QC
879.5
.U45
no.83

NOAA Technical Report NESS 83

Atmospheric Sounding User's Guide

Washington, D.C.
April 1981

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Earth Satellite Service

NOAA TECHNICAL REPORTS

National Environmental Satellite Service Series

The National Environmental Satellite Service (NESS) is responsible for the establishment and operation of the environmental satellite systems of NOAA.

Publication of a report in NOAA Technical Report NESS series will not preclude later publication in an expanded or modified form in scientific journals. NESS series of NOAA Technical Reports is a continuation of, and retains the consecutive numbering sequence of, the former series, ESSA Technical Report National Environmental Satellite Center (NESC), and of the earlier series, Weather Bureau Meteorological Satellite Laboratory (MSL) Report. Reports 1 through 39 are listed in publication NESC 56 of this series.

Reports in the series are available from the National Technical Information Service (NTIS), U.S. Department of Commerce, Sills Bldg., 5285 Port Royal Road, Springfield, VA 22161, in paper copy or microfiche form. Order by accession number, when given, in parentheses. Beginning with 64, printed copies of the reports, if available, can be ordered through the Superintendent of Documents, U.S. Government Printing Office, Washington, DC 20402. Prices given on request from the Superintendent of Documents or NTIS.

ESSA Technical Reports

NESC 46 Monthly and Seasonal Mean Global Charts of Brightness From ESSA 3 and ESSA 5 Digitized Pictures, February 1967-February 1968. V. Ray Taylor and Jay S. Winston, November 1968, 9 pp. plus 17 charts. (PB-180-717)

NESC 47 A Polynomial Representation of Carbon Dioxide and Water Vapor Transmission. William L. Smith, February 1969 (reprinted April 1971), 20 pp. (PB-183-296)

NESC 48 Statistical Estimation of the Atmosphere's Geopotential Height Distribution From Satellite Radiation Measurements. William L. Smith, February 1969, 29 pp. (PB-183-297)

NESC 49 Synoptic/Dynamic Diagnosis of a Developing Low-Level Cyclone and Its Satellite-Viewed Cloud Patterns. Harold J. Brodrick and E. Paul McClain, May 1969, 26 pp. (PB-184-612)

NESC 50 Estimating Maximum Wind Speed of Tropical Storms From High Resolution Infrared Data. L. F. Hubert, A. Timchalk, and S. Fritz, May 1969, 33 pp. (PB-184-611)

NESC 51 Application of Meteorological Satellite Data in Analysis and Forecasting. Ralph K. Anderson, Jerome P. Ashman, Fred Bittner, Golden R. Farr, Edward W. Ferguson, Vincent J. Oliver, Arthur H. Smith, James F. W. Purdom, and Rance W. Skidmore, March 1974 (reprint and revision of NESC 51, September 1969, and inclusion of Supplement, November 1971, and Supplement 2, March 1973), pp. 1--6C-18 plus references.

NESC 52 Data Reduction Processes for Spinning Flat-Plate Satellite-Borne Radiometers. Torrence H. MacDonald, July 1970, 37 pp. (COM-71-00132)

NESC 53 Archiving and Climatological Applications of Meteorological Satellite Data. John A. Leese, Arthur L. Booth, and Frederick A. Godshall, July 1970, pp. 1-1--5-8 plus references and appendixes A through D. (COM-71-00076)

NESC 54 Estimating Cloud Amount and Height From Satellite Infrared Radiation Data. P. Krishna Rao, July 1970, 11 pp. (PB-194-685)

NESC 56 Time-Longitude Sections of Tropical Cloudiness (December 1966-November 1967). J. M. Wallace, July 1970, 37 pp. (COM-71-00131)

NOAA Technical Reports

NESS 55 The Use of Satellite-Observed Cloud Patterns in Northern Hemisphere 500-mb Numerical Analysis. Roland E. Nagle and Christopher M. Hayden, April 1971, 25 pp. plus appendixes A, B, and C. (COM-73-50262)

NESS 57 Table of Scattering Function of Infrared Radiation for Water Clouds. Giichi Yamamoto, Masayuki Tanaka, and Shoji Asano, April 1971, 8 pp. plus tables. (COM-71-50312)

NESS 58 The Airborne ITPR Brassboard Experiment. W. L. Smith, D. T. Hilleary, E. C. Baldwin, W. Jacob, H. Jacobowitz, G. Nelson, S. Soules, and D. Q. Wark, March 1972, 74 pp. (COM-72-10557)

NESS 59 Temperature Sounding From Satellites. S. Fritz, D. Q. Wark, H. E. Fleming, W. L. Smith, H. Jacobowitz, D. T. Hilleary, and J. C. Alishouse, July 1972, 49 pp. (COM-72-50963)

NESS 60 Satellite Measurements of Aerosol Backscattered Radiation From the Nimbus F Earth Radiation Budget Experiment. H. Jacobowitz, W. L. Smith, and A. J. Drummond, August 1972, 9 pp. (COM-72-51031)

(Continued on inside back cover)

PB 81-230476

QC
879.5
.U45
no.83

NOAA Technical Report NESS 83

Atmospheric Sounding User's Guide

Adolf Werbowetzki, Editor

Washington, D.C.
April 1981

U.S. DEPARTMENT OF COMMERCE
Malcolm Baldrige, Secretary

National Oceanic and Atmospheric Administration
James P. Walsh, Acting Administrator

National Earth Satellite Service
David S. Johnson, Director

81 1954

SILVER SPRING
CENTER
JUL 14 1
N.O.A.A.
U. S. Dept. of Commerce

National Oceanic and Atmospheric Administration
TIROS Satellites and Satellite Meteorology

ERRATA NOTICE

One or more conditions of the original document may affect the quality of the image, such as:

Discolored pages
Faded or light ink
Binding intrudes into the text

This has been a co-operative project between the NOAA Central Library and the Climate Database Modernization Program, National Climate Data Center (NCDC). To view the original document contact the NOAA Central Library in Silver Spring, MD at (301) 713-2607 x124 or Library.Reference@noaa.gov.

HOV Services
Imaging Contractor
12200 Kiln Court
Beltsville, MD 20704-1387
January 26, 2009

81 1954

TABLE OF CONTENTS

TABLE OF CONTENTS ---------- iii
LIST OF FIGURES ---------- iv
LIST OF TABLES ---------- iv
ACKNOWLEDGMENTS ---------- v

1. INTRODUCTION ---------- 1
2. TOVS PROCESSING SYSTEMS ---------- 7
2.1 The Operational TOVS Processing System ---------- 7
2.1.1 TIROS Preprocessor ---------- 7
2.1.2 TIROS Atmospheric Radiance Module (TARM) ---------- 7
2.1.3 TIROS Stratospheric Mapper (TSM) ---------- 8
2.1.4 TIROS Retrieval Module (TRET) ---------- 9
2.2 The Experimental Interacting TOVS Processing System ---------- 9
3. THE TOVS COEFFICIENT DATA BASE ---------- 11
3.1 Initial Coefficient Generation ---------- 11
3.1.1 Band Correction Coefficients ---------- 11
3.1.2 Transmittance Generating Coefficients ---------- 13
3.1.3 Limb Correction Coefficients ---------- 15
3.1.4 Retrieval Coefficients ---------- 17
3.2 Updated Coefficients ---------- 17
3.2.1 Input Data For Generation Of Updated Coefficients ---------- 17
3.2.2 Coefficients And Eigenvectors For The TOVS Atmospheric Radiance Module (TARM) ---------- 18
3.2.3 Retrieval Coefficient Generation ---------- 18
4. INSTRUMENTATION AND DATA TRANSMISSION SYSTEMS ---------- 25
4.1 TIROS Operational Vertical Sounder (TOVS) ---------- 25
4.1.1 High Resolution Infrared Radiation Sounder (HIRS/2) ---------- 25
4.1.2 Stratospheric Sounding Unit (SSU) ---------- 26
4.1.3 Microwave Sounding Unit (MSU) ---------- 27
4.2 High Resolution Picture Transmission (HRPT) Characteristics ---------- 28
4.3 HRPT Format ---------- 28
4.3.1 Detailed Description Of HRPT Minor Frame Format ---------- 28
4.4 Direct Sounder Broadcast (DSB) Transmission Characteristics ---------- 28
4.5 TIROS Information Processor (TIP) Data Format ---------- 28
5. CALIBRATION ---------- 43
5.1 HIRS/2 ---------- 44
5.2 MSU ---------- 45
5.3 SSU ---------- 47
5.4 Application Of Calibration Coefficients To Earth View Data ---------- 49
6. INSTRUMENT DATA BASES ---------- 51
6.1 HIRS/2 ---------- 51
6.2 MSU ---------- 57
6.3 SSU ---------- 58
7. SCAN TIMING AND GEOMETRY ---------- 61
8. TOVS SOUNDING PRODUCT ---------- 65
9. ORDERING TOVS DATA AND PRODUCTS FROM SDSD ---------- 75
REFERENCES ---------- 76
ACRONYMS AND ABBREVIATIONS ---------- 78
APPENDIX ---------- 81

FIGURES

1. TOVS Weighting Functions ---------- 4
2. HIRS And MSU Scan Patterns For Two Consecutive Orbits ---------- 5
3. Organization Of Coefficient Data Base (CDB) ---------- 12
4. TIROS-N/NOAA Real Time Systems Data Flow ---------- 29
5. TIROS-N/NOAA HRPT Minor Frame Format ---------- 30
6. TIP Minor Frame Format ---------- 39
7. HIRS/2 And SSU Scan Patterns Projected On The Earth ---------- 63
8. HIRS/2 And MSU Scan Patterns Projected On The Earth ---------- 64

TABLES

1. Characteristics Of TOV Sounding Channels ---------- 3
2. CDB Coefficients ---------- 20
3. CDB Eigenvectors, Eigenvalues, And Means ---------- 22
4. CDB Constants, Parameters, And Flags ---------- 23
5. HIRS/2 Instrument Parameters ---------- 25
6. HIRS/2 Spectral Characteristics ---------- 26
7. SSU Channel Characteristics ---------- 26
8. SSU Instrument Parameters ---------- 27
9. MSU Channel Characteristics ---------- 27
10. MSU Instrument Parameters ---------- 27
11. HRPT Characteristics ---------- 31
12. HRPT Parameters ---------- 31
13. HRPT Transmission Parameters ---------- 32
14. HRPT Minor Frame Format ---------- 33
15. DSB Transmission Parameters ---------- 37
16. DSB TIP Parameters ---------- 38
17. Detailed Description Of TIP Minor Frame ---------- 40
18. HIRS/2 Digital A Data Output ---------- 52
19. HIRS/2 Channel Word Location ---------- 54
20. MSU Scan Line Format ---------- 55
21. MSU Bit Formats For Each IFOV ---------- 56
22. Acceptable Scan Angles ---------- 57
23. 30-Word SSU Data Sampling ---------- 59
24. Instrument Scan Timing Parameters ---------- 61
25. Scan Line Timing Of The TOVS Instruments ---------- 62
26. Structure of TOVS Sounding Product Tape ---------- 67

ACKNOWLEDGMENTS

Most of the material in this report has been compiled from previously published manuscripts. The documents are included in the references. Special acknowledgment is given to Rita J. Southall for her contribution of Chapter 3, which describes the generation and many uses of coefficients residing in the TOVS coefficients data base. Also deserving special mention are Judy Thompson, who spent many hours typing and correcting this manuscript, and Robert W. Popham for his assistance in producing and editing the final report.

ATMOSPHERIC SOUNDING USER'S GUIDE

ABSTRACT: The TIROS Operational Vertical Sounder (TOVS) on TIROS-N series satellites replaced the Vertical Temperature Profile Radiometer (VTPR) flown on earlier polar orbiting spacecraft. Since the successful launch of TIROS-N and the change-over to TOVS, many papers and articles have been presented concerning the various aspects of the TOVS hardware/software system. This report was compiled to provide users with a document which would include all the significant features of the TOVS operational system.

1. INTRODUCTION

Initial planning for the TIROS-N Operational Vertical Sounder (TOVS) began in 1970 and was formalized in 1971. At that time the concepts of indirect sounding of the atmosphere were supported by observations from the SIRS and IRIS instruments on the Nimbus-3 and -4 satellites. Yet to be tested were the ITPR, NEMS, and SCR on Nimbus-5, the HIRS, SCAMS, and PMR on Nimbus-6, and the VTPR on the NOAA-2 to -5 operational satellites. (See NASA Goddard Space Flight Center, 1969,1970,1972,1975, for a description of these instruments).

The profusion of acronyms associated with the instruments obscures the progressive refinement of the observations needed to deduce useful profiles of temperature and humidity. Early experiments were more simple in the sense that known limitations were imposed by the technology of the mid-1960s. Improvements in infrared detectors, solid-state devices for microwave radiometry, and the reliability of other components of satellite systems opened the way for more sophisticated experiments leading to operational systems for indirect sounding.

At the time the TOVS was planned, experience showed that several considerations had to be taken into account:

1) Clouds represented a major limitation. To combat this, two approaches were open:

   a) The infrared signals from a number of contiguous fields of view can be combined to process a single sounding. The influence of clouds can be deduced from variations in the signals due to breaks in the cloudiness, and the signal for a cloud-free atmosphere extracted.

   b) Microwave emissions are largely uninhibited by cloud droplets. Thus, in the presence of clouds opaque to the infrared channel, soundings can be made from emissions in the microwave spectral region.

2) To obtain accurate temperature soundings, it is necessary to conduct simultaneous measurements from which water vapor and ozone can be deduced. This is because atmospheric absorptions at all wavelengths are caused by a combination of atmospheric gases.

3) Indirect soundings in the troposphere are improved if the measurements extend through the stratosphere. This is because the upwelling radiation is integrated throughout the entire atmosphere.

Additionally, experience suggested that:

4) The large temperature dependence of thermal radiation at short wavelengths makes it desirable to conduct at least a portion of the measurements in the spectral region from 3.5-5 um.

5) There is an optimum number of spectral samples for obtaining soundings (Weinreb and Crosby, 1972), and increasing the number will be of little benefit relative to the spectral region being used and a given signal-to-noise ratio.

The TOVS instruments that evolved from the initial study reflect the above considerations and the experience gained as the later experiments were flown. Final design specifications represented the accumulation of our knowledge up to 1976.

The TOVS consists of three instruments: 1) the second version of the High resolution Infrared Radiation Sounder (HIRS-2) originally tested aboard the Nimbus-6 satellite, 2) the Microwave Sounding Unit (MSU), which is similar to the Scanning Microwave Spectrometer (SCAMS) flown on Nimbus-6, and 3) the Stratospheric Sounding Unit (SSU) provided by the British Meteorological Office and which is a Pressure Modulated Radiometer (PMR) similar to the one flown on Nimbus-6. Table 1 provides the characteristics and purpose of the radiance observations provided by the various spectral channels of each instrument. Demonstration of the vertical resolution of the radiation observed within each channel is given in Fig. 1. Each curve in the figure shows the sensitivity of the radiance observed in the spectral interval of the indicated channel to a local variation in atmospheric temperature. These are usually referred to as "weighting functions" because they appear as weights in the integral equations relating atmospheric temperature to the observed radiances. These weighting functions vary somewhat according to the water vapor and ozone content of the atmosphere, and also weakly with atmospheric temperature.

The scan pattern of the HIRS and MSU instruments for two adjacent orbits over North America is portrayed in Fig. 2. The HIRS instrument resolves a circular area that is 30 Km diameter at the subsatellite point (represented by the dots in Fig. 2), whereas the MSU resolves a circular area of 110 km diameter at the satellite subpoint. The MSU samples 11 fields of view along its swath having the same linear extent. The fields of view enlarge and become elliptical as the instruments scan away from the satellite subpoint. Each SSU scan line (not shown) has eight fields of view with a linear extent of 1500 km. As a consequence there is no overlap of the SSU fields of view and the HIRS and MSU fields of view at the edges of the HIRS and MSU swaths. The problem of incomplete spatial coverage of SSU data is treated in the data processing as described below.

TABLE 1. Characteristics of TOV Sounding Channels.

HIRS Channel number	Channel central wavenumber	Central wavelength (μm)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	668	15.00	CO_2	30 mb	*Temperature sounding.* The 15-μm band channels provide better sensitivity to the temperature of relatively cold regions of the atmosphere than can be achieved with the 4.3-μm band channels. Radiances in Channels 5, 6, and 7 are also used to calculate the heights and amounts of cloud within the HIRS field of view.
2	679	14.70	CO_2	60 mb	
3	691	14.50	CO_2	100 mb	
4	704	14.20	CO_2	400 mb	
5	716	14.00	CO_2	600 mb	
6	732	13.70	CO_2/H_2O	800 mb	
7	748	13.40	CO_2/H_2O	900 mb	
8	898	11.10	Window	Surface	*Surface temperature* and cloud detection.
9	1 028	9.70	O_3	25 mb	*Total ozone* concentration.
10	1 217	8.30	H_2O	900 mb	*Water vapor sounding.* Provides water vapor corrections for CO_2 and window channels. The 6.7-μm channel is also used to detect thin cirrus cloud.
11	1 364	7.30	H_2O	700 mb	
12	1 484	6.70	H_2O	500 mb	
13	2 190	4.57	N_2O	1 000 mb	*Temperature sounding.* The 4.3-μm band channels provide better sensitivity to the temperature of relatively warm regions of the atmosphere than can be achieved with the 15-μm band channels. Also, the short-wavelength radiances are less sensitive to clouds than those for the 15-μm region.
14	2 213	4.52	N_2O	950 mb	
15	2 240	4.46	CO_2/N_2O	700 mb	
16	2 276	4.40	CO_2/N_2O	400 mb	
17	2 361	4.24	CO_2	5 mb	
18	2 512	4.00	Window	Surface	*Surface temperature.* Much less sensitive to clouds and H_2O than the 11-μm window. Used with 11-μm channel to detect cloud contamination and derive surface temperature under partly cloudy sky conditions. Simultaneous 3.7- and 4.0-μm data enable reflected solar contribution to be eliminated from observations.
19	2 671	3.70	Window	Surface	
20	14 367	0.70	Window	Cloud	*Cloud detection.* Used during the day with 4.0- and 11-μm window channels to define clear fields of view.

MSU	Frequency (GHz)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	50.31	Window	Surface	*Surface emissivity* and *cloud attenuation* determination.
2	53.73	O_2	700 mb	*Temperature sounding.* The microwave channels probe through clouds and can be used to alleviate the influence of clouds on the 4.3- and 15-μm sounding channels.
3	54.96	O_2	300 mb	
4	57.95	O_2	90 mb	

SSU	Wavelength (μm)	Principal absorbing constituents	Level of peak energy contribution	Purpose of the radiance observation
1	15.0	CO_2	15.0 mb	*Temperature sounding.* Using CO_2 gas cells and pressure modulation, the SSU observes thermal emissions from the stratosphere.
2	15.0	CO_2	4.0 mb	
3	15.0	CO_2	1.5 mb	

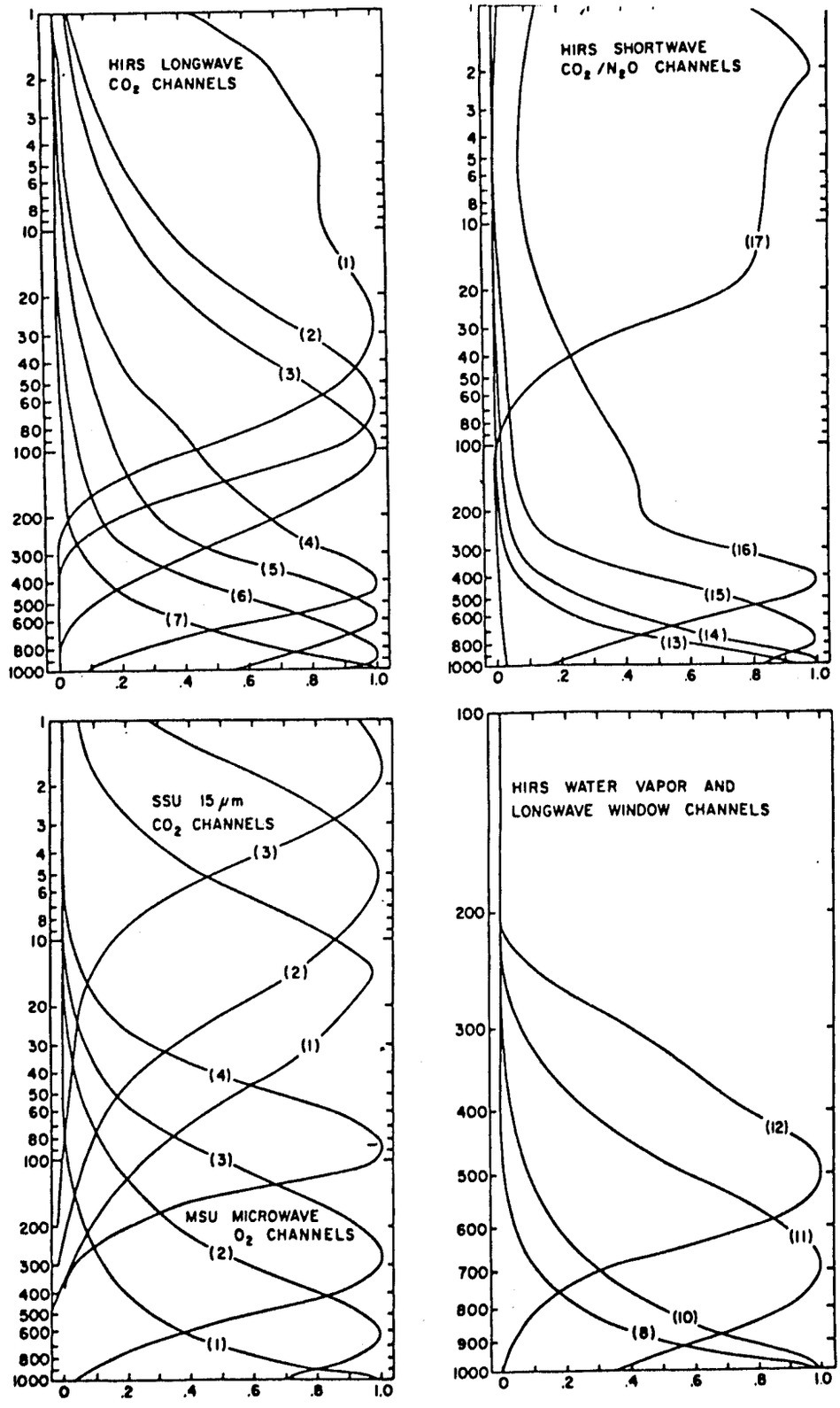


FIG. 1. TOVS Weighting Functions (normalized).

