Climate Data Record (CDR) Program

Climate Algorithm Theoretical Basis Document (C-ATBD)

Fundamental Climate Data Record (CDR) of Reflectance from AVHRR Bands 1, 2 and 3a

(CDR Name: AVHRR_CH1-2-3a_Reflectance)

REVISION HISTORY

Rev.	Author	DSR No.	Description	Date
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1.   Introduction

Reflectance, energy emitted by the sun and reflected by Earth's surface and atmosphere, has been measured in the past several decades by several space-borne sensors, including the Advanced Very High Resolution Radiometer (AVHRR) on the Polar Orbiting Environmental Satellite (POES) series (Figure 1). Global reflectance data measured by a series of these AVHRR instruments are available from 1978 through the present, but have not been utilized to the maximum extent due to their lack of consistent calibration. Long-term, well-calibrated measurements of reflectance, which is especially valuable for detecting clouds, can be used to investigate weather and climate patterns. For this purpose, a data set of calibrated AVHRR reflectance, known as a Fundamental Climate Data Record (FCDR) was produced in 2011 using the Pathfinder Atmospheres – Extended (PATMOS-x) satellite data processing system. The FCDR is hosted at the National Climatic Data Center (NCDC).

Figure 1. A schematic depicting how reflectance is measured. Energy in many wavelengths is emitted by the sun, some of which is reflected back into space by Earth's surface, clouds, and atmosphere. The AVHRR on board the polar-orbiting satellite senses this reflected energy in several wavelength bands. The dotted lines depict the nadir path (bold) and swath width (thin) of the sensor. A single measurement from AVHRR has a footprint on Earth's surface of approximately 1.1 km per pixel at nadir (oval). A single AVHRR passes over one spot on the Earth twice per day. Figure is not to scale.

1.1 Purpose

The purpose of this document is to describe the PATMOS-x algorithm submitted to the National Climatic Data Center by Andrew Heidinger, NOAA STAR, that was used to create the Fundamental Climate Data Record of Reflectance, using the AVHRR bands 1, 2, and 3a. The actual algorithm is defined by the computer program (code) that accompanies this document, and thus the intent here is to provide a guide to understanding that algorithm, from both a scientific perspective and in order to assist a software engineer or end-user performing an evaluation of the code.

1.2 Definitions

Following is a summary of the symbols used to define the algorithm used to calculate calibrated reflectance.

Instrument count related parameters:

$$C \ = instrument\ count. \tag{1}$$

$$C_0 \ = dark\ or\ switch\ count. \tag{2}$$

$$C_{rel} \ = relative\ instrument\ count. \tag{3}$$

Calibration slope-related parameters:

$$S \ = calibration\ slope. \tag{4}$$

$$S_0 \ = calibration\ slope\ at\ launch. \tag{5}$$

$$S_1 \ = calibration\ parameter\ for\ t. \tag{6}$$

$$S_2 \ = calibration\ for\ t^2. \tag{7}$$

$$t = time\ in\ years\ since\ launch. \tag{8}$$

Reflectance related parameters:

$$R_u \ = reflectance\ unadjusted\ for\ sun\text{-}earth\ distance\ or\ solar\ zenith\ angle. \tag{9}$$

$$R \ = reflectance\ adjusted\ for\ sun\text{-}earth\ distance\ and\ solar\ zenith\ angle. \tag{10}$$

$$\theta \ = solar\ zenith\ angle. \tag{11}$$

$$D_{se} \ = sun\text{-}earth\ distance. \tag{12}$$

1.3 Document Maintenance

Periodically, as code is improved and as longer time spans of AVHRR observations become available, new PATMOS-x FCDRs will be produced. Upon each release

of the newest FCDR, this C-ATBD will be updated to reflect any changes to the algorithms and calibrations.

2.   Observing Systems Overview

2.1   Products Generated

The data products in the PATMOS-x FCDR hosted by NCDC consist of calibrated reflectances of AVHRR channels 1, 2, and 3a, along with related variables: latitude, longitude, relative sensor-sun azimuth angle, sensor zenith angle, solar zenith angle, scan line time, and other metadata. Reflectance values represent an average reflectance of any mix of clouds, aerosols, surface features, etc. that are in the view of the pixels used in the primary sensor data (see 3.3.1). Data are global in coverage, and subsampled (not interpolated) to a 0.1^0 latitude by 0.1^0 longitude grid. The data set uses all AVHRRs on the TIROS-N (NOAA-5), NOAA-7, -9, -11, -12, -14, -15, -16, -17, -18, -19, and Metop-A satellites, spanning 1978 through 2009. At this time only the ascending node reflectances are available from NCDC. Data products are available from http://www.ncdc.noaa.gov/cdr/operationalcdrs.html .

