



Product user guide – AVHRR FCDR

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1 Introduction

1.1 Scope

This document is the product user guide for the AVHRR FCDR Beta v0.3 data release which is being made available for assessment by trial users. The data record spans the years 1988-2016 and is a preliminary version of the forthcoming full FCDR which it is hoped will be long enough to generate climate data records (CDRs) for climate research. This guide gives:

1. an overview of the specifications of the data record;
2. the science used to define, process and generate the data record;
3. information related to any limitations of the current version of the data record;
4. technical details on the file format and on how to access the data.

1.2 Version Control

Version	Reason	Reviewer	Date of Issue
0.1	Release of v0.4 pre-Beta version	JM,RP	10/01/2018
1.0	Project end v1.0 of code	RP	23/08/2019

1.3 Applicable and Reference Documents



- RN_004, Release Note: Pre-Beta release of the AVHRR FCDR
- RN_016, Release Note: v1.0 release of the AVHRR FCDR
- D2.2a, Principles of FCDR Effects Tables
- D2.2d, AVHRR FCDR Uncertainty
- Instrument Noise characterization and the Allan/M-sample variance, J. Mittaz
<http://www.fiduceo.eu/content/instrument-noise-characterization-and-allanm-sample-variance>
- CF-standards version 1.7, <http://cfconventions.org/Data/cf-conventions/cf-conventions-1.7/cf-conventions.html>
- FIDUCEO Website: <http://www.fiduceo.eu>

1.4 Glossary

AVHRR	Advanced Very High Resolution Radiometer
BT	Brightness Temperature
CEDA	Centre for Environmental Data Archiving
CF	Climate and Forecast
CLASS	Comprehensive Large-Array Stewardship System
CPIDS	Calibration Parameters Instrument Data Set
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FIDUCEO	Fidelity and Uncertainty in Climate data records from Earth Observations
FOV	Field of View
IASI	Infrared Atmospheric Sounding Interferometer
ICCT	Internal Cold Calibration Target
IWCT	Internal Warm Calibration Target
METOP	Meteorological Operational satellite
NCC	National Calibration Centre
NESDIS	National Environmental Satellite, Data and Information Service
NOAA	National Oceanic and Atmospheric Administration
NORAD	North American Aerospace Defence Command
NPL	National Physical Laboratory
PRT	Platinum Resistance Thermistor
SNO	Simultaneous Nadir Observations
SRF	Spectral Response Function
STAR	Centre for Satellite Applications and Research
TLE	Two Line Element
TIROS	Television Infra-Red Observation Satellite
UOR	University of Reading
UTC	Coordinated Universal Time

2 FCDR characteristics

General	FCDR name	FIDUCEO AVHRR FCDR Beta v0.3.
	FCDR reference	A journal article and technical documentation is in preparation.
	FCDR digital identifier(s)	A DOI will be issued later.
	FCDR description	Recalibrated brightness temperatures for AVHRR/1, AVHRR/2 and AVHRR/3 with metrologically-traceable uncertainty estimates. Error covariance information is also provided. In this release, relative reflectance for channels 1,2 and 3A (when available) together with estimated independent, common and structured uncertainties are also provided.
	FCDR type	Easy
	FCDR period	1980-01-01—2016-12-31
	FCDR satellites	NOAA-11 NOAA-12

	NOAA-14
	NOAA-15
	NOAA-16
	NOAA-17
	NOAA-18
	NOAA-19
	MetOp-A
FCDR content	Brightness temperatures and uncertainties generated with FCDR_AVHRR version 0.3 (Beta)
  Instrument name	Advanced Very High-Resolution Radiometer (AVHRR)

Instrument description The AVHRR is a broadband, four, five or six channel (depending on the model) across-track scanner (collecting pixels as a sequence of scan lines at right angles to the direction of travel of the satellite over the ground) that senses in the visible and thermal infrared portions of the electromagnetic spectrum.

Cross-track scanning is accomplished by a continuously rotating scan mirror (oriented at 45 degrees with respect to the axis of rotation to avoid the variation of polarization effects across the swath) that is directly driven by a motor. Each pass of the satellite provides a 2399 km wide swath. The satellite orbits the Earth 14 times each day from 833 km above its surface.

The thermal channels are calibrated before launch as well as in-flight, using measurements of an internal warm calibration target (IWCT) and of a cold (deep space) target (DST). The calibration cycle is undertaken during every full scan, i.e. about 40000 times per full orbit. The in-flight calibration procedure consists of 10 measurements (as counts) per scan line when viewing the IWCT and 10 measurements per scan line of counts for a space view. Four PRTs measure the temperature of the IWCT and allow an estimate of the spectral radiance and channel-integrated spectral radiance from the IWCT to be made.

The basic quantity recorded are digital counts corresponding to the total incident radiance including instrument self-emission. In operation, all the detectors are actively cooled to a temperature of 105 K to reduce detector noise and increase sensitivity. The electronics have been configured such that the counts reduce with increasing radiance. In order to maintain a dynamic range, the voltage from the space view (or cold target) observations are actively electronically clamped and are used as a reference voltage. This means that the detected signal is implicitly the total radiance observed by the detectors at the time of observation minus the radiance observed by the detectors when viewing space. The recorded counts are the result of a conversion of the analogue detected signal to a 10-bit binary form within the instrument.

While radiances are calibrated in units of $\text{mW m}^{-2} \text{sr}^{-1} \text{cm}$, measurements are converted to Brightness Temperatures in units of kelvin.

For channels 1,2 and 3A, the reflectance ratio or albedo is provided.

Data	<p>Input data</p> <ul style="list-style-type: none"> • L1B data files obtained from the NOAA CLASS archive and the University of Miami • Spectral response functions obtained from NOAA NESDIS STAR • PRT coefficients obtained from CPIDS and NOAA • TLE orbit data provided by NORAD
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	Output data	AVHRR Easy FCDR brightness temperatures with associated independent, structured and common uncertainties estimates and error covariance data.
	Format	The data are provided in NetCDF4 format and complies with CF standard version 1.6 (and version 1.7 where possible).
Access	CEDA	The data is hosted by CEDA and is available on request by contacting the FIDUCEO team at: fiduceo-coordinator@lists.reading.ac.uk .
	Delivery	Made available from CEDA by FTP and Xfc cache.
Resolution	Horizontal	Footprint size is 1.1km x 1.1 km at nadir.
	Vertical	Surface and sounding channels. The actual resolution depends on the atmospheric state.
	Temporal	Polar-orbiting GAC (~14 orbits per day). Orbit files are split at equatorial crossings with reference to the daytime ascending node.
Physical Content	FCDR physical quantity	The core physical quantities generated are Planck brightness temperatures for each channel and Earth view. Associated information stored in the same files comprises: independent, structured and common uncertainties, cross-channel and cross-pixel correlation information, and geolocation information (e.g. latitudes, longitudes, zenith angles etc).
	FCDR physical description	The data is distributed as one netCDF file per orbit, with a total of 453,818 files in the Easy FCDR occupying a disk volume of 19.4 Tb on CEMS. The total size per satellite is as follows: NOAA-11: 26,834 files = 1.5 Tb, NOAA-12: 33,518 files = 1.8 Tb, NOAA-14: 34,596 files = 1.9 Tb, NOAA-15: 56,258 files = 2.4 Tb, NOAA-16: 48,156 files = 2.3 Tb, NOAA-17: 67,657 files = 1.8 Tb, NOAA-18: 54,361 files = 2.7 Tb, NOAA-19: 37,890 files = 1.9 Tb, METOP-A: 94,548 files = 2.2 Tb.
Uncertainty target	Accuracy	Metrologically-traceable independent, structured and common uncertainties are provided for each measurement.
	Precision	Brightness temperatures and their uncertainties are stored with a precision of 0.01K.

