3.0 AVHRR Level lb Data Base

This section contains more specific information on the AVHRR instrument. Section 3.1 describes the GAC data characteristics and the tape formats available (full copy, selective extracts, and unpacked format). Similarly, Section 3.2 contains specific information about LAC/HRPT data. Section 3.3 describes the calibration procedures for AVHRR data (both visible and thermal). **NESDIS has instituted several improvements to the original Level 1b format. The current enhancement and resulting data format is detailed in this section, with previous enhancements detailed in Appendices K and L.**

3.0.1 AVHRR Instrument Description

The Advanced Very High Resolution Radiometer (AVHRR) represents an improvement over the VHRR sensor flown aboard the ITOS series of operational satellites (the last of which was-NOAA-5). The AVHRR is a cross-track scanning system similar to the VHRR, but features four or five spectral channels, compared to just two for the VHRR. The AVHRR flown aboard TIROS-N, NOAA-6, NOAA-8, and NOAA-10 has four channels, and the AVHRR aboard NOAA-7, NOAA-9, NOAA-11, NOAA-12 and NOAA-13 has five channels. Subsequent satellites in the series will have five. Provision has been made for five channels in the data format for all satellites. Channel 5 contains a repeat of Channel 4 data, when only four different channels are available.

The spectral band widths (in micrometers) of the AVHRR channels for the TIROS-N series and those proposed for the remaining spacecraft are shown in Table 3.0.1-1. In addition, the Instantaneous Field of View (IFOV) in milliradians (mr) is included for each channel in Table 3.0.1-1. The spectral response functions for each satellite are contained in the figures in Section 1.4.

Table 3.0.1-1. Spectral band widths (micrometers) of the AVHRR.

Channel #	TIROS-N	NOAA-6,-8, -10	NOAA-7,-9, -11,-12,-14	NOAA-13	IFOV (mr)
1	0.55-0.90	0.58-0.68	0.58-0.68	0.58-0.68	1.39
2	0.725-1.10	0.725-1.10	0.725-1.10	0.725-1.0	1.41
3	3.55-3.93	3.55-3.93	3.55-3.93	3.55-3.93	1.51
4	10.5-11.5	10.5-11.5	10.3-11.3	10.3-11.3	1.41
5	Channel 4 repeated	Channel 4 repeated	11.5-12.5	11.4-12.4	1.30

The IFOV of each channel is approximately 1.4 mr leading to a resolution at the satellite subpoint of 1.1 km for a nominal altitude of 833 km. The scanning rate of the AVHRR is 360 scans per minute. The time within each scan line of AVHRR data represents IFOV #1.

The analog data output from the sensors is digitized on board the satellite at a rate of 39,936 samples per second per channel. Each sample step corresponds to an angle of scanner rotation of 0.95 mr. At this sampling rate, there are 1.362 samples per IFOV. A total of 2048 samples will be obtained per channel per Earth scan, which will span an angle of ∀55.4 degrees from the nadir (subpoint view).

The IR channels are calibrated in-flight using a view of a stable blackbody and space as a reference. No in-flight visible channel calibration is performed (although the spaceview is available as one reference point). Although these will vary from instrument to instrument, the design goals for the IR channels were an NEdT (Noise Equivalent differential Temperature) of 0.12 K (@ 300 K) and a S/N (signal to noise ratio) of 3:1 @ 0.5% albedo.

Users should be aware that AVHRR Channel 3 data on each-TIROS-N series spacecraft have been very noisy due to a spacecraft problem and may be unusable, especially when the satellite is in daylight.

As a result of the design of the AVHRR scanning system, the normal operating mode of the satellite calls for direct transmission to Earth (continuously in real-time) of AVHRR data. This direct transmission is called HRPT, for High Resolution Picture Transmission. In addition to the HRPT mode, about ten minutes of data may be selectively recorded on each of two recorders on board the satellite for later playback. These recorded data are referred to as LAC (Local Area Coverage) data. LAC data may be recorded over any portion of the world as selected by NOAA/NESDIS and played back on the same orbit as recorded or during a subsequent orbit. LAC and HRPT data have identical formats.

The full resolution data is also processed on board the satellite into GAC (Global Area Coverage) data which is recorded only for readout by CDA stations. GAC data contains only one out of three original AVHRR lines and the data volume and resolution are further reduced by starting with the third sample along the scan line, averaging the next four samples, and skipping the next sample. The sequence of average four, skip one, is continued to the end of the scan.

3.1 GAC Data

This section describes the data characteristics and magnetic tape format of Global Area Coverage (GAC) data. Section 3.1.1 contains the data characteristics and Section 3.1.2 contains the tape formats available. The tape formats include the full data set copy, the 16-bit unpacked format, and the selective extract subsets. **NESDIS has enhanced the Level 1b format for GAC and the most recent format (for data collected after Nov. 15, 1994) is included in this section. Previous formats are included in Appendices K and L.**

3.1.1 Data Characteristics

The processor on board the satellite samples the real-time AVHRR data to produce reduced resolution GAC data. Four out of every five samples along the scan line are used to compute one average value, and the data from only every third scan line are processed. As a result, the spatial resolution of GAC data near the subpoint is actually 1.1 km by 4 km with a 3 km gap between pixels across the scan line, although generally treated as 4 km resolution. All of the GAC data computed during a complete pass are recorded on board the satellite for transmission to Earth on command. The 10-bit precision of the AVHRR data is retained.

3.1.2 **Magnetic Tape Formats**

The data set format for full data set copies (all channels) is different from the format for selective extract subsets (selected channels). Sections 3.1.2.1 and 3.1.2.2 contain formats for GAC full data set copies and GAC selective extract subsets, respectively. Section 3.1.2.1 also includes an explanation of the 16-bit unpacked data format.

3.1.2.1 **Full Data Set Copies**

Each GAC data set contains an individual satellite recorder playback (or a portion of a playback if there is an interruption in the data due to noise, etc., in which case a single playback may be fragmented into a number of data sets). Data within each GAC data set is in chronological order with one logical record per scan. Two logical records are written per 6440-byte physical record. Each **logical** record contains 3220 bytes written in binary format as shown in Table 3.1.2.1-1. This table contains the format of the GAC data record which was implemented on Nov. 15, 1994.

