NOAA Technical Report NESDIS 30

Planning for Future Operational Sensors and Other Priorities

Washington, D.C.
June 1987

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Environmental Satellite, Data, and Information Service

NOAA TECHNICAL REPORTS

National Environmental Satellite, Data, and Information Service

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NESDIS 11 Tropical Cyclone Intensity Analysis Using Satellite Data. Vernon F. Dvorak, September 1984. PB85 112951)

NESDIS 12 Utilization of the Polar Platform of NASA's Space Station Program for Operational Earth Observations. John H. McElroy and Stanley R. Schneider, September 1984. (PB85 1525027AS)

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I. INTRODUCTION

The Special Projects Division of the Office of Systems Development is responsible for planning the operational payloads for the future earth observing satellite system. This planning includes both the geostationary and the polar orbiting satellites.

The design of the polar orbiting system is set through NOAA-M, which will operate through 1996. The geostationary system is also firm, as far as operational status extends, through GOES-M, which will provide a operational system into the late 1990's.

Present planning is for a payload of operational instruments ready for the first Polar Platform of the Space Station Program, which is planned to be operational in 1995. The Polar Platform is needed in 1995 to avoid a gap in operational service and to have an overlap period with NOAA-M. Sensors on the Polar Platform will designed to be "serviceable". It is also planned to expand operational earth observations on the Polar Platform to include additional and more advanced sensors.

Future satellites in the geostationary series are assumed to be a more advanced version of the GOES-I through M series, which is a three-axis stabilized spacecraft, instead of today's spin stabilized spacecraft. This assumption is based on the need to have a larger stabilized platform for earth viewing and for mounting more advanced of sensors. The GOES-I through M series will operate the first operational imager and sounder designed for a geostationary satellite with continuous earth-viewing. The sounder is a filter-wheel radiometer infrared sensor and thus, as is the problem with any infrared instrument, is limited in its ability to provide data in the presence of clouds. The geostationary sensors support mesoscale atmospheric phenomena and require instruments with better horizontal and vertical resolution than those now in use.

This paper sets forth the plans of the Special Projects Division to define sensors that meet the users requirements. The need for Phase A and B instrument studies stemming from those requirements are presented. The paper is divided into four sections with each section defining and outlining areas of interest to which FY 87 funds are to be committed. Section II defines the studies which are applicable to the polar orbiting system. Section III defines the studies which are applicable to the geostationary system and Section IV defines the studies which are applicable to both systems.

The studies outlined in Section II are based on the need to define the payload for the Polar Platform, with procurement of the sensors to begin in FY 89. Studies discussed in Section III are for concepts to advance the geostationary sensors and to provide information to procure the follow-on systems.

The operational payload planned for the Polar Platform, GOES-I through M and for GOES-NEXT include many more instruments than are mentioned in this document. These will be the subject of separate technical reports from the Special Projects Division.

II. POLAR ORBITING SYSTEM STUDIES

II.1. GLOBAL OZONE MONITORING RADIOMETER (GOMR)

II.2. EARTH RADIATION BUDGET INSTRUMENT (ERBI)

II.3. POLAR PLATFORM SCATTEROMETER AND ALTIMETER STUDY

II.4. ADVANCED MEDIUM RESOLUTION IMAGING RADIOMETER (AMRIR)

II.1. GLOBAL OZONE MONITORING RADIOMETER (GOMR)

The Global Ozone Monitoring Radiometer (GOMR) planned for the Polar Platform is conceived as two elements: a Nadir Sounder (GNS) for determining total ozone and a Limb Sounder (GLS) for determining vertical distributions of ozone, temperature and other trace gases at altitudes above the tropopause. The GNS is based on the Nimbus TOMS system, and is well understood in an engineering sense. The Nimbus TOMS system is defined in Table I.

The current operational ozone profile instrument is the SBUV/2. It will continue on the Advanced TIROS-N (ATN) spacecraft series through the NOAA-M satellite. It is planned to replace the nadir-viewing SBUV/2 with the limb-viewing GLS beginning with the Polar Platform. The GLS described here is based on the technology of the Nimbus LIMS instrument detailed in Table II.

General Measurement Requirements

Stratospheric ozone is extremely important to life on earth because it prevents biologically harmful solar ultraviolet radiation wavelengths from reaching the earth's surface. There is widespread concern that human activities and natural processes could lead to a reduction in the total ozone column. Ozone monitoring must be designed to give the earliest possible indication of such changes, and as much information as possible on their causes.

For these reasons it is necessary to measure the vertical ozone distribution as well as the total column amount. The first indication of some predicted reductions will be an ozone decrease in a thin layer in the upper stratosphere. The altitude of this layer and the extent of the depletion provide strong indicators of the chemical processes causing the decrease.

Such a high altitude change may also lead to an increase in ozone in the lower stratosphere, at and below 25 km, which for a time can compensate for the high altitude decrease. The nature of this "self healing" can also provide a strong indication of the chemical processes that are operating. A change in the vertical distribution of ozone will also lead to changes in the temperature structure in the stratosphere, and climatic effects at the earth's surface.

Two-dimensional models suggest that the largest total column reductions would occur in high latitudes, in the lower stratosphere, and during the winter.

Measurements to monitor ozone are therefore required to be accurate, of high precision and capable of maintaining measurement stability over long periods. The vertical resolution should be of the order of half a

TABLE I

NIMBUS 7 TOMS

The NIMBUS 7 TOMS was designed as a single Ebert-Fastie spectrometer with a fixed grating and an array of exit slits. The TOMS had a 3 degree by 3 degree instantaneous field of view and measured six discrete wavelengths ranging from 312.5 to 380 nm with a 1 nm bandwidth. The NIMBUS 7 TOMS was a cross-course scanning instrument. A scanning mirror scans across the track ±51 degrees from the nadir in 3 degree steps. One complete cross scan takes eight seconds, including one second for retrace, while recording the data for 35 scenes. At each scene during stepping, the chopper sequentially gates all six wavelengths four times such that the selected wavelengths are gated in succession and the order of gating is reversed in the next sampling. The total time spent at each scene was 200 ms which includes 168 ms for six wavelengths data sampling and 32 ms for the scanner settling.

The TOMS uses the same type of photomultiplier tube as the SBUV, and has a mercury-argon lamp for wavelength calibration and a depolarizer. The TOMS also has a diffuser for solar irradiance measurement.

Wavelengths of TOMS

Wavelengths Step (nm)
380.0
360.0
339.8
331.2
317.5
312.5

scale height (about 3.5 km), have the ability to measure from the tropopause region to the lower mesosphere, and extend essentially from pole to pole at all times.

A recommendation was recently (October 1985) formulated by the Middle Atmosphere Program Panel of the Committee on Solar-Terrestrial Research, National Academy of Sciences on this topic. It included the following:

> A program to define, plan and implement long-term limb-sounding measurements of temperature and constituents in the middle atmosphere from satellites should be initiated immediately. The critical advantage of the limb-sounding technique is the high vertical resolution obtainable for simultaneous measurements of temperature, ozone and other constituents of importance in ozone photochemistry. Limb emission measurements allow the determination of these quantities at night and in the polar darkness. Temperature and constituent retrievals are deterministic and independent of climatology or first-guess profiles. Precise measurements with good vertical resolution are essential if we are to diagnose the causes of temperature and ozone changes in the middle atmosphere. The long time-scales of natural and anthropogenic changes in the middle atmosphere require a long-term measurement program which could be effected from the operational Earth-observing platforms of the future.

CURRENT OPERATIONAL SYSTEM

SBUV/2 is a daylight sensor limited to the sunlit portion of the earth. As such, it does not provide data in the polar night nor on the nighttime portion of the orbit. This restricts ozone analyses to the local time of the observation (e.g., 2:00 pm for NOAA satellites) which is then merged with the synoptic meteorological map (1200 GMT). Such a merge may not cause serious errors in the lower to mid-stratosphere where the diurnal variation appears to be small but may be significant at the higher levels. SBUV/2 provides total ozone and also vertical profiles from about 16 km to 55 km. The retrieval at the lower levels, however, is dictated by the total ozone amount and algorithm climatology. Actual information derived by the instrument weighting function extends from about 25 km to 55 km.

The vertical resolution of the current SBUV/2 is about 8 km which is set by the width of the contribution functions, the accuracy of the albedo measurement and the magnitude of the off-diagonal elements of the a priori covariance matrix used in the retrieval algorithm. Horizontal resolution is defined by its 200 km x 200 km footprint at the earth's surface and the nadir viewing geometry.

APPLICATION OF LIMB SCANNING

GENERAL

The infrared limb scanning method has been used successfully to measure ozone, temperature, and other gases by the Limb Radiance Inversion Radiometer (LRIR) on Nimbus 6 and the Limb Infrared Monitor of Stratosphere (LIMS) on Nimbus 7.

Characteristics of the results obtained by these experiments include coverage from the upper troposphere into the middle mesosphere, measurements at all latitudes and seasons, and a vertical resolution capable of distinguishing layers about 3 km thick.

Through comparison with other measurements, it has been established that the accuracy of these measurements is 5-10% over most of the stratosphere. The accuracy may be better; the ability to assess it is limited by the accuracy of the standards against which the results are compared. The precision is generally less than 5% of the local value.

The radiometric accuracy of the instruments was checked twice a minute by viewing an in-flight calibration target. This was a small temperature controlled cavity that emitted a known, reproducible stream of blackbody radiation.

OZONE

Limb scanning can meet the requirements for operational monitoring of ozone profiles. Data can be obtained with the necessary coverage in altitude and latitude, with the requisite vertical resolution, high long term stability, high accuracy and precision. There are three areas of previously flown instruments that should be studied for changes:

1. Method of cooling the detectors. In order to take advantage of the inherent high resolution of the limb scanning technique, it is necessary to use a narrow field of view, which reduces the available signal. To get high signal to noise ratios, the detectors must be cooled. For the research experiments on Nimbus, this was accomplished through the use of small solid cryogen packs which gave a lifetime of 7 months. There are several alternatives for providing the cooling for an operational instrument. They include the use of solid cryogens, with the amount sized for a desired lifetime, the use of passive cooling, or the use of mechanical refrigeration devices. The most flexible and cost effective would seem to be a refrigerator, perhaps in combination with passive cooling. Small refrigerators that should be applicable are being developed for the UARS and other programs .

2. <u>Direction of line of sight</u>. The previous experiments viewed out of the orbital plane, which reduced the latitudinal coverage slightly. In addition, in the data reduction, corrections must be made for gradients along the line of sight. The coverage will be increased and the corrections somewhat easier if the instrument views along the orbit.

