MEMORANDUM FOR The Record

FROM Xiangqian Wu, Instrument Scientist, NOAA/NESDIS/STAR
Jerry Sullivan, Short and Associated
Fangfang Yu, ERT, Inc.

SUBJECT Calibration Parameter Input Data Sets for NOAA-N' AVHRR (A308)

DATE September 19, 2008: Initial release
November 05, 2008: Amended with IR calibration parameters
December 05, 2008: Add *A*' and *B*' in Table 3, $1+b_1$ in Table 4, and modified Section 13 accordingly. Removed SRF print-out.

The Advanced Very High Resolution Radiometer, Series Number 308 (S/N A308), is scheduled for launch with NOAA-N' in February 2009. This memorandum documents the derivation of Calibration Parameter Input Data Set (CPIDS) that supports the satellite instrument calibration in the Ground System operation. Unless specified otherwise, the data are derived from the ITT Handbook for this instrument (ITT 2008). The actual CPIDS is summarized at the end.

SOLAR REFLECTIVE CHANNELS

1. Relative Spectral Responses

The relative spectral responses (RSRs) for the six AVHRR channels of NOAA-N' (A308) are plotted in Appendix A and are available in digital format from http://www.star.nesdis.noaa.gov/smcd/spb/fwu/solar_cal/spec_resp_func/index.html. These are measured system responses summarized in Table 4.5-7/8/9/10/11/12 of the Handbook. We have verified these data according to the test procedure described in Section 4.2 and the similar results in Table 4.5-1/2/3/4/5/6 of the Handbook. Also plotted in Appendix A are the RSRs for the same channel of other Flight Modules to show the similarity among these channels.

2. Extraterrestrial Solar Spectral Irradiance

In the past, NESDIS and ITT used the extraterrestrial solar spectral irradiance by Neckel and Labs (1984) as modified by Rossow et al (1985). For AVHRR/3, which has a new channel at 1.6 μm, that data became inadequate. Data sets of unknown source were used for NOAA-15/16/17. For NOAA-18, we noted that Wehrli (1985) compiled the data published by several researchers, including Brasseur and Simon (1981) for 200-310 nm, Arvesen et al (1969) for 310-330 nm, Nickel and Labs for 330-870 nm, and Smith and Gottlieb (1974) for 870-10,000 nm. A portion of the compilation over the spectrum of 200-3000 nm at 0.5 nm resolution has been used since NOAA-18. It is available from http://www.star.nesdis.noaa.gov/smcd/spb/fwu/solar_cal/solrad/twrc_dat_200_3000.html. This set of extraterrestrial solar spectral irradiance was chosen for consistency.

3. Equivalent Band Width

The equivalent width for each channel, *w*, is the width, in unit of length (μm), of a hypothetical channel whose RSR is unity (one) for in-band wavelengths, zero for out-of-band wavelengths, and has the same area under its RSR as the actual channel. It is computed from:

$$w = \int_{\lambda_{\min}}^{\lambda_{\max}} \Phi(\lambda) d\lambda \qquad (1)$$

where Φ is RSR, λ is wavelength, λ_{min} and λ_{max} are the cut-on and cut-off wavelength. Nominally, λ_{min} and λ_{max} are defined as the first encounter where $\Phi(\lambda)$ is less than 0.001 when moving from the peak RSR towards the two wings[1]. While measurements at other wavelength are necessary to prove the absence of out of band RSR, they normally are irrelevant in this computation. The value of 0.001 is chosen since AVHRR is digitized at 10-bit so values less than 1/1000 of the peak value are likely to be dominated by noise. While the choice of λ_{min} and λ_{max} is somehow arbitrary, it is consistent with A305 on METOP-A. Prior to that, the values of λ_{min} and λ_{max} were fixed to values corresponding to RSR of 0.5 for A301 on NOAA-16.

4. In-Band Solar Irradiance

The in-band solar irradiance for each channel, *H*, is the total amount of solar irradiance, in unit of irradiance (W m^{-2}), that the channel at the top of the atmosphere (TOA) would receive when the Sun is at zenith and at its mean distance from the Earth (unity Astronomical Unit or 1 AU). It is computed from:

$$H = \int_{\lambda_{\min}}^{\lambda_{\max}} E_{sun}(\lambda) \Phi(\lambda) d\lambda \qquad (2)$$

where $E_{sun}(\lambda)$ is extraterrestrial solar spectral irradiance.

5. Effective Central Wavelength

The effective central wavelength, λ_e, is the weighted mean wavelength, in unit of length (μm), weighted by the spectral solar irradiance received by the sensor. It is computed from:

[1] Paul's memo

$$\lambda_e = \frac{\int_{\lambda_{\min}}^{\lambda_{\max}} E_{sun}(\lambda)\Phi(\lambda)\lambda d\lambda}{\int_{\lambda_{\min}}^{\lambda_{\max}} E_{sun}(\lambda)\Phi(\lambda) d\lambda} \quad (3)$$

This definition for central wavelength was chosen for consistency.

6. Results

Table 1: Cut-on and cut-off wavelength, equivalent band width, effective central wavelength, and in-band solar irradiance for NOAA-N' AVHRR (A308).