Table 3.1.2.1-1. Format of GAC data record (implemented November 15, 1994).

Byte #	# of bytes	Contents
1-2	2	Scan line number from 1 to n
3-8	6	Time code (year, day, hour, minute, second)
9-12	4	Quality indicators (see Table 3.1.2.1-2)
13-52	40	Calibration coefficients
53	1	Number of meaningful zenith angles and Earth location points appended to scan (n)
54-104	51	Solar zenith angles
105-308	204	Earth location
309-448	140	Telemetry (HRPT minor frame format)
449-3176	2728	GAC video data
3177-3196	20	Additional decimal portion of 51 solar zenith angles
3197-3198	2	Clock drift delta in milliseconds x 2 + indicator: 0 = no time adjustment 1 = time adjustment
3199-3220	22	Spare

The **time code** consists of the year, Julian day, and UTC time of day in milliseconds. The year is contained in the first 7 bits of the first two bytes, the 9-bit day of year is right-justified in the first two bytes and the 27-bit millisecond UTC time of day is right-justified in the last four bytes. All other bits are zero. The time code will always have the same format for all Level 1b data sets.

The **quality indicators** are contained in four bytes. The first byte contains processing detected conditions and the last three bytes contain DACS quality indicators. If bit is one (on), then condition is true. The format of the quality bytes is contained in Table 3.1.2.1-2.

Table 3.1.2.1-2. Format of quality indicators.		
Byte #	**Bit #**	**Contents**
9	7	FATAL FLAG - Data should not be used for product generation
	6	TIME ERROR - A time sequence error was detected while Processing this frame
	5	DATA GAP - A gap precedes this frame
	4	DATA JITTER - Resync occurred on this frame
	3	CALIBRATION - Insufficient data for calibration
	2	NO EARTH LOCATION - Earth location data not available
	1	ASCEND/DESCEND - AVHRR Earth location indication of Ascending (=0) or descending (=1) data
	0	P/N STATUS - Pseudo Noise (P/N) occurred (=1) on the frame, data not used for calibration computations
10	7	BIT SYNC STATUS - Drop lock during frame
	6	SYNC ERROR - Frame Sync word error greater than zero
	5	FRAME SYNC LOCK - Frame Sync previously dropped lock
	4	FLYWHEELING - Flywheeling detected during this frame
	3	BIT SLIPPAGE - Bit slippage detected during this frame
	2	CHANNEL 3 SOLAR BLACKBODY CONTAMINATION (SBBC) INDICATOR 0 = no correction 1 = solar contamination corrected
	1	CHANNEL 4 SBBC INDICATOR 0 = no correction 1 = solar contamination corrected
	0	CHANNEL 5 SBBC INDICATOR 0 = no correction 1 = solar contamination corrected
11	7	TIP PARITY - In first minor frame
	6	TIP PARITY - In second minor frame
	5	TIP PARITY - In third minor frame
	4	TIP PARITY - In fourth minor frame
	3	TIP PARITY - In fifth minor frame
	0-2	SPARE
12	2-7	SYNC ERRORS - Number of bit errors in frame sync
	0-1	SPARE

The **calibration coefficients** consist of slope and intercept values for each of the five channels. The use of these coefficients is described in Section 3.3. Each value is stored in four bytes in the following order:

Channel 1 slope coefficient
Channel 1 intercept coefficient

Channel 2 slope coefficient
Channel 2 intercept coefficient
Channel 3 slope coefficient
Channel 3 intercept coefficient
Channel 4 slope coefficient
Channel 4 intercept coefficient
Channel 5 slope coefficient
Channel 5 intercept coefficient

A fixed number of **zenith angles** and **Earth location** points are appended to each scan. However, only the first n zenith angles and the first n Earth location points have meaningful values (n is defined in byte #53). The maximum number of points possible in a scan is 51. There are 409 points in a GAC scan line. However, the solar zenith angles and Earth location data (latitude and longitude) are sampled every eight points starting at the fifth point (5, 13, 21,..., 389, 397, 405). There are 51 possible solar zenith angles and Earth location values for each scan line. Each zenith angle requires one byte and is stored as degrees x 2. The latitude and longitude values are each stored in two-byte fields in 128ths of a degree (0 to 180E positive, 0 to 180W negative). See Section 2.0.1 for explanation of negative binary integers in two's-complement notation.

The **telemetry data** contain information which may be used to compute calibration coefficients when these are not included in the data. The telemetry data are stored in 140 bytes. The first 103 (10 bit) words are packed three (10 bit) words in four bytes, right justified. The last four byte group contains one (10 bit) word with 20 trailing bits. All unused bits are set to zero. The contents of these 103 words are contained in Table 3.1.2.1-4, which is the entire HRPT minor frame format. For more information, refer to NOAA Technical Memorandum NESS 107 entitled, *Data Extraction and Calibration of TIROS-N/NOAA Radiometers*.

The **GAC video data** consist of five readings (one for each channel) for each of the 409 points in a scan. They are packed as three (10-bit) samples in four bytes, right-justified. The last four-byte group contains two (10-bit) samples with 10 trailing zero bits. The first two bits of each four-byte group are zero. The 2,045 samples (409 points x 5 channels) are ordered scan point 1 (Channel 1, 2, 3, 4, 5), scan point 2 (Channel 1, 2, 3, 4, 5), etc., which is also known as Band Interleaved by Pixel (BIP). Note for TIROS-N, NOAA-6, NOAA-8, and NOAA-10, there is no sensor for Channel 5 so Channel 4 data is repeated in the Channel 5 position. The video data are stored in binary. See Figure 2.2.1-1 for the arrangement of the GAC channels (packed format).