	Stability	Good. The data record is continuous, with several satellites operational at the same time for large portions of the time series.
Data record characteristics	Known problems	<p>1) While, PyGAC blacklisting is integrated in the L1C processing of this release and the capacity for PyGAC geolocation is encoded, geolocation is calculated from TLEs - but should be considered as approximate in this release.</p> <p>2) The data has been harmonized. However, since the accuracy of the harmonisation is itself subject to a small but quantified uncertainty in the parameters, it should be treated with caution. In particular, for polar locations the SST products show that harmonisation has some problems.</p> <p>3) Sensor-specific cross-line correlation scale lengths (in number of scanlines) are provided as the median empirical value produced by a model of constant BT as a function of smoothing width, and should be treated as tentative.</p> <p>4) Structured uncertainties on reflectance ratios have been set to 0.03 for channel 1 and 0.05 for channels 2 and 3A. These estimates are included for completeness in the Easy FCDR, but are not based upon any metrological process.</p>

3 Background

AVHRR is a passive infrared radiometer with 6 channels measuring in the visible and the infrared (see below). The first edition was launched on-board TIROS-N in 1978. The first edition covered by the FIDUCEO AVHRR FCDR is AVHRR/1 launched on NOAA-06 1979. In line with FIDUCEO deliverable, the Easy FCDR spans the years 1982—2016. Table 1 presents an overview of the AVHRR instruments covered by FIDUCEO.

Table 1: AVHRR editions covered by FIDUCEO

Generation	Satellite	Start	End
AVHRR/2	NOAA-11/H	1988-10-12	1994-10-07
AVHRR/2	NOAA-12/D	1991-09-16	1998-12-14
AVHRR/2	NOAA-13	Launch failure	-
AVHRR/2	NOAA-14/J	1995-01-18	2002-10-07
AVHRR/3	NOAA-15/K	1998-09-24	2010-12-31
AVHRR/3	NOAA-16/L	2000-10-11	2010-12-31
AVHRR/3	NOAA-17/M	2002-07-10	2010-12-31
AVHRR/3	NOAA-18/N	2005-06-05	2016-12-31
AVHRR/3	NOAA-19/P	2009-02-22	2016-12-31
AVHRR/3	MetOp-A	2006-11-21	2016-12-31

Note that this table corresponds to Level 1B input data used to generate the Level 1C Easy FCDR and is the “theoretical” instrument lifetime. Current AVHRR FCDR data availability is more limited for several reasons, some of which are covered in the Section 6.4.

The 6 channels of AVHRR consist of 3 reflectance channels (Si and InGaAs detectors) and 3 infrared channels (InSb and HgCdTe detectors). While reflectance channel data processing is outside the remit of FIDUCEO, reflectance ratios are provided plus estimates of their independent and structured uncertainties. In this release, BTs are fully processed. Table 2 contains an overview of the channels covered by AVHRR.

Table 2: Overview of AVHRR channels.

Channel	AVHRR/1	AVHRR/2	AVHRR/3	Detector
1	0.58-0.68 μm (VIS)	0.58-0.68 μm (VIS)	0.58-0.68 μm (VIS)	Si
2	0.725-1.1 μm (NIR)	0.725-1.1 μm (NIR)	0.725-1.1 μm (NIR)	Si
3A	-	-	1.58-1.64 μm (NIR)	InGaAs
3B	3.55-3.93 μm (MIR)	3.55-3.93 μm (MIR)	3.55-3.93 μm (MIR)	InSb
4	10.50-11.50 μm (TIR)	10.30-11.30 μm (TIR)	10.30-11.30 μm (TIR)	HgCdTe
5	-	11.5-12.5 μm (TIR)	11.5-12.5 μm (TIR)	HgCdTe

The FCDR of recalibrated IR radiances and metrologically traceable uncertainties corresponds to Task 4.4 in the Horizon-2020 project FIDUCEO (see <http://www.fiduceo.eu>).

4 Differences with existing products

The FIDUCEO AVHRR FCDR improves on existing AVHRR level-1B data (such as that processed by NOAA or EUMETSAT):

- the calibration has been improved with a measurement function approach such that the data is of better quality (noise has been reduced, outliers have been filtered)
- all metrologically traceable uncertainties have been derived together with their associated effects
- cross-channel correlations and long-term correlation structures have now been calculated from the processed data and are being understood and used to improve data quality and consistency
- the sensors are calibrated to a common reference (AATSR series).
- the products have been harmonised across the satellite series using Simultaneous (Nadir) Overpasses (SNOs).

5 Calibration and uncertainty approach¹

The AVHRR FCDR is built on the measurement function which calculates the Earth Radiance L_E from the Earth Count C_E . A correction is made for the instrument self-emission radiance in Earth view, \tilde{L}_{ICT} , which

$$L_E = a_0 + \frac{(\epsilon + a_1)L_{ICT} - a_2 - a_3(\bar{C}_S - \bar{C}_{ICT})^2}{\bar{C}_S - \bar{C}_{ICT}} (\bar{C}_S - C_E) + a_3(\bar{C}_S - C_E)^2 + a_4 f(T_{inst}) + 0$$

¹ For further detail please refer to D2-2

is itself a function of the instrument temperature, T_{inst} and an offset correction is determined from the averaged space view counts during the calibration cycle, \bar{C}_S . T_{inst} is estimated for every scanline. The $+0$ term represents the assumption that this form of the equation is valid. The calibration coefficients a_0, a_1, a_2, a_3 and a_4 have been determined precisely during harmonisation to the ATSR reference sensor.

5.1 Measurement Function Diagram

The measurement equation details all physically-traceable (to SI) effects. The v0.3 (Beta) AVHRR Easy FCDR currently includes uncertainty calculation for 4 effects: IWCT counts noise, Earth counts noise, Space counts noise, mean PRT temperature which are combined and propagated. Please refer to document D2.2a and D2.2 (AVHRR) for details. Total independent, structured and common uncertainties are output to netCDF-4 for each of the channels: 1,2,3A (reflectances) and 3B,4,5 (brightness temperatures). Figure 1 illustrates the complete measurement function diagram for the AVHRR.

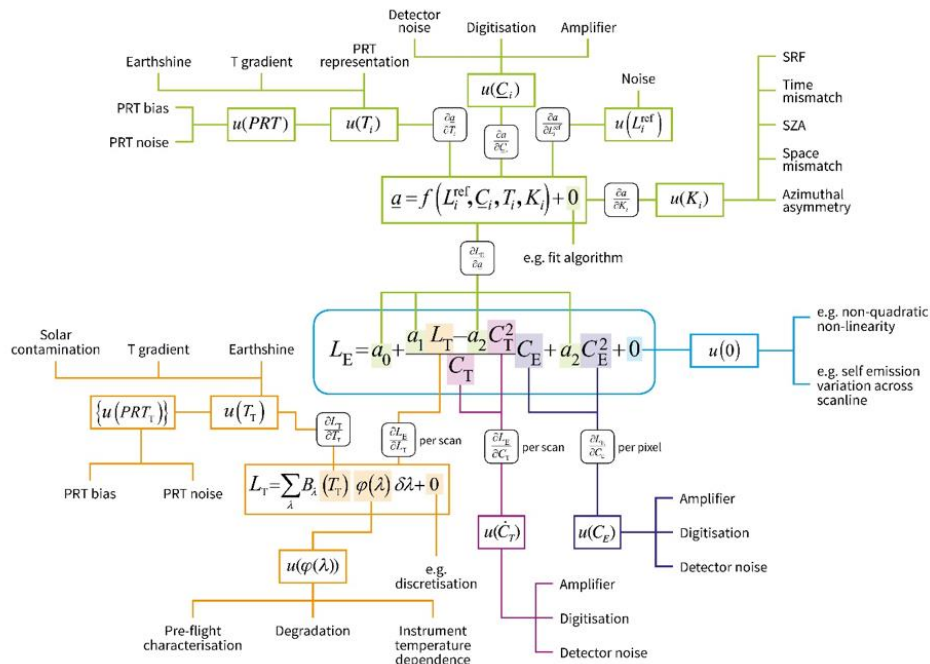


Figure 1: The measurement function tree for AVHRR. Note the measurement equation is a simplified form where $C_T = (\bar{C}_S - \bar{C}_{IWCT})$ and $C_E = (\bar{C}_S - \bar{C}_{Earth})$. Here also we have not included a temperature correction term related to changes in the satellites thermal environment as the orbit drifts: $a_3 f(T_{\text{inst}})$. The nature of this term is still to be fully determined but is discussed further in the appendix of D2.2d (AVHRR).

