PyGAC AVHRR FDR Release 1
Product Users Guide

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1 INTRODUCTION

1.1 Purpose and Scope

This document describes the PyGAC AVHRR Fundamental Data Record (FDR) Release 1 and provides information needed to order, download, decode, and use the data. In addition, it provides summary information on the validation, including facts limiting the use of the data if there are any.

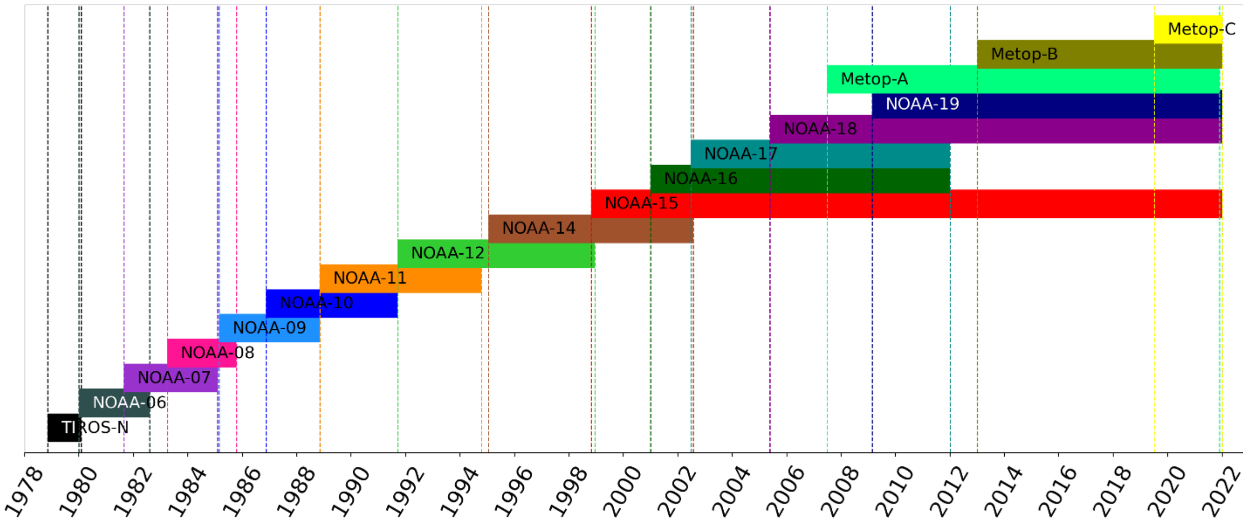

Figure 1: *List of NOAA and Metop satellites carrying an AVHRR instrument used for the PyGAC FDR.*

This guide provides:
1. An overview of the specifications of the data record;
2. Scientific and technical details on the generation and definition of the data record;
3. Information on characteristics and limitations of the product;
4. Technical details on the format.

1.2 Reference Documents

ATBD PyGAC FDR, EUMETSAT 2022a, EUM/USC/DOC/22/1290471.

Devasthale, A., M. Raspaud, C. Schlundt, T. Hanschmann, S. Finkensieper, A. Dybbroe, S. Hornquist, N. Hakansson, M. Stengel and K-G. Karlsson, 2017: PyGAC: An open-source, community-driven Python interface to preprocess nearly 40-year AVHRR Global Area Coverage (GAC) data record, GSICS Quarterly Newsletter, Vol. 11, No. 2, 3-5. DOI: 10.7289/V5R78CFR

Heidinger, A. K., W. C. Straka, C. C. Molling, J. T. Sullivan, and X. Q. Wu, 2010: Deriving an inter-sensor consistent calibration for the AVHRR solar reflectance data record, International Journal of Remote Sensing, vol. 31, no. 24, pp. 6493-6517.

Kidwell, K. B., 1995: NOAA Polar Orbiter Data Users Guide / edited by Kidwell, K.B. and National Climatic Data Center (U.S.). National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service, National Climatic Data Center, Satellite Data Services Division

PyGAC AVHRR Radiance FDR Release 1 Validation Report, EUMETSAT 2022b, EUM/OPS/DOC/22/1282616.

1.3 Acronyms and abbreviations

ATBD	Algorithm Theoretical Basis Document
AMV	Atmospheric Motion Vector
AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperature
CDR	Climate Data Record
CLARA-A3	CM SAF Cloud, Albedo, Radiation data record
CPIDS	Calibration Parameters Input Data Set
DOI	Digital Object Identifier
DS	Data Store
ECMWF	European Centre for Medium-range Weather Forecasts
EUMETSAT	EUropean organisation for the exploitation of METeorological SATellites
ERA	European ReAnalysis
FCDR	Fundamental Climate Data Record
FDR	Fundamental Data Record
GAC	Global Area Coverage
IR	InfraRed
K	Kelvin
KLM	NOAA K,L,M,N,N' satellites (NOAA-15 to -19 and MetOpA-C)
LAC	Local Area Coverage
NOAA	National Oceanic and Atmospheric Administration
Metop	Meteorological Operational Satellite
NetCDF	Network Common Data Form
NH	Northern Hemisphere
NIR	Near Infrared
PACS	Polar Acquisition and Control Subsystems
POD	Polar Orbit Data NOAA TIROS-N and A,C,D,E,F,G,H,I,J satellites (NOAA-6 to -14)
PyGAC	A python package to read and calibrate NOAA AVHRR GAC data
RTTOVS	RadiaTive Transfer TOVS
SAF	Satellite Application Facility
TIR	Thermal InfraRed
TOVS	Tiros Operational Vertical Sounders
UTC	Universal Time Coordinate
VIS	Visible

2 BACKGROUND

This is the Product User Guide (PUG) for the Fundamental Data Record (FDR) of measurements from the Advanced Very High Resolution Radiometer (AVHRR) at full Global Area Coverage (GAC) resolution. The AVHRR GAC FDR has been generated by EUMETSAT and is used as an input for processing of the CM SAF CLARA-A3 and AVHRR polar Atmospheric Motion Vectors (AMV) Climate Data Records (CDR)[1]. The FDR period ranges from 1978 – 2021, and is based on observations from 17 AVHRR instruments on board NOAA satellites TIROS-N to NOAA-19 as well as EUMETSAT satellites Metop-A, -B, and -C. For calibration the PATMOS-X calibration coefficients have been applied (version 2017r1) to visible channels and the nominal operational calibration has been used for the infrared channels.

