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AA Technical Memorandum NESS 107 — Rev. 1

DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

Washington, D.C.
November 1979
Revised October 1988

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

NOAA TECHNICAL MEMORANDUMS

National Environmental Satellite, Data, and Information Service

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NESS 113 Satellite Indentification of Surface Radiant Temperature Fields of Subpixel Resolution. Jeff Dozier, December 1980. (PB81 184038)

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NESS 115 Publications and Final Reports on Contracts and Grants, 1980. Nancy Everson, June 1981. (PB82 103219)

NESS 116 Modified Version of the TIROS N/NOAA A-G Satellite Series (NOAA E-J) - Advanced TIROS-N (TN). Arthur Schwalb, February 1982. (PB82 194044)

NESS 117 Publications and Final Reports on Contracts and Grants, 1981. Nancy Everson, April 1982. (PB82 229204)

NESS 118 Satellite Observation of Great Lakes Ice - Winter 1979-80. Sharolyn Reed Young, July 1983. (PB84 101054)

NESS 119 Satellite Observation of Great Lakes Ice: 1980-81. A.L. Bell, December 1982. (PB83 156877)

NESDIS 1 Publications and Final Reports on Contracts and Grants, 1982. Nancy Everson, March 1983. (PB83 252528)

NESDIS 2 The Geostationary Operational Environmental Satellite Data Collection System. D.H. MacCallum and M.J. Nestlebush, June 1983. (PB83 257634)

NESDIS 3 Nimbus-7 ERB Sub-Target Radiance Tape (STRT) Data Base. L.L. Stowe and M.D. Fromm, November 1983. (PB84 149921)

NESDIS 4 Publications and Final Reports on Contracts and Grants, 1983. Nancy Everson, April 1984. (PB84 192301)

NESDIS 5 A Tropical Cyclone Precipitation Estimation Technique Using Geostationary Satellite Data. Leroy E. Spayd Jr. and Roderick A. Scofield, July 1984. (PB84 226703)

NESIDS 6 The Advantages of Sounding with the Smaller Detectors of the VISSR Atmospheric Sounder. W. Paul Menzel, Thomas H. Achtor, Christopher M. Hayden and William L. Smith, July 1984. (PB851518/AS)

NESDIS 7 Surface Soil Moisture Measurements of the White Sands, New Mexico. G.R. Smith, September 1984. (PB85 135754)

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Walter G. Planet (Editor)

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Preface

In 1979, NOAA Technical Memorandum NESS 107 was published as a guide for direct readout users of the Automatic Picture Transmission (APT), High Resolution Picture Transmission (HRPT), and Direct Sounder Broadcast (DSB) services from the TIROS-N/NOAA series spacecraft. It provided the basic information necessary to extract data from the telemetry streams that are unique to a given sensor, to calibrate these data, and to develop an understanding of the accuracy and precision that can be expected of the calibrated data.

After working with the data for nearly a decade, NOAA scientists and the user community recognized the necessity to clarify and upgrade some of the material contained in that document. This publication is a result of their efforts, and supersedes TM NESS 107.

Like TM NESS 107, information contained within this publication will enable users with varying degrees of hardware capability and interest to realize the maximum utility from their particular systems. For example, an APT user may be interested only in the service that provides low resolution image products. On the other hand, a station that is equipped to read out, decommutate, and process HRPT data may wish to develop and produce quantitative products. In either case, the information will enable the user to realize the maximum capability from his system.

Also like TM NESS 107, much of the material describing the TIROS-N/NOAA instruments, data frame formats downlink characteristics, etc., has been drawn from NOAA publications. However, the material has been updated to reflect changes in instrumentation, operations, and data acquisition and processing.

In order to use the guidelines in this publication for operational purposes, users still will need to obtain the information in Appendix B published in conjunction with each satellite launch. In the early 1990's, changes in satellite instruments may render the information in this document obsolete, or at least minimally useful. Users are therefore advised to write to NESDIS requesting to be added to direct readout mail lists for copies of Appendix B for current operational satellites and for information concerning future spacecraft series.

An additional section on earth-locating data from NOAA polar satellites is included as Appendix C.

Contributors to this revision were M.P. Weinreb, S.R. Brown, J.K. Ellickson, L.A. Lauritson, E.P. McClain, T.M. Wrublewski, and P. Abel, all of the National Environmental Satellite, Data and Information Service (NESDIS). Many valuable suggestions and critical comments were provided by L.L. Stowe and R.W. Popham (NESDIS), G. Rochard (Centre de Meteorologie Spatiale, Lannion, France), S.J. Stringer (Meteorological Office, Bracknell, United Kingdom), and R. Saunders and J.R. Eyre (Hooke Institute for Atmospheric Research, Oxford University, United Kingdom). Monique Wilson prepared the final version of the revisions to the manuscript.

Walter G. Planet
Editor
TM NESS 107 (Revised)

CONTENTS

DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

Levin Lauritson, Gary J. Nelson
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Washington, D. C.

ABSTRACT. The TIROS-N/NOAA series is the third generation of environmental satellites providing real-time data to direct readout users. This publication has been prepared for the direct readout user of the Automatic Picture Transmission (APT) service, the High Resolution Picture Transmission (HRPT) service and the Direct Sounder Broadcast (DSB) service transmitted from these satellites. Information is presented that will enable users to extract from the telemetry streams data that are unique to a given sensor, to calibrate these data, and to develop an understanding of the accuracy and precision that can be expected of the calibrated data.

1. INTRODUCTION

This publication has been prepared for the user of the direct readout of the Automatic Picture Transmission (APT) service of the High Resolution Picture Transmission (HRPT) service, or of the Direct Sounder Broadcast (DSB) service from the TIROS-N/NOAA series spacecraft. It is intended to provide the information necessary to extract data from the telemetry streams that are unique to a given sensor, to calibrate these data, and to develop an understanding of the accuracy and precision that can be expected of the calibrated data.

Information is provided that will enable users with varying degrees of hardware capability and interest to realize the maximum utility from their particular systems. For example, an APT user may be interested in only the service that provides low resolution image products. On the other hand, a station that is equipped to read out, decommutate, and process HRPT data may wish to develop and produce quantitative products. In either case, the information will enable the user to realize the maximum capability from his system.

Much of the material contained in this document describing the TIROS-N/NOAA instruments, data frame formats, downlink characteristics, etc., has been published before. Schwalb (1978) describes the TIROS-N/NOAA A-G satellite series in detail in NOAA Technical Memorandum, NESS-95. Schneider (1976) describes TIROS-N ground receiving stations. This publication is an attempt to bring together, under one cover, the informational content of much of that material.

2. INSTRUMENTS

2.1 Advanced Very High Resolution Radiometer (AVHRR)

The AVHRR provides data for transmission to both APT and HRPT users. HRPT data are transmitted at full resolution (1.1 km); the APT resolution is reduced to maintain allowable bandwidth. The AVHRR for TIROS-N is a scanning radiometer, sensitive in four spectral regions; a fifth channel will be added on later satellites in this series. Deployment of four- and five-channel instruments is as follows: four-channel instruments are planned for TIROS-N, NOAA-A/6, NOAA-B, NOAA-C/7, and NOAA-E/8; five-channel instruments for NOAA-D, NOAA-F/9, NOAA-G/10, NOAA-H, NOAA-I, and NOAA-J.

The APT system transmits data from any two of the AVHRR channels selected by command from the National Environmental Satellite Service (NESS) Spacecraft Operations Control Center (SOCC). The HRPT system transmits data from all AVHRR channels. To avoid future changes on the spacecraft and in the ground receiving equipment, the TIROS-N/NOAA series HRPT data format has been designed to handle five AVHRR channels from the outset.

When operating with a four-channel instrument, the data from the 11 um channel are inserted in the data stream twice so that the basic HRPT data format is the same for both the four- and five-channel versions.

Table 2-1 lists the spectral characteristics of the four- and five-channel instruments and designates the spacecraft on which they are planned to be deployed.

Table 2-2 is a listing of the basic AVHRR parameters.

2.2 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

b. Stratospheric sounding unit

c. Microwave sounding unit

Note: Page numbers followed by "rev." have been revised.

Table 2-1. Spectral characteristics of the TIROS-N/NOAA AVHRR instruments

Four-channel AVHRR, TIROS-N				
Ch 1 0.55-0.9 μm	Ch 2 0.725-1.1 μm	Ch 3 3.55-3.93 μm	Ch 4 10.5-11.5 μm	Ch 5 Data from Ch 4 repeated
Four-channel AVHRR - NOAA-A, -B, -C, and -E				
Ch 1 0.58-0.68 μm	Ch 2 0.725-1.1 μm	Ch 3 3.55-3.93 μm	Ch 4 10.5-11.5 μm	Ch 5 Data from Ch 4 repeated
Five-channel AVHRR, NOAA-D, -F, -G, -H, -I and -J				
Ch 1 0.58-0.68 μm	Ch 2 0.725-1.1 μm	Ch 3 3.55-3.93 μm	Ch 4 10.3-11.3 μm	Ch 5 11.5-12.5 μm

Note: Changes to the above deployment scheme may occur as a result of instrument availability or changing requirements.

Table 2-2. AVHRR instrument parameters

Parameter	Value
Calibration	Stable blackbody and space for IR channels. No inflight visible channel calibration other than space.
Cross track scan	±55.4° from nadir
Line rate	360 lines per minute
Optical field of view	1.3 milliradians
Ground resolution (IFOV)[1]	1.1 km @ nadir
Infrared channel NEΔT[2]	<0.12 K at 300 K
Visible channel S/N[3]	3:1 @ 0.5% albedo

1) Instantaneous field of view
2) NEΔT - Noise equivalent differential temperature
3) Signal-to-noise ratio

2.2.1 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 2-3 is a listing of the nominal HIRS/2 parameters.

Table 2-3. HIRS/2 instrument parameters

Parameter	Value
Calibration	Stable blackbodies (2) and space background
Cross-track scan	±49.5° (±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 2-4 is a listing of the nominal 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.

2.2.2 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 height of the weighting function peaks in the atmosphere. SSU characteristics are shown in tables 2-5 and 2-6.

Table 2-4. HIRS/2 spectral characteristics

Channel	Channel frequency (cm^{-1})	μm	Half power bandwidth (cm^{-1})	Maximum scene temperature (K)	Specified NEΔN FM 3-7
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
10A[1.]	797	12.55	16	290	0.20
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
17A[1.]	2,240	4.13	28	330	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})

1. 10A and 17A are used on FM 1I, 2I, and 3I. 10 and 17 are used on FM 1-7.

Table 2-5. SSU channel characteristics

Channel number	Central wave no. (cm^{-1})	Cell pressure (mb)	Pressure of weighting function peak (mbar)	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 2-6. SSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background
Cross-track scan	±40° (±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

2.2.3 The Microwave Sounding Unit (MSU)

The MSU is a four-channel Dicke radiometer making passive measurements in the 5.5-μm oxygen band with characteristics as shown in tables 2-7 and 2-8.

Table 2-7. 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 2-8. MSU instrument parameters

Parameter	Value
Calibration	Stable blackbody and space background each scan cycle
Cross-track scan angle	±47.35°
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

2.3 Data Collection and Location System (DCLS)

The Data Collection and Location System (DCLS) for the TIROS-N/NOSS series was designed, built, and furnished by the Centre National D'Etudes Spatiales (CNES) of France, who refer to it as the ARGOS Data Collection and Location System. The ARGOS provides a means for locating the position of fixed or moving platforms and for obtaining environmental data from them (e.g., temperature, pressure, altitude, etc.). Location information may be computed by differential Doppler techniques using data obtained from the measurement of platform carrier frequency received on the satellite. When several measurements are received during a given contact with a platform, location can be determined. The environmental data messages sent by the platform will vary in length depending on the type of platform and its purpose. A technical discussion of the DCLS and the processing of its data is not included in this publication. Detailed information concerning the DCLS, including technical requirements for platforms and criteria for use of the system can be obtained by writing to:

Service ARGOS
Centre Spatial de Toulouse
18, avenue Edouard Belin
31055 Toulouse Cedex
France

2.4 Space Environment Monitor (SEM)

The SEM instrument, incorporated as a subsystem in the TIROS-N/NOAA A-H satellites, consists of three independent components designed and built by Ford Aerospace and Communication Corporation. The instrument measures solar proton, alpha particle, electron flux density, energy spectrum, and the total particulate energy disposition at the altitude of the satellite.

The three components are:

a. Total energy detector (TED)

b. Medium energy proton and electron detector (MEPED)

c. High energy proton and alpha detector (HEPAD).

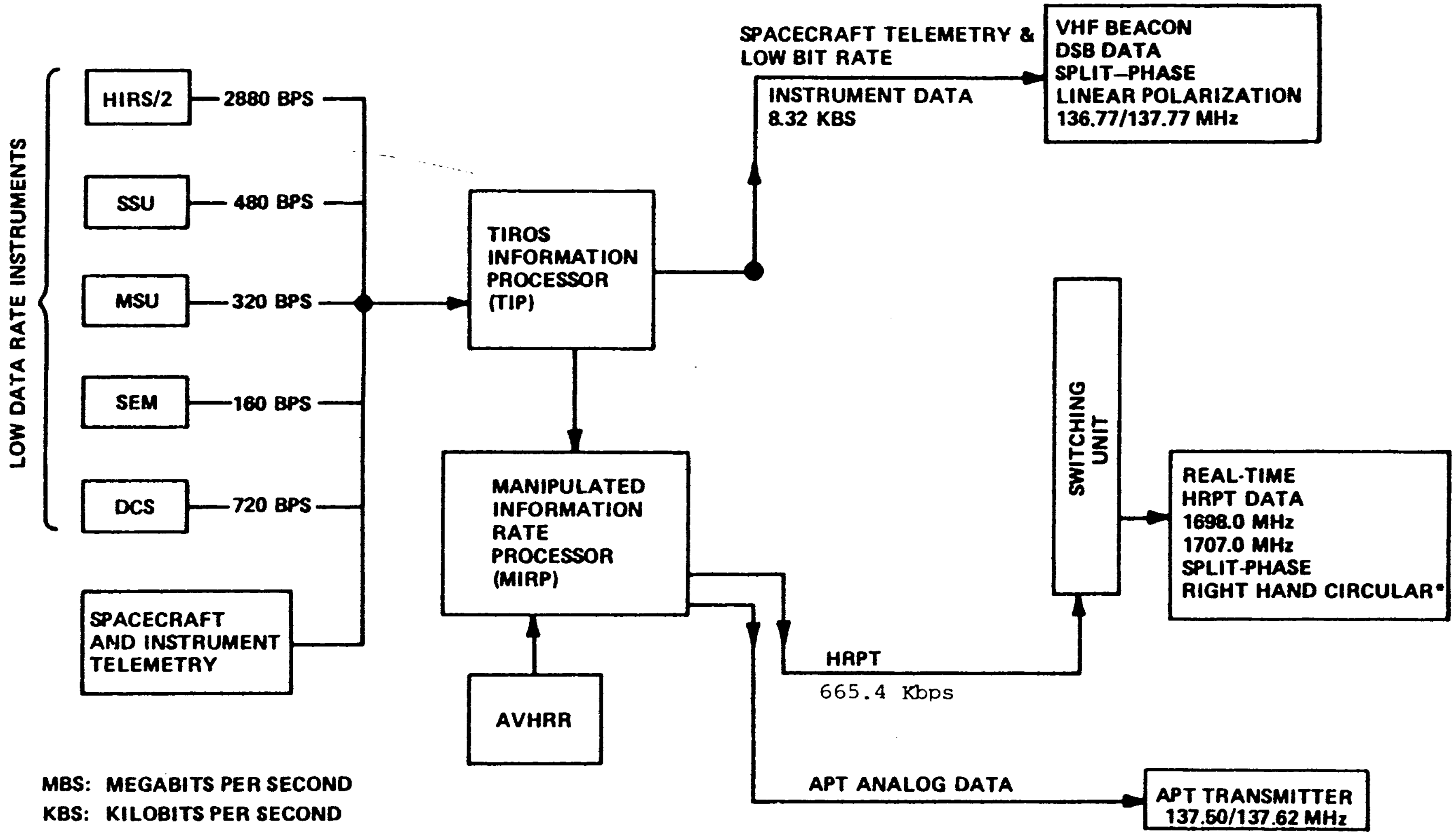
This instrument is a follow-on to the solar proton monitor (SPM) flown on the ITOS series of NOAA satellites. The new instrument modifies the SPM capabilities and adds the monitoring of high energy protons and alpha flux. The package also includes a monitor of total energy deposition into the upper atmosphere. The instrument augments the measurements being made by NOAA's Geostationary Operational Environmental Satellite (GOES). The last HEPAD on the NOAA Polar Orbiting Satellites was flown on NOAA-7, launched on June 23, 1981. The remaining HEPADS were transferred to the GOES program for flights on GOES D, E, F, and G.

A technical discussion of the SEM and the processing of its data is not included in this publication. Information can be obtained by contacting:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration
Environmental Research Laboratory
Space Environmental Laboratory
Boulder, Colorado 80303

3. Direct Readout Data Transmission Service

As mentioned previously, three separate real-time data services are available from the TIROS-N/NOAA series direct readout satellites. The data flow for these services, on board the spacecraft, is shown in Figure 3-1; their characteristics are described in Table 3-1.



NOTE: DCS H, I, J is 960 bps; K,L,M will be 2,560 bps.

* 1702.5 MHz, LEFT HAND CIRCULAR AVAILABLE BUT NOT PLANNED FOR HRPT USE

Figure 3-1. TIROS-N/NOAA real-time systems data flow

Table 3-1. Real-time data transmission characteristics

System	Characteristics
APT	VHF, AM/FM 2.4-kHz subcarrier
HRPT	S-band, digital, split phase 665.4 kbps
DSB (includes low-bit-rate instruments such as TOVS)	VHF, digital, split phase 8.32 kbps, keyed PSK (Phase Shift Keyed)

3.1 APT Transmission Characteristics

Video data for transmission on the APT link (output at the rate of 120 lines per minute) are derived from the AVHRR high resolution data.

The digital outputs of two selected AVHRR channels are processed in the manipulated information rate processor (MIRP) to reduce the ground resolution (from 1.1 km to 4 km) and produce a linearized scan so that the resolution across the scan is essentially uniform. After digital processing, the data are time multiplexed along with appropriate calibration and telemetry data. The processor then converts the multiplexed data to an analog signal, low-pass filters the output, and modulates a 2400-Hz subcarrier. The maximum subcarrier modulation is defined as the amplitude of gray scale wedge number eight (see figure 3-3), producing a modulation index of 87 ± 5 percent.

Tables 3-2 through 3-4 and figures 3-2 through 3-4 identify the pertinent APT characteristics.

3.2 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), the Solar Backscatter Ultraviolet Radiometer (SBUV/2) and from the space environment monitor (SEM), the Data Collection and Location System (DCLS), and the spacecraft housekeeping telemetry.

General characteristics of the HRPT system appear in table 3-5.

Table 3-2. APT characteristics

Line rate (lines per minute)	120
Data resolution	4 km nearly uniform
Carrier modulation	Analog
Transmit frequency	137.50 MHz for VTX-1 or 137.62 MHz for VTX-2
Transmit power	6 watts nominal
Transmit antenna polarization	Right hand circular
Subcarrier frequency	2.4 kHz
Carrier deviation	±17 kHz
Ground station low pass filter	1400 Hz 7th order linear recommended
Synchronization	7 pulses at 1040 pps. 50% duty cycle for channel A; 7 pulses at 832 pps, 60% duty cycle for channel B

3.3 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 rate. That is, the three minor frames that make up a 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 3-6 and the HRPT minor frame format is shown in figure 3-5.

Specific characteristics of the HRPT transmission system are detailed in table 3-7.

Table 3-3. APT transmission parameters

Type of transmitted signal	VHF, AM/FM 2.4-kHz DSB-AM 1.44-Hz video
System output	
Frequency, polarization	137.50-MHz right circular polarization or 137.62-MHz right circular polarization
EIRP at 63° from nadir	33.5 dBm worst case 37.2 dBm nominal
Antenna	
Gain at 63° from nadir	-0.5 dBi, right circular polarization
Ellipticity	4.0 dB, maximum
Circuit losses	2.4 dB
Transmitter	
Power	5.0 watts minimum
Carrier modulation index	±17, ±0.85 kHz
Premodulation bandwidth ±0.5 dB	0.1 to 4.8 kHz
Frequency stability	$+2 \times 10^{-5}$
Subcarrier modulator	
Subcarrier frequency	2400 ±0.3 Hz
Subcarrier modulation index	87 ±5%
Post modulator filter, type 3-dB bandwidth	3-pole Butterworth 6 kHz, minimum
Premodulator filter, type 3-dB bandwidth	3-pole Butterworth-Thompson 2.4 kHz, minimum

Table 3-4. APT format parameters

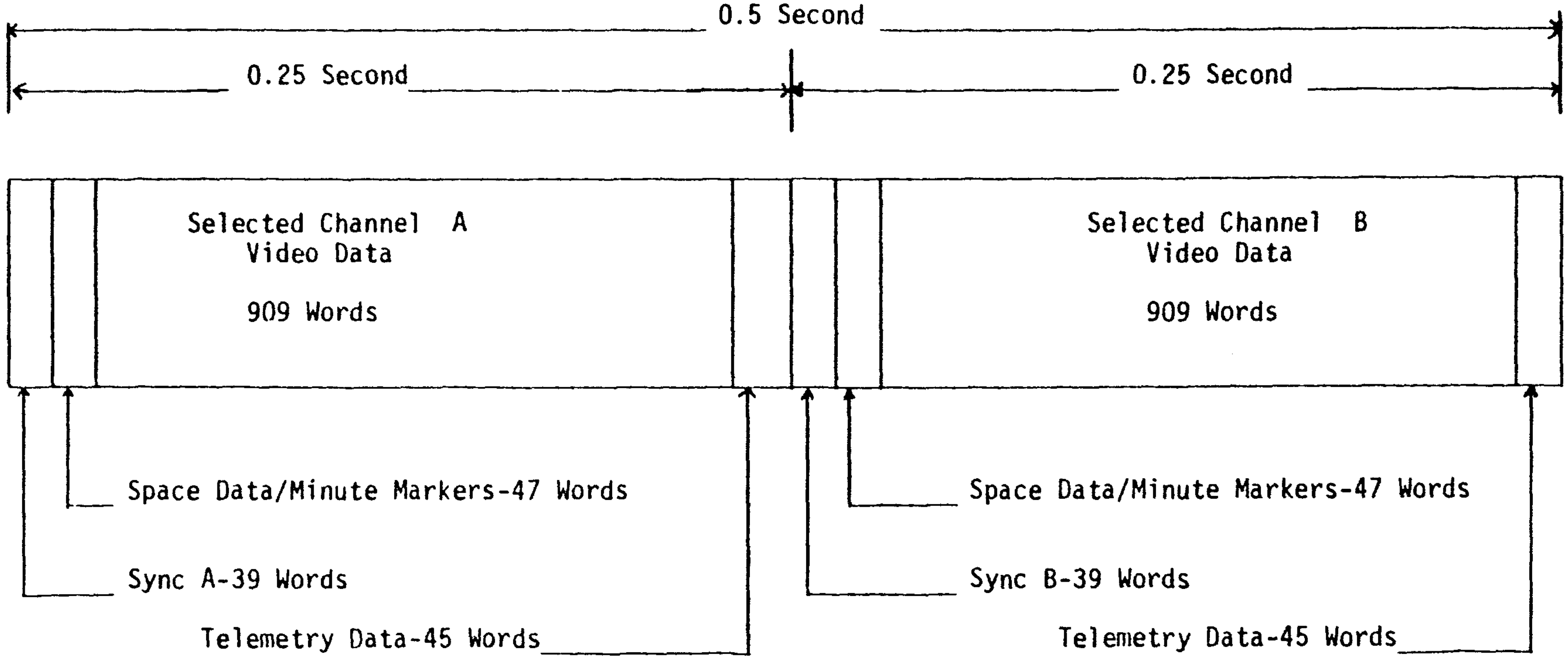
<u>Frame</u>	
Rate	1 frame per 64 seconds
Format	See figure 3-3
Length	128 lines
<u>Line</u>	
Rate	2 lines/second
Number of words	2080
Number of sensor channels	Any 2 of the 5; selected by command
Number of words/sensor chan.	909
Format	See figure 3-2
Line sync format	See figure 3-4
<u>Word</u>	
Rate	4160 per second
Analog-to-digital Conversion accuracy	The 8 MSB's* of each 10-bit AVHRR word
<u>Low-Pass Filter</u>	
Type	3rd order Butterworth-Thompson
3 dB bandwidth	2400 Hz

*Most significant bits (MSB)

Table 3-5. 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	8 watts nominal
EIRP (approximate)	39.0 dBm
Polarization	Right hand circular
Spectrum bandwidth	3 dB bandwidth of 2.4 MHz

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



Notes:

1. Equivalent output digital data rate is 4160 words/second
2. Video line rate - 2 lines/second
3. APT frame size - 128 lines
4. Any two of the five AVHRR channels may be selected for use
5. Sync A is a 1040-Hz square wave - 7 cycles
6. Sync B is a 832-pps pulse train - 7 pulses
7. Each of 16 telemetry points are repeated on 8 successive lines
8. Minute markers are repeated on 4 successive lines, with 2 lines black and 2 lines white

Figure 3-2. APT video line format (prior to D/A converter)