5.2 Independent, structured and common uncertainties

In the aforementioned equations, all terms not defined as equations of other terms have uncertainties associated with them. Those sources of uncertainty arise from various physical effects, and each has a specific correlation structure. A separate set of documents, D2-2a and D2-2(AVHRR), describe in detail all sources of uncertainty along with their correlation structures and how the magnitude of the uncertainty has been estimated.

In the present Easy FCDR, all sources of uncertainty from effects that are not completely independent from pixel to pixel (i.e. “structured”) or which arise from a “common” source or processing step have been

separated into structured (scale lengths within an orbit) and common (scale lengths of an orbit or greater up to lifetime of sensor), whereas the uncertainty due to Earth count noise is the sole source of uncertainty that varies randomly from pixel to pixel (and here is called “independent”).

When processing the FCDR for the generation of a CDR, the user might calculate averages of multiple pixels, in particular in the case of generation of L3 products.

5.2.1 Principles

The FIDUCEO approach to uncertainty analysis and metrological traceability is to start with the measurement function, which is the function that is used to obtain a measured output quantity value from input quantity values. The measurement function takes a general form $Y = f(X_1, X_2, \dots, X_N) + 0$, where the output quantity Y is determined from the input quantities, the X_i . We include a “plus zero” to explicitly represent assumptions (in the form of effects expected to have zero mean) built into the form of the measurement equation.

The Guide to the Expression of Uncertainty in Measurement (GUM) describes the propagation of uncertainty through a measurement function. For this we need to consider each source of uncertainty associated with each of the input quantities and consider the error covariance between any two input quantities. We do this by considering the underlying physical effects that cause (unknown) errors in each input quantity.

For the development of an FCDR, the measurement function is that which converts raw data (e.g. measured counts and calibration target values) into the FCDR quantity (e.g. radiance or reflectance). In almost all cases, the input effects are metrologically independent (they have no common error) and the propagation of uncertainty requires only information on the magnitude of the uncertainty associated with each effect and the sensitivity coefficient that converts the uncertainty in that effect into the uncertainty associated with the FCDR measurand (e.g. radiance).

For the development of a CDR, however, the measurement function often takes as input FCDR values from different spectral bands, along with additional inputs relating to the model used. This means that we require an understanding of the error covariance between the FCDR quantities as measured in different spectral bands. Furthermore, gridded, filled or smoothed products the measurement function combines data from different spatial pixels. We therefore need an understanding of the error covariance between the FCDR quantities as measured in different pixels of an image.

To account for this, the FCDR development in FIDUCEO has included an analysis of the error correlation structure across spectral bands and across space (from pixel to pixel within a scanline and from scanline to scanline within an orbit/image). Information about this process is given in the D2-2 reports.

The Easy FCDR provides complete error covariance information necessary for CDR development and application.

We are providing covariance information in the following format:

- Uncertainties considered as three components: independent, structured and common correlation matrices.
- A typical scale for the error correlation for structured effects

- A Channel to Channel covariance matrix

Note that this is a significant simplification of the full situation but it provides valuable information.

5.2.2 Using the spatial correlation information

FIDUCEO FCDR error covariance information results from a full analysis of the spatial error correlation. We have developed tools to calculate this and the FCDR includes both the cross-line and cross-element spatial error correlation length per orbit.

Typically, this information is given in the form of a number of scanlines over which the structured effects can be considered correlated. If no information is provided about pixels within a scanline, we can assume that structured effects are also fully correlated from pixel to pixel within a scanline.

If we are averaging n scanlines, each containing m pixels and the correlation length scale is L scanlines, then:

- The uncertainty associated with independent effects can be considered to reduce by $\sqrt{n \times m}$
- If $n < L$, then the uncertainty associated with structured effects is not reduced by averaging
- If $n > L$, then the uncertainty associated with structured effects is reduced by $\sqrt{\text{int}(n/L)}$, where the ratio n/L is rounded down to the nearest integer.

For the AVHRR, the most important time scale for the structured effects is the time over which the thermal state of the IWCT remains approximately constant. Initial analysis has been performed for each sensor. A median estimate is 40 scanlines (256 seconds) as described in more detail in section 7.4.2.

5.3 Included effects

Full details of all effects to be included are described in D2-2. The easy FCDR contains a subset of those effects.

- Uncertainty due to Earth counts noise. Estimated from the Allan deviation of IWCT views. The magnitude of the uncertainty due to Earth counts noise is equal to the value contained in the easy FCDR data variable `u_independent`.
- Uncertainty due to calibration views (IWCT and space). Estimated as for Earth counts noise but this propagates into the calibration coefficients, and therefore is a structured effect. It is one of the components that makes up the easy FCDR data variable `u_structured`.
- Uncertainty from IWCT temperature error corrections, expressed as `u_common`
- Uncertainty from the PRT systematic biases, expressed as `u_common`
- Uncertainty from the Harmonisation process

6 Product definition

6.1 Product contents

The L1B data were generated from the on-board AVHRR instrument flying on various NOAA satellites, and subsequently processed by NOAA and archived in CLASS. The FIDUCEO team obtained the L1B data from the NOAA CLASS archive and processed it with tagged version v1.00 of the FCDR_AVHRR software available at:

https://github.com/FIDUCEO/FCDR_AVHRR.

AVHRR FCDR files have been processed such that each file contains one orbit from equator to equator, as defined by the satellite sub-satellite point (or more precisely, its 28th ground pixel). There are no overlaps or gaps between adjacent orbit files. As a consequence, AVHRR FCDR files do not correspond exactly to NOAA L1B files. Geolocation is provided by PyGAC: <https://github.com/pytroll/pygac> and uses a list of daily blacklisted orbits provided by TLEs from NORAD: <https://celestrak.com/NORAD/elements/>. In terms of generated contents, the AVHRR Easy FCDR files descriptions correspond to those of the NOAA L1B files such that each AVHRR Easy FCDR file contains:

- Basic telemetry: longitude, latitude, time, satellite zenith and azimuth angles, solar zenith and azimuth angles;
- Brightness temperatures for channels 3B,4 and 5;
- Independent uncertainty information (also known as random uncertainty) for channels 1--6;
- Structured uncertainty information which have a correlation length scale of greater than an orbit for channels 1--6. This is a sum of all uncertainties and common effects (such as PRT errors and T errors) that are not totally random from pixel to pixel;
- Common uncertainty information for channel 1—6 arising from effects that impact all channels (such as harmonisation, any geolocation errors, thermal effects).
- A cross-channel error correlation matrix for independent, structured and common uncertainties post-harmonisation;
- Two bit fields indicating problems with the data. See below for details.

The data has the following dimensions:

- x – position along the scanline
- y – scanline number. The coordinates correspond to the scanline number in the original L1B files.
- channel – The channel number, 1—6.

The data files contain coordinates corresponding to each of the dimensions.

6.1.1 Bit masks

There are two data variables that communicate flags through bit masks (set once per scanline):

```
ubyte quality_scanline_bitmask(y) ;
quality_scanline_bitmask:long_name = "bitmask for quality per scanline" ;
quality_scanline_bitmask:standard_name = "status_flag" ;
quality_scanline_bitmask:flag_masks = "1,2,4,8,16,32,64" ;
quality_scanline_bitmask:flag_meanings = "do_not_use bad_time bad_navigation
bad_calibration channel3a_present solar_contamination solar_in_earth_view" ;
ubyte quality_channel_bitmask(y, channel) ;
quality_channel_bitmask:long_name = "bitmask for quality per channel" ;
quality_channel_bitmask:standard_name = "status_flag" ;
quality_channel_bitmask:flag_masks = "1,2" ;
quality_channel_bitmask:flag_meanings = "bad_channel
some_pixels_not_detected_2sigma" ;
```

For both of them, the variable attributes `flag_masks` and `flag_meanings` are used as defined in the CF conventions. There is a list of bitmasks, and there is a list of flag names. The order is the same.