AVHRR GAC measurements have been processed using the PyGAC software that includes the conversion from counts to reflectance or brightness temperature as well as cross-calibration of the visible channels of the AVHRR sensor. The data are accompanied by additional metadata (such as orbit overlap and equator crossing time) as well as basic quality indicators.

The FDR output data format is NetCDF. NOAA nomenclature is used for the data record, i.e., that it is labelled as AVHRR L1c containing reflectance/brightness temperature values.

[1] http://doi.org/10.15770/EUM_SEC_CLM_0056

3 DATA RECORD OVERVIEW

General	Data record name	AVHRR GAC FDR Release 1
General	Data record digital identifier	DOI: 10.15770/EUM_SEC_CLM_0060
General	Data record short description	AVHRR level-1c data reprocessed using the PyGAC software from observations obtained by 17 AVHRR instruments in GAC resolution aboard Metop and NOAA satellites
General	Record type	Fundamental Data Record (FDR)
General	Content	AVHRR level 1c
Coverage	Temporal coverage	• TIROS-N: AVHRR/1, 05 November 1978 – 30 January 1980 • NOAA-06: AVHRR/1, 01 January 1980 – 03 August 1982 • NOAA-07: AVHRR/2, 24 November 1981 – 01 February 1985 • NOAA-08: AVHRR/1, 01 April 1983 – 14 October 1985 • NOAA-09: AVHRR/2, 25 February 1985 – 07 November 1988 • NOAA-10: AVHRR/1, 17 November 1986 – 16 September 1991 • NOAA-11: AVHRR/2, 08 November 1988 – 16 October 1994 • NOAA-12: AVHRR/2, 16 September 1991 – 14 December 1998 • NOAA-14: AVHRR/2, 20 January 1995 – 26 July 2002 • NOAA-15: AVHRR/3, 26 October 1998 – 31 December 2021 • NOAA-16: AVHRR/3, 01 January 2001 – 31 December 2011 • NOAA-17: AVHRR/3, 25 June 2002 – 31 December 2011 • NOAA-18: AVHRR/3, 21 May 2005 – 31 December 2021 • NOAA-19: AVHRR/3, 22 February 2009 – 31 December 2021 • Metop-A: AVHRR/3, 28 June 2007 – 27 November 2021 • Metop-B: AVHRR/3, 01 January 2013 – 31 December 2021 • Metop-C: AVHRR/3, 03 July 2019 – 31 December 2021
	Temporal frequency	14 Orbits per day, twice daily coverage
	Spatial coverage	Global
	Content	Orbits of AVHRR brightness temperature and reflectance
	Generation frequency	For every available orbit
	Algorithm version	• version_pygac: 1.4.0 • version_pygac_fdr: 0.2.1 • version_satpy: 0.30.0
Instrument	Instruments names	AVHRR
Instrument	Instruments descriptions	The Advanced Very High Resolution Radiometer (AVHRR) is an imaging radiometer in the visible and infrared (IR) portions of the electromagnetic spectrum with channels in the range between 0.58 - 12.5 micrometre. In total three instruments versions have been in operation. AVHRR/1 has four channels (TIROS-N, NOAA-6/8/10), AVHRR/2 has five channels (NOAA-7/9/11/12/13/14) and AVHRR/3 (from NOAA-15 and Metop) six channels. Channel 4 is the same for all three versions.
Instrument Data	Input data	• AVHRR GAC • PATMOS-X calibration coefficients v2017r1 + provisional coefficients for Metop-C
Instrument Data	Output data	Brightness temperature and reflectance in GAC resolution
Instrument Data	Format	NetCDF4
Access	Delivery	Download from EUMETSAT Data Store: https://data.eumetsat.int/

4 DATA RECORD DEFINITION

4.1 Product generated

The FDR contains AVHRR reflectance and brightness temperatures for each available orbit and all available channels. The daily AVHRR data obtained from one satellite provide nearly complete coverage of the entire globe (Figure 2).

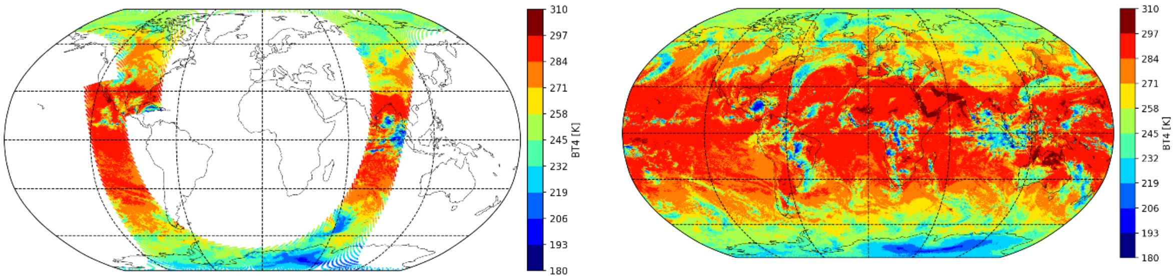

Figure 2: *Example of AVHRR channel 4 BT for one orbit of NOAA15 on the 26th of October 1998 (left) and the 14 orbits of that day (right).*

4.2 Temporal and Spatial coverage

The FDR is produced for each available orbit at Global Area Coverage (GAC) resolution. Each scan line contains 409 pixels, the number of scan lines per orbit varies from file to file.

The AVHRR data are available in two spatial resolutions. Firstly, the full resolution, Local Area Coverage (LAC) format, which provides observations at original pixel resolution with 1.1x1.1 km^2 at the sub-satellite point. Secondly, the slightly downscaled resolution in GAC format, in which four out of every five samples along the scan line are used to compute one average value. The data from only every third scan line are processed, resulting in a spatial resolution of GAC data near the sub-satellite point of 1.1x4.4 km^2 with a 2.2 km gap between two scan lines. For the instruments on the NOAA satellites, this format was created because the data volume of the original format was too high to be stored onboard the satellite until the data were downlinked to the major ground station. Metop data are available in LAC format and have been reformatted to the GAC format for this FDR generation. The LAC to GAC resampling principles are illustrated in Figure 3. The size of the pixels are changing across the scanline of the AVHRR instrument as shown on Figure 4.