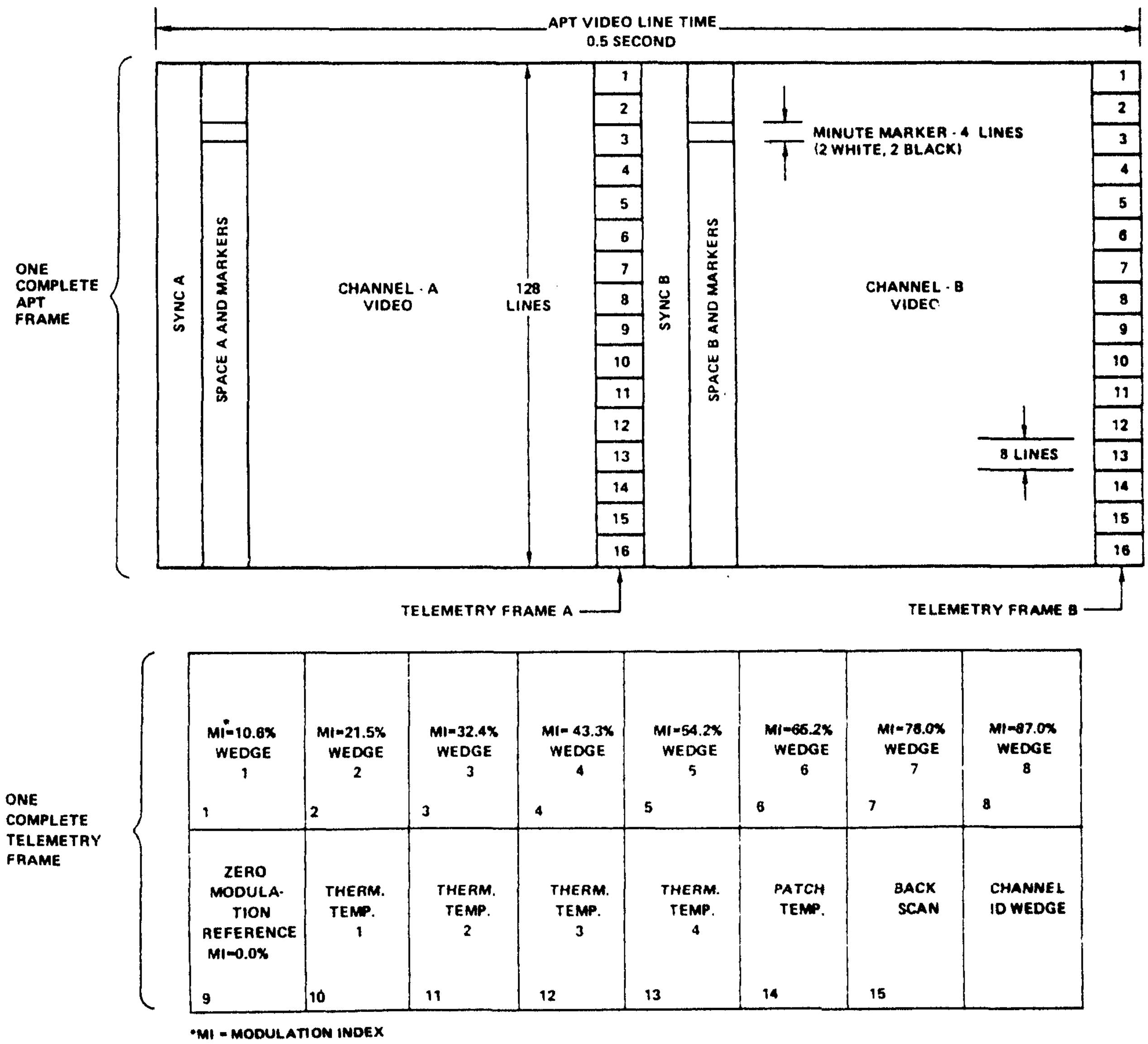
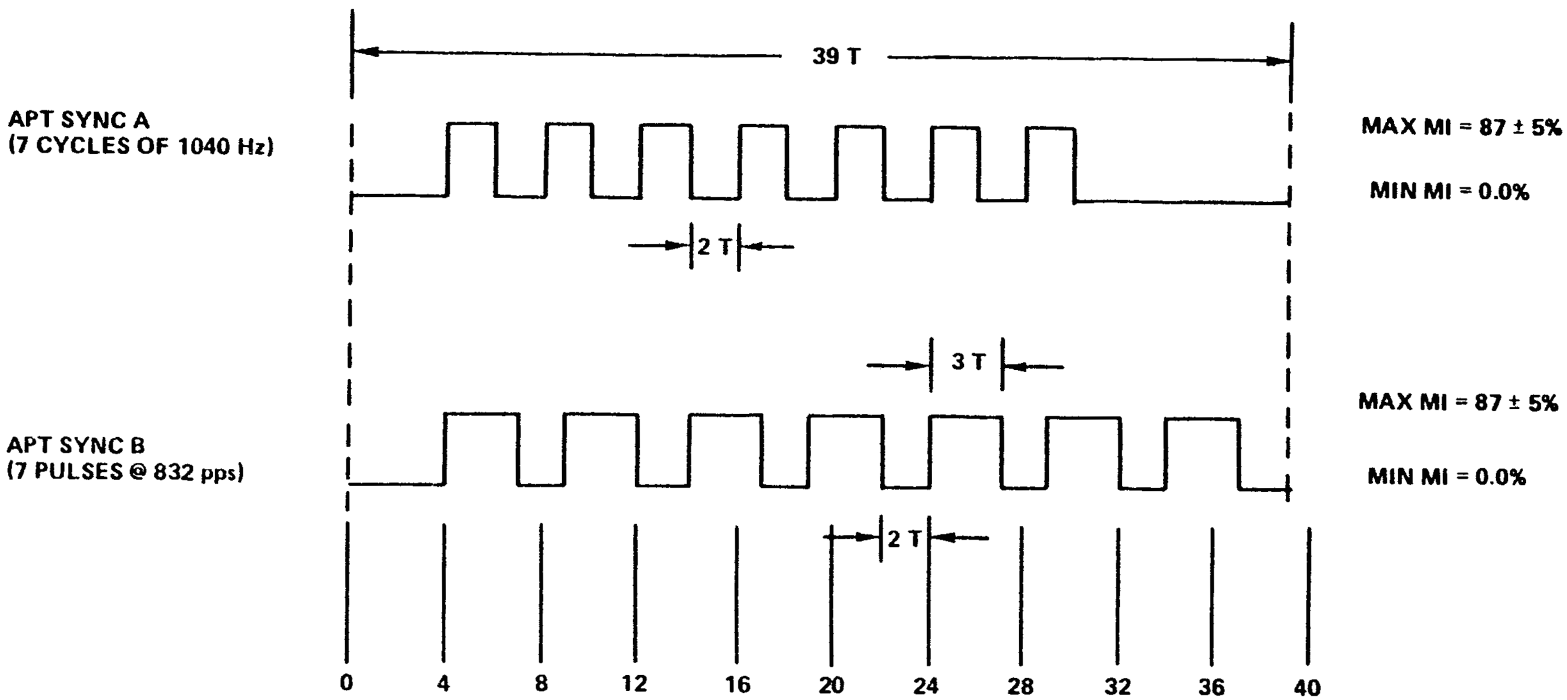


Figure 3-3. APT frame format



NOTES:

(1) $T = \frac{1}{4160} = 0.24038$ MILLISECOND

(2) SYNC A PRECEDES CHANNEL-A DATA

(3) SYNC B PRECEDES CHANNEL-B DATA

Figure 3-4. APT sync details

Table 3-6. HRPT parameters

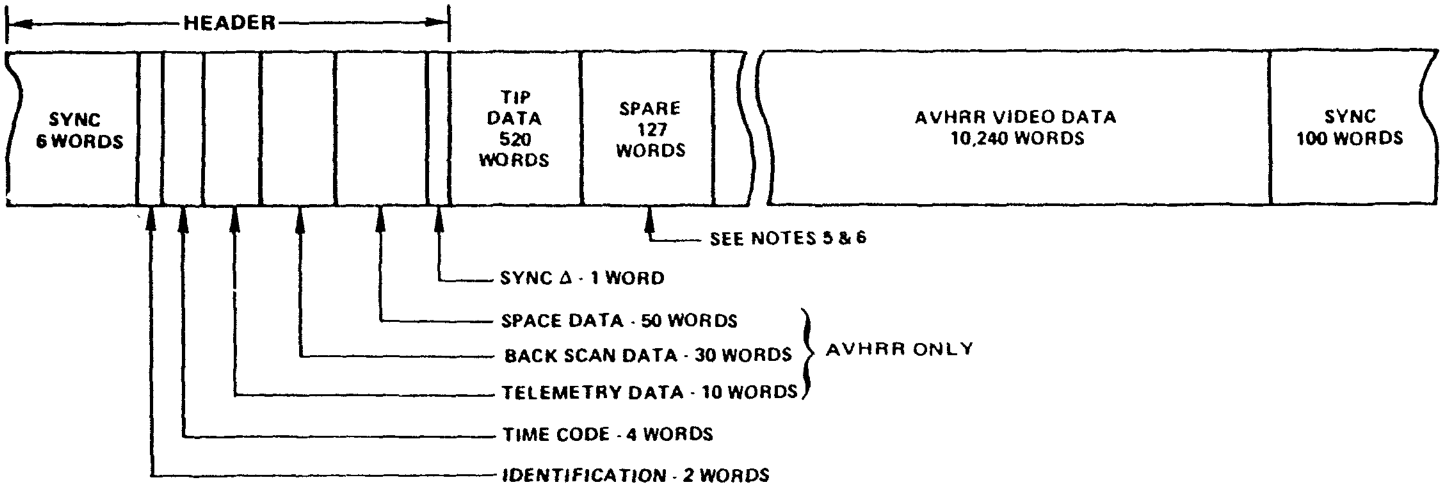
Major Frame	
Rate	2 fps
Number of minor frames	3
Minor Frame	
Rate	6 fps
Number of words	11,090
Format	See figure 3-5
Word	
Rate	66,540 words per second
Number of bits	10
Order	Bit 1 = MSB* Bit 10 = LSB** Bit 1 transmitted first
Bit	
Rate	665,400 bps
Format	Split phase
Data 1 definition	
Data 0 definition	

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

Table 3-7. 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 minimum
Modulation index	2.35 ± 0.12 radians
Premodulation filter, type 3 dB bandwidth	5th order, 0.5°, equiripple phase 2.4 MHz
Frequency stability	$\approx 2 \times 10^{-5}$

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



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	
		2-3	FRAME ID	
7	CHANNEL-4 TARGET TEMP (5 PT SUBCOM)	4-7	SPACECRAFT ADDRESS	
8	CHANNEL-5 TARGET TEMP (5 PT SUBCOM)	8	RESYNC MARKER	
9	CHANNEL-3 PATCH TEMP	9	DATA 0	
10	SPARE	10	DATA 1	

Figure 3-5. TIROS-N/NOAA HRPT minor frame format

3.3.1 Detailed Description of HRPT Minor Frame Format

While figure 3-5 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 3-8. Bit 1 is defined as the most significant bit (MSB) and bit 10 is defined as the least significant bit (LSB).

3.4 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 3-9.

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 3-10. A detailed description of the TIP frame format is given in section 3.4.

3.5 TIP Data Format

The format of a TIP minor frame is shown in figure 3-6. 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 3-11.

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 multiplexed into the HRPT data stream, two bits are added to each TIP word. This is described under Function, TIP data in table 3-8.

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 3-8. 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 3-8. 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 3-8 (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 } Each of these words is a 5-ch subcom, 4 words of IR data plus a subcom referance value 0 0 0 0 0 0 0 0 0 1 spare
	(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 3-8 (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 3-8 (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 3-9. 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° tolerance
Premodulation filter, type	7-pole linear phase filter
3-dB bandwidth	16 kHz minimum, 22 kHz maximum
Frequency stability	$+2 \times 10^{-5}$

[1]Observed by an optimum polarization diversity receiver.

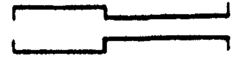
Each TIP minor frame contains information identifying the major and minor frame count. The major frame counter is located in bits 4, 5, and 6 of TIP word 3 and cycles from 0 to 7. The minor frame counter is composed of 9 bits. MSB is bit 8 of word 4, and the LSB is bit 8 of word 5. The minor frame count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

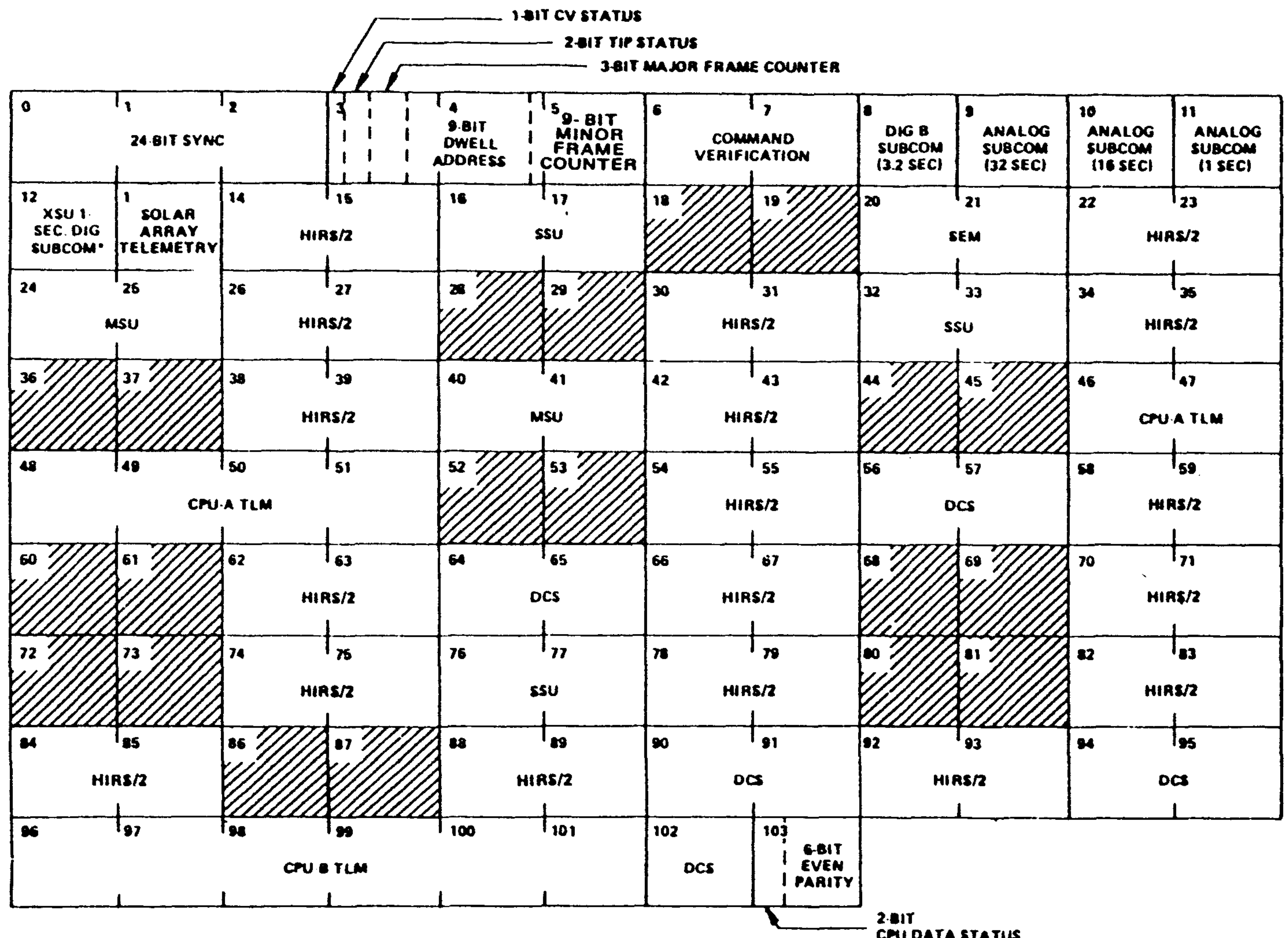
A 40-bit time code is inserted into the TIP data stream once every 32 seconds.

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 3-10. 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.

TIROS-N
Figure 3-6. TIP minor frame format

NOTE: Changes for NOAA-F & G with ERBE
Changes to NOAA-H, -I, -J for DCS

Table 3-11. 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 Bits 1-7 9-bit dwell mode address of analog channel that is being monitored continuously. MSB 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
1-sec analog subcom (1)	11	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.

*mv: millivolts

Table 3-11 (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

The day-counter has the capability of updating through day 511 before being automatically reset. In practice, however, NESS manually resets the day counter to 1 on Jan. 1 at 0000 GMT.

4. CREATION OF 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 for the TOVS and AVHRR only.

4.1 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 3-6).

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 4-1. 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 4-2. 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 4-1). 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.

Table 4-1. 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)
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

Table 4-1. HIRS/2 digital A data output (continued)

Element 62 (continued)

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
*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 4-2. HIRS/2 channel word location

Word location	Nominal central wave number (ν_c)	Radiometric channel number
1	668.4	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

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 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.

4.2 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 3-6). 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 4-3, and the formats of the data words are shown in table 4-4. 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 4-4.)

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 4-5. These position variations are negligible for all practical purposes.

Table 4-3. MSU scan line format

IFOV		WORD 1: INSTRUMENT VOLTAGES	WORD 2: INSTRUMENT TEMP (SYSTEM A)	WORD 3: INSTRUMENT TEMP (SYSTEM B)	WORD 4: CHANNEL 1 DATA (RADIOMETRIC DATA)	WORD 5: CHANNEL 2 DATA (RADIOMETRIC DATA)	WORD 6: CHANNEL 3 DATA (RADIOMETRIC DATA)	WORD 7: CHANNEL 4 DATA (RADIOMETRIC DATA)	WORD 8: 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 4-4. MSU bit formats for each IFOV

Typical format for all words except word 8

MSB (bit 16)															LSB bit 1
1	1	Ø	Z	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 bit 16															LSB bit 1
1	0	1	Z	S	R	R	R	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

Table 4-5. 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 indicating 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. Consequently, 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	257
5	211
6	147
7	83

4.3 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 4-6.

Digital words 1, 2, and 3 in table 4-6 are described as follows. In digital work 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 4-6. 30-word SSU data sampling (repeated 32 times per SSU scan)

SSU Data	Words
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.

4.4 AVHRR

The AVHRR data are located in two sections of the HRPT minor frame. The radiometric calibration data and telemetry information are contained in the 103-word header. The radiometric Earth view data are located in that portion of the minor frame labeled AVHRR VIDEO (figure 3-5, section 3.2). Each minor frame contains a complete scan line of AVHRR data from all five channels. The AVHRR video data are located starting at HRPT word 751 and contains 10,240 words (2048 ten-bit words per channel). These data words are multiplexed sequentially into the video portions of the minor frame according to table 3-8. Every five words represent one simultaneous radiometric sample from each of the channels.

Space data and internal target data, required for calibration of the IR channels, are located in the header portions of the HRPT minor frame (figure 3-5). The order in which these data are multiplexed is shown in table 3-8, section 3.3.

4.5 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 4-7.

The start time of each instrument scan line can be derived by using the TIP 32-second time code that was described in section 3.4. Table 4-8 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 4-8), 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 4-7. Instrument scan timing parameters

Instrument	Time between start of each scan line	Step and dwell time	No. of Earth view steps per line	*ΔTime
HIRS/2	6.4 sec	0.1 sec	56	0.05 sec
MSU	25.6 sec	1.893 sec	11	0.98 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 (see figures 4.1 and 4.2)

Table 4-8. Scan line timing of the TOVS instruments

Scan start time (seconds)	HIRS/2	TIP major minor frame SSU	MSU
*TC (0/0)			
+6.4	0/1	0/0	0/19
+12.8	0/65		
+19.2	0/129		
+25.6	0/193		
	0/257		
*TC (1/0)	1/1	1/0	0/275
+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 4-1 and 4-2 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.

5. RADIOMETRIC CALIBRATION

In general, radiometric calibration involves exposing a radiometer to sources of radiation that have been calibrated against primary or secondary standards and determining a relationship between the output of the radiometer and the intensity of the incident radiation (radiance).

All the radiometers flown on the TIROS/NOAA satellites undergo extensive prelaunch testing and calibration by their manufacturers to characterize their performance. Visible and near-infrared channels are calibrated with radiation from integrating spheres whose calibrations are traceable to the National Bureau of Standards (NBS) in the United States. The prelaunch procedure for these channels, carried out in air at ambient temperature, is described fully in Rao (1987). Infrared channels are calibrated against precision blackbody sources whose calibrations are traceable to NBS.

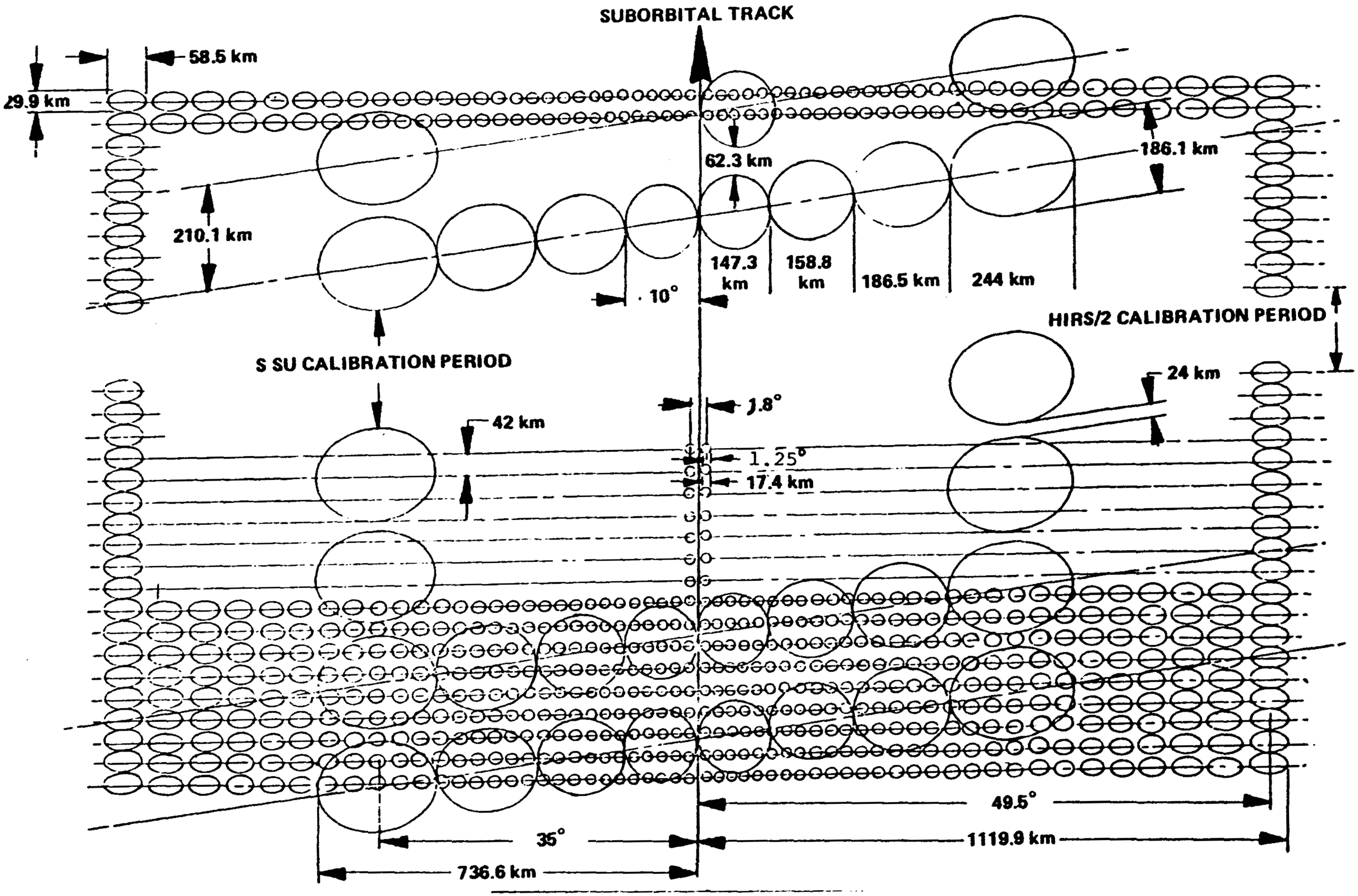


Figure 4-1. TIROS operational vertical sounder HIRS/2 and SSU scan patterns projected on Earth

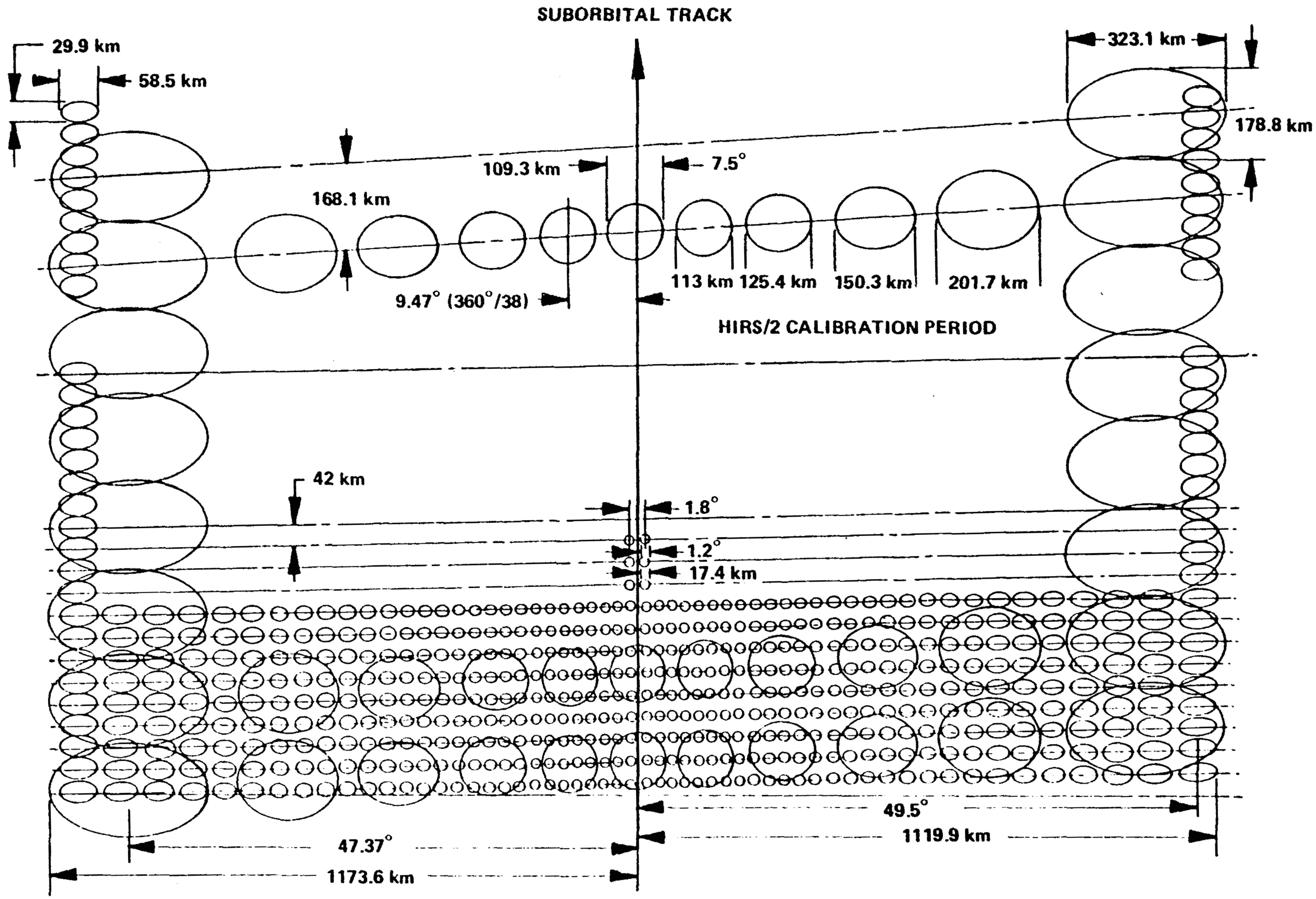


Figure 4-2. TIROS operational vertical sounder HIRS/2 and MSU scan patterns projected on Earth

Prelaunch calibrations of the infrared and microwave channels are carried out in a thermal/vacuum chamber to minimize absorption of radiation in the path between the source and the radiometer and to simulate conditions in space. The radiometer sequentially views the warm calibrated laboratory blackbody (in place of the earth "target"), a blackbody cooled to approximately 77°K (representing the cold space view), and its own internal blackbodies. Temperatures of all blackbodies are sensed with thermistors or platinum resistance thermometers (PRT's). Radiances for each channel can be computed from those temperatures by the methods described in Appendix A. Data are collected as the laboratory blackbody is cycled through a sequence of temperature plateaus approximately 10°K apart between 175 and 320°K, which spans the entire range of earth target temperatures. The entire procedure is carried out independently for several instrument operating temperatures (e.g., 10, 15 and 20°C for the AVHRR and 5, 10, 15, and 20° for the HIRS/2) that bracket the range of operating temperatures encountered in orbit. The operating temperature is represented by the temperature of the instrument's baseplate, which is also approximately the same as the temperature of its internal warm blackbody.

The instrument manufacturers and NESDIS independently analyze the data from the prelaunch tests to determine operating characteristics of the instruments, such as their signal-to-noise ratios, stability, linearity of response, and sensitivity (ouput in digital counts per unit incident radiance). However, we cannot expect those characteristics to be the same in orbit as they were before launch. One reason is that the thermal environment varies with position in the orbit, causing sensitivities to vary orbitally. Also, instrument components age in the several years that usually elapse between the time of the prelaunch tests and launch, and the aging process continues during the two or more years the instrument typically operates in orbit. Therefore, the TIROS/NOAA radiometers have been designed to view cold space and one or more internal warm blackbodies as part of their normal scan sequences in orbit. (The temperatures of these blackbodies are sensed by thermistors or PRT's.) This provides data in the microwave and infrared channels for determining signal-to-noise and radiometric slopes and intercepts, as will be described in the following sections. Unfortunately, there are no on-board calibration sources for the visible region; in the visible channels, we use the calibration determined before launch.