2.2   Instrument Characteristics

The Advanced Very High Resolution Radiometer (AVHRR) came in four versions, AVHRR, AVHRR/1, AVHRR/2, and AVHRR/3. Channels 1 and 2 are solar reflectance channels and are on all AVHRR versions. Channel 3a is only on AVHRR/3 and senses a mix of reflected solar energy and energy emitted from Earth (Figure 2).
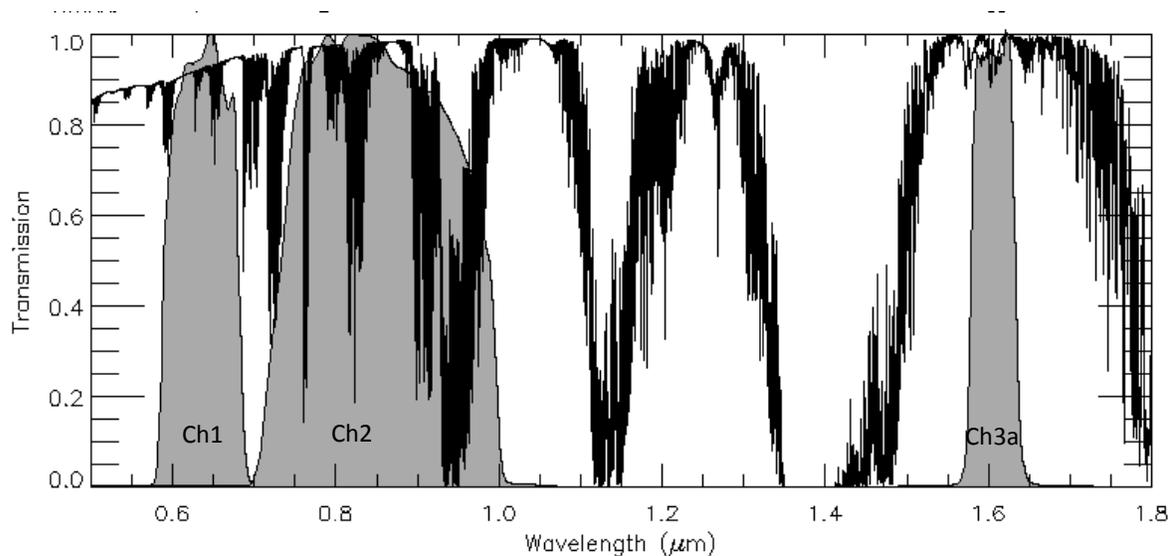
Figure 2. NOAA-17 AVHRR solar reflectance channel spectral response functions (grey regions) overlaid onto a nadir transmission spectrum for a standard tropical atmosphere (McClatchey et al., 1971). Channels 1 and 2, and 3a are labeled.

Descriptions and characteristics of each AVHRR can be found in the NOAA Polar Orbiter Data (POD) User's Guide (Kidwell, 1998) and the NOAA KLM User's Guide with NOAA-N, N' Supplement (Robel, 2009). Table 1 gives a summary of the characteristics.

Table 1: A summary of characteristics of the AVHRRs on NOAA and Metop polar orbiting satellites. *Note: Channel 3a senses a mix of solar and Earth emitted wavelengths. Channel 3b is equivalent to channel 3 on non-AVHRR/3 instruments.

	AVHRR	AVHRR/1	AVHRR/2	AVHRR/3
Channels	1, 2, 3, 4	1, 2, 3, 4	1, 2, 3, 4, 5	1, 2, 3a, 3b, 4, 5
Solar Channels	1, 2	1, 2	1, 2	1, 2, 3a*
Thermal Channels	3, 4	3, 4	3, 4, 5	3a*, 3b, 4, 5
Channel 1 wavelengths (µm)	0.55-0.90	0.58-0.68	0.58-0.68	0.58-0.68
Channel 2 wavelengths (µm)	0.725-1.10	0.725-1.10	0.725-1.10	0.725-1.00
Channel 3a wavelengths (µm)	not present	not present	not present	1.58-1.64
Gain	Single	Single	Single	Dual
Footprint at nadir (km)	1.1	1.1	1.1	1.1
Platforms	TIROS-N	NOAA-6, -8, -10	NOAA-7, -9, -11, -12, -14	NOAA-15, -16, -17, -18, -19, Metop-A

3.   Algorithm Description

3.1   Algorithm Overview

The software package used to create the PATMOS-x FCDR is also referred to as PATMOS-x. However, it is a sequence of programs. Below we describe how those programs are used to create the final data product.