3. <u>Addition of another spectral channel</u> to optimize the ozone retrievals. As stated above, the ozone retrievals from the previous instruments were very good. However, little attention has been paid to the optimization of the results in the lowest levels of the stratosphere; some improvement may be possible with the addition of a specially tailored spectral channel.

TEMPERATURE

As noted above, it is necessary to determine the temperature in order to derive the ozone distribution. The temperature soundings have considerable information on the temperature and pressure in the tropopause region. This is a region in which nadir soundings have been less accurate in the past, because the vertical scale of the changes is smaller than the width of the weighting functions. Unpublished studies suggest that the combination of limb and nadir retrievals should result in higher accuracy temperature retrievals in the troposphere. This comes about because the limb derived temperatures in the stratosphere provide better information on the contributions of the stratospheric nadir channel weighting functions. Their information can then be used primarily to produce better tropospheric retrievals.

SBUV/2 provides information on solar irradiance, total ozone and ozone profiles from about 25-55 km. Temperatures, which are provided by separate instrumentation, extend from the earth's surface to 55 km, but it is becoming increasingly clear above about 45 km, that the errors increase rapidly. This results in precise temperatures above 45 km and less precise ozone measurements from 45 km down to 25 km. This is not a desirable situation.

OTHER SPECIES

Water vapor and other trace species are crucial climatic variables and indicators. Stratospheric water vapor plays a role in the radiative balance of the stratosphere, and is the source of the OH radical, which is crucial in ozone chemistry. In addition, the amount of water is an extremely sensitive indicator of the temperature of the tropical tropopause, and thus of the vertical motions responsible for troposphere-stratosphere exchange in the tropics. The distribution of stratospheric water vapor is an indicator of stratospheric motions and transports, and an aid in interpreting the ozone distribution. It is relatively inexpensive to include channels for water vapor and other species in an operational limb scanner, and the benefits appear to be large.

INSTRUMENT CONSIDERATIONS

In general, two approaches to remote sensing are employed. One involves use of high spectral resolution obtained along the Earth's limb, for example, with a Michelson interferometer, and the other uses intermediate or low resolution measurements made with a radiometer. The interferometer approach is very powerful since a spectral scan can be obtained, usually over a wide region, allowing many gases to be measured with one instrument. The radiometer, on the other hand, employs fixed channels defined by a low resolution grating or optical filter and is gas specific. The radiometer can usually measure far less numbers of gases than the interferometer.

In long-term operational monitoring, some of the prime considerations are data rate, complexity of data reduction, and instrument size. In all of these cases, the radiometer method (like GLS, for example) has distinct advantages over the interferometer. Since relatively broad bands are used, spectral line shapes need not be reproduced in the retrieval, calculations can generally be done quicker, and the problem of data reduction automation is easier since much less data have to be examined and evaluated. An interferometer measurement retrieval is considerably more complex because the fitted and measured line shape must be carefully studied. Much more information must be examined to verify retrieval validity, and the reduction is much more time consuming because of "man in the loop" requirements. The data rate is also much higher (maybe a factor of 10 to 50) for an interferometer and generally, the instrument is physically larger and usually more sensitive to optical alignment changes. There is the added challenge of handling the interferogram smearing effect, which occurs due to the fact that a limb scan is occurring while a spectral scan is being made. This effect can be handled but it adds considerable difficulty to the data interpretation and processing.

An important use for an interferometer experiment is to perform a spectral survey of the atmosphere that in turn may be asked to guide the design, development, and implementation of a gas specific experiment. It may provide the only way to measure some radical gases such as OH and HO_2 and other very tenuous species whose spectral properties do not allow easy isolation. For monitoring purposes, only a selected set of key gases need to be observed over a long time, as opposed to the many gases that could be measured with an interferometer. Current monitoring needs call for observation of temperature, O_3, H_2O, and perhaps NO_2, all of which can be measured with a radiometer. Thus, the complexity and associated data handling problems of an interferometer are not required.

PROPOSED PROGRAM (FY 87)

The objective of the proposed study program is to provide a Phase B design for instrumentation to continue ozone monitoring on the Polar Platform at a higher accuracy and greater data utilization, to provide an independent satellite determination of stratospheric temperature profiles and to initiate measurements for monitoring purposes of water vapor and other stratospheric trace species of photochemical importance. An instrument requirements document will be generated and a competitive procurement will be issued. The requirements document will request that various infrared limb scanning methods be evaluated with respect to observational requirements. The Phase B study will result in instrument parameter specifications for use in Phase C and D procurement in 1989.

SCHEDULE

Phase B Requirements Document Complete	3/87
RFP Complete and to Contracts	4/87
RFP Issued	6/87
Contract Awarded	9/87

II.2. EARTH RADIATION BUDGET INSTRUMENT (ERBI)

INTRODUCTION

The Earth Radiation Budget Instrument (ERBI) planned for the Polar Platform is conceived to be similar to the ERBE instrument currently on-board NOAA 9 and 10. In addition to the excellent ground characterization and calibration, the ERBE instruments are sufficiently insensitive to thermal perturbations, stability, and in-flight calibration capabilities.

The ERBI will have two measurement systems: one scanning (S) and one non-scanning (NS). The S-system will measure the Earth radiation budget (ERB) parameters at Top-Of-the-Atmosphere (TOA) with a spatial resolution of about 250 km. The NS-system will do the same with a spatial resolution of about 3000 km. One of the strengths of this system is the ability to intercompare radiometric measurements and instantaneous TOA fluxes along the satellite measurement swath. This is a useful tool for quality control of the final data.

The current operational ERB instrument through NOAA-J is the AVHRR. With NOAA-K, L, M it will either continue to be the AVHRR, or, under consideration, is a HIRS with channel 20 modified to measure a broader portion of the spectrum of reflected sunlight (0.4 micron to 1.5 micron). The discussion of the ERBI is based primarily on the known technology of the ERBE instrument.

GENERAL MEASUREMENT REQUIREMENTS

The Earth radiation budget is the balance between the shortwave radiation from the sun (wavelengths from 0.3 micron to 5.0 micron) and the long-wave radiation (5.0 micron to 50.0 micron) emitted by the Earth. Observed estimates of the ERB are at the foundation of many scientific studies and applications within the traditional as well as emerging disciplines of Earth sciences. Oceanographers and meteorologists are interested in ERB because meridional and to a lesser extent zonal gradients in the net radiation (absorbed solar minus emitted thermal fluxes) are the fundamental energy sources which drive the general circulation of the atmosphere and ocean. The ERB also plays a central role in theories of climate change because anomalies in planetary radiative fluxes, as caused by increases in atmospheric carbon dioxide, are recognized as the dominant mechanism of climate change on decadal to longer time scales. A number of international and national documents have underscored the necessity for measuring and monitoring ERB at the top of the atmosphere. In a memorandum from Dr. Richard Hallgren, NOAA Assistant Administrator for the National Weather Service, to the former Assistant Administrator of NESDIS, Dr. John McElroy, dated 2/23/84, it is stated that:

"The weather service, through the National Meteorological Center, is quite prepared to examine and make routine use of high quality, validated radiation measurements. We are especially anxious to have a good source of data available for the systematic validation of improved radiation and cloudiness parameterizations in our forecast models. Further, the Climate Analysis Center of NMC would include such data in the diagnostics data base they regularly compile and have available to the scientific community. Albedo data is particularly important, according to the recent National Academy report "Changing Climate: to the detection and interpretation of change such as may be caused by increasing atmospheric carbon dioxide."

The accuracy requirements for the measurements needed by NMC, as stated in a memorandum from J. S. Winston, to E. L. Heacock, dated 12/2/80, are: estimates of the daily average reflected solar and emitted thermal radiation fluxes should be measured with an absolute accuracy of 5 Wm^{-2}, stable to 5 Wm^{-2}, interannually, with a precision of 10-15 Wm^{-2}. The accuracy and stability requirements for total solar irradiance are the same, but the required precision is 1 Wm^{-2}.

CURRENT OPERATIONAL SYSTEM

The shortwave reflected flux is estimated from the radiance in channel one of the AVHRR. The following assumptions are made: 1) albedo in the broad spectral band is the same as albedo in the channel one spectral band (0.58 - 0.68 um); 2) the Earth/atmosphere system reflects radiation isotropically, i.e., the reflected radiance is the same in all directions; 3) the albedo of the Earth/atmosphere system is independent of solar zenith angle; and 4) clouds do not vary over the day from the conditions at the time of observation. Theoretical simulations and empirical satellite intercomparisons have indicated that the errors introduced by these assumptions into the estimate of daily average reflected flux may be as large as 50 Wm^{-2}. This accuracy does not meet the NMC requirements.

The estimate of daily average longwave flux is computed from channel 5 (11.5 - 12.5 um) of AVHRR, using theoretically and empirically derived relationships between radiance and viewing angle, and between equivalent black body temperature for filtered (ch. 5) and unfiltered (5 - 50 um) radiation. Again using theoretical simulations and empirical intercomparisons, these estimates of daily average longwave flux are believed to have errors which are less than 10 Wm^{-2}, which is acceptable for some of NMC's applications.

As a result, the longwave flux estimates are currently the only ones being used by NMC for the purposes discussed in Dr. Hallgren's memo. The ERBI system would provide data for all of NMC's current applications.

ENVISIONED ERBI OPERATIONAL SYSTEM

The proposed ERBI instrument, as discussed in the introduction, is based on the ERBE instrument now aboard NOAA 9 and 10. Like ERBE, the ERBI instrument will be made up of two packages. One, the non-scanner (NS-system), will contain two Earth-viewing detectors and a solar monitor. The other, the scanner (S-system) will contain three telescopes each with a detector to measure shortwave (0.2 to 5 um), longwave (5 to 50 um) and total waveband radiation (shortwave and longwave combined). Both packages will provide calibration traceability to the International Practical Temperature Scale - 1968 (IPTS68) and to the solar constant. The ties to the IPTS68 are made with ground and in-flight blackbodies that contain platinum resistance thermometers (PRTs). The ties to the solar constant are made by solar observations in special operating modes. In addition, detailed analytical models of the instruments' operation have been developed by the ERBE project to provide ties between the underlying physics by which the radiation is detected and the equations used in data reduction.

Unlike the ERBE, the ERBI NS-system will view the Earth with only one spatial resolution, a limb-to-limb view, called the Wide-Field-Of-View (WFOV) channels. The ERBE Medium-Field-Of-View (MFOV) channels, with a view limited to about a 1000 km diameter circle directly below the spacecraft, is considered to be of research value, only. Satellite measurements of the Earth's radiation budget, dating back to the early 1960's, have always included WFOV channels, and the continuation of them for ERBI is intended to extend this record of ERB measurements as long as possible. The WFOV channels also provide data which can be used to validate the calibration and data reduction algorithms used for the scanner channels. There are two WFOV channels, a total spectral channel, which is sensitive to all wavelengths, and a shortwave channel, which uses a high-purity, fused silica filter dome to transmit only the radiation from 0.2 um to about 5 um. Because of concern for spectral flatness and high accuracy, the detectors for the WFOV and solar channels are active-cavity radiometers. Thermally operated instruments are potentially sensitive to extraneous heat flows. Therefore, great care has been exercised in the ERBE program in dealing with the heat flow within the instruments. The detectors will be enclosed in a module that is mounted in a rotatable structure for the channels to observe the Sun or internal calibration sources for in-flight calibration.