Enhancements implemented on Sept. 7, 1994, included clock drift corrections and orbit parameters format change from IBM real numbers to scaled integers. These enhancements were made to both the TOVS and AVHRR Level 1b data. However, the new system did not function properly for AVHRR and was removed the same day with the old process resumed. Problems were encountered with the data record time codes in the GAC Level 1b data and NESDIS was forced to remove the updates from the AVHRR processing. Initially, NESDIS tried turning off the clock drift corrections, but time codes were still incorrect so the old process was resumed. The AVHRR data were processed with the old on-line earth location software until updates could be reinstalled. The following list of orbits were affected for the AVHRR:

NOAA-12

clock corrections on:
HRPT - S1542.E1550.B1722626.GC
LHRR - S1402.E1402.B1722525.GC (time sequence errors)
GHRR - S1359.E1539.B1722526.GC
LHRR - S1359.E1411.B1722525.GC
LHRR - S0934.E0946.B1722222.GC
HRPT - S1902.E1914.B1722828.GC

clock corrections off:
GHRR - S1723.E1900.B1722728.GC
GHRR - S1534.E1727.B1722627.GC
LHRR - S1729.E1738.B1722727.GC
LHRR - S1652.E1658.B1722627.GC
LHRR - S1532.E1543.B1722626.GC

NOAA-11

clock corrections on:
HRPT - S1722.E1734.B3068787.GC
GHRR - S1542.E1719.B3068687.GC
GHRR - S1353.E1547.B3068586.GC
LHRR - S1516.E1527.B3068586.GC
LHRR - S1342.E1353.B3068585.GC

NOAA-9

clock corrections on:
GHRR - S0825.E1019.B5019596.WI
GHRR - S0128.E0321.B5019092.WI

On November 15, 1994, NESDIS re-implemented the following changes to the Level 1b GAC data stream: 1) Current orbital parameters in the header were switched to four byte integers rather than 8 byte floating point numbers. 2) Calibration algorithms were updated to remove the effects of sunlight impinging on the internal calibration target (Solar Blackbody Contamination - SBBC). SBBC detection indicators were added to the AVHRR data record quality indicators. 3) Navigation software was updated to remove satellite clock errors from the data time codes. 4) Navigation quality control parameters were provided in the header record.

An anomalous dip occurs in the AVHRR Channel 3 blackbody counts between 70S and 80S latitude shortly after the spacecraft comes out of eclipse but only for sun angles less than 25 degrees above the horizon. This dip, which produces an anomalous increase in the calibration gain coefficient, has been attributed to reflected sunlight impinging onto the internal calibration target (ICT). Evidence suggests that this dip may have occurred in all of the afternoon satellites in the current NOAA series.

When SBBC is detected, the slope and intercept are replaced by the running average of the twenty-four previous good values. If no checking is done, the value is set to zero. Currently, only NOAA-11 shows this contamination. On Dec. 1, 1993, AVHRR gain anomaly corrections were implemented for NOAA-11 beginning with data set:
NSS.GHRR.NH.D93335.S1408.E1554.B2673132.GC. However, for 24 hours, the following datasets for NOAA-12 were affected:
NSS.GHRR.ND.D93335.S1303.E1457.B1324445.GC through
NSS.GHRR.ND.D93336.S0535.E0729.B1325455.WI.

The drift in the onboard TIP clock for each polar satellite introduces a timing error in the instrument data time codes. This error is reflected as an along-track Earth location error. SOCC measures this error and corrects it periodically to maintain a maximum of approximately ∀ 0.5 seconds. Under Phase II of the navigation enhancements, SOCC error corrections will be used to adjust the instrument time codes and eliminate its Earth location error effect. The adjusted values will be stored in the scan data record and an indicator flag will be set for users. Consequently, users are apprized of the magnitude of the adjustment and also have the flexibility of removing the correction, if needed.

This enhancement also results in improved navigation parameters. The operational quality control (QC) of Earth location data will be improved. A nadir Earth location tolerance value will be used to indicate when the Earth location data are beyond an acceptable range. An independent calculation of the latitude and longitude values at nadir will be compared to the operational values. This comparison will be performed approximately four times per orbit. If differences are beyond the acceptable tolerance range, a "BAD EARTH LOCATION" flag is set, and a message identifying the scan is generated. The Earth location tolerance range will be provided in the header record as an integer, scaled to 0.1 km (ranges from 0.1 to 25.5). If no checking is done, the value is set to zero.

See Table 2.0.4-2 for the current format of the Level 1b header record which was implemented Nov. 15, 1994.

The 16-bit unpacked format for full copy GAC data has the same format as the "packed" data described above except for the video data. The video data values for each channel are contained in the 10 least significant bits and the 6 most significant bits are zero filled. The record length is 4540 bytes. Table 3.1.2.1-3 contains the format for the unpacked GAC video data (for all five channels).

Table 3.1.2.1-3. Format of unpacked GAC video data (five channels).

Point #	Byte #	Bit #	Content
1		10-15	Zero filled
	449-450	0-9	1st value of Channel 1
		10-15	Zero filled
	451-452	0-9	1st value of Channel 2

	453-454	0-9	1st value of Channel 3
	455-456	0-9	1st value of Channel 4
	457-458	0-9	1st value of Channel 5
2	459-460	0-9	2nd value of Channel 1
...	...	...	...
409	4537-4538	0-9	409th value of Channel 5
	4539-4540	0-15	Zero filled (so record will be on word boundary)

Table 3.1.2.1-4. HRPT Minor Frame Format.

Function	No. of Words	Word Position	Bit No. Plus Word Code & 1 2 3 4 5 6 7 8 9 10 Meaning
Frame Sync	6	1	1 0 1 0 0 0 0 1 0 0
		2	0 1 0 1 1 0 1 1 1 1
		3	1 1 0 1 0 1 1 1 0 0 See Note 1.
		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 Addresses; Bit 4=MSB, Bit7=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 zeroes; spare 1, 0, 1 Bits 4-10; Part of binary msec of day count; Bit 4=MSB of msec count
		11	Bits 1-10; Part of binary msec of day count;
		12	Bits 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 AHVRR Channel #2
		15	Ramp Calibration AHVRR Channel #3
		16	Ramp Calibration AHVRR Channel #4
		17	Ramp Calibration AHVRR Channel #5
		18	PRT Reading 1
		19	PRT Reading 2 See Note 2.
		20	PRT Reading 3
		21	AVHRR Patch Temperature

