas (Reference Section 3.1):

1. Effects of pollutants on atmospheric radiative transfer.
2. Atmospheric sulfur pollution.
3. Atmospheric carbon pollution.
4. Global distribution of ozone.
5. Effect of aircraft activity on the atmosphere.
6. Effect of Chlorofluoromethanes (CMF's) on the atmosphere.
7. Effect of N_2O on the atmosphere.
8. Surface - atmosphere interaction.
9. Properties and role of aerosols.
10. Meterological effects on atmosphere.
11. Effects of natural and man made disturbances.

Payload Characteristics

Payload Pointing Accuracy

Limb measurements are the driving requirements for payload and spacecraft pointing, although the limb sensors provide internal attitude control for the pointing mirror in order to attain the desired vertical resolution of 1 km. The payload should provide pointing, as referenced at the payload/spacecraft interface plane, of 0.04 degree (assuming fine pointing by the sensor internal mirror).

Payload Power

Assuming a continuous duty cycle for all sensors, the payload power will be 1500 watts.

Mission Sensors

The sensors and their preliminary specifications are shown on Table 6.1-1.

Mission Timeframe

The mission addresses the objectives within the technology capabilities of passive sensors, which corresponds to the timeframe of approximately 1989-1992.

Orbit

The mission requires a free-flying satellite:

Altitude:	700 km
Inclination:	64 degrees

Mission Duration: 3 - 5 years without maintenance in orbit.

Measurement Capabilities/Limitations

Following is a realistic estimate of the capability of the Mission No. 1 payload to perform the measurements as defined in Section 3.2. This estimate considers the impact of the technology advancements in sensors, but recognizes the physical limitations inherent in the sum of the measurements.

For example, the vertical resolution and, in some cases, the accuracy of gas concentration profile measurements is limited when using passive sensors as compared to active optical sensors. Concerning the tropospheric sensors which use ground radiance and operate in the "nadir/off-nadir" mode, the horizontal resolutions ranging from 5 km to 200 km can be met, even at the high incidence angles of 60^{o} - 70^{o} utilized in those measurements. However, we will depend on limb sensors for providing the vertical resolution in the stratosphere and upper troposphere, since it is unlikely that nadir-looking sensors will be able to attain the required 1 km vertical resolution in most of the troposphere. Most of the nadir-looking measurements will provide total burdens for the trace gases of interest, or possibly 4 to 7 km resolution in the troposphere and upper atmosphere.

Table 6.1-1. Sensor Characteristics - Multidisciplinary AOS Mission 1 (H = 700KM)

SENSOR	VIEWING MODE	TOTAL F.O.V. (DEGREES)	I.F.O.V. (DEGREES)	SWATH WIDTH (KM)	HORIZONTAL RESOLUTION (KM X KM)	VERTICAL RESOLUTION (KM)	TYPE OF DETECTOR	NO. OF CHANNELS	DYNAMIC RANGE (MOLECULES CC)	RADIOMETRIC ACCURACY %	PRECISION %
UV/VIS SPECTROMETER	L	1.9(elev.) 360 (Azim.)	0.019 (0-15 KM) 0.06 (15-100 KM)	5760	500 x 500	1 (0-15KM) 3 (15-100KM)	ARRAYS	24	10^4	3-5	2.5
CRYO. IR RADIOMETER/ SPECTROMETER	L	1.9(elev.) 360 (Azim.)	0.019 (0-15 KM) 0.05 (15-100 KM)	5760	500 x 500	1 (0-15 KM) 3 (15-100 KM)	ARRAYS	32	10^4	3-5	2.5
PRESSURE MODULATED RADIOMETER (PMR)	L	1.9(elev.) 360(Azim.)	0.015 (0-15 KM) 0.05 (15-100 KM)	5760	500 x 500	1 (0-15 KM) 3 (15-100 KM)	ARRAYS	5	10^4	3-5	2.5
GAS FILTER RADIOMETER	N	102	6	1927	100 x 100	5-7	ARRAYS	5	10^4	3-5	2.5
SUB-MM WAVE RADIOMETER	L	1.6 60 (Az.)	0.06 (15-100 KM)	1000	500 x 500	3 (15-100 KM)	MW HETERODYNE REC.	3	10^3	3-5	1
ADVANCED SOLAR OCCULATION RAD. (HALOE	S	1.9(elev.) 360 (Azim.)	0.019 (0-15 KM) 0.05 (15-100 KM)	N/A	>100 x 500	1 (0-15 KM)	ARRAYS	9	10^4	3-5	2.5
PARTIAL SCAN INTERFEROMETER	N	102	6	1927	100 x 100	5-7	DISCRETE	3	10^4	3-5	2.5
	S	1.9(elev.) 360(Azim.)	0.019 (0-15 KM) 0.05 (15-100 KM)	N/A	-	1 (0-15 KM) 3 (15-100 KM)	DISCRETE	3 N/A	10^4 10^4	3-5 3-5	2.5 2.5
INTERFEROMETER SPECTROMETER	N	102	12	1927	200 x 200	5-7	DISCRETE (MICHELSON INTERFER.)	N/A	10^4	3-5	2.5
	S	1.9(elev.) 360 (Azim.)	0.019 (0-15 KM) 0.05 (15-100 KM)	N/A	-	1 (0-15 KM) 3 (15-100 KM)		N/A	10^4	3-5	2.5
TEMPERATURE SOUNDER	N	102	1.2	1927	25 x 25	3 KM	ARRAYS	17	0-300°K	(1 K)	(0.5 K)
MULTISPECTRAL LINEAR ARRAY	N	102	0.23	1927	5 x 5	N/A	ARRAYS	12	10^3 LEVELS	3-5	2.5
PASSIVE M-WAVE RADIOMETER	N	102	0.46	1927	10 x 10	1 (0-15 KM) 3 (15-100 KM)	21 TO 94 GHz RADIOMETER	4	10^3 LEVELS	3-5	2.5

* SENSOR HAS 360° AZIMUTH RANGE

The limb sensors, namely, the UV/VIS Spectrometer, Cryogenic IR Radiometer/Spectrometer, Pressure Modulated Radiometer and Advanced HALOE will be capable of meeting the required vertical resolution. The required horizontal resolution (500 km) is attainable in the limb mode, but the actual values are usually better, but will vary depending on the altitude of the atmospheric layer being observed, the trace gas mixing ratio, and the noise. The latter (noise) is particularly significant at the higher altitudes where total emission or absorption are small.

Several of the measurements that have been specified as needed to satisfy the knowledge objectives (K.O.) will be particularly difficult in this mission.

This includes:

1. The NO_x and O'(D) measurements in K.O. #1, Effects of Pollutants or Atmospheric Radiative Transfer.
2. Sulfur compounds such as HS and SO_3, in K.O. #2, Atmospheric Sulfur Pollution.
3. The accuracy of three-dimensional wind measurements using passive (doppler) techniques is unknown.
4. Measurements of several chlorofluoromethanes (CMF) such as CHF_2Cl and CH_3 CL in K.O. #6, Effect of CMF's on the Atmosphere.

6.2 MISSION SPECIFICATION - NO. 2

Mission Name: Geosynchronous Mission

Mission Objectives: This high altitude mission will support those multidisciplinary measurements requiring high frequency of observation and/or continuous monitoring for long periods of time (e.g., several hours). Examples of those aspects in the Knowledge Objectives that would benefit from the frequent observations provided by this mission are as follows:

K.O. #2 - Atmospheric Sulfur Pollution:

1. Photochemistry of sulfur containing species
2. Investigation of acid rain
3. Interaction of species with aerosols
4. Intense convective activity

K.O. #5 - Effect of Aircraft activity on the Atmosphere:

1. Pollutant transport from aircraft contrails
2. Pollutant interactions

K.O. #8 - Surface - Atmosphere Interchange:

1. Observation of dust effects
2. Observation of storms, ocean turbulence effects

K.O. #11 - Meterological Effects on Atmospheric Composition and Radiative Transfer:

1. Investigation of effects of lightning
2. Severe storm distribution and characterization

K.O. #12 - Effect of Natural and Man Made Disturbances

1. Volcanic particulate distribution and effects (during active periods)

Payload Physical Characteristics

Pointing Accuracy

The driving requirement for spacecraft pointing is the 5 km x 5 km pinel size in the multispectral two-dimensional array. A nominal attitude control accuracy of 0.002 degree is required in all axes (assuming a 1/3 pixel allowable error).

Payload Power

Assuming a continuous duty cycle for all sensors, the payload power will be 500 watts.

Mission Sensors

The sensors and their preliminary specifications are shown on Table 6.2-1.

Mission Timeframe

This mission is envisioned for a 1990-1992 time-frame, prior to the deployment of active sensors such as LIDAR in L.E.O.

Orbit

Altitude:	36127 km, quasi-geosynchronous
Inclination:	equatorial
Longitudinal Drift:	4 degrees/day

Table 6.2-1. Sensor Characteristics - Multidisciplinary Mission No. 2 (Geosynchronous)

SENSOR	VIEWING MODE	TOTAL F.O.V. (DEGREES)	I.F.O.V. (DEGREES)	SWATH WIDTH (KM)	HORIZONTAL RESOLUTION (KM X KM)	VERTICAL RESOLUTION (KM)	TYPE OF DETECTOR	NO. OF CHANNELS	DYNAMIC RANGE MOL./CC	ACCURACY %	PRECISION %
1. GEOSYNCHRONOUS GAS FILTER RAD. (GGFR)	N	18	0.14	14900	100 x 100	5-7	2 D-ARRAY	10	10^4	5	2.5
2. TEMP. SOUNDER	N	18	0.14	14900	100 x 100	3	PUSH-BROOM ARRAY	17	(150-300K)	(0.5° K)	(0.1 K)
3. LASER HETERODYNE SPECTROMETER	N	18	0.14	14900	100 x 100	3 KM	HET. RECEIVER	2	TBD	3-5	2.5
4. INTERFEROMETRIC SPECTROMETER	N	18	0.14	14900	100 x 100	5-7	(Hg, Cd) Te	(SPECTRUM)	10^4	3-5	2.5
5. MULTISPECTRAL TWO DIMENSIONAL ARRAY	N	18	0.007	14900	5 x 5	N/A	2 D-ARRAY	12	(10^3 LEVELS)	0.5	2.5

Mission Duration

Minimum of five years without maintenance in orbit.

Measurement Capabilities/Limitations

The most significant measurement capabilities of this mission relates to the ability to observe a 14900 x 14900 km area of the globe concurrently, using multiple instruments in various wavelengths. (The limitation in the total area viewed from two-dimensional array sensors such as the GGFR is due to the geometric distortions due to extreme incidence angles.) The most significant limitation is the inability to perform limb measurements over large areas in a reasonable period of time (i.e., only 1.1% of the earth's surface could be covered each day, using a limb sensor that would cover 360° from a geosynchronous orbit with 4°/day drift). The earth-looking measurements will be limited to the troposphere, except in those cases where cloud-top reflection will permit upper atmospheric measurements.

6.3 MISSION SPECIFICATION - MISSION NO. 3

Mission Name: Low Earth Orbit Mission using Active (LIDAR) and Passive Optical Sensors

Mission Objectives: This mission addresses the same eleven knowledge objectives as Mission No. 1 (Section 6.1), but taking full advantage of the capabilities of the LIDAR sensor. It is envisioned that a set of detailed investigations will be identified as a result of the early missions, for further experimental study using the LIDAR sensor.

Payload Characteristics

Pointing Accuracy

The driving requirement in pointing accuracy is the sub-mm radiometer which has an instantaneous field of view of 0.13 degree. Assuming a fixed-mount for this instrument on the spacecraft (e.g., no gimbals) in all three axes the accuracy requirement will be 0.04°.

Payload Power

Assuming continuous duty cycle for all sensors, the payload power will be approximately 15 kilowatts.

Mission Sensors

Table 6.3-1 shows the sensors for this mission and their preliminary specifications.

Mission Timeframe

The technology for the LIDAR subsystem should be ready by the mid-1990's, with 1994 as a nominal availability date. This projection assumes that these will be precursory developmental tests on-board the Shuttle orbiter, as discussed in Section 4.4 of the AOS Phase I Report.

Mission Duration

A minimum of 3 years in orbit is projected for this mission. The requirements for in-orbit maintenance cannot be defined until the laser sources for LIDAR have been designed and their life cycles have been established.

6.4 MISSION SPECIFICATION - MISSION 4

Mission Name: Intermediate Altitude Orbit Mission using Passive Sensors

Mission Objectives: The objectives of this mission relate to Knowledge Objectives Nos. 1 through 11, as shown in Section 6.1, Mission No. 1. This mission is considered an alternative to Mission No. 1, since it contains the same sensor complement. The only significant difference will be the orbit, which provides a more frequent repeat cycle over any given area, and thus enhances the spatial-temporal coverage of the data. This is particularly useful in observing the effects of atmospheric chemical and physical reactions whose time constant is in the order of four to six hours. Although this intermediate orbit does not provide the continuous coverage of the geosynchronous orbit in Mission No. 2, consideration should be given to using Mission No. 4 as an alternate to the Geosynchronous Mission. This compromise option cannot be fully evaluated until the aircraft air quality experiment program establishes the criticality of measurements related to very rapid reactions.

Table 6.3-1. Sensor Characteristics - Multidisciplinary Mission No. 3 (LIDAR) (H = 520KM)

SENSOR	VIEWING MODE	TOTAL F.O.V. (DEGREES)	I.F.O.V. (DEGREES)	SWATH WIDTH (KM)	HORIZONTAL RESOLUTION (KMXKM)	VERTICAL RESOLUTION	TYPE OF DETECTOR	NO. OF CHANNELS	DYNAMIC RANGE MOL./CC	ACCURACY %	PRECISION %
1. LIDAR SENSOR	N	96	N/A	704	200 GRID	1 KM (0-15KM 5 KM (15-100 KM)	DIAL	15	10^4	5	2.5
2. TEMP. SOUNDER	N	96	1.7	704	25 x 25	3	MLA	17	(0-300 K)	(1 K)	(0.5 K)
3. MULTISPECTRAL LINEAR ARRAY	N	96	0.34	704	5 x 5	N/A	MLA	12	(10^3 LEVELS)	5	2.5
4. SUB-MM RADIOMETER	L	60 AZ 1.5 EL	0.13	4982	500 x 500	6	MW. HETERODYNE RAD.	3	10^3	5	1

Payload Characteristics

Payload Pointing Accuracy

In order to attain 1 km vertical resolution in the lower atmospheric layers, the required pointing accuracy of the instrument will be 0.001 degree. It is unlikely that the spacecraft will be required to provide this accuracy; more likely, it will provide coarse pointing accuracy and fine pointing will be established by the instrument in conjunction with a payload inertial reference. That level of support for coarse pointing will not be more stringent than one order of magnitude from the 0.001 degree, or 0.01 degree.

Payload Power

Same as Mission No. 1, namely 1500 watts.

Mission Sensors

The sensors and their preliminary specifications are shown on Table 6.4-1.

Mission Timeframe

The timeframe of this payload is the same as that for Mission No. 1, namely 1989 to 1992. However, due to the higher orbit and, the attendant requirements for larger antennas in the Passive Microwave Radiometer, and Van-Allen belt radiation protection for electronic and electro-optical components, a nominal launch date is projected for 1991.

Orbit

Altitude:	2500 km (circular)
Inclination:	55 degrees

Sensor Measurement Capabilities/Limitations

Same as Mission No. 1, Section 6.1

6.5 SIGNIFICANCE OF THE MISSION SPECIFICATIONS

The missions described above are merely a mission model constructed by the study team for the purpose of deriving developmental requirements, some of which are technological in nature. The similarity between some of the multidisciplinary missions and the tropospheric missions of Part I of the study were not assumed a priori; however, their parallelism suggests that no compromises are necessary in addressing the objectives of both mission types

Table 6.4-1. Sensor Characteristics - Multidisciplinary AOS Mission 4 (Alternate) (2500KM)

SENSOR	VIEWING MODE	TOTAL F.O.V. (DEGREES)	I.F.O.V. (DEGREES)	SWATH WIDTH (KM)	HORIZONTAL RESOLUTION (KM X KM)	VERTICAL RESOLUTION (KM)	TYPE OF DETECTOR	NO. OF CHANNELS	DYNAMIC RANGE MOLECULE/CC	ACCURACY %	PRECISION %
UV/VIS SPECTROMETER	L	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	9810	500 x 500	1 (0-15KM) 3 (15-100KM)	ARRAYS	24	10^4	3-5	2.5
CRYO. IR RADIOMETER/ SPECTROMETER	L	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	9810	500 x 500	1 (0-15 KM) 3 (15-100 KM)	ARRAYS	32	10^4	3-5	2.5
PRESSURE MODULATED RADIOMETER (PMR)	L	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	9810	500 x 500	1 (0-15 KM) 3 (15-100 KM)	ARRAYS	5	10^4	3-5	2.5
GAS FILTER RADIOMETER	N	102	6	6120	100 x 100	5-7	ARRAYS	5	10^4	3-5	2.5
SUB-MM WAVE RADIOMETER	L	1.6 60 (Az.)	0.06 (15-100 KM)	3430	500 x 500	3 (15-100 KM)	MW HETERODYNE REC.	3	10^3	3-5	1
ADVANCED SOLAR OCCULATION RAD. (HALOE)	S	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	N/A	>100 x 500	1.3 (0-15 KM)	ARRAYS	9	10^4	3-5	2.5
PARTIAL SCAN INTERFEROMETER	N	102	6	6120	100 x 100	5-7	DISCRETE	3	10^4	3-5	2.5
	S	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	N/A	-	1 (0-15 KM) 3 (15-100 KM)	DISCRETE	3 N/A	10^4 10^4	3-5 3-5	2.5 2.5
INTERFEROMETER SPECTROMETER	N	102	12	6120	200 x 200	1 (0-15 KM)	DISCRETE (MICHELSON INTERFER.)	N/A	10^4	3-5	2.5
	S	1.2 (elev.) 360 (Azim.)	0.012 (0-15 KM) 0.04 (15-100 KM)	N/A	-	1 (0-15 KM) 3 (15-100 KM)		N/A	10^4	3-5	2.5
TEMPERATURE SOUNDER	N	102	0.4	6120	25 x 25	3	ARRAYS	17	0-300°K	(1°K)	(0.5 K)
MULTISPECTRAL LINEAR ARRAY	N	102	0.08	6120	5 x 5	N/A		12	10^3 LEVELS	3-5	2.5
PASSIVE M-WAVE RADIOMETER	N	102	0.17	6120	10 x 10	1 (0-15 KM) 3 (15-100 KM)	21 TO 94 GHz RADIOMETER	4	10^3 LEVELS	3-5	2.5

* SENSOR HAS 360° AZIMUTH RANGE

with the same set of orbits, namely two low-orbits and one geosynchronous one. Shuttle sorties will undoubtedly prove to be a cost-effective way to culminate the development and demonstration of the new sensors. Their use was treated in Missions No. 1 and 4 of the Part I Study; therefore, they were not reintroduced here.

SECTION 7

PAYLOAD CHARACTERISTICS

The purpose of this analysis was to determine the projected technology drivers due to the accommodation of the sensors in a payload module and the accommodation and system support of the payload module by the spacecraft. The synthesized missions were reviewed for potential technology content derived from the multi-disciplinary nature of the missions. A recommendation was made and subsequently was approved by NASA to use Mission No. 1 as the model. The rationale for this choice is as follows:

1. Mission No. 1 has the largest number of sensors.
2. The sensors in Mission No. 1 include a variety of viewing aspects, including limb and Earth-looking. This is in contrast with the Geosynchronous Mission which contains no limb measurements.
3. Mission No. 1 is significantly different than its counterpart in AOS Part I, namely Mission No. 3, whereas the LIDAR mission in Part II is very similar to Mission No. 6 in Part I.

The following paragraphs describe the main aspects and components of the payload.

7.1 PAYLOAD PACKAGING AND DIMENSIONS

Figure 7.1-1 shows the arrangement of the eleven sensors in Mission No. 1, integrated in a payload package. There are basically three rows of sensors. The forward row contains large sensors operating in the limb mode, such as the Cryogenic IR Radiometer/Spectrometer. The middle row includes several nadir/off-nadir looking sensors such as the interferometer Spectrometer and Gas Filter Radiometer. The aft row is reserved for the Passive Microwave Radiometer (PMWR) which is approximately five meters wide in the operating (deployed) mode.

In the stowed mode, which requires folding of the large (21 GHz) microwave antennas, overall dimensions of the payload are as follows:

1. 6.5 meters along the X axis
2. 4.0 meters along the Y axis
3. 2.3 meters along the Z axis

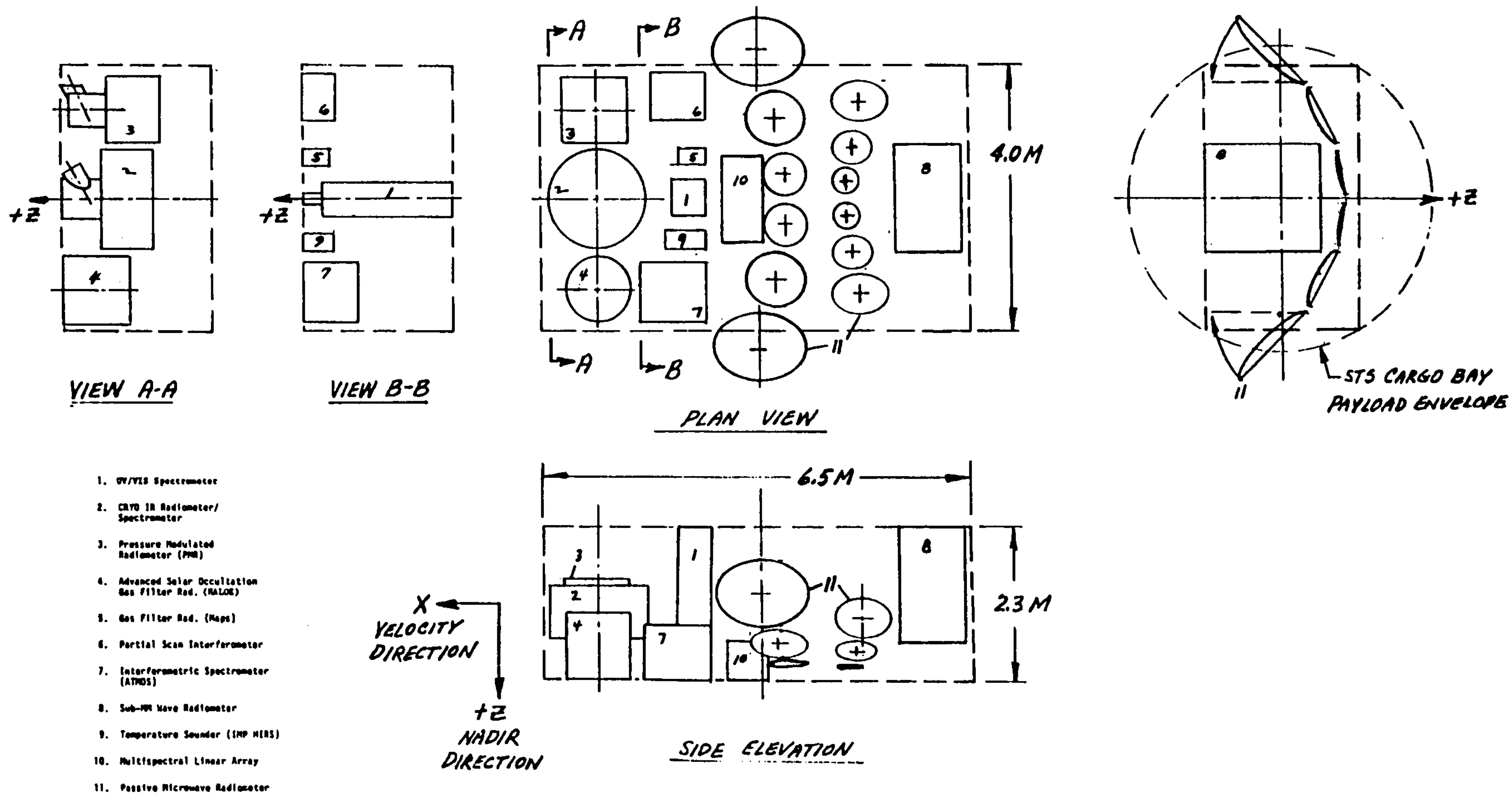


Figure 7.1-1. Mission 1 Payload Configuration

Figure 7.1-1 also shows the cross-section of the payload relative to the 4.6 meters diameter envelope of the Shuttle Cargo bay. It may be seen that a one-dimensional rotation of the large PMWR antennas over an arc of approximately 40^0 will maintain the payload well within the envelope of the cargo bay.

One of the main features of the payload concept presented herein is the optics-plane mount for the sensors. By placing the optical apertures at approximately the same level, we avoid field-of-view interferences. This is particularly critical in the limb sensors, which look at a band extending from the Earth's horizon to 100 km above the horizon within the entire 3.0 azimuth range.

Possible F.O.V. interferences with spacecraft appendages can be minimized by restricting all booms solar arrays and antennas not to protrude beyond the aforementioned sensors' "optics plane".

7.2 SENSOR ACCOMMODATION PARAMETERS

This section of the report includes the main physical and operational characteristics that woud be useful in future accommodation analyses of the sensors in projected spacecraft concepts. The dimensional characteristics of the sensors is shown in Table 7.2-1.

The sensors viewing characteristics are presented in Table 7.2-2, including viewing mode, field of view (total), angular range from nadir, and scanning or viewing direction. Table 7.2-3 shows the sensor weight, power and approximate data rates. The external configuration of each sensor is shown in Figures 7.2-1 through 7.2-11.