The ERBI S-system package, like the ERBE, will contain three radiometric channels, each of which views the Earth, internal-calibration sources, and a solar diffuser plate. The detectors are thermistor chips, coated with a thin layer of black paint to enhance spectral flatness.

They are located at the focal point of an f/1.84 Cassegrain telescope with aluminum-coated primary and secondary mirrors. One of the channels has no filter, and absorbs radiation at all wavelengths. A second channel has a fused-silica filter which transmits only shortwave radiation. The third has a multilayer filter on a diamond substrate to reject shortwave energy and accept only longwave radiation. The spatial resolution of each channel will be about 40 km directly below the satellite. Upon command, the channel will be rotated into position to view a diffuse reflector directly illuminated by the sun for in-flight calibration.

Because of the similarity of the ERBI to the ERBE design, the data processing system for ERBE will be adaptable to the ERBI data processing. This complex analysis system accounts for small adjustments for spectral non-flatness of the measurements, bi-directional reflectance and solar zenith angle dependence of albedo for the Earth/atmosphere system, viewing angle dependence of emitted thermal radiation, and may, as a result of the ERBE research, provide methods to account for the average effects of diurnal variations in cloudiness.

This analysis system will provide estimates of daily and monthly averaged radiation budget parameters at a spatial resolution varying from 250 km to hemispheric and global. These results will extend the record of broadband radiation measurements begun with ERB on NASA's Nimbus-6 and 7 satellites, continued by ERBE on NASA's Earth Radiation Budget Satellite (ERBS) and on the NOAA 9 and 10 polar orbiters, satisfying the requirement for long term monitoring of the Earth's radiation budget at the top of the atmosphere.

PROPOSED PROGRAM

The ERBE instrumentation represents the state-of-the-art for measuring broadband radiances and instrument irradiances at satellite altitude. The only known weak spots in the ERBE instrument are in scanner electronics design, which would need to be redone to eliminate offset instability with scan angle, and non-uniform degradation of the fused-silica dome of the shortwave WFOV channel.

To study methods of correcting for the few apparent design flaws of the ERBE instrument packages, it is proposed to conduct a Phase B contract study for a ERBI instrument on the Polar Orbiting Platform of the Space Station Program. The requirements document for the study would include the redesign of the ERBE scanner electronics, the WFOV dome, and any other design weaknesses that can be defined prior to the contract award.

However, prior to being fully committed to the ERBE concept for the Polar Platform ERB measurements system, several other alternatives to ERBE should be examined. The radiation budget scientists of the Federal Republic of Germany (FRG) have proposed a conical scanning instrument for satellite measurement of the ERB components. Also, the European Space Agency has included a provision for ERB measurements from their Columbus program polar platform, the proposed European contribution to the U.S. Space Station Program. The FRG conical scanner and the Nimbus-7 ERB bi-axial scanner and non-scanner packages are the two being considered as candidates to satisfy the Columbus Program measurement requirements. NASA is also considering the development of an instrument for ERB parameter measurements as part of its Earth Observing System (EOS) of the Space Station program. It would seem advisable to develop an Earth radiation budget instrument for the Polar Platform through coordination with these other governments and agencies. For example, it might be possible for all interested parties to collaborate on an ERB measurement system that will satisfy all operational requirements.

It is planned that a meeting of ERBI specialists (both users and measurers) be held in the Spring of 1987, to allow these groups to interact and ascertain whether mutual cooperation and support of a Polar Platform ERBI measurement system is feasible. At the same meeting, the requirements for ERBI measurements would be reviewed and a consensus on instrument and data processing conceptual designs would be developed. Soon thereafter, the requirements document for the Phase B study would be completed and a NOAA Technical Memorandum would be published containing the proceedings of the meeting. This meeting would also ensure that, if and ERBI instrument concept is adopted, flaws in its design would have been identified and included in the Phase B study.

The timing of the Specialists Meeting is critical. It would have to be no later than mid April, and preferably before the end of March, to allow time for the requirements document of the RFP to be revised prior to release.

PROPOSED SCHEDULE

Phase B Requirements Document Drafted	3/15/87
ERBI Specialists Meeting	3/30/87
RFP Complete and to contracts	4/15/87
RFP Issued	6/15/87
NOAA Technical Memorandum Published	8/1/87
Phase B Contract Awarded	9/30/87

II.3 POLAR PLATFORM SCATTEROMETER AND ALTIMETER STUDY

The scatterometer and altimeter are planned as part of the operational payload for the polar platform. As these two instruments were part of the NROSS payload the status of development is such that these instruments are considered carry over instruments. As such, minor Phase B effort is required. The study contractor will perform a pre-Phase C and D effort on the scatterometer and altimeter with attention in the following areas:

1. Perform an analysis to determine what changes must be done to the instrument to make it serviceable and/or replaceable for use on the polar platform.

2. Instrument requirement specifications will be prepared for both the scatterometer and the altimeter. These specifications will be prepared with sufficient information to allow a competitive procurement for both the scatterometer and the altimeter if that requirement is deemed necessary.

3. A final report, which will contain the specifications and the results of the servicing study, will be issued on both the scatterometer and the altimeter at the conclusion of the study.

The scatterometer study will be performed by the Jet Propulsion Laboratory. JPL has the experience with the scatterometer as they designed and built the NROSS instrument.

The altimeter study will be performed by NASA/GSFC with assistance from John Hopkins Applied Physics Laboratory. It is anticipated that the altimeter will be the same type of instrument that is on NROSS.

PROPOSED SCHEDULE

Work Statement Drafted	12/15/86
Transfer of Funds to NASA	3/15/87
Studies Complete	11/30/87

II.4. ADVANCED MEDIUM RESOLUTION IMAGING RADIOMETER (AMRIR)

The Advanced Medium Resolution Imaging Radiometer (AMRIR) has the requirements that will satisfy the present Advanced Very High Resolution Radiometer (AVHRR) and the High resolution Infrared Radiometer Sounder (HIRS) while offering improved resolution and signal-to-noise requirements in the prime AVHRR channels. The study is also taking a look at incorporating the basic requirements of the DoD's Defense Meteorological Satellite Program (DMSP) imaging data requirements.

The following pages are the requirement specification for the design study which will be underway in 1987 and fully describe the requirements of the Phase B study effort for the AMRIR. It is NOAA's intent to award to parallel contracts for the AMRIR. Each contract will be for a period of twelve to eighteen months. Contract awards are presently set for September 1987.

SYSTEM PERFORMANCE SPECIFICATION FOR THE
ADVANCED MEDIUM RESOLUTION IMAGING RADIOMETER (AMRIR)
NESDIS OSD-100001

1.0 Scope

The scope of this Statement of Work (SOW) is the undertaking of a design effort to determine the feasibility, impacts, and actual design, as well as costs associated with, the operational satellite instrument described below. The SOW listed below describes the NOAA requirements for an advanced instrument specified to replace the present Advanced Very High Resolution Radiometer (AVHRR) and the High Resolution Infrared Sounder (HIRS) on the present series of NOAA polar orbiting satellites. The first operational Advanced Medium Resolution Imaging Radiometer (AMRIR) will replace the AVHRR and HIRS beginning with the Polar Platform in 1995. The Design Study Contractors shall examine the feasibility of designing an instrument to meet the planned data requirements of both NOAA and the Defense Meteorological Satellite Program (DMSP). The NOAA requirements for orbit, equatorial crossing times and instrument Instantaneous-Field-of-View (IFOV) shall be considered as baseline. The more exacting DMSP requirements for orbit, equatorial crossing times and instrument IFOV should be addressed by the contractor through augmentations to the basic instrument design.

NOAA proposes to operate AMRIR aboard Polar Platforms in the mid-1990's and beyond, if such provides Federal benefits. DoD proposes autonomous spacecraft for its DMSP mission in that era. This design study, among other purposes, calls for the contractors to investigate the practicality of developing an AMRIR design that meets NOAA requirements and, concurrently, can serve as a proposed design of a future sensor component for the DMSP Operational Linescan System (OLS). To aid the contractors in this investigation, specific DMSP sensor requirements for the OLS and the proposed replacement for the OLS, are provided as an attachments to this SOW and to various sections of the SOW. A third document, survivability of the DMSP imager, is not yet available from DoD and may be furnished as a referenced document after contract award. Not more than 10% of the Federal monies of the contract award is to be used by the contractors to make and report their findings in the area of survivability.

The NOAA cost of AMRIR operations aboard Polar Platforms will be influenced by the on-orbit serviceability costs associated with the instrument. NOAA guidelines are now being established for estimating the funding benefits of serviceability trade-offs. These guidelines are expected to be available during the period of this design study, in which case the guidelines will be provided to and the contractors will be required to report on the serviceability cost factors associated with their proposed designs.

The requirements for the AMRIR are written as if a radiometer is the basic instrument being procured. The study is open to any proposed instrument design or technique. The Proposer is encouraged to submit other designs that will satisfy the basic requirements.

The purpose of the AMRIR is to scan the earth across the spacecraft orbital track ± 56.25 degrees about Nadir and measure the radiation in eleven spectral bands as defined below. The radiometer may scan through the sun on several successive scans per orbit and shall be capable of scanning direct solar input without damage or reduction of life time. It is assumed that the data taken during a view of the sun is worthless.

The AMRIR will consist of an optical system, detectors, associated electronics and scanning system. The AMRIR, for the purpose of this specification, will be considered to be mounted flat against the spacecraft and for thermal purposes will exchange no more than ± 5 watts with the spacecraft interface.

The AMRIR shall be designed to operate within specification for a life of four years in the orbital environment. The AMRIR may be stored for up to three years prior to use, either on the ground or in a space environment.

The NOAA nominal orbit will be circular with an altitude of 833 km ± 92 km (450 ± 50 NMi) and a sun synchronous inclination of 98.8 degrees and a 0930 Local Solar Time (LST) descending node or a 1330 LST ascending node. The period will be 101 minutes. The spacecraft will be designed to operate over a range of sun angles from 0 degrees to 80 degrees. The sun angle is defined in Section 3.4. For purposes of this specification the DMSP nominal orbit is assumed to be the same as the NOAA orbit except that the descending and ascending node may be specified to be anytime with the twenty four hour period.