There are other coefficients necessary for in-orbit calibration that must be derived from prelaunch test data. These include the coefficients to account for the nonlinearity in the AVHRR's response, which will be described in section 5.1, and the coefficients for calibrating the temperature sensors in the internal blackbodies of the AVHRR and the HIRS/2, described here.

The HIRS/2 has two internal blackbodies. The temperatures of each are measured with four thermistors. The AVHRR has a single internal blackbody, whose temperature is measured with four PRT's. The MSU has two blackbodies, one for each of the two antennas. The temperature of each blackbody is sensed with two PRT's.

Polynomials are used to convert the outputs of the each thermistor or PRT to temperature, i.e.,

$$T = \sum_{j=0}^{4} a_j X^j \qquad \text{(nn)}$$

where X is the thermistor or PRT output in digital counts, T is temperature in degrees Kelvin, and a_j are coefficients that are specific to each thermistor or PRT. A set of coefficients for each thermistor or PRT, determined by calibration against a thermometric standard, is provided by the instrument manufacturers.

However, if the in-orbit calibration is to be traceable to the laboratory blackbody and thence to the NBS standard, those coefficients should relate brightness temperature (not kinetic temperature) to counts. For the TIROS/NOAA instruments, we achieve this by using the instrument itself to transfer the calibration of the laboratory blackbody to the PRT's or thermistors. This process utilizes data from the pre-launch tests. The data are analysed by ITT for the HIRS/2 instruments and by NESDIS for the AVHRR's, as follows:

1. The radiometer calibration, i.e., the relationship between target radiance and output of the AVHRR or HIRS/2, in digital counts, is derived from data collected when the radiometer viewed the calibrated laboratory blackbody.

2. The radiometer's outputs on viewing its internal blackbody are now converted from counts to radiances and then to equivalent brightness temperatures. (See Appendix A for the radiance-to-brightness temperature conversion.) In other words, the radiometer itself measures the brightness temperatures of its internal blackbody.

   A data set of internal target brightness temperatures vs the outputs, in digital counts, of the internal blackbody's PRT's or thermistors is thereby assembled. The number of samples is determined by the number of laboratory blackbody temperature plateaus and the number of instrument operating temperature plateaus.

3. A polynomial relating brightness temperature of the internal blackbody to PRT or thermistor output, in counts, is fitted to the data by regression. The coefficients are the a_j for Eq. (nn).

The coefficients produced in this way were used for the AVHRR's on the TIROS-N and NOAA-6 through -9 satellites and for the HIRS/2's on the TIROS-N and NOAA-6 through -8 satellites. However, for the AVHRR on the NOAA-10 satellite and the HIRS/2 on the NOAA-9 and -10 satellites, the original sets of coefficients, determined from the thermometric standard, were used. The coefficients that were in use for the AVHRR's and HIRS/2's on each satellite are tabulated in Appendix B.

5.1 AVHRR

5.1.1 Infrared Channels Calibration

5.1.1.1 In-Orbit Calibration Procedure

The pre-launch calibration relates the AVHRR's output, in digital counts, to the radiance of the scene. (In pre-launch tests, the scene is represented by the laboratory blackbody.) The calibration relationship is a function of channel and baseplate temperature. For channel 3, which uses an InSb detector, the calibration is highly linear. However, as channels 4 and 5 use HgCdTe detectors, their calibrations are slightly nonlinear.

To characterize the calibration when the AVHRR is in orbit, the only data available are those acquired when the AVHRR views space and the internal blackbody. This gives two points on the calibration curve, sufficient to determine only a straight-line approximation to the calibration. The linear approximation is what is applied to determine scene radiances. Scene brightness temperatures are then derived via the temperature-to-nonlinearity look-up table described in Appendix A. The methods for handling the nonlinearity will be discussed later in this section.

The information required for producing AVHRR IR channel calibration coefficients is located in the 103-word HRPT header. (See Figure 3-5 and Table 3-8) Header words 18, 19, and 20 each contain a five-point subcommutation of the outputs of the four PRT's that monitor the temperature of the internal blackbody. Each of these words contain redundant information. Any one of these words, when extracted from five consecutive HRPT minor frames, produces a reference (REF) value and one sample of each of the four PRT's. The pattern is as follows:

HRPT minor frame	Parameter sample
.	.
.	.
n	REF
n+1	PRT1
n+2	PRT2
n+3	PRT3
n+4	PRT4
n+5	REF
.	.
.	.
.	.

The reference value is easily identified as it is the only output having a count value of less than 10. NESDIS averages 10 samples from each PRT to produce a mean PRT count value for conversion to temperature units. The 30 words of internal target data (header words 23-52) provide 10 samples each for IR channels 3, 4, and 5. The 50 words of space view data (header words 53-102) provide 10 samples each for all five AVHRR channels. (These data are multiplexed as described in Table 3-8. NESDIS averages 50 samples of space and internal target radiometric data per channel to produce mean count values.

To calculate the internal blackbody radiance, it is first necessary to compute the target temperature. The conversion of PRT mean counts to temperature uses the following:

$$T_i(K) = \sum_{j=0}^{4} a_{ij}\overline{X}_i^{\,j}$$

where $\overline{X}_i$ is the mean count for PRT_i where i=0,1,2,3,4; a_{ij} are the coefficients of the conversion algorithm; and T_i is the temperature of the internal blackbody calculated from PRT_i. For example, the conversion of PRT_1 count value ($\overline{X}_1$) into temperature (K) is

$$T_1(K) = a_{1,0} + a_{1,1}\overline{X}_1 + a_{1,2}\overline{X}_1^2 + a_{1,3}\overline{X}_1^3 + a_{1,4}\overline{X}_1^4$$

The coefficient a_{ij} are supplied in Appendix B. The average temperature of the internal target is computed by

$$\overline{T} = \sum_{i=1}^{4} b_i T_i$$

Where $\overline{T}$ is the average of the internal blackbody temperatures (K) and b_i is the weighting factor of each PRT (supplied in Appendix B). The conversion of $\overline{T}$ to radiance units (N) is described in Appendix A.

Assume for the time being that the count output (X) of each channel is a linear function of the observed radiance (N), so that

$$N = MX+I,$$

where M is termed the channel slope, and I is termed the channel intercept. The quantity M (in units of radiance/count) is calculated for each channel from the equation

$$M = (\overline{N}_T - N_{SP}) / (\overline{X}_T - \overline{X}_{SP})$$

where N_{SP} is the radiance of deep space, N_T is the radiance when the instrument views its internal radiance calibration target, and $\overline{X}_{SP}$ and $\overline{X}_T$ are the mean counts associated with several observations of space and the internal target, respectively. The number of observations in each case is sufficient to effectively eliminate the residual variances in $\overline{N}_T$ and $\overline{X}_T$ as contributors to the uncertainty in the derived value of M. The intercept (I) is calculated for each channel from the equation

$$I = N_{SP} - M\overline{X}_{SP}$$

The non-linearity in the calibration is accounted for through the addition of a correction term to the brightness temperature of the scene. The appropriate correction term is determined by interpolation in a table of correction terms vs. scene brightness temperatures specified at 10 degree intervals between approximately 200 and 320K. The corrections, also functions of the AVHRR's internal blackbody temperatures, are made available in Appendix B for internal blackbody temperatures of 10, 15, and 20C for each channel. The appropriate correction is determined by interpolation on the internal blackbody temperature. The derivation of the corrections is described in Section 5.1.1.2.

It should be noted that the updated versions of Appendix B corresponding to NOAA-8 and earlier did not use the procedures outlined above. The variation in the non-linearity correction with internal blackbody temperature was not allowed for, and a negative radiance of space, N_{SP}, was introduced to minimize temperature errors in the range 225-310K.

5.1.1.2 Non-Linearity Corrections

To account for nonlinearities, NESDIS provides corrections in the Appendix B of this report that are added to the scene brightness temperatures computed from the linear calibration. The corrections are tabulated against scene temperature, and there is a separate table for each channel and each baseplate temperature. The tables are derived from the pre-launch test data. as follows:

a. A quadratic is fitted by least squares to the scene radiance vs. AVHRR output count data.

b. The quadratic equation is aplied to the AVHRR response, in counts, when it viewed its internal blackbody. This determines the radiance of the internal blackbody. In effect the AVHRR itself is used to transfer the calibration of the laboratory blackbody to the internal blackbody. Note that no assumptions have been made about the emissivity of the internal blackbody.

c. Using data from the "view" of the cold target (whose radiance is assumed to be zero) and the internal target, the linear calibration equation is formulated.

d. The linear calibration is then applied to the AVHRR output, in counts, obtained when the AVHRR viewed the laboratory blackbody. This produces radiances, one for each of the temperature plateaus of the laboratory blackbody. The radiances are converted to brightness temperatures by the method of Appendix A.

e. The brightness temperatures are subtracted from the actual temperatures of the laboratory blackbody, determined from its PRT's. The differences are the correction terms.

Note that in this procedure the calibration of the laboratory blackbody is transferred directly to the internal blackbody, the sand radiance of the internal blackbody is computed without recourse to the measurements by its four PRT's. However, for in-orbit calibrations, the radiances of the internal blackbody must be based on measurements by the PRT's. Therefore, it is important that the calibration of the laboratory blackbody be transferred to the PRT's of the internal blackbody. The technique for doing this was described on page 44.

5.1.2 Visible Channel Calibration

There are no calibrated sources of visible radiation within the AVHRR instrument, so that the user must either rely on pre-launch calibration information for AVHRR channels 1 (500 to 700 nm) and 2 (710 to 1000 nm), or rely on the results of ground-based experimental techniques for deriving the calibration equations for these channels on the orbiting AVHRR. The target albedo (A) expressed as a percentage of that for a perfectly reflecting Lambertian surface illuminated by an overhead sun is linearly related to the count level (X):

$$A = MX + I.$$

Values of the associated slope (M) and intercept (I) deduced from pre-launch calibration data are given in Appendix B.

A detailed account of the pre-launch calibration procedures for the AVHRR has been given by Rao (1987). The calibration is traceable to NBS second ary standards of spectral irradiance.

In pre-launch calibration, the AVHRR observes an aperture cut into an internally illuminated sphere with optically diffusing walls. The value of the spectral radiance emerging through the aperture shows strong uniformity across the aperture, and is traceable to the NBS standard of spectral radiance in the visible region of the spectrum.

The user is cautioned that there is strong evidence that the values of M for the NOAA-7 and the NOAA-9 AVHRR had decreased after 2 years in orbit by 10 to 20% of their measured pre-launch values for different satellite-channel combinations. Channel degradation in this range has been calculated by Frouin and Gauthier (1987). Aircraft-based observations by Smith et al. (1987) yielded very similar results. Several users of the data have reported evidence consistent with significant reductions in M. There is scant evidence presently available on the dependence of M on time-in-orbit. The evidence suggests that the degradation in M for the NOAA-7 and NOAA-9 AVHRRs is in the 0 to 15% range after 1 year in orbit and that M tends to stabilize after 2 years in orbit. Aircraft-based observations of the in-orbit value of M for the NOAA-10 AVHRR in late December 1987 are being analyzed.

To convert from percent albedo, A, to radiance, I ($W.M^{-2}um^{-1}.st^{-1}$) use the equation,

$$I = \frac{F}{W} \cdot \frac{A}{\pi} \cdot \frac{1}{100}$$

where F is the integrated solar spectral irradiance weighted by the spectral response function of the channel, and W is the equivalent width of the spectral response function of the channel.

Values of F and W are given in Appendix B. The value of F depends on the function assumed for the solar irradiance at the mean Earth-sun distance. Values of F are given based on the Air Force (1965), Thekaekara (1974) and Neckel and Labs (1984) measurements.

5.2 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 4.2 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 and are supplied in appendix B.

The algorithm is:

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

where C is the radiometric count output, d_i is the nonlinearity correction coefficient and C' 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 temperature of this target is 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 4-3).

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 supplied in appendix B.

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 4-3.

The second algorithm, converting R to temperature is:

$$T = \sum_{i=0}^{2} e_i R^i$$

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 coefficients e_i are supplied in appendix B.

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 appendix A.

Channel gains are calculated by:

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

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

Channel intercepts are calculated by:

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

5.3 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 4.3, 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:

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

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 the 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 4-6) 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 4-6) 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 contained in appendix 2, 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 contained in appendix B 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 appendix A. Channel gains are calculated by:

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

where G is the gain of channel, 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 Calibration of 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 the 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 4-1). The output of each thermistor is converted to temperature K by:

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

where T is the temperature indicated by the thermistor, $\bar{X}$ is the average of 200 samples for that thermistor (40 lines x 5 samples per line), and a_j are the conversion coefficients supplied in appendix B.

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 appendix A. 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 slopes are computed by:

$$M = \frac{(N_{SP} - N_{IWT})}{(\overline{X}_{SP} - \overline{X}_{IWT})}$$

where M is the slope for each channel, N_{sp} and N_{IWT} are the radiance of space and the internal warm target, $\overline{X}_{sp}$ is the mean space value (in counts) of the 48 usable space data samples, and $\overline{X}_{IWP}$ is the mean IWT value (in counts) of the 56 usable IWT data samples.

The channel intercepts are computed from the equation

$$I = N_{SP} - M\overline{X}_{SP}.$$

The slope (M) of the visible channel of HIRS/2 is not measured in flight. Values of I for the visible channel are available in the same manner as the other channels of the instrument. A pre-launch value for M is measured through the same calibration procedure described by Rao (1987) for the AVHRR, which was briefly described in Section 5.1. Pre-launch values of M and I to calculate apparent albedo for a Lambertian surface illuminated by an overhead sun are given in Appendix B.

5.5 Application of Calibration Coefficients to Earth View Data

The slopes and intercepts as computed for each instrument (sections 5.1 to 5.4) are used to convert Earth view radiometric samples (X_E in counts) to calibrate radiance values (N_E). The algorithm is

$$N_E = M\, X_E + I$$

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

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

5.6 APT

The APT frame format is shown in figure 3-3. Space data for the selected channel (instrument output while viewing space) appear in each APT video line immediately following the synchronization pulses. All of the other data necessary to perform the calibration appear in the telemetry frame.

The outputs of the four sensors, which monitor the housing blackbody target temperature, appear in telemetry points 10, 11, 12, and 13 (thermal temperature number 1 through 4, respectively). Each thermal temperature is repeated on eight successive APT video lines. Thermal temperature #1, for example, begins on line 73 and is repeated through line 80; thermal temperature #2 begins on line 81; #3 on line 89, and #4 on line 97.

The output of the instrument when viewing the housing blackbody target appears in telemetry point 15 (back scan) that begins on APT video line 113.

It must be emphasized that APT is processed AVHRR data. Two selected channels from AVHRR are time division multiplexed into an output data stream that has been processed to achieve both bandwidth reduction and geometric correction. This processing is accomplished in the digital domain before being converted to an analog signal for output on the APT transmitter.

To affect calibration of the selected IR channel, the AVHRR calibration data must be related to the APT video signal. This is accomplished by determining the relative signal level using the eight wedge levels as a scale. A minimum signal level would be equivalent to telemetry point 9; a maximum signal would be equivalent to point 8. Calibration curves showing the relationships of the four housing blackbody temperature sensors to the eight-level wedge scale are presented in figures 5-1 and 5-2.

The blackbody temperature sensors that have been used in the AVHRR instruments flown since TIROS-N (up to NOAA-10 at this writing) have been well matched such that figures 5-1 and 5-2 have remained accurate for APT use with these instruments. Future updates to Appendix B to this document will include the ITT/AOD supplied calibration equations for these four temperature sensors and an in-flight blackbody calibration table, should the APT user desire or need to recreate these curves for future instruments.

The calibration procedure is as follows:

a. Determine the temperature of the housing blackbody by normalizing (scaling) the output of thermal temperatures 1 through 4 to the wedge levels.

Plot the values found on the appropriate graph (figures 9 and 10). There will be flight differences between the sensors in indicated temperatures because of thermal gradients induced in the blackbody by solar input energy and Earth albedo; therefore, an average of the four indicated temperatures will be a good representation of the effective blackbody temperature.

b. Determine the IR channel output while viewing the blackbody by scaling the data appearing in telemetry point 15 (back scan) to the eight-level wedge.

c. Determine the IR channel output while viewing space by normalizing the data immediately following the synchronization pulses to the eight-level wedge.

d. On figure 5-3 (3.7-um channel) or figure 5-4 (11-um channel) plot the normalized value determined in step 2 against the blackbody temperature found in step 1.

e. On figure 5-3 or 5-4, plot the normalized value determined in step 3 against the minimum temperature shown on the graph (240 K for the 3.7-um channel and 150 K for the 11-um channel).

The slope of a line connecting the two points plotted in steps 4 and 5 above is a measure of the response of the selected channel.

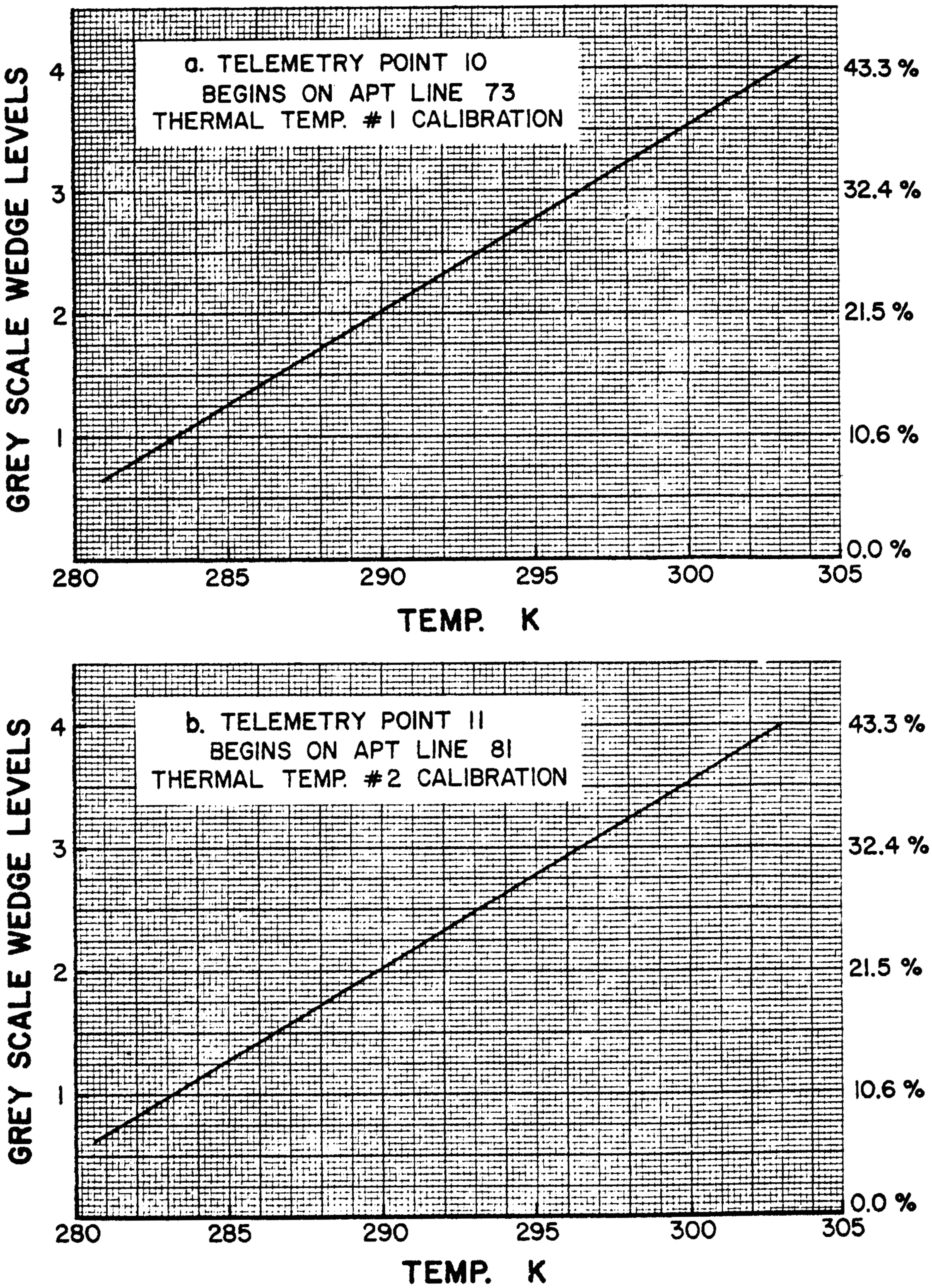
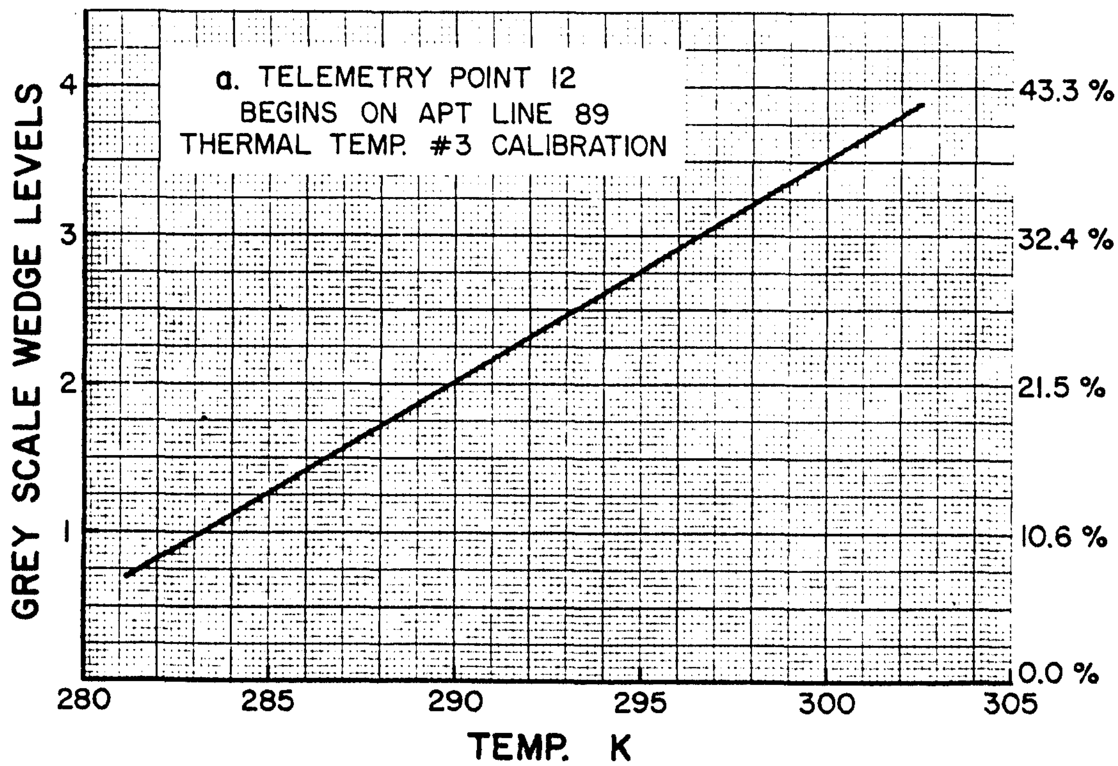