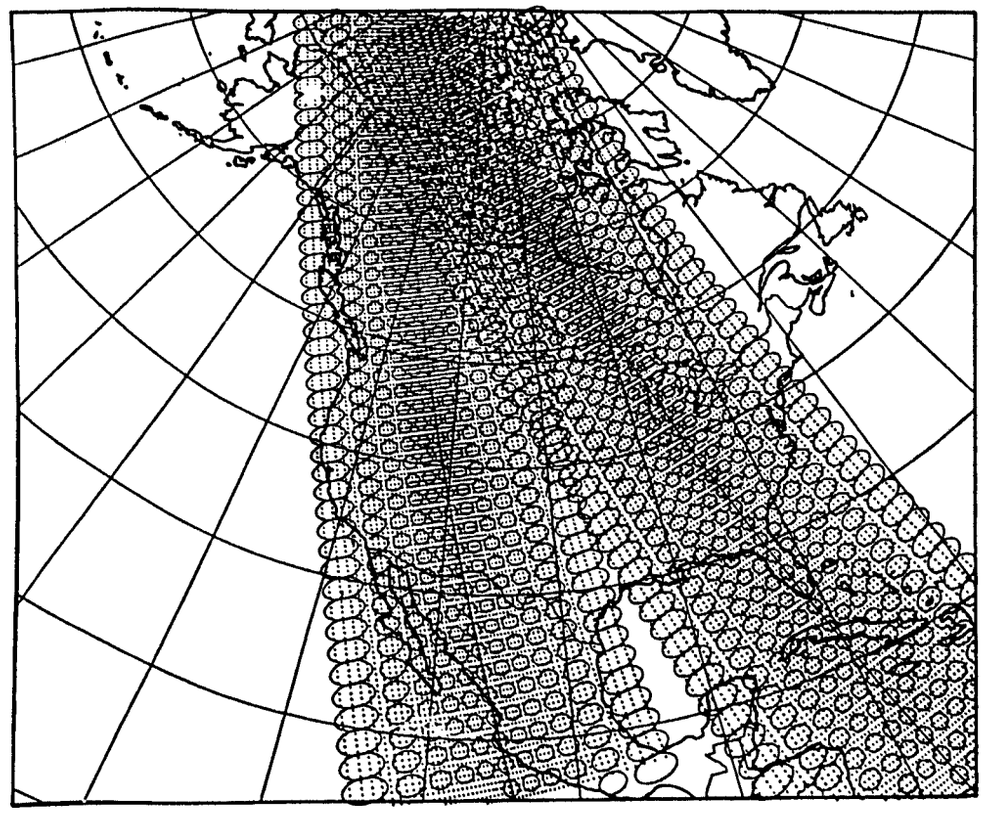


FIG. 2. HIRS and MSU Scan Patterns For Two Consecutive Orbits.

Blank page retained for pagination

2. TOVS PROCESSING SYSTEMS

2.1 The Operational TOVS processing system

The transformation of radiances measured in the 27 spectral intervals of the TOVS system (20 HIRS, 4 MSU, 3 SSU) into vertical profiles of atmospheric temperature and water vapor is accomplished by the operation of four principal software modules on an IBM 360/195 computer system: Preprocessor, Atmospheric Radiance, Stratospheric Mapper, and Retrieval. The functions of each module will be described briefly.

2.1.1 TIROS Preprocessor

The main function of the Preprocessor is to organize the output of the TOVS data ingestion system into a form convenient for scientific processing. Input to this module consists of time-coincident sets (nominally, one readout orbit) of HIRS, MSU, and SSU measurements with earth location and calibration information appended. Calibration equations are applied, converting the digital counts to radiances, and earth location parameters are incorporated with the measurements for each earth-viewed spot. The SSU data are set aside for further processing by the Stratospheric Mapper module. The MSU measurements are corrected for antenna side lobe and limb (slant-path) and surface emissivity effects, while HIRS measurements are corrected for limb and-in the case of window channels-water vapor absorption effects. These two data sources are combined by interpolation of the MSU measurements to the HIRS scan positions. (The correction procedures are similar to those described by Smith et al. (1974)). Ancillary data, such as solar zenith angle, terrain elevations and initial-guess values of surface skin temperature, and, for daytime conditions, surface albedo, are obtained and incorporated with the radiometric observations. All this information is read out, one HIRS scan line at a time, to a staging disk for access by the next module.

The regression coefficients used in the "limb" corrections, as well as several other sets of statistically based coefficients employed by the subsequent modules, are contained in a coefficient file that is accessed by various modules as necessary.

2.1.2 TIROS Atmospheric Radiance Module (TARM)

The function of TARM is to transform the single field of view (FOV) data provided by the Preprocessor into sets of atmospheric (or sounding) radiances representative of much larger areas, for determination of atmospheric parameters by the retrieval module.

The major research and development effort to date has been directed toward this process; it also accounts for most of the computer time expended in routine proccessing of TOVS data.

The nominal horizontal resolution of soundings from TOVS has been set at 250 km. Information from the Preprocessor is organized to permit formation of "boxes" whose dimensions are 9 scan spots across the satellite track by 7 scan

spots along the track. All subsequent operations within the TARM module are in terms of these 63-FOV ensembles. The purpose of those operations is to produce a single set of radiances in the 24 spectral intervals of HIRS and MSU, from which an atmospheric sounding will be obtained in the Retrieval Module.

The physical problem that is addressed in TARM is to extract, from the ensemble of radiance measurements, the true thermal emission of the atmosphere within the volume being sampled. Since there are likely to be clouds over such a region, and since several of the spectral measurements of HIRS are subject to contamination by clouds, this task has come to be known as "the clear column radiance problem." There are in essence two approaches: either find sufficient "holes" in the clouds, from whose uncontaminated observations the desired volume estimate can be obtained or apply physical and mathematical techniques to infer clear-column radiances from the contaminated ensemble. Both methods are employed in TARM.

Initially, the observations for each FOV in a box are given objective tests to determine the probable presence of clouds. The tests involve measured reflectance vs. expected surface albedo, longwave vs. shortwave window channel comparisons, longwave window brightness temperature vs. observed microwave (MSU) brightness temperature. The expected surface temperature is obtained from analyses of ship and satellite sea surface temperatures and shelter temperatures over land. The regression test is worthy of elaboration. The vertical weighting functions of several tropospheric-sensing HIRS spectral intervals bracket those of the MSU channels as seen in Fig. 1. Therefore, it is physically reasonable to expect high accuracy in predicting the latter from the former in the absence of clouds, the HIRS-predicted MSU radiance will be too low.

As the software is currently configured, a box is judged to be clear if as few as four clear FOVs are found. The "clear" value for each of the parameters associated with the box is a weighted average over the clear FOVs. The weight for each clear FOV is the reciprocal of the difference between observed and predicted MSU channel 2 measurements as obtained from the last test mentioned.

If fewer than four clear FOVs are found in the "clear search", a second approach is taken. The method employed is the adjacent-pair, or N*, technique using eigenvectors as described in Smith and Woolf (1976). The clear-radiance estimates obtained from each pair are subjected to quality control tests similar to those employed in the clear-search. Four is the minimum number of good pairs for N* success. The output is again a weighted average, with the weight for each pair being proportional to the reciprocal of the error in the regression estimate of the MSU brightness temperature based upon the HIRS clear-column radiance determination.

Should both clear-search and N* fail (i.e., fewer than four clear FOVs and fewer than four good clear-radiance pairs) the output for the box is a simple spatial average of each of the four channels of the MSU and of the four highest-sensing HIRS channels-those presumed not subject to cloud contamination. Currently, this "third path" comprises about 20% of the system output.

2.1.3 TIROS Stratospheric Mapper (TSM)

As noted earlier, the cross-track scan of the SSU instrument does not cover as large an area on the earth's surface as those of HIRS and MSU. In order to

have SSU radiances available for temperature retrieval at all sounding locations determined in TARM, the SSU data are used to update a global latitude-longitude gridpoint analysis, from which they can be interpolated to the sounding locations. The TSM module performs this mapping, or analysis, function. The measurements are first corrected for limb effects, then used to adjust the gridpoint values of the preexisting, or "guess," field, which is the output of the previous run.

2.1.4 TIROS Retrieval Module (TRET)

This module accesses the data output by TARM and TSM, as well as the coefficient file, and produces vertical profiles of atmospheric temperature, water vapor mixing ratio, and (relative) geopotential thickness. Estimates of total ozone content, and the vertical distribution of cloudiness within the "box" represented by the sounding are also obtained. The basic retrieval technique is statistical: eigenvector regression (Smith and Woolf, 1976) is employed for water vapor and temperature below 100 mb, while multiple linear regression is used for temperature above 100 mb and total ozone. A combination of eigenvector and linear regression is utilized in the retrieval of cloud altitude and amount (Smith and Woolf, 1976). Currently, the regression coefficients are derived from a dependent sample of measured radiances and quasi-coincident radiosonde observations. The TARM and TRET coefficient updating is done on a weekly basis.

2.2 The experimental interactive TOVS processing system

Clouds and surface characteristics affect outgoing radiation in a manner difficult to account for in fully automated retrieval procedures. Stringent filtering, averaging, and quality control techniques must be employed in the automated operational system in order to avoid erroneous soundings. The resulting network of soundings has coarse (250 km or greater) spacing and, despite the automatic quality control steps, soundings tend to be less reliable in the critical disturbed atmospheric regions.

An experimental processing system utilizing manual interaction in the sounding retrieval process has been developed in an attempt to overcome the limitations of the fully automated approach (Smith et al., 1978). The approach utilizes the McIDAS interactive processor and video display system developed by the Space Science and Engineering Center at the University of Wisconsin.

The interactive processing system differs from the operational system in that an operator, by inspecting a video image of cloud cover and thermal radiance pattern constructed from the HIRS and MSU data, selects those individual fields of view of the TOVS best suited for sounding retrieval. The operator can ensure that adequate coverage of sounding data is achieved in the critical regions of the disturbed atmosphere. As is done objectively in the operational system, one of three types of retrievals (clear, N*, or microwave only) can be selected by the operator, depending upon cloud condition. Numerous display programs have been developed to enable the operator to recognize and delete erroneous TOVS soundings on the basis of meteorological inconsistencies. The erroneous data are recognized from either internal horizontal inconsistencies or inconsistencies with other meteorological data (e.g. rawinsonde) that are displayed with the TOVS soundings on a television monitor at the McIDAS operator's terminal. The end result is a dense network of meteorologically consistent TOVS soundings.

The interactive processing system is currently being utilized on a daily basis by a joint group of National Environmental Satellite Service (Mesoscale Applications Branch) and University of Wisconsin (Space Science and Engineering Center) scientists to process direct readout TOVS data over North America as part of a research program for improving the detection of the antecedent conditions of localized severe weather. In this application hourly surface data are used to enhance the TOVS product. The interactive processing procedure is also being used as part of a "Special Effort" to provide improved sounding and cloud-motion wind data for FGGE-Global Weather Experiment (Greaves et al., 1979), as well as being tested for its operational utility by the Office of Operations, National Earth Satellite Service (NESS).

3. THE TOVS COEFFICIENT DATA BASE

A repository for twenty-seven sets of coefficients, mean values, numerous flags, eigenvectors, and pre-defined constants, the TOVS Coefficient Data Base (CDB) plays an essential role in the processing of TOVS data. It has been constructed to meet four basic goals:

1. The data must be easily and quickly accessed by several users.

2. The data must be easily updated or changed to meet new requirements.

3. Changes in the type, number or content of the data for one user must remain transparent to other users.

4. It must be protected against accidental or unauthorized changes.

The process involved in the generation of the CDB ranges from the simple definition of values to the procedures of statistical modeling for the computation of coefficients. CDB parameters, flags and constants, while numerous, are defined values. The placement requires item-by-item consideration. All are needed at some point, however, to generate or apply coefficients. Coefficient generation is a complex and time consuming task. Here eigenvalues, eigenvectors and related mean values are included, as they are frequently produced as a by-product of coefficient generation. The fact that one third of the total TOVS processing software is devoted to initial and updated coefficient generation, is evidence of its enormity.

The data base is organized such that coefficients are divided into eight GROUPs (labeled commons) with the seventh and eighth GROUPs being further subdivided into 5 (latitude) ZONEs. A full eight-GROUP set of coefficients constitutes a CDB AREA. A maximum of 5 AREAs are assigned to a given CDB dataset, a work AREA and four permanent AREAs. Each permanent AREA may accommodate all the coefficients for a single satellite. The access routine, (GETCDB) permits reading an entire GROUP for a given satellite AREA and ZONE (if GROUP 7 or 8). The access routine (PUTCDB), similarly, permits writing of an entire GROUP, but only to the work AREA. CDB organization is summarized in Figure 3.

In the discussion which follows, the coefficient generation processes will be highlighted. In most cases, regression coefficients are computed by software that is part of the Coefficient Generation Subsystem (Chalfant et. al. 1979), a comprehensive network of programs and data files. Regression coefficients are generated according to specific algorithms and stored in the CDB disk file. For specific forms of the individual regression relationships, and associated algorithms, the reference given in table 2 should be consulted.

3.1 Initial Coefficient Generation

3.1.1 Band Correction Coefficients

Band correction coefficients (BNDCOR) are calculated for 19 HIRS/2 channels. Filter transmittance data and the instrument optical system

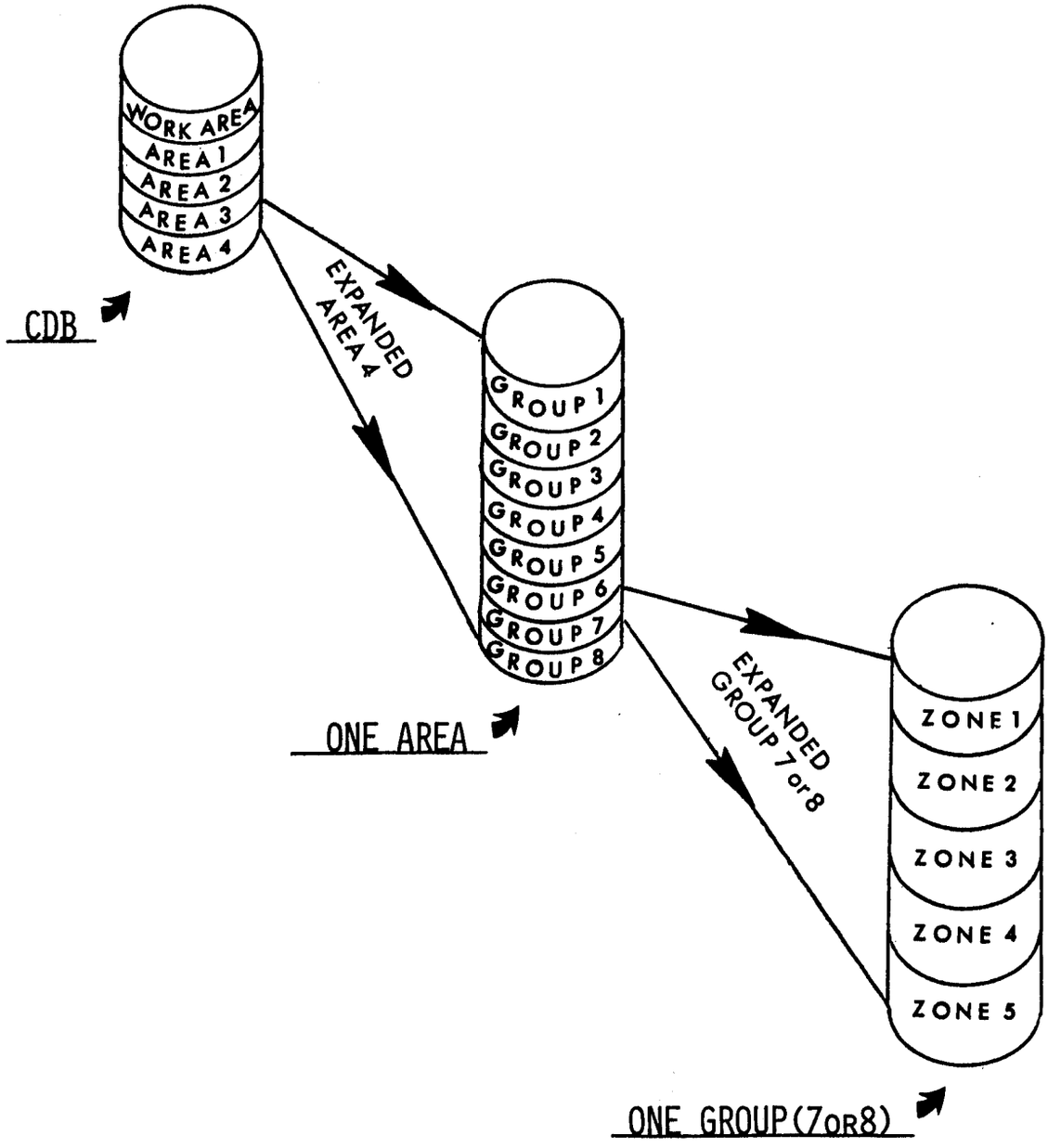


FIGURE 3. - - COEFFICIENT DATA BASE ORGANIZATION

transmittance data are used as input. A linear regression is used to obtain the coefficients. In application, these coefficients (a and b) are used to define a pseudo temperature T' where:

$$T' = a + bT$$

which minimizes the error in calculating Planck radiances due to a finite filter bandwidth. This set of coefficients is used indirectly in the generation of other CDB coefficients wherever conversions are required between channel radiances and channel brightness temperatures. For the remaining channels, HIRS/2 channel 20, MSU and SSU, no band correction is required. Here, therefore, the band correction coefficients are set to the appropriate constants (a=0,b=1).

3.1.2 Transmittance Generating Coefficients

To enable the rapid computation of transmittances for instrument channels, eleven sets of coefficients must be computed and stored in the CDB. A complete set of transmittance generating coefficients is unique for a given satellite. Once computed, they need not be seasonally updated. They are exclusively used in the pre-launch simulation of satellite data. To obtain simulated radiances or brightness temperatures for a given channel and arbitrary atmosphere, transmittances are needed at each pressure level.