6.2 File format

Files are provided in NetCDF-4 and adhere to CF Conventions v1.6 (and to CF Conventions v1.7 where possible). All data fields are internally compressed using parameters chosen based on the dynamic range of meaningful values. Filenames follow the FIDUCEO standard where all filenames have the following structure:

`FIDUCEO_[record]_[data]_[sensor]_[platform]_[startdate]_[enddate]_[type]_[processor_version]_[format_version].nc`

For the AVHRR Easy FCDR generated from Level 1B data from the NOAA and MetOp-A satellites, the file format for cases where there is no channel 3A and 3B switching (1.6 μ m/3.7 μ m) is:

`FIDUCEO_FCDR_L1C_AVHRR_NxxALL_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

`FIDUCEO_FCDR_L1C_AVHRR_MTAALL_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

where `xx` corresponds to the NOAA satellite number and is in the range 11 to 19, `YYYYMMDDHHMMSS` is the standard date/time format used for the start and end of the orbit in UTC respectively, `vxx.x` is the version of the data release, and `fvxx.x` is the version of the CF format applied. An example filename for AVHRR/3 flying on MetOp-A in the v0.3 (Beta) AVHRR Easy FCDR data release is:

`FIDUCEO_FCDR_L1C_AVHRR_N11ALL_19881012221257_19881013001800_EASY_v0.3Bet_fv2.0.0.nc`

For the case where there is channel 3A and 3B switching (some of NOAA-16, NOAA-18, NOAA-19 and MetOp-A) the filename format is

`FIDUCEO_FCDR_L1C_AVHRR_NxxC3A_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

`FIDUCEO_FCDR_L1C_AVHRR_MTAC3A_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

For times when channel 3A was used (1.6 μ m). For channel 3B (3.7 μ m) the filename convention is

`FIDUCEO_FCDR_L1C_AVHRR_NxxC3B_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

`FIDUCEO_FCDR_L1C_AVHRR_MTAC3B_YYYYMMDDHHMMSS_YYYYMMDDHHMMSS_EASY_vxx.x_fvxx.x.nc`

NetCDF format is self-documenting. Each file contains global attributes with general information, and a set of data variables. The names of data variables follow standard names from the CF Conventions for those cases where a standard name exists. Where no standard name exists, the FIDUCEO team has introduced a name not included in the standard. All data variables are stored as compressed scaled integers. Data variable attributes describe each variable and its scaling. Section 7.5 contains an example of the headers for a particular file.

6.3 File sizes

A typical (full) orbit file is around 50-60Mb for the Easy FCDR.

6.4 Known Problems

The current release of the AVHRR FCDR is v1.00 and includes the most of the effects described in detail in D2,2d (AVHRR).

- In the Easy FCDR, all uncertainties from structured effects are added together.
- Error correlations between different effects are currently not considered.

7 Example contents

The figures below show a few examples of the contents the FCDR.

7.1 Orbit level time series

A typical (full) orbit file is ~50Mb. Figure 2 shows time series plots for the AVHRR/1 GAC full orbit from NOAA-06 on 1980-03-21 at 14:56 UCT.

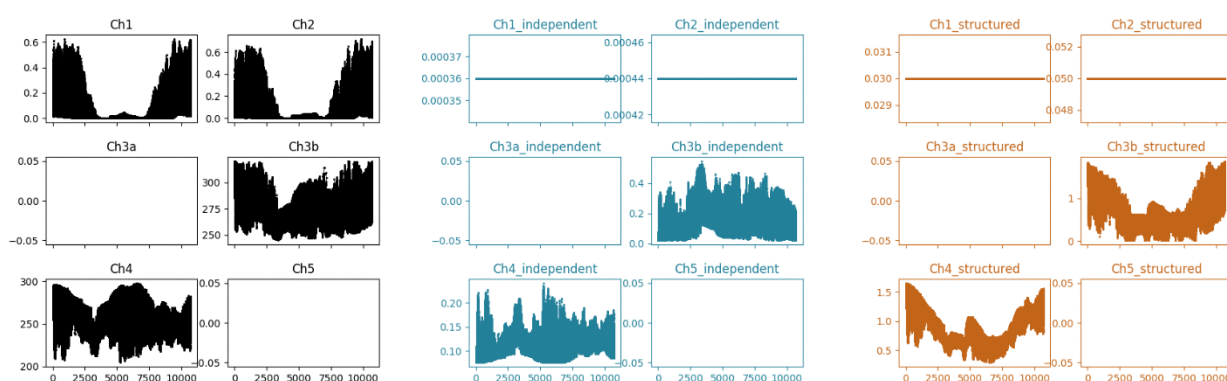
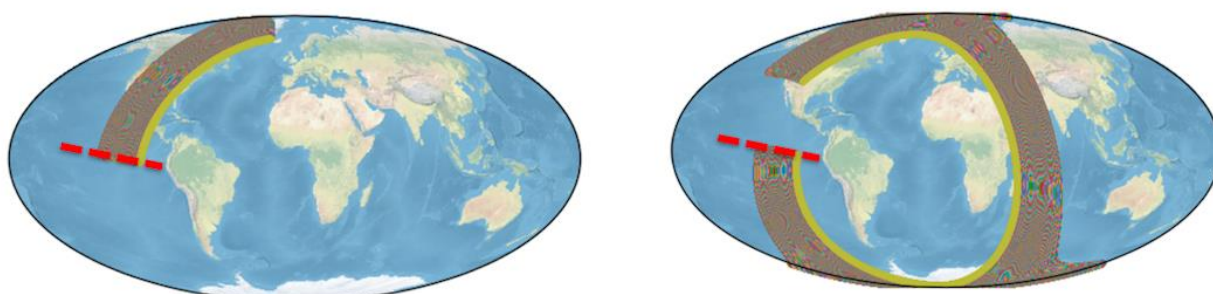


Figure 2: Time series of the channel data and the associated independent and structured uncertainties for the AVHRR/1 GAC full orbit from NOAA-06 on 1980-03-21 at 14:56 UCT.

7.2 Equator-to-equator orbits

Orbit files are split at equatorial crossings with reference to the daytime ascending node. Figure 3 shows examples of this for two orbit files on 1980-03-21 for NOAA-06



ECT1 = 14:56
ECT2 = 16:25

FIDUCEO_FCDR_L1C_AVHRR_NOAA06_19800321143214_19800321145600_EASY_v0.2pre_fv1.1.1
FIDUCEO_FCDR_L1C_AVHRR_NOAA06_19800321145600_19800321162531_EASY_v0.2pre_fv1.1.1

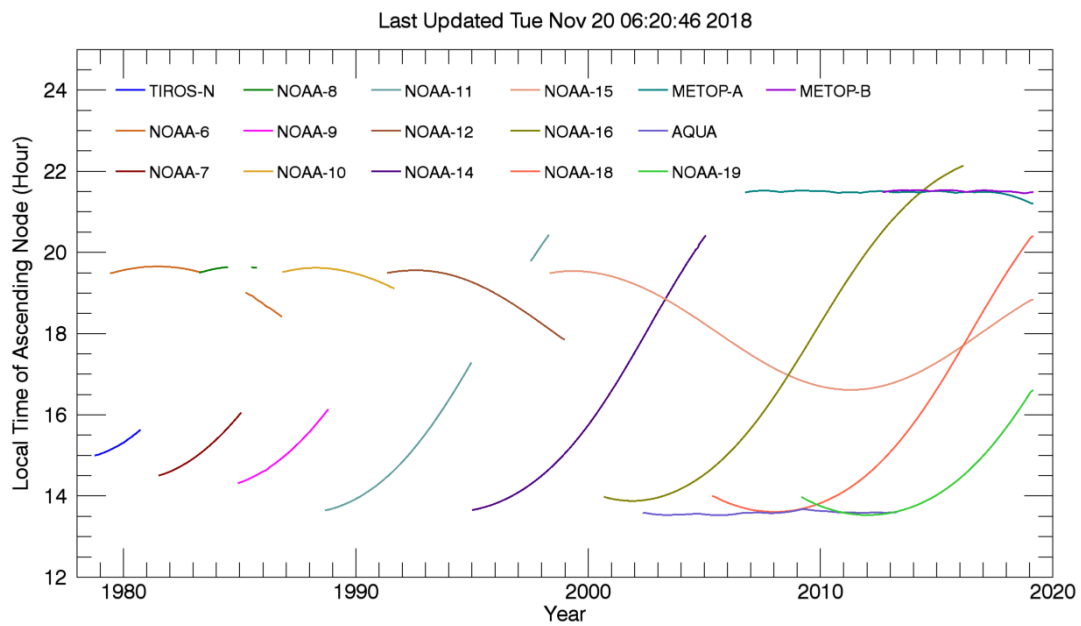


Figure 3: Example orbits files on 1980-03-21 for NOAA-06 (upper plots) and the LTAN for AVHRR sensors (lower plot)..