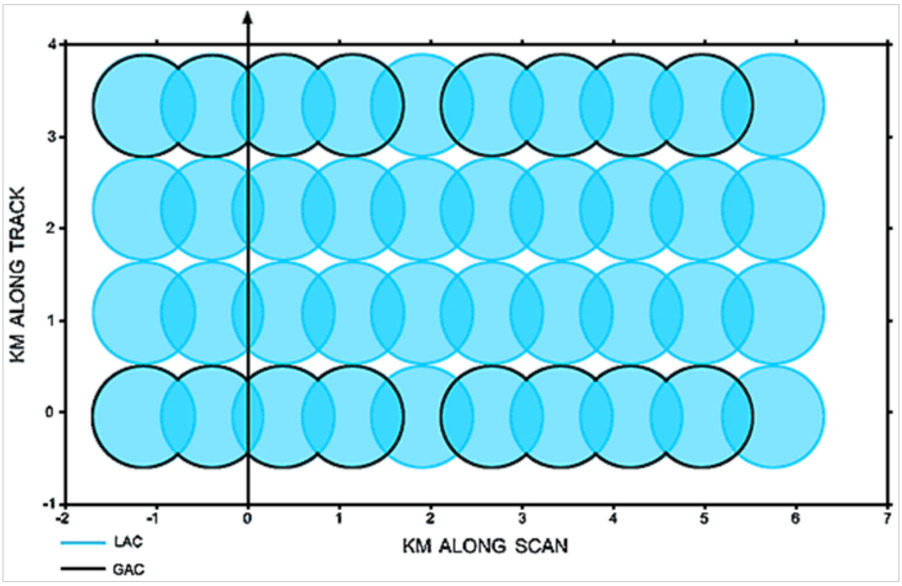

Figure 3: *Idealised view of LAC and GAC spatial sampling.*

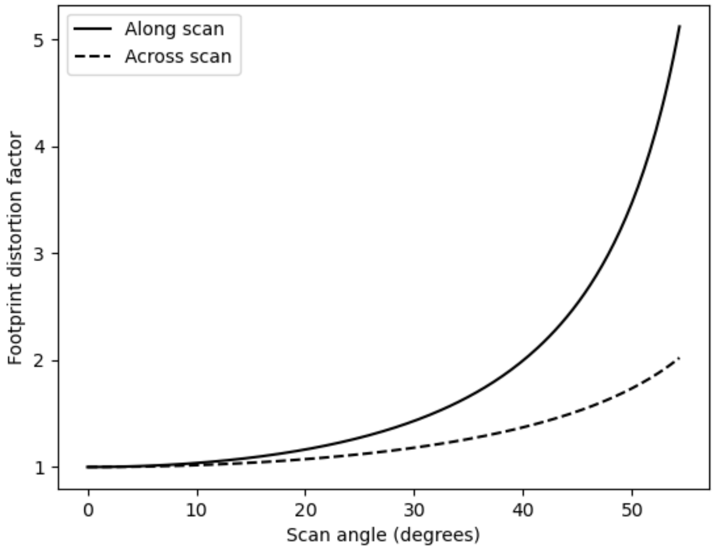

Figure 4: *Footprint distortion of a pixel along the scanline. This was computed using lats/lons of a real NOAA-6 orbit and an approximate altitude of 833km. Reference: Capderou, Michel (2014): Handbook of Satellite Orbits, Springer. Section 12.2 - 12.3.*

5 DATA RECORD GENERATION SUMMARY

5.1 Major steps of the data processing

The FDR dataset is based on AVHRR Level 1B data in NOAA-GAC format. Three open source Python packages are used to reprocess the L1B data archive and generate the FDR dataset (see Figure 5).

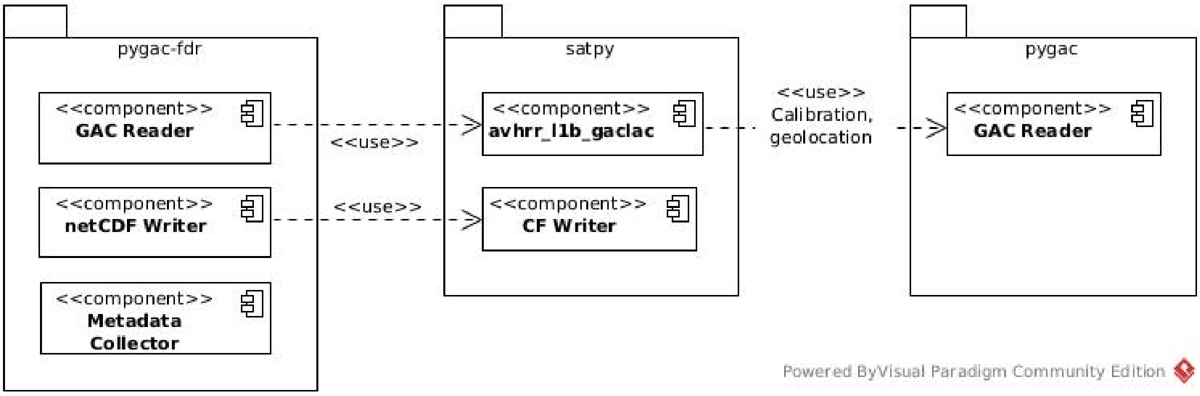

Figure 5: *Open Source software packages used to create the dataset*

The retrieval is done in three main parts:

- *satpy*[2], reading and writing happens through this module, which provides easy access to PyGAC's GAC reader and a general-purpose netCDF-CF writer;
- *pygac*[3]*,* is used for decoding the GAC format as well as calibrating raw counts to reflectances or brightness temperatures and navigating the data;
- *Pygac-fdr*[4], is responsible for saving the results to CF-compliant NetCDF files and enhancing their metadata.