Of the eleven sets of coefficients, six are needed to construct HIRS/2 transmittances. Two of these (CVTNC and ANGCDF) become necessary in the construction of transmittances for the uniform mixing ratio gases (carbon dioxide, carbon monoxide, oxygen, nitrous oxide and methane). A single set (CONST) of continuum coefficients combine the effects of three components, water vapor foreign-broadening, water vapor self-broadening, and pressure induced nitrogen continuum. A single set of coefficients treating the effects of water vapor line absorption (CTNW) is needed to construct transmittance. The four remaining sets (T2577, T480Z, CTN01, and CTN02) are needed to construct ozone transmittances. In contrast to the others, T257Z and T480Z are not regression coefficients but vertical transmittances for atmospheres of 257- and 480- dobson total ozone amounts. Without using regression coefficients, ozone vertical transmittances are constructed by an interpolation technique. CTN01 and CTN02 are regression coefficients that are needed to correct for slanted viewing angles. Total transmittances are then computed as products of the four constituents, uniform gases, water vapor, continuum and ozone.

A computer program (CO2) calculates the uniform gas transmittance coefficients. Among the uniform gases, the dominant absorber in the spectral region of interest is carbon dioxide. For this reason, references to carbon dioxide in the procedures will likely intend the inclusion of all the uniform gases. The following input data is required:

1. 19 dry atmospheric profiles.
2. HIRS filter response functions.
3. Raw spectral data in the form of transmittances.

Raw spectral data is convoluted with the filter functions to yield transmittances. Vertical transmittance coefficients are calculated (CVTNC) via multiple linear regression, following the transmittance model of McMillin and Fleming (1976). In addition, the program calculates slant path correction coefficients (ANGCOF) utilizing the technique suggested by Fleming and McMillin (1977).

Via computer program (H2O), the calculation of water vapor transmittance regression coefficients is performed. The following basic data is required:

1. Transmittances for 144 homogeneous paths.
2. HIRS filter response functions.
3. 6 temperatures, 6 pressures and 6 sets of 12 water concentrations. (Concentrations are given in cm of precipitable water)

Transmittances are convoluted with the filter functions by the program. It then forms the temperature-pressure-water dependent predictor functions and the transmittance dependent predictand functions. These functions are in keeping with the transmittance model for water vapor described by Weinreb and Neuendorffer (1973). Regressing predictor against predictand, a stepwise multiple linear regression is performed to compute the coefficients (CTNW).

As with the first two components, the treatments of data necessary for the construction of ozone and continuum transmittances have similarity but are certainly not identical. A single program (OZCON) handles the processing of ozone and continuum data to be stored in the CDB. It first requires the 19 HIRS filter response functions. Two atmospheres for ozone transmittances are input. The sample atmospheres represented contain total ozone amounts of 257 and 480 dobson units. The ozone transmittances are convoluted with the filter functions and stored in the CDB as convoluted vertical transmittances (T257Z and T480Z). Using slant path convoluted transmittances, the zenith angle transmittance adjustment coefficients (CTN01 and CTN02) are computed for the two atmospheres.

Pre-computed continuum transmittance coefficients (CONST) are provided to the program. For details of the method of computation, see Weinreb and Hill (1980).

The model for the construction of MSU transmittances makes use of absorption coefficients for oxygen and water vapor. Absorption coefficients are computed from regression coefficients (REGMSU). A computer program (MSUCOF) performs the regression. It is supplied with 32 sample atmospheres, each containing atmospheric temperatures at 40 pressure levels and water vapor mixing ratios at the lower 20 pressure levels. For each atmosphere oxygen and water vapor absorption coefficients are computed using a line-by-line evaluation. Regressing the computed absorption coefficients (predictands) against the predictor functions, the program uses multiple linear regression to obtain the coefficients (REGMSU). Predictor functions for oxygen are (1) temperature and (2) temperature squared. For water vapor they are (1) temperature, (2) mixing ratio, and (3) the product of temperature and mixing ratio.

For the construction of SSU transmittances, two sets of regression coefficients (RESSUN and RESSUA) must be calculated (program SSUCOF). The basic data fed to the program consists of 19 dry atmospheric temperature profiles and the SSU transmittance table. After interpolating for cell pressure, the program

carries out a procedure identical to the one used for uniform gases in the HIRS case. Vertical coefficient (RESSUN) calculation precedes the computation of slant path correction coefficients (RESSUA).

3.1.3 Limb Correction Coefficients

Four sets of limb correction coefficients are generated, one set for each instrument and a fourth set to correct the HIRS/2 window channels for attenuation (HRSLC,XMSULC,SSULC and HRSLIM). Here the CDB coefficients computed to yield atmospheric transmittances become necessary. All limb correction coefficients depend upon simulated channel data. A global representation, one hundred (100) atmospheric temperature profiles and corresponding water vapor mixing ratio profiles are used with the transmittance generating coefficients to compute simulated channel radiances. Then radiances are converted to brightness temperatures. Limb brightness temperature correction coefficients are computed using stepwise multiple linear regression with selected channel brightness temperatures as predictors. These CDB coefficients are used in the pre-processing of satellite data. Since data is collected at zero as well as non-zero scan angles, the limb correction coefficients permit the non-zero data to be angle corrected.

Limb correction coefficients for HIRS channels are calculated by computer program (LMCORH), at five intervals of scan angle. The first interval begins at the 4th scan spot (field of view) and traverses a total of five spots. The remaining 4 intervals are 5 spots wide as well. Treatments to the left or right of a zero nadir angle are symmetrical. It is, therefore necessary to compute coefficients only once to be used for either side of nadir.

To process the first interval, channel data must be simulated for each angle of the 5 included spots. Data simulated for a single spot consists of 1700 sets of channel radiances. This represents 100 profiles times 17 cloud conditions (1 clear and 16 variations of cloud). A full sample for an angular interval of 5 spots contains 8500 sets of simulated radiances. Radiances for a single profile are calculated with constructed transmittances and profile data. There is an exception in the case of HIRS channel 9. Centered at 1030 (1/cm), this channel's response is highly affected by ozone absorption. The resident algorithm, while adequate for other channels, is not used in this case. Channel 9 transmittances are supplied directly from data fed to the program. Simulated radiances are converted to brightness temperatures and form the first part of what shall hereafter be called the 'observed' sample. The second part of the 'observed' sample consists of the corresponding set of 100 vertically sensed MSU channel brightness temperatures (channels 2 through 4).

Recall that the 'observed' HIRS data is entirely slant-path data. In the same way, data is simulated for a vertical path which shall hereafter be called 'truth'. Predictands are formed as differences between 'truth' and 'observed'. Predictors are formed from the products of secant of zenith angle and 'observed' along with secant of zenith angle.

At most 19 HIRS channels, 3 MSU channels and secant of zenith angle could be selected as predictors. Since it is known in advance that certain combinations of channels are most suitable as predictors, flags are used to pre-screen the selection of predictors. Regressing predictands against

predictors, coefficients (HRSLC) are computed via stepwise multiple linear regression.

Again, the process is carried out for the second through fourth angular intervals. Each time slant-path data must be simulated, predictors formed and regression coefficients (HRSLC) computed. In addition to the full-predictor set of coefficients a pass is made in which MSU predictors are completely excluded.

Window channels of the HIRS instrument (8, 18, and 19) are corrected for attenuation during pre-processing. Removal of contamination utilizes a set of regression coefficients (program WATVAP). The procedure is very similar to limb correction. Here, however, no cloud contaminated data is used. Since the correction is applied after limb correction, no slant-path data is needed. 'Truth' is the surface temperature. 'Observed' data is formed from vertically sensed clear radiance simulation. This sample of 100 cases is further reduced by a special condition. If the difference in brightness temperatures between channels 8 and 10 is less than 3 degrees absolute, the case is withdrawn. Predictands are 'truth' less 'observed' window channel brightness temperatures. Predictors are taken from the 'observed' data. Predictands are regressed against predictors and coefficients (HRSLIM) computed via stepwise regression for cases with and without MSU predictor data.

MSU limb correction (program LMCORM), in addition to angle correction, removes the effects of a special characteristic of microwave antennas known as 'side lobes'. The signal perceived by the MSU sensor is not the true signal from the field of view due to the fact that the antenna does not focus exclusively on the field of view. This is a result of diffraction, since the wavelength of the radiation (approximately 5mm) is not negligible compared to the dimensions of the antenna. Separate sets of coefficients are generated for land and water. Anything that is not water (e.g. land, snow, ice) is treated as land.

For the 100 global profiles, 'truth' data is simulated. 'Truth' channel brightness temperatures are vertical, with no side lobes, and unit emissivity. 'Observed' data is simulated, i.e. antenna temperatures with side lobes, at instrument nadir angles and over slightly varying surface emissivity. Further modification to the simulated data for every tenth profile in the land case is made. For these selected profiles, simulated precipitating clouds are randomly introduced. For both land and water, additional hybrid samples are simulated for every fifth profile. 'Observed' data is regressed against predictands ('truth' minus 'observed') using stepwise regression to compute coefficients (XMSULC). It should be noted that the MSU scan pattern of 11 fields of view only produces 6 different nadir angles needing correction. Except for the nadir field of view, they are symmetric about the orbital path.

The SSU instrument scans with no nadir field of view. Eight fields of view produce only 4 different nadir angles needing correction. "truth' data is comprized of channel brightness temperatures simulated for vertical viewing. Brightness temperatures simulated for each of the 4 slant-path angles make up the 'observed'. Predictands are formed from the differences ('truth' minus 'observed'), predictors from the 'observed' data plus vertically sensed HIRS data of channels 1, 2, and 3. Stepwise regression is used to compute coefficients (SSULC).

3.1.4 Retrieval Coefficients

The cloud height regression coefficient module (CLDCOF) generates coefficients for five latitude zones which are used as input in the operational system to predict cloud heights. Given the full data base of geographically stratified (three latitude zones) atmospheric profiles, clear and cloud contaminated radiances are simulated for specific channels of the HIRS instrument. For each profile, adjacent channel ratios of clear-minus cloudy radiances are calculated at three randomly selected cloud levels. At the same three cloud levels, the adjacent channel clear-minus-cloudy radiance ratios are calculated using radiances that have been contaminated with instrumental noise. Eigenvectors are then calculated from those ratios that have not been contaminated with noise and the individual eigenvector magnitudes (coefficients) are determined from the contaminated ratios. A stepwise regression is performed, where the eigenvector magnitudes are individually regressed against pressure, to determine cloud height coefficients. Finally these coefficients (CCLD) are pre-multiplied and placed in the appropriate latitude zone and group of the CDB.

Pre-computed ozone, regression coefficients (furnished by the Office of Research) are transported to their CDB locations for each season, channel combination, and latitude zone by computer program (OZCOF). The data includes, for each season, mean total ozone (TOTOM) , mean ozone-predicting channel brightness temperatures (BTOTOM) and the regression coefficients (CTOTO).

3.2 Updated Coefficients

Certain sets of the CDB coefficients (RGCOF, COFHI, COFHR, COFMSU, SGCOF, CTMPLO, CTMPHI, CWV, and CWATGH) along with eigenvectors and mean values are essential to retrievals. Further, they are latitude zone dependent. For this reason, there is a distinct set corresponding to each of 5 latitude zones, (+90 to +60, +60 to +30, +30 to -30, -30 to -60 and -60 to -90). Initially, there must be simulated channel data available for use in retrieval coefficient production.

3.2.1 Input Data for Generation of Updatable Coefficients

The atmospheric profile data base (PDS1200), made up of 1200 records, supplies data for 3 latitude zones. Each record (400 per zone) containing temperatures at 40 pressure levels and 20 water vapor mixing ratios corresponding to the lower pressure levels. Necessary transmittance construction is limited to the clear, vertical case and need only include the first 17 HIRS channels, 3 SSU channels and MSU channels 2, 3, and 4 (program PRDGNA). Stored transmittances for three zones are fed to a radiance simulating program (PRDGNB), which calculates and stores the simulated radiances used for all initial retrieval coefficients. Initially, zone-one data applies in both zones 1 and 5, and zones 2 and 4 share zone-2 data.

Methods of computation for initial or updated retrieval coefficients are identical. It is the data that changes. Updated coefficients use radiosonde-matched, satellite-instrument-sensed channel radiances (or brightness temperatures). Atmospheric temperature - mixing ratio profiles are supplied in

radiosonde data. Independently, sample accumulations exist for each of the 5 latitude zones. Data for coefficient updating is more representative of the current atmospheric conditions. Further, symmetrical applications made with simulated data are absent.

When generating initial coefficients from the simulated data, channel 9 (ozone channel) of the HIRS instrument is excluded. As mentioned earlier, the transmittances algorithm for ozone is inadequate for channel 9. Available transmittance data only covers one hundred (100) of the 1200 atmospheric profiles used in this sample. The use of channel 9 is recovered with the first generation of updated coefficients.

3.2.2 Coefficients and Eigenvectors for the TOVS Atmospheric Radiance Module (TARM)

Coefficients for TARM are generated to meet the needs of either of two algorithms. The first generation (TARM I) required 6 sets of values (EGVT1, EGVT2, EGVT3, EGVT4, RMEAN, and RGCOF). There are four sets of interchannel radiance eigenvectors for specific channel combinations, mean channel radiances, and inter-channel brightness temperature regression coefficients. For use in the second generation TARM module (TARM II), 4 sets of values are produced (COFHT, COFHR, COFMSU and SGCOF). At the time of this writing, both generations of the TARM coefficients were in CDB residence.

TARM eigenvectors, eigenvalues, and regression coefficients are calculated by computer program (PRGNC1 for initial, PRGNU1 for updating) which employs an eigenvector regression technique to compute coefficients. No eigenvector quantities are needed for TARM II. Calculation of the required regression coefficients is accomplished with the same regression technique as was used for TARM I. The differences are in the channel combinations required by the algorithm. TARM II coefficients are generated for 5 latitude zones in the update mode only.

3.2.3 Retrievial Coefficient Generation

Lower level temperature retrieval coefficients (CTMPLO) are generated by computer program (PRGNC2 for initial, PRGNU2 for updated). Atmospheric temperatures are regressed against channel brightness temperatures using eigenvector regression to compute coefficients. A selected number of predictor channel combinations were chosen to give the best information at lower levels. A regression pass and coefficient product correspond to each predictor combination. Upper level temperature retrieval coefficients (CTMPHI) are calculated similarly (programs PRGNC5, PRGNU5), but with different predictor channel combinations.

The ability to update upper level coefficients with radiosonde-matched satellite data is limited. Upper pressure levels span pressures between 100 and .1 mb. The uppermost of these levels are beyond the range of conventional radiosonde measurement capabilities. The probability of obtaining a sample above the 100 mb. deminishes so rapidly that at levels beyond 10 mb. the chance is nill. Furthermore, the latitudinal regions of sparse stations have lower sample accumulation rates, compounding the limitations (particularly in zone 5).

In time, sample accumulation can permit updating of the 10 levels between 100 and 10 mb. This, however, is the most optimistic expectation, since updating is contingent upon the availability of an adequate sample. For these reasons upper level coefficients are updated level-by-level to the extent that an adequate sample exists at the pressure level and latitude zone. For the most part, coefficients at levels above 10 mb remain initial, with simulated data as their basis.

Regression coefficients for the retrieval of water vapor mixing ratios are computed for two cases. First, channel brightness temperatures are regressed against mixing ratios (program PRGNC2 or PRGNU2) using eigenvector regression to produce coefficients (CWV). Second, lower atmospheric temperatures are regressed against mixing ratios (PRGNC3 or PRGNU3) to produce coefficients (CWATGH).

To apply any of these retrieval coefficients, mean values of all independent predictors and dependent predictands must be available. These values are computed in the respective programs and passed to the CDB with coefficients. The list of mean germane pertain to temperature and water vapor retrievals (BTMHI, BTMLO, BTMWV, TMHI, TMMLO, and WVM) is included in Table 2.

The set of brightness temperature eigenvectors (BTEIGF) and mean channel brightness temperatures (CLBTMN) are computed (program PRGNC6 or PRGNU6) for use in the retrieval module (TRET). These too are computed for each of 5 latitude zones, initialized from simulated data, and updated using radiosonde-matched satellite data.

TABLE 2. CDB COEFFICIENTS

Array Label	Group	Description	Reference
ANGCOF	4	Carbon dioxide slant path transmittance correction coefficients	Fleming & McMillin (1977)
BNDCOR	1	Band correction coefficients	
CCLD	8	coefficients	
COFHR	7	Regression coefficients to predict HIRS short wave radiances from HIRS long wave radiances (TARM II)	
COFHT	7	Regression coefficients to predict HIRS short wave temperatures from HIRS long wave temperatures (TARM II)	
COFMSU	7	Regression coefficients to predict MSU channel 2 radiances from the sealed HIRS long wave radiances (TARM II)	
CONST	4	Continuum transmittance generating coefficients	Weinreb & Hill (1980)
CTMPHI	8	Retrieval coefficients for upper atmospheric temperatures	
CTMPLO	8	Retrieval coefficients for lower atmospheric temperatures	
CTNO1	4	Ozone slant path interpolation coefficients for 257 Dobsons	
CTNO2	4	Ozone slant path interpolation coefficients for 48 dobsons	
CTNW	4	Water vapor transmittance generating coefficients	
CTOTO	8	Total ozone coefficients	
CVTNC	4	Carbon dioxide nadir angle transmittance generating generation coefficients	McMillin & Fleming (1976)
CWATGH'	8	Retrieval coefficients for temperature predicted water vapor mixing ratios	
CWV	8	Retrieval coefficients for water vapor mixing ratios	
HRSLC	2	HIRS limb correction Coefficients	

TABLE 2 (Continued)

Array Label	Group	Description	Reference
HRSLIM	2	HIRS window channel water vapor attenuation correction coefficients	
REGMSU	3	MSU atmospheric absorption regression coefficients	
RESSUA	3	SSU atmospheric transmittance regression coefficients	Fleming & McMillin (1977)
RESSUN	3	SSU atmosphere transmittance regression coefficients for angle correction	McMillin & Fleming (1976)
RGCOF	7	Interchannel regression coefficients used in TOVS atmospheric radiance module (TARM I)	
SGCOF	7	Interchannel regression coefficients (TARM II)	
SSULC	1	SSU limb correction coefficients	
T2577	4	Ozone nadir angle transmittances at 257 dobson units	
T480Z	4	Ozone nadir angle transmittances at 480 dobson units	
XMSULC	2	MSU limb correction coefficients	

TABLE 3. CDB EIGENVECTORS, EIGENVALUES, AND MEANS

Array Label	Group	Description
BTEIGF	8	Brightness temperature eigenvectors for selected channel combinations
BTMHI	8	Mean channel brightness temperatures for predicting upper level atmospheric temperatures
BTMLO	8	Mean channel brightness temperatures for predicting lower level atmospheric temperatures
BTMWV	8	Mean channel brightness temperatures for predicting water vapor mixing ratios
BIOTOM	8	Mean brightness temperatures of channels used to predict total ozone
CCLDM	8	Mean cloud height (mb)
CLBTMN	8	Mean channel brightness temperatures for HIRS channels 1...17, MSU channels 2...4
EGVL	7	Channel radiance eigenvalues - TARM I
EGVT1	7	Radiance eigenvectors for HIRS channels 13...17
EGVT2	7	Radiance eigenvectors for HIRS channels 13...17 MSU channels 2...4 (TARM I)
EGVT3	7	Radiance eigenvectors for HIRS channels 1...12
EGVT4	7	Radinace eigenvectors for HIRS channels 1...12 MSU channels 2...4 (TARM I)
EVLMSU	7	Eigenvalues for MSU channels 2...4
EVTMSU	7	Eigenvectors for MSU channels 2...4
RDRM	8	Mean radiance difference ratios
RMEAN	7	Mean channel radiances (TARM I)
TMHI	8	Mean upper Level atmospheric temperatures
TMLO	8	Mean lower level atmospheric temperatures
TOTOM	8	Mean total ozone for each season
WVM	8	Mean water vapor mixing ratios

TABLE 4. CDB CONSTANTS, PARAMETERS, AND FLAGS

Array Label	Group	Description
BANDW	1	Band widths for the 27 instrument channels (1/cm)
CON20	2	A value representing the solar radiance from a perfect diffuse reflector for solar zenith angle of zero, for a given number of channel 20.
ERREST	8	Error of estimate for total ozone for each season and channel combination
FK1	1	Planck coefficients for each channel used in numerator of the function
FK2	1	Planck coefficients for each channel used in the numerator of the function
GAMT	1	Transmittance correction factor for each channel
HIGHT	1	Height of the subsatellite point of the spacecraft in kilometers
ICHF	8	20 HIRS channel flags
IDOCHN	4	Table of source contribution flags for channel transmittance computation
IECFL	6	Coefficient availability flag
ICEFLG	5	A flag denoting the availability of error regression coefficients
IEDRP	2	Ending Ramp point for SSU Ramp
IGPNML	5	A flag to specify if products should be computed for non-mandatory pressure layers
IPROFL	1	200 system control files
ISATEM	6	A flag specifying which parts of SATEM code are to be processed
ISSUCH	2	List of TOVS channels being sent to the United Kingdom
ISTRP	2	Starting Ramp point for SSU Ramp
LEVUP		
LNDOFF	6	Flags specifying whether retrievals are to be processed over land
LOFF	5	A flag denoting if soundings are processed over land
LSTAG	2	Land/Sea tag flag array
MPIRM	2	A map of HIRS spot locations which are coincident to MSU spot locations used for easy colocation for the U.K. product
MPIRS	2	A map of HIRS spot locations which are coincident to SSU spot locations used
NCHF	8	Number of channel flags for the U.K. product
NCRIT	8	Critical channel flags

TABLE 4 (Continued)

Array Label	Group	Description
NHATM	1	Number of HIRS and SSU atmospheres used in transmittance regression coefficient program
NHC	1	Number of HIRS channels
NLEVS	1	Number of retrieval levels
NMC	1	Number of MSU channels
NOREJ	1	Flags used by SSU mapper module
NSC	1	Number of SSU channels
NWLEVS	1	Number of water vapor retrieval levels
PRET	1	Pressure values in MB of each of the 40 TOVS levels
SIGMAN	1	Standard deviation of the noise distributions for each of the instrument channels used for simulating random noise
SIGPRO	1	Standard deviation of the instrument-plus-atmospheric noise distribution for each channel
SSUFUG	1	Correction factors for removing systematic errors in the SSU transmittance tables
TREF	4	The reference temperature profile (U.S. standard 1962 atmosphere
WVND	1	Central frequencies for each channel (1/cm)

4. INSTRUMENTATION AND DATA TRANSMISSION SYSTEMS

4.1 TIROS Operational Vertical Sounder (TOVS)

The TOVS provides data for transmission to both HRPT and DSB receiving stations. The data are transmitted in digital format at full instrument resolution and accuracy.