NOAA-19 A308 Channel	Integration Limits Min (μm)	Max (μm)	Equivalent Width (μm)	Effective Wavelength (μm)	In-Band Irradiance ($W.m^{-2}$)
1	0.579	0.693	0.077580	0.636153	126.773
2	0.701	1.012	0.217591	0.832045	225.698
3A	1.574	1.647	0.043610	1.610063	10.6560

7. Pre-Launch Calibration Coefficients

The pre-launch calibration coefficients are derived from instrument response to known radiance during pre-launch tests, summarized in Table C-6/7/8. of the Handbook. The procedure of derivation is described in a Technical Memorandum (http://www.star.nesdis.noaa.gov/smcd/spb/fwu/solar_cal/AVHRR3_Prelaunch_CalCoeff.html). The NOAA-N' (NOAA-19) AVHRR (A308) pre-launch calibration equations are:

Ch_1_lo = 0.055091*count - 2.1415, count<496.43 (4-1)
Ch_1_hi = 0.16253 *count - 55.863, count>496.43 (4-2)

Ch_2_lo = 0.054892*count - 2.1288, count<500.37 (4-3)
Ch_2_hi = 0.16352 *count - 56.445, count>500.37 (4-4)

Ch_3_lo = 0.027174*count - 1.0881, count<496.11 (4-5)
Ch_3_hi = 0.18798 *count - 81.491, count>496.11 (4-6)

THERMAL EMISSIVE CHANNELS

8. Conversion of PRT Count to Temperature

Four Platinum Resistance Thermometers (PRTs) were embedded in the AVHRR Internal Calibration Target (ICT, or blackbody) that reports its temperature in counts C_{PRT}. The PRT temperature, T_{PRT}, is derived from these counts as the following:

$$T_{PRT}^{i} = d_0^i + d_1^i C_{PRT} + d_2^i C_{PRT}^2 \quad (5)$$

where i=1, 2, 3, 4 are PRT index and coefficients d's are provided by ITT in Table 3.1.2-1 of the handbook, for converting signal in volt to temperature in Celsius. To obtain the corresponding coefficients that convert signal in count to temperature in Kelvin, we note that 1024 counts is equivalent to 6.4 volt and 0C is 273.15K. So we add 273.15 to d_0, multiply d_1 with (6.4/1024), and multiply d_2 with $(6.4/1024)^2$. The following coefficients should be used in Eq. (5):

Table 2: Coefficients for Eq. (5) to convert PRT signal in count to PRT temperature in Kelvin.

PRT #	d_0	d_1	d_2
ICT 1	276.6067	0.051111	1.405783E-06
ICT 2	276.6119	0.051090	1.496037E-06
ICT 3	276.6311	0.051033	1.496990E-06
ICT 4	276.6268	0.051058	1.493110E-06

9. Computation of ICT temperature

In orbit, a different PRT is sampled each scan line. After all four PRTs are sampled, the PRT count for the fifth scan line is set to a value less than 15 (nominally 0) to indicate the frame synchronization. The ICT temperature is computed as a weighted average of the four PRT temperatures**:**

$$T_{PRT} = \frac{\sum_{i=1}^{4} w_i T_{PRT}^{i}}{\sum_{i=1}^{4} w_i} \quad (6)$$

The weights are initially set to 1 for all PRTs. It is part of the CPIDS data.

10. Band Correction

The Planck's function converts blackbody temperature $T_{BB} = T_{PRT}$ to monochromatic radiance R_{mono}, however the AVHRR thermal infrared channels measurements, R_{BB}, is the radiance within a finite band of spectrum, over which both spectral response function $\Phi(\lambda)$ and monochromatic radiance R_{mono} varies. Therefore users are advised to use the following procedure (Weinreb et al 1981) to convert between band radiance R_{BB} and blackbody temperature T_{BB}:

Brightness Temperature to Radiance

$$T_{BB}^{*} = A + B * T_{BB} \quad (7)$$

$$R_{BB} = \frac{c_1 \nu_c^3}{\exp\left[\frac{c_2 \nu_c}{T_{BB}^*}\right] - 1} \tag{8}$$

Radiance to Brightness Temperature

$$T_{BB}^* = \frac{c_2 \nu_c}{\ln\left[\frac{c_1 \nu_c^3}{R_{BB}} + 1\right]} \tag{9}$$

$$T_{BB} = \frac{T_{BB}^* - A}{B} = B' T_{BB}^* + A' \tag{10}$$

where

c_1 = 1.1910427 x 10^{-5} (mW · m^{-2} · sr^{-1} · cm^4)
c_2 = 1.4387752 (cm · K)
T_{BB} = Brightness temperature (K)
ν_c = Centroid wavenumber (cm^{-1}), to be elaborated in the next section.
A, *B*: Band correction coefficients supplied by this memo (next section).

The band correction coefficients are derived by regression. For T_{BB} between 180K and 340K in increment of 0.1K, R_{BB} is computed as:

$$R_{BB} = \int_{\lambda_{\min}}^{\lambda_{\max}} B(\nu_c, T_{BB}) \Phi(\nu) d\nu \tag{11}$$

from which T^*_{BB} is computed by (9). We then assume that

$$T_{BB}^* = A + B * T_{BB} + \varepsilon \tag{12}$$

and find the coefficients *A* and *B* through linear regression that minimize the residual ε.

11. Centroid Wavenumber

The R_{BB} computed from Eq. (11), and consequently the T^*_{BB} from Eq. (9), depend on the choice of a representative wavenumber of the band, for example the area or moment center wavenumber provided by ITT in Table 4.4-4/5/6 of the Handbook. Each choice of wavenumber results in a set of regression coefficients *A* and *B*, with the associated residual ε. It was found that slightly different choice of wavenumber may reduce the residual ε. To find the optimal wavenumber, referred to as centroid wavenumber ν_c, we start with ν_c = int(ν_a) (the area central wavenumber truncated to the nearest integer) and perform the regression for $\nu = \nu_c$-10, ν_c-9, …, ν_c+10; this reveals the ν_c that minimizes ε.