3.2   Processing Outline

The FCDR is produced by first creating an archive of all the AVHRR Global Area Coverage (GAC) Level1b files and all needed ancillary data. Once the archive is complete, the PATMOS-x executable clavrxorb is run on each Level1b file for each day during the instrument record. Clavrxorb produces one Level2 file for each Level1b file, and these Level2 files contain reflectances, locations, angles, and times for each GAC pixel, whether clear, cloudy, or a mix. Both ascending and descending nodes are processed, however, the FCDR consists only of the daytime node data.

The following discussion of clavrxorb refers to the flowchart (see Appendix B) contained in http://www1.ncdc.noaa.gov/pub/data/sds/cdr/docs/patmos-x-flowchart.pdf. Processing in clavrxorb begins by reserving memory for each of the modules and declaring local variables. User options are read in from the command line and/or the OPTIONSLIST. These determine where files are to be found and which processing options to use. Next, the static ancillary data files (see section 3.3.2) are read in. Arrays and grids are initialized. Then the FILELIST is read in to determine the various AVHRR GAC input and PATMOS-x output directories, and the list of files to be processed (more than one AVHRR file can be processed per execution). For each Level1b file to be processed, clavrxorb reads in the type of the 1b file, creates needed arrays for that format, and reads in all the rest of the header data. Next the sensor constant files are read in (contain calibration information). Any sensor-specific ancillary data files are subsequently read. The non-static ancillary files and numerical weather prediction (NWP) files are read in. Any needed lookup tables are read/populated. Clock error is interpolated. If diagnostic files were requested, these are opened. Then for each orbit segment, the processing is computed: Level1b data read in, geolocation recomputed, fundamental pixel-level arrays computed, ancillary data interpolated to pixel arrays, NWP and radiative transfer model (RTM) values computed for each segment, spatial metrics generated, pixel-level products generated, and products to output files written (Level2 and any requested diagnostic). Once all segments are processed for the 1b file, the Level2 file, the diagnostic files, and the non-static ancillary files are closed. The next 1b file is then processed in an identical manner. Once all files in the FILELIST are processed, the FILELIST is closed, the static ancillary data files are closed, and the remaining memory deallocated before the program ends.

The Level2b files are computed from the Level2 GAC pixel level files with the executable comp_asc_des_level2b. Level2b files are files which contain subsetted pixels on a regular lat/lon grid. There is no interpolation, rather data from the pixel in the Level2 file

closest to the desired lat/lon location is chosen and written to the 2b file. The resolution of the Level2b files is 0.1^0 latitude by 0.1^0 longitude. Level2b data are reflectances and related data at the selected pixel, whether cloudy, clear, or mixed.

3.3   Algorithm Input

3.3.1   Primary Sensor Data

The primary sensor data are AVHRR Level1b Global Area Coverage (GAC) files containing channel 1, 2, and 3a (when available) instrument counts. An individual AVHRR pixel is a circle approximately 1.1 km in diameter at nadir, and an oval about 6.5 km x 2.3 km at 55^0 from nadir, which is near the maximum scan angle of 55.4^0. GAC files contain subsampled (every third scan) and averaged (four adjacent samples with the fifth skipped) data, and is global in coverage. GAC resolution is nominally 1.1 km x 4 km with a 3 km gap along the direction of orbit, but is generally considered to have a 4 km resolution. Level1b GAC are digital, raw data that are quality controlled and have navigation information appended.

The GAC files exist in several versions, with version 1 applying to TIROS-N through NOAA-14 and versions 2-4 applying to NOAA-15 and later. GAC files were used in their original versions. Files were downloaded from NOAAs Comprehensive Large Array-data Stewardship System (http://www.class.ngdc.noaa.gov). The total collection used (including files for NOAA-6, -8, and -10, which are not included in the FCDR) is 10.8 Tb, compressed with gzip.

See Kidwell (1998) and Robel (2009) for more details on the GAC data types and formats.