The TOVS consists of three independent instrument subsystems from which data may be combined for computation of vertical atmospheric temperature and humidity profiles. These are:

a. High resolution infrared radiation sounder mod. 2 (HIRS/2)
b. Stratospheric sounding unit (SSU)
c. Microwave sounding unit (MSU)

4.1.1 High Resolution Infrared Radiation Sounder (HIRS/2)

The HIRS/2 is an adaptation of the HIRS/1 instrument flown on the Nimbus-6 satellite. The instrument, built by the Aerospace/Optical Division of the International Telephone and Telegraph Corporation, Fort Wayne, Indiana, measures incident radiation in 19 regions of the IR spectrum and one region of the visible spectrum. Table 5 is a listing of the HIRS/2 parameters.

Table 5. HIRS/2 instrument parameters

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	$\pm 49.5^{\circ}$ ($\pm$1125 km) nadir
Scan time	6.4 seconds per line
Number of steps	56
Optical field of view	1.25°
Step angle	1.8°
Step time	100 milliseconds
Ground resolution (*IFOV) (nadir)	17.4 km diameter
Ground resolution (IFOV) (end of scan)	58.5 km cross-track by 29.9 km along track
Distance between IFOV's	42 km along-track @ nadir
Data rate	2880 bits/second

*Instantaneous field of view.

Table 6 is a listing of the HIRS/2 spectral characteristics and noise equivalent differential radiance (NEΔN's). Note: There will be some variation in the achieved parameters from one HIRS/2 instrument to another, particularly in the NEΔN's.

Table 6. HIRS/2 spectral characteristics

Channel	Channel frequency (cm^{-1})	μm	Half power bandwidth (cm^{-1})	Maximum scene temperature (K)	Specified NEΔN
1	669	14.95	3	280	3.00
2	680	14.71	10	265	0.67
3	690	14.49	12	240	0.50
4	703	14.22	16	250	0.31
5	716	13.97	16	265	0.21
6	733	13.64	16	280	0.24
7	749	13.35	16	290	0.20
8	900	11.11	35	330	0.10
9	1,030	9.71	25	270	0.15
10	1,225	8.16	60	290	0.16
11	1,365	7.33	40	275	0.20
12	1,488	6.72	80	260	0.19
13	2,190	4.57	23	300	0.006
14	2,210	4.52	23	290	0.003
15	2,240	4.46	23	280	0.004
16	2,270	4.40	23	260	0.002
17	2,360	4.24	23	280	0.002
18	2,515	4.00	35	340	0.002
19	2,660	3.76	100	340	0.001
20	14,500	0.69	1000	100% A	0.10% A

NEΔN in mW / (sr m^2 cm^{-1})

4.1.2 The Stratospheric Sounding Unit (SSU)

The SSU, which has been provided by the United Kingdom, employs a selective absorption technique to make measurements in three channels. The spectral characteristics of each channel are determined by the pressure in a carbon dioxide gas cell in the optical path. The pressure of carbon dioxide in the cells determines the weighting function peaks in the atmosphere. SSU characteristics are shown in tables 7 and 8.

Table 7. SSU channel characteristics

Channel number	Central wave no. (cm^{-1})	Cell pressure (mb)	Pressure of weighting function peak (mb)	NEΔT mW/ (sr m^2 cm^{-1})
1	668	100	15	0.35
2	668	35	5	0.70
3	668	10	1.5	1.75

Table 8. SSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background
Cross-track scan	$\pm 40^{\circ}$ ($\pm$737 km)
Scan time	32 seconds
Number of steps	8
Step angle	10°
Step time	4 seconds
Ground resolution (IFOV) (at nadir)	147 km diameter
Ground resolution (IFOV) (at scan end)	244 km cross-track by 186 along-track
Distance between IFOV's	210 km along-track @ nadir
Data rate	480 bps

4.1.3 The Microwave Sounding Unit (MSU)

The MSU is a four-channel Dicke radiometer making passive measurements in the 5.5-um oxygen band with characteristics as shown in tables 9 and 10.

Table 9. MSU channel characteristics

Parameter	Value
Channel frequencies	50.3, 53.74, 54.96, 57.95 GHz
Channel bandwidths	200 MHz
NEΔT	0.3 K

Table 10. MSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background each scan cycle
Cross-track scan angle	$\pm 47.35^{\circ}$
Scan time	25.6 seconds
Number of steps	11
Step angle	9.47°
Step time	1.84 seconds
Angular resolution	7.5° (3 dB)
Data rate	320 bps

4.2 HRPT Transmission Characteristics

All spacecraft instrument data are included in the HRPT transmission.

Output from the low data rate system, TIROS information processor (TIP) on board the spacecraft is multiplexed with the AVHRR data and becomes part of the HRPT output available to users. The low data rate system includes data from the three instruments of the TIROS operational vertical sounder (TOVS) and from the space environment monitor (SEM), the Data Collection and Location System (DCLS), and the spacecraft housekeeping telemetry (see figure 4).

4.3 HRPT Format

The HRPT format provides a major frame made up of three minor frames. The AVHRR data are updated at the minor frame rate while the TIP data are updated at the major frame will contain the same TIP data. The HRPT is provided in a split-phase format to the S-band transmitter. The split-phase data, (1), is defined as positive during the first half of the bit period and negative during the second half of the bit period. The split-phase data, (0), is defined as negative during the first half of the bit period and positive during the second half of the bit period. The HRPT critical parameters are given in table 12 and the HRPT minor frame format is shown in figure 5.

Specific characteristics of the HRPT transmission system are detailed in table 13.

4.3.1 Detailed Description of HRPT Minor Frame Format

While figure 5 shows the identification and relative location of each segment of the HRPT minor frame, a detailed description of each of these segments appears in table 14. Bit 1 is defined as the most significant bit (MSB) and bit 10 is defined as the least significant bit (LSB).

4.4 DSB Transmission Characteristics

The TIROS-N/NOAA DSB contains the TIP output. These data are transmitted at 8.32 kbps, split phase at either 136.77 or 137.77 MHz linearly polarized. Transmission parameters are summarized in table 15.

The TIP output on the DSB contains a multiplex of analog housekeeping data, digital housekeeping data and low bit rate instrument data. The key parameters of the data format are contained in table 16.

4.5 TIP Data Format

The format of a TIP minor frame is shown in figure 6. This figure identifies the relative location of the instrument data within each TIP minor frame. A detailed description of a TIP minor frame is given in table 17.

Each TIP minor frame is composed of 104 eight-bit words. Bit 1 is defined as the most significant bit (MSB) and bit 8 is defined as the least significant bit (LSB). This format is retained for the DSB. When the TIP data are

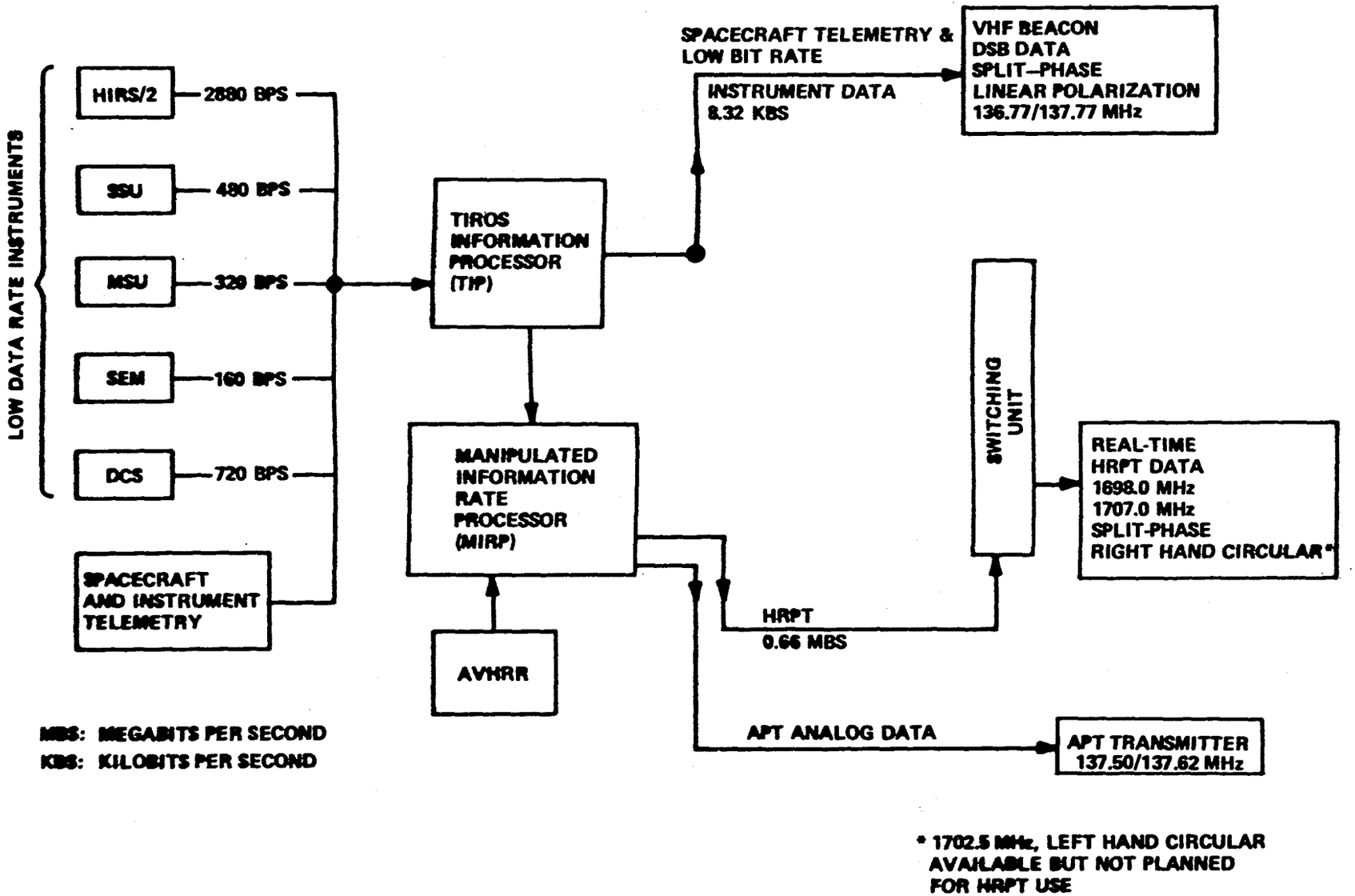
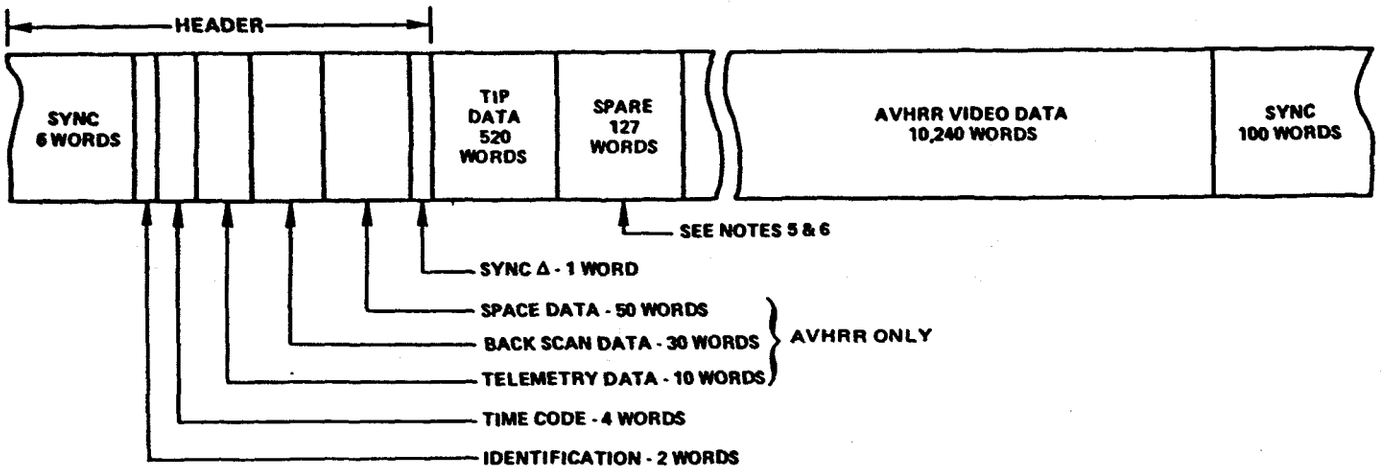


Figure 4. TIROS-N/NOAA Real-Time Systems Data Flow



NOTES:

(1) MINOR FRAME LENGTH - 11,090 WORDS
(2) THREE MINOR FRAMES PER MAJOR FRAME
(3) MINOR FRAME RATE - 6 FRAMES/SECOND
(4) WORD LENGTH - 10 BITS/WORD
(5) ALL SPARES ARE 10TH DEGREE P-N CODE (BAR).

TLM WORD ALLOCATIONS		ID WORD BIT ALLOCATIONS		
		1ST ID WORD		2ND ID WORD
1-5	RAMP CALIBRATION			(SPARE)
6	CHANNEL-3 TARGET TEMP (5 PT SUBCOM)	1	SYNC ID	
7	CHANNEL-4 TARGET TEMP (5 PT SUBCOM)	2-3	FRAME ID	
8	CHANNEL-5 TARGET TEMP (5 PT SUBCOM)	4-7	SPACECRAFT ADDRESS	
9	CHANNEL-3 PATCH TEMP	8	RESYNC MARKER	
10	SPARE	9	DATA 0	
		10	DATA 1	

Figure 5. TIROS-N/NOAA HRPT Minor Frame Format

Table 11. HRPT Characteristics

Line rate	360 lines/minute
Carrier modulation	Digital split phase, phase modulated
Transmit frequency	1698.0 MHz* or 1707.0 MHz
Transmit power	5 watts
EIRP (approximate)	39.0 dBm
Polarization	Right hand circular
Spectrum bandwidth	Less than 3 MHz

*1702.5-MHz left hand circular polarization available in the event of failure of the primary frequencies.

Table 12. HRPT parameters

Major Frame	
Rate	2 fps
Number of minor frames	3
Minor Frame	
Rate	6 fps
Number of words	11,090
Format	See figure 5
Word	
Rate	66,540 words per second
Number of bits	10
Order	Bit 1 = MSB* Bit 10 = LSB** Bit 1 transmitted first
Bit	
Rate	665,400 bps
Format	Split phase
Data 1 definition	
Data 0 definition	

*MSB - Most significant bit
**LSB - Least significant bit

Table 13. HRPT transmission parameters

Type of transmitted signal	S-band phase modulated Split phase 665.4 kbps
System output	
Frequency & polarization	1698.0 MHz right hand circular 1707.0 MHz right hand circular 1702.5 MHz* left hand circular
EIRP at 63° from nadir	36.8 dBm worst case 40.4 dBm nominal
Antenna	
Gain at 63° from nadir	2.1 dBi, minimum
Ellipticity	4.5 dB, maximum
Transmitter	
Power out	5.25 watts mininum
Modulation index	2.35±0.12 radians
Premodulation filter, type 3 dB bandwidth	5th order, 0.5^{o}, equiripple phase 2.4 MHz
Frequency stability	$\pm 2 \times 10^{-5}$

*Not planned for HRPT use unless 1698 and 1707 MHz transmitters have failed.

multiplexed into the HRPT data stream, two bits are added to each TIP word. This is described under Function, TIP data in table 14. These bits are the two LSB's of each 10-bit word and, once removed, produce a TIP frame identical to that of the DSB TIP.

Each HRPT minor frame contains five unique TIP minor frames. HRPT minor frames 2 and 3 contain TIP data identical to that contained in the first HRPT minor frame. HRPT minor frames 1, 2, and 3 can be identified by examining bits 2 and 3 of data word 7 of the 103 word header, as previously defined in table 14. All further discussion of the TIP minor frame format will assume that the TIP data have been eliminated from 2 of the 3 HRPT minor frames and that the 2 extra bits have been removed from each 10-bit word of the remaining TIP data.

Table 14 HRPT Minor Frame Format

	Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus word code & meaning
HEADER	Frame sync	6	1	1 0 1 0 0 0 0 1 0 0	First 60 bits from a 63-bit PN(1) generator started in the all 1's state. The generator polynominal is $X^6 + X^5 + X^2 + X + 1$
			2	0 1 0 1 1 0 1 1 1 1	
			3	1 1 0 1 0 1 1 1 0 0	
			4	0 1 1 0 0 1 1 1 0 1	
			5	1 0 0 0 0 0 1 1 1 1	
			6	0 0 1 0 0 1 0 1 0 1	
	ID(AVHRR)	2	7		Bit 1; 0 = internal sync; 1 = AVHRR sync Bits 2 & 3; 00 = not used; 01 = minor frame 1; 10 = minor frame 2, 11 = minor frame 3 Bits 4-7; spacecraft address; bit 4 = MSB, bit 7 = LSB Bit 8; 0 = frame stable; 1 = frame resync occurred Bits 9-10; spare; bit 9 = 0, bit 10 = 1
			8		Spare word; bit symbols undefined
	Time code	4	9		Bits 1-9; binary day count; bit 1 = MSB; bit 9 = LSB Bit 10; 0; spare
			10		Bits 1-3; all 0's; spare 1, 0, 1 Bits 4-10; part of binary msec of day count; bit 4 = MSB of msec count
			11		Bit 1-10; part of binary msec of day count;
			12		Bit 1-10; remainder of binary msec of day count; bit 10 = LSB of msec count
	Telemetry (AVHRR)	10	13		Ramp calibration AVHRR channel 1
			14		Ramp calibration AVHRR channel 2
			15		Ramp calibration AVHRR channel 3
			16		Ramp calibration AVHRR channel 4

(1) PN = pseudo noise

Table 14 (continued)

	Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10 Plus Word Code & Meaning
HEADER	Telemetry (cont.) (AVHRR)	10	17 18 19 20 21 22	Ramp calibration AVHRR ch 5 AVHRR internal target[2] temperature data AVHRR patch temperature 0 0 0 0 0 0 0 0 0 1 spare } Each of these words is a 5-ch subcom, 4 words of IR data plus a subcom referance value
	(AVHRR) Internal target data	30	23 ↓ 52	10 words of internal target data from each AVHRR ch 3, 4, and 5. These data are time multiplexed as ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Space data (AVHRR)	50	53 ↓ 102	10 words of space-scan data from each AVHRR channel 1, 2, 3, 4, and 5. These data are time multiplexed as ch 1 (word 1), ch 2 (word 1), ch 3 (word 1), ch 4 (word 1), ch 5 (word 1), ch 1 (word 2), ch 2 (word 2), ch 3 (word 2), ch 4 (word 2), ch 5 (word 2), etc.
	Sync Δ (AVHRR)	1	103	Bit 1; 0 = AVHRR sync early; 1 = AVHRR sync late Bits 2-10; 9-bit binary count of 0.9984-MHz periods; bit 2 = MSB, bit 10 = LSB

(2) As measured by a platinum resistance thermometer embedded in the housing.