We then repeat the process by performing the regression for $\nu = \nu_c$-1, ν_c-0.9, …, ν_c+1; this reveals the ν_c, accurate to 0.1 cm^{-1}, that minimizes ε. This could be repeated to refine ν_c to 0.01 cm^{-1}, but that results are not used because the reduction in ε is negligible.

Table 3: Centroid wavenumber for Channel 3B, 4, 5 of NOAA-N' AVHRR (A308).

Channel	ν_c	A	B	A'	B'
3B	2670.0	1.67396	0.997364	1.678384	1.002643
4	928.9	0.53959	0.998534	0.540382	1.001468
5	831.9	0.36064	0.998913	0.361032	1.001088

12. Nonlinear Correction

The Mercury-Cadmium-Telluride (HgCdTe) detectors used for 10.8 μm and 11.9 μm channels (4 and 5, respectively) have a nonlinear response to radiance. To correct for this effect, the radiance calibration (Sullivan, 1999) takes the following forms:

$$R_{LIN} = R_{space} + \frac{\left(R_{BB} - R_{space}\right)}{\left(C_{BB} - C_{space}\right)}\left(C_{earth} - C_{space}\right) \tag{13}$$

$$R_{COR} = b_0 + b_1 R_{LIN} + b_2 R_{LIN}^2 \tag{14}$$

$$R_{earth} = R_{LIN} + R_{COR} \tag{15}$$

$$R_{earth} = b_0 + \left(1 + b_1\right) R_{LIN} + b_2 R_{LIN}^2 \tag{15'}$$

where

C_{BB}, C_{space}, C_{earth}: Count values when viewing blackbody, space, and earth
R_{BB}: Computed in Eq. (8)
R_{space}, b_0, b_1, b_2: Calibration coefficients supplied by this memo

Note that Eqs. (15) and (15') are equivalent, but Eq. (15) is used in document for clarity and Eq. (15') is used in operation for simplicity. Channel 3B needs no nonlinearity correction, effectively $R_{space} = b_0 = b_2 = 0$ and $b_1 = 1$. Values of relevant parameters are provided in Table 4.

Table 4: Nonlinearity correction coefficients for NOAA-N' AVHRR (A308)

Channel	R_{space}	b_0	b_1	$1+b_1$	b_2
3B	0	0	0	1	0
4	-5.49	5.70	-0.11187	0.88813	0.00054668
5	-3.39	3.58	-0.05991	0.94009	0.00024985

13. CPIDS

In summary, the CPIDS for NOAA-N' AVHRR (A308), in compliance with the nomenclature and format used in operation, are as following:

AVHRRPRI.CALPRM.EQFILWID (3,0,0,0) / R

0.077580 0.217591 0.043610

These are Equivalent Width in micron for Channel 1, 2, and 3A, respectively, of NOAA-N' AVHRR (A308). The values are from the 4th column of Table 1.

AVHRRPRI.CALPRM .SOFILIRR (3,0,0,0) / R

126.773438 225.697754 10.655996

These are In-Band Extraterrestrial Solar Irradiance in W m^{-2} for Channel 1, 2, and 3A, respectively, of NOAA-N' AVHRR (A308). The values are from the last column of Table 1.

AVHRRPRI.CALPRM.VISCAL (5,3,3,0) / R

0.055091	-2.1415	0.16253	-55.863	496.43
0.054892	-2.1288	0.16352	-56.445	500.37
0.027174	-1.0881	0.18798	-81.491	496.11
0.055091	-2.1415	0.16253	-55.863	496.43
0.054892	-2.1288	0.16352	-56.445	500.37
0.027174	-1.0881	0.18798	-81.491	496.11
0.055091	-2.1415	0.16253	-55.863	496.43
0.054892	-2.1288	0.16352	-56.445	500.37
0.027174	-1.0881	0.18798	-81.491	496.11

These are Calibration coefficients for Channel 1, 2, and 3A for NOAA-N' AVHRR (A308) that convert raw count to reflectance. The five elements in the first row are, respectively, slope (low), intercept (low), sloe (high), intercept (high), and break point for Channel 1. The next two rows are those for Channel 2 and 3A. These three rows are "Operational Calibration Coefficients". The next three rows are "Pre-launch Calibration Coefficients", followed by three rows of "Test Calibration Coefficients". At launch, all three sets of calibration coefficients are identical. The values are from Eq. (4).

AVHRR .GENERAL .WAVENUM (3,0,0,0) / R

.2670000E+04 .9289000E+03 .8319000E+03

These are centroid wavenumber (cm^{-1}) used in Eqs. (8), (9), and (11) for channel 3B, 4, and 5, respectively, for NOAA- N' AVHRR (A308). The values are from the 2nd column of Table 3.

AVHRRPRI.CALPRM .NONLINCC (3,3,0,0) / R

.0000000E+00 .1000000E+01 .0000000E+00

.5700000E+01 .8881300E+00 .5466800E-03

.3580000E+01 .9400900E+00 .2498500E-03

These are the nonlinearity correction coefficients used in Eq. (15') to compute R_{earth} for Channel 3B, 4, and 5, respectively, for NOAA-N' AVHRR (A308). The values are from the 3rd, 5th, and 6th columns of Table 4.

AVHRRPRI.CALPRM .RADSPACE (3,0,0,0) / R
.0000000E+00 -.5490000E+01 -.3390000E+01

These are the space radiance (mW/m^2 sr cm^{-1}) used in Eq. (13) for Channel 3B, 4, and 5, respectively, for NOAA-N'AVHRR (A308). The values are from the 2nd column of Table 4.

AVHRRPRI.CALPRM .TRCNVCNA (3,0,0,0) / R
.1673960E+01 .5395900E+00 .3606400E+00

These are the coefficients *A* used in Eq. (7) to convert T_{BB} to T^*_{BB} for Channel 3B, 4 and 5, respectively at the NOAA- N'AVHRR (A308). The values are from the 3rd column of Table 3.