Figure 5-1. Thermal temperatures 1 and 2



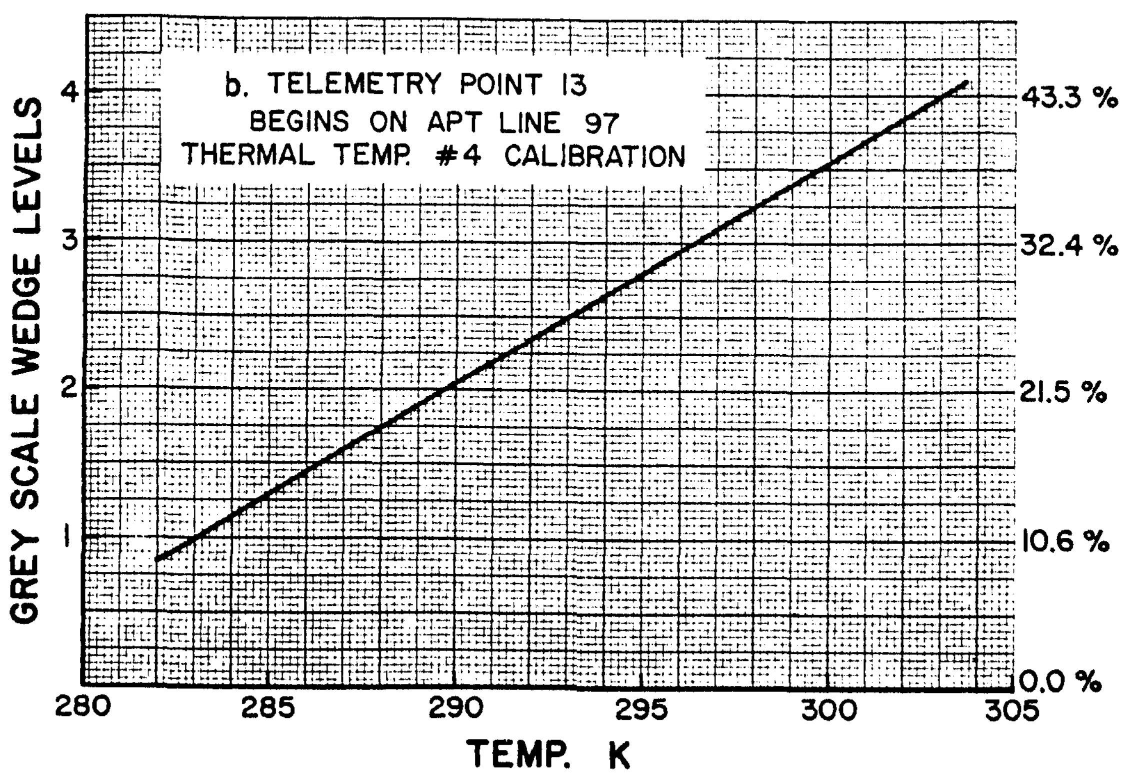


Figure 5-2. Thermal temperatures 3 and 4

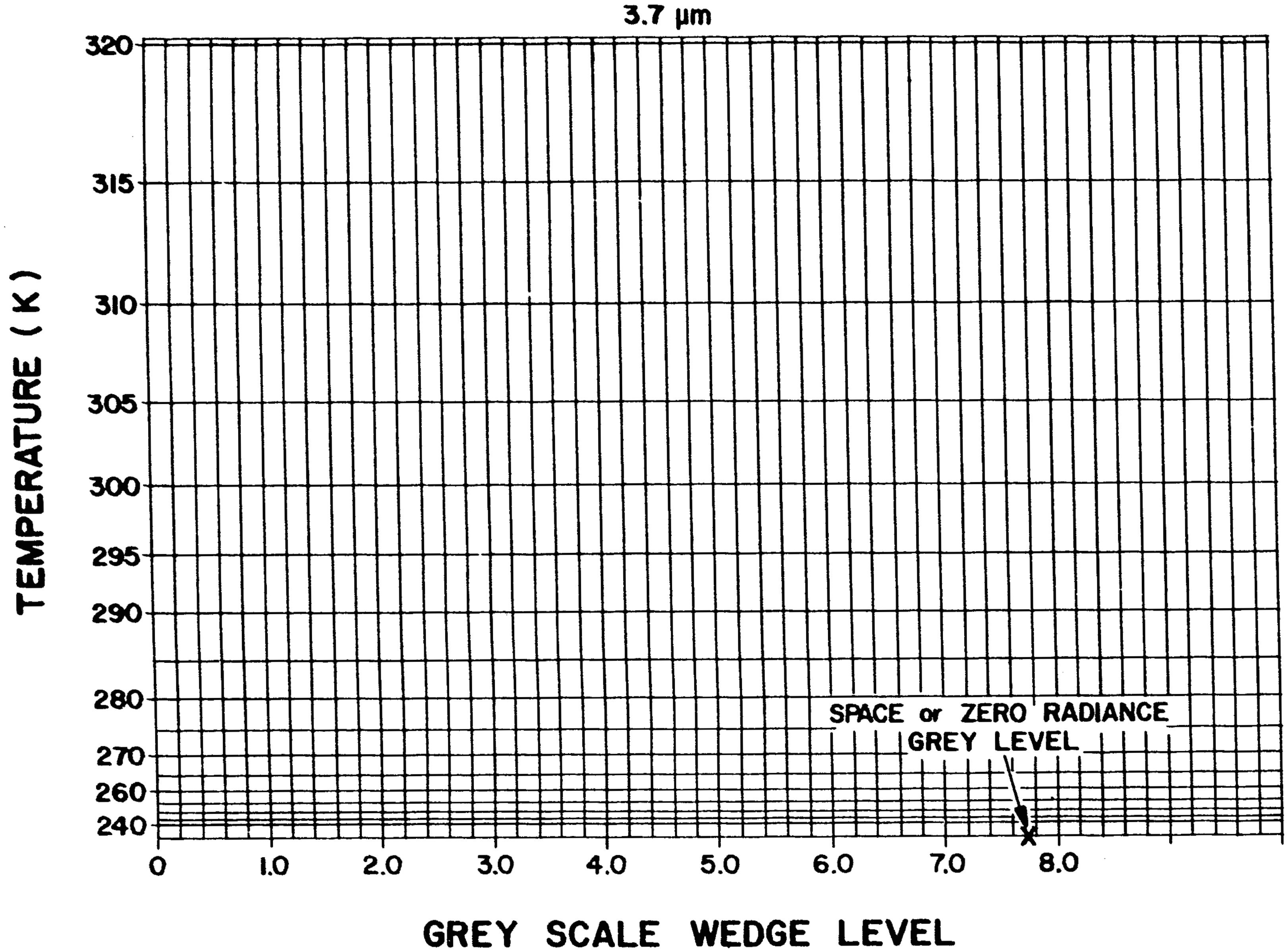


Figure 5-3. Grey level equivalent blackbody temperature, 3.7 µm

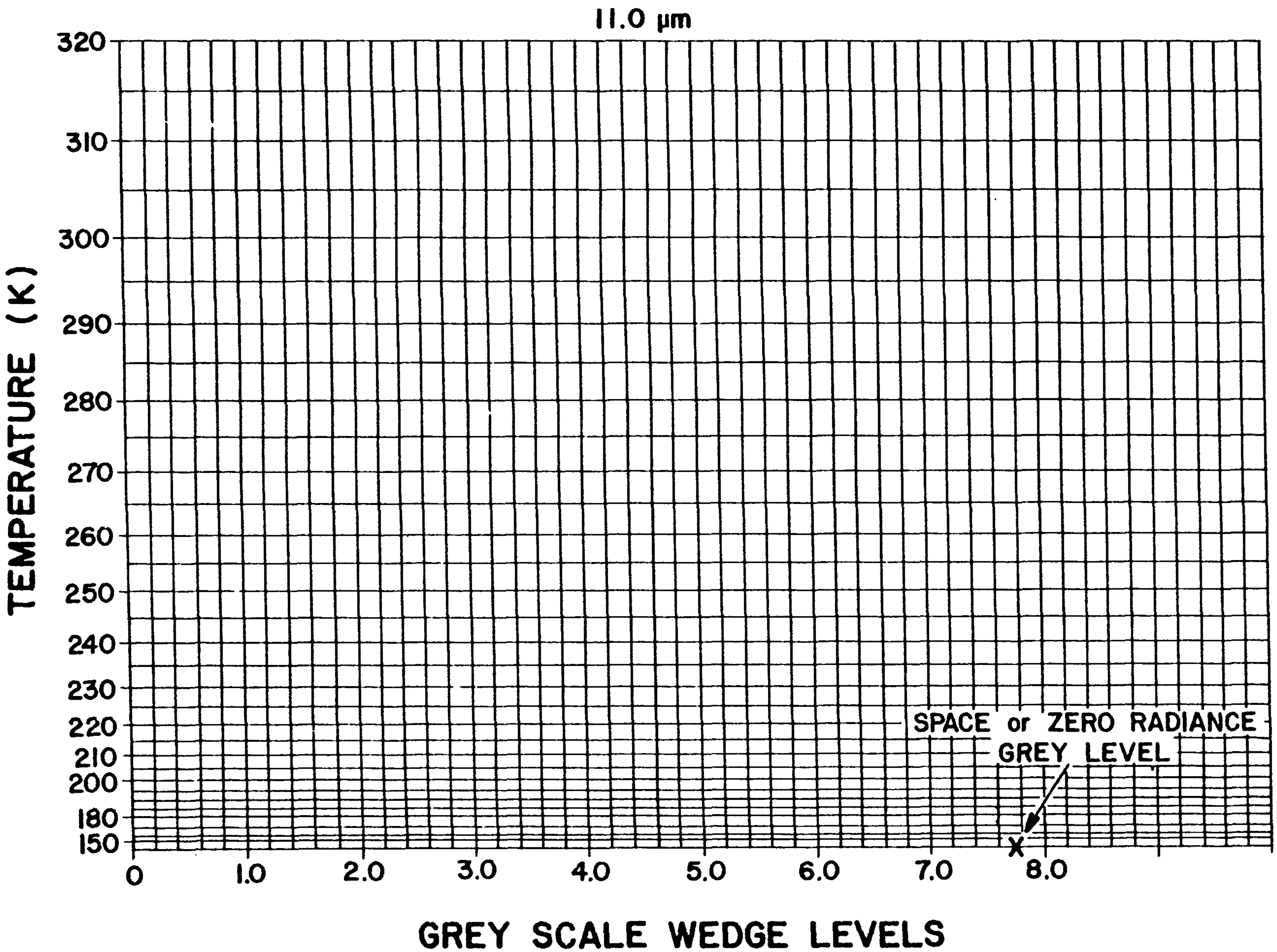


Figure 5-4. Grey level equivalent blackbody temperature, 11.0 µm

Note that scene temperature retrieved using this response curve may be in error by several degrees. For quantitative work, factors such as instrument and modulation nonlinearities (±2 percent), and atmospheric attenuation must be considered.

A separate set of calibration curves (figures 5-2 and 5-3) will be required for each new spacecraft in the TIROS/NOAA series and will be published in an APT information note.

APPENDIX A. Temperature-to-Radiance Conversion

The radiance N sensed in a particular channel from a blackbody at temperature T is the weighted mean of the Planck function over the spectral response function of the channel; i.e,

$$N(T) = \int_{\nu_1}^{\nu_2} B(\nu,T)\phi(\nu)d\nu / \int_{\nu_1}^{\nu_2} \phi(\nu)d\nu, \tag{A1}$$

where ν is wavenumber (cm^{-1}), ϕ is the spectral response function, and ν_1 and ν_2 are its upper and lower limits. The Planck function $B(\nu,T)$ is given by

$$B(\nu,T) = C_1\nu^3/(\exp(C_2\nu/T) - 1).$$

The constants C_1 and C_2 are 1.1910659×10^{-5} mW/(m^2 sr cm^{-4}) and 1.438833 K/cm^{-1}, respectively.

For the MSU and the SSU, Eq.(1) is approximated by

$$N(T) = B(\nu_c,T), \tag{A2}$$

where ν_c is the central wavenumber chosen to optimize the accuracy of this approximation. Values of ν_c are tabulated in Appendix B.

For the AVHRR and the HIRS/2, Eq.(A1) is evaluated numerically by

$$N(T) = \sum_{i=1}^{n} B(\nu_i,T)\phi(\nu_i)\Delta\nu \Big/ \sum_{i=1}^{n} \phi(\nu_i)\Delta\nu. \tag{A3}$$

Appendix B lists the values of $\nu_1, \Delta\nu$, and $\phi(\nu i)$ for each infrared channel of the HIRS/2 and AVHRR. In actual practice at NESDIS, we use Eq.(A3) only to generate look-up tables relating temperature to radiance. There is one table for each channel. Each table specifies the radiance at every tenth of a degree (K) between 180 and 320 K. Thereafter, the tables are used whenever we convert temperature to radiance or vice versa.

Many users nevertheless prefer the simplicity of calculating radiances in AVHRR and HIRS/2 channels with Eq.(A2). One can improve the accuracy somewhat by modifying the arguments of the Planck function appropriately. For historical reasons, at NESDIS we have promoted two different modifications, one for the AVHRR and another for the HIRS/2. In the case of the AVHRR, ν_c, the centroid wavenumber, is replaced with a new value ν^* chosen to force Eq.(A2) to reproduce the exact radiance from Eq.(A3). The value of ν^* varies with the blackbody temperature. Values of ν^*, called "central wavenumbers", are tabulated in Appendix B for four temperature intervals. They were derived by forcing equality between Eqs. (A2) and (A3) at the midpoints of the temperature intervals.

For the HIRS/2, one evaluates Eq.(A2) using ν_c, the centroid wavenumber, but with the blackbody temperature T replaced by an "effective" temperature T^*. One calculates T^* from T by

$$T^* = b + cT.$$

The constants b and c, the "band-correction coefficients", are tabulated in Appendix B. This approach was first suggested by Smith and Abel (1974). A complete description, including how the coefficients b and c are derived, is presented in Weinreb et al. (1981).

Appendix B

This Appendix presents the calibration data most frequently required by users to interpret in-flight measurements by the TIROS-N/NOAA radiometers. The data for each satellite have been computed from results of pre-launch tests by the radiometers' manufacturers. More specialized calibration information as well as compilations of pre-launch test results can be provided by NESDIS upon request. This document contains Appendix B for TIROS-N, NOAA-9 and NOAA-10. Appendix B for other spacecraft will be issued separately.

Appendix B

TIROS-N

I. AVHRR (Section 5.1)

a_{ij} - coefficients to convert PRT counts to temperature (K)

PRT	a_o	a_1	a_2	a_3	a_4
i=1	277.73	0.047752	8.29×10^{-6}	0.0	0.0
2	277.41	0.046637	11.01×10^{-6}	0.0	0.0
3	277.14	0.045188	14.77×10^{-6}	0.0	0.0
4	277.42	0.046387	10.59×10^{-6}	0.0	0.0

b_i - PRT weighting factors

b_i	b_2	b_3	b_4
0.25	0.25	0.25	0.25

Normalized response function (See appendix A)

Channel 3

$\nu 1$	2496.1357 cm^{-1}
$\Delta\nu$	6.36541 cm^{-1}
n	60

$\phi(\nu_1)$	0.0	0.92952E-03	0.19064E-02	0.28019E-02
	0.34776E-02	0.38782E-02	0.40496E-02	0.40441E-02
	0.39138E-02	0.37108E-02	0.34871E-02	0.32947E-02
	0.32635E-02	0.30885E-02	0.30618E-02	0.30753E-02
	0.31211E-02	0.31912E-02	0.32775E-02	0.33720E-02
	0.34668E-20	0.35539E-02	0.36257E-02	0.36805E-02
	0.37193E-02	0.37434E-02	0.37539E-02	0.37520E-02
	0.37389E-02	0.37158E-02	0.36838E-02	0.36442E-02
	0.35982E-02	0.35468E-02	0.34887E-02	0.34209E-02
	0.33399E-02	0.32459E-02	0.31493E-02	0.30626E-02
	0.29984E-02	0.29687E-02	0.29596E-02	0.29200E-02
	0.27958E-02	0.25408E-02	0.21780E-02	0.17654E-02
	0.13610E-02	0.10103E-02	0.71843E-03	0.48297E-03
	0.30148E-03	0.17153E-03	0.88544E-04	0.41631E-04
	0.18720E-04	0.77809E-05	0.28887E-09	0.0 $\phi(\nu_{60})$

Channel 4

	$\nu 1$	840.0337	
	$\Delta\nu$	2.41389	
	n	60	

$\phi(\upsilon^1)$	0.0	0.37701E-04	0.73654E-04	0.10611E-03
	0.14390E-03	0.24906E-03	0.50024E-03	0.95828E-03
	0.15939E-02	0.23496E-02	0.31779E-02	0.40893E-02
	0.51155E-02	0.62748E-03	0.74753E-02	0.85702E-02
	0.94211E-02	0.10012E-01	0.10418E-01	0.10718E-01
	0.10961E-01	0.11164E-01	0.11335E-01	0.11489E-01
	0.11635E-01	0.11786E-01	0.11954E-01	0.12147E-01
	0.12374E-01	0.12644E-01	0.12877E-01	0.12887E-01
	0.12539E-01	0.12331E-01	0.12071E-01	0.11931E-01
	0.11982E-01	0.12175E-01	0.12387E-01	0.12766E-01
	0.13462E-01	0.14131E-01	0.14239E-01	0.13355E-01
	0.11367E-01	0.87492E-02	0.60630E-02	0.38563E-02
	0.23495E-02	0.13991E-02	0.84093E-01	0.51723E-03
	0.33615E-03	0.24878E-03	0.20690E-03	0.16664E-03
	0.11659E-03	0.59942E-04	0.61584E-08	0.0 $\phi(\nu_{60})$

Channel 5--Repeat of channel 4 data.

N_{sp}- Radiance of space including nonlinearity correction

Channel	N_{SP} (mW/sr M^2 cm^{-1})
3	0.0
4	-1.151
5	-1.151

Visible channel coefficients

Channel	M (% albedo/count)	I (% albedo)
1	0.1071	-3.9
2	0.1051	-3.5

Equivalent Width (W), Solar Irradiance (F) and Effective Center Wavelength (λ)

TIROS-N

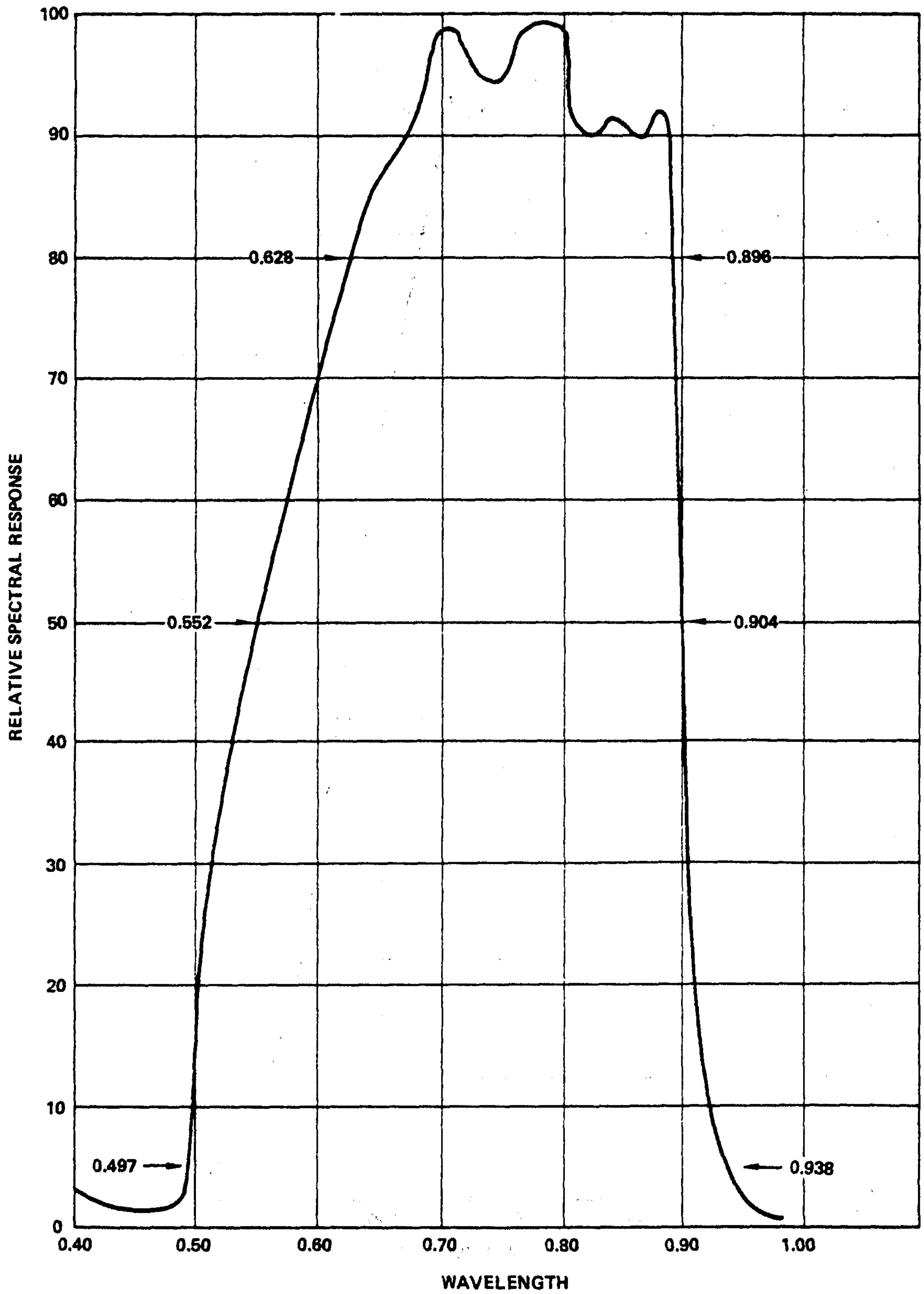
	W	F_1	λ_1	F_2	λ_2	F_3	λ_3
Ch. 1	0.109	183.8	0.631	179.0	0.631	169.6	0.632
Ch. 2	0.223	230.4	0.832	233.7	0.834	228.0	0.834

Notes: 1. Using the Air Force (1965) solar spectral irradiance data.
2. Using the Nechel and Labe (1964) solar spectral irradiance data.
3. Using the Thekaekara (1974) solar spectral irradiance data.

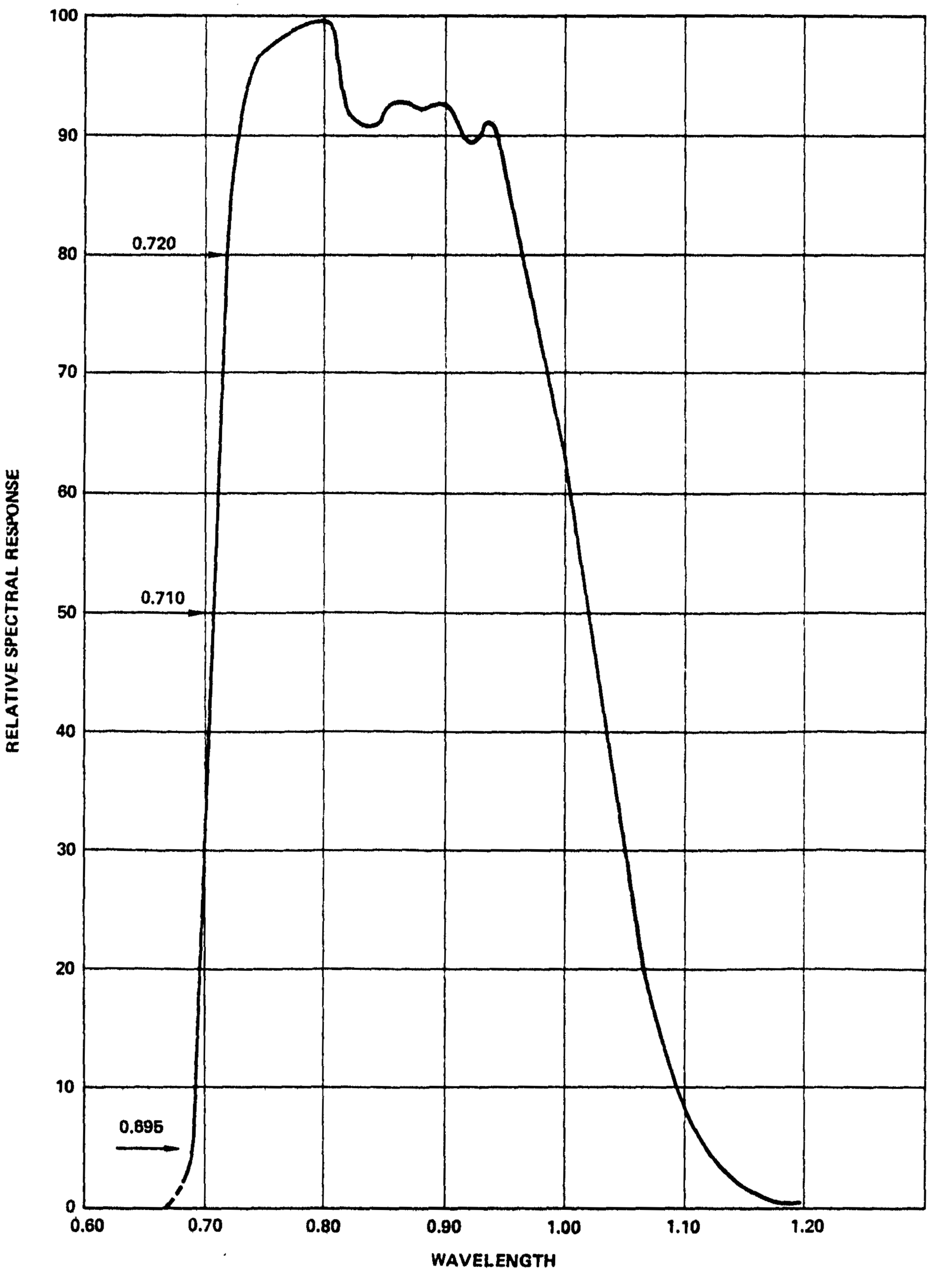
AVHRR 11.5-μm nonlinearity errors

Target temperature (K)	Error (K)
304.9	1.25
294.9	0.98
285.0	0.0
275.1	-0.03
264.9	-0.08
255.1	-0.1
234.9	-0.75
224.9	-0.95
204.9	-1.67
0.0	0.0

The error is the difference between the actual target temperature and that temperature derived from a two-point linear calibration.



Channel #1. AVHRR Spectral Response



Channel #2. AVHRR Spectral Response

II. MSU (Section 5.2)

d_i - nonlinearity correction coefficients

Channel	d_0	d_1	d_2
1	35.54	0.09303	1.9666×10^{-5}
2	26.85	0.09400	1.7264×10^{-5}
3	20.47	0.09639	0.9941×10^{-5}
4	22.23	0.09649	0.9659×10^{-5}

PRT count to resistance conversion coefficients

K_0	495.6
K_1	107.8

e_i - PRT resistance-to-temperature conversion coefficients

PRT	e_0	e_1	e_2
1A	29.10	0.42596	0.3187×10^{-4}
2A	27.55	0.42787	0.3185×10^{-4}
1B	29.05	0.42710	0.3206×10^{-4}
2B	28.95	0.42836	0.3175×10^{-4}

Normalized response functions

Channel	ν_c (cm^{-1})
1	1.6779
2	1.7927
3	1.8337
4	1.9331

N_{sp}-Radiance of space

Channel	N_{SP} (mW/sr M^2 cm^{-1}
1	0.000086
2	0.000096
3	0.000084
4	0.000092

III. SSU (Section 5.3)

a_i - PRT count-to-temperature (K) conversion coefficient

a_o	a_1	a_2
285.082	4.5542×10^{-3}	9.6285×10^{-9}

h_i and c_i - Thermistor to temperature (K) conversion coefficient

b_o	b_1	b_2	b_3
375.969	-203.161	179.13	-85.16
c_o	c_1	c_2	c_3
375.969	-203.161	179.13	-85.16

Centroid of spectral response function

Channel	$\nu_c (cm^{-1})$
1	668.988
2	668.628
3	668.357

IV. HIRS - (Section 5.4, Calibration of HIRS/2)

IWT PRT count-to-temperature conversion coefficients

PRT	a_0	a_1	a_2	a_3	a_4
1	301.4624	6.51558×10^{-3}	9.15434×10^{-8}	4.71066×10^{-11}	6.83373×10^{-16}
2	301.3504	6.51439×10^{-3}	9.15816×10^{-8}	4.70945×10^{-11}	6.85893×10^{-16}
3	301.425	6.51738×10^{-3}	9.16252×10^{-8}	4.71175×10^{-11}	6.87601×10^{-16}
4	301.4035	6.52364×10^{-3}	9.00018×10^{-8}	4.71042×10^{-11}	6.61634×10^{-16}

CHANNEL 1

ν_1 0.64478E+03

$\Delta\nu$ 0.15569E+01

η 30

$\varphi(\nu_1)$ 0.0	0.0	0.0	0.0	0.0
0.59535E-03	0.13780E-02	0.19544E-02	0.22813E-02	0.37781E-02
0.67337E-02	0.65331E-02	0.10956E-01	0.37600E-01	0.10773E+00
0.24056E+00	0.13744E+00	0.42285E-01	0.16070E-01	0.96671E-02
0.70848E-02	0.45358E-02	0.30782E-02	0.19029E-02	0.14659E-03
0.0	0.0	0.0	0.0	0.0 $\varphi(\nu_{30})$

CHANNEL 2

0.64963E+03

0.17348E+01

30

0.0	0.38536E-04	0.61955E-04	0.55126E-04	0.48187E-05
0.0	0.18996E-04	0.24868E-03	0.54076E-03	0.98188E-03
0.19493E-02	0.53736E-02	0.15249E-01	0.35984E-01	0.56572E-01
0.66207E-01	0.71556E-01	0.73453E-01	0.70851E-01	0.67441E-01
0.57290E-01	0.32595E-01	0.12600E-01	0.37951E-02	0.17191E-02
0.11304E-02	0.57940E-03	0.20094E-03	0.0	0.0

CHANNEL 3

0.66239E+03

0.18372E+01

30

0.0	0.12939E-03	0.25370E-03	0.49574E-03	0.74091E-03
0.68609E-03	0.15904E-02	0.29565E-02	0.54024E-02	0.10279E-01
0.16939E-01	0.25465E-01	0.35152E-01	0.46499E-01	0.58506E-01
0.65313E-01	0.65012E-01	0.60953E-01	0.54585E-01	0.43027E-01
0.25858E-01	0.12643E-01	0.56397E-02	0.23568E-02	0.11728E-02
0.99069E-03	0.77027E-03	0.56020E-03	0.34185E-03	0.49624E-07

CHANNEL 4

0.67213E+03

0.20952E+01

30

0.0	0.19732E-03	0.26173E-03	0.31839E-03	0.43452E-03
0.59934E-03	0.74702E-03	0.93328E-03	0.30657E-02	0.71495E-02
0.15859E-01	0.29669E-01	0.43223E-01	0.51285E-01	0.55779E-01
0.56275E-01	0.54627E-01	0.51420E-01	0.45299E-01	0.30597E-01
0.15455E-01	0.69094E-02	0.28103E-02	0.12985E-02	0.95467E-03
0.81771E-03	0.66252E-03	0.45631E-03	0.23091E-03	0.27196E-07

CHANNEL 5

0.69215E+03

0.16462E+01

30

0.0	0.0	0.17603E-03	0.42121E-03	0.73494E-03
0.17055E-02	0.31094E-02	0.68216E-02	0.13675E-01	0.25076E-01
0.37010E-01	0.46951E-01	0.53012E-01	0.56768E-01	0.58225E-01
0.58345E-01	0.56076E-01	0.52079E-01	0.45086E-01	0.35510E-01
0.24314E-01	0.14677E-01	0.79779E-02	0.42149E-02	0.22060E-02