Table 14 (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Tip data	520	104 ↓ 623	The 520 words contain five frames of TIP data (104 TIP data words/frame) Bits 1-8: exact format as generated by TIP Bit 9: even parity check over bits 1-8 Bit 10: - bit 1	
Spare words	127	624	1 0 1 0 0 0 1 1 1 0	Derived by inverting the output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10} + X^5 + X^2 + X + 1$ The generator is started in the 1's state at the beginning of word 7 of each minor frame.
		625	1 1 1 0 0 0 1 0 1 1	
		626	0 0 0 0 1 0 1 1 1 1	
		627	1 0 1 1 0 0 0 1 1 1	
		628	1 1 0 1 0 1 0 0 1 0	
		↓	↓	
		748	1 0 0 1 0 1 1 0 1 0	
		749	1 1 0 0 1 0 0 0 1 0	
		750	1 0 0 0 0 0 0 0 0 0	

Table 14 (continued)

Function	No. of Words	Word Position	Bit No. 1 2 3 4 5 6 7 8 9 10	Plus Word Code & Meaning
Earth data (AVHRR)	10,240	751	Ch 1 - Sample 1	Each minor frame contains the data obtained during one earth scan of the AVHRR sensor. The data from the five sensor channels of the AVHRR are time multiplexed as indicated
		752	Ch 2 - Sample 1	
		753	Ch 3 - Sample 1	
		754	Ch 4 - Sample 1	
		755	Ch 5 - Sample 1	
		756	Ch 1 - Sample 2	
		↓	↓	
		10,985	Ch 5 - Sample 2047	
		10,986	Ch 1 - Sample 2048	
		10,987	Ch 2 - Sample 2048	
		10,988	Ch 3 - Sample 2048	
		10,989	Ch 4 - Sample 2048	
		10,990	Ch 5 - Sample 2048	
Auxiliary sync	100	10,991	1 1 1 1 1 0 0 0 1 0	Derived from the noninverted output of a 1023-bit PN sequence provided by a feedback shift register generating the polynominal: $X^{10}+X^5+X^2+X+1$ The generator is started in the all 1's state at the beginning of word 10,991
		10,992	1 1 1 1 1 1 0 0 1 1	
		10,993	0 1 1 0 1 1 0 1 0 1	
		10,994	1 0 1 0 1 1 1 1 0 1	
		↓	↓	
		11,089	0 1 1 1 1 1 0 0 0 0	
		11,090	1 1 1 1 0 0 1 1 0 0	

Table 15. DSB transmission parameters

Type of transmitted signal	VHF, phase modulated, split phase 8320 bits per second
System output	
Frequency	136.77 or 137.77 MHz
EIRP	+19.0 dBm worst case; +24 dBm nominal
Antenna	
Gain at 63° from nadir	-7.5 dBi, minimum[1]
Gain over 90% of sphere	- 18 dBi, minimum[1]
Polarization	Linear
Circuit Losses	3.7 dB
Transmitter	
Power	1.0 watt minimum
Modulation index	±67.5 with a 7.5^{o} tolerance
Premodulation filter, type	7-pole linear phase filter
3-dB bandwidth	16 kHz minimum, 22 kHz maximum
Frequency stability	$\pm 2 \times 10^{-5}$

[1] Observed by an optimum polarization diversity receiver.

Each tip minor frame contains information identifying the major and minor frame count. The major frame counter is located in bits 4, 5, and 6 of TIP word 3 and cycles from 0 to 7. The minor frame counter is composed of 9 bits. MSB is bit 8 of word 4, and the LSB is bit 8 of word 5. The minor frame count will cycle between 0 and 319 for each major frame count.

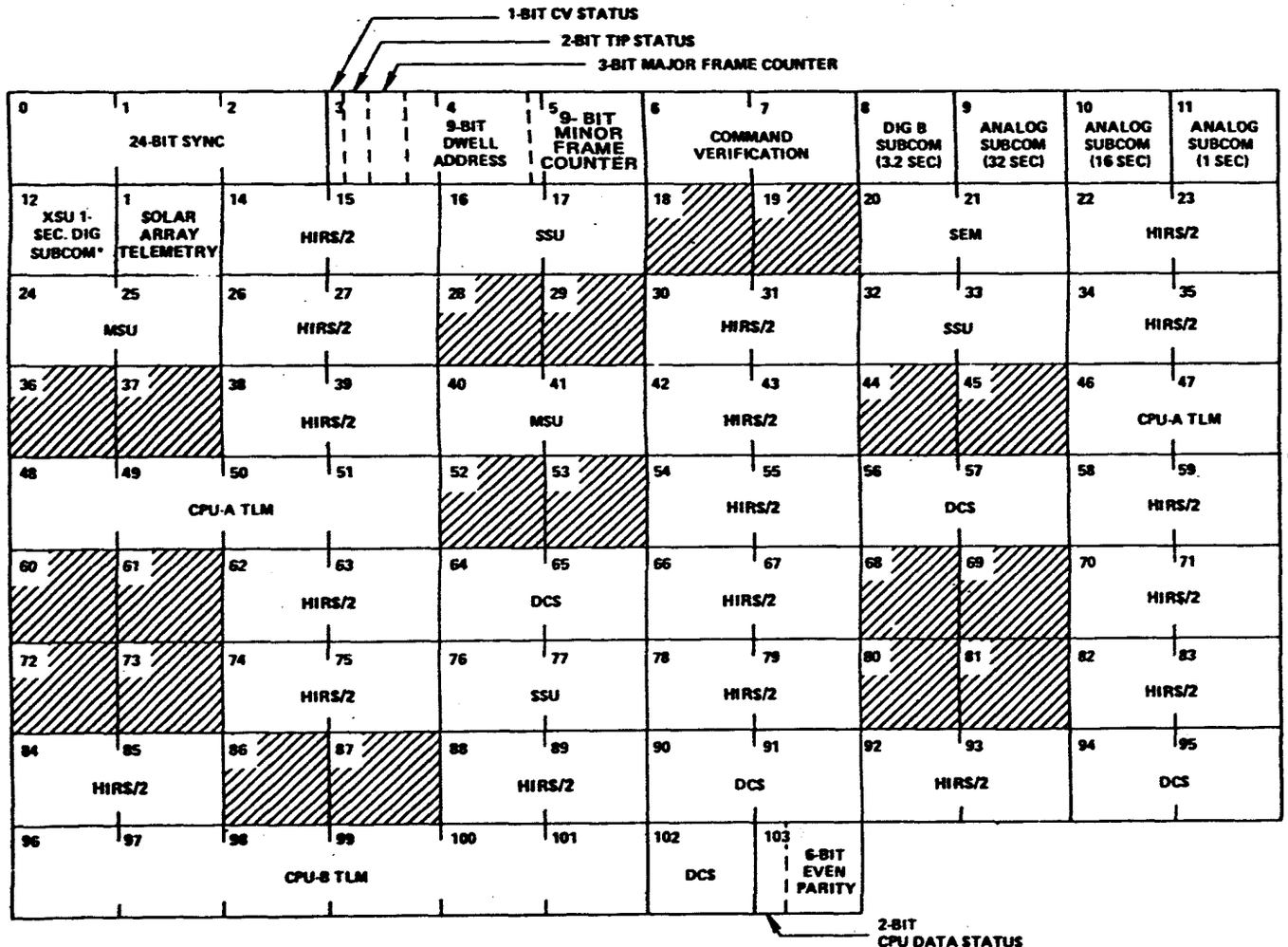
A 40-bit time code is inserted into the TIP stream once every 32 seconds.

These bits will be located in words 8 thru 12 of each minor frame 0. The format of this time code is as follows:

9 bits day count	0	1	0	1	27-bit milliseconds of day count
		4 spare bits			

Table 16. DSB TIP parameters

Major Frame	
Rate	1 frame every 32 seconds
Number of minor frames	320 per major frame
Minor Frame	
Rate	10 frames per second
Number of words	104
Format	See figure 6
Word	
Rate	1040 words per second
Number of bits	8
Order	Bit 1 = MSB Bit 8 = LSB Bit 1 transferred first
Bit	
Rate	8320 bits per second
Format	Split phase
Data 1 definition	
Data 0 definition	



NOTES: NUMBER IN UPPER LEFT HAND CORNER INDICATES MINOR FRAME WORD NUMBER.
TIME CODE DATA SHALL APPEAR DURING MINOR FRAME "0" WORD LOCATIONS 8 THROUGH 12.
////// WORD LOCATIONS ARE SPARE AND CONTAIN CODE 01010101.
* THE SUBCOMMUTATION FUNCTION IS ACCOMPLISHED IN THE EXTERNAL UNIT.

Figure 6 TIP Minor Frame Format

Table 17 Detailed Description of TIP Minor Frame

Function (no. of words)	Word position	Word format and function
Frame sync & S/C ID (3)	0 1 2	1 1 1 0 1 1 0 1 The last 4 bits of 1 1 1 0 0 0 1 0 word 2 are used for 0 0 0 0 A A A A spacecraft ID
Status (1-)	3	Bit 1: Cmd. verification (CV status; 1=CV update word present in frame; 0=no CV update in frame. Bits 2 & 3: TIP status; 00=orbital mode 10=CPU memory Dump mode 01=dwell mode 11 boost mode. Bits 4 - 6: Major frame count: MSB first; Counter incremented every 320 minor frames. 000=major frame 0 111=major frame 7
Dwell mode address (1+)	3 4	Bits 7&8 9-bit dwell mode address of analog channel that is being monitored continuously. MSB Bits 1-7 is first 0 0 0 0 0 0 0 0 0 = Analog ch 0 1 0 1 1 1 0 1 0 1 = Analog ch 383
Minor frame counter (1+)	4 5	Bit 8 0 0 0 0 0 0 0 0 0 = Minor frame 0 Bits 1-8 1 0 0 1 1 1 1 1 1 = Minor frame 319.MSB is first.
Command verification (2)	6 7	Bits 9 through 24 of each received command word are placed in the 16-bit slots of telemetry words 6 and 7 on a one-for-one basis.
Time code (5)	8,9 9 9,10,11,12	9 bits of binary day count, MSB first bits 2-5: 0 1 0 1, spare bits 27 bits of binary msec of day count, MSB first. Time code is inserted in word location 8-12 only in minor frame 0 of every major frame. The data inserted is referenced to the beginning of the first bit of the minor frame sync word of minor frame 0.
3.2 - Sec. digital B subcom (1)	8	A subcommutation of discrete inputs collected to form 8-bit words. 256 discrete inputs (32 words) can be accommodated. It takes 32 minor frames to sample all inputs once (sampling rate = once per 3.2 sec). A major frame contains 10 complete digital B sub-commuted frames.
32-sec analog subcom (1)	9	A subcommutation of up to 192 analog points sampled once every 32 seconds plus 64 analog points sampled twice every 32 seconds (once every 16 seconds). Bit 1 of each word represents 2560 mv while bit 8 represents 20 mv*
16-sec analog (1)	10	These two subcoms are under Programmed. Read Only Memory control. A maximum of 128 analog points can be placed in the 169 slots; super commutation of some selected analog channels is done to fill the 169 time slots. The 170th slot is filled with data from the analog point selected by command. The slot is word number zero of the one-second subcom. The analog point may be any of the 384 analog points available. Bit 1 of each word represents 2560 mv while bit 8 represents 20 mv.
1-sec analog subcom (1)	11	

*mv: millivolts

Table 17 (continued)

Function (no. of words)	Word position	Word format and function
XSU digital subcom (1)	12	The cross strap unit (XSU) generates an 8-word subcom which is read out at the rate of one word per minor frame. The XSU subcom is synchronized with its word 1 in minor frame 0,8,16...
Satellite data subcom (1)	13	Solar array telemetry
Spares (20)	18,19 28,29,36 37,44,45 52,53,60 61,68,69 72,73,80 81,86,87	0 1 0 1 0 1 0 1
HIRS/2 (36)	14,15,22 23,26,27 30,31,34 35,38,39 42,43,54 55,58,59 62,63,66 67,70,71 74,75,78 79,82,83 84,85,88 89,92,93	8-bit words are formed by the HIRS/2 experiment and are read out by the telemetry system at an average rate of 360 words per second.
SSU (6)	16,17,32 33,76,77	8-bit words are formed by the SSU experiment and read out by the telemetry system at an average rate of 60 words per second.
SEM (2)	20,21	8-bit words are formed by the SEM sensor and read out by the telemetry system at an average rate of 20 words per second.
MSU (4)	24,25,40 41	8-bit words are formed by the MSU experiment and read out by the telemetry system at an average rate of 40 words per second.
DCS (9)	56,57,64 65,90,91 94,95,102	8-bit words are formed by the DCS experiment and read out by the telemetry system at an average rate of 90 words per second.
CPU A TLM (6)	46,47,48 49,50,51	A block of three 16-bit CPU words is read out by the telemetry system every minor frame.
CPU B TLM (6)	96,97,98, 99,100,101	A second block of three 16-bit CPU words is read out by the telemetry system every minor frame.
CPU data status (1-)	103	Bits 1&2: 00=All CPU data received 01=All CPU-A data received; CPU-B incomplete 10=All CPU-B data received; CPU-A incomplete 11=Both CPU-A and CPU-B incomplete
Parity (1-)	103	Bit 3: Even parity check on words 2 through through 18 Bit 4: Even parity check on words 19 through 35 Bit 5: Even parity check on words 36 through 52 Bit 6: Even parity check on words 53 through 69 Bit 7: Even parity check on words 70 through 86 Bit 8: Even parity check on words 87 through bit 7 of word 103

Blank page retained for pagination

5. CALIBRATION

Williamson (1977) presents an excellent description of the methodology of calibration for satellite-borne radiometers. In general, the calibration processes involve exposing a radiometer to an extended source that has been calibrated against a primary or secondary standard of one of the national laboratories and establishing a relation between the output of the radiometer and the quantity of radiation (radiance) measured by the radiometer.

All the radiometers flown on the TIROS/NOAA series satellites undergo extensive prelaunch radiometric calibrations at the instrument manufacturer's facilities to establish their stability, linearity of response, and sensitivity in output digital counts per radiance unit. Instruments operating in the thermal infrared and microwave regions of the spectrum are calibrated against precision blackbody sources whose calibrations are, in general, traceable to the National Bureau of Standards (NBS). Instruments operating in the visible and near-infrared regions are calibrated against lamps whose output is viewed through the aperture of an integrating sphere. The calibrations for these lamps are also traceable to NBS.

Prelaunch infrared (IR) calibrations are performed in a thermal/vacuum environment to simulate the environment of space. During the thermal/vacuum exposure, calibrations are performed at several instrument operating temperatures (nominal +10C) to provide a measure of the deviation of the Instrument's response as a function of temperature. Visible and near IR calibrations are performed at ambient temperature in air.

A typical IR or microwave calibration will expose a radiometer to an extended blackbody source whose temperature is varied, in discrete steps, over the entire dynamic range of interest. In the visible, the intensity of the source is varied over the dynamic range of interest. The data recorded during these calibrations then form a baseline from which the accuracy and precision of the radiometer measurements can be determined. Analyses of prelaunch calibration data from each of the primary radiometers on the TIROS/NOAA series satellites are performed at NESS. Information resulting from these analyses, which affect the accuracy or precision of calibration, are provided in later sections.

The extensive nature of the prelaunch calibration program not-withstanding, it is not sufficient to rely on such calibration data to achieve the accuracies desired from today's satellite-borne remote sensing devices. Brower (1977) pointed out that using such static calibration of the ITOS scanning radiometer (in the thermal IR region) yielded temperature differentials of 2C to 4C between thermistor measurements and radiometric measurements of an onboard blackbody. (Radiometric measurements referred to are those made when the instrument itself views the blackbody.)

Another factor to be considered is that satellite-borne radiometers are subject to performance degradations in orbit. Unless some method is provided to assess those degradations, the prelaunch calibrations may shortly become useless or, at best, will yield questionable results. Therefore, the TIROS/NOAA radiometers, have been designed to perform in-orbit calibrations routinely, at

intervals during their scan sequences (in the IR and microwave regions only; no attempt is made to perform in-orbit calibrations in the visible region).

In-orbit calibration is accomplished by programming a given radiometer's scan mirror to view: space (near-zero radiance), and part of its housing, which is a designed blackbody. This onboard blackbody is maintained at approximately the operating temperature of the radiometer (15C or 288 K). Also, it is instrumented with temperature sensors whose outputs are multiplexed into the radiometer's telemetry. Thus, the zero radiance from the space look and the radiance from the 15C onboard blackbody provide a two-point, in-flight calibration.

Calibration of the onboard blackbody is generally performed during the prelaunch calibration program. One method of doing this (and the method preferred by NESS) is to use the instrument itself as a transfer standard. Once the output of the radiometer in counts per radiance unit, has been established (using a precision calibration blackbody), the onboard blackbody temperature sensor outputs are merely correlated with the output of the radiometer when it views the onboard blackbody. Since the radiometer is calibrated at several different temperatures, calibration curves representing radiometrically derived temperatures can be generated for each of the temperature sensors in the onboard blackbody.

In the following sections, the calibration procedures employed by NESS are treated in detail for each of the TIROS/NOAA primary radiometers.

5.1 High Resolution Infrared Radiation Sounder 2 (HIRS/2)

During normal operation, calibration of the HIRS/2 instrument is performed once every 256 seconds (40 lines). Calibration is provided by viewing two internal targets and space. The temperature of both internal targets, a warm target (IWT) (290 K) and a cold target (ICT) (260 K to 270 K), are determined from four thermistors embedded in each target. Because of large temperature gradients induced by solar effects throughout the orbit, the temperature of the ICT cannot be reliably determined with sufficient accuracy to improve calibration. Therefore, only the IWT and space-view data are used for calculating calibration coefficients.

Element 58 of each HIRS/2 line contains five samples of each of the four thermistors used to determine the temperature of the IWT (see table 18). The output of each thermistor is converted to temperature K by:

$$T = \sum_{j=0}^{4} a_j \; X^j$$

where T is the temperature indicated by the thermistor, X is the average of 200 samples for that thermistor (40 lines x 5 samples per line), and a_j are the conversion coefficients.

The temperature of the IWT (T_{IWT}) is determined by averaging the temperatures derived from the four thermistors. The T_{IWT} is converted into radiance (N) as shown in the Appendix. The computation of calibration coefficients requires that for each channel an average value of the space and internal warm target view data be computed. For that line containing space-view data, there are 56 samples per channel. Samples 1 through 8 contain data while the scan mirror is moving to the space target and are, therefore, not usable. For that line containing IWT view data, all 56 samples per channel are usable.

The channel gains are computed by:

$$G = \frac{N_{SP} - N_{IWT}}{\bar{X}_{SP} - \bar{X}_{IWT}}$$

where G is the gain for each channel, N_{SP} and N_{IWT} are the radiance of space and the internal warm target, $\bar{X}_{SP}$ is the mean space value (in counts) of the 48 usable space data samples, and $\bar{X}_{IWT}$ is the mean IWT value (in counts) of the 56 usable IWT data samples.

The channel intercepts are computed by:

$$I = N_{SP} - G\bar{X}_{SP}$$

5.2 Microwave Sounding Unit (MSU)

The parameters necessary for calibrating the MSU are provided with each scan line. Since each scan line contains only one sample for each parameter, an average of these data from several scan lines is used for the calculation of calibration coefficients.

The location of the space and internal target radiometric data is defined in section 6.2 MSU. The calibration coefficients for a specific scan line are computed from an average of the data contained in 25 lines (12 lines prior to and 12 lines subsequent to that line for which coefficients are being computed).

The relationship between input radiance and instrument output counts is not linear in the MSU channels. Since only a linear relation between radiance and instrument output counts can be derived from the in-flight data, a nonlinearity correction algorithm must be applied to each channel. The coefficients for this algorithm are produced by NESS for each instrument, using preflight subsystem calibration information.

