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DATA EXTRACTION AND CALIBRATION OF TIROS-N/NOAA RADIOMETERS

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[Note. This document is an extract of NESS 107. This includes only the part of Chapter 5 in NESS 107 covering calibration of AVHRR data, and Appendix A. The techniques described here were discontinued after NOAA-12 (the NOAA-13 spacecraft failed). Beginning with NOAA-14 and later spacecraft, the calibration technique is fully described in the "NOAA-K,L,M User's Guide" which is available on line.

The references to "Appendix B" are the calibration coefficients that were published and distributed with the launch of each new NOAA spacecraft. These coefficients for all satellites through NOAA-14 are available on line at http://noaasis.noaa.gov/NOAASIS/ml/calibration.html Additions were made to "Appendix B" after each launch.

NESS 107 is considered obsolete and no longer available from NOAA. When NESS 107 was originally published, it was widely distributed to national hydrometeorological agencies, military meteorological services, and universities with meteorological and remote sensing faculties, throughout the world. Users wishing to find this publication may inquire at such offices in their local area.]

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, a*s 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. Header words 18, 19, and 20 each contain a five-point subcommutation of the outputs of the four Platinum Resistance Thermistors (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+l	**PRI1**
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. 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:

$$T_i(K) = \sum_{j=0}^{4} a_{ij}\bar{x}_i^j$$

where $\bar{x}_i$ 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 PRTj. For example, the conversion of PRT$_1$, count value into temperature (K) is

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

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

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

Where $\bar{T}$ 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 $\bar{T}$ 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

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

where Nsp is the radiance of deep space, N_T is the radiance when the instrument views its internal radiance calibration target, and X_{SP} and 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 $\bar{N}_T$ and $\bar{X}_T$ as contributors to the uncertainty in the derived value of M. The Intercept (I) is calculated for each channel from the equation: $I = N_{SP} - M\bar{X}_{SP}$

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, Nsp, 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 applied to the AVHRR response, in counts, when it viewed its internal blackbody. This determines the radiance 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, and the 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.

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 and 2 , 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 (N) and intercept (I) deduced from pre-launch calibration data are given in Appendix B. The calibration is traceable to NBS secondary 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 N 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 N. There is scant evidence presently available on the dependence of M on time-in-orbit. The evidence suggests that the degradation i.n N 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.

[Additional documentation of this effect and new data for the NOAA-14 AVHRR visible channels is available at http://noaasis.noaa.gov/NOAASIS/ml/calibration.html]

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

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

where F is the integrated solar spectral irradiance 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.

APPENDIX A. Temperature-to-Radiance Conversion

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

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

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

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

The constants C_1 and C_2 are 1.1910659x10^{-5} mW/(m^2 sr cm^{-4}) and 1.438833 K/cm^{-1}, respectively.

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

(A2)
$$N(T) = B(\nu_C, T)$$

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 instruments, Eq.(Al) is evaluated numerically by

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

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 ten degrees (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, the centroid wavenumber ν_c, is replaced with a new value $\nu *$ chosen to force Eq.(A2) to reproduce the exact radiance from Eq.(A3). The value of $\nu *$ 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).