The spacecraft stabilization will be no worse than the following:

> Attitude orientation shall be within ± one degree with maximum body rates as follows: 0.072 degrees/second in pitch, 0.050 degrees/second in yaw, and 0.016 degrees/second in roll.

3.0 Performance Requirements

The AMRIR instrument shall be an 11 channel system. The instrument is designed to be a multipurpose sensor. Channels 1, 2, and 3 are specified as visible imaging channels, Channel 4 is a day/night imaging channel to provide information to satisfy DoD requirements, Channels 5, 6, and 7 are sounding channels, Channels 8 and 9 are window channels for measuring sea surface temperature, and Channels 10 and 11 are window channels for IR imaging and for surface temperatures. Channel characteristics for each channel are presented below.

3.1 Channel Assignments/Requirements

3.1.1 Channel 1

The total response characteristics of Channel 1 shall be symmetric about 665.0 nm ± 2.0 nm as follows:

655.0 ± 1.0 nm, and

675.0 ± 1.0 nm

2. 2% response points: ± 1.5 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a solar source which simulates the solar spectral energy distribution. The bandpass region shall defined as the interval between the 2% of the maximum response points.

5. The Channel 1 signal-to-noise requirement shall be 10:1 at 0.5% Albedo.

3.1.2 Channel 2

The total response characteristics of Channel 2 shall be symmetric about 855.0 nm ± 2 nm as follows:

1. 50% of maximum response points:

840.0 ± 2.0 nm, and

870.0 ± 2.0 nm

2. 2% response points: $\pm$ 1.5 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a solar source which simulates the solar spectral energy distribution. The bandpass region shall be defined as the interval between the 2% of the maximum response points.

5. The channel 2 signal-to-noise requirement shall be 10:1 at 0.5% Albedo.

3.1.3 Channel 3

The total response characteristics of Channel 3 shall be symmetric about 1.61 micron $\pm$ 0.01 micron as follows:

1. 50% of maximum response points:

   1.58 $\pm$ 0.01 micron, and

   1.64 $\pm$ 0.01 micron

2. 2% response points: $\pm$ 1.5 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a solar source which simulates the solar spectral energy distribution. The bandpass region shall be defined as the interval between the 2% of the maximum response points.

5. The Channel 3 signal-to-noise requirement shall be 20:1 at 0.5% Albedo

3.1.4 Channel 4

3.1.4.1 The relative spectral response of the AMRIR visible-night channel shall be capable of operation at input solar illumination levels, within the 0.4 to 0.90 micrometer wavelength interval, of 5.5×10^{-5} to $2.2 \times 10^{-2} sr^{-1}$.

3.1.4.2 Spectral Response

The total response characteristics of Channel 4 shall be symmetric about 0.650 nm ± 20.0 nm as follows:

1. 50% of maximum response points:

   400 ± 10.0 nm, and

   900 ± 10.0 nm

2. 2% response points: ± 1.5 half power points.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a solar source which simulates the solar spectral energy distribution. The band-pass region shall be defined as the interval between the 2% of the maximum response points.

5. The Channel 4 signal-to noise requirement shall be 10:1 $10^{-8} W\ cm^{-2} sr^{-1}$.

3.1.4.3 Illumination Distribution

The distribution of solar illumination as observed by the AMRIR from its nominal orbit, as reflected from a spherical earth with uniform reflectance of 1.0, is defined by the radiance column in Table 3.1.4.3. The AMRIR shall adjust the gain of the Channel 4 along the crosstrack to yield a uniform image. In addition the AMRIR shall adjust for variations in lunar illumination and non-isotropic scattering from clouds.

3.1.4.4 Channel 4 Noise (Day)

Channel 4 input to the A/D converter shall have a SNR of 10:1 or greater for a solar spectral radiance in the 400 to 900 nm wavelength interval of 5.5 x 10^{-5}W $cm^{-2}sr^{-1}$. SNR for greater input radiance shall be equal to or greater than 10 times the +0.885 power of the ratio of the input radiance to 5.5 x 10^{-5}W $cm^{-2}sr^{-1}$. SNR for greater input radiances shall be equal to or greater than 141.42 times the square root of the ratio of the input radiance to 1.1 x 10^{-3}W $cm^{-2}sr^{-1}$ up to a maximum requirement of 200 minimum SNR which corresponds to an input radiance of 2.2 x 10^{-3}W $cm^{-2}sr^{-1}$.

3.1.4.4.1 Daytime Radiometric Accuracy.

The one sigma accuracy of the scene radiance determined from the AMRIR, shall be within 7% of the value determined from the calibrated linear transfer function for a given AMRIR system, for input solar spectral radiance in the 400 to 900 nm wavelength interval between 5 x 10^{-5} and 2.2 x 10^{-2}W $cm^{-2}sr^{-1}$ when the gain is such that the output is above half scale.

3.1.4.5 Visible 4 Noise (Night).

Nighttime data input to the A/D converter shall have a SNR of 6:1 or greater in the effective data bandwidth due to along-track integration for a lunar spectral radiance in the 400 to 900 nm wavelength interval of 8.0 x 10^{-9}W $cm^{-2}sr^{-1}$. SNR for greater input radiances shall be equal to or greater than 6.0 times the square root of the ratio of the input radiance to 8.0 x 10^{-9}W $cm^{-2}sr^{-1}$ up to a maximum requirement of 200 minimum SNR.

3.1.4.5.1 Nighttime Radiometric Accuracy.

The one sigma accuracy of the scene radiance determined from the AMRIR, shall be within 60% of the value determined from the calibrated linear transfer function for a given AMRIR system, for input lunar spectral radiance in the 400 to 900 nm wavelength interval between 5 x 10^{-9} and 5 x 10^{-5}W $cm^{-2}sr^{-1}$ when the gain is such that the output is above half scale. This accuracy may include corrections utilizing information from an on-board light-emitting diode calibration source if the instrument is so designed.

Table 3.1.4.3 Solar Illumination Distribution

Solar Elevation (Geocentric degrees)	Radiance ($W\ cm^{-2} sr^{-1}$)	Relative L-Channel Gain (dB)
90	$2.78E^{-2}$	0
80	$2.74E^{-2}$	0.1
70	$2.61E^{-2}$	0.5
60	$2.41E^{-2}$	1.2
50	$2.13E^{-2}$	2.3
40	$1.79E^{-2}$	3.8
30	$1.39E^{-2}$	6.0
20	$9.51E^{-3}$	9.3
10	$4.83E^{-3}$	15.2
5	$2.42E^{-3}$	21.2
4	$1.94E^{-3}$	23.1
3	$1.45E^{-3}$	25.6
2	$9.70E^{-4}$	29.1
1	$4.85E^{-4}$	35.2
0	$1.64E^{-4}$	44.6
-1	$8.94E^{-5}$	49.8
-2	$4.35E^{-5}$	56.1
-3	$1.89E^{-5}$	63.4
-4	$7.06E^{-6}$	71.9
-5	$2.42E^{-6}$	81.2
-6	$7.64E^{-7}$	91.2
-7	$2.42E^{-8}$	101.2
-8	$7.86E^{-8}$	111.0
-9	$2.80E^{-8}$	119.9
-10	$1.04E^{-8}$	128.5
-11	$4.21E^{-9}$	136.4
-12	$1.87E^{-9}$	
-13	$9.48E^{-10}$	
-14	$5.41E^{-10}$	
-15	$3.38E^{-10}$	
-16	$2.31E^{-10}$	
-17	$1.76E^{-10}$	
-18	$1.46E^{-10}$	
-19	$1.28E^{-10}$	
-20	$1.15E^{-10}$	
-30	$8.03E^{-11}$	
-40	$7.35E^{-11}$	
-50	$7.08E^{-11}$	
-60	$6.91E^{-11}$	
-70	$6.79E^{-11}$	
-80	$6.77E^{-11}$	
-90	$6.77E^{-11}$	

3.1.5 Channel 5

The total response characteristics of Channel 5 shall be symmetric about 2210 wavenumbers (cm^{-1}) as follows:

1. Total half-maximum bandwidth shall be 15 wave numbers (cm^{-1}).

2. Total 1 percent bandwidth 45 wave numbers (cm^{-1}).

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K source. The bandpass region shall be defined as the interval between the 1% of maximum response points.

5. The Channel 5 noise equivalent radiance (NE^T) shall be defined as follows:

    a. 500 meter resolution NE^T is 1.0 K

    b. 3.5 Km resolution sample average shall be no greater than 0.2 K.

3.1.6 Channel 6

The total response characteristics of Channel 6 shall be symmetric about 2240 wavenumbers (cm^{-1}) as follows:

1. Total half-maximum bandwidth shall be 15 wavenumbers (cm^{-1}).

2. Total 1 percent bandwidth shall be 45 wavenumbers (cm^{-1}).

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 1% of maximum response points.

5. The Channel 6 noise equivalent radiance (NE^T) shall be as follows:

   a. 500 meter resolution NE^T is 1.0 K.

   b. 3.5 Km resolution sample average shall be no greater than 0.2 K.

3.1.7 CHANNEL 7

The total response characteristics of Channel 7 shall be symmetric about 738 wavenumbers (cm^{-1}) as follows:

1. Total half-maximum bandwidth shall be 15 wavenumbers (cm^{-1}).

2. Total 1 percent bandwidth shall be 45 wavenumbers (cm^{-1}).

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 1% of maximum response points.

5. The Channel 7 noise equivalent radiance (NE^T) shall be defined as follows:

   a. 500 meter resolution NE^T shall be no greater than 1.0 K

   b. 3.5 Km resolution sample average shall be no greater than 0.2 K.

3.1.8 Channel 8

The total response characteristics of Channel 8 shall be symmetric about 3.72 micron $\pm$ 0.01 micron as follows:

1. 50% of maximum response points:

   3.62 $\pm$ 0.06 micron, and

   3.83 $\pm$ 0.06 micron

2. 2% response points: $\pm$ 1.0 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 2% of maximum response points.

5. The Channel 8 noise equivalent radiance (NE^T) shall be 0.10 K at 300 K.

3.1.9 Channel 9

The total response characteristics of Channel 9 shall be symmetric about 4.01 micron ± 0.01 micron as follows:

1. 50% of maximum response points:

   3.92 ± 0.06 micron, and

   4.10 ± 0.06 micron

2. 2% response points: ± 1.0 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 2% of maximum response points.

5. The Channel 9 noise equivalent radiance (NE^T) shall be 0.10 K at 300 K.

3.1.10 Channel 10

The total response characteristics of Channel 10 shall be symmetric about 10.8 micron ±0.06 micron as follows:

1. 50% of maximum response points:

   10.30 ± 0.06 micron, and

   11.30 ± 0.06 micron

2. 2% response points: ± 1.0 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 2% of maximum response points.