The algorithm is:

$$C^1 = \sum_{i=0}^{2} d_i C$$

where C is the radiometric count output, d_i is the nonlinearity correction

coefficient and C^1 is the modified count value to be used in the linear algorithm.

Each of the two inflight calibration targets has two PRT's that are used to determine the temperature of these targets. In-flight target (#1) is viewed by channels 1 and 2. The temperaure of this target derived from PRT 1A and PRT 1B. In-flight target #2 is viewed by channels 3 and 4. The temperature of this target is derived from PRT's 2A and 2B. The output count values from PRT's 1A, 1B, 2A and 2B are located in words 2 and 3 of IFOV's 8 and 9 (see table 20).

The conversion of each PRT count output to temperature (K) requires the use of two algorithms, the first to convert counts to resistance (R) and the second to convert resistance to temperature (K). The first algorithm is:

$$R_A = K_0 + K_1 \frac{C_A - T_A \text{ CAL LO}}{T_A \text{ CAL HI} - T_A \text{ CAL LO}} \quad \text{for PRT 1A \& 2A}$$

or

$$R_B = K_0 + K_1 \frac{C_B - T_B \text{ CAL LO}}{T_B \text{ CAL HI} - T_B \text{ CAL LO}} \quad \text{for PRT 1B \& 2B}$$

where:

R_A is the resistance of PRT 1A or 2A; R_B is the resistance of PRT 1B or 2B; C_A is the count value of PRT 1A or 2A; C_B is the count value of PRT 1B or 2B; K_0 and K_1 are the resistance conversion coefficients.

T_A CAL HI and T_A CAL LO and T_B CAL HI and T_B CAL LO are the high and low calibration reference points for electronic systems A and B respectively.

T_A CAL LO, T_B CAL LO, T_A CAL HI and T_B CAL HI are located in words 2 and 3 of IFOV's 1 and 2 as defined in table 20.

The second algorithm, converting R to temperature is:

$$T = \sum_{i=0}^{i} e_i R^i$$

where T is the temperature (K) of the internal target as derived from the resistance ($R = R_A$ or R_B) and e_i are the temperature conversion coefficients for each PRT.

The temperature of target #1 is the average of the temperature derived from PRT's 1A and 1B. The temperature for target #2 is the average of the temperature derived from the PRT's 2A and 2B.

The target temperature used for the calculation of calibration coefficients is averaged over 25 scan lines.

The conversion of these average temperatures to radiance units (N_T) is described in the appendix.

Channel gains are calculated by:

$$G = \frac{N_{SP} - N_T}{\overline{C}'_{SP} - \overline{C}'_T}$$

where G is the channel gain, N_{SP} and N_T are the radiance of space and the internal target respectively, and $\overline{C}'_{SP}$ and $\overline{C}'_T$ are the corrected count values of the space and internal target views averaged over 25 scan lines.

Channel intercepts are calculated by:

$$I = N_{SP} - G\ \overline{C}'_{SP}$$

5.3 Stratospheric Sounding Unit (SSU)

During normal operation, calibration of the SSU instrument is performed once every 256 seconds. The scan sequence format for the SSU provides 32 seconds (1 line) of radiometric space and internal target view data followed by 7 scan lines of Earth view data.

The SSU calibration line contains four dwell periods of space data followed by four dwell periods of internal target data. These data can be identified by examining bits 7 and 8 of digital word 2, defined in section 6.3, SSU. Each dwell period contains 8 radiometric data samples per channel spaced according to the following timing chart.

Sample (s)	Time (t)
1	0.6 sec
2	1.0 sec
3	1.6 sec
4	2.0 sec
5	2.6 sec
6	3.0 sec
7	3.6 sec
8	4.0 sec

The accumulation of these samples over a four-second dwell period produces a linear relationship between output samples (counts) and time (seconds). The slope of this line is defined as a RAMP (counts per sec). This RAMP is computed using the lease squares equation:

$$RAMP = \frac{8\ \Sigma\ ts - \Sigma\ t\ \Sigma\ s}{8\ \Sigma\ t^2 - \Sigma(\ t)^2}$$

where all the summations over the eight samples and s is the count output value from a data sample at time t.

An average of four RAMP values from the space view and an average of the four RAMP values from the internal target view are used in the calculations of calibration coefficients.

The temperature of the internal target can be calculated from the blackbody PRT data samples (word 21, table 21) during the last 12 seconds of the calibration line and during the entire 32 seconds of the other seven scan lines.

The PRT provides the most precise measure of the internal target temperature. However, should the blackbody PRT fail, the data samples from the two blackbody thermistors (words 8 and 9, table 23) may be used to derive the internal target temperature.

The temperature of the internal target calculated from the blackbody PRT data samples is:

$$T(K) = \sum_{i=0}^{2} a_i \bar{X}^{-i}$$

where a_i are the conversion coefficients and $\bar{X}$ is the averaged PRT data value (in counts). It is sufficient to average only the last 12 seconds of each line to produce $\bar{X}$.

The temperature of the internal target calculated from the blackbody thermistor data samples is:

$$T(K) = \frac{\sum_{i=0}^{3} b_i \bar{X}^{-i} + \sum_{i=0}^{3} c_i \bar{Y}^{-i}}{2}$$

where b_i and c_i are temperature conversion coefficients for each thermistor and $\bar{X}$ is the average of the blackbody thermistor (word 8 divided by the thermistor reference [word 19]). $\bar{Y}$ is the average of the blackbody thermistor (word 9 divided by the thermistor reference [word 19]). Again, it is sufficient to average only the last 12 seconds of each line to produce $\bar{X}$ and $\bar{Y}$.

The internal target temperature is converted to radiance (N) as described in the Appendix. Channel gains are calculated by:

$$G = \frac{N_{SP} - N_T}{\overline{RAMP}_{SP} - \overline{RAMP}_T}$$

where G is the channel gain, N_{SP} and N_T are the radiance of space and the

internal target respectively, and $\overline{RAMP}_{SP}$ and $\overline{RAMP}_T$ are the average ramp value for the space and the internal target views.

Channel intercepts are calculated by:

$$I = N_{SP} - G \ \overline{RAMP}_{SP}$$

5.4 Application of Calibration Coefficients to Earth View Data

The gains and intercepts as computed for each instrument (sections 5.1 to 5.3) are used to convert Earth view radiometric samples (X_E in counts) to calibrated radiance values (N_E). The algorithm is:

$$N_E = G \ X_E + I$$

For the MSU, X_E is defined as the count value modified for instrument nonlinearity (C) (section 5.2).

The calibrated radiance values N_E do not include corrections for atmospheric attenuation, slant path corrections, or other atmospheric phenomena.

Blank page retained for pagination

6. INSTRUMENT DATA BASES

The information necessary for the location of specific instrument data, its extraction from the DSB or HRPT, its arrangement according to instrument scanning geometry, and the identification of calibration and Earth view data is provided in this section.

6.1 HIRS/2

Each TIP minor frame contains 288 bits of HIRS/2 radiometric and telemetry data (36 TIP words). This information is contained in TIP words 14, 15, 22, 23, 26, 27, 30, 31, 34, 35, 38, 39, 42, 43, 54, 55, 58, 59, 62, 63, 66, 67, 70, 71, 74, 75, 78, 79, 82, 83, 84, 85, 88, 89, 92, and 93 (see figure 6).

The HIRS data contained in each TIP minor frame are defined as an element. The identification and location of the data for each element is shown in table 18. A HIRS line is composed of 64 (0-63) successive elements and the extraction of HIRS data for the creation of a line should begin on minor frames 1, 65, 129, 193, or 257 of each major frame.

Bits 27-286 of elements 0-62 contain 20 thirteen-bit data words. Each word is composed of 12 bits of data and 1 sign bit. The sign bit is the MSB and when set to 0 indicates that the value of the 12 bits of data is negative.

Twenty words of data from elements 0-55 contain the digitized radiometric signal outputs of all 20 channels, for a single scan mirror dwell position (one IFOV). The radiometric channel number, with respect to word location, is shown in table 19. The 20 words of data in elements 56-62 contain housekeeping and ancillary instrument data. Elements 58 and 59 contain thermistor data necessary for determining internal cold and warm target temperatures (ICT, IWT).

During normal operation, the HIRS/2 instrument repeats a calibration cycle automatically, once every 40 lines (256 sec). A calibration cycle is one line of space-view radiometric data, one line of ICT radiometric data, and one line of IWT radiometric data. This is followed by 37 lines of Earth scanned data.

The lines containing space and internal target data can be identified by examining the line count provided in element 63, bits 27-39, or by the value of the encoder position, element 0-55, bits 1-8, (table 18). A line count of 0 indicates space view, 1 indicates ICT, and 2 indicates IWT. Line count value of 3-39 indicates the following 37 Earth view scan lines.

A secondary mode of operation of the HIRS/2 is possible where the automatic calibration cycle is overridden by ground command. During this mode, the calibration cycle data normally found for line count 0, 1, and 2 will be replaced with Earth view scan data. Under these conditions, channel gains and intercepts can be derived as a function of the housekeeping parameter data contained in elements 60-62. Should this mode ever be exercised, NESS will supply the necessary coefficients as a supplement to this document.

Table 18. HIRS/2 digital A data output

Element 0-55	
Bit 1-8	Encoder position (1-56=Earth view, 68=space, 105=ICT, 156=IWT)
Bit 9-13	Electronic cal level (0-31)
Bit 14-19	Channel 1 period monitor
Bit 20-25	Element number (1 less than encoder value for Earth views)
Bit 26	Filter sync designator
Bit 27-286	Radiant signal output (20 ch x 13 bits)
Bit 287	Valid data bit
Bit 288	Minor word parity check (odd parity)
Element 56-63	
Bit 1-26	Same as above
Bit 287, 288	Same as above
Element 56	
Bit 27-286	Positive electronic cal. (cal level advances one of 32 equal levels on succeeding scans)
Element 57	
Bit 27-286	Negative electronic cal.
Element 58	
Bit 27-91	Internal warm target #1, 5 times
Bit 92-156	Internal warm target #2, 5 times
Bit 157-221	Internal warm target #3, 5 times
Bit 222-286	Internal warm target #4, 5 times
Element 59	
Bit 27-91	Internal cold target #1, 5 times
Bit 92-156	Internal cold target #2, 5 times
Bit 157-221	Internal cold target #3, 5 times
Bit 222-286	Internal cold target #4, 5 times
Element 60	
Bit 27-91	Filter housing temp. #1, 5 times
Bit 92-156	FIlter housing temp. #2, 5 times
Bit 157-221	Filter housing temp. #3, 5 times
Bit 222-286	Filter housing temp. #4, 5 times
Element 61	
Bit 27-91	Patch temp. expanded, 5 times
Bit 92-156	First-stage temp., 5 times
Bit 157-221	Filter housing control power/temp., 5 times)
Bit 222-286	Electronic cal DAC, 5 times (counts)

Table 18 (Continued)

Element 62		
Bit 27-39	Scan mirror temp.	
Bit 40-52	Primary telescope temp.	
Bit 53-65	Secondary telescope temp.	
Bit 66-78	Baseplate temp.	
Bit 79-91	Electronics temp.	
Bit 92-104	Patch temp. - full range	
Bit 105-117	Scan motor temp.	
Bit 118-130	Filter motor temp.	
Bit 131-143	Cooler housing temp.	
Bit 144-156	Patch control power	
Bit 157-169	Scan motor current	
Bit 170-182	Filter motor current	
Bit 183-195	+15 Vdc	
Bit 196-208	-15 Vdc	
Bit 209-221	+7.5 Vdc	
Bit 222-234	-7.5 Vdc	
Bit 235-247	+10 Vdc	
Bit 248-260	+5 Vdc	
Bit 261-273	Analog ground	
Bit 274-286	Analog ground	
Element 63		
Bit 27-39	Line count	
Bit 40-41	Fill zeros	
Bit 42-44	Instrument serial number	
*Bit 45-52	Command status	
Bit 53-57	Fill zeroes	
*Bit 58-65	Command status	
Bit 66-78	Binary code (1,1,1,1,1,0,0,1,0,0,0,1,1)	+3875 (base 10)
Bit 79-91		+1443
Bit 92-104		-1522
Bit 105-117		-1882
Bit 118-130		-1631
Bit 131-143		-1141
Bit 144-156		+1125
Bit 157-169		+3655
Bit 170-182		-2886
Bit 183-195		-3044
Bit 196-208		-3764
Bit 209-221		-3262
Bit 222-234		-2283
Bit 235-247		-2251
Bit 248-260		+3214
Bit 261-273		+1676
Bit 274-286		+1992
*Bit 45	Instrument ON/OFF	ON = 1
*Bit 46	Scan motor ON/OFF	ON = 0
*Bit 47	Filter wheel ON/OFF	ON = 0
*Bit 48	Electronics ON/OFF	ON = 1
*Bit 49	Cooler heat ON/OFF	ON = 0
*Bit 50	Internal warm tgt. position	True = 0

Table 18 (Continued)

*Bit 51	Internal cold tgt. position	True = 0
*Bit 52	Space position	True = 0
*Bit 58	Nadir position	True = 0
*Bit 59	Calibration enable/disable	Enabled = 0
*Bit 60	Cover release enable/disable	Enabled = 0
*Bit 61	Cooler cover open	Yes = 1
*Bit 62	Cooler cover closed	Yes = 1
*Bit 63	Filter housing heat ON/OFF	ON = 0
*Bit 64	Patch temp. control ON/OFF	ON = 0
*Bit 65	Filter motor power HIGH	Normal = 1

*Command status bits

NOTE:

Each data sample is a 13-bit word with the MSB being the sign bit. The sign convention is such that 1 is positive and 0 is negative. The exceptions are the line number and command status words of element 63.

Table 19. HIRS/2 channel word location

Word location	Nominal central wave number (vc)	Radiometric channel number
1	688.4	1
2	2360.6	17
3	679.23	2
4	691.12	3
5	2190.4	13
6	703.56	4
7	2511.9	18
8	1363.7	11
9	2671.2	19
10	748.27	7
11	897.71	8
12	14367.0	20
13	1217.1	10
14	2212.7	14
15	721.28	6
16	716.05	5
17	2240.1	15
18	1484.4	12
19	2276.3	16
20	1027.9	9

Table 20 MSU Scan Line Format

WORD		1	2	3	4	5	6	7	8
					RADIOMETRIC DATA				
IFOV		INSTRUMENT VOLTAGES	INSTRUMENT TEMP (SYSTEM A)	INSTRUMENT TEMP (SYSTEM B)	CHANNEL 1 DATA	CHANNEL 2 DATA	CHANNEL 3 DATA	CHANNEL 4 DATA	SCAN POSITION LINE COUNT (2)
1		0 INST SCR LO	1 T_A CAL LO	2 T_B CAL LO	3 CH 1 DATA	4 CH 2 DATA	5 CH 3 DATA	6 CH 4 DATA	7 SCAN POS 0 SCAN COUNT
2		8 E CAL LO	T_A CAL HI	T_B CAL HI					15 SCAN POS 1 SCAN COUNT
3		16 E CAL HI	OTH 1 TEMP	OTH 2 TEMP					23
4		24 XTAL 1+	L.O. 1 TEMP	L.O. 2 TEMP					31
5		32 XTAL 1-	L.O. 3 TEMP	L.O. 4 TEMP					39
6		40 XTAL 2+	DICKE LOAD 1 TEMP	DICKE LOAD 2 TEMP					47
7		48 XTAL 2-	DICKE LOAD 3 TEMP	DICKE LOAD 4 TEMP					55
8		56 XTAL 3+	PRT 1A	PRT 1B					63
9		64 XTAL 3-	PRT 2A	PRT 2B					71
10		72 XTAL 4+	ANT. 1 BEARING TEMP	ANT. 2 BEARING TEMP					79
11		80 XTAL 4-	MOTOR TEMP	MOTOR TEMP					87
12	(SPACE)	88 -15. VOLTS	RF CHASSIS	RF CHASSIS					95
13	(INTERNAL TARGET)	96 5 VOLTS	PROG TEMP	PROG TEMP					103 SCAN POS 12 SCAN CNT
14	(SCAN TO IFOV 1)	104 E ZERO	105 PROG TEMP	106 PROG TEMP	107 CH 1 REF	108 CH 2 REF	109 CH 3 REF	110 CH 4 REF	111 SCAN POS X SCAN CNT

NOTES:
1. ALL 12-BIT WORDS; 112 WORDS = 1 SCAN LINE = 25.6 SEC
2. COUNTS TO 5 AND RESETS EVERY 128 SEC

Table 21 MSU Bit Formats For Each IFOV

Typical format for all words except word 8

```
MSB                                                   LSB
(bit                                                  bit
16)                                                   1
1  1  Ø  Z  D  D  D  D  D  D  D  D  D  D  D  D  D
```

D = Data
Z = 1 when in zero reference disable mode; 0 at all other times
Ø = 0 for the first seven words
1 = indicates it is the first word in a scan; 0 for all other words
1 = indicates that the word is a real word; 0 occurs only for an all-zero word

Scan position - line count, word 8

```
MSB                                                   LSB
bit                                                   bit
16                                                    1
1  0  1  Z  S  R  R  R  E  E  E  E  E  E  E  E  E
```

E = Scan angle (position) data
R = Scan line count (reset by 128-sec sync)
S = 1 when in scan disabled mode; 0 at all other times
Z = 1 when in zero reference disable mode
1 = indicates that this is the 8th word in the scan position
0 = indicates that this is not the first word in a scan
1 = indicates that the word is a real word

6.2 Microwave Sounding Unit (MSU)

Each TIP minor frame contains four 8-bit words of MSU data. These data are located in TIP word positions 24, 25, 40 and 41 (figure 6). Each two words (e.g., 24 and 25), when taken as one 16-bit word, represent one data sample of either telemetry or radiometric output data. All future reference to MSU data words will assume a word size of 16 bits.

One scan line of MSU data will contain 512 data words; however, only 112 of these words contain "real" MSU instrument output data. The remaining 400 words are zero filled. The real data are identified by examination of the MSB of each word. If the value of this bit is equal to 1, the word is real and should be included in the 112 words of valid MSU data.

The identification and relative position of the 112 words of MSU data are shown in table 20, and the formats of the data words are shown in table 21. Within the 512 words, real data will be grouped in eight consecutive words. These eight words contain the data accumulated during one dwell position (one IFOV). Each IFOV contains four words of radiometric data (one word per channel), and four words of ancillary data. The first eleven IFOV's contain radiometric Earth view data respectively, and IFOV 14 contains no usable radiometric data. Associated with each dwell position is a scan angle value that is encoded in word eight of each IFOV. (See E bits in table 21.)

Because of slight variations in scan positioning from line-to-line, it is necessary to define several acceptable scan angle values for each scan dwell position (IFOV). The acceptable values are shown in table 22. These position variations are negligible for all practical purposes.

Table 22. Acceptable scan angles

IFOV	Scan Angles
1 and 14	83, 91, 90
2	94, 95, 31
3	24, 26, 27
4	20, 21, 17
5	1, 4, 5
6	8, 10, 11
7	46, 47, 15
8	35, 42, 43
9	38, 39, 36
10	48, 49, 53
11	60, 57, 56
Space (12)	163, 162, 171
Internal Target (13)	200, 201, 202

Formation of the 112 words of MSU data must start when bit 15 has a value of 1 indication that this is the first word of a scan line. The timing of the output of MSU data, relative to the TIP minor frames, varies slightly. Conse-

quently, an MSU scan line will start at one of the TIP major/minor frame counters listed below, or within two minor frames thereafter.

TIP major frame	Minor frame
0	19
0	275
1	211
2	147
3	83
4	19
4	275
5	211
6	147
7	83

6.3 Stratospheric Sounding Unit (SSU)

Each TIP minor frame contains six 8-bit words of SSU data located in word positions 16, 17, 32, 33, 76, and 77. Each two words (e.g., 16 and 17), when taken together as one 16-bit word, represent one data sample of either telemetry or radiometric data. Thus, each TIP minor frame contains three SSU data words. The SSU data word contains 12 bits of information, left justified, within each 16-bit word. The lower order four bits are data value 0. Before processing, the 12 bits of data should be right shifted 4 bits. This can be accomplished by dividing each 16-bit data word by 16. Further discussions of SSU data will assume a 12-bit word.

An SSU scan is 32 seconds in duration (1 TIP major frame or 320 TIP minor frames) beginning at each minor frame 0. The SSU provides a complete sampling of data every second. Recalling that each TIP minor frame is 0.1 second in duration, and that each minor frame contains three SSU data words, this provides 960 data words per scan, at a rate of 30 words per second. Each second of data (30 words) contains two radiometric data samples for each channel. The radiometric data samples for channel 1 are located in words 16 and 28, for channel 2 in words 17 and 29, and for channel 3 in words 18 and 30. The identification of the 30 SSU words is shown in table 23.