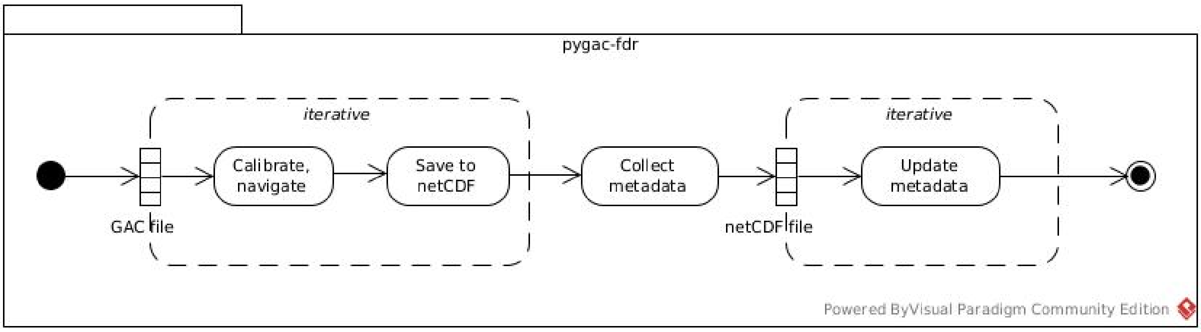

Figure 6: *Reprocessing workflow*

The reprocessing workflow is shown in Figure 6. First all GAC files are converted into calibrated NetCDF files. As there are no dependencies between orbits, this task can be executed in parallel. Afterwards, the following additional metadata are collected per file:

1. Longitude and time of ascending equator crossing(s)

[2] https://github.com/pytroll/satpy
[3] https://github.com/pytroll/pygac
[4] https://github.com/pytroll/pygac-fdr

2. Overlap-free scanline range
3. Global quality flag

Items 2 and 3 require analysis of a file's neighbourhood, which is why all output files are required for this step. Finally, these metadata are added to the global netCDF attributes.

The complete description of the process can be find in the ATBD [EUMETSAT, 2022a].

5.2 AVHRR input data

The FDR is generated from observations collected by 17 individual AVHRR instruments on board various NOAA and EUMETSAT (Metop) satellites (Figure 1, Figure 7).

The NOAA and EUMETSAT satellites circle the Earth 14 times per day at an altitude of about 833 km. The AVHRR instrument takes 2048 Earth views per scan and per channel, having a swath width of 2893 km and a pixel resolution of about 1.1 km at nadir. For the GAC format however, across-track data have been downscaled to 409 observations per scanline (see Figure 3).

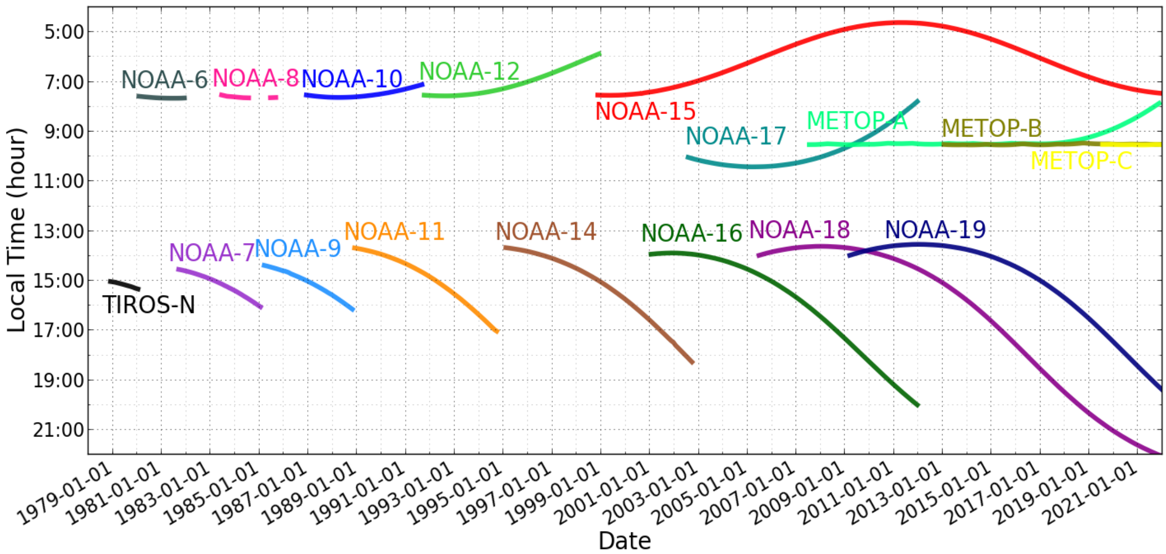

Figure 7: *Global view of the local equator crossing time of each NOAA and Metop satellites carrying an AVHRR instruments.*

AVHRR instrument includes visible (VIS), near infrared (NIR), and thermal infrared (TIR) channels. The AVHRR passive imager was first a 4-channel radiometer and subsequently improved to 5 and 6 channels at wavelengths between 0.55 and 12.5 µm. Table 1 summarises the characteristics of the three generations of AVHRR instruments.

Table 1: *Details about the three versions of the AVHRR instrument. Information from OSCAR WMO websites.*

	AVHRR/1	AVHRR/2	AVHRR/3
Period	1979-8/2001	1981 – 2007	1998 -> 2025
Satellites	TIROS-N, NOAA-6, -8, -10	NOAA-7, -9, -11, -12, -13, and -14	NOAA-15, -16, -17, -18, and -19, Metop-A, -B, and -C
Number of channels	4	5	6
Channels central wavelength (µm) and spectral interval (µm)	1: 0.615 (0.55-0.68) 2: 0.912 (0.725-1.1) 3: 3.74 (3.55-3.93) 4: 11.0 (10.5-11.5)	1: 0.615 (0.55-0.68) 2: 0.912 (0.725-1.1) 3: 3.74 (3.55-3.93) 4: 10.80 (10.3-11.3) 5: 12.00 (11.5-12.5)	1: 0.630 (0.58-0.68) 2: 0.862 (0.725-1.00) 3A: 1.61 (1.58-1.64) 3B: 3.74 (3.55-3.93) 4: 10.80 (10.3-11.3) 5: 12.00 (11.5-12.5)
Swath[5] (in pixels)	cross track: 2048 (LAC), 409 (GAC) along track: 6	cross track: 2048 (LAC), 409 (GAC) along track: 6	cross track: 2048 (LAC), 409 (GAC) along track: 6
Resolution at nadir (km)	1.1 (LAC)	1.1 (LAC)	1.1 (LAC)