5. The Channel 10 noise equivalent radiance (NE^T) shall be 0.10 K at 300 K.

3.1.11 <u>Channel 11</u>

The total response characteristics of Channel 11 shall be symmetric about 12.0 micron ± 0.06 micron as follows:

1. 50% of maximum response points:

   11.50 ± 0.06 micron, and

   12.50 ± 0.06 micron

2. 2% response points: ± 1.0 half power bandwidth.

3. The response between the 80% response points on opposite sides of the center frequency shall always exceed 80%.

4. The total out-of-band response shall be less than 1% of the total integrated response within the bandpass region when viewing a 300 K blackbody source. The bandpass region shall be defined as the interval between the 2% of maximum response points.

5. The Channel 11 noise equivalent radiance (NE^T) shall be 0.10 K at 300 K.

3.2 Radiometric Resolution

All data shall be quantized to at least 12 bits. The contractor shall also investigate and recommend data compaction techniques which could be applied to the output of the instrument in order to reduce the amount of data being stored and being transmitted through the real time links.

3.2.1 Channel 4 Gain Requirements

3.2.1.1 Gain Control Adjustability. AMRIR shall adjust the gain of the Channel 4 along and cross track. The AMRIR shall also adjust the gain for variations in lunar illumination. The gain control algorithm shall utilize the scene solar elevation, the scan angle of AMRIR, and the azimuth angle measured at the scene point between the AMRIR line of sight to the scene point and the sun's direction of illumination to adjust for non-isotropic scattering from clouds and oceans. The gain control through the terminator shall be as smooth as possible with minimum loss of data.

3.2.1.2 Gain Control Accuracy. Along-scan gain control (ASGC) shall be provided utilizing ideal inputs from the spacecraft such that relative gain in Channel 4 is within 2 dB of a predicted smooth curve drawn through the tabulated values of gain value versus scene position. Ideal scene solar elevation which can be predicted without errors due to spacecraft attitude, spacecraft altitude, non-spherical earth, spacecraft solar elevation, or spacecraft solar azimuth. Modifications to the ASGC shall be commandable such that the ideal scene solar elevation may be biased plus or minus from the value computed using spacecraft inputs. Modifications to the ASGC shall be commandable such that the effective rate of scene solar elevation change along-scan may be altered TBD from nominal computed values. The maximum gain setting in the ASGC shall be commandable.

3.3 Detectors

The study shall determine the optimum detector(s) combination that is to be incorporated to meet the requirements of the various channels specified in this document. The study will also address the cooling requirements for the detectors and the temperature range that the detectors are designed to operate within. If detector arrays are used consideration must be given to the maintenance of the offsets and gains among the various elements of the array.

3.4 Instantaneous Field-of-View (IFOV)

NOAA's Requirement

The instantaneous field-of-view of the instrument shall be 500 ±250 meters at Nadir. The scan of the instrument shall be a crosstrack scan ±56.25 degrees about Nadir. The orbit of the spacecraft is a sun synchronous orbit of 450 nautical miles altitude with an orbital time of 101 minutes and a inclination of 98 degrees. The design of the imager shall be such as to accommodate equator crossing times of 0930 Local Solar Time (LST) on a southbound orbit and a equator crossing time of 1330 Local Solar Time (LST) on a northbound orbit.

DMSP's Requirement

The DMSP's requirement on field-of-view is for a constant field-of-view of 500 meter across the entire scan. To meet this requirement the contractor has the option of designing the optics for the 500 meter constant field-of-view across track resolution or designing the sampling/onboard data system to produce and equivalent type of 500 meter resolution data readout

3.4.1 Channel 4 Instantaneous Field-of-View

If the design of the channel 4 is such that the sensitivity specification cannot be met with the IFOV specified in paragraph 3.4, the contractor has the option to double the IFOV of channel 4. This option would allow channel 4 to have a IFOV at nadir of 1000 ±500 meters.

3.4.1.1 Registration of the Elemental Field-of-View

At the Nadir scan position the registration of the elemental field-of-view of all channels shall be within ± 0.25 of one IFOV. Channel to channel registration shall be co-located within 0.5 of one resolution element in any direction.

3.5.1.2 Scanned Field-of-View

The scanned field-of-view is the solid angle resulting from rotation of the elemental field-of-view by the scanning mechanism. The angle between the center of the elemental field-of-view in the 130 degree, 180 degree, and 230 degree rotational angle positions and a plane normal to the optical axis shall be identical within ± 0.05 milliradians. Rotational angles are measured in the direction of scan from the zenith direction. The orientation of the radiometer is as it would be when mounted on the spacecraft. The position of the scan plane shall change less than ± 0.1 milliradian as a direct result of all environmental tests.

3.5.2 Calibration

3.5.2.1 Space

The radiometer shall view a portion of space during some portion of each scan line. Viewing of space will be used as one point for a calibration cycle. An unobstructed view shall be provided both by the instrument housing and the spacecraft for the range of scan angles from the deep space region through the earth scan region.

3.5.2.2 Calibration-IR

The design of the instrument shall provide the capability of viewing an internal target which will be used to provide a second point of the calibration cycle for use in calibrating Channels 5 through 11. The surface of this target area shall be designed to simulate a blackbody radiator and the radiation characteristics shall be determined during the program. The temperature of this calibration target shall be measured to the best accuracy possible using high accuracy temperature detectors appropriately arrayed to adequately define the temperature of the target. The temperature uniformity and the instrumentation shall allow for an absolute calibration accuracy of 1.5 degree K precision to be obtained. The target shall be designed to operate at the instrument's ambient temperature.

3.5.2.3 Radiation Input Range

The maximum radiance input shall be 100 percent albedo assuming normal solar incidence and a diffusely reflecting surface for Channel 1 through 4. The contractor shall define a calibration technique or method for calibration of these channels while in orbit. A better term for this calibration may be "stability monitor". The prime purpose of this stability monitor is to determine changes or degradation in the total optical throughput of the instrument. Full aperture illumination is desired. This part of the design shall address, but not be limited to, the following topics:

1. Type and location of source.
2. Protection from contamination.
3. Additional weight, size, and power requirements that it adds to the instrument design.
4. Radiometric performance and source output versus the channel's dynamic range.
5. It is anticipated that the "calibration" sequence will be performed every 1 to 3 months over the instrument life time.
6. The absolute accuracy of this stability monitor shall be equal to or better than 5 percent over the four year life time of the instrument.

The maximum radiance input shall correspond to a target temperature of 330 degrees K $\pm$ 1.0 degree K for Channels 5 through 11. The signals from the radiometer when viewing a 330 degree K calibration source shall be measured when the radiometer is maintained at its nominal temperature.

The signal obtained (from all channels) when viewing the same source shall not vary more than $\pm$ 1 NE^T when the radiometer temperature is varied from 10 degrees to 30 degrees C. The drift from scan line to scan line shall not exceed one NE^T when viewing a scene of 300 degrees K. Under certain spacecraft attitudes, the radiometer may scan through the sun on several successive scans, once per orbit. The radiometer shall be capable of scanning direct solar input without damage or reduction in life time. The radiometer shall return to its calibrated condition within one revolution of the scanning system after exposure to the sun.

3.5.3 Scan Linearity and Jitter

If a rotating scan mirror is used there shall be less than 0.5 IFOV displacement of the FOV at any point on the scan line referred to the same point on the adjacent scan line for 98% of the data points when data is taken every scan line for a 20 minute period.

3.6 Weight Budget

The weight of the AMRIR will be estimated by the contractor. A detail weight budget will be included as part of the final report.

3.7 Power Budget

The power budget of the AMRIR will be estimated by the contractor. A detailed power budget of the instrument will be included as part of the final report.

3.8 Environmental

3.8.1 Thermal

The instrument shall, for the purpose of this design study, be considered to be hard mounted to the spacecraft. The instrument will be hard coupled to the spacecraft. The thermal analysis will consider the conductive heat transfer as no more than $\pm$ 5 watts into or out of the spacecraft interface.

3.8.2 Detector Cooling

If contractor's thermal design includes passive detector cooling, an adequate margin of operation will be included. Passive coolers will also be fitted with outgassing heaters capable of heating the patch to 300 degrees $\pm$ 5 degrees K.

3.9 Mission Life

The radiometer shall be designed for an in-orbit life of four years; allowance should be made for three months of continuous operation during ground testing. The instrument shall operate within specification for the temperature range of 10 degrees to 30 degrees C as measured at the baseplate. The instrument may be stored on the ground or in orbit for a maximum period of 3 years in addition to the four years of operating.

4.0 Technical Requirements

The AMRIR design study will be an iterative process in that exchange of information with NOAA personnel shall be required before the final design is completed. The design study will cover a maximum of a 24 month period.

4.1 Reviews

Each contractor will conduct two design reviews as described below. These reviews will be conducted at the contractor's facility.

4.1.1 Preliminary Design Review

The Preliminary Design Review (PDR) will be conducted approximately one half of the way into the study. The contractor will recommend a time frame for the PDR. This review will cover all of the design work done to this point. Instrument concepts will be discussed and the instrument concept that is recommended will be presented in detail. Optical analysis and detailed NE^T calculations on the recommended design will be presented. Scanner design will be presented with detailed IFOV's along the scan track. Block diagrams of the electronic will be presented. A design package shall be furnished (12 copies). This design data package shall include, but not be limited to:

1. Electrical Block Diagrams
2. Mechanical Layout Drawings
3. Optical Detail Drawings
4. All transmission and NE^T calculations
5. Details on calibration techniques

4.1.2 Final Design Review

The final Design Review (FDR) will be conducted two months before the end of the study. This review will detail the design of the AMRIR as perceived by the contractor. Possible problem areas and areas of concern will be detailed. This review will cover the contents of the final report. A design data package shall be furnished. (20 copies)

4.2 Reporting

1. A monthly report summarizing all activity for the month and projecting activity for the next month is required (10 copies).

2. A final report describing in detail the findings of the study is required (50 copies).

3. Included in the final report will be a detailed ROM cost of a Protoflight, and three Flight models. The final report will also include detailed detector and filter specifications.