3.3.2   Ancillary Data

In addition to the GAC files, AVHRR instrument files are used that contain instrument-specific data including the mean dark count and the calibration coefficients derived from Heidinger et al. (2010) and Heidinger et al (in preparation). These files are maintained under version control software and available directly from Andrew Heidinger (Andrew.Heidinger@noaa.gov). An example of one of these files, avhrr_17_instr.dat, is shown below.

```
n17         !sat_name
4.2443861   !solar_3b
269.79606   !ew_3b
0.00  0.0000 0.0000000  0.00        !ch3b nonlinear rad coeff and space rad
(Table D.3-2)
-8.55, 8.22, -0.15795, 0.00075579  !ch4 nonlinear rad coeff and space rad
-3.97, 4.31, -0.07318, 0.00030976  !ch5 nonlinear rad coeff and space rad
2669.1414   !nu_3b
-1.7002941  !a1_3b
1.0026724   !a2_3b
928.29959   !nu_4
-0.56634758 !a1_4
```

```
1.0015205   !a2_4
840.20289   !nu_5
-0.37264803 !a1_5
1.0010841   !a2_5
39.99        !ch1_dark_count
39.09        !ch2_dark_count
42.09        !ch3a_dark_count
0.0575  1.707  -0.151   !ch1 low gain, degrad
0.1725  1.707  -0.151   !ch1 high gain, degrad
0.0650  3.117  -0.265   !ch2 low gain, degrad
0.1950  3.117  -0.265   !ch2 high gain, degrad
0.0308  4.06   -0.37    !ch3a low gain, degrad
0.2153  4.06   -0.37    !ch3a high gain, degrad
2002.47912   !date of launch
501.12       !count at which ch1 gain switches
500.73       !count at which ch2 gain switches
501.37       !count at which ch3a gain switches
276.628 0.05098 1.371e-06 0 0  !PRT1 coefficients
276.538 0.05098 1.371e-06 0 0  !PRT2 coefficients
276.761 0.05097 1.369e-06 0 0  !PRT3 coefficients
276.660 0.05100 1.348e-06 0 0  !PRT4 coefficients
0.25 0.25 0.25 0.25              !PRT weighting
0.992818, 2.49916, 0.915103, -271.206        !day sst mask coef
1.01015, 2.58150, 1.000541, -276.590         !night sst mask coef
!$Id: avhrr_17_instr.dat,v 1.1 2011/10/21 20:12:16 heidinger Exp $!
```

The calibration values are also contained in the global attributes section of the Level2b output files. If a user requests a time series from the NCDC web site (http://www.ncdc.noaa.gov/cdr/operationalcdrs.html), the calibrations values in the global attributes are valid for the first day of the time span requested.

3.3.3 Derived Data

Not Applicable.

3.3.4 Forward Models

Not Applicable.

3.4 Theoretical Description

The calculation of calibrated reflectance is fairly simple. The basic order of operations is this for data from each of the three channels:

1. Read in raw count, dark count, angles, sun-earth distance, time, and navigation from Level1b file.
2. Read in constants from instrument file.
3. Compare dark count to average dark count. Reject observation if different by more than 5 counts.
4. Subtract dark count from count to get relative count or subtract switch count from count to get high gain relative count.
5. Compute days since launch using time (1b) and launch date (instrument file).

6. Compute calibrated slope using days since launch and calibration parameters (instrument file).
7. Multiply relative count by calibrated slope to get calibrated reflectance.
8. Correct for sun-earth geometry using sun-earth distance and solar zenith angle.
9. Correct navigation.
10. Write reflectances and related variables (angles, time) to output file.

3.4.1 Physical and Mathematical Description

Reflectance is obtained from an electronic instrument in the following way: The instrument's sensors are sensitive to a certain band of wavelengths. The AVHRR instrument has sensors that are capable of measuring energy in the visible red (Channel 1), the near infrared (Channel 2), and the middle infrared (Channel 3a). The corrected spectral response functions for these three AVHRR channels can be found at http://www.star.nesdis.noaa.gov/smcd/spb/calibration/avhrr/nrf.html. The electronics convert the energy sensed in the band to a digital count. The greater the magnitude of this energy (signal), the larger the count. The older AVHRRs have a linear signal:count response or gain, while the AVHRR/3s have a two-segment linear gain (see Table 1). The sensor also points into deep space during one part of each scan to record a dark count. The dark count is used to anchor the reflectance equation at zero. A calibration slope is used to convert the counts to reflectance units. This slope includes any factors involved: spectral response function, solar constant, instrument gain, etc.

$$R_u = S * (C - C_0),\qquad\qquad(13)$$

Where R_u is the reflectance unadjusted for sun-earth distance or solar zenith angle, S is the calibration slope, C is the instrument count, and C_0 is the dark count. For AVHRR/3, counts below the switch count use the above equation with the low gain slope. For counts above the switch count, the switch count is used for C_0, and the high gain slope applied.