0.15867E-02	0.10903E-02	0.51661E-03	0.17387E-03	0.21101E-07

CHANNEL 6

0.70292E+03
0.20697E+01
30

0.0	0.10683E-03	0.35175E-03	0.54755E-03	0.71655E-03
0.10437E-02	0.24346E-02	0.43927E-02	0.93891E-02	0.17538E-01
0.29015E-01	0.39233E-01	0.48418E-01	0.55492E-01	0.56534E-01
0.53720E-01	0.49329E-01	0.43743E-01	0.33313E-01	0.19285E-01
0.88276E-02	0.39846E-02	0.18884E-02	0.10136E-02	0.67522E-03
0.77611E-03	0.71517E-03	0.48018E-03	0.22767E-03	0.26550E-07

CHANNEL 7

0.71868E+03
0.21469E+01
30

0.0	0.12999E-03	0.25128E-03	0.41487E-03	0.47051E-03
0.60941E-03	0.13171E-02	0.24532E-02	0.64535E-02	0.16744E-01
0.34688E-01	0.48257E-01	0.49030E-01	0.47343E-01	0.48389E-01
0.49120E-01	0.47376E-01	0.42798E-01	0.32389E-01	0.18733E-01
0.89446E-02	0.42907E-02	0.20624E-02	0.10671E-02	0.79916E-03
0.59123E-03	0.41487E-03	0.36511E-03	0.32464E-03	0.52829E-07

CHANNEL 8

0.85874E+03
0.29503E+01
30

0.0	0.20970E-04	0.11557E-03	0.26923E-03	0.42594E-03
0.71324E-03	0.20680E-02	0.63747E-02	0.16130E-01	0.27272E-01
0.31854E-01	0.28090E-01	0.23958E-01	0.23597E-01	0.26615E-01
0.30642E-01	0.29340E-01	0.23980E-01	0.18849E-01	0.15587E-01
0.12560E-01	0.93453E-02	0.57336E-02	0.29580E-02	0.13134E-02
0.54309E-03	0.30317E-03	0.20612E-03	0.98819E-04	0.79949E-08

CHANNEL 9

0.97327E+03
0.35114E+01
30

0.0	0.0	0.32686E-04	0.15474E-03	0.23178E-03
0.34605E-03	0.44637E-03	0.58700E-03	0.11863E-02	0.26227E-02
0.58356E-02	0.13746E-01	0.24057E-01	0.30806E-01	0.31946E-01
0.30989E-01	0.30931E-01	0.33060E-01	0.34309E-01	0.24791E-01
0.10504E-01	0.41005E-02	0.16395E-02	0.90045E-03	0.48867E-03
0.43136E-03	0.33065E-03	0.21892E-03	0.10863E-03	0.75578E-08

CHANNEL 10

0.11664E+04
0.43724E+01
30

0.0	0.72668E-04	0.20591E-03	0.39377E-03	0.15113E-02

0.63529E-02	0.16438E-01	0.15287E-01	0.13630E-01	0.14088E-01
0.15338E-01	0.16610E-01	0.16912E-01	0.16326E-01	0.15880E-01
0.15695E-01	0.15131E-01	0.13897E-01	0.11770E-01	0.93964E-02
0.72436E-02	0.43396E-02	0.13362E-02	0.38562E-03	0.12278E-03
0.14573E-03	0.12214E-03	0.62856E-04	0.21571E-04	0.10519E-08

CHANNEL 11

0.13002E+04

0.44690E+01

30

0.0	0.13828E-03	0.21610E-03	0.31746E-03	0.42389E-03
0.45338E-03	0.73419E-03	0.14339E-02	0.33733E-02	0.76183E-02
0.14344E-01	0.19363E-01	0.22858E-01	0.25275E-01	0.25850E-01
0.25140E-01	0.23369E-01	0.20228E-01	0.14814E-01	0.89935E-02
0.46482E-02	0.21809E-02	0.82877E-03	0.40805E-03	0.30361E-03
0.20551E-03	0.14941E-03	0.98024E-04	0.10751E-04	0.0

CHANNEL 12

0.13850E+04

0.65379E+01

30

0.0	0.16205E-04	0.48341E-04	0.91743E-04	0.11248E-03
0.13542E-03	0.17451E-03	0.63797E-03	0.28377E-02	0.91147E-02
0.12855E-01	0.12997E-01	0.12396E-01	0.11942E-01	0.12265E-01
0.12240E-01	0.11054E-01	0.92167E-02	0.79691E-02	0.80158E-02
0.82459E-02	0.78370E-02	0.77852E-02	0.40281E-02	0.67062E-03
0.15221E-03	0.60740E-04	0.37131E-04	0.21406E-06	0.0

CHANNEL 13

0.21574E+04

0.26276E+01

30

0.0	0.30060E-04	0.22036E-03	0.38340E-03	0.60588E-03
0.93276E-03	0.21316E-02	0.53916E-02	0.12933E-01	0.24509E-01
0.34065E-01	0.39017E-01	0.45438E-01	0.49207E-01	0.47191E-01
0.39833E-01	0.30792E-01	0.21572E-01	0.12694E-01	0.64428E-02
0.33730E-02	0.15011E-02	0.96914E-03	0.72675E-03	0.45805E-03
0.18337E-03	0.0	0.0	0.0	0.0

CHANNEL 14

0.21713E+04

0.26414E+01

30

0.0	0.0	0.24504E-04	0.13143E-03	0.25461E-03
0.37555E-03	0.50986E-03	0.87127E-03	0.18636E-02	0.38958E-02
0.91194E-02	0.18925E-01	0.30354E-01	0.39493E-01	0.43922E-01
0.43988E-01	0.41861E-01	0.40717E-01	0.39441E-01	0.32244E-01
0.17690E-01	0.70879E-02	0.26174E-02	0.12528E-02	0.71984E-03
0.54343E-03	0.41303E-03	0.23317E-03	0.46055E-04	0.83335E-09

CHANNEL 15
0.22007E+04
0.22966E+01
30

0.0	0.79733E-04	0.21621E-03	0.37126E-03	0.57019E-03
0.72901E-03	0.95111E-03	0.17292E-02	0.33760E-02	0.67461E-02
0.12594E-01	0.19282E-01	0.26297E-01	0.31995E-01	0.36159E-01
0.37675E-01	0.37255E-01	0.35665E-01	0.35300E-01	0.36850E-01
0.37685E-01	0.33881E-01	0.22589E-01	0.10155E-01	0.40117E-02
0.16927E-02	0.90866E-03	0.54144E-03	0.16167E-03	0.81766E-08

CHANNEL 16
0.22042E+04
0.45552E+01
30

0.0	0.14519E-04	0.90289E-04	0.19591E-03	0.27279E-03
0.29177E-03	0.38869E-03	0.73598E-03	0.13389E-02	0.28889E-02
0.60880E-02	0.11783E-01	0.18138E-01	0.22411E-01	0.23877E-01
0.24405E-01	0.25845E-01	0.28875E-01	0.27099E-01	0.14968E-01
0.54040E-02	0.20352E-02	0.90562E-03	0.51643E-03	0.37920E-03
0.32251E-03	0.20182E-03	0.60547E-04	0.0	0.42874E-12

CHANNEL 17
0.23206E+04
0.26448E+01
30

0.0	0.79604E-06	0.13127E-03	0.29242E-03	0.41079E-03
0.68353E-03	0.12220E-02	0.27048E-02	0.59437E-02	0.11609E-01
0.20172E-01	0.28871E-01	0.34953E-01	0.37382E-01	0.37032E-01
0.35416E-01	0.35438E-01	0.38234E-01	0.38378E-01	0.26748E-01
0.13460E-01	0.45415E-02	0.19994E-02	0.10384E-02	0.53769E-03
0.43853E-03	0.30908E-03	0.13971E-03	0.18749E-04	0.0

CHANNEL 18
0.24413E+04
0.44793E+01
30

0.0	0.56051E-04	0.16357E-03	0.31492E-03	0.43911E-03
0.62260E-03	0.10040E-02	0.19815E-02	0.31389E-02	0.48298E-02
0.66208E-02	0.89415E-02	0.11866E-01	0.16394E-01	0.22548E-01
0.27661E-01	0.28402E-01	0.25735E-01	0.22139E-01	0.17642E-01
0.11452E-01	0.57890E-02	0.27498E-02	0.12093E-02	0.51102E-03
0.50647E-03	0.36630E-03	0.15953E-03	0.89575E-05	0.0

CHANNEL 19
0.24870E+04
0.10672E+02
30

0.0	0.82141E-05	0.32770E-04	0.63039E-04	0.94635E-04
0.13096E-03	0.17462E-03	0.24440E-03	0.36272E-03	0.77008E-03
0.16924E-02	0.36865E-02	0.64839E-02	0.83669E-02	0.91290E-02
0.92284E-02	0.89148E-02	0.84298E-02	0.82562E-02	0.89863E-02
0.92917E-02	0.58195E-02	0.21922E-02	0.72760E-03	0.33192E-03
0.12578E-03	0.83615E-04	0.54912E-04	0.17244E-04	0.0

CHANNEL 20

nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS
653.7	0.055	669.3	0.402	685.7	1.000	703.0	0.931	721.1	0.260
654.5	0.059	670.2	0.440	686.6	1.000	703.8	0.912	722.0	0.237
655.3	0.065	671.0	0.492	687.4	0.997	704.7	0.893	722.9	0.216
656.0	0.069	671.8	0.523	688.3	0.994	705.6	0.861	723.9	0.196
656.8	0.078	672.6	0.575	689.1	0.991	706.5	0.832	724.8	0.179
657.6	0.086	673.4	0.643	690.0	0.988	707.4	0.794	725.7	0.165
658.3	0.096	674.2	0.686	690.8	0.988	708.3	0.755	726.7	0.152
659.1	0.105	675.0	0.728	691.7	0.987	709.2	0.711	727.6	0.139
659.9	0.116	675.8	0.770	692.5	0.984	710.1	0.678	728.6	0.128
660.7	0.127	676.6	0.823	693.4	0.984	711.0	0.627	729.5	0.118
661.4	0.138	677.5	0.856	694.2	0.983	711.9	0.585	730.5	0.109
662.2	0.153	678.3	0.881	695.1	0.983	712.8	0.536	731.4	0.101
663.0	0.171	679.1	0.913	696.0	0.982	713.7	0.500	732.4	0.093
663.8	0.191	679.9	0.938	696.8	0.979	714.6	0.466	733.3	0.087
664.6	0.213	680.7	0.959	697.7	0.977	715.5	0.431	734.3	0.079
665.4	0.235	681.6	0.979	698.6	0.973	716.5	0.394	735.3	0.076
666.2	0.259	682.4	0.989	699.4	0.968	717.4	0.362	736.2	0.071
667.0	0.285	683.2	0.994	700.3	0.963	718.3	0.333	737.2	0.067
667.8	0.320	684.1	1.000	701.2	0.957	719.2	0.307	738.2	0.064
668.6	0.351	684.9	1.000	702.1	0.946	720.1	0.282	739.1	0.059
								740.1	0.055

Band-correction coefficients

Channel	ν_c	b	C
1	668.00	.99986	.047
2	679.23	.99979	.067
3	691.12	.99962	.131
4	703.56	.99991	.015
5	716.05	.99993	.010
6	732.38	.99974	.092
7	748.27	1.00015	-.101
8	897.71	1.00013	-.252
9	1027.87	.99978	.118
10	1217.10	.99903	-.132
11	1363.69	.99982	.136
12	1484.35	.99948	.424
13	2190.43	.99969	-.015
14	2212.65	1.00011	.041
15	2240.15	1.00032	.074
16	2276.27	1.00057	.143
17	2360.63	1.00025	.060
18	2511.95	1.00020	.110
19	2671.18	1.00175	.650

Appendix B

NOAA-F/9 Coefficients
(Republished August, 1987)

I. AVHRR (Section 5.1) - Instrument FM 202

PRT	A0	A1	A2	A3	A4
1	277.018	.05128	0.0	0.0	0.0
2	276.750	.05128	0.0	0.0	0.0
3	276.862	.05128	0.0	0.0	0.0
4	276.546	.05128	0.0	0.0	0.0

Bi - PRT Weighting Factors

B1	B2	B3	B4
0.25	0.25	0.25	0.25

Nsp= Radiance of space including nonlinearity correction

Channel	Nsp ($mW/sr\ M^2\ cm^{-1}$)
3	0.0
4	-3.384
5	-2.313

Note: At NOAA/NESDIS on the day of the launch of NOAA-10 (xxxxxx) the radiance of space for both NOAA-9 and NOAA-10 was taken to be zero. Non-linearity corrections are then applied to the target temperatures used by applications software. NOAA-9 non-linearity corrections using both methods are given below.

Visible Channel Coefficients

	M	I
1	.1063400366	-3.846375952
2	.107491067	-3.877005621

Equivalent Width (W), Solar Irradiance (F) and Effective Center Wavelength (λ)

NOAA-9

	W	F_1	λ_1	F_2	λ_2	F_3	λ_3
Ch. 1	0.117	196.4	0.635	191.3	0.635	181.5	0.636
Ch. 2	0.239	248.1	0.831	251.8	0.833	245.5	0.833

Notes:
1. Using the Air Force (1965) solar spectral irradiance data.
2. Using the Nechel and Labe (1984) solar spectral irradiance data.
3. Using the Thekaekara (1974) solar spectral irradiance data.

NORMALIZED RESPONSE FUNCTIONS

Channel 3:

Starting Wave Number: 2469.1355

Delta Wave Number: 7.76849

Response at Starting Wave Number + N * Delta Wave Number

N = 0 through 59

0.0	0.75765E-05	0.14659E-04	0.23167E-04
0.43949E-04	0.91160E-04	0.18353E-03	0.35407E-03
0.68830E-03	0.12443E-02	0.18939E-02	0.24721E-02
0.29108E-02	0.31837E-02	0.33195E-02	0.33728E-02
0.33888E-02	0.34053E-02	0.34316E-02	0.34478E-02
0.34401E-02	0.34075E-02	0.33552E-02	0.33039E-02
0.32757E-02	0.32835E-02	0.33344E-02	0.34060E-02
0.34511E-02	0.34509E-02	0.34395E-02	0.34470E-02
0.34542E-02	0.34294E-02	0.33826E-02	0.33584E-02
0.33815E-02	0.34250E-02	0.34563E-02	0.34623E-02
0.34406E-02	0.33943E-02	0.33365E-02	0.32740E-02
0.31516E-02	0.28842E-02	0.24409E-02	0.19012E-02
0.13559E-02	0.87464E-03	0.51259E-03	0.30171E-03
0.19524E-03	0.13052E-03	0.74406E-04	0.31412E-04
0.75269E-05	0.0	0.0	0.0

Channel 4

Starting Wave Number: 862.0688

Delta Wave Number: 2.37812

Response at Starting Wave Number + N * Delta Wave Number

N = 0 through 59

0.0	0.30603E-04	0.64563E-04	0.10523E-03
0.17057E-03	0.37139E-03	0.85488E-03	0.17526E-02
0.29947E-02	0.43718E-02	0.56739E-02	0.67844E-02
0.77153E-02	0.84881E-02	0.91222E-02	0.96298E-02
0.10022E-01	0.10310E-01	0.10525E-01	0.10708E-01
0.10903E-01	0.11130E-01	0.11370E-01	0.11596E-01
0.11786E-01	0.11949E-01	0.12111E-01	0.12299E-01
0.12523E-01	0.12746E-01	0.12926E-01	0.13022E-01
0.13039E-01	0.13030E-01	0.13047E-01	0.13135E-01
0.13274E-01	0.13419E-01	0.13522E-01	0.13518E-01
0.13274E-01	0.12640E-01	0.11466E-01	0.97239E-02
0.76698E-02	0.56031E-02	0.38225E-02	0.25039E-02
0.15835E-02	0.97002E-03	0.57192E-03	0.31626E-03
0.16604E-03	0.88422E-04	0.50625E-04	0.27594E-04
0.13455E-04	0.52455E-05	0.53119E-09	0.0 /

Channel 5

Starting Wave Number: 793.6506

Delta Wave Number: 1.71045

Response at Starting Wave Number + N * Delta Wave number

N = 0 through 59

0.0	0.0	0.0	0.15207E-04
0.49409E-03	0.13229E-02	0.24498E-02	0.38133E-02
0.53498E-02	0.69507E-02	0.84644E-02	0.97377E-02
0.10632E-01	0.11173E-01	0.11486E-01	0.11700E-01
0.11932E-01	0.12210E-01	0.12526E-01	0.12868E-01
0.13226E-01	0.13583E-01	0.13923E-01	0.14227E-01
0.14479E-01	0.14678E-01	0.14826E-01	0.14928E-01
0.14989E-01	0.15030E-01	0.15082E-01	0.15175E-01
0.15339E-01	0.15557E-01	0.15773E-01	0.15930E-01
0.15971E-01	0.15888E-01	0.15756E-01	0.15658E-01
0.15675E-01	0.15847E-01	0.16041E-01	0.16079E-01
0.15785E-01	0.14993E-01	0.13702E-01	0.12032E-01
0.10104E-01	0.80408E-02	0.59652E-02	0.40025E-02
0.22783E-02	0.91823E-03	0.38213E-04	0.0
0.0	0.0	0.0	0.0

AVHRR Nonlinearity Errors (Revised 2/12/86)

The nonlinearity errors are calculated in two ways. In the first table the error is the difference between the best quadratic fit to the actual target temperature and that temperature derived from a two-point linear calibration using a radiance of space of zero. The error in the second table is the difference between the quadratic fit and the temperature derived from a two-point fit using the corrected radiance of space.

Zero Radiance of Space:

Target Temperatures (DegK)	Error (DegK) 10.8u	Error (DegK) 11.8u
315	+1.8	+1.0
305	+.9	+.6
295	+.2	+.2
285	-.4	-.1
275	-.9	-.5
255	-1.4	-.8
245	-1.6	-1.0
225	-1.5	-1.3
205	-1.0	-1.4

Non-Linearity Corrections (Continued)

Corrected Radiance of Space:

Target Temperatures (DegK)	Error (DegK) 10.8u	11.8u
315	+1.2	+.6
305	+.5	+.3
295	+.1	+.1
285	-.2	0
275	-.3	-.1
255	+.1	+.1
245	+.4	+.2
225	+2.2	+.8
205	+5.6	+2.1

AVHRR Nonlinearity Errors (Revised 2/12/86)

The artifice of using a "corrected" non-zero radiance of space was eliminated. The corrections were calculated for three temperatures of the internal blackbody, 10, 15, and 20°C. To determine the appropriate correction, the user must interpolate in the following tables on the actual blackbody temperature in orbit.

CH.4 Non-Linearity Correction Table

Target Temperatures (Deg. K)	Correction at Blackbody Temp. (Deg. C) 10	15	20
320	+2.3	+2.3	+2.3
315	+1.8	+1.9	+1.8
310		+1.4	+1.3
305	+1.3	+1.0	+0.9
295	+0.7	+0.4	+0.2
285	0.0		-0.5
275	-0.5	-0.7	-0.9
265	-0.8	-1.1	-1.2
255	-1.0	-1.3	-1.6
245	-1.1	-1.3	-1.7
235	-1.2	-1.4	
225	-1.3	-1.3	-1.5
215	-1.2	-1.5	-1.4
205	-1.6	-1.5	-0.7

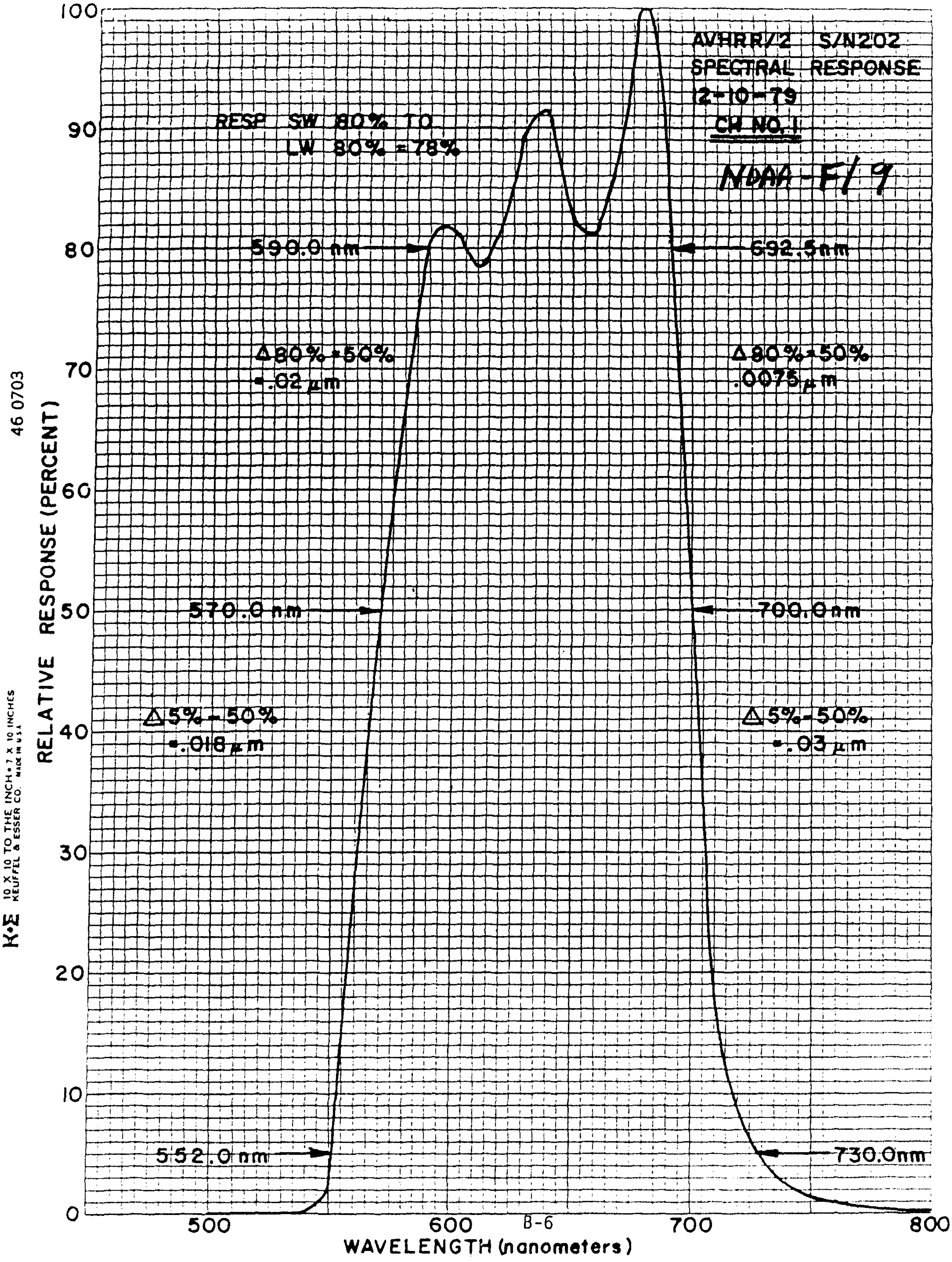
CH.5 Non-Linearity Correction Table

Target Temperatures (Deg. K)	Correction at Blackbody Temp. (Deg. C) 10	15	20
320	+0.8	+1.0	+1.2
315	+0.6	+0.9	+0.9
310		+0.7	+0.7
305	+1.1	+0.4	+0.5
295	+0.4	+0.2	+0.1
285	0.0		-0.2
275	-0.3	-0.3	-0.5
265	-0.5	-0.6	-0.7
255	-0.7	-0.8	-1.0
245	-0.8	-0.8	-1.2
235	-1.1	-1.2	
225	-1.2	-1.0	-1.1
215	-1.2	-1.4	-1.4
205	-1.7	-1.6	-1.1

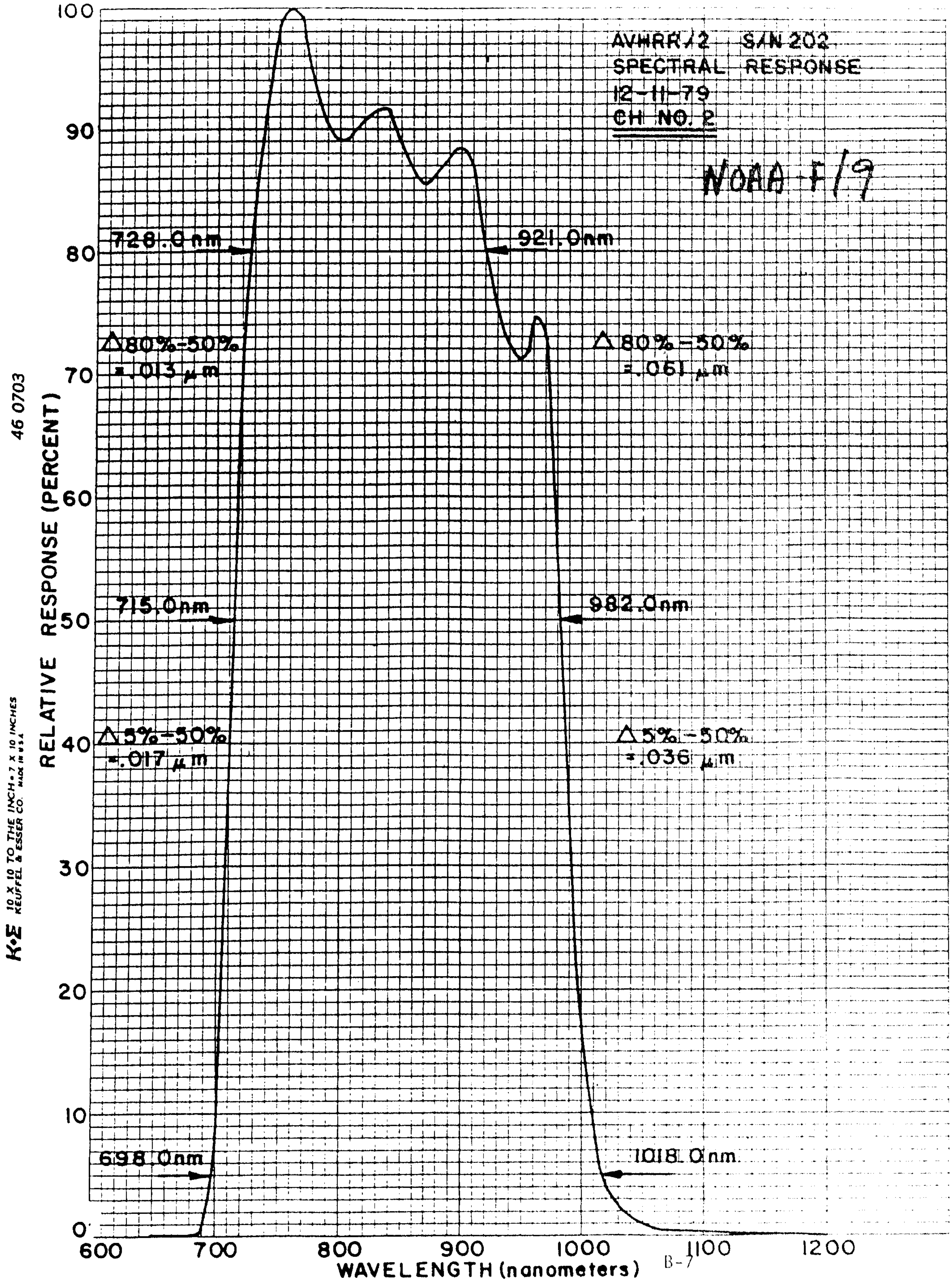
Central Wave Numbers

When used by the Inverse Planck function these central wave numbers give the minimum error for the specified temperature bands. The fourth band may be useful for sea surface temperatures.