III. GEOSTATIONARY SYSTEM STUDIES

III.1 ADVANCED SOUNDER -- BEYOND GOES-K

III.1 ADVANCED SOUNDER -- BEYOND GOES-K

An important requirement of the next generation GOES sounding radiometer is the provision of temperature and moisture profiles with a vertical resolution commensurate with the horizontal and temporal resolutions afforded by the geostationary satellite. The relation between horizontal and vertical wavelengths of atmospheric phenomena is about 100:1. Mesoscale atmospheric phenomena possess horizontal wavelengths of about 200 km and are, therefore, associated with vertical features exhibiting a wavelength of about 2 km. The time scale of mesoscale weather-producing features is one to several hours. The medium spectral resolution filter radiometer, which is under construction for flying on the GOES-I through M series, is capable of achieving the horizontal and temporal resolutions required to resolve mesoscale phenomena; but its 4-5 km vertical resolution severely limits the utility of these data for weather forecast applications. In particular, the impact of these soundings on forecasts generated by the mesoscale numerical prediction models, expected to be operational during the 1990's, may be severely limited by the vertical resolution of these data. The National Weather Service has made an improvement in the vertical resolution of the mesoscale sounding the top priority for the late 1990's. A microwave sounder which is envisioned for the geostationary satellites will not improve the vertical resolution over that now provided by the GOES-I infrared sounder.

PERFORMANCE IMPROVEMENT OF THE INTERFEROMETER APPROACH

To approach the vertical temperature profile resolution required, the sounding instrument must achieve a spectral resolution of 0.1% to avoid smearing contributions to the upwelling radiances from relatively opaque absorption line centers with the transparent regions in between the absorption lines. For example, a spectral resolution of 0.7 cm^{-1} is needed in the 600-700 cm^{-1} (15um) and 2 cm^{-1} in the 2300-2400 cm^{-1} (4.3um) thermal emission bands of CO_2. Although this spectral resolution is beyond the capabilities of filter radiometers, it can be achieved using a Michelson interferometer (High-resolution Interferometer Sounder (HIS) Phase A design study, 1981).

The HIS aircraft instrument aboard the NASA U-2 aircraft has proven the performance capabilities of an interferometer. Ground calibration tests and airborne science missions have demonstrated the ability of the HIS to measure radiometrically accurate emission spectra with a resolution far exceeding the performance of contemporary radiometers. Radiance spectra have been obtained during more than 30 aircraft missions with a resolution of 0.35 cm^{-1} as compared to the typical 15.0 cm^{-1} resolution of filter radiometers such as the one planned for GOES-I/M.

Figure 1 shows a typical spectrum of infrared radiation brightness temperature sensed by the HIS. The half-band widths of the filters planned for the initial GOES-I/M sounding radiometer are superimposed. As can be seen, the filter radiometer severely smears the fine scale spectral radiance structure of the atmosphere. This spectral smearing causes unwanted absorption contamination in atmospheric "windows" used for sensing the earth's surface temperature and it greatly limits the vertical resolution of temperature and water vapor profiles, because it broadens the atmospheric weighting functions.

Figure 2 shows more clearly the effect of spectral resolution on radiance smearing. It can be seen from these brightness temperature spectra that the 15 cm^{-1} resolution of the GOES-I/M filter instrument causes an extreme smearing of energy emission from lower atmospheric levels (brightness temperatures in excess of $290^{o}K$) as revealed in the high resolution brightness temperature structure observed by HIS.

Figure 3 shows a comparison of the vertical resolution of atmospheric temperature profiles as sensed by the GOES-I/M filter radiometer and the interferometer sounder. Figure 4 shows the expected sounding accuracy of the GOES-I/M filter instrument as compared to the proposed modified version. As can be seen from Figures 3 and 4, dramatic improvements are made in vertical resolution and accuracy as a result of the interferometer modification.

In addition to greatly improving atmospheric sounding resolution and accuracy, the modified GOES Sounder would provide more accurate measurements of cloud altitudes and atmospheric soundings beneath thin and/or broken cloud. Observing the infrared spectrum in detail will also provide concentrations of atmospheric gases such as ozone and methane, and the state of the land and sea surface. The interferometer sounder, once implemented aboard the geostationary satellite, will help satisfy observational requirements for climatology, oceanography, and geology as well as operational meteorology.

FEASIBILITY CONSIDERATIONS FOR MODIFYING GOES-I/M SOUNDER

There is a practical way to provide improved vertical resolution GOES soundings for the mesoscale operational activities of the mid-1990's. Modifying the GOES-I Sounder to replace the filter wheel with an interferometer is an attractive approach, which would yield the highest vertical resolution soundings possible with a passive device. Interferometers have a record of successes in space beginning with Nimbus-3, and modern interferometers have even proven that they can handle the rigors of aircraft applications. An upgraded instrument could be available in time for GOES-L and M in the 1994/1995 time frame. The step which needs to be taken now, is to begin a detailed feasibility study as soon as possible.

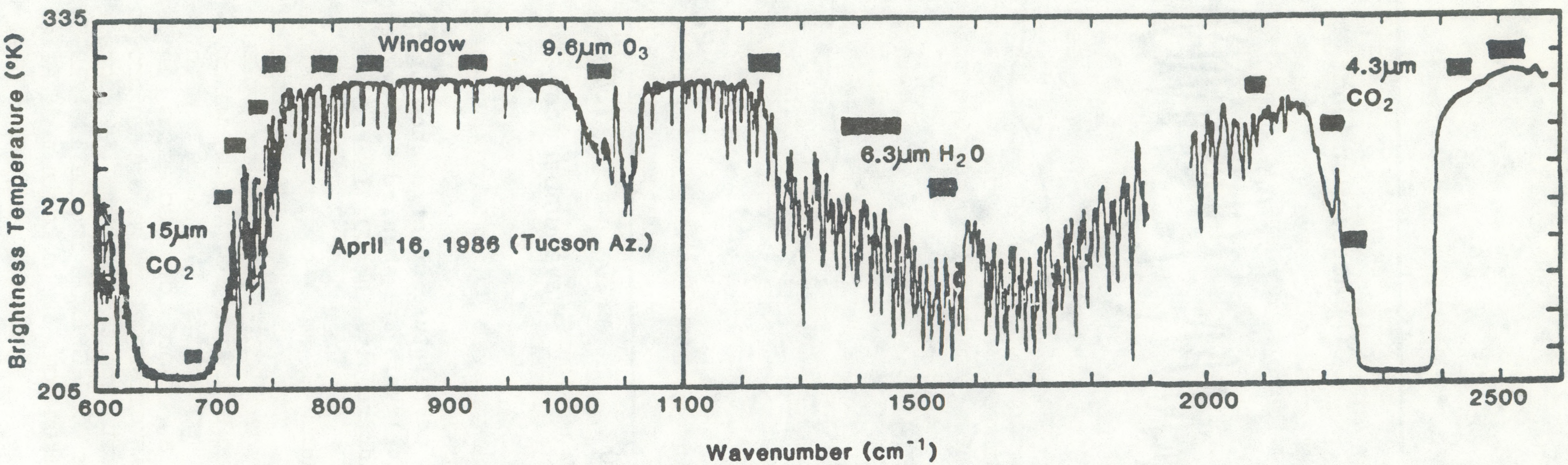

Fig. 1 Radiation brightness temperature spectrum as observed by HIS from the NASA U-2 aircraft over Tucson, Arizona with the half bandwidths of the GOES-NEXT filters superimposed.

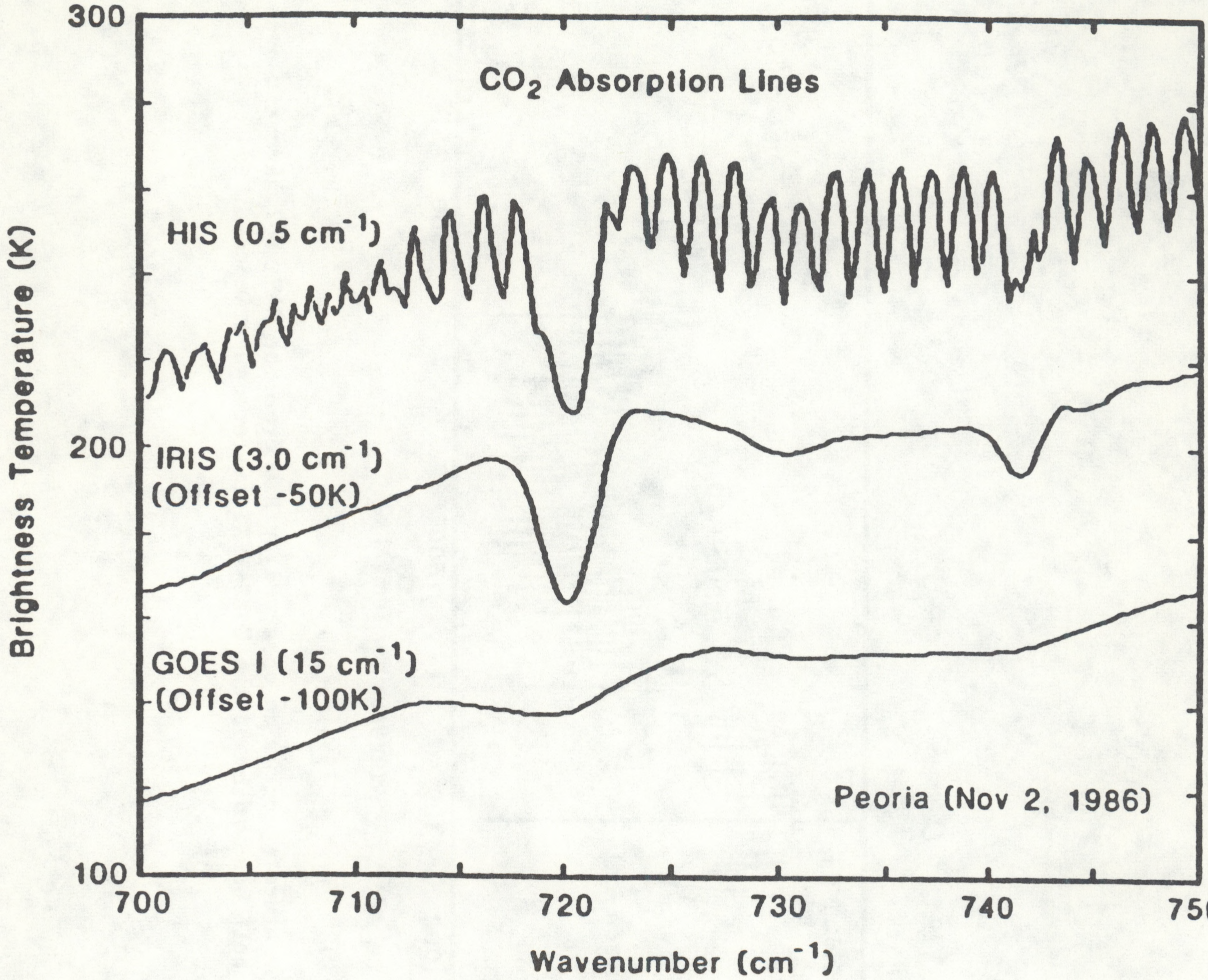

Fig. 2 Brightness temperature spectra showing how emissions from different atmospheric levels are smeared by low resolution measurements, which cannot resolve the CO_2 lines.