AVHRRPRI.CALPRM .TRCNVCNB (3,0,0,0) / R
.9973640E+00 .9985340E+00 .9989130E+00

These are the coefficients *B* used in Eq. (7) to convert T_{BB} to T^*_{BB} for Channel 3B, 4 and 5, respectively at the NOAA- N'AVHRR (A308). The values are from the 4th column of Table 3.

AVHRRPRI.CALPRM .TRCNVCN1 (3,0,0,0) / R
-.1678380E+01 -.5403820E+00 -.3610320E+00

These are the coefficients *A'* used in Eq. (10) to convert T_{BB} from T^*_{BB} for Channel 3B, 4 and 5, respectively at the NOAA- N'AVHRR (A308). The values are from the 5th column of Table 3.

AVHRRPRI.CALPRM .TRCNVCN2 (3,0,0,0) / R
.1002643E+01 .1001468E+01 .1001088E+01

These are the coefficients *B'* used in Eq. (10) to convert T_{BB} from T^*_{BB} for Channel 3B, 4 and 5, respectively at the NOAA- N'AVHRR (A308). The values are from the 6th column of Table 3.

AVHRRPRI.PRTDATA .CONVCOEF (6,4,0,0) / R
.2766067E+03 .5111077E-01 .1405783E-05
.2766119E+03 .5108993E-01 .1496037E-05
.2766310E+03 .5103335E-01 .1496990E-05
.2766268E+03 .5105827E-01 .1493110E-05

These are the coefficients used in Eq. (5) to convert the PRT count to PRT temperature in Kelvin for the four PRT sensors on NOAA-N' AVHRR (A308). The values are from Table 2.

AVRRPRI.PRTDATA .PRTWGHT (4,0,0,0) / I
1 1 1 1

These are the weight used in Eq. (6) to compute the T_{PRT} from the four PRT temperatures T^{i}_{PRT}, i=1, 2, 3, 4. The values are from the explanation following Eq. (6).

AVHRR.SCANGEOM.NUMCALVW (1,0,0,0) / I
10

This is the number of space and calibration target (CT) views per channel per scan line, as provided by the instrument manufacturer.

AVHRR.SCANGEOM.NUMFOV (2,0,0,0) / I
2048 409

These are the number of field-of-views (FOVs) per scan line for LAC/HRPT and GAC, respectively, as provided by the instrument manufacturer.

AVHRR.SCANGEOM.PERIOD (2,0,0,0) / R
.1666670E+03 .5000000E+03

These are the minimum time (in millisecond) it takes for the instrument to return to a given point in LAC/HRPT and GAC, respectively, as provided by the instrument manufacturer.

14. References:

Arvesen, J. C., R. N. Griffin, and B. D. Pearson, 1969: Determination of extraterrestrial solar spectral irradiance from a research aircraft. *Appl. Optics*, **8**, 2215-2232.

Brasseur, G., and P. C. Simon, 1981: Stratospheric chemical and thermal response to long-term variability in solar UV irradiance. *J. Geophys. Res*., **86**, 7343.

ITT Industries, 2008: AVHRR/3 A308 Alignment/Calibration Handbook ("Handbook"), Doc. No. 8196475, Rev. E, October 2008, Space Systems Division, ITT Industries.

Neckel, H., and D. Labs, 1984: The solar radiation between 3300 and 12500 Angstroms. *Solar Phys.*, 90, 205-258.

Rossow, W. B., E. Kinsella, A. Wolf, and L. Gardner, 1985: Description of reduced resolution radiance data. WCRP/ISCCP, WMO/TD No. 58, 132 pp.

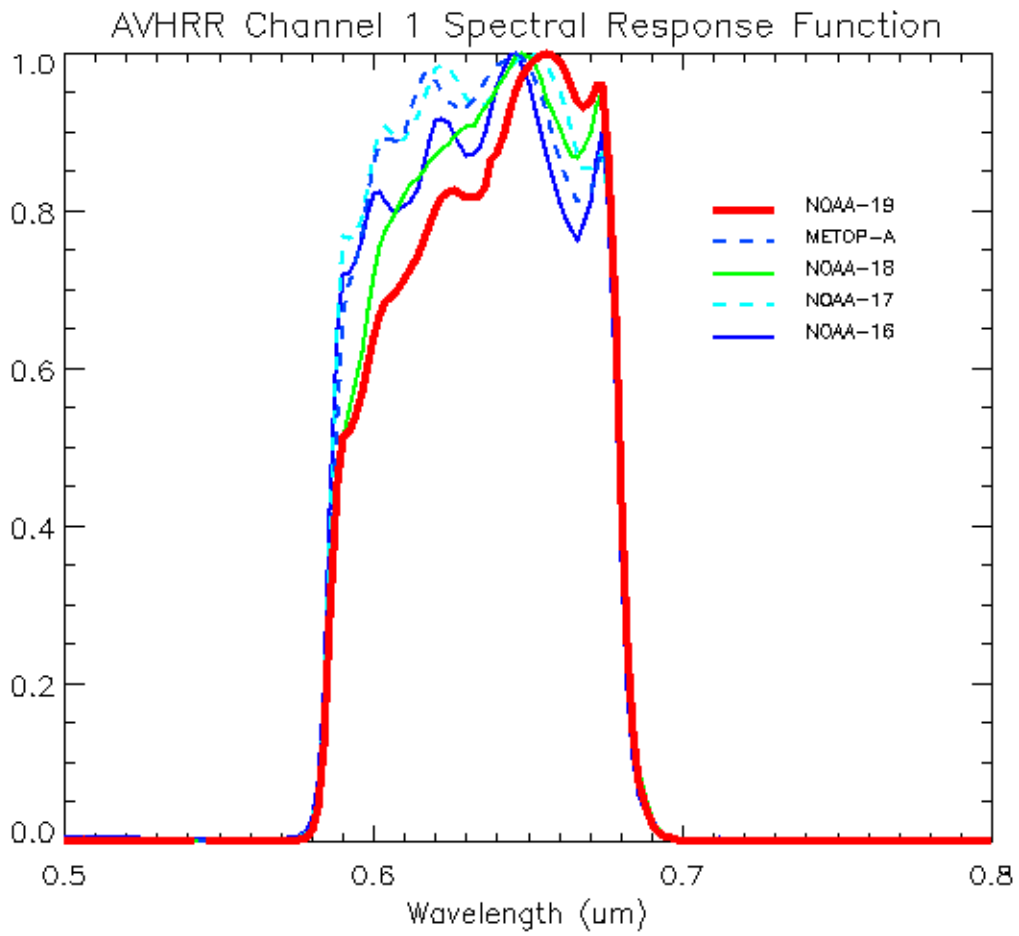
Sullivan, J., 1999: New radiance-based method for AVHRR thermal channel nonlinearity corrrections. *Int. J. Remote Sens*. 20, 3493-3501.