		22	0 0 0 0 0 0 0 0 0 1 Spare
Internal Target Data (AVHRR)	30	23	10 words of internal target data from each AVHRR channel 3, 4 and 5. These data are time multiplexed as chan 3 (word 1), chan 4 (word 1), chan 5 (word 1), chan 3 (word 2), chan 4 (word 2), chan 5 (word 2), etc.
Space Data (AVHRR)	50	53 thru 102	10 words of space scan data from each AVHRR channel 1,2,3,4, and 5. These data are time multiplexed as chan 1 (word 1), chan 2 (word 1), chan 3 (word 1), chan 4 (word 1), chan 5 (word 1), chan 1 (word2), chan 2 (word 2), chan 3 (word2), chan 4 (word 2), chan 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
TIP data	520	104 thru 623	The 520 words contain five frames of TIP data (104 TIP data words/frame). See Note 3. 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
		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
		...	... See Note 4
		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
Earth Data (AVHRR)	10,240	751	Chan 1 - Sample 1
		752	Chan 2 - Sample 1
		753	Chan 3 - Sample 1
		754	Chan 4 - Sample 1
		755	Chan 5 - Sample 1
		756	Chan 1 - Sample 2
		...	...See Note 5
		10,985	Chan 5 - Sample 2047
		10,986	Chan 1 - Sample 2048
		10,987	Chan 2 - Sample 2048
		10,988	Chan 3 - Sample 2048
		10,989	Chan 4 - Sample 2048

		10,990	Chan 5 - Sample 2048
Auxiliary Sync	100	10,991	1 1 1 1 1 0 0 0 1 0
		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
		...	...See Note 6
		11,089	0 1 1 1 1 1 0 0 0 0
		11,090	1 1 1 1 0 0 1 1 0 0

Notes:
1) First 60 bits from 63 bit PN generator started in the all 1's state. The generator polynomial is X6+X5+X2+X+1
2) AVHRR Internal Target Temperature Data. Three readings from one of the four platinum resistance thermometers (PRT). Each of these words is a 5 channel subcom, 4 words of IR data plus a subcom reference value.
3) 104 words includes 103 words of the AMSU frame plus the first word of TIP.
4) Derived by inverting the output of a 1023 bit PN sequence provided by a feedback shift register generating the polynomial: X10+X5+X2+X+1. The generator is started in all 1's state at the beginning of word 7 of each minor frame.
5) 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.
6) Derived from the non-inverted output of a 1023 bit PN sequence provided by a feedback shift register generating the polynomial: X10+X5+X2+X+1. The generator is started in the all 1's state at the beginning of word 10,991.

3.1.2.2 **Selective Extract Subsets**

The following sections describe the data set format for GAC data sets which have been produced using channel selection (16-bit format) or by choosing the 8-bit format offered by SAA. Section 3.1.2.2.1 describes the 16-bit format and Section 3.1.2.2.2 describes the 8-bit format. SSB is aware of a problem which affects the format of both the 8-bit and the 16-bit (unpacked) data for the Level 1b AVHRR. The problem involves the omission of 22 bytes of extra precision information containing the Solar Zenith angle and clock drift delta in each record. These bytes were added to the Level 1b data record (on October 24, 1992) after the extraction software was written, and were therefore not included. If users of the 8- or 16-bit format data want this extra precision data, they are only available if the user requests packed format output from the SAA=s online archive of Level 1b data sets.

3.1.2.2.1 **16-bit format**

When channels are selected for GAC data, the format is identical to that described in Section 3.1.2.1 except for the GAC video data. In the GAC video data, the selected channels are packed in consecutive half words (16 bits). The data values for each channel selected are contained in the ten least significant bits and the remaining six most significant bits are zero filled. The GAC video data have the format shown in Table 3.1.2.2.1-1 when two channels are selected.

Table 3.1.2.2.1-1. Format for GAC video data (two channels).			
Point #	**Byte #**	**Bit #**	**Content**
1	449-450	10-15	Zero-filled.
		0-9	First value, First selected channel.
2	451-452	10-15	Zero-filled.
		0-9	First value, Second selected channel.
3	453-454	10-15	Zero-filled.
		0-9	Second value, First selected channel.
4	455-456	10-15	Zero-filled.
		0-9	Second value, Second selected channel.
...	...	...	...
409	2083-2084	10-15	Zero-filled.
		0-9	409th value, Second selected channel.

The total record length for the two channel selective GAC would be 4168 bytes (2 x 2084, since there are 2 scans/record) with no spare bytes trailing. Similarly, if one channel was selected the record would contain 820 bytes (409 points/scan + 1 (to make a whole word) x 2 bytes/point) for the GAC video, which would make the entire record 2536 bytes long (2 x 1268).

3.1.2.2.2 8-bit format

When the 8-bit format is chosen (from SAA), the normal 10-bit video data are truncated to 8-bits. (The 2 least significant bits of data are dropped.) The format is identical to that described in Section 3.1.2.1 except for the GAC video data. In the GAC video data, the data are packed in consecutive bytes (four data points per 32-bit word). Because there are an odd number of data points (409) in the video data, the last three bytes are zero filled in order to pad the data to a full word boundary. The GAC video data have the format shown in Table 3.1.2.2.2-1.

Table 3.1.2.2.2-1. 8-bit format for GAC video data (one channel).				
Word #	**Point #**	**Byte #**	**Bit #**	**Content**
113	1	449	0-7	First video data value (First scan).
	2	450	0-7	Second video data value (First scan).
	3	451	0-7	Third video data value (First scan).
...	...	...	...	...
214	408	856	0-7	408th video data value (First scan).
215	409	857	0-7	409th video data value (First scan).
		858	0-7	Zero filled.
		859	0-7	Zero filled.
		860	0-7	Zero filled.
216		860-762	0-15	Scan line number (Second scan).
...	...	...	...	...
327	1	1309	0-7	First video data value (Second scan).

	2	1310	0-7	Second video data value (Second scan).
...	...	...	...	...
429	408	1716	0-7	408th video data value (Second scan).
430	409	1717	0-7	409th video data value (Second scan).
		1718	0-7	Zero filled.
		1719	0-7	Zero filled.
		1720	0-7	Zero filled.

The record length for one channel selected GAC in the 8-bit format would be 1720 bytes (2 x 860, since there are 2 scans/record) with the last three trailing bytes zero filled.

Similarly, a user may select channels and request them in the 8-bit format. The output physical record length information for GAC is included in Table 3.1.2.2.2-2.

Table 3.1.2.2.2-2. Output physical record length for GAC (in bytes).