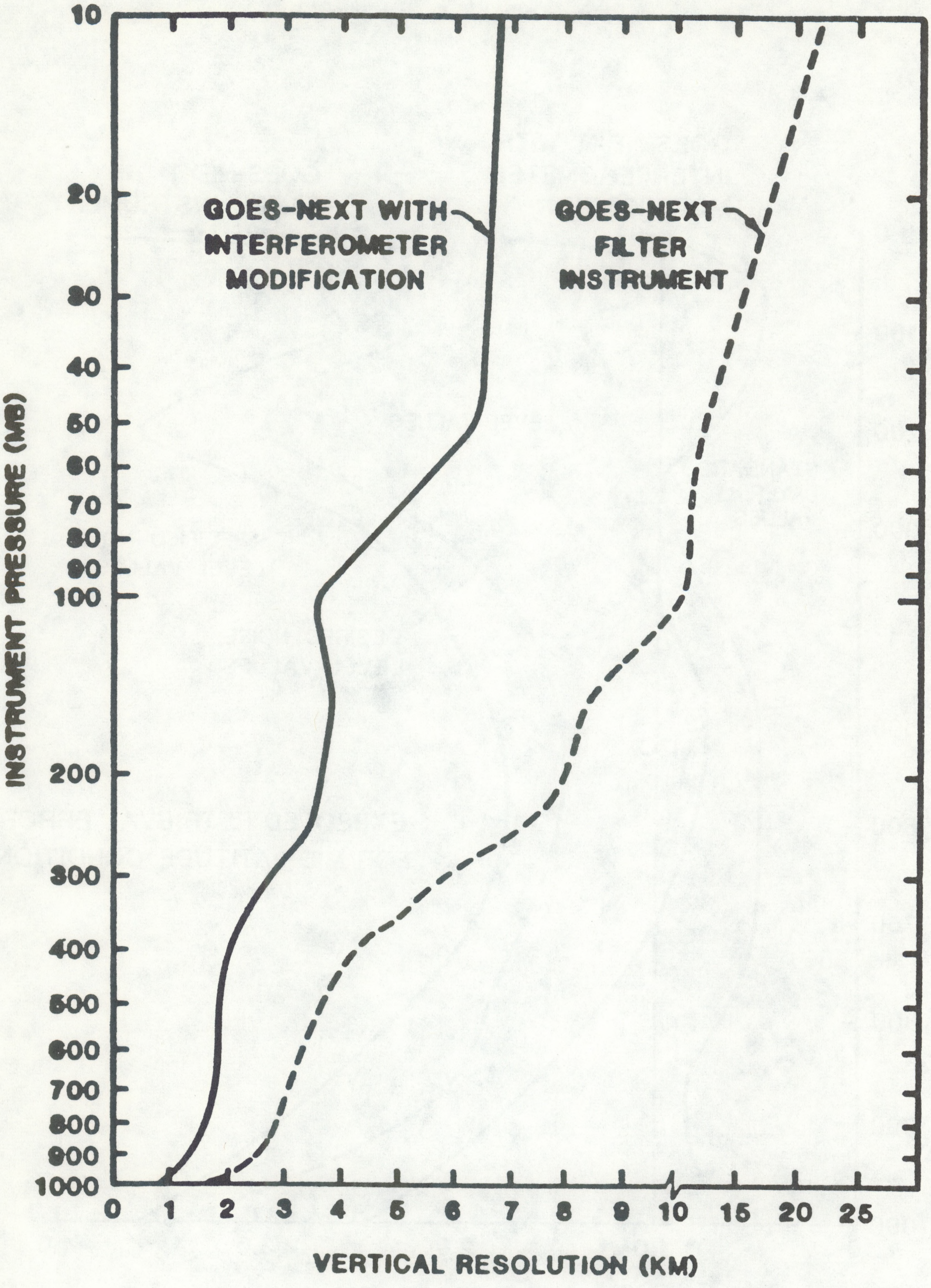

Fig. 3 Improvement in vertical temperature profile resolution from modifying GOES-NEXT to use an interferometer.

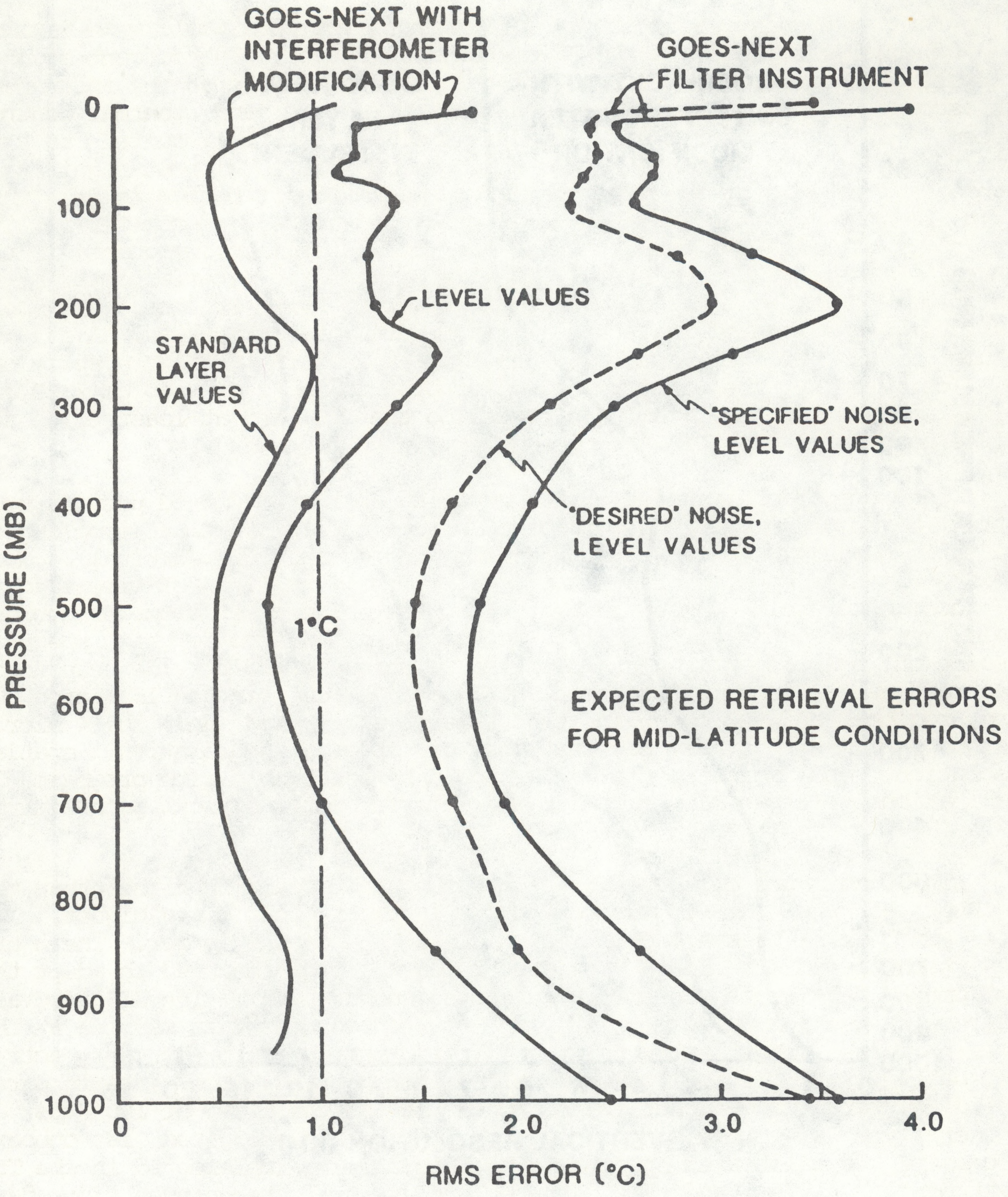

Fig. 4 Improvement in vertical temperature profile RMS retrieval errors from modifying GOES-NEXT to use an interferometer.

This approach to improving soundings from GOES would make maximum use of the instrument systems already developed. The current sounder subsystems that account for most of the mass and volume of the instrument (telescope, pointing system, mechanical structure and thermal control system, and detector and cooler system) are well-suited to the interferometer implementation and could be maintained without significant change. The mass of the current filter wheel and aft optics is less than seven percent of the total sounder mass, and the interferometer and its aft optics would be even less of the total. Similar components in the Thermal Emission Spectrometer (TES), a radiometric interferometer being designed for geological observations from Mars Orbiter, are only one-fourth the mass of the sounder filter wheel and aft optics. Also, the volume available for these components is ample. The available space has been defined by the instrument contractor to be 40 cm x 40 cm x 20 cm, which is about three times that needed on the TES, and at least twice the volume needed for the GOES interferometer.

The operational modes of the modified instrument would provide much better balance between the scales of horizontal and vertical sampling of the atmosphere. The GOES-I sounder will undersample the vertical because of its limited spectral resolution, while its 10 km field-of-view spacing is incommensurately dense in the horizontal. The interferometer sounder would use the spatial sampling schemes to allow time for high spectral resolution measurements. This sampling technique would provide unapodized spectral resolutions of between 0.35 and 0.7 cm^{-1} in the 15 micron CO_2 band region, and 2 cm^{-1} in the water vapor band and the 4 micron region. Many other combinations of spectral resolution, spatial resolution, and noise performance would be selectable with programmable combinations of scan mirror motion and interferometer optical path limits.

The data rate of the interferometer sounder would be higher than the 40 Kbps of the GOES-I sounder, but only two to four times higher. The rate would still be small compared to the 2 Mbps of the imager. There are many techniques for onboard data processing which can be used to adapt the instrument data rate to communications constraints. The HIS aircraft instrument uses numerical filtering to reduce the data sampled at the laser sample fringe rate to the minimum rate which preserves spectral information. If only numerical filtering and some interferogram co-adding were used, the rates would be on the order of 100 Kbps. A further type of processing which should be investigated is onboard processing to calibrated spectra, a technique being implemented in the TES instrument. In addition, there are several techniques for data compression which could be useful for reducing data rates. The optimum use of onboard processing is an important part of the feasibility study.

STUDY ORGANIZATION AND TASKS

The organization and major tasks of the proposed study are summarized in the following table.