Temp	3.7u	10.8u	11.8u
180-225	2670.93	928.50	844.41
225-275	2674.81	929.02	844.80
275-320	2678.11	929.46	845.19
270-310	2677.67	929.39	845.12



AVHRR/2 S/N202
SPECTRAL RESPONSE
12-10-79
CH NO. 1
NOAA-F/9
RESP SW 80% TO
LW 80% = 78%
590.0 nm
692.5nm
Δ80%-50%
=.02 μm
Δ80%-50%
.0075 μm
570.0 nm
700.0nm
Δ5%-50%
=.018 μm
Δ5%-50%
=.03 μm
552.0 nm
730.0nm
RELATIVE RESPONSE (PERCENT)
WAVELENGTH (nanometers)
0
10
20
30
40
50
60
70
80
90
100
500
600
700
800
K•E 10 X 10 TO THE INCH • 7 X 10 INCHES
KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0703



AVHRR/2 S/N 202
SPECTRAL RESPONSE
12-11-79
CH NO. 2
NOAA-F/9
728.0nm
921.0nm
Δ80%-50% =.013 μm
Δ80%-50% =.061 μm
715.0nm
982.0nm
Δ5%-50% =.017 μm
Δ5%-50% =.036 μm
698.0nm
1018.0nm
RELATIVE RESPONSE (PERCENT)
WAVELENGTH (nanometers)
100
90
80
70
60
50
40
30
20
10
0
600
700
800
900
1000
1100
1200
K+E 10 X 10 TO THE INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A.
46 0703

II. MSU (Section 5.2) - Instrument FM 6

Nonlinearity correction coefficients (Preliminary)

	d0	d1	d2
1	28.15	.9594	1.11514E-05
2	20.59	.9662	0.98935E-05
3	103.25	.9061	1.93189E-05
4	102.91	.9081	1.86008E-05

PRT Count to resistance coefficients

K0	495.6
K1	107.8

PRT Resistance to temperature coefficients

	e0	e1	e2
1A	29.4294	.4283514	.3223351E-04
2A	29.2639	.4338180	.3334592E-04
1B	29.5416	.4248521	.3188156E-04
2B	29.5778	.4243732	.3264424E-04

Response functions

Channel	Central Wave # (cm^{-1})
1	1.6779
2	1.7927
3	1.8334
4	1.9331

Radiance of space (Nsp)

Channel	Nsp ($mW/sr\ M^2\ cm^{-1}$)
1	0.000086
2	0.000096
3	0.000084
4	0.000092

III. SSU (Section 5.3) - Instrument FM 5

aj - PRT count-to-temperature coefficients

a0	a1	a2
284.249	4.889×10^{-3}	2.6×10^{-9}

Thermistor to temperature coefficients

b0	b1	b2	b3
375.969	-203.161	179.13	-85.16
c0	**c1**	**c2**	**c3**
375.969	-203.161	179.13	-85.16

Normalized Response Function

Channel	Central Wave (cm^{-1})
1	669.988
2	669.628
3	669.357

IV. HIRS (Section 5.4) - Instrument FM 6

IWT PRT count-to-temperature coefficients

PRT	a0	a1	a2	a3	a4
1	301.38	6.5225E-03	8.6282E-08	4.8144E-11	0.0
2	301.37	6.5193E-03	8.5968E-08	4.8101E-11	0.0
3	301.38	6.5245E-03	8.6193E-08	4.8146E-11	0.0
4	301.37	6.5196E-03	8.5893E-08	4.8105E-11	0.0

NOAA-F HIRS/2 FM6 Band-correction coefficients (Revised 3/6/85)

Channel	Vc	b	c
1	667.67	.034	.99989
2	679.84	.024	.99991
3	691.46	.092	.99975
4	703.37	.002	.99993
5	717.16	.013	.99991
6	732.64	-.023	.99997
7	749.48	-.006	.99995
8	898.53	.126	.99969
9	1031.61	.187	.99987
10	1224.74	.569	1.00010
11	1365.12	.033	.99961
12	1483.24	.353	.99911
13	2189.97	-.001	.99980
14	2209.18	.007	.99984
15	2243.14	.027	1.00003
16	2276.46	.099	1.00038
17	2359.05	.004	.99977
18	2518.14	.084	1.00012
19	2667.80	.448	1.00040

Normalized Response Functions (from 30 point spline fit)

Channel 1

0.64856E+03	0.13234E+01	0.0	0.72485E-03	0.13501E-02
0.17758E-02	0.19540E-02	0.20299E-02	0.23090E-02	0.31753E-02
0.29396E-02	0.23318E-02	0.89790E-02	0.14331E-01	0.33525E-01
0.82800E-01	0.19488E+00	0.23926E+00	0.86803E-01	0.37796E-01
0.16265E-01	0.60768E-02	0.28910E-02	0.35640E-02	0.35479E-02
0.26320E-02	0.19149E-02	0.12051E-02	0.54532E-03	0.12095E-03
0.0	0.0			

Channel 2

0.66139E+03	0.13759E+01	0.25096E-04	0.48553E-03	0.67047E-03
0.74618E-03	0.18225E-02	0.28045E-02	0.60576E-02	0.13820E-01
0.30882E-01	0.48370E-01	0.59111E-01	0.64049E-01	0.67652E-01
0.70337E-01	0.72033E-01	0.73486E-01	0.73180E-01	0.60550E-01
0.41055E-01	0.20066E-01	0.86978E-02	0.40688E-02	0.18572E-02
0.11723E-03	0.98958E-03	0.96741E-03	0.85838E-03	0.64738E-03
0.36834E-03	0.55354E-04			

Channel 3

0.66488E+03	0.18197E+01	0.88077E-04	0.30244E-03	0.39268E-03
0.26873E-03	0.32164E-03	0.12847E-02	0.34640E-02	0.63900E-02
0.10459E-01	0.16649E-01	0.24458E-01	0.34030E-01	0.46904E-01
0.61087E-01	0.67231E-01	0.66775E-01	0.62145E-01	0.55662E-01
0.42149E-01	0.25240E-01	0.10312E-01	0.51916E-02	0.25572E-02
0.17047E-02	0.13943E-02	0.11553E-02	0.92366E-03	0.67031E-03
0.36615E-03	0.51082E-07			

Channel 4

0.67286E+03	0.21069E+01	0.0	0.14726E-03	0.24259E-03
0.23424E-03	0.14622E-03	0.19096E-03	0.60959E-03	0.15672E-02
0.40960E-02	0.94410E-02	0.20622E-01	0.36991E-01	0.49266E-01
0.55726E-01	0.57893E-01	0.56362E-01	0.52712E-01	0.48043E-01
0.38267E-01	0.22305E-01	0.93495E-02	0.46924E-02	0.22138E-02
0.11672E-02	0.80695E-03	0.66892E-03	0.48131E-03	0.29764E-03
0.14142E-03	0.16207E-07			

Channel 5

0.68988E+03	0.19983E+01	0.0	0.88964E-04	0.14818E-03
0.14889E-03	0.20891E-03	0.71764E-03	0.17090E-02	0.41589E-02
0.96738E-02	0.21668E-01	0.39052E-01	0.51247E-01	0.56770E-01
0.59666E-01	0.58824E-01	0.54520E-01	0.48809E-01	0.39980E-01
0.25946E-01	0.14439E-01	0.65067E-02	0.29550E-02	0.15103E-02
0.86691E-03	0.46164E-03	0.22646E-03	0.10870E-03	0.55967E-04
0.24357E-04	0.28425E-08			

Channel 6

0.70499E+03	0.20693E+01	0.0	0.26090E-03	0.49909E-03
0.68646E-03	0.10580E-02	0.22934E-02	0.40356E-02	0.81392E-02
0.15302E-01	0.25323E-01	0.34728E-01	0.44495E-01	0.51810E-01
0.54809E-01	0.53734E-01	0.50211E-01	0.45485E-01	0.37923E-01
0.25000E-01	0.12900E-01	0.60694E-02	0.28389E-02	0.12683E-02
0.11186E-02	0.98376E-03	0.84149E-03	0.69771E-03	0.51866E-03
0.27761E-03	0.33658E-07			

Channel 7

0.72249E+03	0.19228E+01	0.24279E-04	0.10014E-03	0.18138E-03
0.27335E-03	0.38154E-03	0.67529E-03	0.17339E-02	0.41158E-02
0.10499E-01	0.23071E-01	0.39112E-01	0.48525E-01	0.50304E-01
0.51419E-01	0.53564E-01	0.54024E-01	0.51618E-01	0.44586E-01
0.34448E-01	0.23132E-01	0.13956E-01	0.64280E-02	0.32311E-02
0.16954E-02	0.11711E-02	0.69419E-03	0.49226E-03	0.36718E-03
0.22727E-03	0.79168E-04			

Channel 8

0.85002E+03	0.31052E+01	0.0	0.0	0.60666E-04
0.18677E-03	0.23710E-03	0.32694E-03	0.41802E-03	0.78007E-03
0.21275E-02	0.54518E-02	0.13396E-01	0.22294E-01	0.26214E-01
0.28753E-01	0.30530E-01	0.30712E-01	0.28820E-01	0.27131E-01
0.27481E-01	0.30439E-01	0.27640E-01	0.12195E-01	0.40924E-02
0.13243E-02	0.60416E-03	0.28024E-03	0.25220E-03	0.23565E-03
0.80130E-04	0.34009E-08			

Channel 9

0.98232E+03	0.32303E+01	0.0	0.13841E-03	0.26470E-03
0.36742E-03	0.44267E-03	0.52058E-03	0.76074E-03	0.99485E-03
0.25849E-02	0.55389E-02	0.11506E-01	0.21081E-01	0.30289E-01
0.32968E-01	0.32601E-01	0.31671E-01	0.31679E-01	0.33768E-01
0.32924E-01	0.22566E-01	0.10159E-01	0.36077E-02	0.14292E-02
0.59977E-03	0.32660E-03	0.31520E-03	0.26449E-03	0.15980E-03
0.49960E-04	0.27771E-08			

Channel 10

0.11618E+04	0.41931E+01	0.10158E-04	0.86769E-04	0.15246E-03
0.20315E-03	0.42028E-03	0.13462E-02	0.35325E-02	0.94420E-02
0.16095E-01	0.18040E-01	0.18132E-01	0.17341E-01	0.16495E-01
0.15906E-01	0.15540E-01	0.15225E-01	0.15141E-01	0.15459E-01
0.14696E-01	0.11976E-01	0.10122E-01	0.10121E-01	0.94109E-02
0.25686E-02	0.56361E-03	0.18001E-03	0.11707E-03	0.97796E-04
0.72674E-04	0.65619E-05			

Channel 11

0.13260E+04	0.34138E+01	0.0	0.37570E-03	0.12138E-02
0.19291E-02	0.33887E-02	0.63608E-02	0.12621E-01	0.19542E-01
0.23891E-01	0.25196E-01	0.25653E-01	0.25826E-01	0.25951E-01
0.25540E-01	0.23470E-01	0.18695E-01	0.14593E-01	0.12448E-01
0.10267E-01	0.72468E-02	0.39659E-02	0.19915E-02	0.11940E-02
0.71708E-03	0.11769E-03	0.80020E-04	0.24347E-03	0.26582E-03
0.16397E-03	0.12521E-07			

Channel 12

0.13998E+04	0.57345E+01	0.0	0.64834E-04	0.11286E-03
0.15260E-03	0.17680E-03	0.69670E-03	0.24059E-02	0.72630E-02
0.11507E-01	0.12043E-01	0.11354E-01	0.10725E-01	0.10341E-01
0.10454E-01	0.10871E-01	0.10688E-01	0.11042E-01	0.99484E-02
0.92918E-02	0.91051E-02	0.92225E-02	0.91199E-02	0.91742E-02
0.65458E-02	0.14755E-02	0.33317E-03	0.13995E-03	0.93483E-04
0.40421E-04	0.16350E-08			

Channel 13

0.21592E+04	0.23241E+01	0.0	0.14665E-03	0.24565E-03
0.41151E-03	0.56707E-03	0.12011E-02	0.26430E-02	0.57785E-02
0.12346E-01	0.22655E-01	0.35842E-01	0.42237E-01	0.45726E-01
0.48898E-01	0.44567E-01	0.42825E-01	0.40116E-01	0.34017E-01
0.23874E-01	0.13225E-01	0.60787E-02	0.28046E-02	0.13695E-02
0.52186E-03	0.59235E-03	0.54569E-03	0.44874E-03	0.38124E-03
0.23468E-03	0.26447E-07			

Channel 14

0.21701E+04	0.27552E+01	0.0	0.12817E-03	0.19927E-03
0.26444E-03	0.35911E-03	0.39606E-03	0.48291E-03	0.85633E-03
0.22117E-02	0.63882E-02	0.16848E-01	0.32564E-01	0.39652E-01
0.40867E-01	0.42958E-01	0.45544E-01	0.44092E-01	0.39570E-01
0.27298E-01	0.13463E-01	0.48389E-02	0.16424E-02	0.89625E-03
0.52404E-03	0.37056E-03	0.19391E-03	0.15946E-03	0.12535E-03
0.68391E-04	0.62776E-08			

Channel 15

0.22091E+04	0.21552E+01	0.10685E-04	0.11331E-03	0.20066E-03
0.26779E-03	0.39227E-03	0.52966E-03	0.78320E-03	0.17932E-02
0.40775E-02	0.90727E-02	0.16285E-01	0.25890E-01	0.34837E-01
0.41186E-01	0.43358E-01	0.43951E-01	0.42962E-01	0.42085E-01
0.41538E-01	0.40229E-01	0.34242E-01	0.21754E-01	0.10731E-01
0.38675E-02	0.16701E-02	0.10177E-02	0.66801E-03	0.34489E-03
0.17764E-03	0.24942E-07			

Channel 16

0.22151E+04	0.40483E+01	0.62564E-04	0.76396E-04	0.10637E-03
0.16861E-03	0.26930E-03	0.42111E-03	0.75843E-03	0.15477E-02
0.32786E-02	0.70898E-02	0.11896E-01	0.17867E-01	0.22422E-01
0.24138E-01	0.24608E-01	0.25111E-01	0.26699E-01	0.28948E-01
0.25503E-01	0.14117E-01	0.61423E-02	0.23840E-02	0.10917E-02
0.57874E-03	0.53725E-03	0.40791E-03	0.34449E-03	0.29111E-03
0.16585E-03	0.10543E-07			

Channel 17

0.23050E+04	0.31034E+01	0.0	0.63895E-06	0.71770E-05
0.25514E-04	0.61545E-04	0.12063E-03	0.18601E-03	0.21299E-03
0.24125E-03	0.39357E-03	0.39497E-03	0.10344E-02	0.31947E-02
0.94901E-02	0.24428E-01	0.36009E-01	0.37560E-01	0.39026E-01
0.41211E-01	0.40584E-01	0.36955E-01	0.27670E-01	0.13475E-01
0.55739E-02	0.22501E-02	0.10347E-02	0.44650E-03	0.36685E-03
0.28868E-03	0.26330E-07			

Channel 18

0.24547E+04	0.44931E+01	0.0	0.85781E-04	0.15578E-03
0.19566E-03	0.19647E-03	0.38823E-03	0.81127E-03	0.19745E-02
0.45149E-02	0.86248E-02	0.14567E-01	0.19618E-01	0.22752E-01
0.25885E-01	0.27653E-01	0.26140E-01	0.22801E-01	0.18252E-01
0.12939E-01	0.76306E-02	0.35340E-02	0.16406E-02	0.82370E-03
0.47192E-03	0.31681E-03	0.24275E-03	0.18818E-03	0.11857E-03
0.51888E-04	0.26777E-08			

Channel 19

0.25014E+04	0.10366E+02	0.0	0.69446E-05	0.17601E-04
0.36993E-04	0.71060E-04	0.84877E-04	0.15252E-03	0.35573E-03
0.76693E-03	0.16147E-02	0.33138E-02	0.58704E-02	0.74674E-02
0.83216E-02	0.86388E-02	0.86430E-02	0.92136E-02	0.88858E-02
0.93931E-02	0.10312E-01	0.81579E-02	0.30981E-02	0.11331E-02
0.44181E-03	0.21494E-03	0.10105E-03	0.83840E-04	0.60142E-04
0.16299E-04	0.21977E-09			

CHANNEL 20

nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS
633.0	-0.000	656.3	0.114	681.7	1.000	708.6	0.524	737.6	0.047
634.2	-0.000	657.6	0.153	683.0	0.998	709.9	0.463	739.1	0.043
635.3	-0.000	658.8	0.175	684.3	0.993	711.3	0.406	740.6	0.042
636.4	-0.000	660.0	0.201	685.6	0.988	712.7	0.344	742.2	0.040
637.6	-0.000	661.2	0.236	686.9	0.984	714.1	0.292	743.7	0.035
638.7	-0.000	662.5	0.287	688.3	0.983	715.5	0.255	745.3	0.034
639.8	0.001	663.7	0.343	689.6	0.983	717.0	0.217	746.8	0.031
641.0	0.003	665.0	0.409	690.9	0.981	718.4	0.190	748.4	0.029
642.1	0.005	666.3	0.471	692.3	0.980	719.8	0.171	750.0	0.026
643.3	0.009	667.5	0.554	693.6	0.977	721.3	0.151	751.6	0.026
644.5	0.014	668.8	0.639	695.0	0.972	722.7	0.135	753.1	0.026
645.6	0.018	670.1	0.704	696.3	0.961	724.2	0.115	754.7	0.024
646.8	0.023	671.4	0.784	697.7	0.943	725.6	0.105	756.3	0.023
648.0	0.030	672.7	0.854	699.0	0.915	727.1	0.093	757.9	0.024
649.1	0.038	674.0	0.900	700.4	0.879	728.6	0.082	759.5	0.024
650.3	0.048	675.3	0.939	701.7	0.841	730.1	0.075	761.2	0.023
651.5	0.057	676.5	0.965	703.1	0.786	731.6	0.070	762.8	0.022
652.7	0.066	677.8	0.984	704.5	0.727	733.1	0.060	764.4	0.021
653.9	0.082	679.1	0.992	705.8	0.659	734.6	0.057	766.0	0.019
655.1	0.096	680.4	0.997	707.2	0.582	736.1	0.051	767.7	0.018
								769.3	0.016

Visible Coefficients

Channel	G (% albedo/count)	I (% albedo)
20	0.01762	63.39

Equivalent Width (W), Solar Irradiance (F) and Effective Center Wavelength (λ)

NOAA-9

	W	F_1	λ_1	F_2	λ_2	F_3	λ_3
Ch.20	0.0484	68.76	0.689	67.48	0.689	65.00	0.689

Notes:
1. Using the Air Force (1965) solar spectral irradiance data.
2. Using the Nechel and Labe (1984) solar spectral irradiance data.
3. Using the Thekaekara (1974) solar spectral irradiance data.

Appendix B

NOAA-G/10 Coefficients
(Republished August, 1987)

I. AVHRR (Section 5.1)- Instrument FM 101

PRT	a0	a1	a2	a3	a4
1	276.659	.051275	1.363E-06	0.0	0.0
2	276.659	.051275	1.363E-06	0.0	0.0
3	276.659	.051275	1.363E-06	0.0	0.0
4	276.659	.051275	1.363E-06	0.0	0.0

bi - PRT Weighting Factors

b1	b2	b3	b4
0.25	0.25	0.25	0.25

Nsp - Radiance of space

Channel	Nsp (mW/sr M^2 cm^{-1})
3	0.0
4	0.0

Visible Channel Coefficients

	M	I
Channel 1	.105879896	-3.52793526
Channel 2	.106072663	-3.47665053

Equivalent Width (W), Solar Irradiance (F) and Effective Center Wavelength (λ)

NOAA-10

	W	F_1	λ_1	F_2	λ_2	F_3	λ_3
Ch. 1	0.108	183.8	0.628	178.8	0.628	169.4	0.628
Ch. 2	0.222	228.0	0.834	231.5	0.836	225.7	0.836

Notes: 1. Using the Air Force (1965) solar spectral irradiance data.
2. Using the Nechel and Labe (1984) solar spectral irradiance data.
3. Using the Thekaekara (1974) solar spectral irradiance data.

NORMALIZED RESPONSE FUNCTIONS

Channel 3:

Starting Wave Number: 2424.24219

Wave Number Increment: 8.17773

Response at Wave Number + N * Wave Number Increment,
N = 0 through 59

0.0	0.13751E-05	0.39496E-05	0.79338E-05
0.11357E-04	0.15556E-04	0.26964E-04	0.50379E-04
0.90236E-04	0.17211E-03	0.33730E-03	0.63486E-03
0.11045E-02	0.16912E-02	0.22951E-02	0.27927E-02
0.30806E-02	0.32169E-02	0.33036E-02	0.33819E-02
0.34655E-02	0.35293E-02	0.35407E-02	0.35122E-02
0.34747E-02	0.34587E-02	0.34906E-02	0.35512E-02
0.35920E-02	0.36036E-02	0.36146E-02	0.36384E-02
0.36644E-02	0.36805E-02	0.36761E-02	0.34652E-02
0.36451E-02	0.36007E-02	0.35607E-02	0.35293E-02
0.35021E-02	0.34652E-02	0.33925E-02	0.32785E-02
0.31784E-02	0.31404E-02	0.30626E-02	0.27733E-02
0.16517E-02	0.11382E-02	0.72913E-03	0.41352E-03
0.18744E-03	0.53037E-04	0.36903E-05	0.30597E-05
0.99799E-05	0.75164E-05	0.85569E-12	0.0

Channel 4:

Starting Wave Number: 840.33594

Wave Number Increment: 2.41476

Response at Wave Number + N * Wave Number Increment,
N = 0 through 59

0.0	0.95537E-06	0.93891E-05	0.32781E-04
0.85461E-04	0.20529E-03	0.43520E-03	0.82424E-03
0.14425E-02	0.23647E-02	0.36140E-02	0.50077E-02
0.63116E-02	0.73295E-02	0.80726E-02	0.86233E-02
0.90618E-02	0.94490E-02	0.98355E-02	0.10270E-01
0.10765E-01	0.11299E-01	0.11848E-01	0.12379E-01
0.12847E-01	0.13202E-01	0.13409E-01	0.13505E-01
0.13552E-01	0.13609E-01	0.13713E-01	0.13882E-01
0.14132E-01	0.14472E-01	0.14884E-01	0.15344E-01
0.15822E-01	0.16164E-01	0.16103E-01	0.15373E-01
0.13800E-01	0.11625E-01	0.92035E-02	0.68878E-02
0.49065E-02	0.32916E-02	0.20569E-02	0.12120E-02
0.70445E-03	0.43396E-03	0.29898E-03	0.20697E-03
0.13060E-03	0.71096E-04	0.29818E-04	0.72388E-05
0.0	0.19847E-05	0.93339E-05	0.0

Channel 5: Repeat of Channel 4

AVHRR Nonlinearity Corrections for Channel 4

The nonlinearity corrections are the difference between the measured target temperature and that temperature derived from a two-point linear calibration using a radiance of space of zero. By first calculating the calibration blackbody temperature, the nonlinearity correction can be interpolated from the following table.

Target Temperatures (Deg. K)	Correction at Blackbody Temp. (Deg. C) 10	15	20
320	+2.1	+1.6	+1.5
315	+1.8	+1.3	+1.2
305	+1.1	+0.7	+0.6
295	+0.5	+0.2	+0.1
285	+0.1	-0.3	-0.3
275	-0.2	-0.5	-0.6
265	-0.5	-0.9	-0.9
255	-0.9	-1.1	-1.2
245	-1.3	-1.4	-1.4
235	-1.5	-1.5	-1.6
225	-1.7	-1.7	-1.8
215	-2.0	-1.9	-1.8
205	-2.3	-2.1	-1.8

Central Wavenumbers

When used by the Inverse Planck function these central wavenumbers give the minimum error for the specified temperature bands. The fourth band may be useful for sea surface temperatures.

Temp	Ch.3	Ch.4
180-225	2652.89	908.73
225-275	2657.60	909.18
275-320	2660.76	909.58
270-310	2660.35	909.52

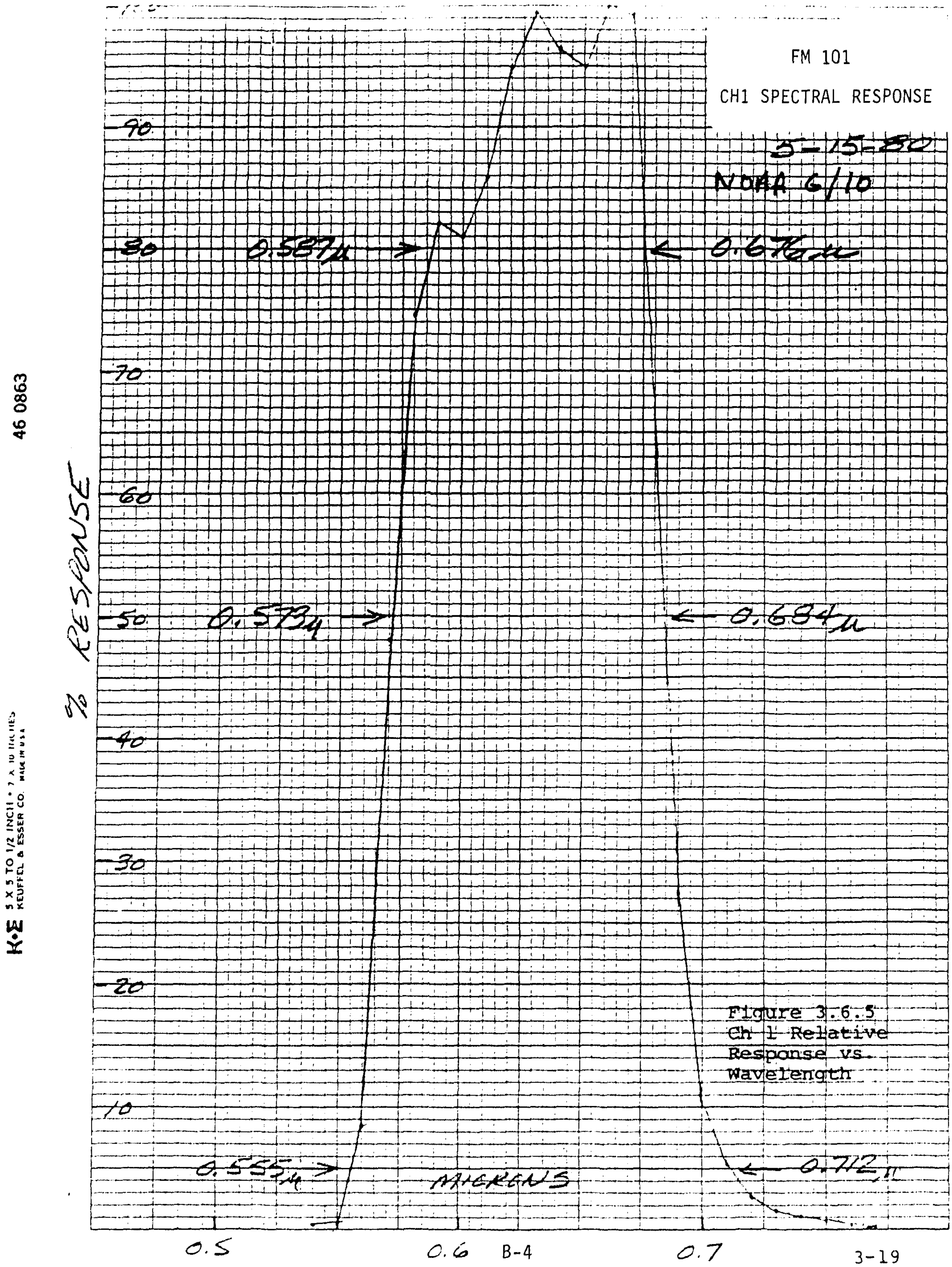


Figure 3.6.5
Ch 1 Relative
Response vs.
Wavelength

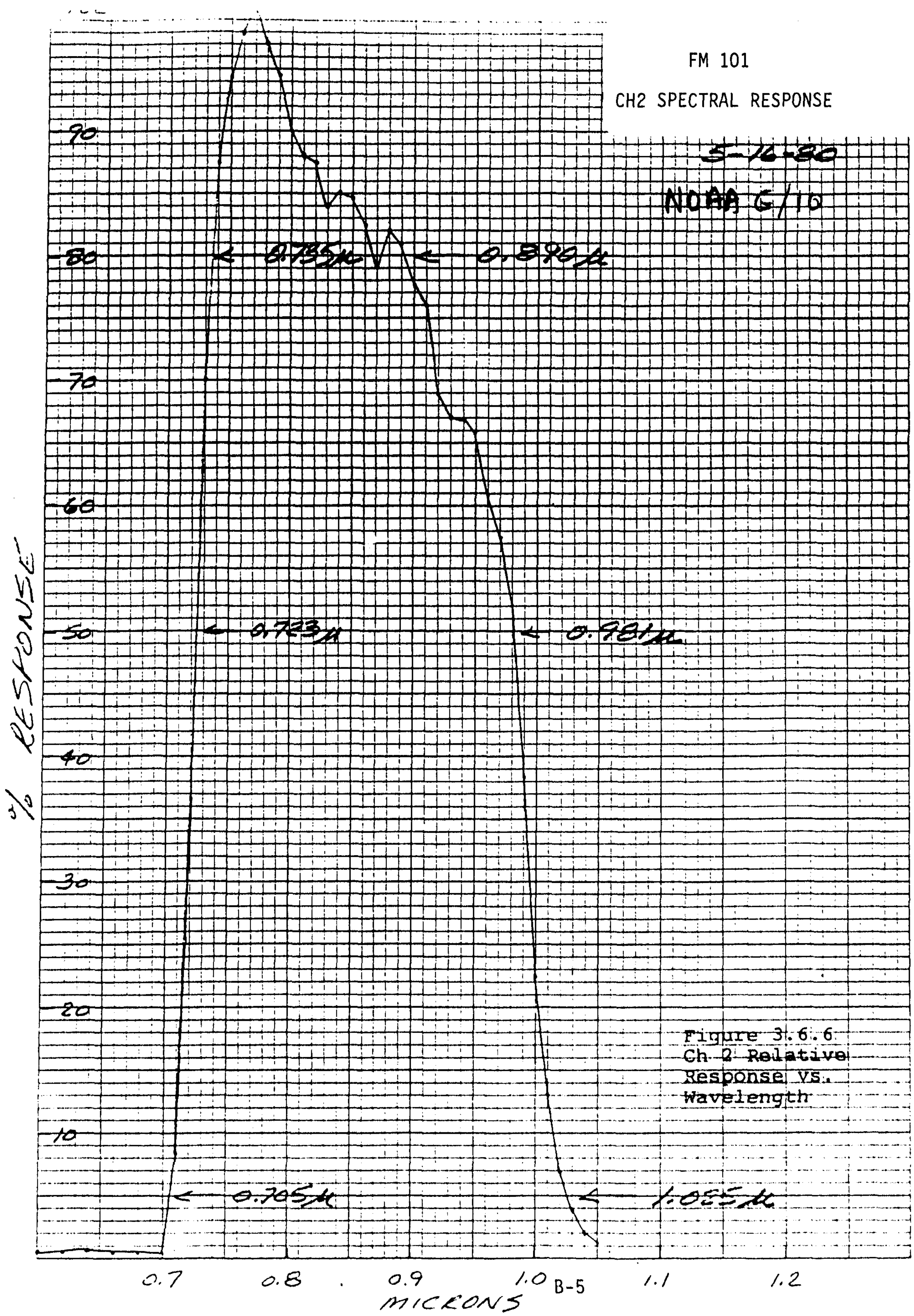


Figure 3.6.6 Ch 2 Relative Response vs. Wavelength

K•E 5 X 5 TO 1/2 INCH • 7 X 10 INCHES KEUFFEL & ESSER CO. MADE IN U.S.A. 46 0863

II. MSU (Section 5.2) - Instrument FM 5

Nonlinearity correction coefficients

	do	d1	d2
1	36.051	.955271	1.17040E-05
2	38.469	.954615	1.10622E-05
3	106.724	.907674	1.88402E-05
4	105.227	.908741	1.88795E-05