Some calibrations, such as those published in the POD and KLM Guides, use a slope and intercept directly on the count and do not use the dark count. Using or not-using the dark count is built into any calibration, and is neither right nor wrong, so long as the calibration can return a zero reflectance for counts below some threshold.

The AVHRR calibration is originally done pre-launch, but once the instrument is launched, this calibration typically changes (immediately, due to launch conditions, and over time as the instrument ages). After launch, the instrument can only be calibrated indirectly, as there is no on-board calibration source for Channels 1-3a. Heidinger et al. (2010) and Heidinger et al. (in preparation) describe how the calibration slopes in this FCDR are computed. An ATBD for the Channel 1 and 2 calibrations is also available at https://gsics.nesdis.noaa.gov/wiki/Development/AtbdCentral .

3.4.2 Data Merging Strategy

For each Level1b file from a single satellite, a Level2 (pixel level) file is produced. From all Level2 files for each satellite-day, two equal angle Level2b files are produced, one

for the ascending nodes and one for the descending nodes of the orbits. The pixel chosen for each location in the gridded Level2b file is the pixel that has the smallest sensor view angle if there are overlapping scenes, and is closest in distance to the target lat/lon coordinate. Data from different satellites are not merged, so that for any one day, there may be more than one set of Level2b files available, if there are multiple operational AVHRRs. At this time only the ascending node Level2b data are available on line. If a user wishes the single "best" value, the user must look at the satellite view angle and scan time for pixels in the region of interest, and then select the Level2b file that contains data that meets the user's requirements.

3.4.3   Numerical Strategy

Not Applicable.

3.4.4   Calculations

Once the channel counts are read in, the space count or switch count is subtracted to form a relative count, C_{rel}, and then the calibration is applied. The calibration converts raw counts to reflectance. The calibration parameters are a function of time since launch:

$$S(t) = S_0 \left(100 + S_1 t + S_2 t^2\right)/100 \tag{14}$$

where S is the calibration slope (reflectance in %/count), S_0, S_1, and S_2 are the calibration terms, and t is the time in years since launch. If the instrument is dual gain, the raw absolute count is compared to the gain switch. If the count is less than the switch, the low gain calibration parameters are applied; if above, the high gain calibration is applied. The calibration parameters S_0, S_1, and S_2, respectively, are found in the instrument file (see Section 3.3.2) in the lines marked with a comment, for example "!ch1 low gain, degrade". S_0 is considered to be the calibrated slope at launch, while S_1 and S_2 are the time-dependent degradation coefficients.

Reflectance is then calculated by multiplying the relative count by the slope, and correcting for geometry:

$$R = (S * C_{rel})/\cos(\theta) * D_{se}^2, \tag{15}$$

where R is the reflectance, θ is the solar zenith angle, and D_{se} is the sun-earth distance.

3.4.5   Look-Up Table Description

Other than the instrument files, discussed in Section 3.3.2, the only look-up tables used are clock correction tables stored in the code. These were obtained from the University of Miami (see http://yyy.rsmas.miami.edu/groups/rrsl/pathfinder/Processing/proc_index.html). These are used to correct navigation only. They do not alter reflectance values.

3.4.6 Parameterization

   Other than the calibration slopes mentioned above, no parameterizations are used.

3.4.7 Algorithm Output

   While the algorithm produces Level2b files in HDF4 (Hierarchical Data Format 4) format, these files are not available to the public on line. The web interface at http://data.ncdc.noaa.gov/thredds/patmosxCatalog.html allows the user to obtain a subset of the data, rather than having to download entire daily files. As this process is done at NCDC, the process will not be described here. The web interface returns a single netcdf file containing metadata plus one or more of the following variables

- latitude – latitude in degrees_north

- longitude – longitude in degrees_east

- anchor_relative_azimuth – relative azimuth angle in degrees

- anchor_sensor_zenith – sensor zenith angle in degrees

- anchor_solar_azimuth – solar azimuth angle in degrees

- anchor_solar_zenith – solar zenith angle in degrees

- ch1_reflectance – channel 1 top of atmosphere bidirectional reflectance in percent

- ch2_reflectance – channel 2 top of atmosphere bidirectional reflectance in percent

- ch3a_reflectance – channel 3 top of atmosphere bidirectional reflectance in percent

- packed_pixel_meta_data – pixel quality flags packed into one byte

- scan_line_time – scan line time in hours

- time – character time to use for labeling

The term "anchor" refers to the value at the "anchor pixel," the pixel closest to the lat/lon coordinate. Files are named (for example), patmosx_n19.ncml.nc, where the three characters after the underscore indicate the satellite bearing the AVHRR, e.g., NOAA-19 is n19; Metop-A is m02. If the user requests all the variables, a single file for one satellite-day covering the entire globe is 204 Mb.