University of Wisconsin, Space Science and Engineering Center (UW/SSEC) (PRIME)

--Manage project and subcontracts
--Establish specifications with NESDIS
--Define expected performance using HIS aircraft data
--Define processing and data trade-offs
--Participate with SBRC in interferometer hardware feasibility design

Santa Barbara Research Center (SBRC) (Subcontract)

--Interferometer/aft optics design and option definition
--Feasibility design for onboard processing

International Telephone and Telegraph (ITT) (Subcontract)

--Define GOES Sounder interfaces
--Participate in approach definition
--Feasibility of alternate scan modes

The involvement of ITT is essential, but will be kept at a minimum to prevent any impact on the GOES-I schedule. The ITT subcontract will be sole sourced, based on their role as the GOES I/M imager and sounder contractor. The SBRC subcontract will also be sole sourced because of their technical experience relevant to the study and because of the need to proceed expeditiously to meet the target date of February 1988 for influencing the FY90 budget. SBRC is especially well-suited for the interferometer hardware and onboard software study because of their ongoing involvement in the HIS GOES Phase A design and aircraft instrument programs, and because of their experience in designing the TES interferometer for Mars Orbiter. The onboard processing techniques developed for TES are especially important for the data handling trade-offs to be considered in the study.

SCHEDULE

Contract Award to UW/SSEC	June 1987
Define Interface Requirements	July 1987
Preliminary System Design Complete	November 1987
Final Conceptual Design Complete	February 1987
Final Review	May 1987

IV. SYSTEM SUPPORT APPLICABLE TO BOTH POLAR AND GEOSTATIONARY SYSTEMS

IV.1. MICROWAVE SOUNDING CONFERENCE

IV.2. MICROWAVE SCIENCE SUPPORT

IV.1 MICROWAVE SOUNDING CONFERENCE

Much effort has been done in the past few years in developing the microwave sounding instrumentation and techniques. In the past, when the requirements for the Advanced Microwave Sounding Unit (AMSU) were being formulated, a group designated the AMSU Working Group met as needed to provide advice to the requirements of the AMSU. This group was originally formed by NASA and then later taken over by NESDIS when NESDIS assumed the lead in providing the funding for operational instruments. The last meeting of the AMSU Working Group was in 1983 and since that time the contract for AMSU has been awarded and requirements for a geostationary microwave sounder have began to appear.

The NESDIS Office of System Development will call the members of the AMSU Working Group together to inform them of the progress of the instrument development and to provide a overview of the software development. This meeting will also look at the requirements and technology needed to provide a geostationary microwave sounder.

PROPOSED PROGRAM

There is to be a three day conference/workshop in the June 1987. The conference would be divided into two parts the first part covering the AMSU with status, science, engineering and products covering the first half. The second half is devoted to the geostationary instrument covering also engineering, science and products. The output of the conference is a report and recommendations. Attendees would consist of government and industry representatives from not only the United States but from the world community of users and instrument manufacturers.

SCHEDULE

Conference Site Established	11/15/86
Agenda and invitations out	2/1/87
Conference Convened	6/1/87
Conference Report Published	10/1/87

IV.2. MICROWAVE SCIENCE SUPPORT

In years past the support of the scientific community for microwave soundings has been strong at the Massachusetts Institute of Technology (MIT) with the principle investigator being Dr. David Staelin. Funding for this support through fiscal 1984 was provided by the NESDIS Office of Research. Beginning in 1985 the funding for the microwave science support has come from the NOAA-K Implementation Budget with the justification being that all of the effort of MIT was being directed towards the NOAA-K/AMSU effort.

It is proposed that the NESDIS Office of System Development begin funding the MIT effort from its in-house study funds. The MIT work statement will be expanded to include geostationary microwave sounding science and in view of this MIT will assist NESDIS in conducting the Microwave Workshop being planned for June 1987.

PROPOSED PROGRAM

We propose to augment the ongoing effort entitled "Algorithms for Estimating Surface Emissivities and Precipitation Using AMSU Data." The primary objective of this effort is to support NOAA's charter to develop improved operational satellite systems, and, in particular, to support the development of the operational data reduction system for AMSU. Sufficient discrepancies have been observed by satellite between the predicted and measured microwave radiances in the 5-mm wavelength band that attention should be focused on the expressions used for the microwave transmittances of atmospheric oxygen and water vapor. MIT will also assist and serve as consultants for the instrument development effort at the contractor's facility. MIT will attend major AMSU design reviews and offer critical comment on the proposed design.

A Review of proposed methods of developing a microwave sounder for the geostationary orbit is needed. The European Space Agency (ESA) are into Phase B studies of a microwave sounder for the geostationary orbit and this effort needs to be followed in order that NOAA can take advantage of the work being done in Europe. It is proposed to add the geostationary effort to the MIT work statement. This effort would include taking an active part in the Microwave Workshop and reviewing the work being done by ESA.

SCHEDULE

Contract Modified to include new work statement	8/1/87

V. SUMMARY

Sections II through IV have defined the study programs that the NESDIS Office of Systems Development is in the process of initiating during 1987.

As is evident, the main thrust of the sensor design studies is to prepare an operational payload for NOAA's participation in the Polar Platform portion of the Space Station Program. Participation in the Polar Platform will permit NOAA to expand its operational core payload to include, not only the data base that is available from the polar orbiters today, but a greatly expanded data base. The expanded data base will include a variety of atmospheric and ocean state sensors that have not been available in the past from one satellite system.

The Advanced Medium Resolution Infrared Radiometer (AMRIR) will be a replacement for the Advanced Very High Resolution Radiometer (AVHRR) and the High resolution Infrared Radiometer Sounder (HIRS). The AVHRR and the HIRS are now operational on the NOAA series of polar orbiters through NOAA-M, scheduled for launch in 1995. The Polar Platform is presently scheduled for launch in 1995, which will replace NOAA-M as the operational spacecraft.

The Global Ozone Monitoring Radiometer (GOMR) will replace the Solar Backscatter Ultraviolet (SBUV) on the Polar Platform as the operational ozone monitor. The SBUV is the operational instrument on the afternoon satellite through NOAA-M for monitoring ozone.

The remaining instruments being studied are not replacing sensors on the present spacecraft. These sensors are being designed to provide new and exciting data to NOAA operational data base and will greatly expand NOAA's product services to the users of environmental data.

Beginning in 1989 NOAA will be introducing a new series of geostationary environmental satellites. The new series, beginning with GOES-I, will offer improved image products and for the first operational sounder from a geostationary satellite. Even though the sounder is not going operational until GOES-I, requirements are being defined that will require better accuracy and vertical resolution than is capable from the GOES-I sounder. The sensor study defined in Section III begins the process of improving the GOES-I sounder to meet the new requirements. If this study shows that the improvements are possible than the modifications would be included in the GOES-L or GOES-M satellites.

The major portion of the effort will not be finished until 1989 or later. As requirements change the definition studies for the instruments will be modified to incorporate the changed requirements. This report provides the reader with the guidelines for the sensors as they are known today.

(Continued from inside cover)

NESDIS 13 Summary and Analyses of the NOAA N-ROSS/ERS-1 Environmental Data Development Activity. John W. Sherman III, February 1984. (PB85 222743/43)

NESDIS 14 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Activity. John W. Sherman III, February 1985. (PB86 139284 A/S)

NESDIS 15 NOAA N-ROSS/ERS-1 Environmental Data Development (NNEEDD) Products and Services. Franklin E. Kniskern, February 1985, (PB86 213527/AS)

NESDIS 16 Temporal and Spatial Analyses of Civil Marine Satellite Requirements. Nancy J. Hooper and John W. Sherman III, February 1985. (PB86 212123/AS)

NESDIS 17 reserved

NESDIS 18 Earth Observations and the Polar Platform. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 177624/AS)

NESDIS 19 The Space Station Polar Platform: Intergrating Research and Operational Missions. John H. McElroy and Stanley R. Schneider, January 1985. (PB85 195279/AS)

NESDIS 20 An Atlas of High Altitude Aircraft Measured Radiance of White Sands, New Mexico, in the 450-1050nm Band. Gilbert R. Smith, Robert H. Levin and John S. Knoll, April 1985. (PB85 204501/AS)

NESDIS 21 High Altitude Measured Radiance of White Sands, New Mexico, in the 400-2000nm Band Using a Filter Wedge Spectrometer. Gilbert R. Smith and Robert H. Levin, April 1985. (PB85 206084/AS)

NESDIS 22 The Space Station Polar Platform: NOAA Systems Considerations and Requirements. John H. McElroy and Stanley R. Schneider, June 1985. (PB86 6109246/AS)

NESDIS 23 The Use of TOMS Data in Evaluating and Improving the Total Ozone from TOVS Measurements. James H. Lienesch and Prabhat K.K. Pandey, July 1985. (PB86 108412/AS)

NESDIS 24 Satellite-Derived Moisture Profiles. Andrew Timchalk, April 1986. (PB86 232923/AS)

NESDIS 25 reserved

NESDIS 26 Monthly and Seasonal Mean Outgoing Longwave Radiation and Anomalies. Arnold Gruber, Marylin Varnadore, Phillip A. Arkin, and Jay S. Winston, October 1987. (PB87160545/AS)

NESDIS 27 Estimation of Broadband Planetary Albedo from Operational Narrowband Satellite Measurements. James Wydick, in press.

NESDIS 28 The AVHRR/HIRS Operational Method for Satellite Based Sea Surface Temperature Determination. Charles Walton, in press.

NESDIS 29 The Complementary Roles of Microwave and Infrared Instruments in Atmospheric Sounding. Larry McMillin, February 1987. (PB87 184917/AS)

NESDIS 30 Planning for Future Generational Sensors and Other Priorities. James C. Fischer, in press

NESDIS 31 Data Processing Algorithms for Inferring Stratospheric Gas Concentrations from Balloon-Based Solar Occultation Data. I-Lok Chang (American University) and Michael P. Weinreb, April 1987. (PB87 196424)

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Department of Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic impact of natural and technological changes in the environment and to monitor and predict the state of the solid Earth, the oceans and their living resources, the atmosphere, and the space environment of the Earth.

The major components of NOAA regularly produce various types of scientific and technical information in the following kinds of publications:

PROFESSIONAL PAPERS—Important definitive research results, major techniques, and special investigations.

CONTRACT AND GRANT REPORTS—Reports prepared by contractors or grantees under NOAA sponsorship.

ATLAS—Presentation of analyzed data generally in the form of maps showing distribution of rainfall, chemical and physical conditions of oceans and atmosphere, distribution of fishes and marine mammals, ionospheric conditions, etc.

TECHNICAL SERVICE PUBLICATIONS—Reports containing data, observations, instructions, etc. A partial listing includes data serials; prediction and outlook periodicals; technical manuals, training papers, planning reports, and information serials; and miscellaneous technical publications.

TECHNICAL REPORTS—Journal quality with extensive details, mathematical developments, or data listings.

TECHNICAL MEMORANDUMS—Reports of preliminary, partial, or negative research or technology results, interim instructions, and the like.

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