PRT Count to resistance coefficients

K0	495.6
K1	107.8

PRT Resistance to temperature coefficients

	e0	e1	e2
1A	29.2589	.4245799	.3169871E-04
2A	29.4633	.4250778	.3192864E-04
1B	29.2350	.4289328	.3232162E-04
2B	29.4680	.4275379	.3221571E-04

Centroid of spectral response functions

Channel	vc(cm^{-1})
1	1.6779
2	1.7927
3	1.8334
4	1.9331

Nsp - Radiance of space

Channel	Nsp(mW/sr M^2 cm^{-1})
1	0.000086
2	0.000096
3	0.000084
4	0.000092

III. SSU (Section 5.3)

NOAA-G has a dummy SSU.

IV. HIRS (Section 5.4) - Instrument FM 5

IWT PRT Count to Temperature Coefficients

PRT	a0	a1	a2	a3	a4
1	301.38	6.5216E-03	8.6344E-08	4.8114E-11	0.0
2	301.38	6.5161E-03	8.5966E-08	4.8042E-11	0.0
3	301.38	6.5207E-03	8.6131E-08	4.8083E-11	0.0
4	301.38	6.5197E-03	8.6161E-08	4.8073E-11	0.0

NOAA-G HIRS/2 FM5 Band-Correction Coefficients

Channel	Vc	b	c
1	667.70	.033	.99989
2	680.23	.018	.99992
3	691.15	-.006	.99994
4	704.33	-.002	.99994
5	716.30	-.064	1.00007
6	733.13	.065	.99980
7	750.72	.073	.99979
8	899.50	.218	.99957
9	1029.01	.195	.99987
10	1224.07	.327	.99965
11	1363.32	.046	.99963
12	1489.42	.645	1.00064
13	2191.38	.072	1.00036
14	2208.74	.079	1.00045
15	2237.49	-.026	.99947
16	2269.09	.041	1.00019
17	2360.00	.040	1.00019
18	2514.58	.098	1.00025
19	2665.38	.462	1.00067

Normalized Response Functions (from 30 point spline fit)

Channel 1

0.64954E+03	0.10500E+01	0.28952E-02	0.11456E-02	0.35737E-03
0.80488E-03	0.12849E-02	0.12951E-02	0.12941E-02	0.17624E-02
0.18794E-02	0.25033E-02	0.31979E-02	0.60040E-02	0.11062E-01
0.10962E-01	0.36390E-01	0.70573E-01	0.13582E+00	0.21212E+00
0.18695E+00	0.11508E+00	0.59065E-01	0.34843E-01	0.15580E-01
0.99889E-02	0.67518E-02	0.62376E-02	0.40001E-02	0.31974E-02
0.14151E-02	0.26090E-06			

Channel 2

0.65808E+03	0.15372E+01	0.0	0.14250E-04	0.91136E-04
0.24638E-03	0.41122E-03	0.61216E-03	0.12544E-02	0.29604E-02
0.78131E-02	0.20065E-01	0.40189E-01	0.54178E-01	0.61059E-01
0.66313E-01	0.70482E-01	0.73633E-01	0.74915E-01	0.73132E-01
0.54128E-01	0.25978E-01	0.11191E-01	0.42373E-02	0.19504E-02
0.12871E-02	0.14514E-02	0.99427E-03	0.89115E-03	0.69068E-03
0.40292E-03	0.67083E-07			

Channel 3

0.66108E+03	0.19293E+01	0.0	0.16470E-03	0.27148E-03
0.40035E-03	0.48548E-03	0.75806E-03	0.11049E-02	0.21491E-02
0.42357E-02	0.76089E-02	0.12804E-01	0.20481E-01	0.29793E-01
0.41089E-01	0.55038E-01	0.63531E-01	0.64882E-01	0.62523E-01
0.57770E-01	0.42813E-01	0.25035E-01	0.11547E-01	0.49174E-02
0.29419E-02	0.16253E-02	0.15447E-02	0.12338E-02	0.10063E-02
0.59626E-03	0.85160E-07			

Channel 4

0.67541E+03	0.19103E+01	0.0	0.10765E-03	0.21150E-03
0.28609E-03	0.35714E-03	0.44633E-03	0.72349E-03	0.17841E-02
0.39374E-02	0.84213E-02	0.17002E-01	0.27366E-01	0.38466E-01
0.51391E-01	0.61261E-01	0.66755E-01	0.64712E-01	0.58785E-01
0.49907E-01	0.35319E-01	0.17921E-01	0.82371E-02	0.37662E-02
0.21293E-02	0.13036E-02	0.10287E-02	0.83181E-03	0.63273E-03
0.34852E-03	0.70500E-07			

Channel 5

0.69433E+03	0.15424E+01	0.21598E-04	0.10213E-03	0.20254E-03
0.49540E-03	0.10914E-02	0.23230E-02	0.45259E-02	0.93299E-02
0.16502E-01	0.29243E-01	0.39898E-01	0.47588E-01	0.54117E-01
0.58211E-01	0.60980E-01	0.60314E-01	0.57998E-01	0.53704E-01
0.47667E-01	0.38460E-01	0.27632E-01	0.16689E-01	0.94315E-02
0.55790E-02	0.29761E-02	0.16634E-02	0.83566E-03	0.40350E-03
0.31435E-03	0.11471E-03			

Channel 6

0.70502E+03	0.20283E+01	0.0	0.14629E-03	0.34989E-03
0.53416E-03	0.74083E-03	0.19246E-02	0.35348E-02	0.71033E-02
0.13620E-01	0.22980E-01	0.32953E-01	0.42291E-01	0.50417E-01
0.55254E-01	0.55225E-01	0.52381E-01	0.49569E-01	0.41956E-01
0.28561E-01	0.15808E-01	0.74655E-02	0.32914E-02	0.18949E-02
0.11640E-02	0.11559E-02	0.86782E-03	0.74246E-03	0.69209E-03

Normalized Response Functions (Continued)

Channel 7

0.71497E+03	0.24217E+01	0.0	0.17040E-04	0.58290E-04
0.15469E-03	0.28940E-03	0.40697E-03	0.50690E-03	0.11861E-02
0.24564E-02	0.66889E-02	0.16921E-01	0.34769E-01	0.42932E-01
0.43736E-01	0.45910E-01	0.49018E-01	0.50233E-01	0.46151E-01
0.35372E-01	0.18403E-01	0.87187E-02	0.35738E-02	0.17878E-02
0.10920E-02	0.80859E-03	0.67031E-03	0.53620E-03	0.34440E-03
0.20419E-03	0.49630E-07			

Channel 8

0.85387E+03	0.31079E+01	0.0	0.63493E-04	0.13257E-03
0.20459E-03	0.23202E-03	0.30185E-03	0.73795E-03	0.18662E-02
0.62341E-02	0.15678E-01	0.23498E-01	0.26212E-01	0.28493E-01
0.30424E-01	0.30924E-01	0.29537E-01	0.27065E-01	0.27454E-01
0.30669E-01	0.25546E-01	0.11002E-01	0.31279E-02	0.12657E-02
0.41519E-03	0.27150E-03	0.22544E-03	0.12430E-03	0.50088E-04
0.55440E-05	0.0			

Channel 9

0.97611E+03	0.33686E+01	0.0	0.29071E-04	0.71443E-04
0.15040E-03	0.28280E-03	0.40022E-03	0.46202E-03	0.87610E-03
0.14398E-02	0.31020E-02	0.79475E-02	0.16115E-01	0.25058E-01
0.30968E-01	0.32875E-01	0.33281E-01	0.33146E-01	0.33531E-01
0.32821E-01	0.24080E-01	0.11421E-01	0.45709E-02	0.17882E-02
0.10164E-02	0.51867E-03	0.36041E-03	0.27467E-03	0.18411E-03
0.10574E-03	0.95634E-08			

Channel 10

0.11651E+04	0.43138E+01	0.48626E-04	0.12867E-03	0.20162E-03
0.22237E-03	0.75812E-03	0.22515E-02	0.65148E-02	0.13557E-01
0.17254E-01	0.18093E-01	0.17266E-01	0.16301E-01	0.15391E-01
0.15073E-01	0.14743E-01	0.14506E-01	0.14655E-01	0.14512E-01
0.12161E-01	0.98724E-02	0.94420E-02	0.12240E-01	0.53081E-02
0.80378E-03	0.17240E-03	0.15707E-03	0.11159E-03	0.55437E-04
0.18718E-04	0.90781E-09			

Channel 11

0.13048E+04	0.40966E+01	0.0	0.90983E-04	0.21512E-03
0.29537E-03	0.34935E-03	0.40217E-03	0.82058E-03	0.14973E-02
0.35604E-02	0.81027E-02	0.14456E-01	0.19327E-01	0.23901E-01
0.25472E-01	0.26009E-01	0.25728E-01	0.24446E-01	0.22107E-01
0.18024E-01	0.13246E-01	0.79663E-02	0.35512E-02	0.21191E-02
0.12237E-02	0.49968E-03	0.26430E-03	0.22540E-03	0.12974E-03
0.84697E-04	0.59518E-08			

Channel 12

0.13799E+04	0.69069E+01	0.0	0.48862E-04	0.83681E-04
0.10839E-03	0.13417E-03	0.16307E-03	0.24874E-03	0.10088E-02
0.33877E-02	0.81498E-02	0.10443E-01	0.10186E-01	0.97795E-02
0.10142E-01	0.11639E-01	0.12843E-01	0.12191E-01	0.11595E-01
0.11333E-01	0.90919E-02	0.67177E-02	0.64379E-02	0.75988E-02
0.11057E-02	0.19462E-03	0.82871E-04	0.46485E-04	0.19387E-04
0.58340E-05	0.16312E-09			

Normalized Response Functions (Continued)

Channel 13

0.21417E+04	0.35655E+01	0.77226E-04	0.65365E-04	0.43130E-04
0.31119E-05	0.14633E-04	0.21111E-03	0.39583E-03	0.75284E-03
0.75284E-03	0.22916E-02	0.64304E-02	0.18192E-01	0.31111E-01
0.40372E-01	0.41793E-01	0.38312E-01	0.41913E-01	0.40783E-01
0.12184E-01	0.27971E-02	0.82781E-03	0.67306E-03	0.44480E-03
0.26990E-03	0.10735E-03	0.87938E-04	0.13390E-03	0.10876E-03
0.20673E-04	0.12472E-08			

Channel 14

0.21551E+04	0.27586E+01	0.0	0.27397E-04	0.10965E-03
0.22026E-03	0.23359E-03	0.29368E-03	0.34528E-03	0.43339E-03
0.55569E-03	0.62908E-03	0.61908E-03	0.12679E-02	0.29989E-02
0.72705E-02	0.14808E-01	0.24424E-01	0.32497E-01	0.38690E-01
0.41574E-01	0.40685E-01	0.39172E-01	0.41831E-01	0.41306E-01
0.22047E-01	0.70235E-02	0.18844E-02	0.76343E-03	0.45196E-03
0.35124E-03	0.24046E-07			
0.45715E-03	0.60869E-07			

Channel 15

0.22054E+04	0.22793E+01	0.0	0.16393E-03	0.18693E-03
0.33230E-03	0.42432E-03	0.60316E-03	0.70166E-03	0.15957E-02
0.41033E-02	0.10253E-01	0.30494E-01	0.48187E-01	0.42389E-01
0.34238E-01	0.32954E-01	0.34953E-01	0.38076E-01	0.39074E-01
0.35334E-01	0.29166E-01	0.22342E-01	0.15121E-01	0.87763E-02
0.49382E-02	0.21235E-02	0.12012E-02	0.62032E-03	0.34540E-03
0.36352E-04	0.0			

Channel 16

0.22200E+04	0.31000E+01	0.0	0.45164E-04	0.69335E-04
0.96402E-04	0.12305E-03	0.11927E-03	0.21534E-03	0.28818E-03
0.35969E-03	0.11548E-02	0.33889E-02	0.10206E-01	0.25236E-01
0.37843E-01	0.41259E-01	0.40342E-01	0.38117E-01	0.38449E-01
0.41514E-01	0.28683E-01	0.91061E-02	0.32119E-02	0.12346E-02
0.47226E-03	0.46931E-03	0.35131E-03	0.20305E-03	0.40309E-04
0.0	0.0			

Channel 17

0.23240E+04	0.24103E+01	0.41739E-04	0.13575E-03	0.20635E-03
0.32909E-03	0.46160E-03	0.54673E-03	0.85425E-03	0.19242E-02
0.45545E-02	0.10383E-01	0.22357E-01	0.35108E-01	0.41138E-01
0.43621E-01	0.43537E-01	0.41995E-01	0.41116E-01	0.42054E-01
0.40046E-01	0.25383E-01	0.10495E-01	0.41351E-02	0.15245E-02
0.95818E-03	0.64994E-03	0.51025E-03	0.39435E-03	0.28667E-03
0.15750E-03	0.84954E-05			

Channel 18

0.24527E+04	0.45207E+01	0.0	0.30699E-04	0.11547E-03
0.19516E-03	0.28523E-03	0.56791E-03	0.11736E-02	0.30267E-02
0.67261E-02	0.11899E-01	0.17000E-01	0.21197E-01	0.24981E-01
0.27816E-01	0.27778E-01	0.24741E-01	0.20414E-01	0.14863E-01
0.92413E-02	0.46679E-02	0.21106E-02	0.95136E-03	0.52470E-03
0.31538E-03	0.25704E-03	0.16913E-03	0.11596E-03	0.47851E-04
0.39494E-05	0.0			

Normalized Response Functions (Continued)

Channel 19

0.25324E+04	0.87138E+01	0.0	0.17547E-04	0.27415E-04
0.48882E-04	0.18580E-03	0.43181E-03	0.83340E-03	0.16585E-02
0.32004E-02	0.54446E-02	0.76137E-02	0.89879E-02	0.95373E-02
0.95250E-02	0.91496E-02	0.86422E-02	0.82849E-02	0.83280E-02
0.89930E-02	0.95913E-02	0.77842E-02	0.38231E-02	0.14850E-02
0.66251E-03	0.31012E-03	0.12396E-03	0.53476E-04	0.16933E-04
0.21522E-05	0.49429E-11			

CHANNEL 20

nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS	nm	RSPNS
632.5	0.001	655.7	0.071	680.7	0.975	707.7	0.776	736.9	0.065
633.6	0.001	656.9	0.085	682.0	0.993	709.1	0.710	738.5	0.059
634.8	0.001	658.2	0.101	683.3	1.000	710.5	0.640	740.0	0.054
635.9	0.001	659.4	0.115	684.6	0.998	711.9	0.579	741.5	0.049
637.0	0.003	660.6	0.132	686.0	0.994	713.4	0.513	743.1	0.044
638.2	0.005	661.8	0.152	687.3	0.985	714.8	0.450	744.6	0.041
639.3	0.003	663.0	0.184	688.6	0.972	716.2	0.397	746.2	0.038
640.4	0.002	664.3	0.214	689.9	0.962	717.7	0.350	747.7	0.036
641.6	0.007	665.5	0.254	691.3	0.953	719.1	0.303	749.3	0.034
642.8	0.010	666.8	0.290	692.6	0.949	720.6	0.261	750.9	0.032
643.9	0.013	668.0	0.340	694.0	0.945	722.0	0.227	752.4	0.029
645.1	0.014	669.3	0.397	695.3	0.944	723.5	0.199	754.0	0.026
646.2	0.016	670.5	0.487	696.7	0.944	725.0	0.173	755.6	0.023
647.4	0.018	671.8	0.550	698.0	0.943	726.4	0.150	757.2	0.022
648.6	0.025	673.0	0.634	699.4	0.941	727.9	0.130	758.9	0.023
649.8	0.032	674.3	0.713	700.8	0.933	729.4	0.111	760.5	0.024
651.0	0.042	675.6	0.781	702.2	0.921	730.9	0.096	762.1	0.024
652.1	0.049	676.9	0.842	703.5	0.899	732.4	0.086	763.7	0.022
653.3	0.059	678.2	0.910	704.9	0.866	733.9	0.078	765.3	0.021
654.5	0.065	679.4	0.943	706.3	0.824	735.4	0.070	767.0	0.020
								768.6	0.020

Channel 20: (visible) G = 0.02148 (% albedo/count)
I = 77.11 (% albedo)

Equivalent Width (W), Solar Irradiance (F) and Effective Center Wavelength (λ)

NOAA-10

	W	F_1	λ_1	F_2	λ_2	F_3	λ_3
Ch.20	0.0483	70.78	0.693	69.47	0.693	67.01	0.693

Notes:
1. Using the Air Force (1965) solar spectral irradiance data.
2. Using the Nechel and Labe (1984) solar spectral irradiance data.
3. Using the Thekaekara (1974) solar spectral irradiance data.

APPENDIX C

FORMULATION OF A GENERIC ALGORITHM FOR EARTH LOCATING DATA FROM NOAA POLAR SATELLITES

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FORMULATION OF A GENERIC ALGORITHM FOR EARTH LOCATING DATA FROM NOAA POLAR SATELLITES

SECTION 1--GENERAL

This document describes a general algorithm for computing Earth location values for data from scanning radiometers flown on three - axis stabilized polar orbiting satellites. Given the following information about any data point, a corresponding latitude and longitude on Earth can be computed:

1) Position and Velocity of the satellite as a function of time

   a. $\vec{P}_s(t) = (x_{sat}, y_{sat}, z_{sat})_I$

      the position of a point "P" in an inertially fixed coordinate system "I" (e.g., equator and equinox of date) according to a time "t" in a standard time system (such as UTC).

   b. $\vec{V}_s(t) = (\dot{x}_{sat}, \dot{y}_{sat}, \dot{z}_{sat})_I$

      the velocity of the satellite in the same inertially fixed coordinate system "I" and at the same time "t".

2) Rotation of the Earth in the same time system, "t", in the inertially fixed coordinate system, I, with a rotation angle written G(t), commonly called the "Greenwich Hour Angle".

3) Misalignments of the instrument from the coordinate system in which the nadir position of the scanner points towards the subsatellite point and scanning is perpendicular to the velocity vector / position vector plane (see note below).

   a. the misalignments are constant instrument mounting and/or attitude errors

   b. misalignments of attitude errors as functions of time in the "t" system

4) The time difference between the "t" system and the time-tagging system of the satellite,(i.e., the onboard computer).

5) The timing and angular displacements of each data sample in the scanning cycle.

Notes on Misalignments of the Instruments:

The constant instrument mounting and/or time dependent attitude errors for NOAA satellites are minimized by the Attitude Determination and Control System (ADACS) onboard the spacecraft. This system orients the satellite in such a way that the nadir position of the scanning instruments always points toward the sub-satellite point. The residual errors of this system are reported in the data stream and could be used to correct the earth locations calculations in this paper. However, the handling of these misalignment errors, as a function of time, is somewhat complicated and beyond the intended scope of this algorithm description. These misalignment are included here for the sake of completeness.

SECTION 2--CALCULATING THE EARTH'S COORDINATES

Consider an inertial coordinate system, I, whose origin is the center of the earth (Figure 2.1). The line joining the center of the earth to the Vernal Equinox constitutes the X-axis. Z-axis is perpendicular to the equatorial plane and in the direction of the North pole. Y-axis is defined such that the vectors X, Y, Z constitute a right handed system (Y = Z x X). Let $\vec{P}_s$ and $\vec{L}$ be position vectors of the satellite and the scan spot respectively. Then the equation of the straight line through space, connecting the satellite location, P_s, to the scan spot, L, on the earth in the inertial coordinate system corresponding to the given data point can be expressed in equation 2.1.

$$\begin{bmatrix} x_e \\ y_e \\ z_e \end{bmatrix}_I = \begin{bmatrix} x_{sat} \\ y_{sat} \\ z_{sat} \end{bmatrix}_I + R \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix}_I \qquad 2\text{-}1$$

or

$$\vec{L}_I = \vec{P}_{sI} + R\vec{d}_I \qquad 2\text{-}2$$

R is the range or distance from satellite to the scan spot and (d_x,d_y,d_z) are the direction cosines of the line. The subscript I designates the inertial coordinate system. See Figure 2-1.

In order to solve for $\vec{L}\ (x_e,y_e,z_e)_I$ a new coordinate system, centered at the spacecraft, is established. The scanner mounting frame is taken as the origin. The X-axis is in the direction of the negative position vector. The Z-axis is along the spin axis of the mirror, positive in the direction of the velocity vector. The Y-axis is perpendicular to the velocity vector/position vector plane (i.e., in the direction of the orbital angular momentum vector) that completes a right handed system. The spacecraft will always "look down" along P or nadir, and the instrument mirror will scan perpendicular to the orbit plane(see Figure 2-2).