7.3 Summary statistics

For each orbit file, summary statistics have been calculated (min, max, mean, robust standard deviation, variance and the quartiles Q1, Q2 and Q3). Tables 3 and 4 show the min-max range of the independent, structured and common uncertainties for each channel over each sensor series and Figures 4-12 show the variation of the orbital median value for all sensors processed in generation of the FCDR v0.3 (Beta)..

Table 3: Sensor-series level min-max ranges for reflectance channels 1,2 and 3A measurement data and the independent and structured uncertainties extracted from the processed orbit data.

U_INDEPENDENT	CH1_REF		CH2_REF		CH3A_REF	
	Min	Max	Min	Max	Min	Max
AVHRR11	0	2	0	2		
AVHRR12	0	2	0	2		
AVHRR14	0	2	0	2		
AVHRR15	0	2	0	2	0	2
AVHRR16	0	2	0	2	0	2
AVHRR17	0	2	0	2	0	2
AVHRR18	0	2	0	2	0	2
AVHRR19	0	2	0	2	0	2
METOP-A	0	2	0	2	0	2

U_STRUCTURED	CH1_REF		CH2_REF		CH3A_REF	
	Min	Max	Min	Max	Min	Max
AVHRR11	0	0.056447	0	0.065117		
AVHRR12	0	0.055699	0	0.027308		
AVHRR14	0	0.054728	0	0.07402		
AVHRR15	0.000761	0.01291	0.000904	0.030484	0.05	0.05
AVHRR16	0.000807	0.02951	0.000715	0.011393	0.001146	0.01413
AVHRR17	0.002344	0.062436	0.002334	0.055840	0.001334	0.035868
AVHRR18	0	0.020537	0	0.017532	0.05	0.05
AVHRR19	0.001305	0.016143	0.001010	0.010239	0.05	0.05
METOP-A	0.001295	0.013819	0.001047	0.012615	0.000737	0.024017

U_COMMON	CH1_REF		CH2_REF		CH3A_REF	
	Min	Max	Min	Max	Min	Max
AVHRR11	0.03	0.03	0.05	0.05		
AVHRR12	0.03	0.03	0.05	0.05		
AVHRR14	0.03	0.03	0.05	0.05		
AVHRR15	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR16	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR17	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR18	0.03	0.03	0.05	0.05	0.05	0.05
AVHRR19	0.03	0.03	0.05	0.05	0.05	0.05
METOP-A	0.03	0.03	0.05	0.05	0.05	0.05

Table 4: Sensor-series level min-max ranges for channel 3B, 4 and 5 brightness temperature measurement data and the independent and structured uncertainties extracted from the processed orbit data.

U_INDEPENDENT	CH3B_BT		CH4_BT		CH5_BT	
	Min	Max	Min	Max	Min	Max
AVHRR11	0.050476	6.470093	0.035812	0.277786	0.050308	5.813946
AVHRR12	0.042877	5.446594	0.039520	0.550560	0.044632	5.915047
AVHRR14	0.072418	6.925682	0.034561	4.498123	0.050491	5.820747
AVHRR15	0.016998	6.476151	0.031021	0.442863	0.041595	5.981331
AVHRR16	0.014862	6.421608	0.042068	0.628197	0.059387	6.171013
AVHRR17	0.016052	6.239769	0.037415	8.606041	0.045502	4.999519
AVHRR18	0.015015	3.584381	0.036682	0.542519	0.046661	5.844456
AVHRR19	0.014694	0.565308	0.040482	0.521713	0.050583	4.531155
METOP-A	0.013550	6.247513	0.039108	0.907043	0.045578	0.590279

U_STRUCTURED	CH3B_BT		CH4_BT		CH5_BT	
	Min	Max	Min	Max	Min	Max
AVHRR11	0.003845	1.385956	0.000595	0.259129	0.001160	3.535042
AVHRR12	0.004807	1.388107	0.001434	0.065628	0.002121	3.012844
AVHRR14	0.007935	4.241554	0.001389	1.363319	0.001984	3.341862
AVHRR15	0.001633	4.550003	0.001358	0.052353	0.001740	2.333336
AVHRR16	0.001572	4.452499	0.001602	0.086967	0.002167	3.270191
AVHRR17	0.004013	4.927956	0.002121	4.278458	0.002731	1.404118
AVHRR18	0.002426	4.596382	0.001419	0.096130	0.001938	1.152206
AVHRR19	0.002335	4.437653	0.001617	0.050171	0.002075	1.103317
METOP-A	0.002060	4.443283	0.001465	0.046791	0.001770	0.055847

U_COMMON	CH3B_BT		CH4_BT		CH5_BT	
	Min	Max	Min	Max	Min	Max
AVHRR11	0.097107	5.350052	0.026772	0.853714	0.02739	6.416988
AVHRR12	0.155701	5.286316	0.030083	0.812347	0.024475	2.671524
AVHRR14	0.098373	4.889793	0.029022	2.605286	0.018562	4.297691
AVHRR15	0.031540	4.870689	0.024246	0.454742	0.016785	1.665398
AVHRR16	0.03833	4.576859	0.025330	0.437515	0.014816	1.708141
AVHRR17	0.067261	5.349716	0.023407	0.686813	0.019691	1.166485
AVHRR18	0.069832	4.198486	0.024391	0.627808	0.015770	0.625443
AVHRR19	0.076538	4.162422	0.029961	0.346176	0.025635	0.466331
METOP-A	0.047279	4.443863	0.018745	0.366821	0.036003	0.370239