Digital words 1, 2, and 3 in table 23 are described as follows: In digital word 1, bit 1 (LSB) identifies the mirror synchronous recovery status, and is normally 0. Bits 2-12 comprise an 11-bit second counter that is reset to 0 at the beginning of the space view.

Table 23. 30-word SSU data sampling
(repeated 32 times per SSU scan)

SSU Data Type	Word number
Digital word 1	1
Digital word 2	2
Digital word 3	3
Space port temperature	4
Earth port temperature	5
PMC bulkhead temperature	6
Detector temperature	7
Black body thermistor	8
Black body thermistor	9
Cell temperature ch 1	10
Cell temperature ch 2	11
cell temperature ch 3	12
Base plate temperature	13
Middle bulkhead temperature	14
Optics baseplate temperature	15
Radiometric sample ch 1	16
Radiometric sample ch 2	17
Radiometric sample ch 3	18
Thermistor reference	19
Mirror fine position	20
Black body PRT	21
PMC Amplitude ch 1	22
PMC Amplitude ch 2	23
PMC Amplitude ch 3	24
ADC Calibration 5% of full scale	25
ADC Calibration 50% of full scale	26
ADC Calibration 90% of full scale	27
Radiometric sample ch 1	28
Radiometric sample ch 2	29
Radiometric sample ch 3	30

Digital word 2 contains instrument configuration information as defined below:

Bit 12 (MSB)	Power on/off ('1' = on)
11	Mirror inhibit on/off ('1' = on)
10	Calibration mode auto/manual ('1' = manual)
9	Calibration verification (normally '0')
8	Mirror in position space view ('0' if in position)
7	Mirror in position blackbody ('0' if in position)
6	Mirror in position Earth view 1 ('0' if in position)
5	Mirror in position Earth view 5 ('0' if in position)
4	Mirror in position Earth view 8 ('0' if in position)
3	Mirror position correct (fine position sensor) yes/no ('0' = yes)
2-1	Channel identification for frequency reading 00 = channel 3 (1.4 mb) 01 = channel 1 (14 mb) 10 = channel 2 (4 mb)

Digital word 3 contains information necessary for evaluating the pressure modulated cell (PMC) channel frequencies. A data value will be inserted into this position once every 32 seconds. This will occur at minor frame 0 of each major frame. Word 2, bits 1 and 2, must be used with word 3 for proper identification of the PMC being sampled.

An SSU scan line consists of eight, 4-second Earth/calibration dwell periods. During each dwell period, eight radiometric data samples are taken for each channel (2 per second).

These eight radiometric data samples require additional processing to derive a final radiometric data value for a given dwell period.

During normal operations, the SSU instrument repeats a calibration cycle once every eight lines (256 seconds). A calibration cycle consists of one line of data, beginning at TIP major frame 0, minor frame 0. This line contains radiometric data samples taken while the instrument views space and the internal calibration target. The remaining seven scan lines contain radiometric Earth view data samples.

7. SCAN TIMING AND GEOMETRY

The purpose of this section is to provide the user with the information necessary to establish the timing and scan geometry relationships between the TOVS instruments. The timing relationships are shown in table 24.

The start time of each instrument scan line can be derived by using the TIP 32-second time code that was described in section 4.5. Table 25 identifies the start of each instrument scan line relative to that time code.

This table also identifies the major and minor frame numbers that correspond to the start of each scan line. Noted that the minor frame counters corresponding to the start of each scan are not the same for each instrument. For example, at the time corresponding to major frame 0, minor frame 0(TC(0/0) in table 25), all instruments begin their scan sequence. However, the data that corresponds to the start of the HIRS/2 scan line appears in major/minor frame 0/1, for SSU in 0/0, and for MSU in 0/19.

Since the TIP major frame count value cycles from 0 to 7, table 4-8 can be expanded by replacing major frame values 0, 1, 2, and 3 with major frame values 4, 5, 6, and 7 respectively.

Table 24. Instrument scan timing parameters

Instrument	Time between start of each scan line	No. of Earth step and dwell time	view steps per line	*ΔTime
HIRS/2	6.4 sec	0.1 sec	56	0.5 sec
MSU	25.6 sec	1.81 sec	11	0.9 sec
SSU	32 sec	4.0 sec	8	2 sec

*ΔTime - the difference between the start of each scan and the center of the first dwell period.

Table 25. Scan line timing of the TOVS instruments

Scan start time (seconds)		TIP major/minor frame HIRS/2	SSU	MSU
*TC (0/0)		0/1	0/0	0/19
	+6.4	0/65		
	+12.8	0/129		
	+19.2	0/193		
	=25.6	0/257		0/275
*TC (1/0)		1/1	1/0	
	+6.4	1/65		
	+12.8	1/129		
	+19.2	1/193		1/211
	+25.6	1/257		
*TC (2/0)		2/1	2/0	
	+6.4	2/65		
	+12.8	2/129		2/147
	+19.2	2/193		
	+25.6	2/257		
*TC (3/0)		3/1	3/0	
	+6.4	3/65		3/83
	+12.8	3/129		
	+19.2	3/193		
	+25.6	3/257		

*TC (n/0) is the time calculated from TIP major frame n and minor frame 0, where n=0, 1, 2, and 3.

Note: This timing table for major frames 0-3 repeats for major frames 4-7.

Figures 7 and 8 show the relationship between the scan patterns of each of the TOVS instruments.

All TOVS instruments scan in the same direction, Sun to anti-sun. It should be noted that the scan direction of the AVHRR instrument is opposite that of the TOVS instruments.

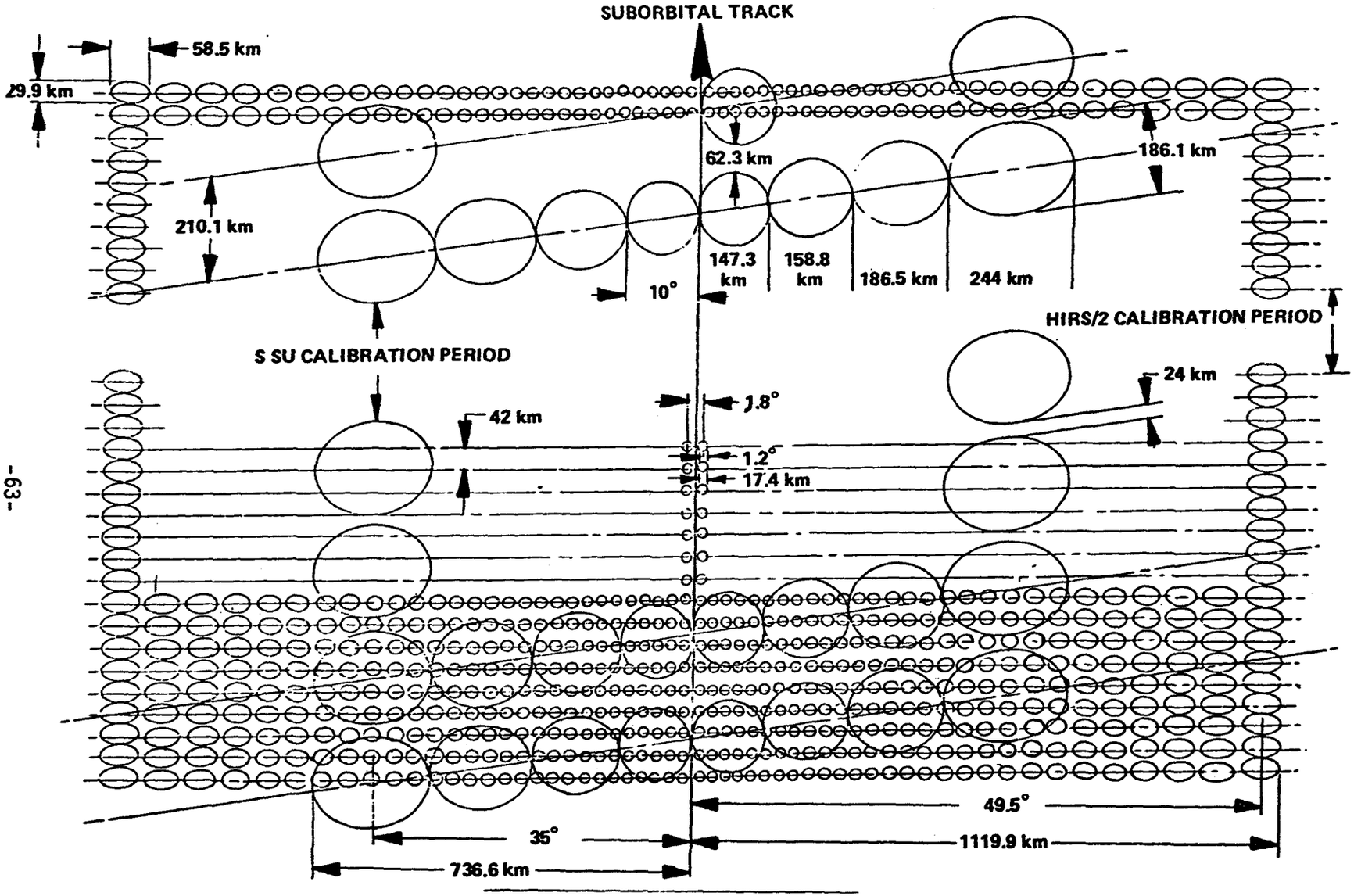


Figure 7 TIROS Operational Vertical Sounder HIRS/2 and SSU Scan Patterns Projected on Earth

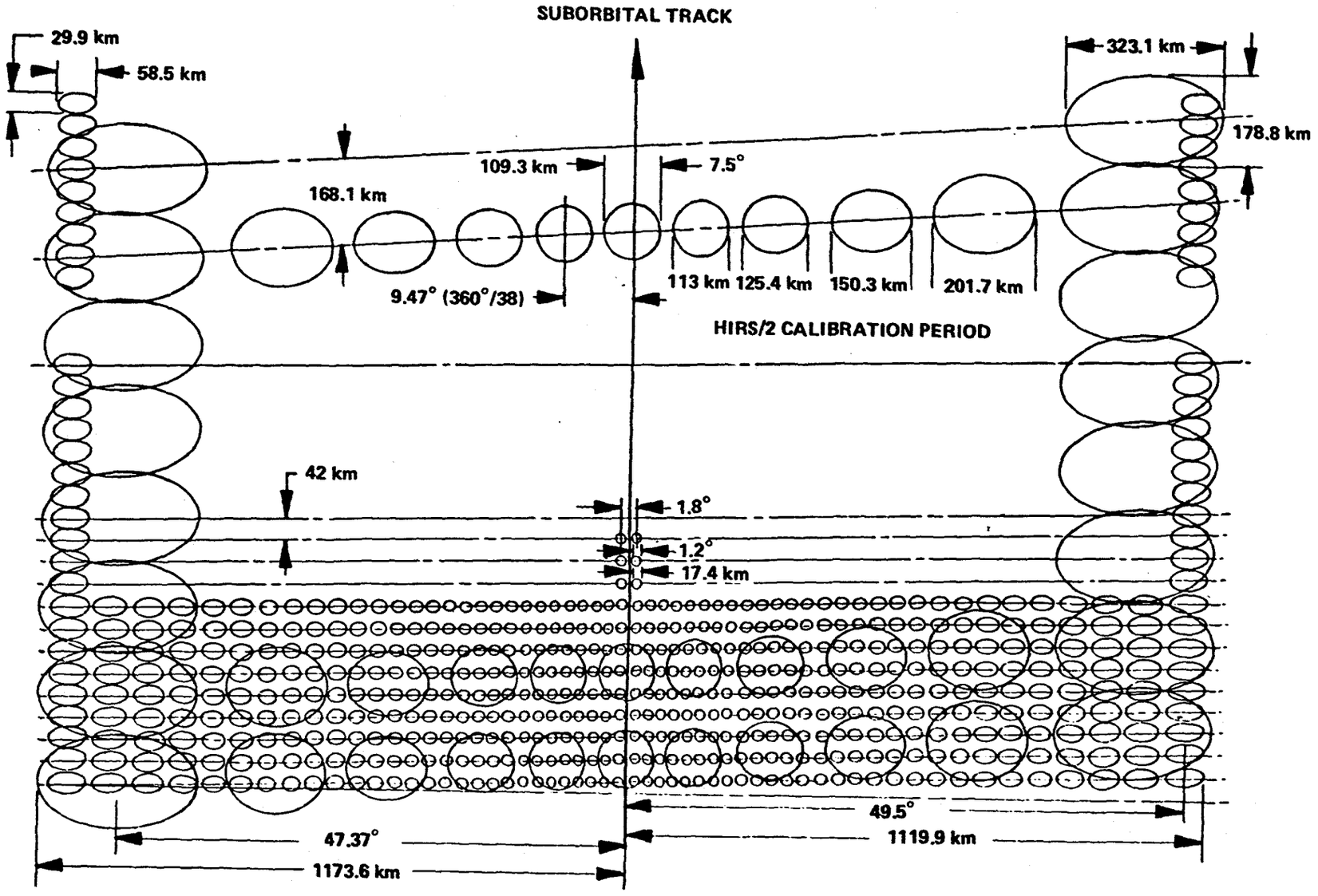


Figure 8 TIROS Operational Vertical Sounder HIRS/2 and MSU Scan Patterns Projected on Earth

8. TOVS SOUNDING PRODUCT

NESS has the capability of producting a maximum of 20,000 soundings every 24 hours from two operational spacecraft. Typically, they produce 7,000 to 8,000 soundings per satellite per day. These soundings are provided to SDSD on a weekly basis (7 days/tape).

Individual soundings stored on tape will be formatted according to the NMC/EDIS Dataset Format which is described in detail later in this section. Each tape will contain a data directory found at the beginning of the tape which will describe the contents of the tape. The data directory acts as a housekeeping file and consists of two parts: 1) an element containing directory information, and 2) the elements related to the data on the tape. The purpose of the EDIS archive housekeeping file is to aid users in determining the location of time categorized, satellite-derived soundings on the tape. The end of each group of time categorized soundings, as described by the individual data directory elements, is indicated by an end-of-file (EOF). A double EOF marks the end of data on tape as described by the last directory element in the housekeeping file. Together, the EOF markers and the housekeeping file are intended to provide the user with a means of selectively choosing soundings from the tape.

The format of the EDIS archive housekeeping file is in two parts. The first part of the file is the directory information element which contains 20 bytes in the following format.

DIRECTORY INFORMATION ELEMENT

Byte #	Contents
1-2	Number of data directory elements in housekeeping file
3-6	Total number of soundings (reports) on the tape
7-8	Processing year (2 digits)
9-10	Processing month (2 digits)
11-12	Processing day (2 digits)
13-20	Spares (denoted by "6666")

The second part of the housekeeping file are the directory elements which contain 20 bytes per element in the following format.

DATA DIRECTORY ELEMENT

Byte #	Contents
1-2	Time category of reports stored
3-4	Number of reports in time category
5-6	Year of reports (Century x 256 + day)
7-8	Month and day of reports (Month x 256 + day)
9-10	Time of day (GMT) of earliest report (Hours x 256 + minutes)
11-12	Time of day (GMT) of latest report (Hours x 256 + minutes
13-20	Spares (denoted by "6666")

The time category (listed as the first two bytes of the Data Directory Element) is defined as follows:

TIME CATEGORY

Category Number	Time Range (GMT)
1	0000 - 0259
2	0300 - 0559
3	0600 - 0859
4	0900 - 1159
5	1200 - 1459
6	1500 - 1759
7	1800 - 2059
8	2100 - 2359

The overall structure of each EDIS-TOVS archive tape is shown in Table 26. It shows the n+1 elements in the housekeeping file and the corresponding TOVS soundings files which are in the NMC/EDIS dataset format.

Table 26. Structure of TOVS Sounding Product Tape

```
-----------------------------------------------
Directory Information Element                   >   Housekeeping File
                                                >
Data Directory Element #1                       >
"    "         "       #2                      >
"    "         "       #3                      >
"    "         "       #n                EOF   >
-----------------------------------------------
TOVS Soundings described by
                                                >
Data Directory Element #1                 EOF   >
-----------------------------------------------
TOVS Soundings described by
                                                >   Data Files
Data Directory Element #2                 EOF   >
-----------------------------------------------
TOVS Soundings described by
                                                >
Data Directory Element #3                 EOF   >
-----------------------------------------------
                                                >
-----------------------------------------------
                                                >
TOVS Soundings described by
                                                >
Data  Directory  Element  #n                    >                    EOF
-----------------------------------------------
                                          EOF
```

The TOVS Sounding Product tape will have a logical record length of 280 bytes and a block size (physical record length) of 6440 bytes. However, the housekeeping file has a variable length record. It ranges from a minimum of 280 bytes to maximum of 3080 bytes because of the variable nature of the directory. The 6440 byte block size will hold 23 reports of 280 bytes each. A missing or undefined data value is denoted by "7777" , a spare is "6666", and an end-of-report is indicated by "8888". The TOVS sounding data files are written in the NMC/EDIS dataset format. This format is in binary and contains 44 bytes of documentation and 236 bytes of sounding products/information for a maximum of seven data type categories. The format for the documentation portion is as follows:

NMC/EDIS Documentation Format

Byte #	Contents
1-2	Satellite Identification
3-4	Year x 256 + month
5-6	Day x 256 + hour (GMT)
7-8	Minutes x 256 + seconds (GMT)
9-10	Latitude (Degree x 100, +N, -S, range +90 to -90)
11-12	Longitude (Degree x 100, +E, -W, range +180 to -180)
13-14	Solar zenith angle (Degree x 100, +day, -night, range +90 to -90)
15-16	Land/Sea Indicator (if land, surface elevation in meters, if sea, zero)
17-18	Surface (skin) Temperture degree K x 10
19-20	Estimated Surface Model Pressure (mb x 10)
21-22	Instrument and/or Channel Combination used to obtain various products
23-24	Retrieval Method
25-26	Standard Deviation of low-level HIRS/2 channel (7) (degree K x 100, range 0-10)
27-28	Standard Deviation of mid-level HIRS/2 channel (5)
29-30	Average value N*[1], range 0 to 1 (dimensionless x 1000)
31-32	Superswath and box counter for FGGE (Superswath x 100 + Box Counter)

NMC/EDIS Documentation Format (Cont.)

Byte #	Contents
33-34	Interactive edit flag: 0 = Not examined 1 = Examined; good 2 = Examined; questionable
35-36	Day of month and hour (GMT) when edit flag is written to file (Day x 256 = hour)
37-38	Minute and second (GMT) when edit flag is written to file (Minutes x 256 + seconds)
39-44	Spare

NMC/EDIS Sounding Products/Information Format

The sounding products/information portion has the following format (arranged in categories):

Byte #	Contents
	Category 1 - Layer-mean temperature (maximum 15 layers)
45-46	Pressure at lower boundary (mb x 10)
47-48	Pressure at upper boundary (mb x 10)
49-50	Layer - mean temperature (degree K x 10)
51-52	Quality (degree K x 10)
53-164	Repeat of Category 1 data for 14 layers
	Category 2 - Layer precipitable water (maximum 3 layers)
165-167	Pressure at lower boundary (mb x 10)
168-169	Pressure at upper boundary (mb x 10)
170-171	Layer precipitable water (mm)
172-173	Quality (percent)
174-188	Report of Category 2 data for 2 layers
	Category 3 - Tropopause parameters
189-190	Pressure (mb x 10)
191-192	Temperature (degree K x 10)
193-194	Quality (mb x 10)
195-196	Spare
	Category 4 - Ozone
197-198	Total ozone amount (Dobson units)
199-200	Quality (percent)

NMC/EDIS Sounding Products/Information Format (Cont.)

Byte #	Contents
	Category 5 - Cloud cover
201-202	Pressure (mb x 10)
203-204	Amount (percent)
	Category 6 - Sounding radiances
205-244	Twenty HIRS/2 channel equivalent blackbody temperatures (degree K x 64 except for Channel 20 which has degree K x 16)
245-252	Four MSU channel equivalent blackbody temperatures (degree K x 64)
253-258	Three SSU channel equivalent blackbody temperatures (degree K x 64)
259-260	Spare
261-276	New Category(s) Spare
277-278	Spare
279-280	End of Report

1 The N* method is used to compute clear radiance values when there are some clouds obstructing the surface.

Category 6 contains radiometric information supplied in the form of equivalent blackbody or brightness temperatures. These can be transformed to radiances (mW/m^2 - steradian - cm^{-1}) by application of the Planck function. The Planck function requires channel central wave numbers and temperature-adjustment coefficients which are spacecraft/instrument dependent.