Table 7.2-1. AOS Sensor Physical Characteristics

Sensor	Dimensions (CM)
1. UV/VIS Spectrometer	50 x 50 x 230
2. CRYO IR Radiometer/ Spectrometer	150 DIA x 140
3. Pressure Modulated Radiometer (PMR)	100 x 100 x 150
4. Advanced Solar Occultation Gas Filter Rad. (HALOE)	100 DIA x 100
5. Gas Filter Rad. (Maps)	25 x 40 x 40
6. Partial Scan Interferometer	70 x 80 x 50
7. Interferometric Spectrometer (ATMOS)	90 x 100 x 85
8. Sub-MM Wave Radiometer	100 x 160 x 175
9. Temperature Sounder (IMP HIRS)	25 x 60 x 45
10. Multispectral Linear Array	60 x 130 x 60
11. Passive Microwave Radiometer	375 x 470 x 110

Table 7.2-2. AOS Sensor Viewing Characteristics

SENSOR	VIEWING MODE	TOTAL FOV (DEGREES)	NADIR ANGLE (DEGREES)	VIEWING DIRECTION (DEGREES)
1. UV/VIS Spectrometer	L	1.9	± 64.3	360
2. CRYO IR Radiometer/Spectrometer	L	1.9	± 64.3	360
3. Pressure Modulated Radiometer (PMR)	L	1.9	± 64.3	360
4. Advanced Solar Occultation Gas Filter Rad. (HALOE)	S	1.9	± 64.3	360
5. Gas Filter Rad. (Maps)	N	116	± 58	± Y
6. Partial Scan Interferometer (CIMATS)	N S	116 1.9	± 58 ± 64.3	± Y 360
7. Interferometric Spectrometer (ATMOS)	N S	116 1.9	± 58 ± 64.3	± Y 360
8. Sub-MM Wave Radiometer	L	1.6	± 64.6	± 30° from X-axis
9. Temperature Sounder (HIRS-IMP)	N	116	± 58	± Y
10. Multispectral Linear Array	N	116	± 58	± Y
11. Passive Microwave Radiometer	N	116	± 58	± Y

Table 7.2-3. AOS Sensor Resource Characteristics

SENSOR	WEIGHT (Kg)	POWER (WATTS)	DATA RATES (BPS)
1. UV/VIS Spectrometer	130	40	3.4K
2. CRYO IR Radiometer/ Spectrometer	500	60	
3. Pressure Modulated Radiometer (PMR)	85	125	1.2K
4. Advanced Solar Occultation Gas Filter Rad. (HALOE)	80	80	8.5K
5. Gas Filter Rad. (MAPS)	20	43	
6. Partial Scan Interferometer	100	180	4.5K
7. Interferometric Spectrometer (ATMOS)	215	90	100K
8. Sub-MM Wave Radiometer	235	470	2K
9. Temperature Sounder (IMP HIRS)	40	50	100K
10. Multispectral Linear Array	150	165	58K
11. Passive Microwave Radiometer	(245)	(197)	4.8K
Totals	1800	1500	> 291K

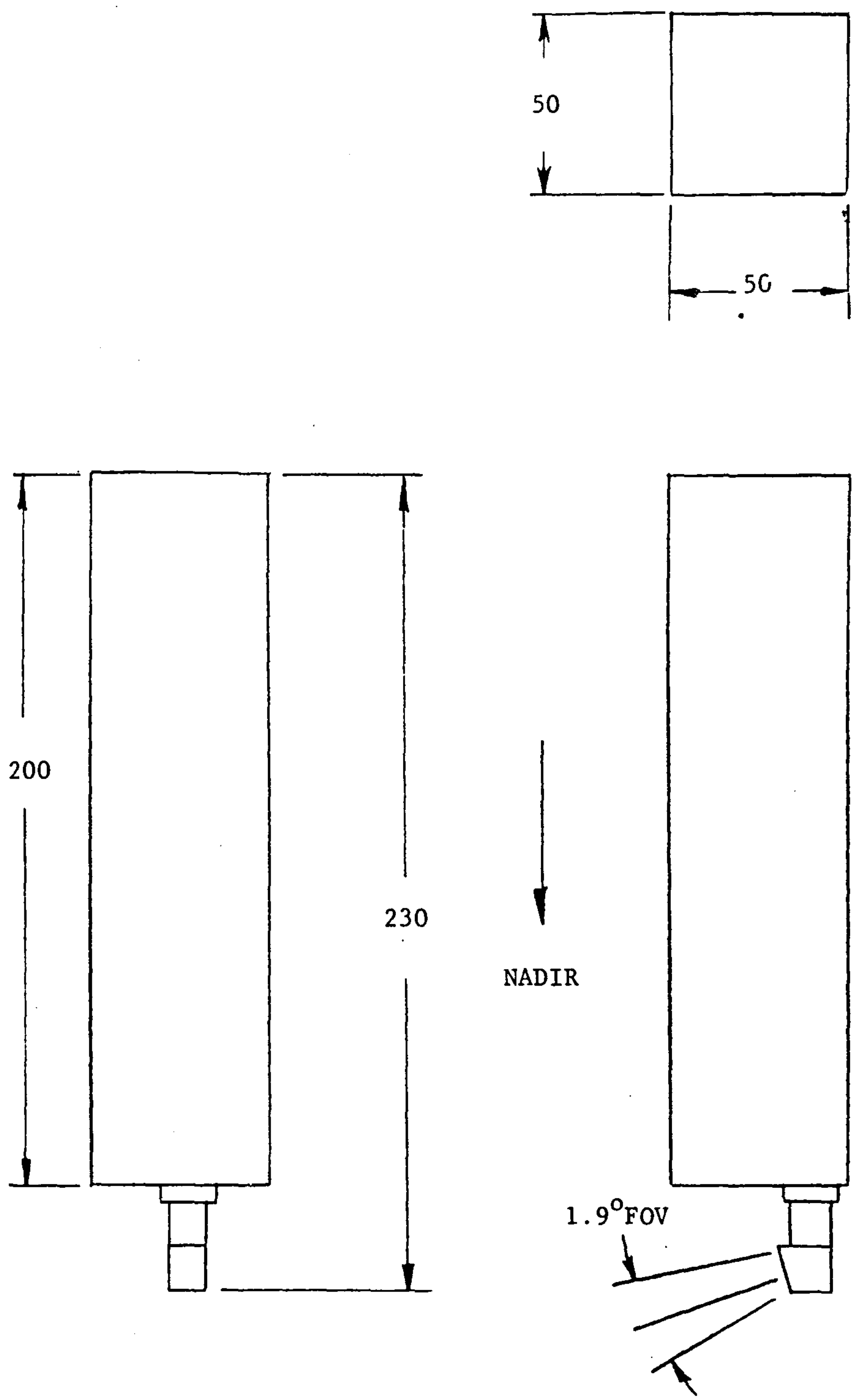


Figure 7.2-1. UV/Visible Spectrometer (AOS-1)

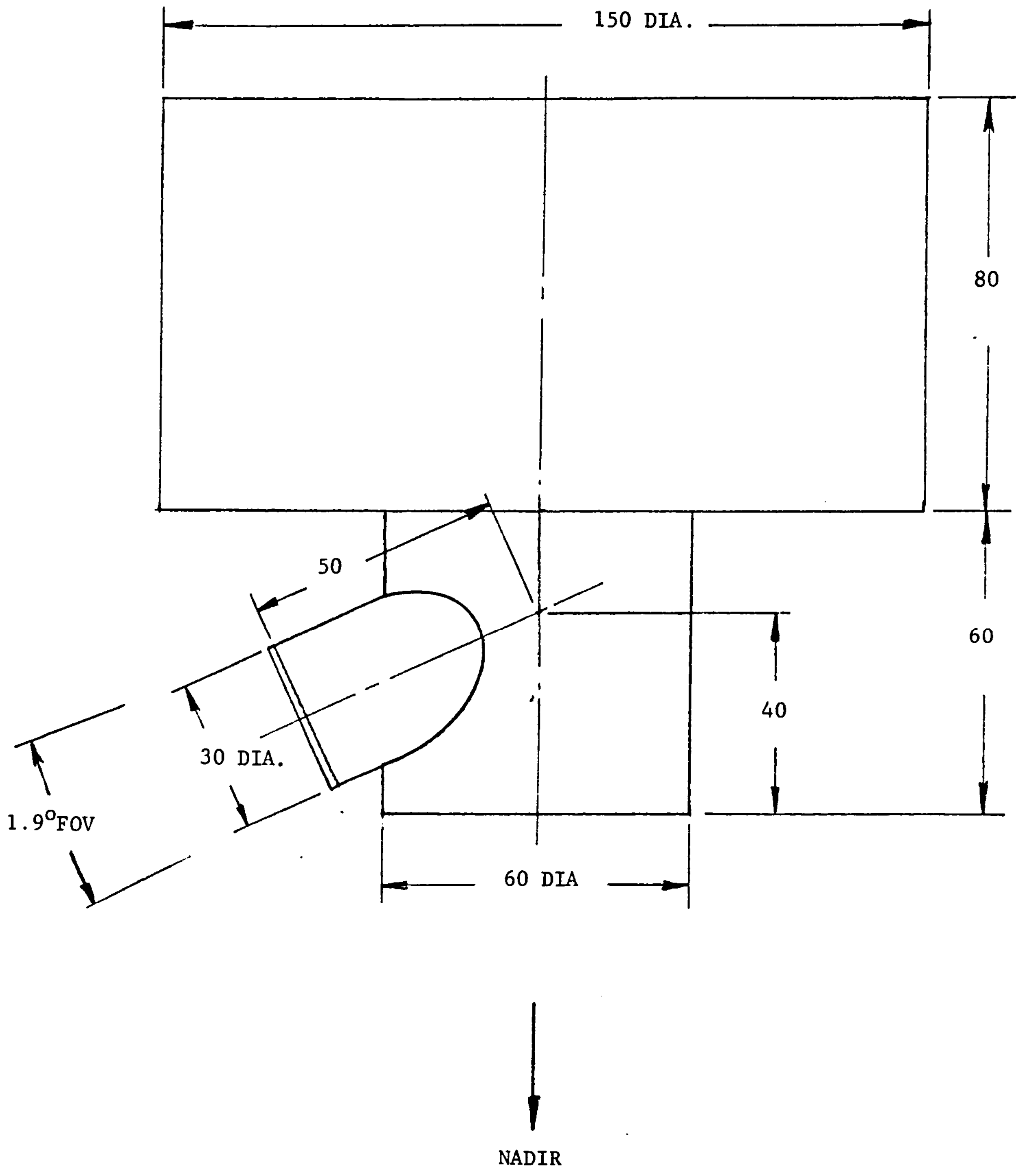


Figure 7.2-2. Cryo IR Radiometer/Spectrometer (AOS-2)

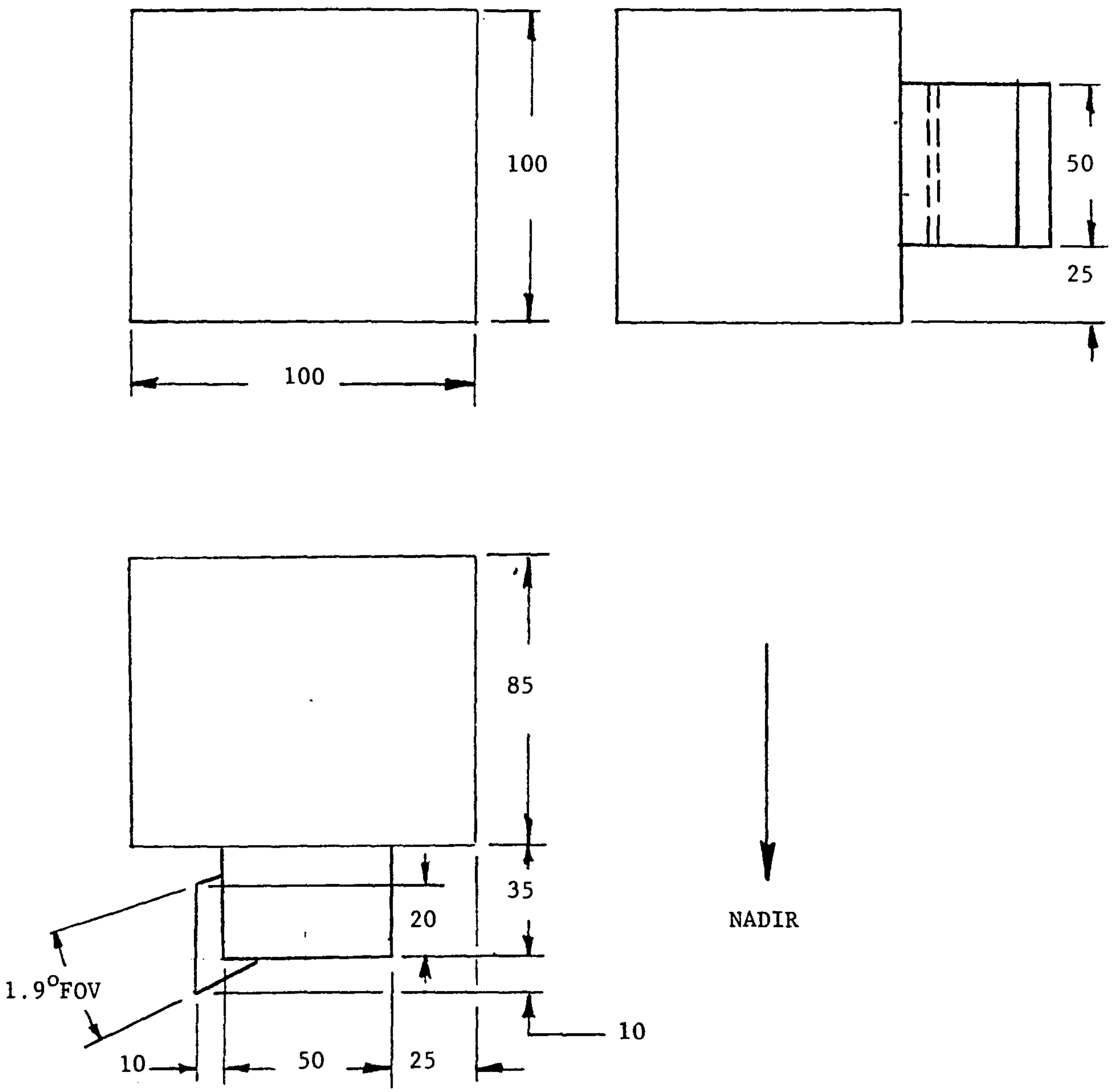


Figure 7.2-3. Pressure Modulated Radiometer (AOS-3)

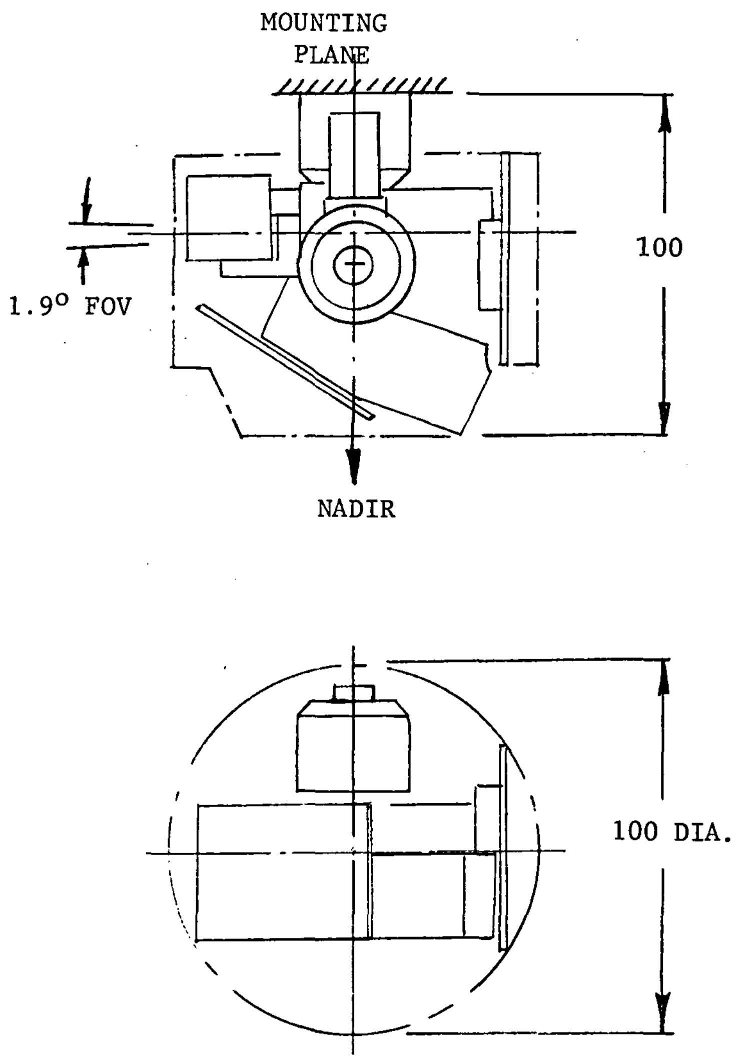


Figure 7.2-4. Advanced Solar Occultation Gas Filter Radiometer (AOS-4)

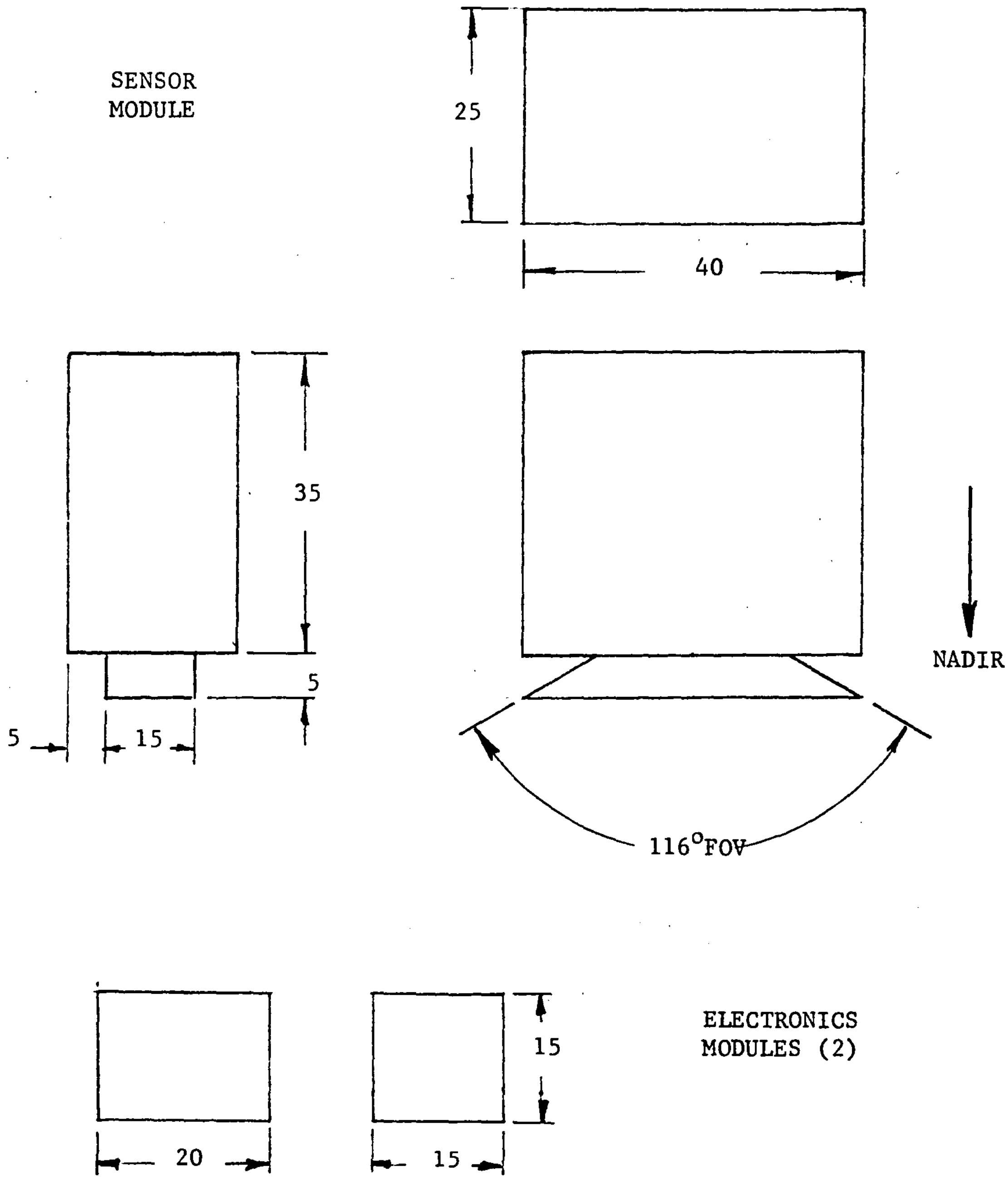


Figure 7.2-5. Gas Filter Radiometer (AOS-5)

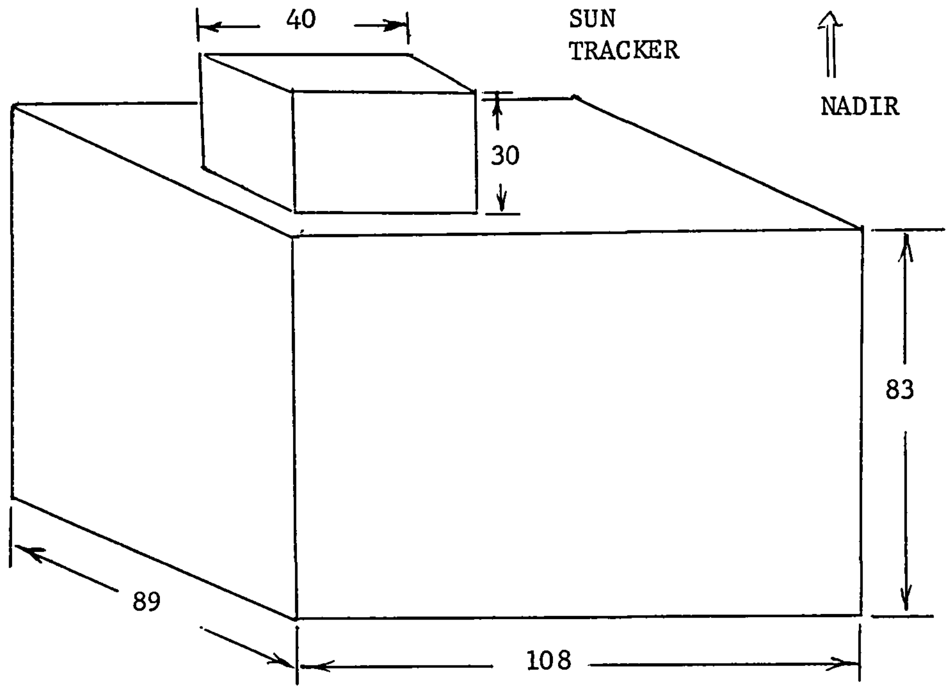


Figure 7.2-7. Interferometer Scatterometer

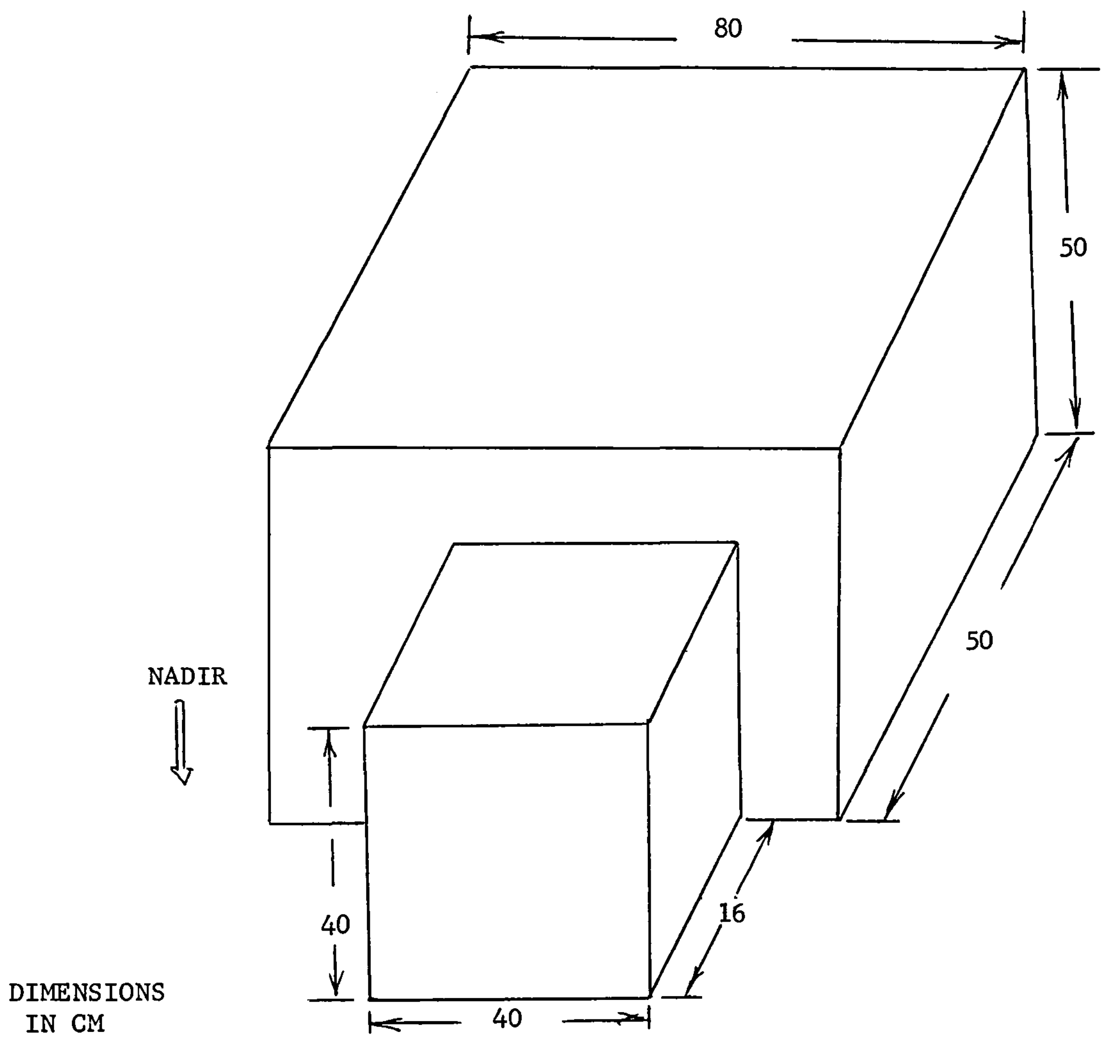


Figure 7.2-6. Partial Scan Interferometer

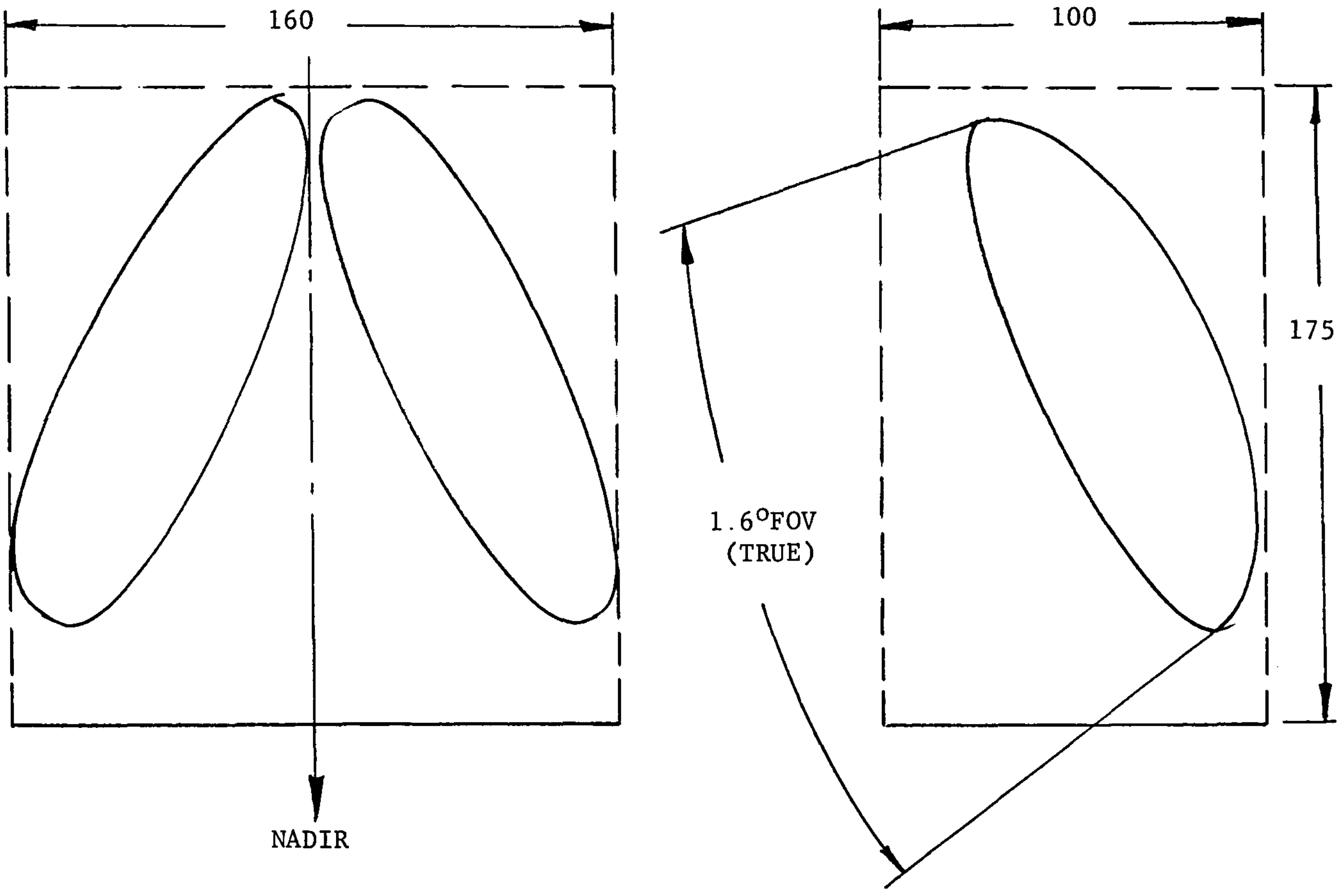


Figure 7.2-8. Sub-MM Wave Radiometer (AOS-8)