4.   Test Datasets and Outputs

4.1   Test Input Datasets

Test inputs for PATMOS-x were actual Level1b files from each AVHRR. Several (random) days for each satellite's period of record were run through the algorithm and the Level2b files examined to make certain the algorithm worked as expected.

4.2   Test Output Analysis

4.2.1   Reproducibility

As the full record for each AVHRR was produced, a checking program was run on each Level2b file to make sure each file was a) present for a valid AVHRR day, and b) could be successfully opened and read. Missing/corrupt files were noted and reprocessed. Randomly sampled files were then examined to make sure the data within were reasonable.

The performance of the algorithm was tested by comparing AVHRR reflectances to those from MODIS for multiple simultaneous nadir overpasses (SNOs). Lists of these SNOs can be found at http://cimss.ssec.wisc.edu/clavr/calibration/modis_avhrr/modis_sno.html .

4.2.2   Precision and Accuracy

Precision of reflectance starts with the fact that the input counts are 10bit. The full range in reflectance, 0 to about 110% (reflectances greater than 100% are possible) is represented by counts ranging from 0 to 1023, implying the counts themselves allow a precision of about 0.1% in reflectance units. However, the calibration slope for each AVHRR determines the precision for that particular instrument and range. Channel 1 slopes at launch (and therefore precision values) range from 0.09 to 0.12 for single gain AVHRRs (TIROS-N through NOAA-14). Dual gain AVHRRs have a higher precision in the low reflectance gain region and lower precision in the high gain region. This ranges (in reflectance units of %) for Channel 1, low gain, from 0.05 to 0.06, and high gain 0.17 to 0.20. Channel 2 precision at launch ranges from 0.08-0.13 for single gain, and 0.05-0.06 and 0.17-0.20 for low and high gain, respectively. Channel 3a is only present on dual gain AVHRRs, and precision at launch ranges from 0.02-0.03 for low gain and 0.18-0.22 for high gain. Slopes and precision values tend to increase after launch. The maximum slopes/precision values are 0.14 for Ch1, 0.22 for Ch2, and 0.24 for Ch3a.

Accuracy, on the other hand is determined by both the calibration and the method of producing the Level2b data. The accuracy of the calibration procedure with respect to MODIS Collection 5 (Heidinger et al., 2010) is 2% for Channel 1 and 3% for Channel 2. Channel 3a's accuracy is 3% (Heidinger et al., in preparation). These accuracies are for the reflectance value itself. Decreasing the accuracy (in a non-predictable way) are errors in navigation. Level1b data contain navigation errors from 2 to 10 km (Heidinger et al. 2002), which introduces an uncertainty in the actual location of each reflectance value of

up to 20km. The practice of choosing the closest pixel from the Level1b-resolution data to write to the gridded Level2b file adds an additional location error of up to 4km. So the total location error of each Level2b reflectance value can be as great as 24km. Reflectance can vary greatly spatially, as one spot on the Earth system could be cloudy (high reflectance) and the next clear (possibly very low reflectance), so relating spatial error to a quantified reflectance accuracy is difficult. In general however, uniform scenes (uniformly covered surface and/or large stratus clouds) will have higher accuracy, and heterogeneous scenes (varying surface coverage and/or small clouds) will have lower accuracy. Also, improved orbit stabilization of the satellites bearing AVHRR/3s will contribute to higher accuracy reflectances due to higher accuracy navigation.

4.2.3   Error Budget

Table 2 contains a summary of the known errors contained in the PATMOS-x CDR and future paths for improvement.

Table 2: Summary of Errors in AVHRR Ch1, Ch2, and Ch3a reflectance data set.

Error	Magnitude of Error	Possible Improvements
Reflectance value errors	Ch1: 2%, Ch2: 3%, Ch3a: 3%	Filling in AVHRR Level1b archive data gaps to provide more data over ground sites and collocations with other satellites for older AVHRRs. Longer period of record for currently operating AVHRRs. Improved calibration/collection of MODIS. Quantification of change in AVHRR spectral response functions over time. More accurate values of reflectance of surface targets. Better knowledge of state of atmosphere over surface targets.
Level1b navigation errors	Up to 20km	Improved navigation for each scene via adjustment to coastlines or other ground features.
Level2b location error	Up to 4km	Higher resolution Level2b grid.

5.   Practical Considerations

The following consider the generation of the original files delivered to NCDC, not the files available to the user from the NCDC site.