Packed: 6440 bytes

# Channels Selected	**Unpacked: (in bytes)**	
	8-bit Format	**16-bit Format**
1	1720	2536
2	2536	4168
3	3352	5808
4	4168	7440
5	4992	9080

3.2 <u>LAC/HRPT Data</u>

This section describes the data characteristics and magnetic tape formats of Local Area Coverage (LAC)/High Resolution Picture Transmission (HRPT) data. Section 3.2.1 contains the data characteristics and Section 3.2.2 contains the tape formats available. The tape formats include the full data set copy, selective extract subsets, and the 16-bit unpacked format which is available for all channels. **NESDIS has enhanced the Level 1b format for LAC/HRPT and the current format (for data collected after Nov. 15, 1994) are included in this section. Previous formats are included in Appendices K and L.**

3.2.1 <u>Data Characteristics</u>

The AVHRR data are digitized to 10-bit precision. The digitized data are both transmitted from the satellite in real-time as High Resolution Picture Transmission (HRPT) data, and selectively recorded on board the satellite for subsequent playback as Local Area Coverage (LAC) data. A maximum of ten minutes of LAC data may be recorded per orbit.

In the event that a user would want SOCC to schedule an AVHRR LAC orbit over a specific area (out of direct readout range of Wallops Island or Fairbanks CDA's), the procedures and requirements are contained in Section 1.3.

3.2.2 Magnetic Tape Formats

The data set format for full data set copies (all channels) is different from the format for selective extract subsets (selected channels). Sections 3.2.2.1 and 3.2.2.2 contain formats for LAC/HRPT full data set copies and selective extract subsets, respectively. Section 3.2.2.1 also includes an explanation of the 16-bit unpacked data format.

3.2.2.1 Full Data Set Copies

Each HRPT data set contains the HRPT data from one CDA contact. Each LAC data set contains an individual satellite recorder playback (10 minutes of recorded HRPT data). The data within each data set are in chronological order with one scan contained in two physical records. The records are written in binary and contain 7,400 bytes in the format shown in Table 3.2.2.1-1. This table includes the enhancements made on Nov. 15, 1994.

Table 3.2.2.1-1. Format of LAC/HRPT data record (implemented November 15, 1994).

Record #	Byte #	# Bytes	Content
1	1-2	2	Scan line number
	3-8	6	Time code
	9-12	4	Quality indicators
	13-52	40	Calibration coefficients
	53	1	Number of meaningful zenith angles and Earth location points appended to scan
	54-104	51	Solar zenith angles
	105-308	204	Earth location
	309-448	140	Telemetry (header)
	449-7400	6952	LAC/HRPT video data
2	10-15704	6704	LAC/HRPT video data
	6705-6724	20	Additional decimal portion of 51 solar zenith angles
	6725-6726	2	Clock drift delta in milliseconds x 2 + indicator: 0 = no time adjustment 1 = time adjustment
	6727-7400	674	Spare

The content and order of the LAC/HRPT records is identical to the GAC record described in Section 3.1.2.1, with the exception of three fields. The three exceptions are the solar zenith angles, Earth location, and LAC/HRPT video data. Also, note that the calibration coefficients are ordered Channels 1, 2, 3, 4, and 5, the same as GAC data. See Section 3.1.2.1 for translation of the **time code**.

There are 2,048 points in a LAC/HRPT scan line. The **solar zenith angle** and **Earth location data** (latitude and longitude) are sampled every 40 points starting at point 25 (25, 65, 105,..., 1945, 1985, 2025). There are 51 possible zenith angles and Earth location values for each scan line. Each solar zenith angle requires one byte and is stored as degrees x 2. The latitude and longitude values are each stored in two-byte fields in 128ths of a degree (0 to 180E positive, 0 to 180W negative). See Section 2.0.2 for explanation of negative binary integers in two's-complement notation.

The **LAC/HRPT video data** contain five values (one for each channel) for each of the 2,048 points in a scan (i.e., 2,048 points x 5 channels = 10,240 samples). The data are packed as three (10-bit) words in four bytes, right-justified. The last four-byte group contains two leading zero bits, one (10-bit) word, and 20 trailing zero bits. The first two bits of each four-byte group are zero. The LAC/HRPT video data is ordered scan point 1 (Channel 1, 2, 3, 4, 5), scan point 2 (Channel 1, 2, 3, 4, 5), etc., which is also known as Band Interleaved by Pixel (BIP). The video data are stored in binary. See Figure 2.2.1-1 for the arrangement of the LAC/HRPT channels (packed format).

The 16-bit unpacked format for full copy LAC/HRPT data has the same format as the "packed" data described above, except for the video data. The video data are unpacked into two 16-bit words in every four bytes. The data values for each channel are contained in the ten least significant bits and the six most significant bits are zero filled. The format for unpacked LAC/HRPT video data (for all five channels) is contained in Table 3.2.2.1-2.

Table 3.2.2.1-2. Format of unpacked LAC/HRPT video data (five channels).

Point #	Record #	Byte #	Bit #	Content
1	1	449-450	10-15 0-9	Zero filled 1st value of Channel 1
		451-452	10-15 0-9	Zero filled 1st value of Channel 2
		453-454	0-9	1st value of Channel 3
		455-456	0-9	1st value of Channel 4
		457-458	0-9	1st value of Channel 5
2	1	459-460	0-9	2nd value of Channel 1
...	...	...	...	...
1002	1	10463-10464	0-9	1002nd value of Channel 3
1002	2	1-2	0-9	1002nd value of Channel 4
...	...	...	...	...
2048	2	10463-10464	0-9	2048th value of Channel 5

Note that one scan of unpacked LAC/HRPT data is contained in two 10,464 byte records. (The decision was made to divide into two records because a 20,928 byte record may have been too large for some smaller computers to handle.)

3.2.2.2 Selective Extract Subsets

This section describes the data set format for LAC/HRPT data sets which have been produced using channel selection (16-bit format) or by choosing the 8-bit format offered by SAA. Section 3.2.2.2.1 describes the 16-bit format and Section 3.2.2.2.2 describes the 8-bit format for LAC/HRPT data. SSB is aware of a problem which affects the format of both the 8-bit and the 16-bit (unpacked) data for the Level 1b AVHRR. The problem involves the omission of 22 bytes of extra precision information containing the Solar Zenith angle and clock drift delta in each record. These bytes were added to the Level 1b data record (on October 24, 1992) after the extraction software was written, and were therefore not included. If users of the 8- or 16-bit format data want this extra precision data, they are only available if the user requests packed format output from the SAA=s online archive of Level 1b data sets.