The documentation portion of the NMC/EDIS dataset format contains two bytes (#21 and 22) which indicates the instrument and/or channel combination used to

obtain various products. If ICC represents the value in these two bytes then it can be defined as follows:

$$ICC = 4096Z + 256Y + 16X + 4W + V$$

where V denotes channel combinations used to obtain layer precipitable water for the layers: surface to 700 mb, 700 to 500 mb, and 500 to 300 mb.

0 no retrieval

1 HIRS/2 + MSU

2 HIRS/2

W denotes channel combinations used to obtain tropopause temperature and pressure.

0 no retrieval

1 HIRS' + MSU

2 MSU

X denotes channel combinations used to obtain total ozone.

0 no retrieval

1 HIRS/2 (1,2,3,8,9,16,17) + MSU(4)

2 HIRS/2 (1,2,3,8,9,16,17)

3 HIRS/2 (1,2,3,9,17) + MSU(4)

4 HIRS/2 (1,2,3,9,17)

Y denotes channel combinations used to obtain mean temperature for the layers; surface to 850 mb, 850 to 700 mb, 700 to 500 mb, 500 to 400 mb, 400 to 300 mb, 300 to 200 mb, 200 to 100 mb.

0 no retrieval

1 HIRS/2 + MSU

2 HIRS' + MSU

3 HIRS/2

4 MSU

Z denotes channel combinations used to obtain mean temperatures for the layers; 100 to 70 mb, 70 to 50 mb, 50 to 30 mb, 30 to 10 mb, 10 to 5 mb, 5 to 2 mb, 2 to 1 mb, 1 to 0.4 mb.

(Continued)

0 no retrieval

1 HIRS' = MSU (3,4)

2 HIRS' + MSU (3,4)

3 SSU + MSU (3,4)

4 HIRS' + SSU

5 HIRS'

6 MSU (3,4) (Output will terminate at 10 mb since there is no meaningful data above that level in this case).

Note that HIRS' is equivalent to HIRS/2 Channels 1(668 cm^{-1}), 2(679 cm^{-1}), 3(601 cm^{-1}), and 17(2360 cm^{-1}).

The retrieval method is contained in bytes 23 and 24 of the documentation of the NMC/EDIS dataset format. If METREC represents the value in the two bytes, then it is defined as follows:

$$METREC = 256A + 16B + C$$

where:

A = 0 no HIRS/2 data

1 clear radiances are derived from completely clear spots

2 clear radiances derived from the N^* approach

B = 0 no HIRS/2 data

1 all HIRS/2 channels are used in the retrieval

2 the tropopause HIRS/2 channels were unusable due to clouds and only stratospheric channels were used in the retrieval

C = 0 a statistical retrieval method was used

1 the minimum information retrieval was used

2 the minimum information retrieval was attempted but the statistical retrieval was used

Blank page retained for pagination

9.0 ORDERING TOVS DATA AND PRODUCTS FROM SDSD

The Satellite Data Services Division (SDSD) of the National Climatic Center, in conjunction with the National Earth Satellite Service, has established a digital archive of data collected from the NOAA operational polar orbiting satellites, TIROS-N (launched in October 1978) and NOAA-A (launched in June 1979 and renamed NOAA-6).

Digital data from the SDSD polar orbiter archive are available in the form of CCT's (Computer Compatible Tape) which may contain complete Level Ib datasets, selective extracts from Level Ib datasets, or copies of NESS operational AVHRR or TOVS products. Hard copy computer listings are also available.

All requests for archieved data should be addressed to:

Satellite Data Services Division
Room 100, World Weather Building
Washington, D.C. 20233
Phone: Commercial (301) 763-8111
(FTS) 763-8111

Standing orders for certain specified products to be produced on a regular basis will be accepted.

Orders for complete or selective tape copies which are not too extensive can generally be filled within ten days.

It may be assumed that all TOVS coverage is global and complete as of January 1, 1979 with some data available from as early as November 1, 1979.

CCT users will be provided complete tape documentation. Questions relating to the contents of the tape, calibration of the data, ordering and availability of the data, etc. should be referred to the above address or phone number.

REFERENCES

Chalfant, Michael P., A. DeChristofaro, N. Kerr 1979, "TIROS-N TOVS Coefficient Generation Subsystem Description Document", Unpublished, U. S. Department of Commerce, NOAA, NESS, Washington, D.C. 20233

Chalfant, Michael P., A. DeChristofaro, N. Kerr 1979, "TIROS-N TOVS Dataset Format Description Document", Unpublished, U. S. Department of Commerce, NOAA, NESS, Washington, D.C. 20233

Fleming, Henry E., L. McMillin, 1977, Atmospheric Transmittance of an Absorbing Gas. 2: A Computationally Fast and Accurate Transmittance Model for Slant Paths at Different Zenith Angles", Appl. Opt., 16, 1366-1370.

Gelman, M. E., and R. M. McInturff, 1979, "Preliminary Evaluation of Stratospheric Data from TOVS", Unpublished, National Meteorological Center, Upper Air Branch, Washington, D.C. 20233

Greaves, J. R., G. DiMego, W. L. Smith, and V. E. Suomi, 1979, "A Special Effort to Provide Improved Sounding and Cloud Motion Wind Data for FGGE", Bull. Amer. Meteorol. Soc., 60, 124-127.

Lauritson, L., G. J. Nelson, F. W. Porto, 1979, "Data Extraction and Calibration of TIROS-N/NOAA Radiometers", NOAA Technical Memorandum, NESS 107, 58 pp.

McMillin, Larry M., H. E. Fleming, 1976, "Atmospheric Transmittance of an Absorbing Gas: A Computationally Fast and Accurate Transmittance Model for Absorbing Gases with Constant Mixing Ratios in Inhomogeneous Atmospheres", Appl. Opt., 15, 358-363.

NASA Goddard Spaceflight Center, 1969, "The Nimbus III User's Guide", NASA Goddard Spaceflight Center, Greenbelt, Md., 20771

NASA Goddard Spaceflight Center, 1970, "The Nimbus IV User's Guide", NASA Goddard Spaceflight Center, Greenbelt, Md., 20771

NASA Goddard Spaceflight Center, 1972, "The Nimbus 5 User's Guide", NASA Goddard Spaceflight Center, Greenbelt, Md., 20771

NASA Goddard Spaceflight Center, 1975, "The Nimbus 6 User's Guide", NASA Goddard Spaceflight Center, Greenbelt, Md., 20771

Phillips, N. A., L. M. McMillin, D. Wark, and A. Gruber, 1979,"An Evaluation of Early Operational Temperature Soundings from TIROS-N", Bull. Amer. Meteorol. Soc., 60, 1188-1197.

Schneider, John R., 1976, "Guide for Designing RF Ground Receiving Stations for TIROS-N", NOAA Technical Report, NESS 75, 126 pp.

Schwalb, Arthur, 1978, "The TIROS-N/NOAA A-G Satellite Series", NOAA Technical Memorandum, NESS 95, 75 pp.

REFERENCES (Cont.)

Smith, W. L., and H. M. Woolf, 1976, "The Use of Eigenvectors of Statistical Covariance Matrices for Interpreting Satellite Sounding Radiometer Observations", J. Atmos. Sci., 33, 1127-1140.

Smith, W. l., H. M. Woolf, C. M. Hayden, D. Q. Wark, L. M. McMillin, 1979, "The TIROS-N Operational Vertical Sounder", Bull. Amer. Meteorol. Soc., 60, 1177-1187.

Smith, W. L., P.G. Abel, C. M. Hayden, M. Chalfant, and N. Grody, 1974, "Nimbus-5 Sounder Data Processing System Part I: Measurement Characteristics and Data Reduction Procedures", NOAA Technical Memorandum NESS 57, 99 pp.

Smith, W. L., C. M. Hayden, H. M. Woolf, H. B. Howell, and F. W. Nagle, 1978, "Interactive Processing of TIROS-N Sounding Data", Preprints, Conference on Weather Forecasting and Analysis and Aviation Meteorology (Silver Spring, Md.), Amer. Meteorol. Soc., Boston, pp. 390-395.

Weinreb, Michael P., M. L. Hill 1980, "Calculation of Atmospheric Radiances and Brightness Temperature in Infrared Window Channels of Satellite Radiometers", NOAA Technical Report NESS 80, 40 pp.

Weinreb, Michael P., A. C. Neuendorffer 1972, "Methods to Apply Homogeneous-Path Transmittance Models to Inhomogeneous Atmospheres", J. Atmos. Sci., 30, 662-666.

Weinreb, Michael P., and D. S. Crosby, 1972, "Optimization of Spectral Intervals for Remote Sensing of Atmospheric Temperature Profiles", Remote Sensing Environ., 2, 193-201.

Williamson, L. Edwin, 1977, "Calibration Technology for Meteorological Satellites", Atmospheric Science Laboratory Monograph Series, U.S. Army Electronics Command, White Sands Missile Range.

ACRONYMS AND ABBREVIATIONS

ADC	analog-to digital converter
AM	amplitude modulated
APT	Automatic picture transmission
ARGOS	French abbreviation for their data collection and location system (Service ARGOS)
ASCII	American Standard Coded Information Interchange
AVHRR	Advanced Very High Resolution Radiometer
BB	Blackbody
BCD	Binary Coded Decimal
BPI	Bits Per Inch
BPS	Bits Per Second
CAL	calibration
CCT	Computer Compatible Tape
CDA	Command and Data Acquisition
CDB	Coefficient Data Base
CEMES	Centre d'Etudes de la Meteorologie Spatiale
ch	channel
cm	centimeter
Cmd.	command
CNES	Centre National D'Etudes Spatiales
CPU	central processing unit
CV	command verification
DAC	digital-to-analog converter
DACS	Data Acquisition and Control Subsystems
dB	decibel
dBm	decibels above (or below) one milliwatt
DCS/DCLS	Data collection and location system
DIG	digital
DSB	Direct sounder broadcast
EBCDIC	Extended Binary Coded Decimal Interchange Code
EDIS	Environmental Data and Information Service
EIRP	effective isotropic radiated power
EOF	End of File
FGGE	First GARP Global Experiment
FM	Frequency modulation
FOV	Field Of View
fps	frames per second
GAC	Global Area Coverage
GARP	Global Atmospheric Research Program
GHz	gigahertz
GMT	Greenwich Mean Time (Zulu)
GOES	Geostationary Operational Environmental Satellite
HEPAD	High energy proton and alpha detector

HIRS/2	High Resolution Infrared Radiation Sounder 2
HRPT	High Resolution Picture Transmission
Hz	hertz
IFOV	Instantaneous Field Of View
ICT	Internal cold target/internal calibration target
ID	identification
IFOV	Instantaneous field of view
IR	infrared
ITOS	Improved TIROS operational system
IWT	Internal warm target
K	Kelvin temperature
kbps	kilobits per second
kHz	kilohertz
km	kilometer
LAC	Local Area Coverage
LSB	Least Significant Bit
LST	Local Solar Time
m	meter
MAX	maximum
mbar	millibar
Mbps	megabits per second
MHz	megahertz
MEPED	Medium energy proton and electron detector
MI	modulation index
MIN	minimum
um	micrometer
MIRP	Manipulated information rate processor
MSB	Most Significant Bit
MSU	Microwave Sounding Unit
mV	millivolt
mW	milliwatt
N/A	Not Available
NEΔN	Noise equivalent radiance difference
NEΔT	Noise equivalent temperature difference
NESS	National Earth Satellite Service
NMC	National Meteorological Center
No.	Number
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Air Defense Command
P/N	Pseudo Noise
PMC	Pressure modulated cell
pps	pulses per second
PRT	Platinum resistance therometer
PT	point
QC	Quality Control
REF	Reference

S/C	spacecraft
SDSD	Satellite Data Services Division
SEC,sec	second
SEM	Space environment monitor
S/N	Signal-to-noise ratio
SOCC	Satellite Operations Control Center
SPM	Solar proton monitor
SR	Scanning Radiometer
SST	Sea Surface Temperature
SSU	Stratospheric Sounding Unit
SUBCOM	subcommunication
SYNC	synchronous
TBM	Tera Bit Memory
TED	Total energy detector
TEMP.	temperature
Tgt.	target
THERM.	thermal
TIP	TIROS Information Processor
TIROS	Television Infrared Observational Satellite
TLM	Telemetry
TOVS	TIROS Operational Vertical Sounder
Vdc	volts, direct current
VHF	very high frequency
VIS	Visible
XSU	cross-strap unit

APPENDIX

Temperature-to-Radiance Conversion

$$N_T = N(T) = \int_{\nu_i}^{\nu_n} \beta(\nu, T)\ \hat{\phi}\ (\nu)\ d\nu$$

where N(T) is the radiance ($mW/(sr\ m^2\ cm^{-1})$) of a blackbody at temperature T(K).

$\beta\ (\nu_1 T)$ is the Planck function

ν is the wave number (cm^{-1})

and

$$\hat{\phi}\ (\nu) = \frac{\phi\ (\nu)}{\int_{\nu_1}^{\nu_n} \phi\ (\nu)\ d\nu}$$

where $\hat{\phi}\ (\nu)$ is the normalized response function and ν_1 and ν_n are the wave numbers at the limits of the response function $\phi(\nu)$.

An approximation of this integral is:

$$N(T) = \sum_{i=1}^{n} \beta\ (\nu_i, T)\hat{\phi}(\nu_i)\Delta\nu$$

and

$$\hat{\phi}\ (\nu_i) = \frac{\phi(\nu_i)}{\sum_{j=1}^{n} \phi\ (\nu_j)\ \Delta\nu}$$

where the normalized response function is defined at n discrete points. The spacing between successive points in $\Delta\nu$ wave numbers.

For calibration purposes n = 1 for the SSU and MSU. Then $\nu_1=\nu_n=\nu_c$ where ν_c is the central wave number. The radiance can now be calculated by:

$$N(T) = \beta\ (\nu_c, T)$$

The Planck function is defined as:

$$\beta(\nu_i, T) = \frac{C_1\ \nu_1^3}{e^{\frac{C_2\ \nu_i}{T}} - 1}$$

where the universal constants are:

$$C_1 = 1.1910659 \quad 10^{-5} \quad \frac{mW}{m^2 \text{ sterad. } cm^{-4}}$$

$$C_2 = 1.438833 \text{ cm K}$$

The values of ν_i, $\Delta\nu$ and $\hat{\phi}(\nu_i)$ where i=1 to n are supplied for each channel for each instrument.

For the HIRS/2 an alternate method for converting temperature into radiance is to apply a band-correction algorithm to T. This algorithm is:

$$T^* = b + cT$$

where T* is the apparent temperature and b and c are the band-correction coefficients for each channel (supplied in appendix B).

The radiance can be computed by:

$$N(T) = \beta(\nu_c, T^*)$$

where ν_c is supplied in appendix B (band-correction coefficients).

U.S. GOVERNMENT PRINTING OFFICE: 1981-0-340-997/1680

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Earth Satellite Service

Washington, D.C.
June 4, 1981

- ERRATA -

NOAA Technical Memorandum NESS 83

ATMOSPHERIC SOUNDING USER'S GUIDE

Adolf Werbowetzki, Editor

Page 82, All references to coefficients supplied in Appendix B should be deleted.

(Continued from inside front cover)

NESS 61 The Measurement of Atmospheric Transmittance From Sun and Sky With an Infrared Vertical Sounder. W. L. Smith and H. B. Howell, September 1972, 16 pp. (COM-73-50020)

NESS 62 Proposed Calibration Target for the Visible Channel of a Satellite Radiometer. K. L. Coulson and H. Jacobowitz, October 1972, 27 pp. (COM-73-10143)

NESS 63 Verification of Operational SIRS B Temperature Retrievals. Harold J. Brodrick and Christopher M. Hayden, December 1972, 26 pp. (COM-73-50279)

NESS 64 Radiometric Techniques for Observing the Atmosphere From Aircraft. William L. Smith and Warren J. Jacob, January 1973, 12 pp. (COM-73-50376)

NESS 65 Satellite Infrared Soundings From NOAA Spacecraft. L. M. McMillin, D. Q. Wark, J.M. Siomkajlo, P. G. Abel, A. Werbowetzki, L. A. Lauritson, J. A. Pritchard, D. S. Crosby, H. M. Woolf, R. C. Luebbe, M. P. Weinreb, H. E. Fleming, F. E. Bittner, and C. M. Hayden, September 1973, 112 pp. (COM-73-50936/6AS)

NESS 66 Effects of Aerosols on the Determination of the Temperature of the Earth's Surface From Radiance Measurements at 11.2 m. H. Jacobowitz and K. L. Coulson, September 1973, 18 pp. (COM-74-50013)

NESS 67 Vertical Resolution of Temperature Profiles for High Resolution Infrared Radiation Sounder (HIRS). Y. M. Chen, H. M. Woolf, and W. L. Smith, January 1974, 14 pp. (COM-74-50230)

NESS 68 Dependence of Antenna Temperature on the Polarization of Emitted Radiation for a Scanning Microwave Radiometer. Norman C. Grody, January 1974, 11 pp. (COM-74-50431/AS)

NESS 69 An Evaluation of May 1971 Satellite-Derived Sea Surface Temperatures for the Southern Hemisphere. P. Krishna Rao, April 1974, 13 pp. (COM-74-50643/AS)

NESS 70 Compatibility of Low-Cloud Vectors and Rawins for Synoptic Scale Analysis. L. F. Hubert and L. F. Whitney, Jr., October 1974, 26 pp. (COM-75-50065/AS)

NESS 71 An Intercomparison of Meteorological Parameters Derived From Radiosonde and Satellite Vertical Temperature Cross Sections. W. L. Smith and H. M. Woolf, November 1974, 13 pp. (COM-75-10432)

NESS 72 An Intercomparison of Radiosonde and Satellite-Derived Cross Sections During the AMTEX. W. C. Shen, W. L. Smith, and H. M. Woolf, February 1975, 18 pp. (COM-75-10439/AS)

NESS 73 Evaluation of a Balanced 300-mb Height Analysis as a Reference Level for Satellite-Derived soundings. Albert Thomasell, Jr., December 1975, 25 pp. (PB-253-058)

NESS 74 On the Estimation of Areal Windspeed Distribution in Tropical Cyclones With the Use of Satellite Data. Andrew Timchalk, August 1976, 41 pp. (PB-261-971)

NESS 75 Guide for Designing RF Ground Receiving Stations for TIROS-N. John R. Schneider, December 1976, 126 pp. (PB-262-931)

NESS 76 Determination of the Earth-Atmosphere Radiation Budget from NOAA Satellite Data. Arnold Gruber, November 1977, 31 pp. (PB-279-633)

NESS 77 Wind Analysis by Conditional Relaxation. Albert Thomasell, Jr., January 1979.

NESS 78 Geostationary Operational Environmental Satellite/Data Collection System. July 1979, 86 pp. (PB-301-276)

NESS 79 Error Characteristics of Satellite-Derived Winds. Lester F. Hubert and Albert Thomasell, Jr. June 1979, 44 pp. (PB-300-754)

NESS 80 Calculation of Atmospheric Radiances and Brightness Temperatures in Infrared Window Channels of Satellite Radiometers. Michael P. Weinreb and Michael L. Hill, March 1980, 43 pp. (PB80 208-119)

NESS 81 Improved Algorithm for Calculation of UTM and Geodetic Coordinates. Jeff Dozier, September 1980, 21 pp. (PB81 132680)

NESS 82 The Effect of Precipitation on Microwave Soundings in Low Latitudes. Lester F. Hubert, Norman C. Grody, Andrew Timchalk, and William C. Shen, April 1981.

3 8398 0003 5086 2
NOAA CENTRAL LIBRARY
CIRC OCEANS LIBRARIES

NOAA SCIENTIFIC AND TECHNICAL PUBLICATIONS

The National Oceanic and Atmospheric Administration was established as part of the Departm Commerce on October 3, 1970. The mission responsibilities of NOAA are to assess the socioeconomic i of natural and technological changes in the environment and to monitor and predict the state of the solid 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.

Information on availability of NOAA publications can be obtained from:

ENVIRONMENTAL SCIENCE INFORMATION CENTER (D822)
ENVIRONMENTAL DATA AND INFORMATION SERVICE
NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
U.S. DEPARTMENT OF COMMERCE

6009 Executive Boulevard
Rockville, MD 20852

NOAA--S/T 81-149