5.1   Numerical Computation Considerations

The software that computes the Level2 files, clavrxorb, has been run on nearly all AVHRR Level1b files available and has not been found to fail numerically. It is feasible, however, that corrupted input files may cause unacceptable behavior of the algorithm. But as this has not been found to happen, we believe clavrxorb to be very robust software. One thing to look out for however, is the size of the output file. Each Level1b file in the file list in clavrxorb_default_options will have an output file produced. If the Level1b file is unreadable or contains no valid data, the corresponding Level2 output file will contain only the header and no pixel data. The file will be very small. Clavrxorb users may wish to check for these files and delete them.

5.2   Programming and Procedural Considerations

There are two areas where the clavrxorb portion of the code might require changing to suit the computer on which it is run. First is the length of the segments processed. Computers with smaller processor memory should have the value of num_scans_per_segment (in avhrr_calnav_routines.f90) decreased, while computers with more memory can have this value increased. The second area is the selection or deselection of which variables will be written to the output file. The file level2.inc contains a list of potential variables to be written out to the Level2 file. These can be turned on/off by changing their flag values to 1/0, and recompiling.

Runtime for clavrxorb can also be changed by selecting which algorithms will be run and diagnostic data sets produced in the file clavrxorb_default_options. Any unneeded algorithms and diagnostic data sets should be turned off there. Runtime is increased, but diskspace decreased if output compression is turned on in clavrxorb_default_options. Runtime may also be affected by the number of files listed at the end of clavrxorb_file_list_viirs, especially if clavrxorb is run in a queueing system which penalizes long programs.

The runtime for the conversion of Level2 files to Level2b is affected mainly by the requested resolution and coverage of the Level2b files.

5.3   Quality Assessment and Diagnostics

Assessing quality can be done visually by plotting the variable in the files of interest to make sure they "look ok". Cross-checking reflectances for the different channels is also useful to determine whether patterns and missing values match. The best method is to compare reflectances to measurements from different instruments, such as MODIS or GOES Imager. For long time periods, plotting time series and comparing with other channels/instruments is advised.

5.4　　Exception Handling

Clavrxorb uses a single missing value, -999., throughout its entire suite of algorithms. Any time an incoming value is outside of its range, an algorithm does not produce a value within the acceptable range, or an invalid answer results, the output value is set to this missing value. These are carried all the way through to the output.

5.5　　Algorithm Validation

Reflectance time series at ground targets in the Libyan Desert and in Greenland were used to validate the data product (see Molling et al. 2010 for an example). It is recommended that reflectance time series at these two targets and over Dome-C, Antarctica be used to validate the calibration portion of the algorithm (for clear scenes only). Any other ground target can be used to validate reflectance if surface observations are present that can be used to infer cloudiness. Comparison with an instrument with on-board calibration (such as MODIS) is also recommended, and can be used for all sky conditions as well.

5.6　　Processing Environment and Resources

The reflectance Level2b data set was created on several 6-core x86_64 machines running Red Hat Enterprise Linux Client release 5.5. Intel Fortran v11.1 build 20091012 was used to compile the code, using the HDF Version 4.2 Release 4 library. Total CPU time was approximately 914 hours, wall clock time was equivalent to 3 months on 6 processors; each processor dealing with a "chunk" of the total amount of data to be processed. About 12Tb of temporary storage was used. The processing code is not parallelized, so performance is highly dependent the number and arrangement of processors with respect to the speed of input and output disk access, and whether these resources are shared (or not) among processes running simultaneously.

6. Assumptions and Limitations

The reflectance data set is calculated using the calibrations against MODIS found in Heidinger et al. (2010) and Heidinger et al. (in preparation). These calibrations are based upon the assumption that MODIS is a well-calibrated instrument. If this is not the case, the calibration will produce the same biases/errors in reflectance as MODIS. Users should also be aware that the reflectance at any one point in the lat/lon grid does not represent exactly the same point on the earth in every file. Rather it is a cluster of locations due to the navigation error of the AVHRR instrument and the selection of the nearest pixel to each target location. Pixel view angle and footprint may also change in the earlier instruments (prior to NOAA-15), whose orbits drifted. Even with orbit stabilization, the view angle and footprint is not constant, as there is a repeat period of about 10 days.

6.1 Algorithm Performance

The algorithm that produces reflectance is fairly simple in that a calibration is applied to relative sensor counts to obtain reflectance directly. The assumption, of course is that the counts are not degraded in any way. One aspect of AVHRR that may produce a spurious relative sensor count is a bad dark count. Occasionally the dark count, which is taken when the sensor views deep space, is taken when the sensor is pointing at the moon. In that case, the resulting relative count and therefore reflectance would be too low. To eliminate most of these situations, the dark count in the Level1b file is compared to the mean dark count for the instrument. If these differ by more than 5 counts, the reflectance calculation is set to missing.