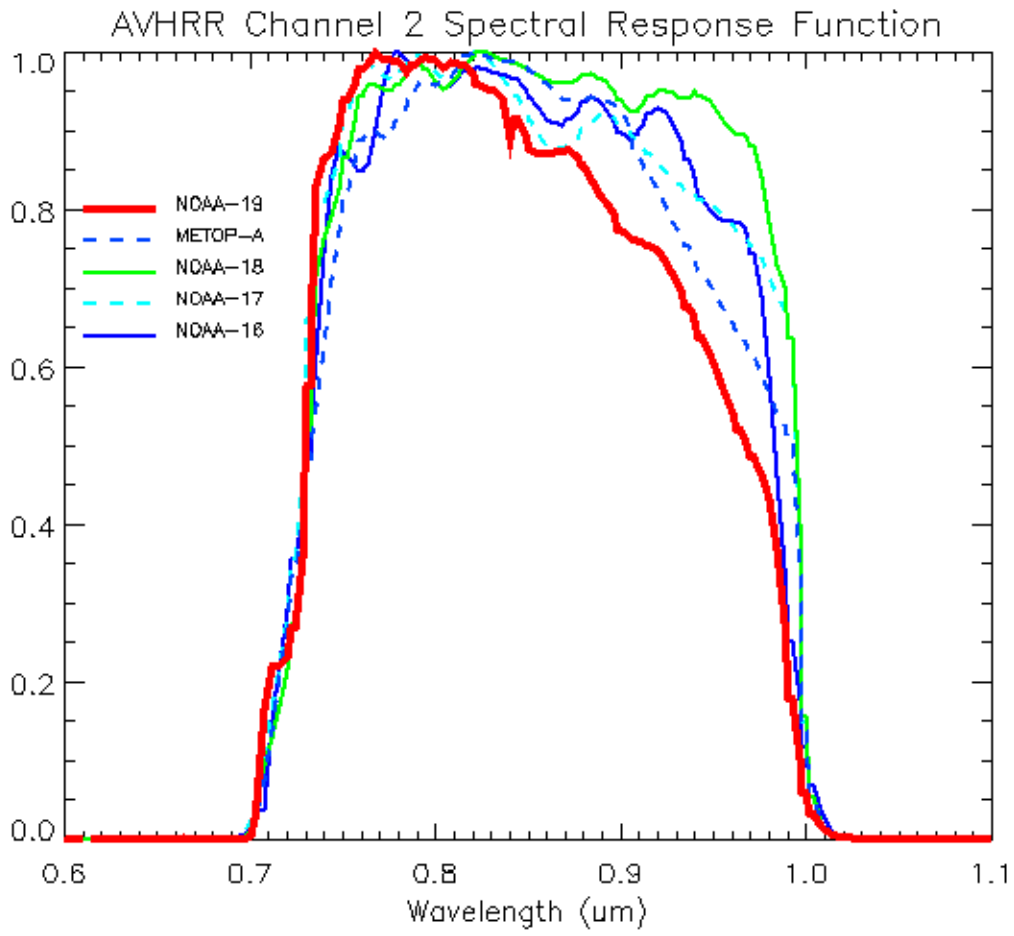
Thekaekara, M. P., 1974: Extraterrestrial solar spectrum, 3000-6100 Å at 1 Å intervals. *Appl. Opt.*, **13**, 518-522.