5.3 Instrument Calibration

There is no on-board calibration system for the AVHRR sensor's visible channels. Consequently, calibration coefficients needed to be calculated based on independent MODIS and ground-truth data. As the MODIS record extends back in time only until the year 2000, calibration information using MODIS/AVHRR SNOs was transferred via AVHRR/AVHRR SNOs also into the pre-MODIS era in order to minimise satellite-to-satellite inconsistencies. PyGAC visible calibration coefficients and their updates were provided by NOAA [M. Foster and A. Heidinger, personal communication, 2021 + 2022], and are based on version PATMOS-x SOLCAL, v2017r1 [M. Foster, personal communication, 2021 + 2022]. This visible calibration minimises spectral differences among the various AVHRR sensors.

The infrared calibration is only based on on-board calibration data, starting from obtaining Platinum Resistance Thermometer (PRT), space and Internal Calibration Target (ICT, blackbody) counts. ICT temperatures are obtained from PRT counts based on coefficients provided in the POD and KLM Data User Guides [Kidwell, 1995].

A detailed description of the calibration method can be found in the ATBD [EUMETSAT, 2022a]. Note that the IR calibration procedure is satellite specific, thus there is no cross-calibration between satellites for IR channels.

[5] The swath and resolution indicated in the table refer of the full AVHRR LAC resolution. The FDR is derived using AVHRR GAC resolution (see figure 3).

6 PRODUCT FORMAT DESCRIPTION

The PyGAC AVHRR FDR is available in the Network Common Data Form (NetCDF) format.

6.1 NetCDF product description

For each AVHRR orbit there is a file that contains several global attributes (Table 2) and 24 variables (Table 3). The dimension of the variables is given in Table 3.
For each orbit, there is an overall quality flag (*global_quality_flag*). It is recommended to use only orbits for which the over quality flag is set to ok (see Table 3). There is also a quality flag per scanline (*qual_flags*).

Table 2: *NetCDF Global attributes. Values are given for the NOAA 15 file AVHRR-GAC_FDR_1C_N15_19981026T180849Z_19981026T195309Z_R_O_20211001T085226Z_0100.nc.*

Name	Value
Conventions	CF-1.8 ACDD-1.3
comment	Developed in cooperation with EUMETSAT, CM SAF, and the PyTroll community.
creator_email	ops@eumetsat.int
creator_name	EUMETSAT
creator_url	https//www.eumetsat.int/
date_created	2021-10-01T085226.145800
disposition_mode	O
end_time	19981026T195309Z
gac_filename	NSS.GHRR.NK.D98299.S1808.E1953.B0236263.GC
geospatial_lat_max	89.96786352149199
geospatial_lat_min	-89.97921921375189
geospatial_lat_resolution	1050 meters
geospatial_lat_units	degrees north
geospatial_lon_max	179.99999338669778
geospatial_lon_min	-179.9999623951717
geospatial_lon_resolution	1050x4 meters
geospatial_lon_units	degrees east
ground_station	GC
id	DOI: 10.15770/EUM_SEC_CLM_0060
institution	EUMETSAT
instrument	Earth Remote Sensing Instruments > Passive Remote Sensing > Spectrometers/Radiometers > Imaging Spectrometers/Radiometers > AVHRR-3
keywords	ATMOSPHERE > ATMOSPHERIC RADIATION > REFLECTANCE, ATMOSPHERE > ATMOSPHERIC RADIATION > OUTGOING LONGWAVE RADIATION, SPECTRAL/ENGINEERING > INFRARED WAVELENGTHS, SPECTRAL/ENGINEERING > VISIBLE WAVELENGTHS
keywords_vocabulary	GCMD Science Keywords, Version 9.1
licence	EUMETSAT data policy https//www.eumetsat.int/website/home/AboutUs/WhoWeAre/LegalFramework/DataPolicy/index.html
naming_authority	int.eumetsat
orbit_number_end	2363
orbit_number_start	2362
platform	Earth Observation Satellites > NOAA POES > NOAA-15
processing_level	1C
processing_mode	R
product_version	1.0.0
references	Devasthale, A., M. Raspaud, C. Schlundt, T. Hanschmann, S. Finkensieper, A. Dybbroe, S. Hornquist, N. Hakansson, M. Stengel and K-G. Karlsson. "PyGAC An open-source, community-driven Python interface to preprocess nearly 40-year AVHRR Global Area Coverage (GAC) data record", GSICS Quarterly Newsletter, Vol. 11, No. 2 (Sept. 2017) 3-5. DOI10.7289/V5R78CFR. Heidinger, A. K., W. C. Straka, C. C. Molling, J. T. Sullivan, and X. Q. Wu, Deriving an inter-sensor consistent calibration for the AVHRR solar reflectance data record, International Journal of Remote Sensing, vol. 31, no. 24, pp. 6493-6517, 2010.
source	AVHRR GAC Level 1 Data
standard_name_vocabulary	CF Standard Name Table v73
start_time	19981026T180849Z
summary	Fundamental Data Record (FDR) of measurements from the Advanced Very High Resolution Radiometer (AVHRR) at full Global Area Coverage (GAC) resolution. AVHRR GAC measurements have been calibrated to Level 1C using the PyGAC software with PATMOS-x calibration coefficients.