3.2.2.2.1 <u>16-bit format</u>

When channels are selected for LAC/HRPT data, the format is identical to that described in Section 3.2.3.1 except for the LAC/HRPT video data. For the LAC/HRPT video data, the selected channels are packed in consecutive halfwords (16 bits). The data values for each channel selected are contained in the ten least significant bits and the remaining six most significant bits are zero filled. If one channel is selected, the LAC/HRPT video data have the format shown in Table 3.2.2.2.1-1.

Table 3.2.2.2.1-1. Format for LAC/HRPT video data (one channel).

Point #	Byte #	Bit #	Content
1	449-450	10-15	Zero filled.
		0-9	First value of selected channel.
2	451-452	10-15	Zero filled.
		0-9	Second value of selected channel.
3	453-454	10-15	Zero filled.
		0-9	Third value of selected channel.
...	...	...	...
2048	4543-4544	10-15	Zero filled.
		0-9	2048th value of selected channel.

Note that all LAC/HRPT data set scans require two records regardless of the number of channels selected. For an example of two channel selection for LAC/HRPT data, use the GAC two-channel format in Section 3.1.2.2 as a guide.

3.2.2.2.2 <u>8-bit format</u>

When the 8-bit format is chosen (from SAA), the normal 10-bit video data are truncated to 8-bits. (The 2 least significant bits of data are dropped.) The format is identical to that described in Section 3.2.2.1 except for the LAC/HRPT video data. In the LAC/HRPT video data, the data are packed in consecutive bytes (four data points per 32-bit word). The LAC/HRPT video data have the format shown in Table 3.2.2.2.2-1.

Table 3.2.2.2.2-1. Format for LAC/HRPT video data (one channel).

Point #	Record #	Byte #	Bit #	Content
1	1	449	0-7	First video data value.
2	1	450	0-7	Second video data value.
3	1	451	0-7	Third video data value.
...	...	...	...	...
2048	1	2498	0-7	2048th video data value.

Similarly, a user may select channels and request them in the 8-bit format. The output record length information for LAC/HRPT is included in Table 3.2.2.2.2-2.

Table 3.2.2.2.2-2. Output physical record length for LAC/HRPT (in bytes).		
Packed: 7400 bytes		
# Channels Selected	**Unpacked:**	
	8-bit Format (in bytes)	**16-bit Format (in bytes)**
1	1,248	2,272
2	2,272	4,320
3	,296	6,368
4	4,320	8,416
5	5,344	10,464

3.3 Calibration of AVHRR Data

AVHRR thermal data values (Channels 3 and 4, and 5 when present) may be converted to temperature values; and AVHRR visible data values (Channels 1 and 2) may be converted to albedos, by the calibration procedures described herein. For more detail on how NESDIS calibrates the TIROS-N/NOAA-A through -J radiometers, refer to NOAA Technical Memorandum NESS 107 which is entitled *Data Extraction and Calibration of TIROS-N/NOAA Radiometers*.

The format and order of the calibration coefficients is described in Sections 3.1.2.1 and 3.2.2.1 for GAC and LAC/HRPT data, respectively. Once the calibration coefficients have been extracted (see Appendix B), they must be scaled. The slope values must be divided by 2^{30} and the intercept values by 2^{22}. The scaled slopes and intercepts may now be used as described below.

New calibration formulae and techniques for the NOAA-14 AVHRR may be examined in depth in a paper by NOAA/NESDIS/ORA=s Dr. C.R. Nagaraja Rao which can be accessed on the Internet at URL: http://orbit-net.nesdis.noaa.gov/ora/text/nrao02.txt. As of November 1996, monthly AVHRR calibration coefficient updates for NOAA-14 Channels 1 and 2 have also been included at URL: http://psbsgi1.nesdis.noaa.gov:8080/EBB/ml/niccal.html, as well as incorporated into the Level 1b datasets. Another source of calibration information for the NOAA polar orbiters can be found on a NOAA/NESDIS home page located at URL: http://www.osdpd.noaa.gov/PSB/CALIB/home.html This page contains calibration quality control monitoring for NOAA-14 and the NOAA KLM series.

3.3.1 **Thermal Channel Calibration**

The scaled thermal channel slope values are in units of mW/(m^2-sr-cm^{-1}) per count and the intercept is in mW/(m^2-sr-cm^{-1}).

The radiance measured by the sensor (Channel i) is computed as a linear function of the input data values as follows:

$$E_i = S_i C + I_i \qquad 3.3.1\text{-}1$$

where E_i is the radiance value in mW/(m^2-sr-cm^{-1}), C is the input data value (ranging from 0 to 1023 counts), and S_i and I_i are respectively the scaled slope and intercept values. The conversion to brightness temperature from radiance is performed using the inverse of Planck's radiation equation:

$$T(E) = \frac{C_2 \nu}{\ln\left(1 + \frac{C_1 \nu^3}{E}\right)} \qquad 3.3.1\text{-}2$$

where T is the temperature (K) for the radiance value E, υ is the central wave number of the channel (cm^{-1}), and C_1 and C_2 are constants (C_1=1.1910659 x 10^{-5} mW/(m^2-sr-cm^{-4}) and C_2=1.438833 cm-K).

Note that the temperatures obtained by this procedure are not corrected for atmospheric attenuation, etc.

The central wave numbers (cm^{-1}) for Channels 3, 4, and 5 as a function of temperature can be found for each satellite in Section 1.4.