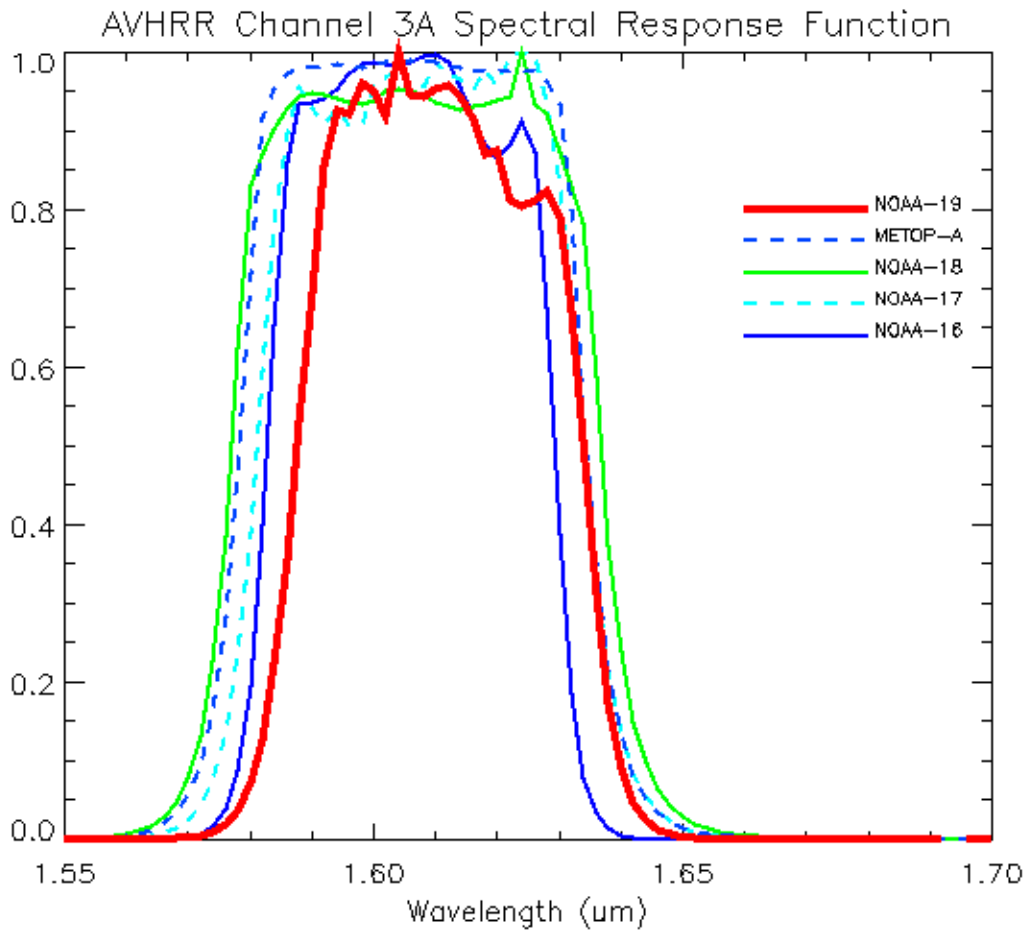
Wehrli, C., 1985: Extraterrestrial Solar Spectrum. WRC Pub. 615.

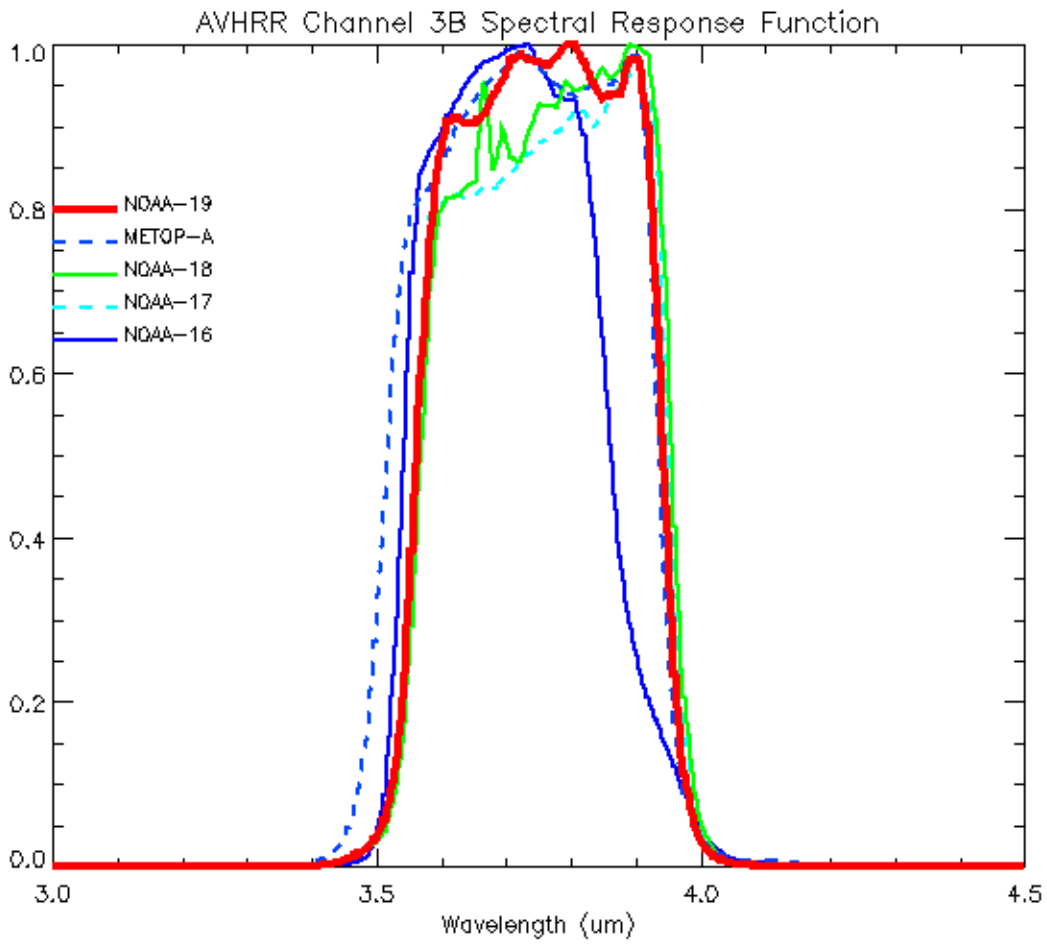
Weinreb, M. P., and co-authors, 1981: NOAA Technical Report NESS 85.