	This includes the conversion from counts to reflectance or brightness temperature as well as inter-sensor calibration. The data are accompanied by additional metadata (such as orbit overlap and equator crossing time) as well as basic quality indicators.
sun_earth_distance_correction_factor	0.9870940654475591
time_coverage_start	19981026T005400Z
title	AVHRR GAC L1C FDR
version_calib_coeffs	PATMOS-x, v2017r1, with provisional coefficients for MetOp-C
version_pygac	1.4.0
version_pygac_fdr	0.2.1
version_satpy	0.30.0
history	Created by pytroll/satpy on 2021-10-01 085226.449087

Table 3: *List of dimensions used for the variables. Exemple of values for AVHRR-GAC_FDR_1C_N15_19981026T010124Z_19981026T024809Z_R_O_20211001T084800Z_0100.nc*

Name	Value
y	12810 - depend of the file
x	409 - fixed
num_flags	7
string50	50
num_eq_cross	2

Table 4: *List of Variables in each NetCDF file*

Variable name	Dimension	Units	Description
y	y		Line number
acq_time	y	seconds since 1970-01-01	Mean scanline acquisition time
x	x		Pixel number
latitude	(y,x)	degrees_north	
longitude	(y,x)	degrees_east	
brightness_temperature_channel_3b	(y,x)	Kelvin	TOA brightness temperature 3.74 µm (3.55-3.93 µm)
brightness_temperature_channel_4	(y,x)	Kelvin	TOA brightness temperature 10.8 µm (10.3-11.3 µm)
brightness_temperature_channel_5	(y,x)	Kelvin	TOA brightness temperature 12.0 µm (11.5-12.5 µm)
num_flags	(num_flags, string50)		**0** - Scan line number **1** - Fatal error flag **2** - Insufficient data for calibration **3** - Insufficient data for navigation **4** - Solar contamination of blackbody in chan 3 **5** - Solar contamination of blackbody in chan 4 **6** - Solar contamination of blackbody in chan 5
qual_flags	(y, num_flags)		Scanline Quality Flags
reflectance_channel_1	(y,x)	%	TOA bidirectional reflectance 0.63 µm (0.58-0.68 µm)
reflectance_channel_2	(y,x)	%	TOA bidirectional reflectance 0.8625 µm (0.725-1.0 µm)
reflectance_channel_3a	(y,x)	%	TOA bidirectional reflectance 1.61 µm (1.58-1.64 µm)
sensor_azimuth_angle	(y,x)	degrees	
sensor_zenith_angle	(y,x)	degrees	
solar_azimuth_angle	(y,x)	degrees	
solar_zenith_angle	(y,x)	degrees	
sun_sensor_azimuth_difference_angle	(y,x)	degrees	Angle of rotation from solar azimuth to platform azimuth
overlap_free_start	()		First scanline (0-based) of the overlap-free part of this file. Scanlines before that also appear in the preceding file
overlap_free_end	()		Last scanline (0-based) of the overlap-free part of this file. Scanlines hereafter also appear in the subsequent file
midnight_line	()		Scanline (0-based) where UTC timestamp crosses the dateline
equator_crossing_longitude	(num_eq_cross,)	degrees_east	Longitude where ascending node crosses the equator

equator_crossing_time	(num_eq_cross,)	seconds since 1970-01-01 00:00:00	UTC time when ascending node crosses the equator
global_quality_flag	()		Global quality flag If this flag is everything else than "ok", it is recommended not to use the file. flag_values/flag_meanings : 0/ok 1/invalid_timestamp 2/too_short 3/too_long 4/duplicate 5/redundant

All variables in the GAC header (Table 5) are not necessarily used for the processing of this FDR. The GAC header is a direct copy of the level 1b file. It is described in details in the POD/KLM user guides [Kidwell, 1995].
To check what was used please refer to the Jason file (https://github.com/pytroll/pygac/blob/main/pygac/data/calibration.json) indicating what was used.

Table 5: *Content of the GAC header (120 variables)*

Variable
data_set_creation_site_id
ascii_blank_=_x20
noaa_level_1b_format_version_number
noaa_level_1b_format_version_year
noaa_level_1b_format_version_day_of_year
reserved_for_logical_record_length
reserved_for_block_size
count_of_header_records
zero_fill0
data_set_name
processing_block_identification
noaa_spacecraft_identification_code
instrument_id
data_type_code
tip_source_code
start_of_data_set_day_count_starting_from_0_at_00h,_1_jan_1950
start_of_data_set_year
start_of_data_set_day_of_year
start_of_data_set_utc_time_of_day
end_of_data_set_day_count_starting_from_0_at_00h,_1_jan_1950
end_of_data_set_year
end_of_data_set_day_of_year
end_of_data_set_utc_time_of_day
year_of_last_cpids_update
day_of_year_of_last_cpids_update
zero_fill1
instrument_status
zero_fill2
record_number_of_status_change
second_instrument_status
count_of_data_records
count_of_calibrated,_earth_located_scan_lines
count_of_missing_scan_lines
count_of_data_gaps
count_of_data_frames_without_frame_sync_word
count_of_pacs_detected_tip_parity_errors
sum_of_all_auxiliary_sync_errors_detected
time_sequence_error
time_sequence_error_code
socc_clock_update_indicator
earth_location_error_indicator
earth_location_error_code
pacs_status_bit_field

data_source
zero_fill3
reserved_for_the_ingester
reserved_for_decommutation
zero_fill4
ramp_auto_calibration_indicators_bit_field
year_of_most_recent_solar_channel_calibration
day_of_year_of_most_recent_solar_channel_calibration
primary_calibration_algorithm_id
primary_calibration_algorithm_selected_options
secondary_calibration_algorithm_id
secondary_calibration_algorithm_selected_options
ir_target_temperature_1_conversion_coefficient_1
ir_target_temperature_1_conversion_coefficient_2
ir_target_temperature_1_conversion_coefficient_3
ir_target_temperature_1_conversion_coefficient_4
ir_target_temperature_1_conversion_coefficient_5
ir_target_temperature_1_conversion_coefficient_6
ir_target_temperature_2_conversion_coefficient_1
ir_target_temperature_2_conversion_coefficient_2
ir_target_temperature_2_conversion_coefficient_3
ir_target_temperature_2_conversion_coefficient_4
ir_target_temperature_2_conversion_coefficient_5
ir_target_temperature_2_conversion_coefficient_6
ir_target_temperature_3_conversion_coefficient_1
ir_target_temperature_3_conversion_coefficient_2
ir_target_temperature_3_conversion_coefficient_3
ir_target_temperature_3_conversion_coefficient_4
ir_target_temperature_3_conversion_coefficient_5
ir_target_temperature_3_conversion_coefficient_6
ir_target_temperature_4_conversion_coefficient_1
ir_target_temperature_4_conversion_coefficient_2
ir_target_temperature_4_conversion_coefficient_3
ir_target_temperature_4_conversion_coefficient_4
ir_target_temperature_4_conversion_coefficient_5
ir_target_temperature_4_conversion_coefficient_6
zero_fill5
ch_1_solar_filtered_irradiance_in_wavelength
ch_1_equivalent_filter_width_in_wavelength
ch_2_solar_filtered_irradiance_in_wavelength
ch_2_equivalent_filter_width_in_wavelength
ch_3a_solar_filtered_irradiance_in_wavelength
ch_3a_equivalent_filter_width_in_wavelength
ch_3b_central_wavenumber
ch_3b_constant_1
ch_3b_constant_2
ch_4_central_wavenumber
ch_4_constant_1
ch_4_constant_2
ch_5_central_wavenumber
ch_5_constant_1
ch_5_constant_2
zero_fill6
reference_ellipsoid_model_id
nadir_earth_location_tolerance
earth_location_bit_field
zero_fill7
constant_roll_attitude_error
constant_pitch_attitude_error
constant_yaw_attitude_error
epoch_year_for_orbit_vector
day_of_epoch_year_for_orbit_vector
epoch_utc_time_of_day_for_orbit_vector
semi-major_axis
eccentricity
inclination
argument_of_perigee
right_ascension_of_the_ascending_node
mean_anomaly
position_vector_x_component