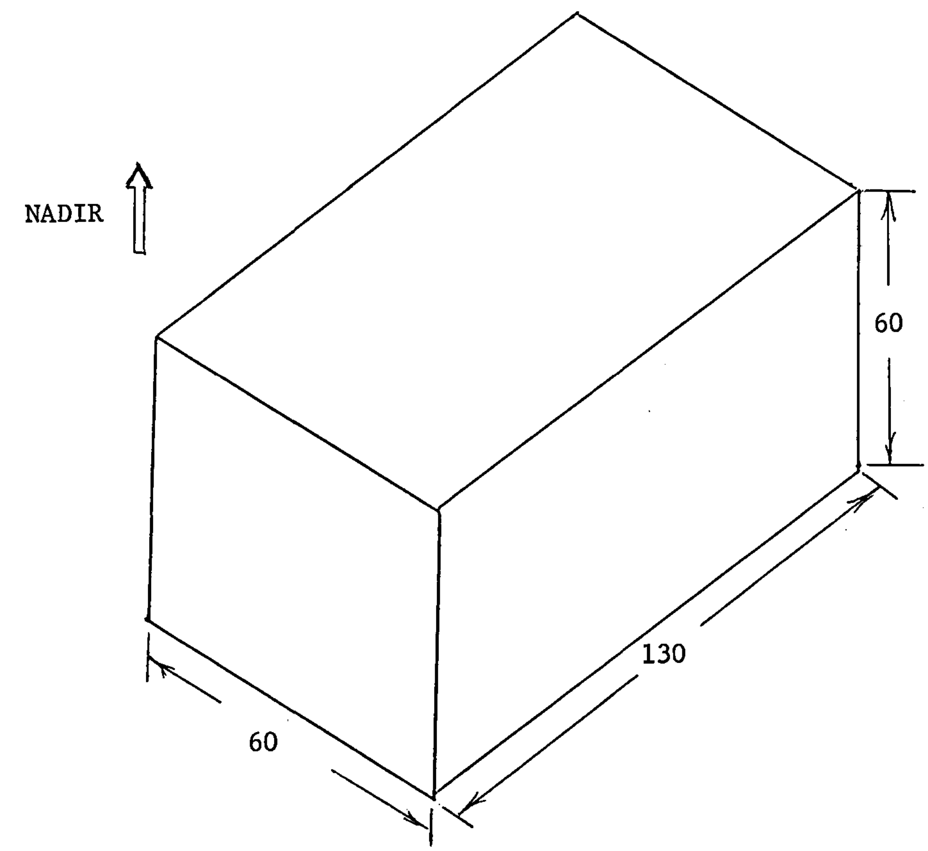


Figure 7.2-10. Multispectral Linear Array

DIMENSIONS IN CM

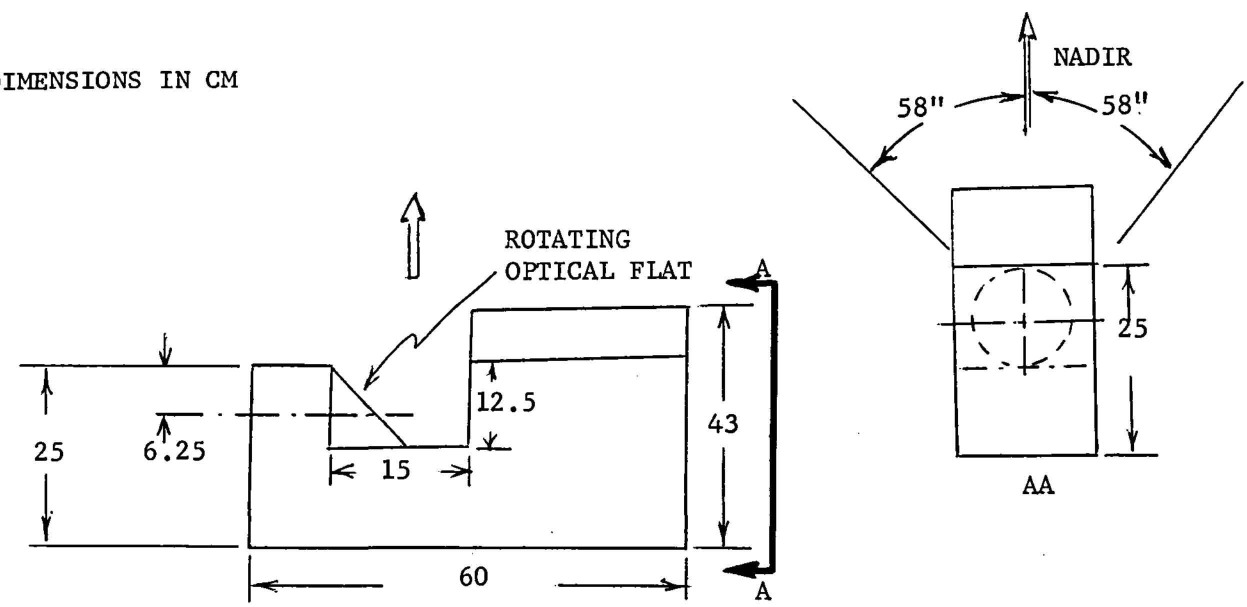
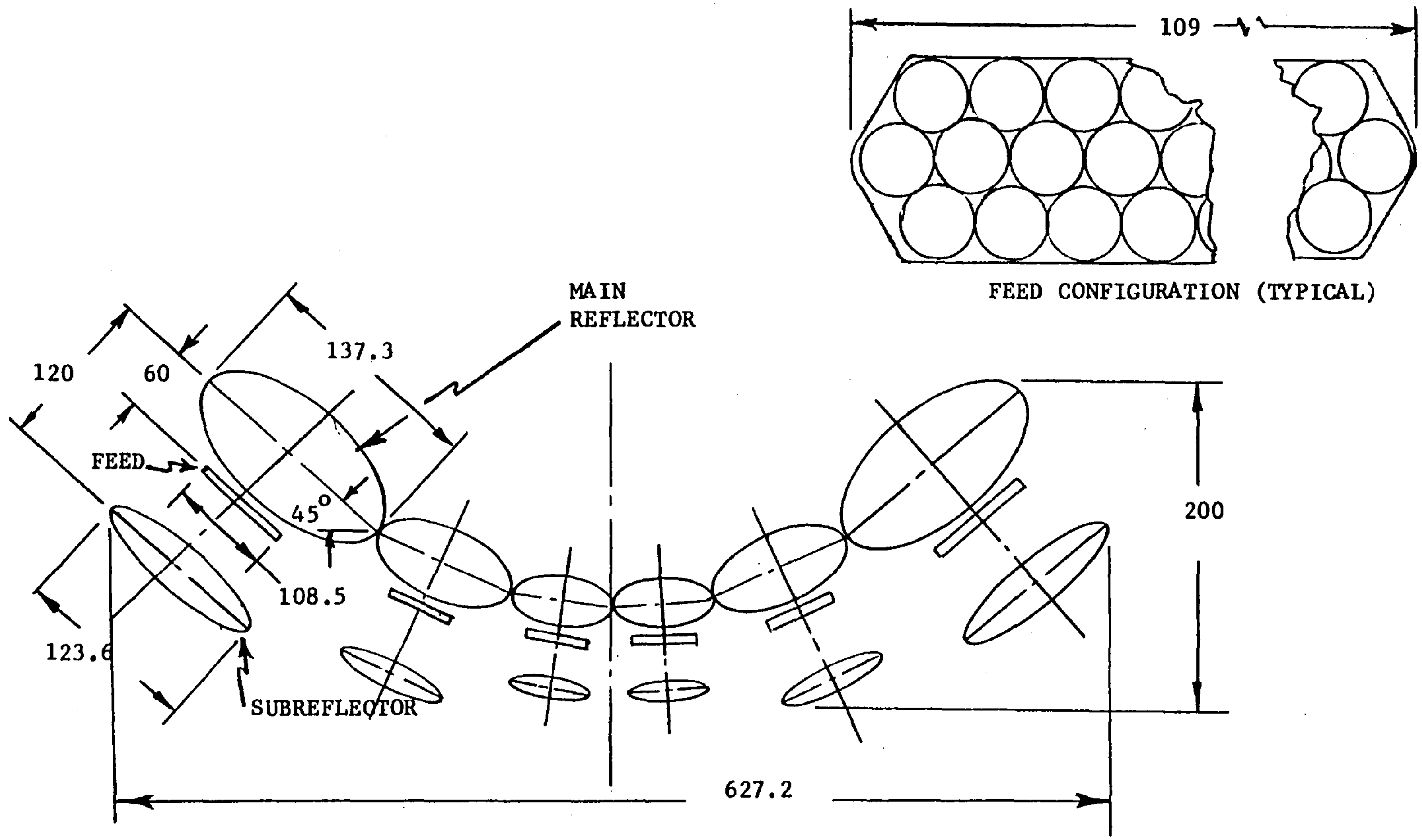


Figure 7.2-9. Temperature Sounder



DIMENSIONS IN CENTIMETERS

Figure 7.2-11. Mission I
AOS Passive Microwave Radiometer Configuration

SECTION 8
DATA MANAGEMENT SYSTEM

The end-to-end data system that was described in the AOS Part I Final Report is generally representative of the type of system necessary for the multidisciplinary missions in Part II. The objective of this section of the report is to examine in more detail the specific needs of the multidisciplinary missions, to permit subsequent assessment of the developmental needs associated with such a system. In order to facilitate the discussion in this section, it has been subdivided into two portions, one dealing with the on-board system and another with the ground-based segment.

8.1 ON-BOARD SEGMENT OF THE DATA MANAGEMENT SYSTEM

The AOS mission can benefit from various processing of the data on-board. In particular, processes which lead to the adaptive operation of sensors provide more effective operation, enable more selective data collection (data with higher information content), reduce downlink data rates, and reduce dependence for operation on ground analyses and communication links both up and down.

Mission No. 1 was selected as the model for this data analysis, since it has the largest number of instruments and largest data rate. Figure 8.1-1 depicts how the data from most of the instruments can operate synergistically to optimize operation under various observed conditions. The four conditions chosen are rain, cloud cover, fronts, and high level pollution events. (Atmospheric temperature inversions were considered but are deemed to be impossible to detect from satellite observation.) These conditions singly or in combination require changes in the operating configuration of several instruments. These configurations may include specific spectral or spatial filters, laser heterodyning frequencies, and sampling rates, temporal and spectral. The traditional approach would require either that the data be collected under all possible configuration conditions; i.e., several simultaneous spectral bands, several frequencies, and several sampling rates; or that the determining conditions be defined by ground station analyses and appropriate commands be transmitted to the spacecraft. The first of these options multiplies the data that must be collected, stored, transmitted, and processed; the second requires continuous real-time links, which are expensive and may involve unacceptable time delays between observation and reconfiguration.

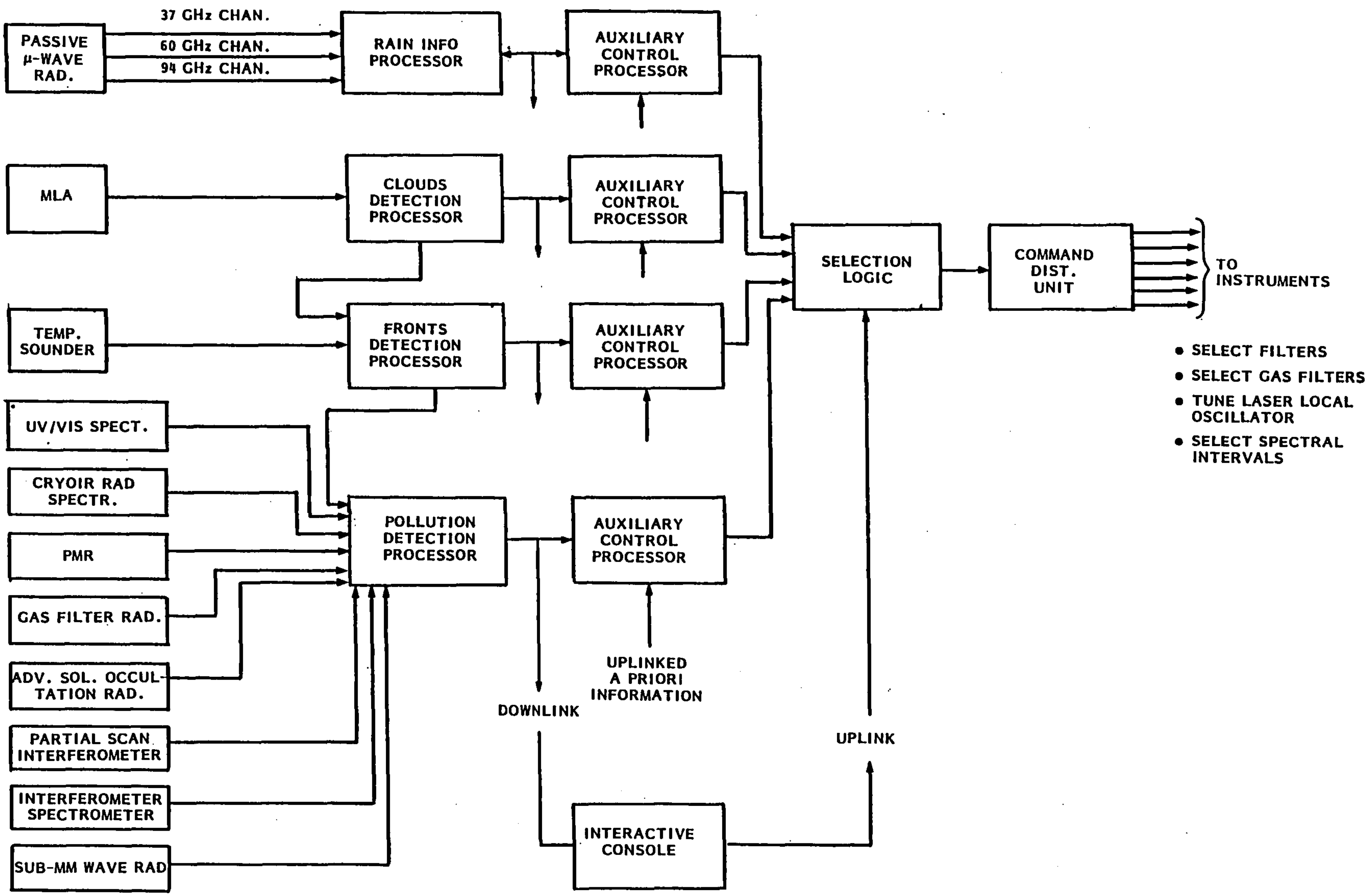


Figure 8.1-1. Adaptive Process Based on Multiple Sensor Inputs

The concept proposed here utilizes the data from appropriate instruments and on-board processors to determine the existence of the conditions requiring reconfiguration of the instrument operating modes. In general, the processes required on-board are not as complex as the full processing which will be subsequently performed on the ground. The processes provide "yes-no" decisions or, at worst, quantum levels determinations to make appropriate selections from a finite set of possible configurations. The full processing, on the other hand, in many cases requires complete determination of finely resolved values from calibrated data. For instance, calibration will be required prior to cloud mapping, a rather complex task for the MLA, especially in the near IR. In most cases calibration will be a second-order effort not required for on-board decisions.

The concept also provides for assistance to the processors in deriving their decision. Auxiliary Control Processors (ACP) will be periodically preloaded with known information regarding the potential for existence of the condition being evaluated. For example, areas with low probability of rain (deserts) would be indicated and the ACP would provide a heavy negative factor in the "Rain-No Rain" decision of the Rain Information Processor. Similarly, the anticipated location of previously detected fronts, and information as to whether cold or warm fronts would assist the Front Detection Processor in the location in the location of such fronts, including the particular algorithms to be used in identifying them; i.e., cold front detection algorithms may well differ from warm front detection algorithms because of the different characteristics of the temperature gradients associated with each.

The capability to include a ground observer in the decision loop is also provided. This capability will probably be used extensively in the initial operation until the processor algorithms have been refined and sufficient confidence has been gained concerning their adequacy. It is intended, however, that the need for this capability be rapidly eliminated since the costs of its use negates the advantages of performing the adaptive processes on-board.

The selection logic function accepts the determination of the conditions defined by the processors, and establishes operating configurations for each of the instruments based on this information. These are translated into specific commands to each affected function which are then transmitted to the appropriate instruments through the Command Distribution Unit.

At this time, the algorithms required to perform the condition determination processes are poorly defined. We can, however, be assumed that some, such as Cloud Detectionwill be simple, and others, such as Front Detection will be complex and provide a potential for technology exploitation. The almost assured uncertainty of the initial algorithms utilized mandate high flexibility to enable the incorporation of improvements in the algorithms. This is most effectively done through the use of general purpose computers whose programs can readily be changed. There is a possibility, however, that some of the processes may combine processing complexity and data rates which will exceed the capabilities of foreseeable space qualified GP computers (1 to 2 MOPS). As a point of reference, the AMACS #1680 computer, used in IAS is an advanced computer that operates at 250 Kops. There will then be a trade-off between developing more powerful computers and designing the processor as a specified processor providing the high capability at a lower cost than the computer but with reduced flexibility. This constitutes a most likely approach to high operational rate processing for the next 5-10 years. Obviously, the level of maturity of the algorithm will be paramount in these trade-offs.

Figure 8.1-2 depicts an on-board adaptive system which both reduces transmitted data rate by direct elimination of collected data containing no information and by controlling another sensor such that it collects only data containing information. The Interferometer Spectrometer scans the entire spectrum between 2 and 14 micrometers. The data is digitized at a rate of approximately 10 Mbps. It is known apriori that information will be contained only within certain bands of the spectrum which constitute approximately $\pm$ one percent of the scanned spectrum. A gate (λ gate) controlled by the scanning system allows only those data within the spectral segments known to contain information to pass to a buffer which eliminates the gap and transmits the 100 Kbps stream to the ground.

The segments containing information are spectral regions where given gases may or may not be radiating. A threshold detector determines when radiation from these gases are present and, based on the scan control location, identifies the radiating gas species.

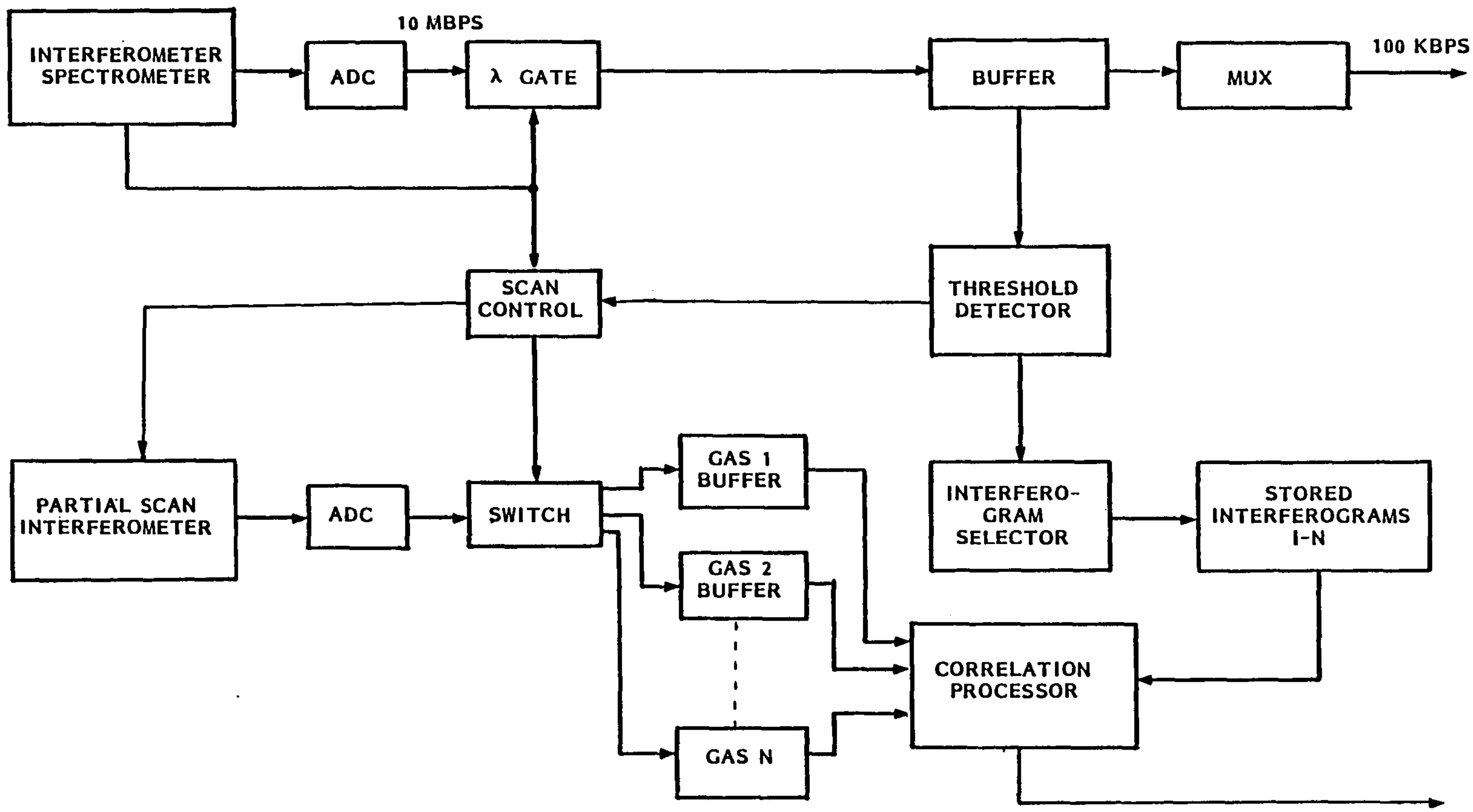


Figure 8.1-2. Adaptive Process Based on Single Sensor Input

The Interferogram selector can then access the stored interferogram of the specific gas from the data base for correlation with samples gathered by the Partial Scan Interferometer or (PSI). The PSI, under the control of the Threshold Detector and the Scan Control collects data only in these regions of the spectrum containing characteristic lines for gases which have been determined to have a concentration above the threshold level. The PSI output are then buffered and correlated with the pre-stored interferograms. The output of the correlator are then the only data transmitted to the ground.

The potential technology drivers related to the adaptive process described herein are associated with the correlator which, depending on the specific algorithms and data rates may be a complex processor. The data base which stores the interferogram may also be a challenge depending on the size required. The selected scheme shows buffers to store the output of the PSI. This permits a non-real-time mode of operation for the processor thereby reducing its required operating speed.

8.2 GROUND SEGMENT OF THE DATA MANAGEMENT SYSTEM

Our intent at this time is to examine the ground processing requirements in more depth to drive out the new technologies that may be required to carry out the AOS mission.