Let

$$\vec{P}_s = \text{satellite position} = (x_{sat},y_{sat},z_{sat})_I \qquad 2\text{-}3$$

$$\vec{V} = \text{satellite velocity} = (x_{sat},y_{sat},z_{sat})_I \qquad 2\text{-}4$$

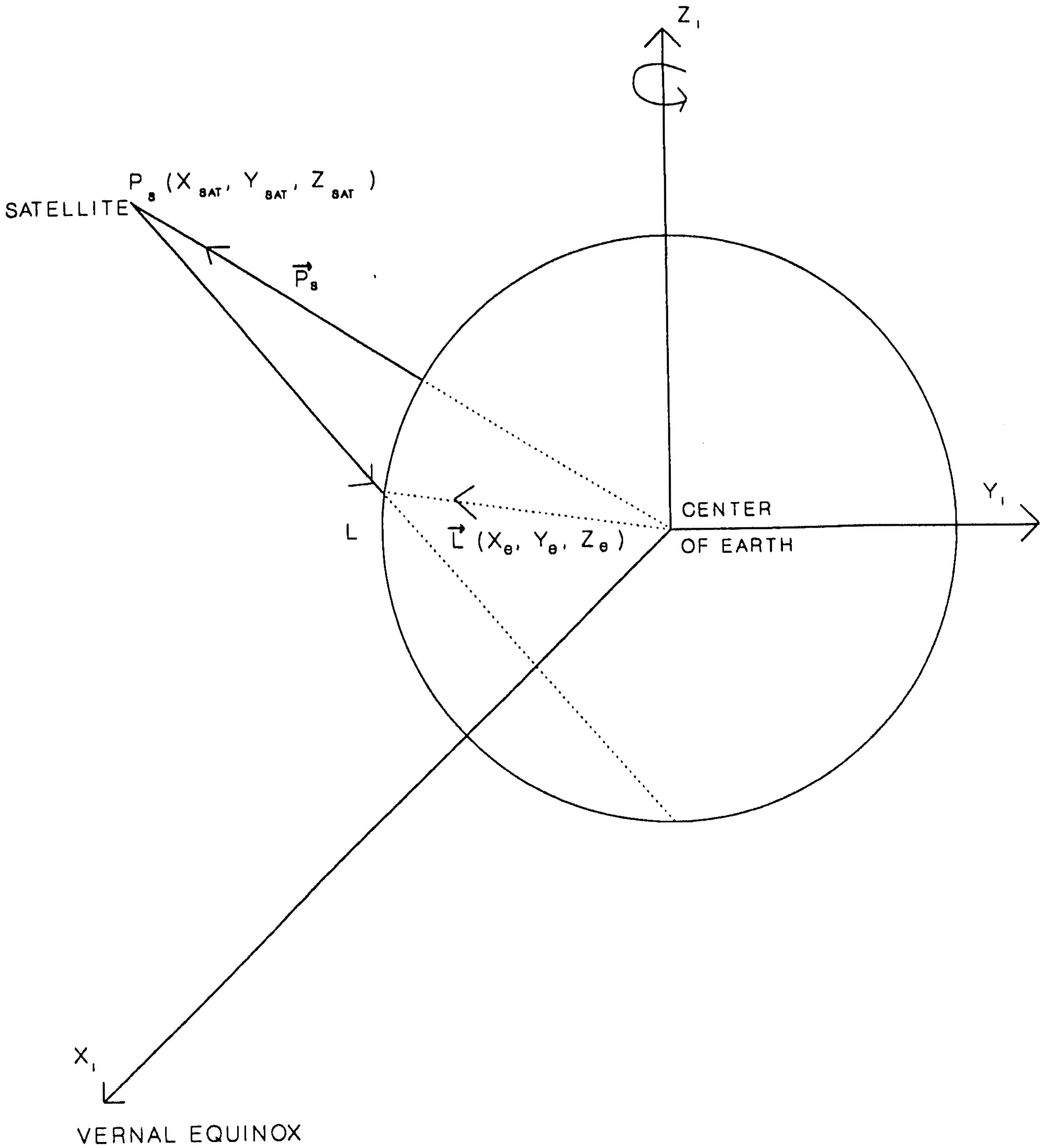
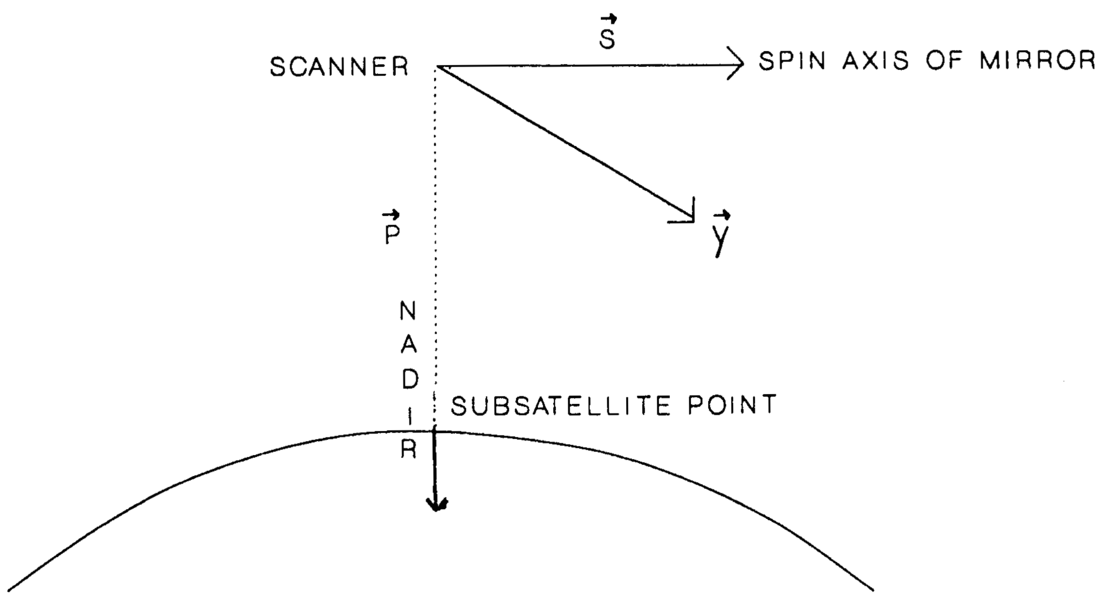

Z$_I$
P$_S$ (X$_{SAT}$, Y$_{SAT}$, Z$_{SAT}$)
SATELLITE
$\vec{P}_S$
Y$_I$
CENTER
OF EARTH
L
$\vec{L}$ (X$_e$, Y$_e$, Z$_e$)
X$_I$
VERNAL EQUINOX

FIGURE 2-1



SCANNER
$\vec{S}$
SPIN AXIS OF MIRROR
$\vec{P}$
$\vec{y}$
NADIR
SUBSATELLITE POINT

FIGURE 2-2

Define:

$$\hat{p} = \frac{-\vec{P}_s}{|\vec{P}_s|} = \left[\frac{-x_{sat}}{\sqrt{x_{sat}^2 + y_{sat}^2 + z_{sat}^2}}, \frac{-y_{sat}}{\sqrt{x_{sat}^2 + y_{sat}^2 + z_{sat}^2}}, \frac{-z_{sat}}{\sqrt{x_{sat}^2 + y_{sat}^2 + z_{sat}^2}} \right]$$

$$= (x_p, y_p, z_p)_I \qquad 2\text{-}5$$

x_p, y_p, and z_p are the direction cosines of the unit vector $\hat{p}$. (We emphasize here that $\hat{p}$ is in the opposite direction from the satellite position vector, $\vec{P}_s$.)

$$v = \frac{\vec{V}}{|\vec{V}|} = \left[\frac{\dot{x}_{sat}}{\sqrt{\dot{x}_{sat}^2 + \dot{y}_{sat}^2 + \dot{z}_{sat}^2}}, \frac{\dot{y}_{sat}}{\sqrt{\dot{x}_{sat}^2 + \dot{y}_{sat}^2 + \dot{z}_{sat}^2}}, \frac{\dot{z}_{sat}}{\sqrt{\dot{x}_{sat}^2 + \dot{y}_{sat}^2 + \dot{z}_{sat}^2}} \right]$$

$$= (v_x, v_y, v_z)_I \qquad 2\text{-}6$$

$$\hat{q} = (\hat{v} \times \hat{p}) \,/\, |\hat{v} \times \hat{p}|$$

$$= (v_y z_p - v_z y_p,\; v_z x_p - v_x z_p,\; v_x y_p - v_y x_p) \,/\, |\hat{v} \times \hat{p}|$$

$$= (x_q, y_q, z_q)_I \qquad 2\text{-}7$$

$$\hat{s} = \text{spin vector} = \hat{p} \times \hat{q} = \hat{p} \times (\hat{v} \times \hat{p})$$

$$= (y_p z_q - z_p y_q,\; z_p x_q - x_p z_q,\; x_p y_q - y_p x_q)$$

$$= (x_{spin}, y_{spin}, z_{spin})_I \qquad 2\text{-}8$$

Likewise, x_q, y_q, z_q and x_{spin}, y_{spin}, z_{spin} are direction cosines of the unit vectors $\hat{q}$ and $\hat{s}$ respectively.

In Figure 2-3, the scanner direction $\hat{d}$ is measured in the PQS system. The unit vector $\hat{d}$ is really $\hat{p}$ rotated about $\hat{s}$ by the scan angle $\sphericalangle$ as shown in Figure 2-3. It should be noted that the scan direction of the AVHRR instrument is opposite that of the TOVS instruments. Each of the TOVS instruments scan in the same direction, sun to anti-sun.

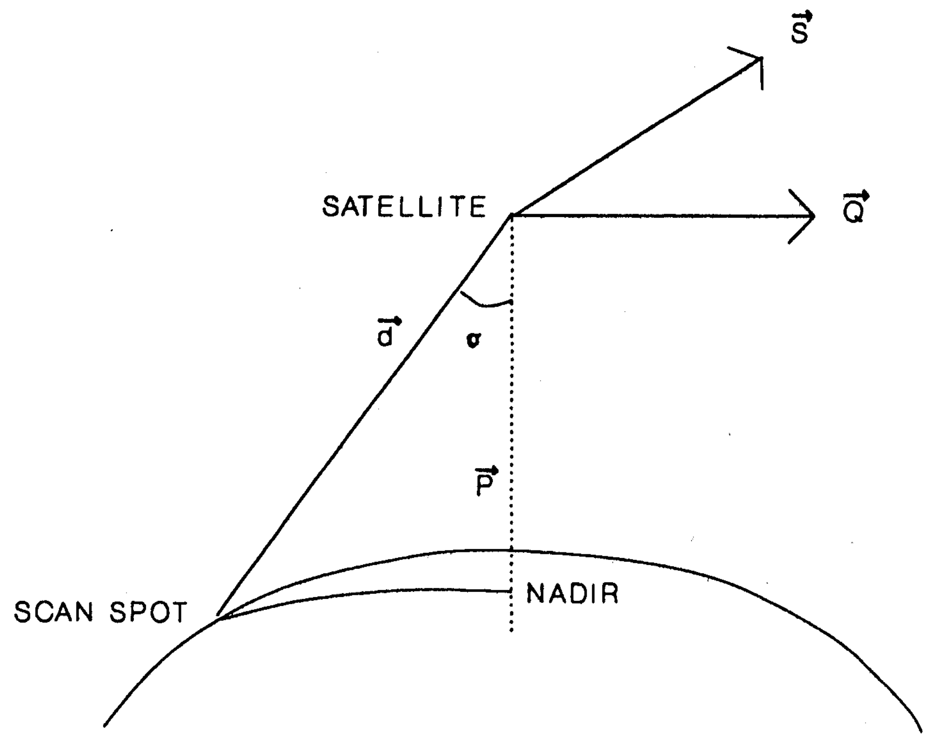


Figure 2-3

To transfer any vector, $\vec{A}$, from the PQS coordinate system to the inertial system,

$$\vec{A}_I = \begin{bmatrix} x_p & ,x_q & ,x_{spin} \\ y_p & ,y_q & ,y_{spin} \\ z_p & ,z_q & ,z_{spin} \end{bmatrix} \vec{A}_{PQS} \qquad 2\text{-}9$$

The unit vector $\hat{d}$ (along the scan direction) in the PQS system can be written as:

$$\hat{d}_{pqs} = \begin{bmatrix} \cos\sigma & \sin\sigma & 0 \\ -\sin\sigma & \cos\sigma & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \qquad 2\text{-}10$$

Using the coordinate transformation given by Eq. 2-9 and employing Eqs. (2-5), (2-7), and (2-8), the vector $\hat{d}_{PQS}$ can be written in the inertial system as

$$\hat{d}_I = \begin{bmatrix} x_p & x_q & x_{spin} \\ y_p & y_q & y_{spin} \\ z_p & z_q & z_{spin} \end{bmatrix} \begin{bmatrix} \cos\sigma & \sin\sigma & 0 \\ -\sin\sigma & \cos\sigma & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 \\ 0 \\ 0 \end{bmatrix} \qquad 2\text{-}11$$

Since $\vec{L}_I = \vec{P}_I + R\vec{d}_I$ and the point L lies on the surface of the Earth, it satisfies the equation

$$\frac{x_e^2}{A_e^2} + \frac{y_e^2}{A_e^2} + \frac{z_e^2}{B_e^2} = 1 \qquad 2\text{-}12$$

or

$$\frac{(x_{sat} + R\, d_x)^2}{A_e^{\,2}} + \frac{(y_{sat} + R\, d_y)^2}{A_e^{\,2}} + \frac{(z_{sat} + R\, d_z)^2}{B_e^{\,2}} = 1 \qquad 2\text{-}13$$

where A_e is the equatorial radius and B_e is the polar radius of the Earth(A_e =6378.144 km and B_e =6356.759 km are used at NOAA). Expanding terms, we have

$$\frac{x^2_{sat}}{A^2_e} + \frac{2\, x_{sat}\, R\, d_x}{A^2_e} + \frac{R^2 d^2_x}{A^2_e} + \frac{y^2_{sat}}{A^2_e} + \frac{2\, y_{sat} R\, d_y}{A^2_e} + \frac{R^2 d^2_y}{A^2_e} + \frac{z^2_{sat}}{B^2_e}$$

$$+ \frac{2\, z_{sat} R\, d_z}{B_e^{\,2}} + \frac{R^2 d_z^{\,2}}{B_e^{\,2}} = 1 \qquad 2\text{-}14$$

or, on simplification

$$AR^2 + BR + C = 0 \qquad 2\text{-}15$$

where

$$A = \frac{d_x^{\,2}}{A_e^{\,2}} + \frac{d_y^{\,2}}{A_e^{\,2}} + \frac{d_z^{\,2}}{B_e^{\,2}} \qquad 2\text{-}16$$

$$B = 2\left[\frac{x_{sat} d_x}{A_e^{\,2}} + \frac{y_{sat} d_y}{A_e^{\,2}} + \frac{z_{sat} d_z}{B_e^{\,2}} \right] \qquad 2\text{-}17$$

$$C = \frac{x^2_{sat}}{A_e^{\,2}} + \frac{y^2_{sat}}{A_e^{\,2}} + \frac{z^2_{sat}}{B_e^{\,2}} - 1 \qquad 2\text{-}18$$

Solving for R in equation 2-15,

$$R = \frac{-B \pm \sqrt{B^2 - 4AC}}{2A} \qquad 2\text{-}19$$

Equation 2-15 is a quadratic in R and, if the scan ray does in fact intersects the surface of the Earth (i.e., real and positive roots), B above should always be negative. Since A is always positive and C is positive (whenever the satellite is above the surface of the Earth) then the radical in 2-19 must be less than -B. Therefore, in the case of the radical being positive and less than -B, the scan ray intersects the Earth's surface at two points, the one closer to the satellite is visible to the satellite and the point away from the satellite is on the opposite side of the Earth. As such the smallest of the two solutions should be taken as the distance of the satellite from the scan spot.

In the equation 2-1

$$\begin{bmatrix} x_e \\ y_e \\ z_e \end{bmatrix}_I = \begin{bmatrix} x_{sat} \\ y_{sat} \\ z_{sat} \end{bmatrix}_I + R \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix}_I = \begin{bmatrix} x_{sat} + R\, d_x \\ y_{sat} + R\, d_y \\ z_{sat} + R\, d_z \end{bmatrix}_I \qquad 2\text{-}20$$

everything on the right hand side is known, so the coordinates of the scan point on the Earth in the inertial coordinate system can be calculated. All that remains is to rotate the Earth using time "t" obtained from the data sample to calculate a point fixed to the spinning Earth.

The Earth Centered Fixed coordinate system (ECF) rotates with the Earth. It has its center at the center of mass of the Earth with the following defined axes (see Figure 2-4):

x_{ECF} = the vector from the center of the Earth through Greenwich Meridian at the equator 2-21

y_{ECF} = 90 degree East longitude 2-22

z_{ECF} = North along the spin axis of the Earth 2-23

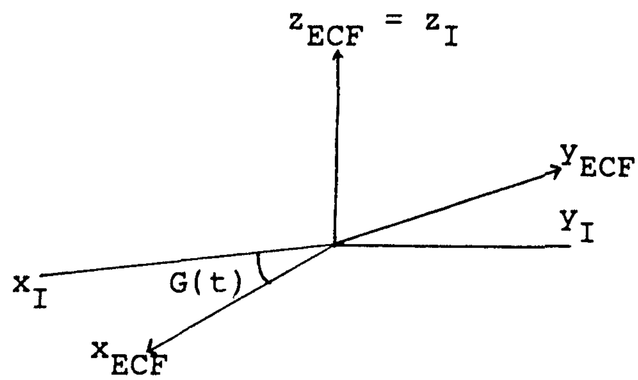


Figure 2-4

Next, we calculate the rotation of the ECF system (the rotating Earth) with respect to the inertially fixed (I) system. The angle G(t), is the rotation of the Greenwich meridian relative to the inertial x-axis. As a function of time,

$$G(t) = G_o + \dot{G}_1 * t_1 + \dot{G}_2 * t_2 \qquad 2\text{-}24$$

where

$G(t)$ = East longitude of Greenwich at time t (radians)

G_o = East longitude of Greenwich at the beginning of the year of interest (radians)

$\dot{G}_1$ = Increase in the longitude of Greenwich per day (= 0.0172027912 radians/day)

t_1 = Day of year for time of interest, t

$\dot{G}_2$ = Rotational rate of the Earth (= 6.300388098 radians/day)

t_2 = Fraction of a day for time of interest, t

Values of G_o can be computed or found in the "American Ephemeris and Nautical Almanac" for the current year (These should be updated as appropriate to account for leap seconds).

In order to transform inertial coordinates to Geocentric Earth Centered Fixed coordinates, the following equations are used:

$$x_{ECF} = x_I \cos(G(t)) + y_I \sin(G(t)) \qquad 2\text{-}25$$

$$y_{ECF} = y_I \cos(G(t)) - x_I \sin(G(t)) \qquad 2\text{-}26$$

$$z_{ECF} = z_I \qquad 2\text{-}27$$

When the "rotating" coordinates are found, the geocentric latitude, Θ, and longitude, Ø , can then be calculated according to equations 2-28 and 2-29.

$$\Theta = \tan^{-1}\left[\frac{z_{ECF}}{\sqrt{x_{ECF}^2 + y_{ECF}^2}}\right] \qquad 2\text{-}28$$

$$\emptyset = \tan^{-1}\left[\frac{y_{ECF}}{x_{ECF}}\right] \qquad 2\text{-}29$$

Geocentric latitude, Θ is the angle between the equatorial plane and a line joining the point, L, on the Earth's surface (scan spot) to the center of mass of the Earth. This is in contrast to the geodetic latitude, Θ' , which is the angle between the normal at L and the plane of the equator. The longitude , Ø , is the angle between two meridian planes both containing the axis of rotation; one of the planes contains L, and the other contains the Greenwich meridian.

Values of latitude given on standard maps are usually "geodetic" latitude. The geodetic latitude, Θ', has the following value:

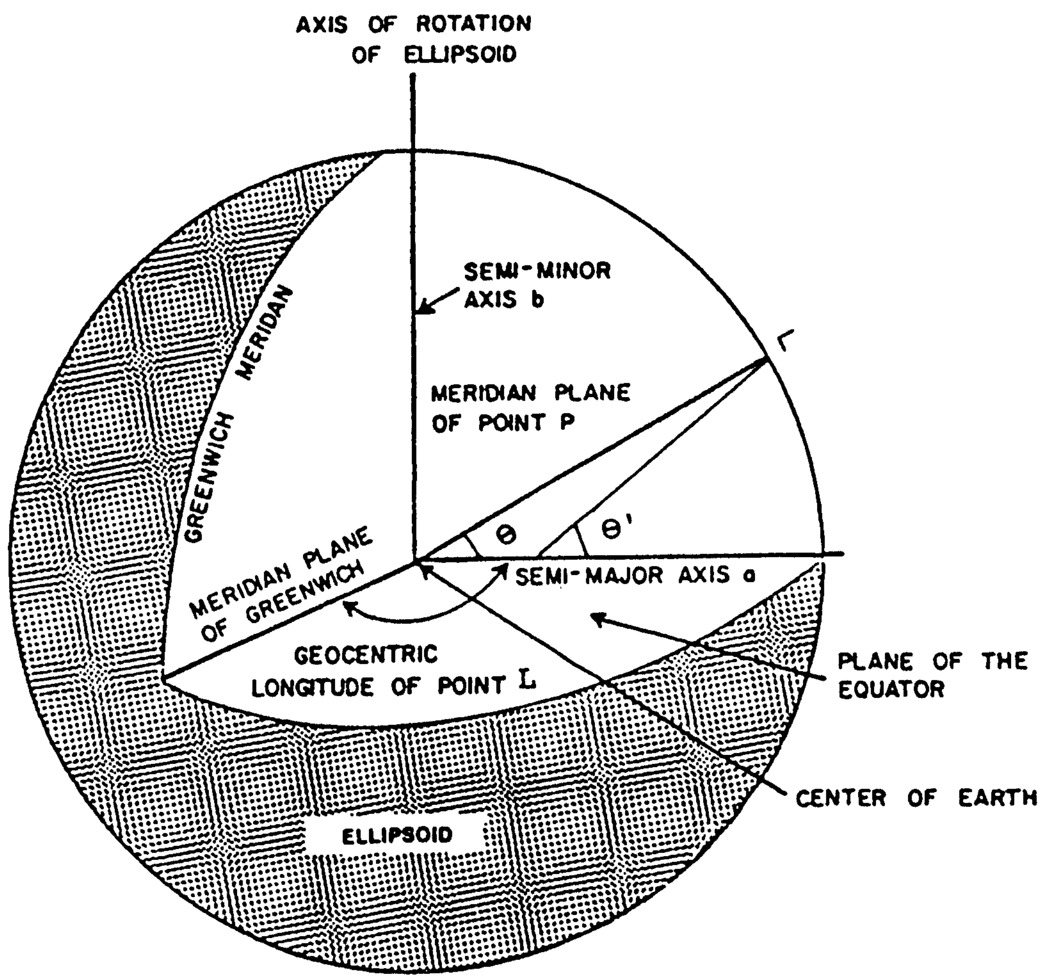
$$\Theta' = \tan^{-1}\left[\frac{z_{ECF}}{\sqrt{x_{ECF}^2 + y_{ECF}^2}\,(1 - e^2)}\right]^* \qquad 2\text{-}30$$

* Escobal, Methods of Orbit Determination, 1965, page 30.

where "e" is the eccentricity of the Earth's surface or

$$e = \sqrt{(A_e^2 - B_e^2)} \; / \; A_e$$

Figure 2-5 is a comparison of the geocentric and geodetic coordinates of point L.



COMPARISON OF GEOCENTRIC AND GEODETIC COORDINATES OF POINT L

Figure 2-5

SECTION 3--TIMING SYSTEMS ON THE SPACECRAFT AND THE EFFECTS OF ERRORS ON EARTH LOCATION

The primary scanning sensors for the NOAA polar satellites are the Advanced Very High Resolution Radiometer, (AVHRR), and the TIROS Operational Vertical Sounder, (TOVS), instruments. Both provide observational data which are processed by the satellite at specific (tagged) times. Since the position of the satellite and the size of the scan angle depends upon time, it is important that the timing of data is as accurate as possible, especially for computing Earth location. The spacecraft moves over the Earth at approximately 380 km per minute so a one second time error results in a location error of 6.5 km.

The AVHRR is an imaging system that scans across the Earth from one horizon to another by a continuous 360 degree rotation of a flat scanning mirror. Once per "minor" frame of telemetry data (a 360 degree rotation of the scan mirror), the count of the spacecraft clock is transmitted by an electronic pulse and a time - of - day is associated with the data frame (i.e. , "time-tagging"). However, the spacecraft clock may drift up to a second over a period of months. To adjust for this drift, the clock is periodically reset by ground command to stay synchronized with Greenwich Mean Time.

The on-board clock times events in units of "Standard Time Units" (STUs), which are 1.001602564 milliseconds. In the AVHRR data, 2048 samples from each of the five spectral channels of Earth view are generated in a scan line between nominally 5.3 and 63.1 STUs from the time tag (Table 3-1). If 34.2 STU from the time tag is accepted as the fixed time for scanning nadir, then any error in timing of the vast amount of data per scan line would be within 31.4 STU. With so much data in such a small amount of time, the error would be almost negligible.

For an instrument that slowly scans the Earth, the actual time for each sample should be calculated. The High Resolution Infrared Radiation Sounder (HIRS/2), the Microwave Sounding Unit (MSU), and the Stratospheric Sounding Unit (SSU), are instruments of the TIROS Operational Vertical Sounder (TOVS). Relative to the 32-second time code of TIROS Information Processor (TIP), the start of each instrument scan line is given by the major and minor frame numbers. The instruments begin the scan sequence at major frame 0, minor frame 0. However, the data that corresponds to the start of each instrument scan line occurs at different times (minor frames). The time between the start of each scan line; the step and dwell time, and the number of Earth view steps per line are all different for each TOVS instrument (Tables 3-2 and 3-3). As a result, there is a need for accurate timing synchronization of the instruments for more " exact " Earth location data.

SECTION 4--DISCUSSION

The algorithms given in this document are generic in the sense that they describe the process of Earth locating data from any scanning instrument on a three-axis stabilized polar orbiting satellite. Once the five types of information in Section 1 are given, accurate Earth location data can be obtained.

Table 3-1

AVHRR SCAN / CALIBRATION TIMING (Nominal Orbit)

Scan Timing Units*	Event
0 to 0.1	Line Sync
0.5 to 1.5	MIRP pre-cursor time
1.8	Space view start
1.9 to 3.5	Space sample
3.5 to 4.0	Ramp calibration
4.8	Space end - worst case early (S/C attitude)
5.3	Space end - nominal
5.8	Space end - worst case late
34.2	Nadir nominal
62.6	Space start - worst case early
63.1	Space start - nominal
63.6	Space start - worst case late
65.6 to 65.8	IR target temperature
65.8 to 66.0	Patch temperature
117.1	IR cal target - full view start
117.6to118.4	IR cal target sample
119.0	IR cal target - full view end
165.0to166.4	MIRP pre-cursor time

(Simulated Voltage Calibration Signals)

4.0 to 65.6	Simulated earth scene
117.6 to 118.4	Simulated calibration target

(Auxiliary Scan Timing)

1.8 to 1.9	1st space sample
3.4 to 3.5	2nd space sample
51.2 to 76.8	Back edge space blanking
160.0 to 12.9	Space window

*Scan Timing Unit = 1.001602564 milliseconds = 1.000 counts

Table 3-2

TIROS OPERATIONAL VERTICAL SOUNDER (TOVS)
INSTRUMENT SCAN TIMING PARAMETERS

Instrument	Time between start of each scan line	Step and dwell time	No. of Earth view steps per line	Delta Time*
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	2.0 sec

*Delta Time = the difference between the start of each scan and the center of the first dwell period.

Table 3-3

TOVS INSTRUMENT SCAN LINE TIMING

Scan Start Time (Seconds)		TIP major/minor frame HIRS/2	SSU	MSU
*TC (0/0)			0/0	0/19
	+6.4	0/1		
	+12.8	0/65		
	+19.2	0/129		
	+25.6	0/193		
		0/257		
*TC (1/0)		1/1	1/0	0/275
	+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.

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ERRATA

Revision to Appendix B - Revised Dec. 6, 1988

NOAA-G/10 AVHRR

Coefficients to Convert PRT Counts to Temperature (K)

PRT	A0	A1	A2	A3	A4
1	276.41	0.051275	1.363×10^{-6}	0	0
2	276.41	0.051275	1.363×10^{-6}	0	0
3	276.41	0.051275	1.363×10^{-6}	0	0
4	276.41	0.051275	1.363×10^{-6}	0	0

Visible-Channel Calibration Coefficients (Counts to Albedo)

Channel	G	I
1	0.10589	-3.7261
2	0.10579	-3.5692

Nonlinearity Correction Terms (K) for Channel 4

	Internal Target Temperature (C)		
Scene Temperature (K)	10	15	20
320	3.50	2.83	2.54
315	2.93	2.19	1.97
305	1.88	1.34	1.11
295	1.12	0.57	0.12
285	0.20	-0.15	-0.38
275	-0.46	-0.53	-1.08
265	-0.76	-0.93	-1.37
255	-1.33	-1.49	-1.77
245	-1.74	-2.09	-2.26
235	-1.79	-2.20	-2.53
225	-2.22	-2.51	-2.53
215	-2.58	-2.65	-2.80
205	-2.47	-2.88	-3.27

(Continued from inside front cover)

NESDIS 8 A Technique that Uses Satellite, Radar, and Conventional Data for Analyzing and Short-Range Forecasting of Precipitation from Extratropical Cyclones. Roderick A. Scofield and Leroy E. Spayd Jr., November 1984. (PB85 164994/AS)

NESDIS 9 Surface Cyclogenesis as Indicated by Satellite Imagery. Frank Smigielski and Gary Ellrod, March 1985. (PB85 191815/AS)

NESDIS 10 Detection of High Level Turbulence Using Satellite Imagery and Upper Air Data. Gary Ellrod, April 1985. (PB85 208452/AS)

NESDIS 11 Publications and Final Reports on Contracts and Grants, 1984. Nancy Everson, April 1985. (PB85 208460/AS)

NESDIS 12 Monthly Infrared Imagery Enhancement Curves: A Tool for Nighttime Sea Fog Identification off the New England Coast. E.M. Maturi and Susan J. Holmes, May 1985. (PB85 237725/AS)

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NESDIS 15 An Experimental Technique for Producing Moisture Corrected Imagery from 1 Km Advanced Very High Resolution Radiometer (AVHRR) Data. Eileen Maturi, John Pritchard and Pablo Clemente-Colon, June 1986. (PB86 24535/AS)

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NESDIS 21 The GVAR Users Compendium (Volume 1). Keith McKenzie and Raymond J. Komajda (MITRE Corp.), May 1988. (PB88-241476)

NESDIS 22 Publications and Final Reports on Contracts and Grants, 1987. Nancy Everson, April 1988. (PB88-240270)

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