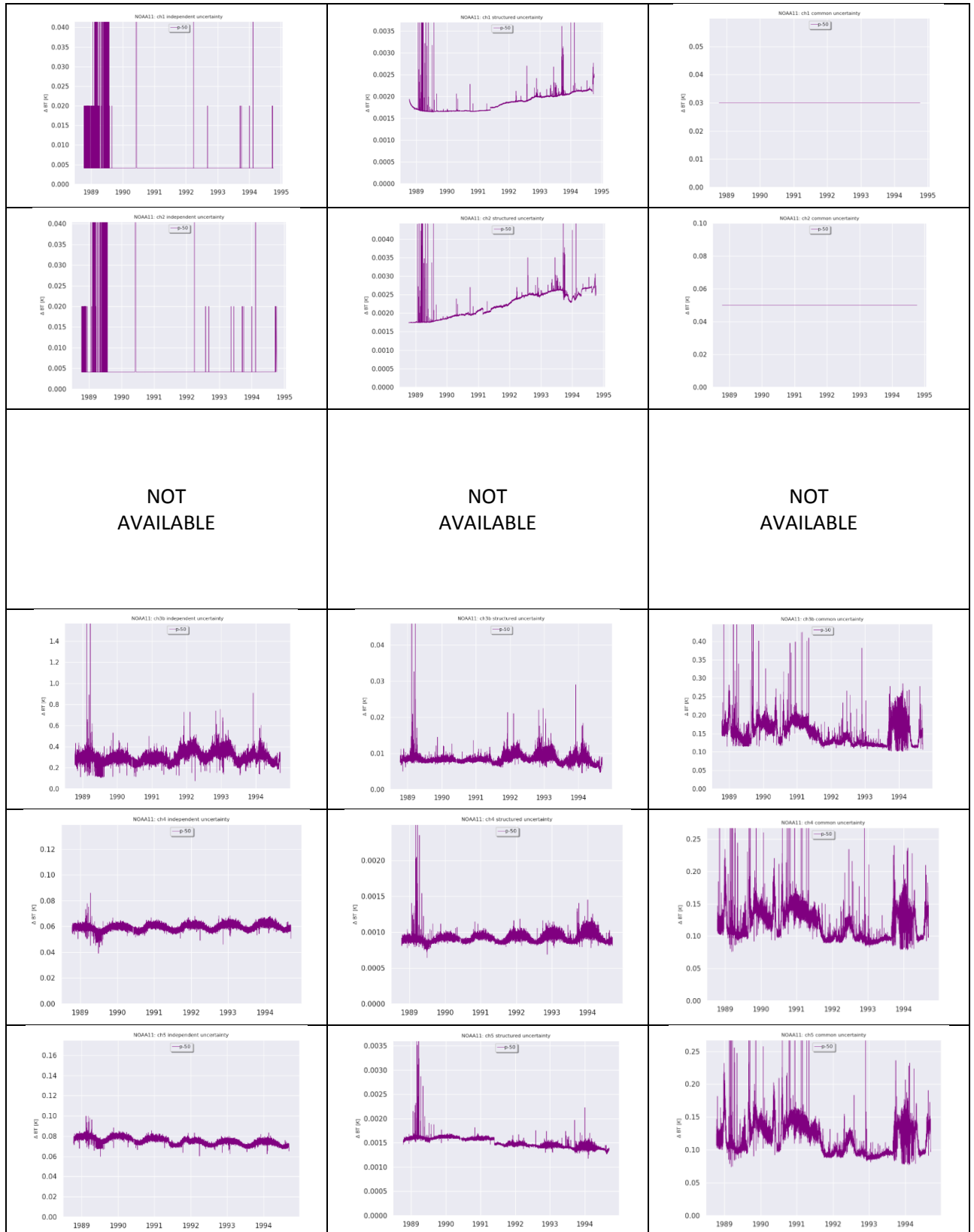


Figure 4: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-11.



Figure 5: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-12.



Figure 6: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-14.



Figure 7: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-15.



Figure 8: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-16.



Figure 9: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-17.

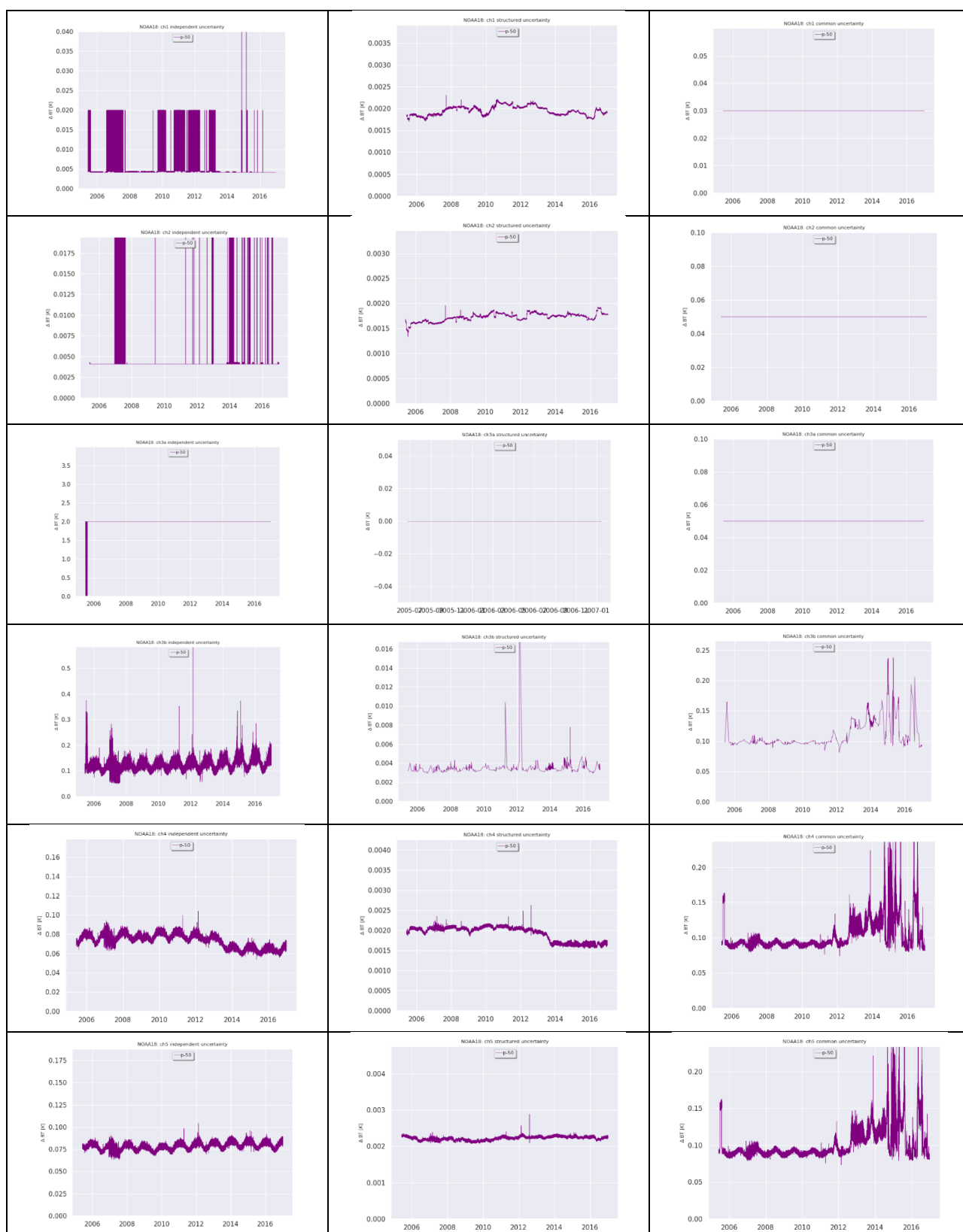


Figure 10: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-18.