Before addressing those requirements, however, a review of definitions of some of our terms might be in order. The following terms have been used to describe the extent of processing of sensor data as it proceeds toward its ultimate goal of being transformed into knowledge.

- Level 0 - Raw data from instrument output.
- Level 1 - Level 0 data which has been converted to engineering units via calibration and spacecraft data. Corrected for radiometric and geometric anomalies.
- Level 2 - Level 1 data which has been converted to geophysical parameters.
- Level 3 - Geophysical parameters which have been correlated and parameterized with external data. Auxiliary data may be geodetic parameters, data from other systems or even combinations of several Level 2 outputs. First step in extracting meaningful information.

Level 4 - Generally, specific user models applied to Level 3 data to extract a particular desired output.

The ground segment shown in Figure 8.2-1 is typical of most, if not all, space systems in which sensor data is delivered to the ground. It consists of the usual operations control functions of mission planning, command generation, telemetry analysis, etc., in addition to the processing of mission data. Since the primary concern in this study is to drive out the technologies required to carry out the AOS mission, we have concentrated on those areas related to sensor data processing rather than the spacecraft control functions, except as they may impact or be impacted by the processing of the sensor data. Therefore, the following discussion will primarily center around those areas in Figure 8.2-1 contained within the "hatched" boxes.

8.2.1 FUNCTIONAL DESCRIPTION OF GROUND SEGMENT

Refer to Figures 8.2.1-1A and 8.2.1-1B for the following discussions. As data are received from a Domsat terminal, it can either be processed in real time or recorded on magnetic tape. The relatively low level of data received (i.e., $\sim$ 1 Mbps) implies that no problems are envisioned in either recording or reading data directly into the Ingest Processor. The function of the Ingest Processor is essentially one of separating sensor, housekeeping and spacecraft data, passing the spacecraft parameters and telemetry data to the proper elements of the ground system for further processing. and separating sensor data into individual streams of data. The sensor data at this point in processing has had nothing done to it, and is therefore considered "raw" (i.e., Level 0). In order to preserve its integrity, and make it available to those experimenters who may require it, it may be stored for future reference.

Each set of sensor data is now converted to Level 1, through the application of pre-determined calibration data as well as the condition and position of the spacecraft at the time of data acquisition. These data may also preserved by storing them in a Level 1 data store. A second conversion now takes place, transforming the Level 1 data (i.e., corrected engineering units) into Level 2 data (i.e., geophysical units). The matrix shown in Figure 8.2.1-1a indicates which set of sensor data is capable of being converted into which output parameters. To make the system more flexible, it is desirable to make this process "selectable"; that is, a user could decide which set of outputs he/she would require, and the system would be made to respond only to that stimulus

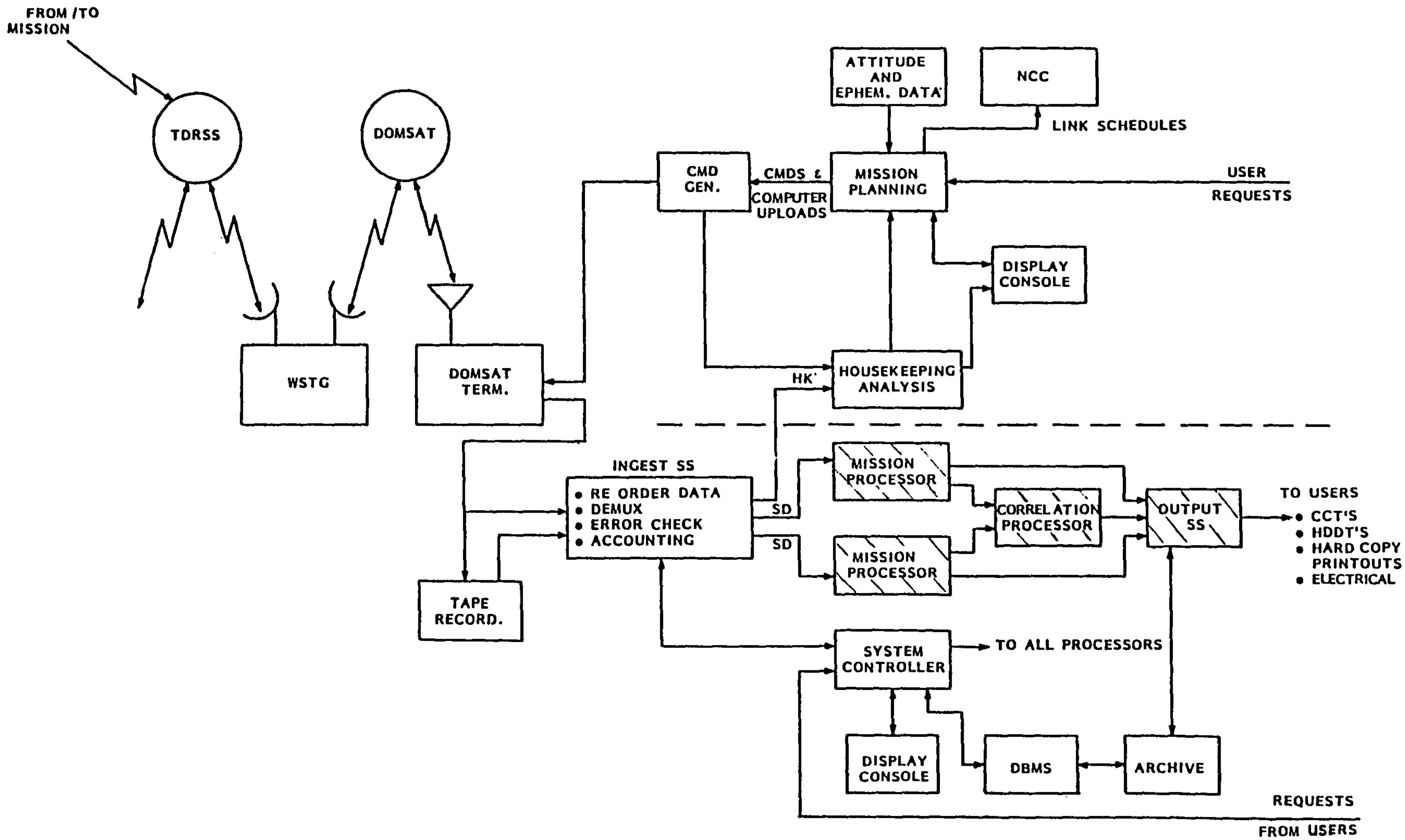


Figure 8.2-1. Ground Segment End-To-End C&DH Subsystem

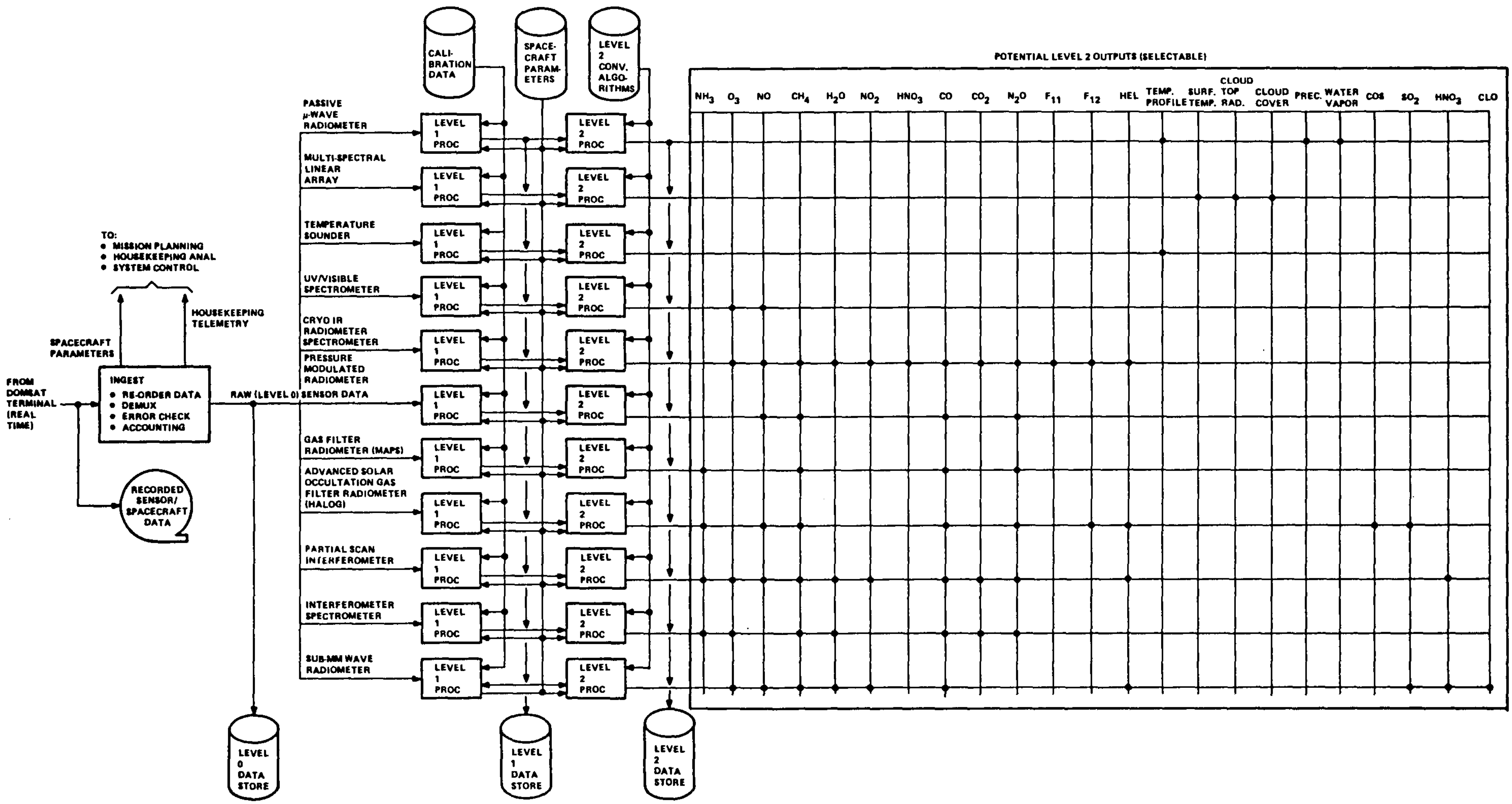


Figure 8.2.1-1A. AOS Ground Data Management Subsystem

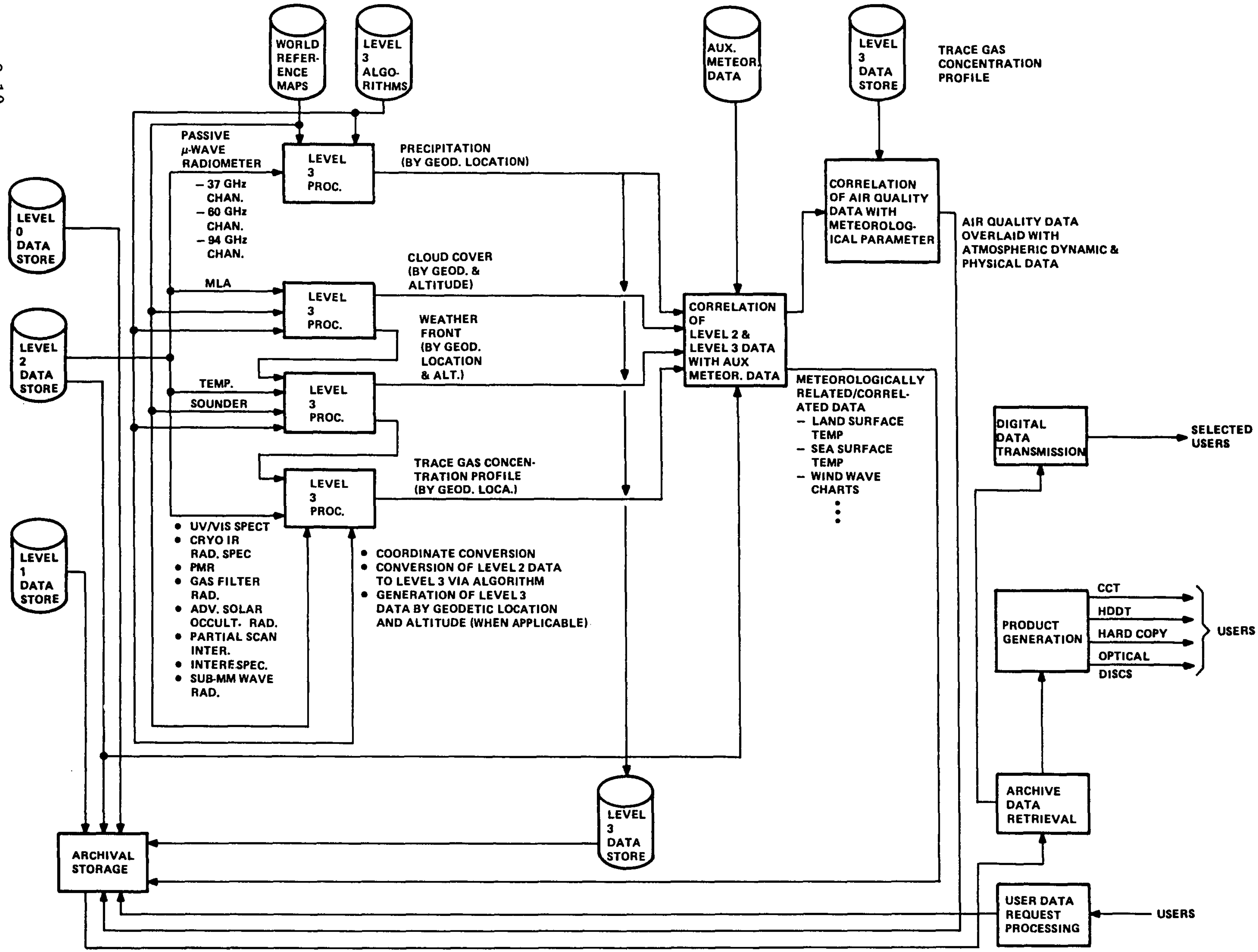


Figure 8.2.1-1B. AOS Ground Data Management Subsystem (Continued)

and no other. Once Level 2 data has been generated, it too will be stored for user retrieval (via the archive).

A point that must be made concerns the algorithms for transforming Level 1 data into Level 2. It is recognized that much work has been done in this area, and that several potentially viable algorithms exist. It is also recognized that the conversion process is a fruitful area for technology pursuit. However, the effort required to identify each and every algorithm and perhaps recommend additional ones, is well beyond the scope of this study; therefore, no further effort will be expended in this area other than to suggest that this might be a potential area for further study.

Through the use of additional algorithms and a standardized World Reference System, Level 2 data will be converted into Level 3 data. These data will include trace gas concentration profiles, by geodetic location, as well as precipitation, cloud cover and weather fronts. They will be stored for future use in a level 3 Data Store. As with the Level 2 algorithms, some work has been done in deriving Level 3 algorithms, but the extent and depth required to evaluate them is beyond the scope of the present study.

Two additional processes are suggested; they involve (1) the correlation of Level 2 and Level 3 data with auxiliary meteorological data (i.e., meteorological data derived from other spacecraft systems, aircraft or ground sensors), and (2) thecorrelation of trace gas concentration profiles with meteorological data as obtained on-board the spacecraft. In each case, the expected output will be a three-dimensional profile of Level 3 data overlaid with atmospheric dynamic and physical data. The correlation function to be performed will require a mathematical analysis of the processes involved in registering non-temporally acquired data in three dimensions. Since the meteorological data will be derived from different sources, coordinate conversions will be performed prior to any convolution or correlation of the data.

These data, along with Levels 0, 1, 2 and 3 data, will be stored in long term archival storage devices, at the discretion of the users.

Any user interested in receiving data collected or derived by the AOS system, will make his desires known to the system. The proper data will then be extracted from the archives, converted to the proper form and format, and delivered to the requestor. The delivery time will depend on the volatility of the data, the nature of the request and the form that the data are to be delivered in. Perhaps 10% of the total data could be delivered within four hours, with the remainder subject to the results of a User Requirements Analysis. Potential output formats might consist of CCT's, HDDT's, hard copy and optical discs (a media expected to be in use during the latter 1980's). Selected users might even have their data transmitted to them over a digital data link, with the actual transmission mode (e.g., satellite link, land line, etc.) being determined by the quantity of the data to be sent and the costs involved.

8.2.2 GROUND DATA MANAGEMENT SYSTEM ASSESSMENT

Our objective at this juncture is to examine the end-to-end data flow described in Section 8.2.1 in an attempt to determine the impact it may make on technology. We will perform this assessment by examining those data system parameters which will aid us in providing a quantitative measure of system capability. As with any system of this nature, there are certain "parameters" that add to the complexity and tend to drive technology. Identification and assessment of those "parameters" will enable us to identify technology needs. In the AOS data system, a measure of data rates, data quantities, processing speeds and algorithm assessment will aid us in our evaluation.

The approach was as follows: we selected one specific sensor (i.e., PMWR - Passive Microwave Radiometer) as a model and where necessary, compared it to a similar sensor (i.e., SMMR - Scanning Multispectral Microwave Radiometer). The SMMR was thoroughly analyzed by NASA, NOAA and DoD in their joint effort on the National Oceanic Satellite System (NOSS) Study and for which a report was issued on 23 March 1979. (We have chosen the SMMR to use as a "comparison sensor" because of its similarity to the PMWR, its overlapping frequencies of operation and the fact that it provides environmental data, albeit on ocean parameters rather than atmospheric parameters). Even though the SMMR is not identical to the PMWR, it is anticipated that data comparison and ratioing of processing speeds, modes and data rates will provide a sufficiently close approximation to allow us to determine the need for technology development.

Once we derived the PMWR data system parameters, we extrapolated them to the entire AOS ground data system.

Prior to making any calculations, however, certain assumptions were made. It should be recognized that these assumptions, although subject to verification, are considered reasonable at this point in time. Further, since they have been used on the joint effort of NASA, NOAA and DoD in their NOSS Study, they do bear some credence in fact.

8.2.3 SIZING OF THE DATA

Assumptions

1. 10% of input data will be processed in two hours (even though four hours may be required; this allows two hours for other processing).
2. 90% of input data will be processed in 18 hours (even though 24 hours may be required; this will allow six hours for other processing).
3. A 32 bit word computer will be used to process the data.
4. An average of 500 operations/words are required for data processing.
5. Level 0, 1, 2 and 3 data plus user required data will be archived for 10 years (as pointed out in Part 1 of the study, related to tropospheric air quality), it may not be necessary to archive Level 0, 1 and 2 data).

Data System Calculations

The input data rate for PMR data is approximately 4.68×10^3 bps, as indicated in Table 8.2.3-1. This means that in a four hour period, a total of 67.4×10^6 bits of data will have been received (this same data rate will result in 4×10^8 bits in 24 hours). This then, results in the following:

a) $\dfrac{67.4 \times 10^6 \text{ bits}}{32 \text{ bits/word}} = 2.1 \times 10^6$ words "to be handled" in two hours

computer word size (assumption #3)

and

$\dfrac{(4 \times 10^8 \text{ bits})}{32 \text{ bits/word}} = 12.5 \times 10^6$ words "to be handled" in 18 hours

Table 8.2.3-1. Storage and Processing Estimates

	INPUT DATA RATE (BPS)		QUANTITY DATA (4 HRS)		QUANTITY DATA (24 HRS)		QUANTITY DATA (10 YRS)		PROCESSING SPEED (PMR SENSOR)			PROC. SPEED ALL SENSORS	PROCESSING SPEED (PMR DATA)			PROC. SPEED (ALL SENSORS)
	PMR SENSORS	ALL SENSORS	PMR SENSORS	ALL SENSORS	PMR SENSORS	ALL SENSORS	PMR SENSORS	ALL SENSORS	NO. 32 BIT WORDS/ 2 HRS	10% PRO-CESSED/ 2 HRS	OPS/ SEC @ 500WDS /OP	APPROX PMR DATA QUAN X 100	NO.32 BIT WORDS/ 18 HRS	90% PROCESSED IN 18 HRS	OPS/ SEC @ 500 OPS/WD	APPROX PMR DATA QUAN X 100
*LEVEL 0	4.68×10^{3}	400×10^{3}	67.4×10^{6}	57.6×10^{8}	4×10^{8}	3.45×10^{10}	1.46×10^{12}	1.26×10^{14}	2.1×10^{6}	$.21\times10^{6}$	14580	1458000	12.5×10^{6}	11.25×10^{6}	86800	8680000
*LEVEL 1			67.4×10^{6}	57.6×10^{8}	4×10^{8}	3.45×10^{10}	1.46×10^{12}	1.26×10^{14}	2.1×10^{6}	$.21\times10^{6}$	14580	1458000	12.5×10^{6}	11.25×10^{6}	86800	8680000
*LEVEL 2			2.4×10^{6}	2.06×10^{8}	14.2×10^{6}	1.23×10^{9}	5.18×10^{10}	4.49×10^{12}	7.5×10^{4}	$.75\times10^{4}$	520	52000	44.6×10^{4}	40.18×10^{4}	3440	344000
*LEVEL 3			2.4×10^{6}	2.06×10^{8}	14.2×10^{6}	1.23×10^{9}	5.18×10^{10}	4.49×10^{12}	7.5×10^{4}	$.75\times10^{4}$	520	52000	44.6×10^{4}	40.18×10^{4}	3440	344000
*USER PRODUCT DATA PROC.			2.4×10^{6}	2.06×10^{8}	14.2×10^{6}	1.23×10^{9}	5.18×10^{10}	4.49×10^{12}	7.5×10^{4}	$.75\times10^{4}$	520	52000	44.6×10^{4}	40.18×10^{4}	3440	344000
								2.65×10^{14} ARCHIVAL STORAGE FOR 10 YRS			30720 OP/SEC FOR PMR DATA (10% IN 2 HRS)	3.072 MOPS OP/SEC FOR ALL SENSOR DATA (10% IN 2 HRS)			184 KOPS OP/SEC FOR PMR DATA (90% IN 18 HRS)	18.4 MOPS OP/SEC FOR ALL SENSOR DATA (90% IN 18 HRS)

*ESTIMATED DATA QUANTITY REDUCTION, AS FOLLOWS:

a) LEVEL 0 → LEVEL 1 - 1:1
b) LEVEL 1 → LEVEL 2 - 28:1
c) LEVEL 2 → LEVEL 3 - 1:1
d) LEVEL 3 → USER PROD. - 1:1

b) applying assumption #1) and 2) (to derive the 10% and 90% figures respectively).

(.1) (2.1×10^6 words) = $.21 \times 10^6$ words in two hours.

(.9) (12.5×10^6 words) = 11.25×10^6 words

c) 500 operations/word (assumption 3.1 d) leads to the following:

$$\frac{.21 \times 10^6 \text{ words}}{2 \text{ hrs.}} \times \frac{1}{60} \times \frac{1}{60} \times \frac{500 \text{ oper}}{\text{word}} = 14580 \frac{\text{oper}}{\text{sec}} \text{ in two hours}$$

$$\frac{11.25 \times 10^6 \text{words}}{18 \text{ hrs.}} \times \frac{1}{60} \times \frac{1}{60 \text{ sec}} \times \frac{500 \text{ oper}}{\text{word}} = 86800 \frac{\text{oper}}{\text{sec}} \text{ in 18 hours}$$

Since we have assumed the same 500 operations/word to go from Level 0 to Level 1, Level 1 to Level 2, Level 2 to Level 3 and Level 3 to user data products, we must sum the above calculations to arrive at a final processing speed. Performing the required summing, results in a processing speed of 30,720 ops/sec for 10% of the data and 184 KOPS for 90% of the data. Thus, a computer with a processing speed of 200 KOPS should be capable of doing all processing required for PMR data. Extrapolating the PMR processing requireents to include all sensors results in a two order of magnitude increase in speed (i.e., 400 Kbps data rate as opposed to a 4 Kbps data rate). This implies that a 21.5 MOPS (i.e., 3.07 + 18.4) processing speed capability would be required. (This figure is consistent with many arrays and parallel processors presently available, and therefore represents no unusual technical challenge).

d) As far as archiving is concerned, the reference sensor (i.e., SMRR of NOSS undergoes a 28 to 1 data reduction in groing from Level 1 to Level 2; Level 3 and user products data quantities remain the same as Level 2. Therefore, for data quantity calculations for all sensors:

1. Level 0 - 400 Kbps or 3.45×10^{10} bits in 24 hrs.
2. Level 1 - 3.45×10^{10} bits in 24 hrs.
3. Level 2 - (1/28 of Level 1) or 1.23×10^9 bits in 24 hrs.
4. Level 3 - (same as Level 2) or 1.23×10^9 bits in 24 hrs.
5. User data (same as Level 2) or 1.23×10^9 bits in 24 hrs.

This results in a daily data quantity of 7.27×10^{10} bits. This means that an archive (assumption #5) of approximately 2.65×10^{14} bits will be required to store 10 years worth of data. Note that this value is consistent with storage capacities of optical disc storage devices expected to be operational by the mid 1980's. No technological challenge is anticipated in this area.

8.2.4 DATA MANAGEMENT SYSTEM ISSUES

The previous analysis raised several issues which should be addressed and solved prior to configuring an AOS Data Management System. Several of them, summarized in Table 8.2.4-1 require analysis, but do not represent a severe technical challenge. However, some of them, as discussed below do require further effort.

8.2.4.1 Algorithms Required to Convert from Level 1 to Level 2

While much is known concerning these algorithms, much remains to be done concerning atmospheric effects. The impact of variables, such as aerosol effects of the atmosphere, effects of thin clouds or partial cloud cover should be further investigated to determine their contribution to deviations from what is known. Error analysis can be expected to quantize these deviations such that empirical solutions will result in models of the real world which can be used with confidence to convert from Level 1 to Level 2. As one would expect, different algorithms would be required for each of the sensors.

8.2.4.2 Algorithms Required to Convert From Level 2 to Level 3

Less is known about these algorithms due to the fact that they are concerned with "optimizing" temperature profile measurements and correlating these results with local terrain data. The techniques by which optimization and correlation takes place must be examined and solutions derived.