position_vector_y_component
position_vector_z_component
velocity_vector_x-dot_component
velocity_vector_y-dot_component
velocity_vector_z-dot_component
earth_sun_distance_ratio
zero_fill8

6.2 Filename convention

The FDR file names follow the WMO file naming convention. An example is given in Table 6.

Table 6: *Description of the NetCDF filename for the FDR.*

Filename convention for reprocessed netCDF AVHRR PyGAC FDR	
W_XX-EUMETSAT-Darmstadt,GAC+RADIOMETER,<SATID>+<PRODUCT>+<INSTRUMENT>_C_<ORIGINATOR>_<START_DATE>_<END_DATE>_eps_r_l1_<VERSION>.nc	
Example of a filename for one orbit of MetopA on the 30th January 2008 ending at 1:50:47	
W_XX-EUMETSAT-Darmstadt,GAC+RADIOMETER,METOPA+PYGAC+AVHR_C_EUMP_20080130T000653Z_20080130T015047Z_eps_r_l1c_0100.nc	
Description	
<SATID>	Satellite used.
<PRODUCT>	PYGAC
<INSTRUMENT>	METOPA (or other like TIROSN or NOAA06)
<ORIGINATOR>	EUMP
<START_DATE>	Date of the start of the orbit (yyyyMMddThhmmssZ)
<END_DATE>	Date of the end of the orbit (yyyyMMddThhmmssZ)
<VERSION >	Release version

6.3 Data volume

The following table describes the volume of data for each satellite.

Table 7: *Size of the AVHRR FDR per platform*

Platform	Size	Platform	Size
TSN	237 Gb	NOAA-15	5.6 Tb
NOAA-6	312 Gb	NOAA-16	2.7 Tb
NOAA-7	892 Gb	NOAA-17	2.2 Tb
NOAA-8	184 Gb	NOAA-18	4.5 Tb
NOAA-9	1.1 Tb	NOAA-19	3.5 Tb
NOAA-10	1.1 Tb	Metop-A	3.7 Tb
NOAA-11	1.7 Tb	Metop-B	2.5 Tb
NOAA-12	2.0 Tb	Metop-C	624 Gb
NOAA-14	2.1 Tb	**Total**	34.94 Tb

7 VALIDATION SUMMARY

The PyGAC AVHRR FDR has been verified and validated, the results are presented in the validation report [EUMETSAT 2022b]. It provides insight into the temporal consistency and possible issues with the data record.

A statistical verification was applied to the FDR. It shows that:

- The FDR processing is overall complete, but the treatment of night-time reflectance is inconsistent between satellites (sometimes these are reported as fill values, sometimes as close to 0). More periods of missing data are found for earlier satellites (prior to NOAA-9).
- The FDR radiances are in line with expected behaviour:
    - Reflectance data display the expected seasonal patterns, such as polar night and day at extreme latitudes and transition from summer to winter illumination conditions (and vice versa) across all latitude bands.
    - Time series of reflectance and brightness temperature at spatially homogeneous desert sites show how changes in equatorial crossing times due to orbital drift impact the measurements. When equatorial crossing times are similar between satellites, simultaneous observations are also similar.
    - Brightness temperatures appear homogeneous and stable in terms of seasonality: hemispheric warming consistently follows sun illumination conditions. Tropical brightness temperatures appear somewhat colder during summer, probably caused by colder tops of deep convective clouds in the ITCZ.

For the IR channels, a quality evaluation was done against some PATMOS-x orbits, FIDUCEO and HIRS data records. Major results are:

- As expected, there is a good agreement for the few PATMOS-x orbits analysed, although minor differences do exist between visible channels.
- Despite the fact that the FDR isn't explicitly harmonised, the comparison with FIDUCEO shows that the PyGAC brightness temperatures exhibit better temporal consistency. This is shown by less and smaller jumps between the split-window channels.
- The comparison with HIRS shows a good quality of the AVHRR FDR in terms of temporal consistency. Considering the differences between both sensors in terms of spectral response functions and spatial sampling, both agree quite well for the majority of AVHRR instruments. Particularly NOAA-15 and newer sensors show over their long time series almost no bias trend. Small trends are found, mainly for the earlier sensors, which cannot be attributed to AVHRR directly based on this comparison.

In addition, the PyGAC FDR was compared with RTTOV radiative transfer calculations using ERA5 reanalyses as input data. Data were compared when they are within 15 minutes and 30 km of an AVHRR observation. The results show that the departures of infrared channels are generally close to 0 (between -1.2 K and 0.4 K for channels 4 and 5) and improve through time. This is likely to result from improvements in reanalysis quality and associated input data (in particular surface emissivity and sea-ice), and improvements in the quality of radiometers. As simulations are clear-sky, contamination by thin clouds increases the bias between AVHRR GAC IR data and simulations. The short-lived effects of volcanic eruptions (El Chichon 1982 and Pinatubo 1991) also do show in the data. For visible channels 1 and 2, effects of instrument ageing are visible throughout all analyses and for all satellites with sufficiently long time series except Metop. Problematic months show as flat or very wide distributions of monthly departures. As simulations are clear-sky, cloud contamination explains the higher occurrence of positive departures. For most recent sensor generations, departures are smaller, with the mode being <= 1% overall.