The following example shows how the raw data values may be converted to temperature values. Let the slope and intercept values for Channels 3 and 4 have the following values:

$$S_4 = -171966195$$
$$S_3 = -1638538$$
$$I_4 = 667267071$$
$$I_3 = 6365951$$

Since these values are scaled they must be divided by the proper scale factor. The slope values must be divided by 2^{30}; therefore,

$$S_4 = -\frac{171966195}{2^{30}} = -.160156 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)overcount}$$

$$S_3 = -\frac{1638538}{2^{30}} = -.001526 \frac{\text{mW/(m}^2\text{-sr-cm}^{-1}\text{)}}{\text{count}}$$

Similarly, the intercept values must be divided by 2^{22}:

$$I_4 = \frac{667267071}{2^{22}} = 159.088867 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

$$I_3 = \frac{6365951}{2^{22}} = 1.517761 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

Now, the video data for Channels 3 and 4 must be extracted from the tape. Assume the data values for spot n are:

$$\text{Channel } 3 = 857$$

$$\text{Channel } 4 = 513$$

For spot n+1, assume the values are:

$$\text{Channel } 3 = 858$$

$$\text{Channel } 4 = 515$$

To convert these values into radiance values, the calibration coefficients must be applied to the data using Equation 3.3.1-1. Therefore, for Channel 4:

$$E_n = -.160156 \text{ x } 513 + 159.088867 = 76.92883 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

$$E_{n+1} = -.160156 \text{ x } 515 + 159.088867 = 76.60853 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

And for Channel 3:

$$E_n = -.001526 \text{ x } 857 + 1.517761 = .209979 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

$$E_{n+1} = -.001526 \text{ x } 858 + 1.517761 = .208453 \text{ mW/(m}^2\text{-sr-cm}^{-1}\text{)}$$

These radiance values can be converted to temperatures by use of Equation 3.3.1-2. Assuming $\upsilon = 2638.05$ cm^{-1} for Channel 3 and $\upsilon = 912.01$ cm^{-1} for Channel 4, the radiance values correspond to 273.94 K and 274.84 K for Channels 3 and 4, respectively.

3.3.1.1 **<u>Non-Linearity Corrections (TIROS-N through NOAA-12)</u>**

Pre-launch 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 thermistors (PRTs). Radiances for each channel can be computed from those temperatures by the methods described in Section 3.3.1. Data are collected as the laboratory blackbody is cycled through a sequence of temperature plateaus approximately 10K apart between 175K and 320K, 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 degrees C for the AVHRR) 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 pre-launch tests to determine operating characteristics of the instruments, such as their signal-to-noise ratios, stability, linearity of response, and gain (output in digital counts per unit incident radiance). However, these characteristics cannot be expected to remain the same in orbit as they were before launch. One reason is that the thermal environment varies with position in the orbit, causing gains to vary orbitally. Also, instrument components age in the several years that usually elapse between the time of the pre-launch test 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. This provides data in the microwave and infrared channels for determining signal-to-noise and radiometric slopes and intercepts. Unfortunately, there are no on-board calibration sources for the visible region. Therefore, the pre-launch calibration must be used for the visible channels.

There are other coefficients necessary for in-orbit calibration that must be derived from pre-launch test data. These include the coefficients to account for the non-linearity in the AVHRR's response, which will be described later in this section.

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, because channels 4 and 5 use HgCdTe detectors, their calibrations are slightly non-linear.

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-radiance look-up tables described in each spacecraft's respective subsection of Section 1.4.

To account for non-linearities, NESDIS provides corrections in each spacecraft's respective subsection of Section 1.4 that are added to the scene brightness temperatures computed from the linear calibration. The corrections are tabulated against scene temperatures, and there is a separate table for each channel and each baseplate temperature. NESDIS derives 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 applied 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 counts from the "view" of the cold target (whose radiance is assumed to be zero) and the internal target (whose radiance was determined in step b., the linear calibration equation is determined.

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 described in NESS 107, Appendix A.

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

It should be noted that the procedures outlined above were **not** used for TIROS-N, NOAA-6, NOAA-7 and NOAA-8. For these spacecraft, 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 of 225-310 K.

3.3.1.2 Non-Linearity Corrections (NOAA-13 and successors)

With the launch of NOAA-13, NESDIS changed its derivation of the non-linearity correction in the calibration of AVHRR Channels 4 and 5. The linear calibration now uses a negative, non-zero value for the radiance of space, instead of the former value of zero. This method makes the dependence of the correction terms on the internal calibration target negligible.

NESDIS continues to supply tables of brightness temperature correction terms for the non-linearity. These correction terms are valid only when applied to "linear" brightness temperatures based on the negative radiance of space. Since the correction terms no longer vary with the internal calibration target temperature, the user does not need to interpolate on the internal calibration target temperature. Otherwise, the user applies the non-linearity corrections as before.

NESDIS also supplies an alternate method of handling the-non-linearity which can be applied to radiances instead of brightness temperatures. For each instrument and for each channel, three coefficients (A, B and D) of a quadratic equation are supplied in Section 1.4 for all spacecraft from NOAA-13 on. The following quadratic equation can be used to compute the corrected radiance, RAD from the "linear" radiance, R_{lin}:

$$RAD = A \times R_{lin} + B \times R_{lin}^{2} + D \qquad 3.3.1.2\text{-}1$$

This new treatment of the non-linearity plot corrections should be an improvement over the previous method because: 1) it is less sensitive to noise in the thermal/vacuum test data, 2) it gives the user a choice of correcting either the radiance or the brightness temperatures, and 3) it is being applied retrospectively in the NOAA/NASA Pathfinder program (see URL: http://daac.gsfc.nasa.gov/DATASET_DOCS/avhrr_dataset.html for more information) to generate a consistent time series of AVHRR radiances from 1981 to the present for use in studies of climate change. Making the same method operational at NESDIS will eliminate a source of inconsistency between the Pathfinder data set and future observations.

3.3.2 Visible Channel Calibration

The scaled visible channel slope values are in units of percent albedo/count for slope and in percent albedo for intercept.

The percent albedo measured by the sensor channel$_i$ is computed as a linear function of the input data value as follows:

$$A_i = S_i C + I_i \qquad 3.3.2\text{-}1$$

where A_i is the percent albedo measured by channel i, C is the input data value in counts, and S_i and I_i are respectively, the scaled slope and intercept values. The visible channels (1 and 2) are calibrated using Equation 3.3.2-1 to obtain the percent albedo.

The calibration procedure is very similar to the linear calibration procedure described above for the thermal channels. The pre-launch slopes and intercepts for AVHRR Channels 1 and 2 are shown in Table 3.3.2-1.

Table 3.3.2-1. Pre-launch slopes and intercepts for AVHRR Channels 1 and 2.