8.2.4.3 3D Correlation of Air Quality and Meteorological Parameters

Correlation of atmospheric parameters in 3D space is a subject which has received some attention, but much remains to be done before a "real-time" algorithm can emerge. The geometry inherent in viewing the same space from two (or more) aspect angles results in variable "solid sectors" which change with respect to altitude being viewed, viewing angle and altitude of sensor. The complex relationship of variables involved must be investigated.

Table 8.2.4-1. Data Management Issues

ISSUES	POTENTIAL AREAS OF INVESTIGATION	ANALYSES REQUIRED
ALGORITHMS REQUIRED TO CONVERT FROM LEVEL 1 TO LEVEL 2	USE FOLLOWING MEASUREMENTS TO AID IN DERIVATION OF ALGORITHMS • AEROSOL EFFECTS • EFFECT OF THIN CLOUDS • PARTIAL CLOUD COVER (e.g. 1-15%)	• MODELING OF ATMOSPHERIC EFFECTS OF RADIANCE MEASUREMENTS • ERROR ANALYSIS
ALGORITHMS REQUIRED TO CONVERT FROM LEVEL 2 TO LEVEL 3	• USE OF TEMPERATURE PROFILE MEASUREMENTS • CORRECT FOR LOCAL TERRAIN	• MODELING OF ATMOSPHERIC EFFECTS ON TRACE GAS CONCENTRATION MEASUREMENTS • ERROR ANALYSIS
3D CORRELATION OF AIR QUALITY WITH METEORLOGICAL PARAMETERS	• CORRELATION WITH MET. DATA FROM SYSTEMS EXTERNAL TO AOS • CORRELATION WITH MET. DATA FROM THE SAME SATELLITE	• DETERMINATION OF EFFECTS OF NON-SIMULTANEOUS MEASUREMENTS • MATHEMATICAL TECHNIQUES FOR CONVERTING FROM ONE COORDINATE SYSTEM TO ANOTHER
ARCHIVAL STORAGE	POTENTIAL OPTIONS ARE: o HDDT o OPTICAL DISCS o MICRO-FICHE/MICHRO-FILM	• OPTICAL DISC SELECTION/ RECOMMENDATION • NOAA/NESS ARCHIVAL UPDATE PLANS
TYPE & FORMAT OF DATA DELIVERED TO USER	POTENTIAL OPTIONS ARE: • LEVEL 1/2/3 DATA • LEVEL 1/2/3 DATA + MAPS OF AIR QUALITY OVERLAID WITH MET. DATA	• USER REQUIREMENTS ANAL. • COST OPTIMIZATION • QUANTITY OF USERS vs. EXTENT OF PROCESSING DESIRED
ON-BOARD vs. GROUND CONTROL	POTENTIAL OPTIONS ARE: • ON-BOARD ADAPTIVE PROCESSING • GROUND INTER-ACTIVE CONTROL	COST/TECHNOLOGY OPTIMIZATION - REAL TIME DATA RETURN - STATUS OF ON-BOARD PROCESSING TECHNOLOGY - SOPHISTICATION OF ADAPTIVE CONTROL ALGORITHMS - SPACECRAFT/GROUND CONTROL LOOP TIME
THROUGHPUT/RESPONSE TIME	POTENTIAL OPTIONS ARE: • {10% in 4 HOURS, 90% in 24 HOURS} • {10% in 4 HOURS, 40% in 24 HOURS, 50% in 72 HOURS}	• USER REQUIREMENTS ANALYSIS • PROCESSING ALTERNATIVES - GENERAL PURPOSES COMP. - SPECIAL PURPOSE COMP. - ARRAY/PARALLEL PROG. - HYBRID

SECTION 9
TECHNOLOGY ASSESSMENT

Previous sections have dealt with the measurements (ref. Section 3), sensors (ref. Section 4), missions (ref. Section 5, 6 and 7), and data management necessary to address the Knowledge Objectives. Throughout the process of constructing this AOS mission model, we have identified areas of developmental need. Some of these developments were considered technological, since they entailed advancements in the state-of-the-art, while others were judged to require engineering development effort. In this section, we identify the areas that were considered actual technology needs during the previous analyses, describe the technology requirements and assess the relative priority within each type of technology.

9.1 TECHNOLOGY CATEGORIZATION

The technology requirements fall within five distinct categories, according to their relationship to the overall system and missions. The categories are as follows:

1. New Measurement Technique - These involve methods of measurement, passive or active sensors, and correlations of data obtained through different modes.
2. Passive Sensors - sensors that detect naturally emitted or reflected/absorbed radiation.
3. Active Sensors and Sources - sensors or components thereof, which utilize laser or active microwave sources.
4. Information Management - technology needs associated with the system's end-to-end data system.
5. Spacecraft and Space Assembly - technology needs related to the spacecraft which provides sensor accommodation and operational support.

9.2 DESCRIPTION OF THE TECHNOLOGY NEEDS

Table 9.2-1 shows the technology needs, listed according to their corresponding categories. (This table was included in the Summary, Section 2). Following is a technology requirement summary for each of the items in Table 9.2-1. In addition to the technology category, identification number and item name, we have listed the "Source/Origin" of the requirement, which

Table 9.2-1. List of Potential Technology Needs for AOS Multidisciplinary Missions

A) NEW MEASUREMENT TECHNIQUES

1. TECHNIQUES FOR INCREASING VERTICAL RESOLUTION IN TROPOSPHERIC CONCENTRATION MEASUREMENTS.
(e.g. LIMB MEASUREMENTS IN UPPER TROPOSPHERE)

2. MEASUREMENTS OF WIND VECTORS USING LASER HETERODYNE SPECTROMETRY

3. IMPROVED MEASUREMENT OF H_2SO_4, HSO_3, H_2S

4. CORRELATION OF GROUND & SPACE OBSERVATIONS OF THE EFFECTS OF AIRCRAFT ACTIVITY (i.e., O_3, NOx, CO)

5. MEASUREMENT OF PRECIPITATION PARAMETERS

6. SPATIAL CORRELATION OF NADIR AND LIMB DATA

B) PASSIVE SENSORS

7. PASSIVE MICROWAVE RADIOMETER WITH FIXED, SHAPED REFLECTOR

8. OPTICS FOR WIDE F.O.V. SENSORS COUPLED WITH MULTISPECTRAL LINEAR ARRAYS

9. 360^{o} - SCAN LIMB SENSORS

10. IMPROVED SOLAR SHIELDING FOR PASSIVE SENSORS

Table 9.2-1. List of Potential Technology Needs for AOS Multidisciplinary Missions (Continued)

C) <u>ACTIVE SENSORS & SOURCES</u>

11. LIDAR TECHNIQUES FOR FAINT SPECIES IN THE STRATOSPHERE
12. DOPPLER RADAR FOR PRECIPITATION MEASUREMENTS
13. BI-STATIC LIDAR MEASUREMENTS
14. SUB-MILLIMETER WAVE SOURCES

D) <u>INFORMATION MANAGEMENT</u>

15. ALGORITHMS FOR AOS LIMB DATA
16. 3-D CORRELATION OF AIR QUALITY AND METEOROLOGICAL PARAMETERS
17. INTERACTIVE AND ADAPTIVE MISSION CONTROL

E) <u>SPACECRAFT & SPACE ASSEMBLY</u>

18. PRECISE ATTITUDE CONTROL FOR LIMB MEASUREMENTS
19. ASSEMBLY OR DEPLOYMENT OF LARGE PASSIVE MICROWAVE ANTENNA ARRAY

indicates where and why the requirement originated. Also shown is a description of the technology development including the scope and salient development information.

9.2.1 TECHNIQUES TO INCREASE VERTICAL RESOLUTION IN TROPOSPHERIC MEASUREMENTS

Technology Category: New Measurement Techniques

Item No.: 1

Source/Origin: Many investigations in the AOS Program will involve measurements of vertical distribution of trace species from the surface through the upper atmosphere. Analysis of this requirement indicates that the technology need is restricted to the lower atmosphere. Although LIDAR potentially will meet this requirement in several of the trace species of interest, it will not be operationally available in the early timeframe for AOS and probably will not be suitable for tropospheric measurements of certain species. Limb measurements will be suitable in the upper atmosphere and possibly in the upper troposphere, but heretofore have been considered infeasible in the lower troposphere.

Description of the Technology Development

The problem to be solved by this development is the passive measurement of tropospheric concentrations of trace gases close to the desired 1 km resolution. It has been indicated that the resolution may be needed in the boundary layer is nominally from 0 to 2 km altitude.

During the AOS - Part I Study, it was estimated that most of the radiometric and spectrometric measurements in the nadir and off-nadir-looking mode (employing Earth radiance as a source) will produce total-burden readings, or at best, differentiate two or three layers in the troposphere. In order to improve the vertical resolution, several basic techniques will require investigation. The first of these involves the extension of the limb sensing technique into the upper troposphere both in the emission mode and solar occultation mode. The latter technique may be more promising due to the higher sensitivity afforded by the high intensity solar source.

Another approach which is used extensively in temperature sounding applications is the use of inversion techniques employing multiple wavelengths for the same specie. This may involve one instrument operating in multiple wavelengths or several instruments; it is envisioned that a set of multi-spectral instruments may be capable of handling a set of concentration profiles for various species.

High spectral resolution measurements may feature prominently in this technology development, since line shape is an important discriminator in terms of altitude. Thus, interferometric and laser heterodyne spectrometry may be used to define the spectral shape of several absorption and/or emission lines for a particular gas being measured.

9.2.2 MEASUREMENT OF TROPOSPHERIC WIND VECTORS USING LASER HETERODYNE SPECTROMETRY

Technology Category: New Measurement Techniques

Item No.: 2

Source/Origin: Wind affects atmospheric transport and diffusion processes and thus is important in understanding the distribution of trace gases and aerosols. Most of the Knowledge Objectives identified in Section 3.1 require this measurement.

Description of the Technology Development

Passive sensing techniques for measuring three-dimensional wind sectors depend upon doppler measurements of the natural electromagnetic frequency shift of radiation emitted by or absorbed/transmitted by a specific gas. Several problems are encountered is such measurements:

1. The ratio of doppler frequency shift to the signal frequency is very low, for instance, a 3 m/sec. wind will cause a doppler frequency shift of 3 MHz at a wavelength of one micrometer; thus, the ratio of delta-f/f = 10^{-7}. This places stringent requirements on the spectral resolution of the instrument; for instance, a resolution of approximately 10^{-4} to 10^{-5} Angstrom would be needed in the example cited above.

2. Pressure broadening in the mid and lower troposphere makes the measurement of doppler shift difficult. Ideally, a line width less than or equal to the desired spectral resolution is required.

3. The need to measure wind at specific altitudes necessitates careful selection of specific lines associated with the altitude layers.

The general specification for wind measurements in this application is as follows:

Wind speed range:	1 meter/sec to 50 meters/second
Wind direction range:	0-360 degrees
Vertical resolution:	1 km from 0-20 km altitude 3 km from 20-100 km
Wind speed accuracy:	25%
Wind direction accuracy:	10^{o}

The measurement technique required for this application must solve the aforementioned problems associated with very high spectral resolution, pressure broadening, and altitude discrimination. A solution to the first of these problems is possible through the development of a high spectral resolution instrument which is an advanced version of current interferometers or heterodyne spectrometers. The last two problems require careful analysis and laboratory investigation to arrive at a suitable selection of lines in different portions of the visible or near IR spectrum where the ambiguities due to pressure broadening and non-homogeneous vertical distribution of winds can be resolved. It is doubtful whether the measurements will be possible at very low altitudes in the troposphere (e.g., boundary layer); however, it will be beneficial to be able to measure winds with a significant portion of the troposphere, as well as the upper atmosphere.

The state of the art in instrumentation for upper atmospheric winds is typified by three instruments under development:

1. "Michelson Interferometer" by Service d'Aeronomie du CNRS, France. This instrument uses a Cassegrainian Telescope with the Michelson Interferometer and operates in the visible region of the spectrum.

2. "High Resolution Doppler Imager" (HRDI) by the Space Physics Research Laboratory, University of Michigan. The heritage for this instrument resides in the Fabry-Perot Interferometer which was developed for the

Dynamics Explorer Satellite. The HRDI operates in the 0.3 to 1.0 micron region and utilizes three Fabry-Perot Interferometers to attain a high spectral resolution that is compatible with characteristic spectral widths of emission lines in the upper atmosphere.

3. "Laser Heterodyne Spectrometer" (LHS).

   Higher spectral resolutions than those attainable with interferometers can be achieved through the Laser Heterodyne Spectrometer (LHS). The current version of the LHS is designed for measuring trace species concentration and altitude distribution. Its spectral resolution is 10^{-4} to 10^{-2} cm^{-1} and it operates in the thermal infrared spectral region. For Doppler measurements, shorter wavelengths will be desirable; for instance, in the visible region of the spectrum. The stability of the laser local oscillator will be important since any drift will degrade the accuracy of the Doppler measurement.

9.2.3 IMPROVED MEASUREMENT OF SULFUR COMPOUNDS: H_2S, H_2SO_3, SO, SO_3

Technology Category: New Measurement Techniques

Item No.: 3

Source/Origin: This requirement is associated with Knowledge Objective No. 2, Atmospheric Sulfur Pollution, with emphasis on understanding the Chemical Conversion of SO_2 to H_2SO_4 in connection with the acid rain problem.

Description of the Technology Development

The concentration of the subject compounds in the atmosphere is low, giving rise to sensitivity problems in the measurement of concentration profile, typically requiring 10% accuracy, with vertical resolution of 1 KM in the troposphere and 2 KM in the lower stratosphere. For instance, atmospheric gaseous burden within a 1 KM resolution element for H_2SO_4 is approximately 4×10^{-5} atm-cm, and for HSO_3 it ranges from 4×10^{-8} to 4×10^{-6}. The problem is aggravated by the lack of detailed spectral definition available for species such as HSO_3, H_2SO_4.

Due to the need for high sensitivity, broad band techniques such as gas filter radiometry may be attractive for this application; however, some of the sulfur compounds will not remain stable inside the gas cell.

Partial scan correlation interferometry has the potential for performing these measurements due to the relatively large optical field of view, and thus a large input signal power can be incorporated into the design as compared with a conventional interferometer. This advantage is afforded by the "field widening" technique, in which the measurement's sensitivity to the difference in interferometric path between the edge of the field and its center can be minimized.

9.2.4 CORRELATION OF GROUND AND SPACE OBSERVATIONS OF THE EFFECTS OF AIRCRAFT ACTIVITY

Technology Category: New Measurement Techniques

Item No.: 4

Source/Origin: Knowledge Objective No. 5 relates to the determination of the effects of high-flying aircraft, particularly the effects on the distribution of nitrogen oxides, hydrocarbons and carbon monoxide, as well as the depletion of ozone.

Description of the Technology Development

The requirement that constitutes an advanced development is to attain an accuracy of location of each volume resolution element within one hundredth of an element (e.g., 100 KM pixel within 1 KM). Following is the rationale for this need.

Horizontal resolutions of less than one kilometer are needed in connection with the observations of gas concentrations in the aircraft contrails. In addition, these measurements will be required at very frequent intervals during periods of high air traffic in the designated commercial air lanes. These observations may be classified as "local" and do not fit the category of global and sub-global measurements that will make use of space remote sensor platforms. Ground based and airborne sensors are more suitable in these detailed measurements; however, these measurements need to be correlated with synoptic data from satellites, such as wind and other meteorological data, to permit an assessment of the gas transport and diffusion processes. The problem that needs to be solved is the spatial/temporal correlations of high resolution ground and aircraft data on concentration and meteorology, with coarser resolution measurements from space in the vicinity of the aircraft air lanes. The observations need to be scheduled so that the satellite data can be interpreted relative to the ground data. The resulting "overlay" must establish precisely the boundaries of the contrail path, and concentrations at various distances for the contrail.

9.2.5 MEASUREMENT OF PRECIPITATION PARAMETERS

Technology Category: New Measurement Technique

Item No.: 5

Source/Origin: Precipitation measurements support Knowledge Objective No. 2, Atmospheric Sulfur Pollution, specifically as it relates to the acid rain problem. In general, it relates to Knowledge Objective No. 2, Meteorological Effects on Atmospheric Composition particularly with respect to vertical transport.

Description of the Technology Development

Precipitation is an important factor in the transport process of trace species, as evidenced by HNO_3 and H_2SO_4 purging during precipitation events. The transport situation is not well understood particularly in large scale phenomena where meteorological conditions are appropriate for gas/aerosol reactions and chemical product washout.

In order to understand the role of precipitation and clouds upon gas transport, the following measurements are needed:

1. Precipitation Rate.
2. Type: Rain Snow, Hail.
3. Vertical Profile of H_2O.
4. Size Distribution.
5. Cloud Thickness.

At the present time remote sensing measurements, both active and passive, in the microwave region are capable of providing information about precipitation and related phenomena. It is important, however, to note the following observations:

1. Atmospheric snow, hail and ice crystals cannot be detected.

2. Size distribution of snow, hail, ice crystals or water droplets cannot be measured. They can only be inferred from well-known distributions such as the Marshall-Palmer one.

3. Vertical profiles can only be determined with active sensors.

At the present time passive sensors can detect only the temperature profile and the total integrated content of water vapor liquid, water content and rain rate. There is some evidence to support the conjecture that by extending the technology into the 100 GHz region, vertical profiles may be obtained through inversion techniques. A brief description of the presently available techniques follows.

Active Sensors

Generally, radars require two independent measurements in order to detect the rain rate, R: the reflectivity factor Z and the attenuation rate K. This can be accomplished by: a) a dual wavelength radar by which both K and Z are measured, b) dual polarization in which Z is measured with two orthogonal polarizations thus permitting K to be inferred. Single parameter techniques are also capable of providing rainfall estimates, however they are not as reliable as those of the dual parameter ones.

Passive Sensors

The sensing of precipitation phenomena by passive radiometric means has continuously been evolved and is now at a high level of maturity. Table 1 indicates the sensing capabilities of a number of presently available and proposed passive systems. There are, however, a number of salient features common to all sensors that should be pointed out. In general the ground resolution of the passive systems as compared to the active ones is poor. For example, the ESMR of the Nimbus 6 is capable of only 25 x 25 KM resolution cell. In the 100 GHz region, for the present size of antennas, resolutions will be of the order of 2 by 2 km.

Although passive systems measure the upwelling radiance, it is possible through inversion techniques to derive the profiles of the atmospheric temperature and infer the three-dimensional wind distribution. For the case, however, of the liquid water content and precipitation profile inversion is not presently possible. The available techniques provide only the total integrated water vapor, liquid content and at best the effective rain rate. There is evidence to support the conjecture that in the measurements in the vicinity of the 118 GHz a water absorption line may be useful for profile inversion. More research, however, is needed to further clarify the proposed sensing concepts.

Table 9.2.5-1 shows a comparison of measuring parameters for precipitation, as compared with those of other atmospheric measurements.

9.2.6 SPATIAL CORRELATION OF NADIR AND LIMB DATA

Technology Category: New Measurement Techniques

Item No.: 6

Source/Origin: The multidisciplinary AOS will perform concurrent measurements of the upper and lower atmosphere. Upper atmospheric measurements will be made primarily in the limb mode, while those of the lower atmospheric will be Earth-looking in the nadir/off-nadir mode. These measurements must be spatially and temporally correlated, to determine the overall distribution of trace species and the transport and diffusion processes.

Description of the Technology Development

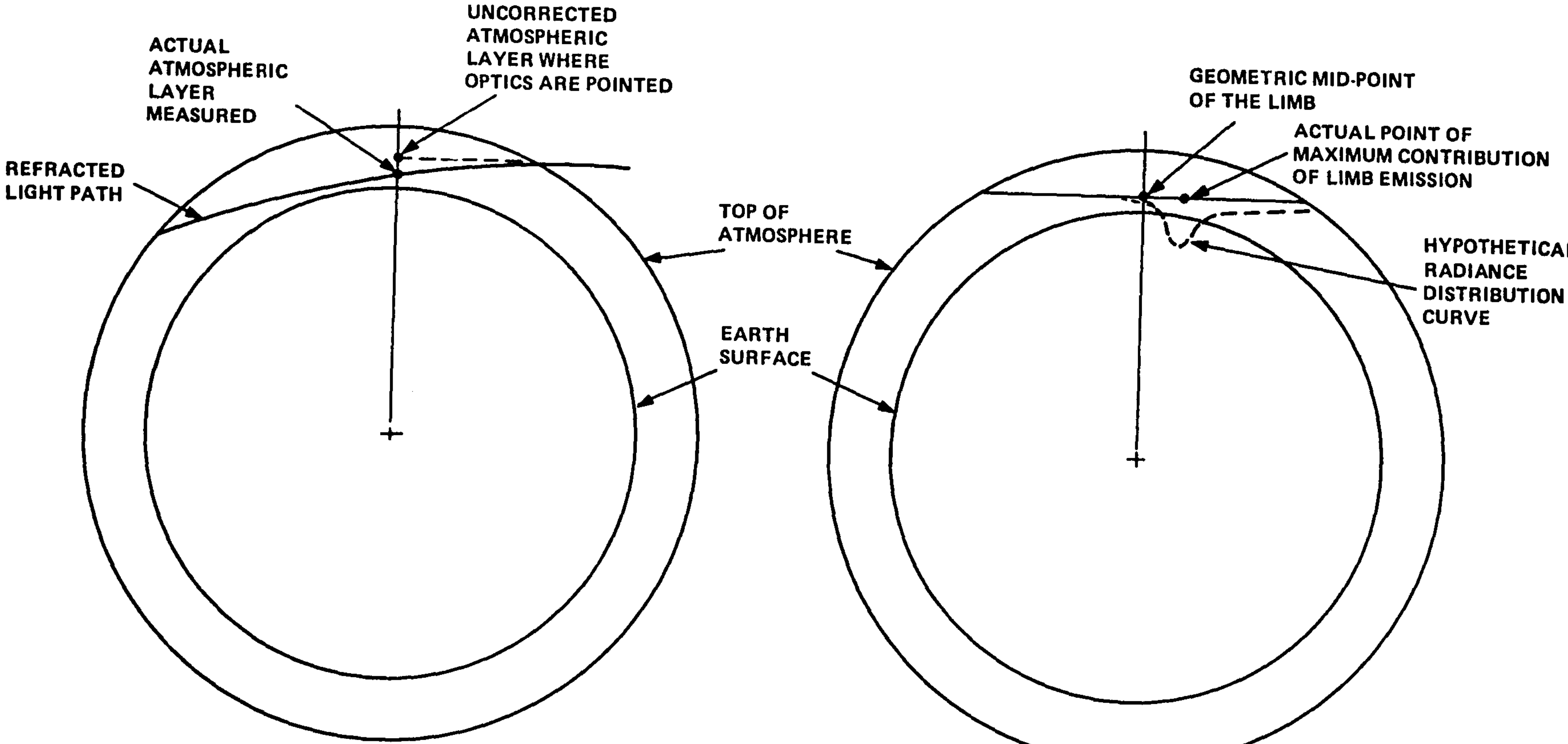
The problem arises from the atmospheric distortions that need to be corrected in order to obtain good registration between limb and nadir/off-nadir data. One of these distortions is due to atmospheric refraction, which can bend the light thus increasing the path-length as much as 30%. In addition, to path-length effects, refraction causes a change in the apparent atmospheric layer observed during profiling measurements, as illustrated in Figure 9.2.6-1.

The second distortion is due to the unsymmetrical contribution of emitted radiance, as sensed at the satellite position, from the entire length of the limb. Specifically, there is a bias tending to shift the region of maximum energy kcontribution towards the satellite. See Figure 9.2.6-1.

A reasonable specification for the accuracy of correlation of the resolution elements is 25% of the smallest linear dimension. For instance, if we were to correlate along the vertical (or Earth-radial) direction a nadir measurement

Table 9.2.5-1. Measurement Parameters Using Passive Sensors

Geophysical Parameter	Sensing Concept	Frequency	Accuracy	Status	Ground Resolution	Comments
Integrated Water Vapor	Vertical Sounding	22.235 GHz and 31.4 GHz	.4 gm/cm^2	Nimbus5 and 6	190 KM with NEMS 150 KM with SCAMS	Over water only
Water Vapor Profile	Vertical Sounding	183 GHz	20%	Proposed Concept		
Liquid Water Content	Vertical Souning	22.235 GHz and 31.4 GHz	.006gm/cm^2 over ocean .012gm/cm^2 over land	Nimbus5 NEMS	190 KM	Effective over water
Precipitation	Vertical Sounding	19.35 GHz	A factor of2 range 1-25 mm/hr	Nimbus 5 ESMR	25 KM	
Precipitation	Vertical Sounding Dual Polar.	37 GHz		Nimbus 6 ESMR	25 KM	
Temperature Profile	Profile Inversion	52.8,53.8 and 55.4 GHz	20 KM Vert.	Nimbus 6 SCAMS	150 KM	Land and Water
Wind Profile	Derived from Temp. profile Doppler Shift in Limb Geometry					
Pressure	Vertical Sounding	Two Frequencies over the pressure broadened wings		Concept Stage		



A

DISTORTION IN VERTICAL
POSITION OF THE LIMB-MEASURED
RESOLUTION ELEMENT,
DUE TO REFRACTION

(EMISSION OR SOLAR OCCULTATION)

B

DISTORTION IN HORIZONTAL
POSITION OF THE LIMB-MEASURED
RESOLUTION ELEMENT,
DUE TO LACK OF SYMETRY

(EMISSION ONLY)

Figure 9.2.6-1. Limb Geometry

of an atmospheric layer 5 km thick with a limb measurement of two km in thickness, the centers of the two elements would need to be located within 1.25 km. Similarly, if the smallest length among the two resolution elements is 100 km, the elements would need to be located within 25 km.

The technology advancement will consist in the formulation of detailed models for determining the geometric corrections to the data to compensate for the two atmospheric effects described above. These detailed models should consider the actual index of refraction, as well as the overall concentration burden, along the line of sight. A precursory error analysis is needed to determine whether the models need to factor in the most recent measurements being gathered by the AOS at that time, or whether the values from an average atmospheric model can be used in the calculations.

9.2.7 PASSIVE MICROWAVE RADIOMETER WITH FIXED, SHAPED REFLECTOR

Technology Category: Passive Sensors

Item No.: 7

Source/Origin: The AOS multidisciplinary mission requires the correlation of meteorological parameters, such as precipitation, with gas species concentration data. The subject radiometer will provide data on water vapor, heavy/light precipitation, temperature sounding.