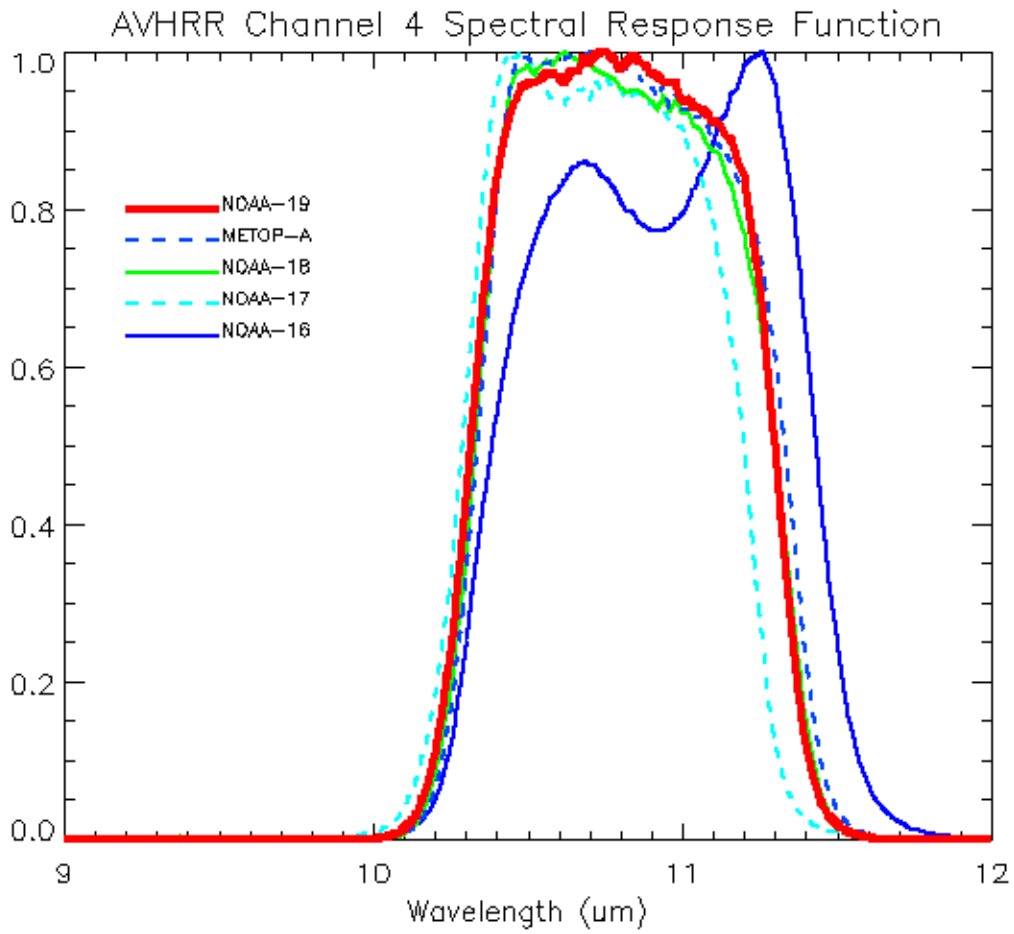
APPENDIX A: Relative Spectral Response of A308

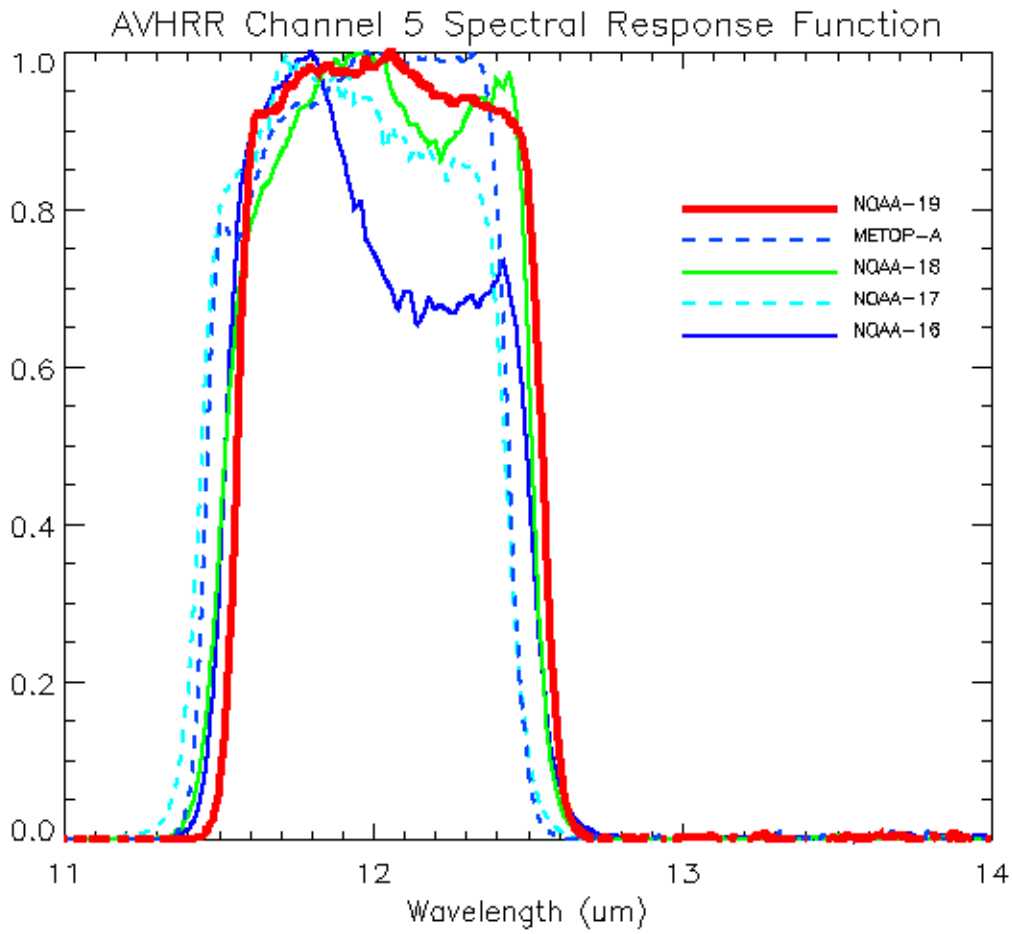



AVHRR Channel 2 Spectral Response Function
NOAA-19
METOP-A
NOAA-18
NOAA-17
NOAA-16
1.0
0.8
0.6
0.4
0.2
0.0
0.6
0.7
0.8
0.9
1.0
1.1
Wavelength (um)