6.2 Sensor Performance

The calibration used for these reflectances correct only for sensor degradation that changes the total response in that channel. The calibration does not correct for any degradation that may actually be due to a change in only one part of the spectral response function that would affect the transformation between MODIS and AVHRR reflectances. So a uniform decrease in the spectral response function is accounted for correctly, but a shift is not.

Individual counts, and therefore reflectances may contain errors due to radiometric noise, a change in incoming above-atmosphere solar radiation, and so forth.

7.   Future Enhancements

It is the intent to recompute the reflectance data set as more years of data become available and when new calibrations are released. The entire data set may not be recomputed each time. For AVHRRs that are no longer operational, the calibration will only change if the method of calculating the calibration alters, or the cross-calibration data (MODIS) changes in some way. For AVHRRs that were operational at the time of the release of the current (for this document) FCDR, the calibration will change from the beginning of record of that AVHRR, because the calibration is a polynomial fit for the entire record of the instrument.

7.1   More Data

Reflectances for AVHRR are being produced operationally, however the calibration for the real-time data does not include the recent past. Approximately once per year, the calibration for operational AVHRRs will be recomputed to include the newest data. Each time a calibration is changed for an individual AVHRR (that on NOAA-19 for example), the entire record of that sensor will be recomputed, as the calibration for the entire time span will change somewhat.

7.2   New Reference Data

Less frequently, newly calibrated MODIS data sets are released. This data set was produced with calibrations derived from MODIS Collection 5. When Collection 6 is available (scheduled for mid-2012), the calibration process will be rerun completely, and a new data set produced.

8.   References

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Appendix A.   Acronyms and Abbreviations

Acronym or Abbreviation	Meaning
AVHRR	Advanced Very High Resolution Radiometer
C-ATBD	Climate Algorithm Theoretical Basis Document
CDR	Climate Data Record
Ch1	Chanel 1
Ch2	Channel 2
Ch3a	Channel 3a
CPU	Central Processing Unit
FCDR	Fundamental Climate Data Record
GAC	Global Area Coverage
GOES	Geostationary Operational Environmental Satellite
HDF	Hierarchical Data Format
MODIS	Moderate Resolution Imaging Spectroradiometer
NCDC	National Climatic Data Center
NOAA	National Oceanic and Atmospheric Administration
NWP	Numerical Weather Prediction
PATMOS-x	Pathfinder Atmospheres - Extended
POD	Polar Orbiter Data
POES	Polar Orbiting Environmental Satellite
RTM	Radiative Transfer Model
SNO	Simultaneous Nadir Overpass
STAR	Center for Satellite Application and Research
TIROS	Television Infrared Observation Satellite

Appendix B.   PATMOS-x High Level Flowchart for the main executable clavrxorb

Begin

↓

Access Modules

↓

Declare local variables

↓

Read and quality check user defined options from command line or OPTIONSLIST

↓

Open high spatial resolution ancillary data files

↓

Initialize Level-2 arrays

↓

Read file directories in FILELIST

↓

Begin loop through AVHRR orbits listed in FILELIST

↓

Read level-1b name from FILELIST

↓

Prepare to read level-1b: determine if file exists, what type it is and create pixel arrays

↓

Read AVHRR header

↓

Read AVHRR sensor constant files

↓

Open sensor specific ancillary data

↓

Open non-static high resolution ancillary data

↓

Read in NW data (GFS or NCEP Reanalysis)

↓

Populate or Read other lookup tables

↓

Interpolate clock error for this orbit

↓

Open diagnostic files

↓

Begin loop over orbit segments

↓

Read AVHRR level-1b data

↓

On first segment, define output files

↓

Recompute geolocation

↓

Compute some fundamental pixel-level arrays

↓

Interpolate ancillary data to each pixel in this segment

↓

Compute NWP mapping and RTM values for each pixel in segment

↓

Spatial metrics processing

↓

Generate pixel-level products

↓

Write to output files (pixel-level)

↓

Write to Diagnostic Output

↓

RTM Structure Memory Deallocation

↓

End of loop over orbital segments

↓

Close output pixel-level files

↓

Close non-static ancillary data files

↓

Deallocate remaining arrays

↓

End loop over files

↓

Close FILELIST

↓

Close static ancillary data files

↓

Final remaining memory deallocation

↓

End of code