Description of the Technology Development

The antenna configuration associated with the generic passive microwave radiometer for this application is an array of shaped dual reflectors which cover a field-of-view of 102^{o}. A fixed, electronically scanning antenna array has been baselined, as compared with a mechanically scanning antenna, to increase reliability and avoid sizeable vibrational perturbations.

The following areas represent potential technological advances necessary in the development of the radiometer:

1. Optimization of the shaped dual reflector optics geometry must be attained within the constraints imposed by the requirements for a very wide field of view (i.e., 102^o). Specifically, the definition of the surfaces must be developed on the basis of the criteria (yet to be defined) concerning the system's geometric optical aberrations.

   Although considerable development is in process concerning shaped dual reflectors, the state-of-the-art is not considered sufficiently mature to support routine development of a radiometer for this application. Items that make this a challenging development are the wide field-of-view (i.e., 102^o), the multiple frequency utilization (i.e., 21-94 GHz). Figure 4.3-4, in Section 4 show a basic configuration of the array.

2. Based on the selected optics configuration, the multimode radiating elements and/or cluster of elements needs to be developed.

3. Methods of construction and thermal control of reflector surfaces will be required with maximum dimensions of four (4) meters and rms surface accuracies of $\lambda/80$. Most technologically challenging is the 94 GHz reflector for the 2500 km altitude mission (Mission #4). Here the wavelength is 0.319 cm, and the $\lambda/80$ criteria yields 0.004 cm rms accuracy for a 242.7 cm diameter reflector. This results in a D/delta (diameter to surface) accuracy ratio of 6×10^4; however, the subreflector surface accuracy generally has to be twice as good as that for the main reflector, in this case 0.002 cm and a D/delta approximately 4×10^4.

9.2.8 OPTICS FOR WIDE FIELD-OF-VIEW SENSORS COUPLED WITH MULTISPECTRAL LINEAR ARRAYS

Technology Category: Passive Sensors

Item No.: 8

Source/Origin: This development supports AOS measurements with passive push-broom sensors requiring frequent global surveys (e.g., once/day or more frequently). The generic sensors for the multidisplinary missions which require wide swaths, in the order of 100^o, coupled with linear detector arrays are:

1. Multispectral Linear Array (MLA).

2. Gas Filter Radiometer.

3. Temperature Sounder.

Description of the Technology Development

The design concept for the wide swath MLA was discussed in Section 4.1. The optics will be of the concentric type, where image quality is not degraded by field of view. Figure 9.2.8-1 illustrates the focal plane array concept. Image quality considerations will require a Schmidt or Bouwers corrector, either reflective or refractive. While the use of concentric optics is not, in itself, a new technological development, the application to multi-spectral push-broom imagers requires technological advancement, particularly in the following areas:

1. Wavelength separation for the multispectral channels. Due to the geometric constraints of the concentric optics, use of beam-splitters (e.g., dichroic mirrors) will be complicated considerably as compared to its use in more conventional, non-concentric optics. A possible approach to circumvent this difficulty is to use filters that are an integral part of the detectors. This would require that precise filter material deposition or attachment be included in the manufacture of the detectors.

2. Gas filters, as required for radiometry, will also require placement in the immediate vicinity of the detectors. The gas filter radiometer utilizes a gas cell containing the gas of interest as a spectral filter. The cell, therefore, must have a significant thickness to afford the required gas path length.

3. A curved focal plane will be required, thus complicating the assembly/alignment of the discrete detectors. The curvature of the cylindrical focal surface (or spherical in the case of a two dimensional array) is comparatively small, typically 14 cm.

9.2.9 360^{o} SCAN LIMB SENSORS

Technology Category: Passive Sensors

Item No.: 9

Source/Origin: The limb mode, sensing emission, is a primary means of passively measuring upper atmospheric species concentration profile. Many of the Knowledge Objectives relating to the upper atmosphere require frequent global coverage (e.g., twice per day) and adequate diurnal sampling. Use of a single limb orientation makes it impossible to attain that frequency of coverage. Adding one or more limb orientations, either in a time-sharing mode or with simultaneous sensing can increase the coverage; and, continuous

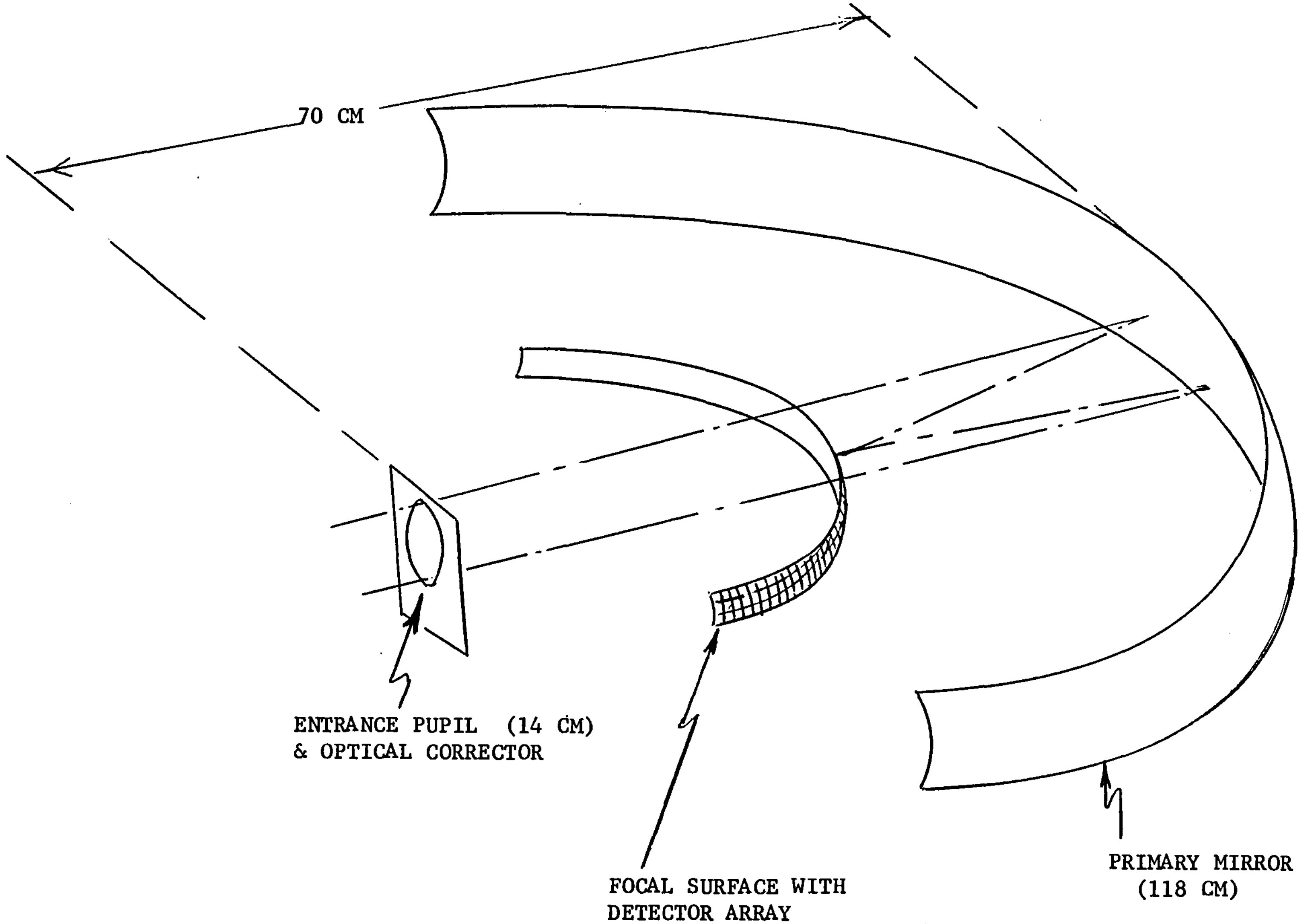


Figure 9.2.8-1. Concentric Optics of Multispectral Linear Array

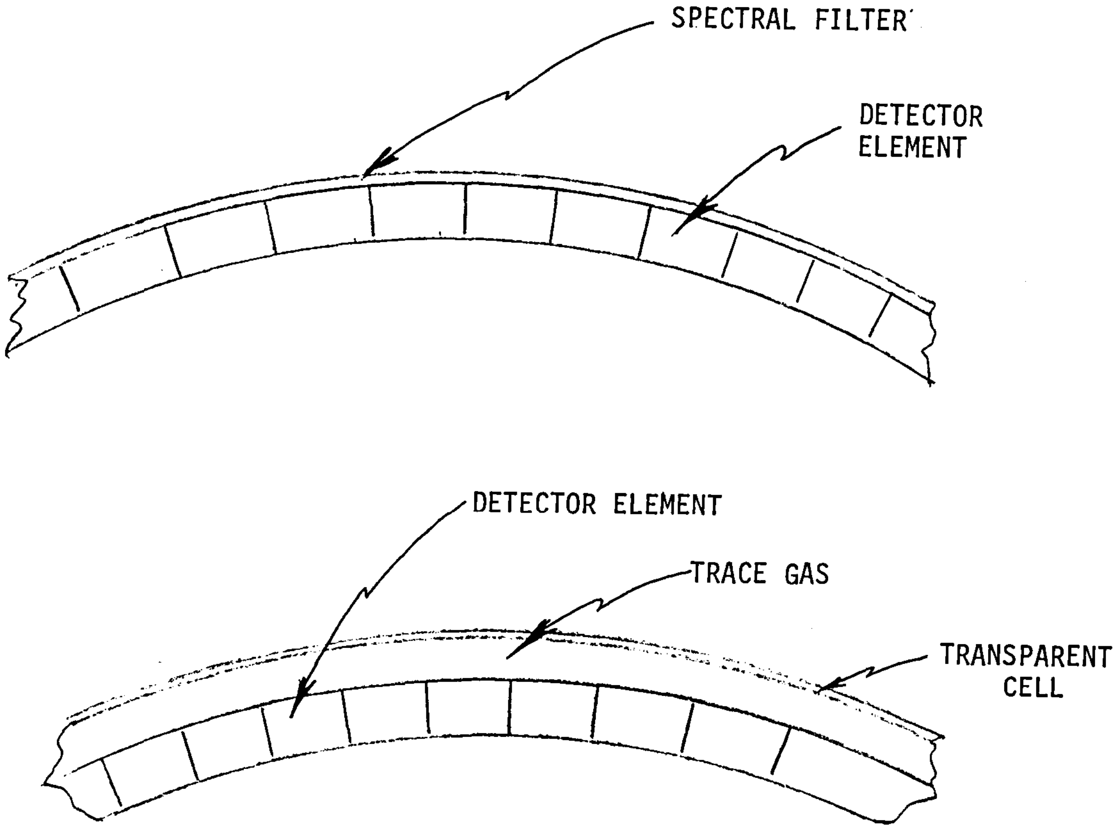


Figure 9.2.8-2. Focal Plane Array Spectral Filtering

(360^o) azimuth pointing can provide the enhanced coverage needed in the Atmospheric Observation System.

It is possible to attain high vertical resolutions, due to the fact that the major radiation contribution comes from the portion of the limb near the tangent height. To do so, the sensors must accept the small instantaneous fields-of-view associated with thin atmospheric layers, which are nominally 1 km thick, and the sensor optics must be precisely pointed to permit proper spatial registration of the various atmospheric layers.

Description of the Technology Development

Missions No. 2 and 4 serve to characterize the pointing requirements for limb measurements. The most stringent requirement is 0.0012^o or 0.02 milliradian, corresponding to the intermediate orbit of 2500 km (Mission No. 4). This requirement is based on a sensor pointing error contribution equivalent to 100 meters in elevation, referenced to the geoidal horizon.

The state-of-the-art in limb sensor pointing accuracy is typified by the sensors (now under development) for the Upper Atmospheric Research Laboratory (UARS). The High Resolution Doppler Imager, for instance, requires three arc-minutes pointing accuracy and 36 arc-seconds knowledge of pointing. However, the pointing problem for AOS is more complex, due to the 360^o (rotating) scan mode, which requires that the sensor be maintained within the prescribed accuracy (typically 36 arc-seconds) relative to the attitude reference during the complete 360^o angular excursion.

9.2.10 IMPROVED SOLAR SHIELDINGS FOR PASSIVE SENSORS

Technology Category: Passive Sensors

Item No.: 10

Source/Origin: Atmospheric emission sensors requiring cooled optics and detectors are susceptible to damage and/or calibration degradation due to solar radiation during measurements where the field-of-view is directed near the solar line-of-sight. The usual countermeasures are to specify a large region of exclusion, that is, an angular range where the sensor would not be able to point or where data would not be acquired. It is desirable to minimize this region of exclusion while providing adequate protection to the instrument and the accuracy of the data.

Description of the Technology Development

Shielding is required for both limb emission measurements and off-nadir requirements. The 360^{0} scan limb sensors will be particularly susceptible due to the high incidence of solar interference during periods near Sunrise and Sunset (precisely when solar occultation measurements are feasible). Off-nadir sensors should be protected during events when the near-horizon solar line-of-sight is nearly coincident with the sensor scan plane (usually the X-Z plane). These conditions are illustrated in Figure 9.2.10-1.

Passive means of shielding include collimation through conventional hoods or baffled solar shields. The nature of the baffling can be tailored to the geometric constraints of the observation, and wavelength and thermal sensitivity of the detectors and optics. Active methods include variable-geometry baffles and/or cooled shielding. The technology challenge consists in developing shielding techniques that are specifically suited to the needs of limb and off-nadir looking instruments, while meeting the system requirements of lightweight and low cost.

9.2.11 LIDAR TECHNIQUES FOR FAINT SPECIES IN THE STRATOSPHERE

Technology Category: Active Sensors

Item No.: 11

Source/Origin: Measurements of stratospheric concentration of trace species can be performed with the required vertical resolution using passive techniques in the "limb" mode. However, the limb mode has limitations with respect to providing horizontal resolutions in the order of 100-200 km, and establishing sufficient sensitivity to support accuracies of 10% for some species, as specified in Section 3. Lidar represents the most promising way to fill these requirements in the mid 1990's, however, present LIDAR techniques are also limited in measuring certain faint species by virtue of their line strengths, attenuation and/or interferences.

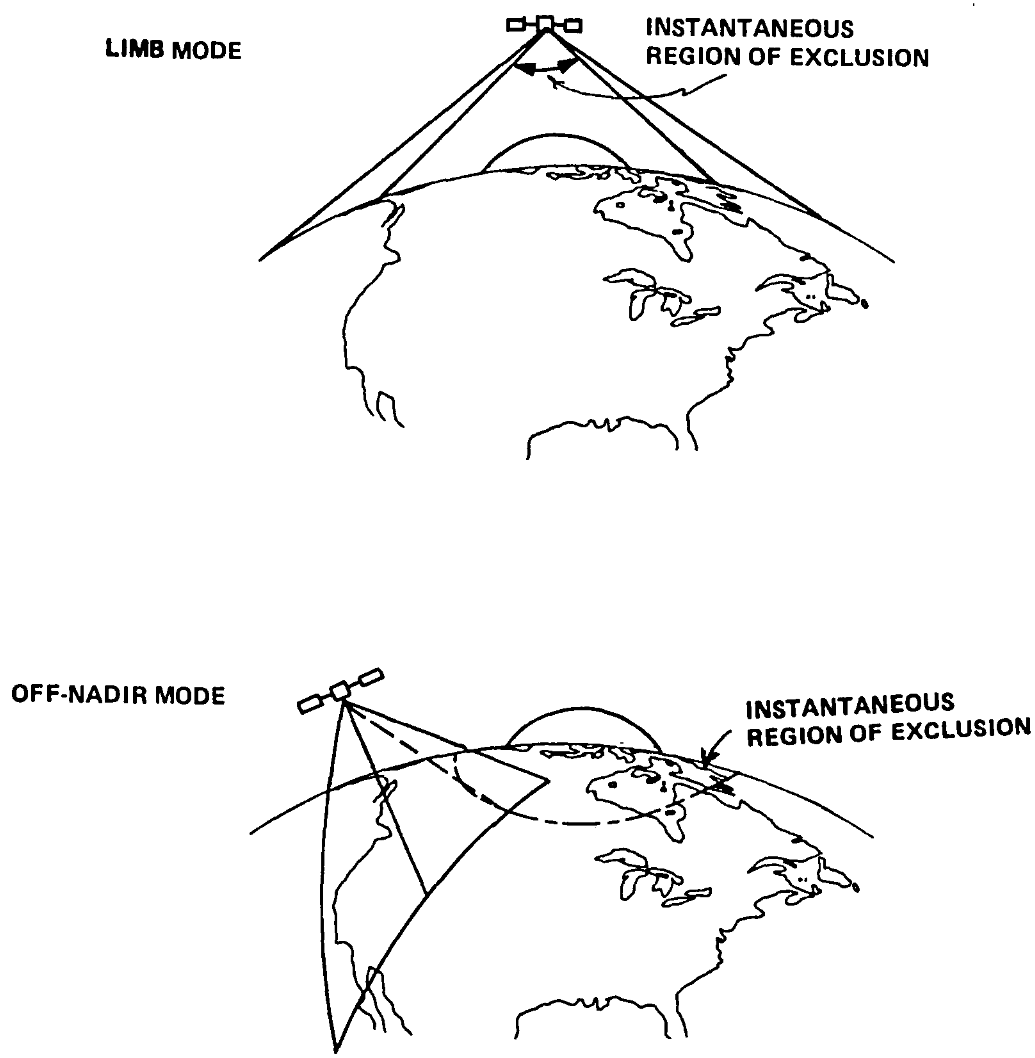


Figure 9.2.10-1. Shielding Constraints of Passive Sensors

Description of the Technology Development

Typical of the species which exhibit the aforementioned difficulty of measurement is sulfur dioxide (SO_2), as discussed in Section 6. The differential attenuation is low and there are serious interferences with ozone in the preferred UV spectral regions.

The brute-force approach of attempting these measurements with a large laser energy (e.g., 100J) should not be our first choice. Examination of alternative spectral regions and specific lines, in combination with the most sensitive LIDAR modes, such as differential absorption and heterodyne detection, may not prove to be the solution. Other techniques may have to be developed, particularly to take into account the interfering species through complementary or independent measurements.

Concurrent tradeoffs need to be made concerning the use of larger optics (e.g., 3M diameter collectors), to reduce the laser energy requirements. These large sensors, in turn would affect the size of spacecraft and the support subsystems.

9.2.12 DOPPLER RADAR FOR PRECIPITATION MEASUREMENTS

Technology Category: Active Sensors

Item No.: 12

Source/Origin: Mesoscale and severe storm measurements and the interaction of these dynamic conditions with the trace gases requires relatively high spatial resolution in the measurement of precipitation. Typically, an area of the Earth 500 x 500 km must be able to be observed with a horizontal resolution of 1 km. Optical measurements are not suitable, due to cloud obscuration and passive microwave techniques, which are suitable for synoptic measurements (e.g., 10 km resolution) and climatological studies, would require prohibitively large radiometer antennas. The alternative is to use radar measurements, using either real-aperture or synthetic aperture. However, the state-of-the-art is not sufficiently advanced to make these measurements, particularly from space satellites.

Description of the Technology Development

Rainfall rate measurements require an estimate or an independent measurement of the drop-size distributions within the rain cells. Attempts have been made to establish whether the drop-size distribution parameters are determinable from the type of rain. Experimental investigations, however, have shown the large variability of these rain-size parameters even under the same rain type conditions.

A promising technique for solving the problem is to use a dual frequency technique where one can alternately measure the effective reflectivity factors at a frequency which gives rise to Rayleigh scattering, and another frequency which produces Mie scattering. An inference of drop-size could be made for the difference between the two scattered returns. Another technique that has been proposed would use dual polarization. The signal return intensity of two orthogonally polarized waves would differ, due to the non-spherical shape of the drops, which are oblate spheroids. The ratio of reflectivities ZH/ZV is a measure of the drop size. The theoretical variations in differential reflectivity (Z_{DR}) and normalized horizontal reflectivity is shown on Figure 9.2.12-1 (as plotted by Al Khatib, 1979).

Dual frequency techniques are considered to be the most promising (R. J. Duviak). Considerable effort is required to verify the theory and implement these radar techniques in operational instrument systems.

9.2.13 BI-STATIC ABSORPTION MEASUREMENTS

Technology Category: Active Sensors

Item No.: 13

Source/Origin: High accuracy measurements of the upper atmosphere are feasible using the solar occultation mode, which takes advantage of a highly energetic source and a long path length. The disadvantage of this mode is the fact that only two opportunities are possible during an orbit (at Sunrise and Sunset) and the geographic location coinciding with these opportunities are not fully controllable. Active techniques can be devised to take advantage of the long path length and an energetic source using an IR laser beam.

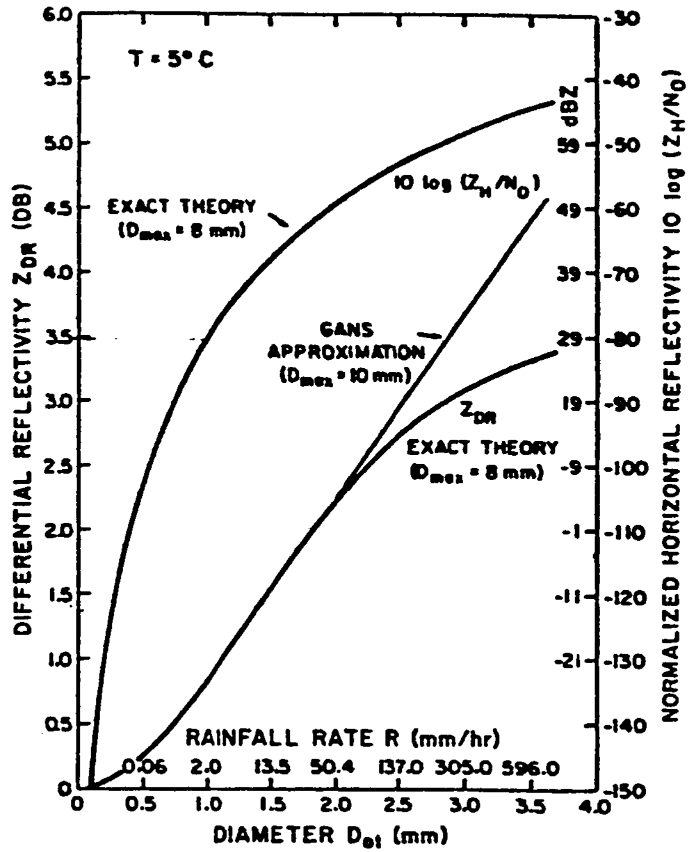


Figure 9.2.12-1. Variations of Z_{DR} and Normalized Horizontal Reflectivity 10 log (Z_H/N_o) with D_{ot}. N_o is in Units of M^{-3} cm^{-1} and $Z_H cm^6/m^3$. R and dBz Scale for N_o = $8x10^4$ m^{-3} cm^{-1} (from Al-Khatib, 1979).

Description of the Technology

The bi-static technique uses a laser transmitter and receiver or reflector located in two separate satellites which are orbiting on opposite sides of the limb. Synchronization of the satellite orbits is essential if the relative position of the spacecraft is to be maintained over long-term observation periods. With coplanar and equal altitude orbits, the minimum altitude of the limb will remain the same. If variable limb minimum altitudes are required, two alternatives are possible: 1) coplanar maneuvering of one of the satellites, or 2) multiple receiving/reflecting satellites in identical orbits, but with different separation distances from the transmitting spacecraft, as shown in Figure 9.2.13-1. The latter alternative has the advantage of permitting concurrent (or simultaneous) measurements of the same general atmospheric regions; also, it requires small propulsive capability for orbit maintenance, as compared to a maneuvering satellite.

An experiment has been proposed by the Atmospheric Lidar Working Group, wherein the continuous wave CO_2 laser would be employed to measure limited species such as O_3, ClO, $ClONO_2$, H_2O_2, CFM's, C_2H_3, Cl, etc.

The proposed retroreflector would be sized in accordance with the accommodation capabilities and the amount of laser transmitted power that is affordable. Figure 9.2.13-2 shows the estimated transmitted power vs optics size for 4000 km separation and integration times ranging for one millisecoind to one second.

Various aspects of this technique require technology development. The receiving/reflecting sub-satellites must be small and inexpensive in order to make the multiple altitude ranging mode practical. The attitude control of the transmitter and receiving optics must be very precise, considering the narrow laser beams that will be employed and the range of the limb measurements (e.g., 4000 km).

The laser life needed during continuous operation in a long-duration mission and must be improved over the current levels. The mathematical inversion model for this technique needs to be developed and adapted to the particular species of interest.