The validation report provides a detailed analysis of the overall quality of this first release of the PyGAC FDR. With this information, any future user will be able to make an informed decision about the data's suitability for a specific usage. The absence of thermal channel cross-calibration and in particular the effects of orbital drift are two major points to be addressed while using this FDR to derive a Climate Data Records (CDR) for a geophysical variable. Whilst this FDR does not satisfy all requirements for climate applications, considerable progress has been made in various aspects to approach this goal.

8 LIMITATIONS AND RECOMMENDATIONS

This is a list of known limitations, and it is very likely that further unknown limitations exist. We strongly advise that the user consults the validation report, and in particular data availability and hovmoeller plots in that report. If in doubt please also use the EUMETSAT User Service Helpdesk for questions by email: *ops@eumetsat.int*.

- Periods of data outages covering at least several days:
  - NOAA-14: 08-1988, 06-1989, 04-1990, 01/02-1991, 12-2001
  - NOAA-12: 10-1993
  - NOAA-15: 07-2000 to 02-2001
  - Metop-B: 04/05-2013
- Periods when channel 3a was turned on at daytime (3b off) and channel 3b at nighttime (3a off):
  - NOAA-15: 1999-03-09 to 1999-04-20, and during NH summer over Alaska from 2016 onwards
  - NOAA-16: until 2003-05-01, and channel 3b always on afterwards
  - NOAA-17: throughout
  - NOAA-18: 2005-06-23 to 2005-08-05, and channel 3b always on otherwise
  - NOAA-19: 2009-03-19 to 2009-05-14, and during NH summer over Alaska from 2016 onwards
  - Metop-A/B/C: throughout
- In the absence of Two Line Element data, angles are computed based on a fixed satellite height of 850 km. The following number of orbits are affected:
  - NOAA-6: 307 orbits
  - NOAA-8: 592
  - NOAA-9: 1385
  - NOAA-10: 3
  - TIROS-N: 94

  Without TLE data, satellite angles will probably be less accurate. We did not assess whether a switch from TLE usage to the non-TLE fallback approach introduces discontinuities into satellite angle time series. If interested, the user can identify such orbits (metadata variable "orbital_parameters_tle" does not exist in NetCDF file) and compare satellite angles to adjacent orbits.
- The orbits of most satellites are not stabilised and thus drift regarding their equator crossing time. This drift introduces artefacts into derived products such as time series and trend analyses. We thus recommend that this PyGAC FDR should be used with extreme caution for climatological applications. The PyGAC FDR itself is not a climate data record.
- There is no on-board calibration of solar channels. Instead, SNOs with MODIS data are used as an independent calibration source. For years before MODIS started operation (i.e. in and before 2000), AVHRR data are intercalibrated through AVHRR-to-AVHRR SNOs, starting with the earliest AVHRR record that was cross-calibrated to MODIS as the initial reference.
- There is no cross-calibration of thermal channels, which are calibrated only based on on-board instrumentation.
- There is no homogeneous treatment of night time observations in VIS channels. For some satellites, these are always set to 0, while for others these are close to 0. We recommend that users flag night-time VIS data as a function of solar azimuth angle.
- There is no blacklisting/filtering of irregular or potentially corrupt orbits. We recommend that the user applies own quality control/monitoring metrics based on the metadata variable "global_quality_flag". For a previous internal release of PyGAC, we found that ~6 % of

orbits were affected by at least one of the issues in the following list. Some issues are probably fixed with this release, in particular those related to timestamp corruption:
  - file overly long due to corrupt l1b timestamps
  - file contains data of 2 or more orbits
  - file containing only redundant orbit fragments
  - negative orbit length, i.e. end date and time before start
  - wrong l1c timestamp
- For this release, the following periods are associated with bad l1c quality:
  - NOAA-17 between 2010-03-01 and 2011-12-31
  - NOAA-6 between 1981-08-14 and 1982-08-02
  - NOAA-8 between 1983-05-04 and 1983-09-19
  - Metop-C channel 3a from 2021 (gradually increasing reflectance); all of these time periods also appear as anomalous in the data availability plots.

  We recommend that users should treat data from such orbits with care. The channel 3a trend for Metop-C is a gradual phenomenon, and affected data might still be useful for qualitative applications. However, the data listed for NOAA-6/8/17 above should be blacklisted completely.
- For this release, the FDR geocoding quality has not been assessed and the geolocation should be taken with care when using the data to derive certain level 2 land products such as snow, vegetation dynamics, lake surface water temperature etc. It is planned to include a geolocation assessment in the next release.

9 PRODUCT ACCESS

The data are accessible via download from the EUMETSAT Data Store (DS). To access the data from EUMETSAT, you need to register with the EUMETSAT EO-Portal.

9.1 Register with EUMETSAT Data Centre and download data

Do this:

1. Register in the EUMETSAT EO-Portal (https://eoportal.eumetsat.int/) by clicking on the New User – Create New Account tab;
2. After finalisation of the registration process, an e-mail is sent to the e-mail address entered in the registration. Click the confirmation link in the e-mail to activate your account;
3. Search for the data in the EUMETSAT Data Store. If the data are no longer available in the DS please contact ops@eumetsat.int for advice.

9.2 Data not available in Data Store

If the data are not available online in the Data Store please contact ops@eumetsat.int indicating the data record that you want to access including its Digital Object Identifier (DOI) number.

10 PRODUCT SUPPORT AND FEEDBACK

For enquiries about the FDR described in this product user guide, please contact the EUMETSAT User Service Helpdesk by email: ops@eumetsat.int .

11 PRODUCT REFERENCING

The data record described in this product user guide has a unique DOI that should be used for referencing. The product's filename provides a unique identifier for each product.

12 AKNOWLEDGEMENTS

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