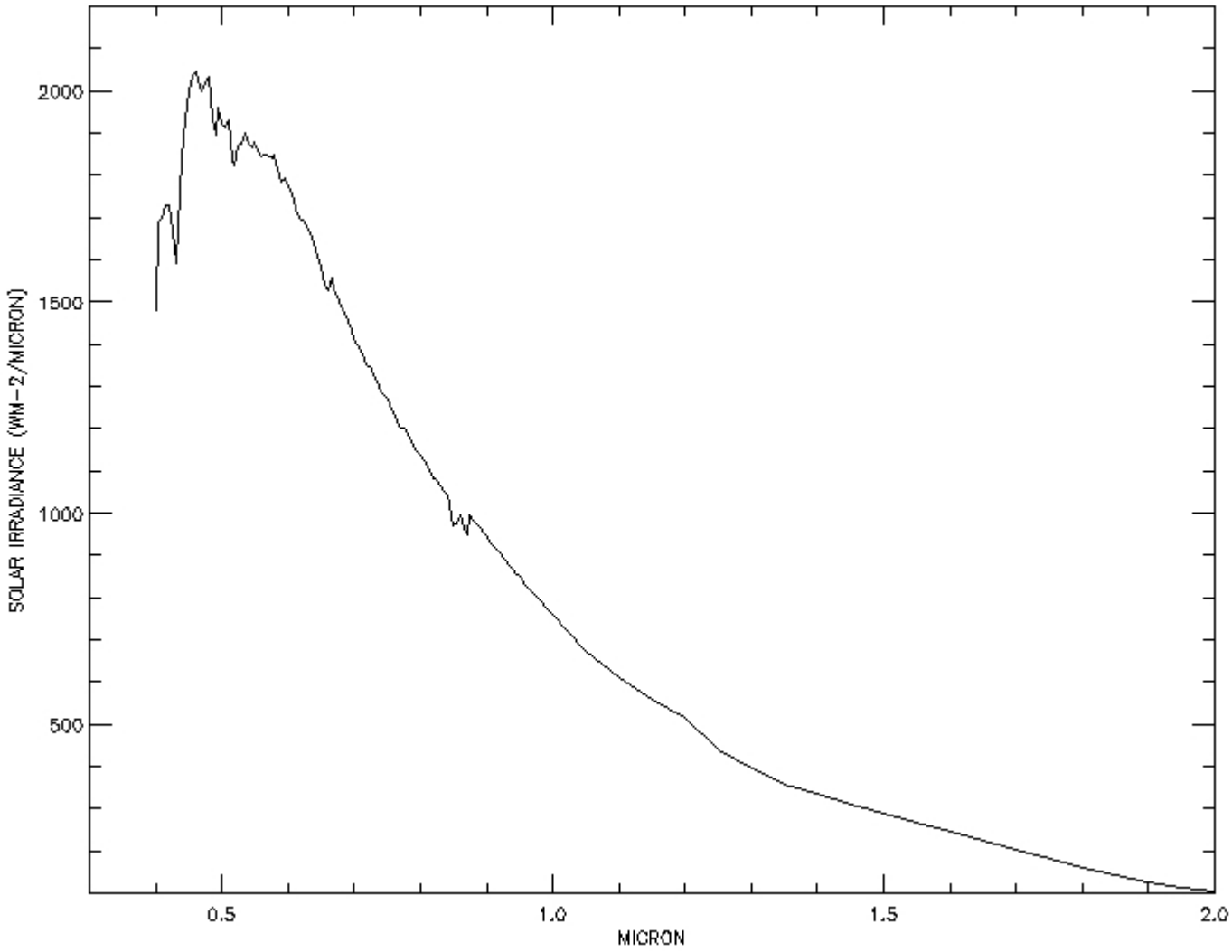

AVHRR Channel 3A Spectral Response Function
1.0
0.8
0.6
0.4
0.2
0.0
1.55
1.60
1.65
1.70
Wavelength (um)
NOAA-19
METOP-A
NOAA-18
NOAA-17
NOAA-16


AVHRR Channel 3B Spectral Response Function
1.0
0.8
0.6
0.4
0.2
0.0
3.0
3.5
4.0
4.5
Wavelength (um)
NOAA-19
METOP-A
NOAA-18
NOAA-17
NOAA-16


AVHRR Channel 4 Spectral Response Function
1.0
0.8
0.6
0.4
0.2
0.0
9
10
11
12
Wavelength (um)
NOAA-19
METOP-A
NOAA-18
NOAA-17
NOAA-16


AVHRR Channel 5 Spectral Response Function
1.0
0.8
0.6
0.4
0.2
0.0
11
12
13
14
Wavelength (um)
NOAA-19
METOP-A
NOAA-18
NOAA-17
NOAA-16

APPENDIX B: Extraterrestrial Solar Spectral Irradiance



micron Watt m^{-2} μm^{-1}