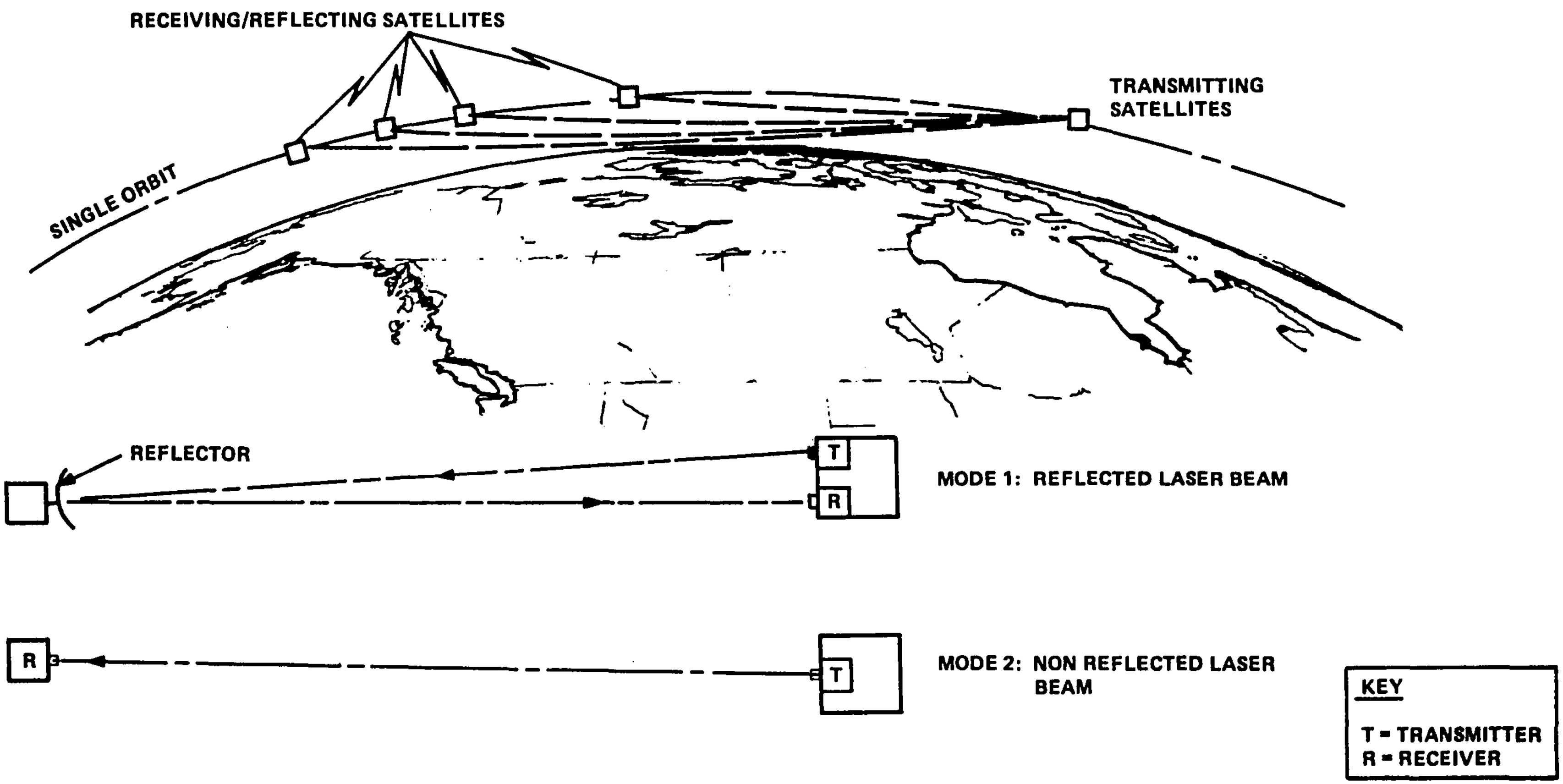


Figure 9.2.13-1. B1 Static Absorption Measurement Technique

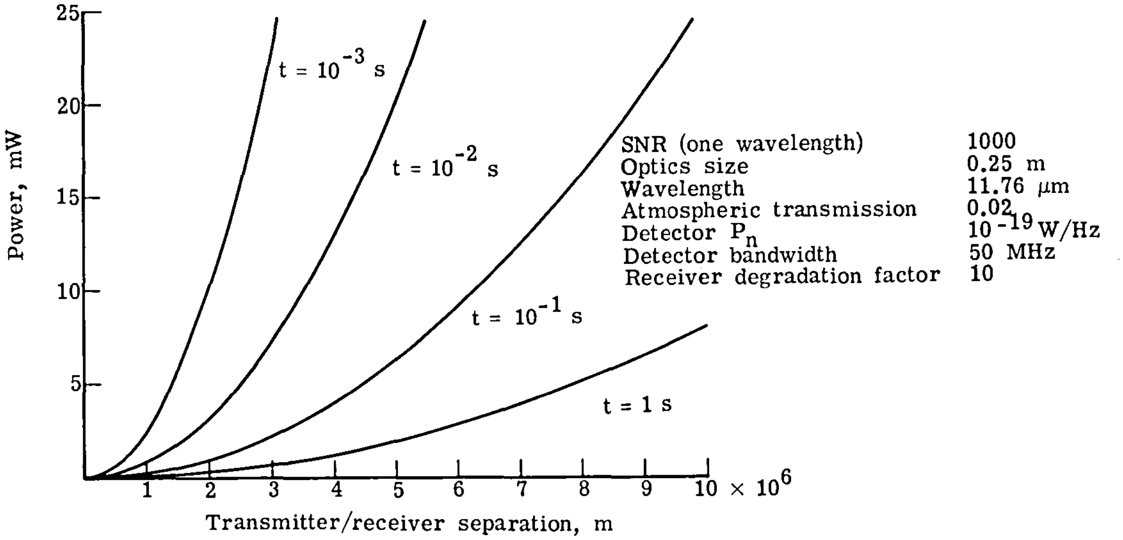


Figure 9.2.13-2B. Transmitted Power as Function of Transmitter/Receiver Separation for Two-Satellite Operation

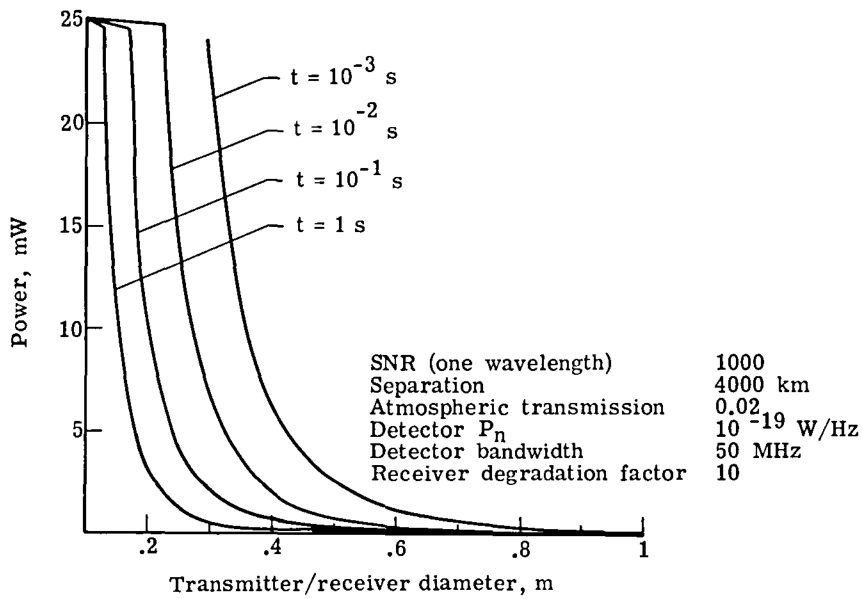


Figure 9.2.13-1A. Transmitted Power as Function of Transmitter/Receiver Diameter for Two-Satellite Operation

* Figures from "Shuttle Atmospheric LIDAR Research Program, final report on Atmospheric LIDAR Working Group" Appendix A

9.2.14 SUB-MILLIMETER WAVE SOURCES FOR HETERODYNE DETECTORS

Technology Category: Active Sensors and Sources

Item No.: 14

Source/Origin: Many Stratospheric Species have strong absorption lines in the sub-millimeter region of the spectrum which can be effectively utilized in Limb Radiometry. Typical species are CLO, HCL, HNO_3, O_3, NO_2, N_2O, NO, CO, SO_2.

Description of the Technology

Sub-millimeter sources can be used as local oscillators in highly sensitive heterodyne radiometers. In the sub-millimeter region the molecular rotational lines are two to five times stronger than the infrared vibrational-rotational transition. There is also evidence that most of the important molecules contain lines in the sub-millimeter spectral region. Considering the desirability of spectral abundance and signal strength, the utilization of this technique is surprisingly low.

Research in the sub-millimeter region has been primarily delayed because of the unavailability of reliable sources. A number of sources have been developed and are now slowly on their way into mainstream of the remote sensing activity. One of the most promising sources is the optically pumped laser which, when used with the Schottky diode, provides excellent receivers. A brief summary of the properties of the sources appears in Table 9.2.14-1. Figure 9.2.14-1 shows the relative output of the known sources over the frequency region of interest.

9.2.15 DEVELOPMENT OF ALGORITHMS FOR AOS LIMB DATA

Technology Category: Information Management

Item No.: 15

Source/Origin: Measurements of vertical profiles of gas concentration are needed for numerous trace species. The limb measurement technique will be used extensively in those measurements, as they relate to the upper atmosphere

Table 9.2.14-1. Sub-Millimeter Sources

TYPE	ADVANTAGES	DISADVANTAGES
OPTICALLY PUMPED MOLECULAR LASERS	NARROW LINEWIDTH EASY CONSTRUCTION WIDE AVAILABILITY RELATIVELY INEXPENSIVE WIDE SPECTRAL RNAGE HIGH FREQUENCY STABILITY PHASE-LOCKED OPERATION VERSATILITY	LACK OF TUNABILITY INEFFICIENT HIGH POWER REQUIREMENTS INCREASED COMPLEXITY LARGE SIZE
CARCINITRONS OR BACKWARD WAVE OSCILLATOR	CONTINUOUS TUNING WIDE RANGE OF TUNABILITY NARROW LINE WIDTH PHASE-LOCKED OPERATION LOW NOISE COMPACT	FABRICATION PROBLEMS HIGH COST UNAVAILABILITY RAPID FALLOFF WITH FREQUENCY REDUCED LIFETIME AT HIGH FREQUENCY
IMPATT DIODES	COMPACT SIZE & RUGGEDNESS POTENTIAL LONG LIFE AND RELIABILITY MODEST DC POWER REQUIREMENTS POTENTIAL HIGH EFFICIENCY	HIGH NOISE LEVELS WIDE LINEWIDTH RAPID POWER FALLOFF AT HIGH FREQUENCIES UNAVAILABILITY
HARMONIC GENERATORS	CONTINUOUSLY TUNABLE SMALL SIZE	SMALL POWER OUTPUT NO POWER ABOVE 247 GHz UNAVAILABLE
GYROTRONS	VERY LARGE POWERS	EXTREMELY HEAVY VERY LARGE SIZE

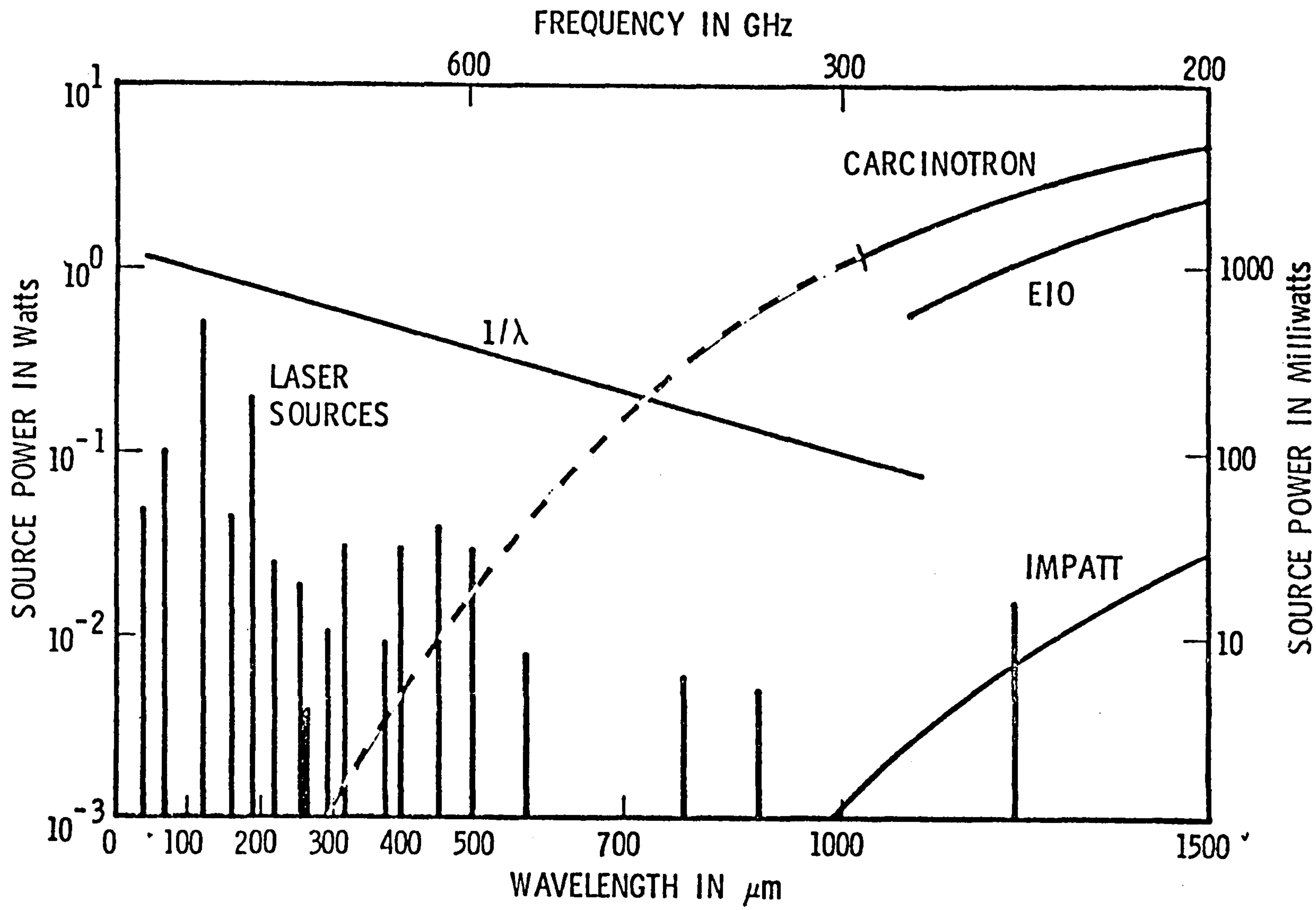


Figure 9.2.14-1. Comparison of CW SMMW Source Technology

and upper troposphere. Initial algorithms exist or are in the process of development by Principal Investigators in the UARS Program. However, the modified limb sensors in AOS will also require that modified algorithms be developed. In addition, the inclusion in AOS of a precise temperature sounder and measurements of other interfering constituents such as H_2O will permit the refinement of such algorithms to produce the required accuracy and vertical resolution.

Description of the Technology Development

Figure 9.2.15-1 shows the radiative path that is typical in a limb measurement. The instrument senses the radiation emitted by the atmosphere along the atmospheric volume described by the instantaneous field-of-view as it traverses the tangent point "P" and all atmospheric layers lying above P on the near side and the far side of the line-of-sight. The radiance contribution by the atmospheric layer immediately above the tangent P is larger than that from other layers, for two reasons: 1) the segment of the limb through this layer is the longest, and 2) the atmospheric density in this layer is the largest since it corresponds to the lower altitudes. The algorithm must consider this geometry and determine the horizontal length over which the measurement is valid (e.g., 500 km).

Weighting functions describing the radiance contribution at various altitudes are different for the limb mode than that for the nadir mode. The limb functions have much larger gradients (peaks) and require a different treatment from the functions for nadir looking instruments. In addition, factoring in of pressure and temperature terms is the algorithm that will require special treatment.

Finally, detailed error analyses are needed for the specific instruments, to insure that the confidence levels of the data obtained are sufficiently high.

9.2.16 3-D CORRELATION OF AIR QUALITY AND METEORDLOGICAL PARAMETERS

Technology Category: Information Management

Item No.: 16

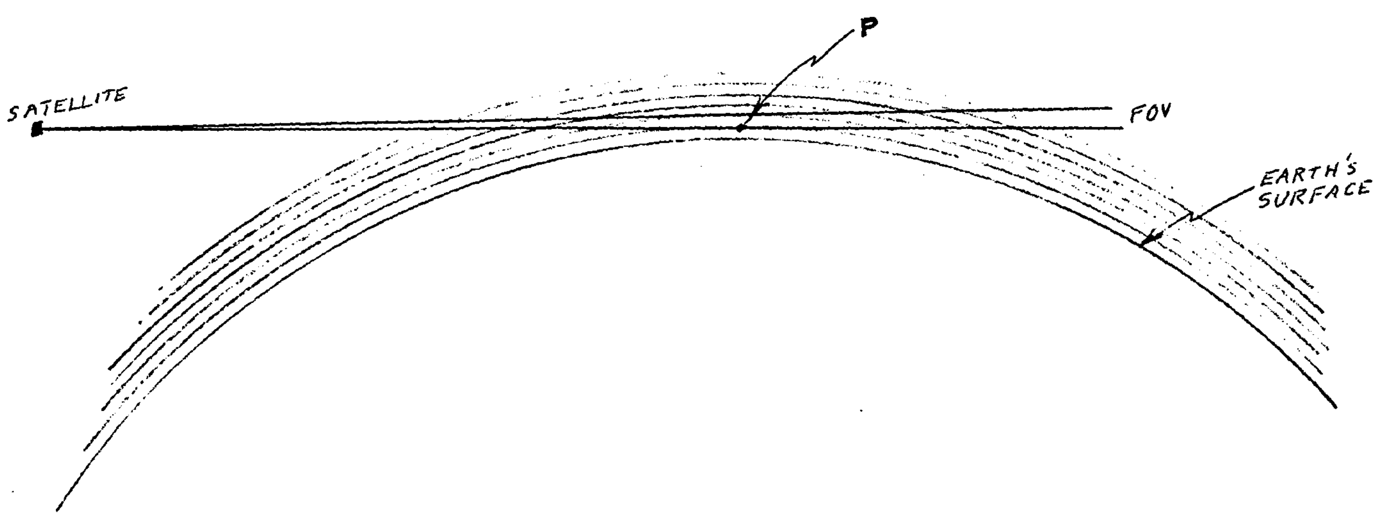


Figure 9.2.15-1. Radiative Path for Limb Measurement

Source/Origin: Data management techniques are required to correlate atmospheric data obtained with different instruments, at different slant angles. The volume and shape of the atmospheric element bounded by the instrument IFOV and the atmospheric band under consideration (e.g., 25 to 28 km) varies with incidence angle. In addition, the elements are displaced along the Earth's coordinates, depending on the incidence angle and the altitude layer under consideration. Correlation of air quality data with meteorological data from other operational satellites such as TIROS is more complex due to the differences in altitude I.F.O.V. and data acquisition time.

Description of the Technology Development

The ground processing that will be required to perform the aforementioned correlation will involve both geometric and geophysical extrapolations, or "resampling". One approach would be to standardize the space between the geoidal surface and the 380 km altitude surface (i.e., sphere 6678 km in diameter) by dividing it into equal and identifiable volume elements, say, 10 km by 10 km by 1 km in altitude. All the data gathered by AOS as well as support data from other satellites would be interpolated to determine the physical parameters pertinent to each volumetric element where the measurements were affected. The measurement value assigned to any one of these volumetric elements, then, would be determined from an interpolation of the surrounding measurements, considering the various corrections inherent in their different geometries. The mathematical relationships describing these interpolations need to consider, not only the geometric variability of different viewing aspects, but also the atmospheric refractive effects, wavelength effects, etc.

9.2.17 INTERACTIVE AND ADAPTIVE MISSION CONTROL

Technology Category: Information Management

Item No.: 17

Source/Origin: There exists a large interrelationship between air quality and meteorological atmospheric parameters, as discussed in Section 3. This is due to the important role of atmospheric dynamics in the mixing, transport, and chemical reactions relative to the trace gas species. From an observational point of view, we will need to program the AOS sensors' on-off cycles and spectral channels not only according to where the spacecraft will fly at any particular time, but also what type of weather conditions will exist at than time. Since these conditions are not fully predictable with a large degree of confidence, the system must adapt to unforeseen situations requiring a change in sensors' data acquisition parameters. The subject technology development would make provisions in the flight portion of the Command and Data Management Subsystem, to permit the detection of the desired condition and transmission of the appropriate commands for taking the necessary action, as described in Section 8.

Description of the Technology Development

Various interaction/adaptation measures are conceptually possible; the mission may adopt one or a combination of several of the following measures:

1. The sensors' activation schedule and channel selection is pre-programmed "N" hours ahead of the sensors passing over an area of interest.

2. Manned interaction will permit overriding of the pre-programmed functions, based on independent weather forecasts and/or weather conditions as sensed by AOS and interpreted by ground personnel.

3. The pre-programmed sensors' schedule will be overriden by automated commands generated on-board the spacecraft, as a result of AOS based detection of the required meteorological or high level of pollution condition.

Specifically, the technology development will need to address the following important aspects related to measure 3 above:

1. The development of detection and pattern recognition techniques for specific conditions of precipitation, clouds, weather fronts and high-level pollution events.

2. The development of on-board processors capable of real-time processing of data necessary for the detection of the conditions mentioned in "1" above.

9.2.18 PRECISE ATTITUDE CONTROL FOR LIMB MEASUREMENTS

Technology Category: Spacecraft

Item No.: 18

Source/Origin: The high vertical resolution of the limb sensors requires precise attitude pointing and knowledge of attitude of the sensors. The degree of accuracy with which the spacecraft supports the sensors depends on the pointing and referencing technique that is employed.

Description of the Technology Development

Considering the stringent pointing accuracy of the instruments (i.e., 0.001°) it would be technologically challenging to require corresponding spacecraft pointing accuracies from the spacecraft attitude control system and structural/thermal stability. Other approaches requiring optical referencing of the sensors with respect to a centralized reference source (e.g., laser beam) will also present a challenge relative to the establishment of unobstructed lines-of-sight between the reference source and the sensors, within the complex types of configurations needed for Atmospheric Observation Systems. The two attitude referencing techniques mentioned above are illustrated in Figure 9.2.18-1.

The technology development to meet the pointing requirements should consider other options which involve precise reference sources that are internal to the scientific instrument itself, while the spacecraft attitude control subsystem provides sufficient support to permit initial acquisition of the field-of-view. A possible technique would be to drive the limb sensor's pointing mirror through a servomechanism that is referenced by the sensor's location of the horizon. However, if the adjacent to the main MLA focal plane, as illustrated in Figure 9.2.18-2. The Earth's horizon would be used as the reference, with the appropriate selection of spectral band to provide a sharp contrast between Earth and sky. It is foreseen that a significant azimuth field of view should be allocated to the horizon sensors, to permit the averaging out of local topographic irregularities that may unduly bias the location of the horizon. The data reduction must take into consideration the overall height of the apparent horizon, as seen by the sensor, relative to the geoid, in order to permit the appropriate correction for atmospheric layer height. This data reduction step, which can be performed using software, will require stored data concerning local topography within the latitude region to be covered by the atmospheric survey. The alternative to this software approach would be to incorporate into the spacecraft inertial reference unit an an auxiliary horizon sensor that would determine in real-time height difference between the local horizon and the geoidal horizon.

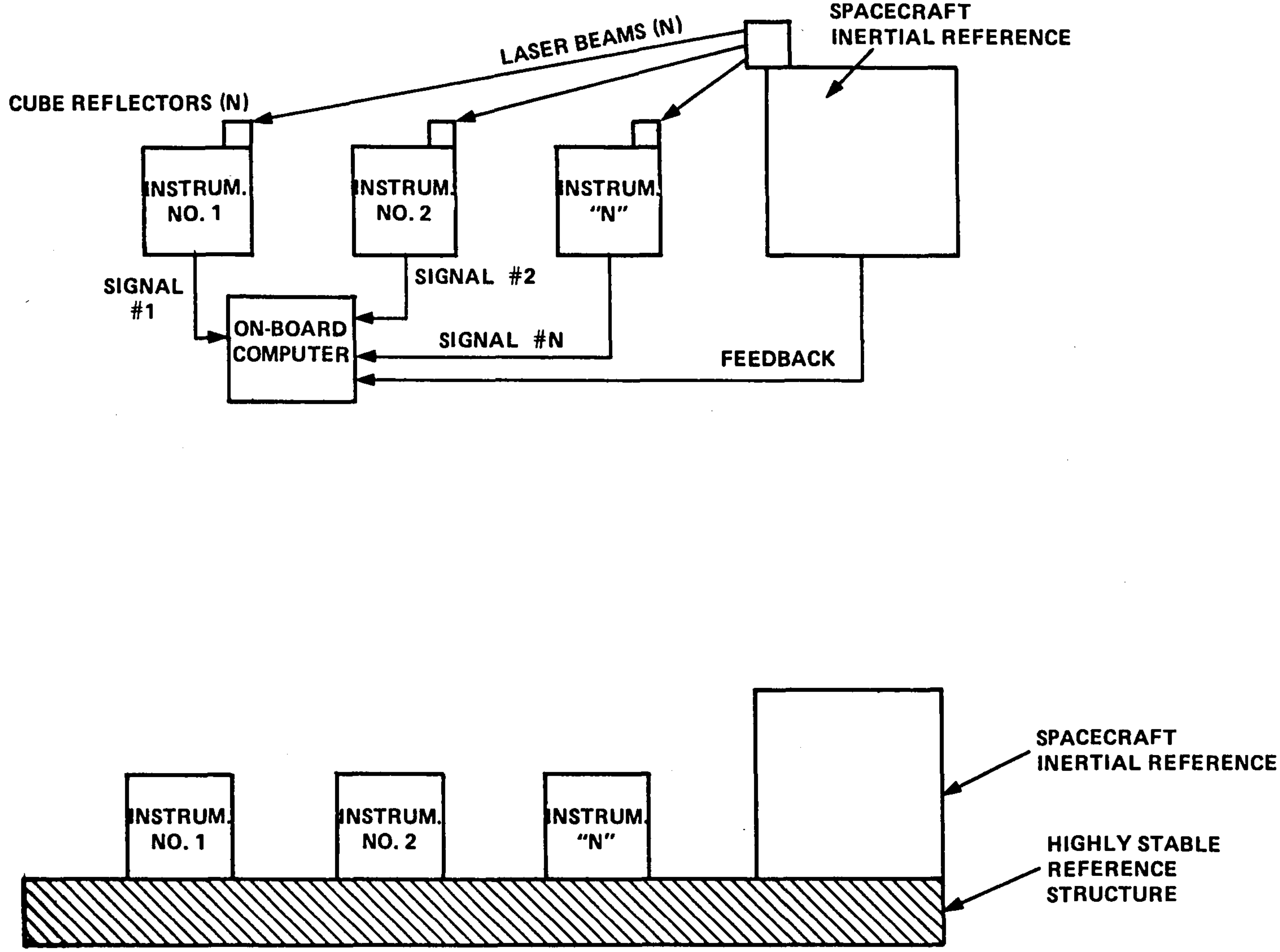


Figure 9.2.18-1. Attitude Reference Approaches

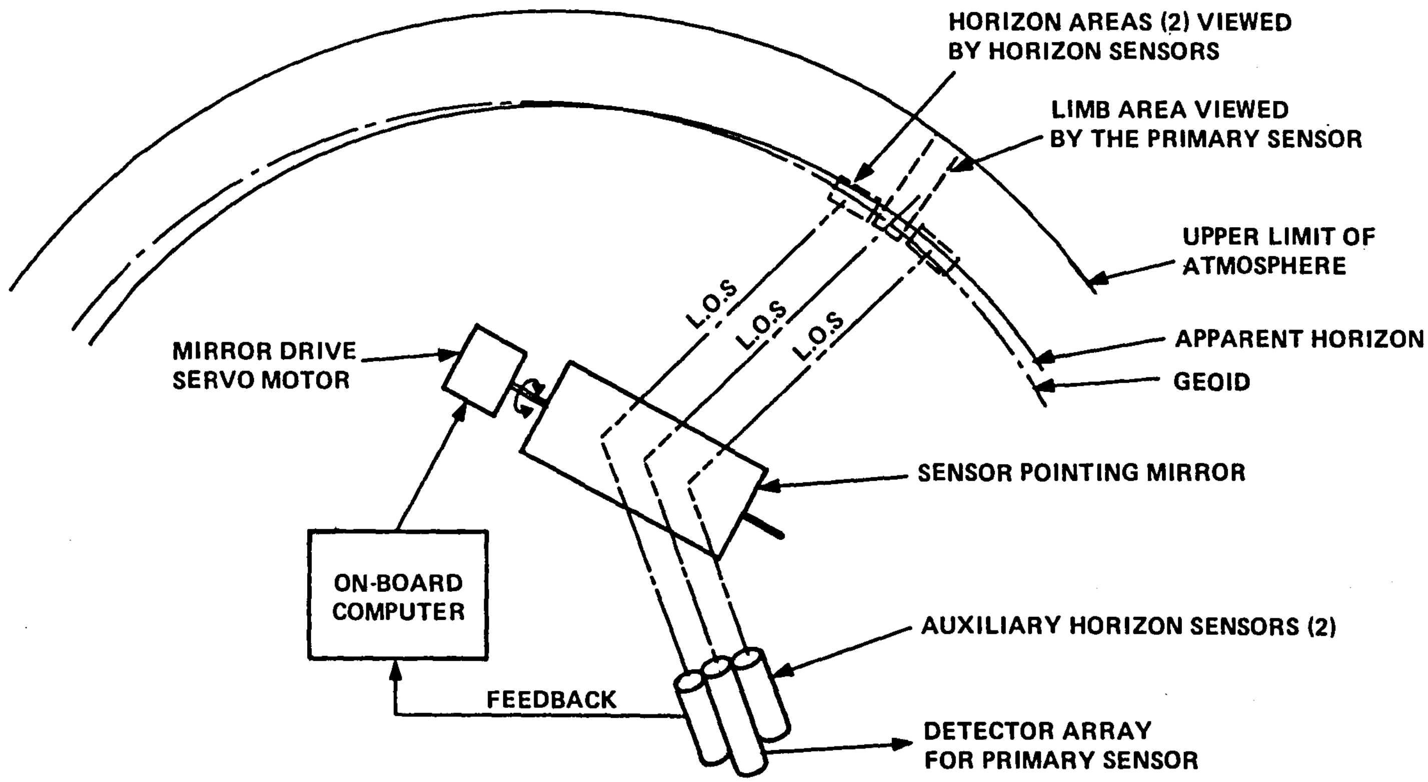


Figure 9.2.18-2. Attitude Reference Integral to The Sensor

9.2.19 ASSEMBLY OR DEPLOYMENT OF LARGE PASSIVE MICROWAVE ANTENNA ARRAY

Technology Category: Spacecraft

Item No.: 19

Source/Origin: The Passive Microwave Radiometer, as described in Section 4.1 would require in-orbit deployment or assembly if used in Mission No. 4 due to the fact that the overall antenna assembly exceeds the diameter dimension of the Shuttle cargo bay.