Satellite	S1	I1	S2	I2
TIROS-N	0.1071	-3.9	0.1051	-3.5
NOAA-6	0.1071	-4.1136	0.1058	-3.4539
NOAA-7	0.1068	-3.4400	0.1069	-3.488
NOAA-8	0.1060	-4.1619	0.1060	-4.1492
NOAA-9	0.1063	-3.8464	0.1075	-3.8770

NOAA-10	0.1059	-3.5279	0.1061	-3.4766
NOAA-11	0.0906	-3.730	0.0900	-3.390
NOAA-12	0.1042	-4.4491	0.1014	-3.9925
NOAA-13	0.1076	-3.9747	0.1035	-3.8280
NOAA-14*	0.1081	-3.8648	0.1090	-3.6749
* Beginning with NOAA-14 in November 1996, the slopes and intercepts for AVHRR Channels 1 and 2 were computed monthly, incorporated into the Level 1b datasets and posted on the NOAASIS home page (URL: http://psbsgi1.nesdis.noaa.gov:8080/EBB/ml/niccal.html).				

The two visible channels on the AVHRR instrument are calibrated prior to launch using the following procedure: the calibration source is a large-aperture integrating sphere equipped with 12 calibrated quartz-halogen lamps. These lamps were carefully selected to match each other as closely as possible in spectral output and operating current. The sphere is then calibrated with all 12 lamps on against a National Institute of Standards and Technology secondary standard of spectral irradiance. The ratio of the output of n lamps to that of 12 lamps is also determined. This yields the spectral output of the sphere when any number of lamps, n, is on. By varying the number of bulbs which are turned on, a calibration curve from dark level to a maximum of 12 lamps output can be obtained.

The following computations must be made in order to present the calibration in terms of percent albedo vs. radiometer output. First, the spectral output of the sphere is integrated with the spectral response function of the AVHRR channel to yield an effective radiance for the spectral band for 12 lamps operating. This is then multiplied by the appropriate K_n factor to convert to n lamps. This is described by equation 3.3.2-2:

$$N_L = K_n \int_{\lambda_1}^{\lambda_2} C(\lambda)\,\phi(\lambda)\,d\lambda \qquad 3.3.2\text{-}2$$

where,

N_L = effective radiance as seen by the channel in the appropriate spectral band.

K_n = the factor to convert to radiance for n lamps.

$C(\lambda)$ = calibrated spectral radiance of the sphere with 12 lamps on.

λ = wavelength, in the spectral region λ_1 to λ_2

$\varphi(\lambda)$ = the measured spectral response of the channel being calibrated.

Similarly, if one takes the solar irradiance at the top of the atmosphere and performs a similar calculation, the results are shown in Equation 3.3.2-3.

$$N_s = \frac{1}{\pi} \int_{\lambda_1}^{\lambda_2} S(\lambda)\, \phi(\lambda)\, d\lambda \qquad 3.3.2\text{-}3$$

where,

N_s = effective radiance of the radiometer viewing reflected sunlight.

$S(\lambda)$ = spectral irradiance viewed at the top of the atmosphere.

$\Phi(\lambda)$ = spectral response function of the channel.

The resultant N_s represents what would be “seen” from space with a 100% reflecting, diffuse surface when the solar zenith angle is zero.

$$A = \frac{N_L}{N_S} \times 100 \qquad 3.3.2\text{-}4$$

Thus, the percent □lbedos A is calculated using Equation 3.3.2-4:
To convert from percent □lbedos A to spectral radiance R (in W/(m^2-micrometer-sr)), the following equation must be used:

where,

$$R = A \left[\frac{F}{100\, \pi\, W} \right] \qquad 3.3.2\text{-}5$$

F = integrated solar spectral irradiance, weighted by the spectral response function of the channel in W/m^2.

W = equivalent width of the spectral response function in micrometers .

Table 3.3.2-2 contains the values of W and F derived from *Neckel and Labs (1984)*.

Table 3.3.2-2. Values of W and F for AVHRR Channels 1 and 2.

Satellite	W1	F1	W2	F2
TIROS-N	0.325	443.3	0.303	313.5
NOAA-6	0.109	179.0	0.223	233.7
NOAA-7	0.108	177.5	0.249	261.9
NOAA-8	0.113	183.4	0.230	242.8
NOAA-9	0.117	191.3	0.239	251.8
NOAA-10	0.108	178.8	0.222	231.5
NOAA-11	0.113	184.1	0.229	241.1
NOAA-12	0.124	200.1	0.219	229.9

NOAA-13	0.121	194.09	0.243	249.42
NOAA-14	0.136	221.42	0.245	252.29

Although the pre-launch calibration procedures are quite extensive, it is not sufficient to rely on these calibration data alone to achieve the desired accuracy from AVHRR data. The instrument characteristics cannot be expected to remain the same in orbit as they were before launch. This situation occurs primarily because the thermal environment varies with the satellite's position in orbit, causing the output in digital counts to vary. Initially, Channels 1 and 2 are observed to degrade in orbit because of the outgassing and launch associated contamination (Rao and Chen, 1994). Continued exposure to the harsh space environment (Brest and Rossow, 1992) is also a contributing factor. In addition, the instrument's components age in the years that elapse between the pre-launch tests and actual launch. Furthermore, this aging process continues during the two or more years that the instrument is typically operational.

Unfortunately, there are no onboard calibration sources for the visible channels and the pre-launch calibration must be used or the user must rely on ground-based experimental techniques for deriving the calibration equations. NOAA and the National Aeronautics and Space Administration (NASA) recognized the inherent problems with the AVHRR data and collaborated to form the NOAA/NASA AVHRR Pathfinder program. The main objective of the Pathfinder program is to reprocess and rehabilitate the long term records of AVHRR and AVHRR-derived geophysical products from 1981 to the present. As part of this program, the AVHRR Pathfinder Calibration activity has determined the in-orbit degradation of the AVHRR visible and near-infrared channels (Rao et al., 1993a). After applying the appropriate formulae to account for in-orbit degradation, most (if not all) spurious trends are removed from the long term records of AVHRR and AVHRR-derived geophysical products. Currently, these formulae exist for the AVHRRs flown on NOAA-7, NOAA-9 , NOAA-11 and NOAA-14 spacecraft.

Post-launch calibration information for NOAA-7, NOAA-9 and NOAA-11 can be accessed on the NOAASIS website at URL: http://www.osdpd.noaa.gov/EBB/noaasis.html or see Appendix G for more information.