Description of the Technology Development

The overall dimensions of the microwave radiometer configuration for Mission 4 are 19 x 6 meters, approximately. This configuration exceeds the capabilities of the cargo bay, which are nominally 18 m x 4.5 m diameter. Since we are dealing with a free-flyer spacecraft, the accommodation of the spacecraft structure and the antenna on a single launch would further complicate the problem. Several approaches may be employed to permit the accommodation of this instrument.

1. The large antenna assembly corresponding to the low frequency (21 GHz) band can be made deployable so that it will "unfold" after the spacecraft is outside the cargo bay.

2. The large antenna assembly (21 GHz) can be assembled in space while the spacecraft is lifted outside the Shuttle cargo bay but while the instrument is still attached to the Orbiter.

3. The spatial resolution of the low frequency band could be degraded and/or the swath width for this channel could be made smaller, if this could be acceptable to the mission.

For the purpose of this assessment, only approach No. 2 has significant technology content, due to the potential involvement of the astronaut in the EVA or remote manipulation (RMS) task.

9.3 TECHNOLOGY NEEDS SUMMARY

The principal part of the assessment addressed in the study concerned the identification of technology needs in the various aspects of system development and implementation. In order to assist the NASA in future decisions related to the selection of the highest priority technology developments for projected atmospheric observation systems, an estimate was made of the importance of each technology within the corresponding category. Table 9.3-1 shows the relative rank of each technology within its group, using the following data for each of the columns:

Second Column

Earliest date when the technology development will need to be sufficiently mature to support a launch of the earliest AOS mission that requires that technology. For instance, assuming a 1989 launch of Mission No. 1, some technologies would need to be developed two or three years prior to that date in order to permit its incorporation in the mission.

Third Column

"Availability assessment" refers to the estimated level of probability that the requirement will be satisfied by the earliest date as specified in the second column. The two levels specified are "high" and "low". A "high" probability implies that there are specific trends or programs which either directly or indirectly indicate that the requirement will be satisfied. A "low" probability implies the opposite, and suggests that there will be a technology gap unless the development is accelerated.

Fourth Column

"Utility category" categorizes the relationship between the technology and the missions, according to whether it enables or enhances the mission. An "enabling" technology is one that makes the mission possible, and without which the mission, in its conceptual approach, is not viable. An "enhancing" technology is one that makes the mission more cost effective, more reliable, or higher in performance.

The last column shows our assessment of the relative rank (or priority) of the technology, which was derived using the following hierarchy as a criterion:

Highest Rank: Technologies that are required early (i.e., 1986-1987), have a low probability of being available when needed, and are classified as "ENABLING".

Second Rank: Technologies that are required later (i.e., 1988-90), have low probability of availability and are ENABLING. The eight ranks are as follows:

Table 9.3-1. Technology Assessment Matrix

TECHNOLOGY	EARLIEST DATE WHEN NEEDED	AVAILABILITY ASSESSMENT (PROBABILITY OF BEING AVAILABLE WHEN NEEDED)	UTILITY CATEGORY (RELATIVE TO MISSIONS) 1*	2	3	RELATIVE RANK (WITHIN EACH TECHNOLOGY CATEGORY)
NEW MEASUREMENT TECHNIQUES						
1. INCREASED VERT. RESOLUTION	1987	HIGH	ENABLING	ENHANCING	--	1
2. WIND MEASUREMENTS (PASSIVE)	1987	LOW	ENHANC.			3
3. MEAS. OF SULFUR COMPOUNDS	1986	LOW	ENHANC.	ENHANC.	ENHANC.	2
4. CORRELATION OF GND. & SPACE OBS.	1987	HIGH	ENHANC.	ENHANC.	--	5
5. MEAS. OF PRECIPITATION PROFILE	1986	HIGH	ENHANC.	--	--	4
6. CORRELATION OF NADIR, LIMB DATA	1987	LOW	ENHANC.	--	--	2
PASSIVE SENSORS						
7. PASSIVE MW RADIOMETER	1986	LOW	ENAB.	--	--	1
8. OPTICS FOR WIDE FOV MLA	1986	LOW	ENHANC.	--	--	2
9. 360° SCAN LIMB SENSORS	1986	LOW	ENAB.	--	--	1
10. IMPROVED SOLAR SHIELDS	1988	HIGH	ENHANC.	ENHANC.	--	3
ACTIVE SENSORS & SOURCES						
11. LIDAR FOR STRATOSPHERIC MEAS.	1990	HIGH	--	--	ENAB.	1
12. DOPPLER RADAR	1986	HIGH	ENHANC.	--	--	3
13. BI-STATIC LIDAR MEAS.	1987	LOW	ENHANC.	--	ENHANC.	2
14. SUB-MM WAVE SOURCES	1986	HIGH	ENHANC.	--	--	3
INFORMATION MANAGEMENT						
15. ALGORITHMS FOR LIMB DATA	1987	LOW	ENAB.	--	--	1
16. 3-D DATA CORRELATION	1987	HIGH	ENAB.	ENHANC.	ENHANC.	2
17. INTERACTIVE/ADAPTIVE MISSION CONTROL	1987	LOW	ENHANC.	--	ENHANC.	3
SPACECRAFT & SPACE ASSEMBLY						
18. PRECISE ATTITUDE CONTROL	1986	HIGH	ENHANC.	--	--	1
19. ASSEMBLY OF PASSIVE MW ANTENNA ARRAY	1987	HIGH	ENHAB. (MISS.#7)	--	--	2

KEY

* ALSO APPLIES TO MISSION #4, WHICH IS AN ALTERNATE TO #1

Rank	Time Frane When Needed	Probability of Being Available	Overall Utility Category
First	Early (1986-87)	Low	ENABLING
Second	Late (1988-90)	Low	"
Third	Early	High	"
Fourth	Late	High	"
Fifth	Early	Low	Enhancing
Sixth	Late	Low	"
Seventh	Early	High	"
Eight	Late	High	"

After the ranks were assessed, the relative ranking of the descriptions (within each category) were determined. In some cases where the absolute ranks were the same for two (or more) technologies, the one with the earliest need-date received the higher rank of the two.

The evaluation shows that there are a significant number of technology needs that warrant increased emphasis and programmatic support typical of these are the following technologies which have received the highest (suggested) rank in this evaluation relative to the multidisciplinary missions:

- #1 - Techniques for increasing the Vertical Resolution in Tropospheric Concentration Measurements
- #7 - Development of a Passive Microwave Reflector with Fixed, Shaped Reflector
- #8 - Optics for Wide Field-of-View Multispectral Linear Array
- #11 - Linear Techniques for Faint Stratospheric Species
- #15 - Algorithms for Limb Data
- #18 - Precise Attitude Control for Limb Measurements

SECTION 10
REFERENCES

1. Upper Atmosphere Research Satellite Science Working Group, P.M. Banks, CH.: "Upper Atmosphere Research Satellite Programs". JPL PUBL-78-54, July 1978.

2. Nagler, R.G.; and Edwin J. Shemy: "Global Service Satellite", Circa 1995" Vol. 2: Environmental and Resource Management Measurement Service (9/30/78) JPL.

3. Atmospheric Lidar Working Group, S.G. Tilford, Chairman, Shuttle Atmospheric Lidar Research Program, NASA SP-433 (1979).

4. Turco, R.P.: "Photodissociation Rates in the Atmosphere" Geophysical Survey, 2 (1975) 153-192.

5. R.D. Hudson; and E.I. Reed, eds.: "The Stratosphere: Present and Future". NASA RP-1049, December 1979.

6. National Climate Program Office "National Climate Program - Five-Year Plan" NOAA, September 1980.

7. Atmospheric Physics Program Comm., S.A. Bowhill, Ch.: "Middle Atmospheric Program Planning Document". U. of Illinois, June 1976.

8. Committee on Atmospheric Science, L.J. Battan, Ch.: "Atmospheric Chemistry, Problems and Scope" National Academy of Science, 1975.

9. K. Ya. Kondratyev; and Yu. M. Timofeev: "Space Remote Sensing of Minor Gas and Aerosol Composition of the Atmosphere". Lenigrad U., 1974.

10. Working Group on Troposphere Program Planning: "NASA Troposphere Program Plan". NASA RP-1062, 1981.

11. American Geophysical Union: "Chemistry and Physics of the Stratosphere", Reviews of Geophysics and Space Physics, Vol. 13, No. 1, February 1975.

12. GCA Company: "Acid Rain Information Book", U.S. Department of Energy, December 1980.

13. J.J. Carmichael; R.G. Eldridge; E.J. Frey; J. Friedman; and A.H. Ghayandlou: "Stratospheric Measurement Requirements and Satellite-Borne Remote Sensing Capabilities". Mitre Tech. Rpt. MTR-7007, February 1976.

14. Wright, M.L.; Proctor, E.K.; Gasiorek, L.S.; and Liston, E.M.: "A Preliminary Study of Air Pollution Measurement by Active Remote Sensing Technqiues". NASA CR-132724, June 1975.

15. NASA Document: "Shuttle Atmospheric Lidar Multisensor Instrument System Science Objectives, Experiment Descriptions Evolutionary Flow Document." NASA Langley Research Center, 1978.

16. "Atmospheric Lidar Multi-User Instrument System Definition Study", R.V. Greco, editor, NASA CR-3303, 1980.

17. Halsey, H.W.; and Yager, W.S.: "Lidar System Development", GE TTS #80-SDS-002, January 1980.

18. Huffaker, R.M., Editor: "Feasibility of Satellite - Borne Lidar Global Wind Monitoring System", NOAA Wave Propagation Laboratory, Boulder, Colorado, NOAA Technical Memorandum No. ERL-WPL-37, September 1978.

19. Staelin, D.H.: "High Resolution Passive Microwave Satellites". MIT Final Report under NASA Goddard Space Flight Center Contract NAS5-23677, 14 April 1978.

20. Staelin, D.H.: "Passive Microwave Techniques for Geophysical Sensing of the Earth from Satellites" IEEE Trans. PGAP, Vol. AP-29, No. 4, July 1981.

21. Staelin, D.H.: "Inversion of Passive Microwave Remote Sensing Data from Satellites". Inversion Methods in Atmospheric Remote Sounding, A. Deepak, New York Academic Press, 1977, pp. 361-394.

22. Shaefer, G.; and Wilheit, T.: "A Passive Microwave Technique for Profiling of Atmospheric Water Vapor". Rad. Sci., vol. 14, pp. 371-375, 1979.

23. Staelin, D.H.; Kunzi, K.F.; Petty, John R.; Poon, R.K.; and Wilcox, R: "Remote Sensing of Atmospheric Water Vapor and Liquid Water with the Nimbus 5 microwave Spectrometer". J. Appl. Meteorology, Vol. 15, pp. 1204-1214, 1976.

24. Rosencranz, P.; Staelin, D.H.; and Grody, N.C.: "Typhoon June (1975) viewed by a scanning microwave spectrometer". J. of Geophysical Research, vol. 83, pp. 1857-1868, 1978.

25. Rosencranz, P.W., et al.: "Microwave Radiometric Measurements of Atmospheric Temperature and Water from and Aircraft". J. of Geophys. Res., vol. 77, pp. 5583-5844, 1978.

26. Grody, N.C.: "Remote of Atmospheric Water Content using Microwave Radiometry". IEEE Trans. on Ant. and Propagation, vol. AP-24, pp. 155-162, 1977.

27. Wilheit, T.T.; Chang, A.T.; M.S. Rao; E.B. Rodgers; and J.S. Theon: "A Satellite Technique for Quantitatively Mapping Rainfall Rates Over Oceans". J. Appl. Meteo., vol. 16, pp. 551-560, 1977.

28. Grody, N.C.; Hayden, C.M.; Shiue, W.C.; Rosencranz, P.W.; and Staelin, D.H.: "Typhoon June Winds Estimated from Scanning Microwave Spectrometer Measurements at 55.45 GHz." J. Geophys. Res., vol. 84, C7 pp. 3689-3697, 1979.

29. Staelin, D.H.: "Progress in Passive Microwave Remote Sensing Non-Linear Retrieval Techniques". Remote Sensing of Atmospheres and Oceans. A. Deepak, ed., New York Academic Press, 1980, pp. 259-276.

30. Doviak, R.: "A Survey of Radar Rain Measurement Techniques". Internal Report National Severe Storms Laboratory, 1981.

31. Bortner M.H. et al.: "Analysis of the Feasibility of an Experiment to Measure Carbon Monoxide in the Atmosphere.

32. Chandrasekhar, S.: Radiative Transfer, Dover Publ. N.Y., 1960.

33. Selby, J.E.A. et al.: "Atmospheric Transmittance from 0.25 to 28.5 Microns Supplement LOWTRAN 3b 1976". AFGL TR-76-0258, Nov. 1976.

34. "U.S. Standard Atmosphere 1976". NOAA, NASA, and U.S. Air Force, Oct. 1976.

APPENDIX A
MULTISPECTRAL LINEAR ARRAY DESIGN CONSIDERATIONS

List of Symbols

B_λ = source brightness, watts/cm^2-ster-micron

A_L = aperture area, cm^2

d = aperture diameter, cm

a = detector area, cm^2

f = focal length, cm

F = focal ratio, f/d

Ω = solid angle subtended by a pixel, steradians

θ = angular subtense of a pixel, radians

$\Delta\lambda$ = spectral bandpass, microns

τ_λ = transmission, dimensionless

m = number of resolvable signal levels

P = power, watts

S_λ = incident radiant power, watts

D^* = detector specific detectivity (a function of signal frequency and wavelength)

Δf = electrical bandwidth, Hz

General Radiometry

The incident radiant power is given by

$$S_\lambda = (B_\lambda \Delta_\lambda T_\lambda) A_L \Omega$$

The noise power competing with signal power is

$$N = \frac{\sqrt{a}\,\sqrt{\Delta f}}{D^*}$$

The input power signal-to-noise ratio is therefore

$$S/N = \frac{(\beta_\lambda \Delta_\lambda \tau_\lambda)(A_L \Omega)\, D^*}{\sqrt{a}\,\sqrt{\Delta f}}$$

These signal and noise powers are transformed to voltages in the detector, the rms output voltage being proportional to input power.

From information theory, the relation between power signal to noise ratio and the number of resolvable levels m is

$$m = \sqrt{1 + \frac{S}{N}}$$

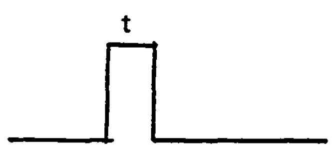
The required input power SNR if m levels are to be resolvable is therefore

$$\frac{S}{N} = m^2 - 1 \approx m^2$$

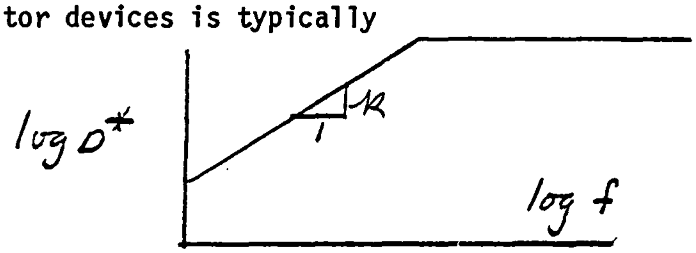
Combining these equations leads to the general expression for the optical requirement

$$A_L \ \Omega \ D^* = \frac{m^2 \sqrt{a}\ \sqrt{\Delta f}}{(B_\lambda \Delta_\lambda \tau_\lambda)}$$

Now let the detector be sampled for a brief interval t. The pulse waveform is

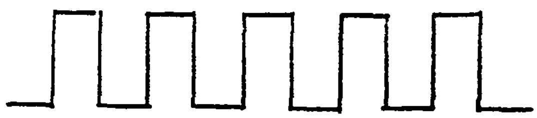


The frequency bandpass is approximately 1/2t and the effective detector operating frequency is approximately 1/4t. The detectivity D* is frequency dependent. For any given wavelength, the detectivity as a function of frequency for all semiconductor devices is typically



The frequency at the knee of the curve is typically 1 KHz and the slope k is typically between 0.5 and 1.0, the exact figure being largely dependent on cooling. The detectivity (basically a S/N measure) falls off rapidly as the frequency declines because of the rapid growth in so-called 1/f noise in semiconductors. When long integration times are used, the effective bandwidth and effective operating frequency both become small, and the detectivity degrades rapidly. A much more effective way to use the detector is to gate it at high frequency to maximize D*, then integrated the pulses.

Let the detector be gated in this manner at a frequency of 1/2t. The detector signal waveform is then a square wave.



Next let these pulses be filtered at 1 KHz, rectified and integrated over a period T. The number of such pulses to be added is then $Q = T/2t$. If Q pulses are added in this way, the total rms signal voltage is increased by a factor Q, but the noise voltage is increased only by a factor $\sqrt{Q}$. The signal to noise ratio of this sum of pulses has therefore increased by a factor of $\sqrt{Q}$ over that of a single pulse. The power signal to noise ratio implicit in the post-detection integrator output is therefore

$$S/N = \frac{(B_\lambda \; \Delta\lambda \; \tau_\lambda)(A_L \Omega) D^* \sqrt{T}}{\sqrt{a}}$$

and the optical demand equation is now

$$A_L \Omega \, D^* = \left(\frac{m^2 \sqrt{a}}{\sqrt{T}}\right)\left(\frac{1}{B_\lambda \; \Delta\lambda \; \tau_\lambda}\right)$$

which can also be written

$$\left(\frac{D^* d}{F}\right) = \frac{4}{\pi} \left(\frac{1}{0}\right) \frac{m^2}{\sqrt{T}} \left(\frac{1}{B_\lambda \; \Delta\lambda \; \tau_\lambda}\right)$$

<u>Application to the Multispectral Linear Array</u>

If we choose the frequency 1/2 t to be 1 Khz or greater, we will be operating the detector beyond the knee of the detectivity curve and detectivity will be maximized. Other numerical quantities that apply to the present situation are:

$T = 5/14$ sec
$m = 256$
$\theta = 5/1225$ radians

Making these substitutions the optical demand becomes

$$(D^*_{1000}\frac{d}{F}) = \frac{4}{\pi}(\frac{1225}{5})(256)^2\sqrt{\frac{14}{5}}(\frac{1}{B_\lambda \; \Delta_\lambda \; \tau_\lambda})$$

If we further assume that $\tau_\lambda = 0.5$ for all wavelengths this becomes

$$(\frac{d}{F}) = \frac{6.84 \times 10^7}{\beta_\lambda \; \Delta\lambda \quad D^*_{1000}}$$

For the visible and near IR the indicated detector choice is silicon. For the 11.5 micron band it is HgCd Te. Substituting radiance and detectivity data we obtain specific optical requirements as follows:

λ	β_λ	Δ_λ	$D^*(\lambda, 1000)$	d/F
0.5	3.5 E-3	0.2	0.9 E12	.109
0.65	1.5 E-3	0.1	1.3 E12	.351
0.75	5.5 E-3	0.1	2.0 E 12	.062
1.0	6.0 E-3	0.2	1.5 E 12	.038
11.5	0.6 E-3	1.0	2.4 E 10	4.75

These figures hold for 256 resolvable levels. If we require 1024 resolvable levels, the corresponding figures are

λ	d/f
0.5	1.74
0.65	5.61
0.75	1.00
1.0	0.61
11.5	76.00

A reasonable approach to design here is to require 1024 levels for the visible and near IR and 256 levels for the 11.5 micron band. This would allow all five bands to be served by an optical system for which the parameter (d/F) $\geqslant 5.6$.

Geometrical Design

For the visible and near infrared the geometrical design requirement is that d/F > 5.6 for a 102^{0} field. We first consider whether a spherical mirror alone will suffice.

The third order blur for a spherical mirror is (from Smith, Modern Optical Engineering).

$$\beta = .0078/F^{3} \text{ rad}$$

If all pixels are to span 5 Km at the ground (implying variable detector size, a refinement not being considered here), the least angular subtense is

$$\theta = 5/700 = .00714 \text{ rad}$$

For good imagery the blur should be no larger than 1/10 the pixel size. Hence a constraint on f/number is

$$F > 2.2$$

On the other hand the size of the instrument will row rapidly with f/number:

$$d = 5.6 \text{ F; } p = 5.6 \text{ F}^{2}\text{; Volume } \alpha \text{ F}^{6}$$

A further consideration is that baffling is generally much easier for F large than for F small. All these factors must be balanced in choosing a design value of F.

A reasonable figure for preliminary design purposes is F = 2.5, yielding the following:

$$\beta/\theta = .070 \quad d = 14 \quad p = 35$$

To avoid obscuration problems and facilitate baffling, an off-axis, unfolded plan is indicaed. The blur will increase by roughly a factor of 4 when going off-axis, so a corrector plate should be added at the pupil. Vignetting will be 63% at the edge of the field.

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
NASA CR-3557		

4. Title and Subtitle	5. Report Date
TECHNOLOGY NEEDS ASSESSMENT OF AN ATMOSPHERIC OBSERVATION SYSTEM FOR MULTIDISCIPLINARY AIR QUALITY/METEOROLOGY MISSIONS - PART 2	September 1982
	6. Performing Organization Code
7. Author(s) *U. R. Alvarado, *M. H. Bortner, *R. N. Grenda, *W. F. Brehm, *G. G. Frippel, *F. Alyea, *H. Kraiman, *P. Folder, and **L. Krowitz	8. Performing Organization Report No.
9. Performing Organization Name and Address General Electric Company Space Systems Division P. O. Box 8555 Philadelphia, PA 19101	10. Work Unit No.
	11. Contract or Grant No. NAS1-16312
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, DC 20546	13. Type of Report and Period Covered Contractor Report March 1981 - Feb. 1982
	14. Sponsoring Agency Code

15. Supplementary Notes *General Electric Company, Philadelphia, PA
**Lowell Krowitz Associates, Philadelphia, PA.
Langley Technical Monitor: Lloyd S. Keafer, Jr.
Final Report

16. Abstract
This report summarizes the results of Part II of a study to identify the technology advancements that will be necessary to implement the atmospheric observation systems in the 1990's. The scope of the original study (Part I - Report CR-3556) was expanded to encompass both upper and lower atmospheric air quality and meteorological parameters necessary to support the air quality investigations. The technology needs were found predominantly in areas related to sensors and measurements of air quality and meteorological measurements. The report indicates that it is beneficial and practical to conduct multidisciplinary missions for atmospheric research and routine observation commencing in the decade of the 1990's.

17. Key Words (Suggested by Author(s))	18. Distribution Statement
Technology needs, atmospheric observation system, multidisciplinary air quality/meteorology missions, remote sensing, trace gas measurements	Unclassified - Unlimited Subject Category 35, 45

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	250	A12

For sale by the National Technical Information Service, Springfield, Virginia 22161

End of Document