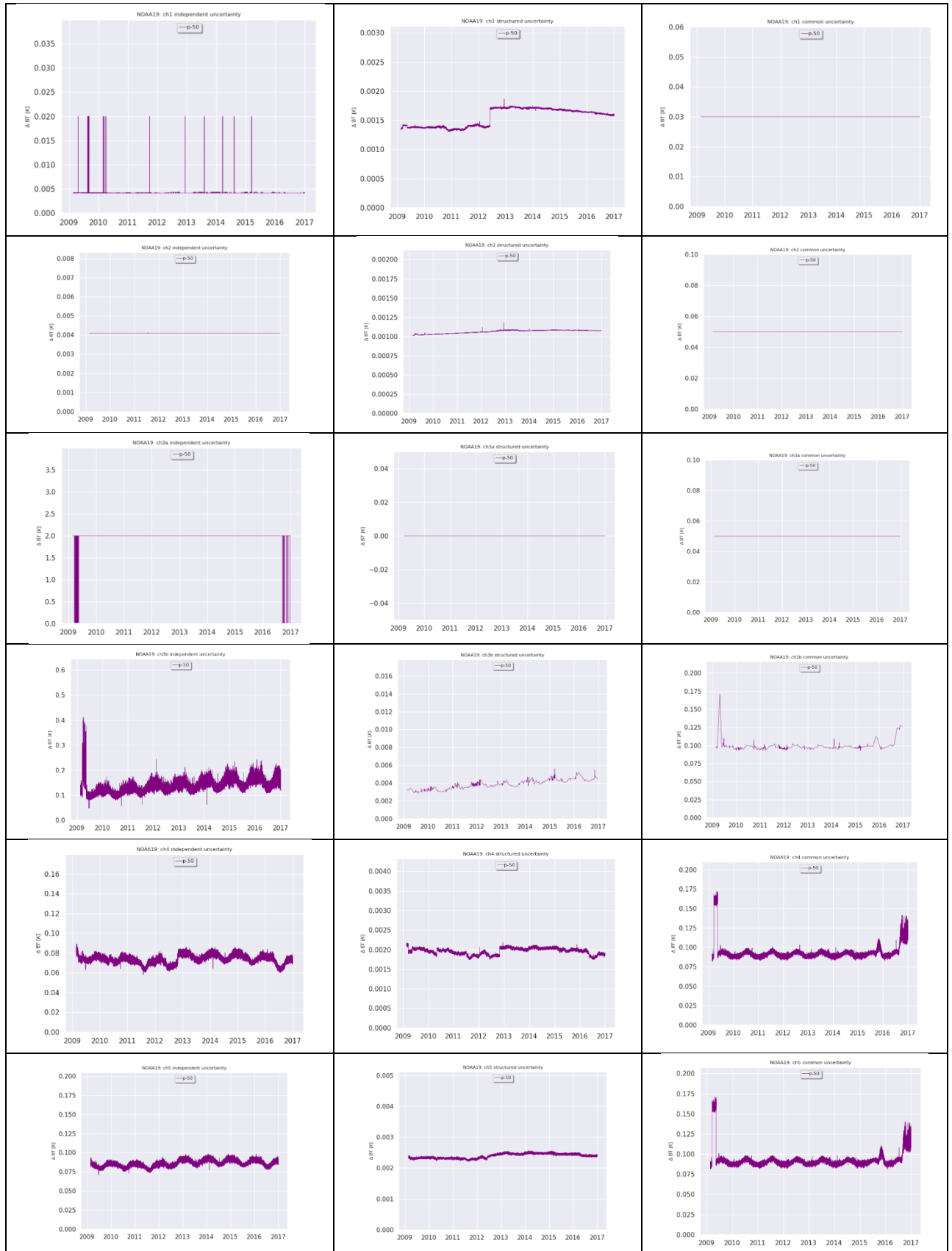


Figure 11: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on NOAA-19.



Figure 12: Sensor-series level median values of the independent, structured and common uncertainties (columns from left to right) for the three reflectance channels (1,2 and 3A) and the three infrared channels (3B,4 and 5) by row, extracted from the processed orbit across all channels on MetOp-A.

7.4 Error covariance matrices

Mathematical recipes have been developed to calculate error covariance matrices over various spatial and temporal scales and have been encoded in this release.

7.4.1 Cross-channel correlation

In this v0.3 (Beta) release, binary cross-channel correlation matrices are included for each uncertainty type. For example, for the L1C orbit file for AVHRR/3 on NOAA-19 on 2011-08-19 at 16:42 with a scale factor of 0.0001:

```
channel_correlation_matrix_independent = 10000, 0, 0, 0, 0, 0,
                                          0, 10000, 0, 0, 0, 0,
                                          0, 0, 10000, 0, 0, 0,
                                          0, 0, 0, 10000, 0, 0,
                                          0, 0, 0, 0, 10000, 0,
                                          0, 0, 0, 0, 0, 10000 ;

channel_correlation_matrix_structured = 10000, 0, 0, 0, 0, 0,
                                         0, 10000, 0, 0, 0, 0,
                                         0, 0, 10000, 0, 0, 0,
                                         0, 0, 0, 10000, 1730, 1708,
                                         0, 0, 0, 1730, 10000, 8390,
                                         0, 0, 0, 1708, 8390, 10000 ;

channel_correlation_matrix_common = 10000, 0, 0, 0, 0, 0,
                                     0, 10000, 0, 0, 0, 0,
                                     0, 0, 10000, 0, 0, 0,
                                     0, 0, 0, 10000, 9961, 9962,
                                     0, 0, 0, 9961, 10000, 9998,
                                     0, 0, 0, 9962, 9998, 10000 ;
```

While there is a non-observation of cross-talk for the 3 IR channels in the independent component of uncertainty, there is clear evidence of strong inter-channel correlation particularly between the 11 and 12 micron channels. This is in stark contrast to what was observed on post TIROS-N satellites shown in Figure 13 where there is no evidence of cross-talk.

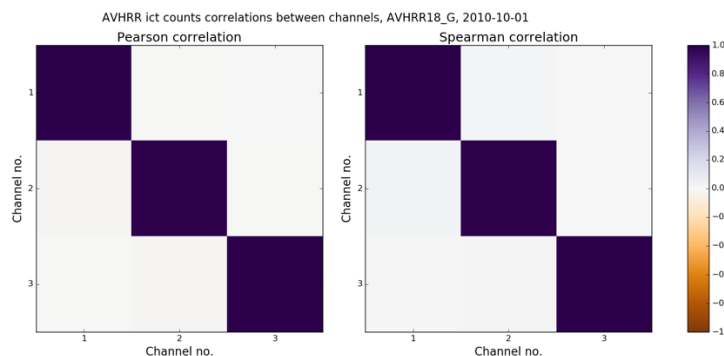


Figure 13: Cross-channel correlation matrices for ICT counts between three IR channels (channels 3B, 4 and 5) for AVHRR-18 on 2010-10-01.

7.4.2 Cross-line correlation

In order to provide an initial estimate of the cross-line correlation, the number of scanlines over which the PRT temperature remains constant is used as a proxy. Figure 15 shows the resulting histogram for AVHRR-14.

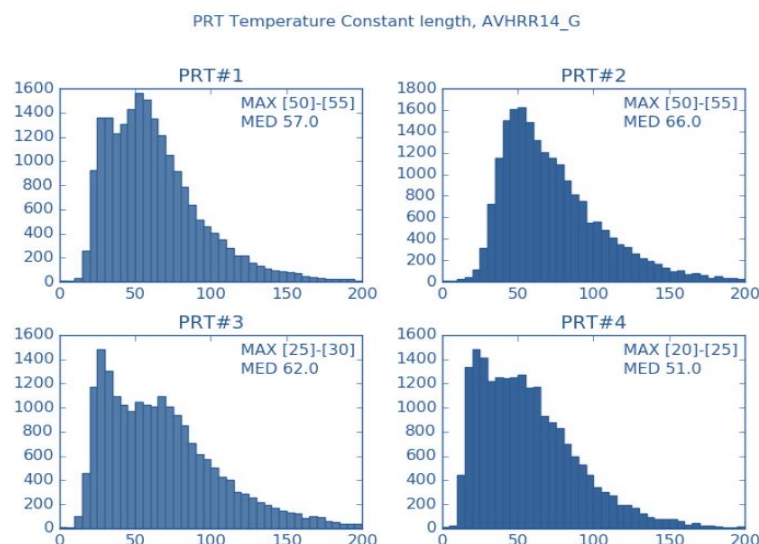


Figure 15: Histogram of PRT temperature constant length (in scanlines) over which each of the PRT temperatures remains constant for NOAA-14.

This was repeated for various sensor series. The mean over AVHRR/1 ~ 67 scanlines (either side of the test scanline), AVHRR/2 ~ 70 scanlines and AVHRR/3 ~ 92 scanlines. Taking half of the fore and aft values as the spatial correlation scale (for the case of PRT temperature) a characteristic scale is ~ 40 scanlines. Table 5 shows how this scale varies with sensor.

Table 5: Variation of the spatial correlation scale with sensor for the PRT temperature (results for AVHRR-14 corresponding to Figure 8 are highlighted)

PRT Smoothing Scale	Prt1	Prt2	Prt3	Prt4	Mean
AVHRR08_G	48	36	42	19	36.25
AVHRR09_G	91	90	85	89	88.75
AVHRR10_G	95	106	95	98	98.5
AVHRR11_G	76	76	78	73	75.75
AVHRR12_G	50	58	49	65	55.5
AVHRR14_G	57	66	62	51	59
AVHRR15_G	99	92	108	99	99.5
AVHRR16_G	59	119	121	112	102.75
AVHRR17_G	37	31	37	31	34
AVHRR18_G	217	220	223	223	220.75
AVHRR19_G	8	8	8	8	8
AVHRRMTA_G	93	81	98	76	87

7.5 Example Header

The extract below shows the header for the full orbit FIDUCEO FCDR L1C file for NOAA-11, AVHRR/2, containing data starting at 1988-10-12 22:12:57 UTC, ending at 1988-10-13 00:18:00, data version v1.0, format version 2.0.0. This corresponds to a single equator-to-equator orbit:

FIDUCEO_FCDR_L1C_AVHRR_N11ALL_19881012221257_19881013001800_EASY_v1.00_fv2.0.0.nc

```
netcdf FIDUCEO_FCDR_L1C_AVHRR_N11ALL_19881012221257_19881013001800_EASY_v1.00_fv2.0.0 {
dimensions:
    y = 15008 ;
    x = 409 ;
    channel = 6 ;
    n_frequencies = 24 ;
    lut_size = 1500 ;
    delta_x = 409 ;
    delta_y = 41 ;
variables:
    short latitude(y, x) ;
        latitude:_FillValue = -32768s ;
        latitude:standard_name = "latitude" ;
        latitude:units = "degrees_north" ;
        latitude:add_offset = 0. ;
        latitude:scale_factor = 0.0027466658 ;
    short longitude(y, x) ;
        longitude:_FillValue = -32768s ;
        longitude:standard_name = "longitude" ;
        longitude:units = "degrees_east" ;
        longitude:add_offset = 0. ;
        longitude:scale_factor = 0.0054933317 ;
    ubyte quality_pixel_bitmask(y, x) ;
        quality_pixel_bitmask:standard_name = "status_flag" ;
        quality_pixel_bitmask:coordinates = "longitude latitude" ;
        quality_pixel_bitmask:flag_masks = "1, 2, 4, 8, 16, 32, 64, 128" ;
        quality_pixel_bitmask:flag_meanings = "invalid use_with_caution invalid_input invalid_geoloc invalid_time
sensor_error padded_data incomplete_channel_data" ;
    double Time(y) ;
        Time:_FillValue = NaN ;
        Time:units = "s" ;
        Time:standard_name = "time" ;
        Time:long_name = "Acquisition time in seconds since 1970-01-01 00:00:00" ;
    short relative_azimuth_angle(y, x) ;
        relative_azimuth_angle:_FillValue = -32767s ;
        relative_azimuth_angle:standard_name = "relative_azimuth_angle" ;
        relative_azimuth_angle:units = "degree" ;
        relative_azimuth_angle:valid_max = 18000LL ;
        relative_azimuth_angle:valid_min = -18000LL ;
        relative_azimuth_angle:coordinates = "longitude latitude" ;
        relative_azimuth_angle:add_offset = 0. ;
        relative_azimuth_angle:scale_factor = 0.01 ;
    short satellite_zenith_angle(y, x) ;
        satellite_zenith_angle:_FillValue = -32767s ;
        satellite_zenith_angle:standard_name = "sensor_zenith_angle" ;
        satellite_zenith_angle:units = "degree" ;
```

```

satellite_zenith_angle:valid_max = 9000LL ;
satellite_zenith_angle:valid_min = 0LL ;
satellite_zenith_angle:coordinates = "longitude latitude" ;
satellite_zenith_angle:add_offset = 0. ;
satellite_zenith_angle:scale_factor = 0.01 ;

short solar_zenith_angle(y, x) ;
    solar_zenith_angle:_FillValue = -32767s ;
    solar_zenith_angle:standard_name = "solar_zenith_angle" ;
    solar_zenith_angle:units = "degree" ;
    solar_zenith_angle:valid_max = 18000LL ;
    solar_zenith_angle:valid_min = 0LL ;
    solar_zenith_angle:coordinates = "longitude latitude" ;
    solar_zenith_angle:add_offset = 0. ;
    solar_zenith_angle:scale_factor = 0.01 ;

short Ch1(y, x) ;
    Ch1:_FillValue = -32767s ;
    Ch1:standard_name = "toa_reflectance" ;
    Ch1:long_name = "Channel 1 Reflectance" ;
    Ch1:units = "1" ;
    Ch1:valid_max = 15000LL ;
    Ch1:valid_min = 0LL ;
    Ch1:coordinates = "longitude latitude" ;
    Ch1:add_offset = 0. ;
    Ch1:scale_factor = 0.0001 ;

short Ch2(y, x) ;
    Ch2:_FillValue = -32767s ;
    Ch2:standard_name = "toa_reflectance" ;
    Ch2:long_name = "Channel 2 Reflectance" ;
    Ch2:units = "1" ;
    Ch2:valid_max = 15000LL ;
    Ch2:valid_min = 0LL ;
    Ch2:coordinates = "longitude latitude" ;
    Ch2:add_offset = 0. ;
    Ch2:scale_factor = 0.0001 ;

short Ch3a(y, x) ;
    Ch3a:_FillValue = -32767s ;
    Ch3a:standard_name = "toa_reflectance" ;
    Ch3a:long_name = "Channel 3a Reflectance" ;
    Ch3a:units = "1" ;
    Ch3a:valid_max = 15000LL ;
    Ch3a:valid_min = 0LL ;
    Ch3a:coordinates = "longitude latitude" ;
    Ch3a:add_offset = 0. ;
    Ch3a:scale_factor = 0.0001 ;

short Ch3b(y, x) ;
    Ch3b:_FillValue = -32767s ;
    Ch3b:standard_name = "toa_brightness_temperature" ;
    Ch3b:long_name = "Channel 3b Brightness Temperature" ;
    Ch3b:units = "K" ;
    Ch3b:valid_max = 10000LL ;
    Ch3b:valid_min = -20000LL ;
    Ch3b:coordinates = "longitude latitude" ;
    Ch3b:add_offset = 273.15 ;
    Ch3b:scale_factor = 0.01 ;

short Ch4(y, x) ;
    Ch4:_FillValue = -32767s ;
    Ch4:standard_name = "toa_brightness_temperature" ;

```

```

Ch4:long_name = "Channel 4 Brightness Temperature" ;
Ch4:units = "K" ;
Ch4:valid_max = 10000LL ;
Ch4:valid_min = -20000LL ;
Ch4:coordinates = "longitude latitude" ;
Ch4:add_offset = 273.15 ;
Ch4:scale_factor = 0.01 ;
short Ch5(y, x) ;
Ch5:_FillValue = -32767s ;
Ch5:standard_name = "toa_brightness_temperature" ;
Ch5:long_name = "Channel 5 Brightness Temperature" ;
Ch5:units = "K" ;
Ch5:valid_max = 10000LL ;
Ch5:valid_min = -20000LL ;
Ch5:coordinates = "longitude latitude" ;
Ch5:add_offset = 273.15 ;
Ch5:scale_factor = 0.01 ;
ubyte data_quality_bitmask(y, x) ;
data_quality_bitmask:standard_name = "status_flag" ;
data_quality_bitmask:long_name = "bitmask for quality per pixel" ;
data_quality_bitmask:flag_masks = "1,2" ;
data_quality_bitmask:flag_meanings = "bad_geolocation_timing_err bad_calibration_radiometer_err" ;
data_quality_bitmask:coordinates = "longitude latitude" ;
ubyte quality_scanline_bitmask(y) ;
quality_scanline_bitmask:long_name = "bitmask for quality per scanline" ;
quality_scanline_bitmask:standard_name = "status_flag" ;
quality_scanline_bitmask:flag_masks = "1,2,4,8,16,32,64" ;
quality_scanline_bitmask:flag_meanings = "do_not_use bad_time bad_navigation bad_calibration
channel3a_present solar_contamination solar_in_earth_view" ;
ubyte quality_channel_bitmask(y, channel) ;
quality_channel_bitmask:long_name = "bitmask for quality per channel" ;
quality_channel_bitmask:standard_name = "status_flag" ;
quality_channel_bitmask:flag_masks = "1,2" ;
quality_channel_bitmask:flag_meanings = "bad_channel some_pixels_not_detected_2sigma" ;
short SRF_weights(channel, n_frequencies) ;
SRF_weights:_FillValue = -32768s ;
SRF_weights:long_name = "Spectral Response Function weights" ;
SRF_weights:description = "Per channel: weights for the relative spectral response function" ;
SRF_weights:add_offset = 0. ;
SRF_weights:scale_factor = 3.3e-05 ;
int SRF_wavelengths(channel, n_frequencies) ;
SRF_wavelengths:_FillValue = -2147483648 ;
SRF_wavelengths:long_name = "Spectral Response Function wavelengths" ;
SRF_wavelengths:description = "Per channel: wavelengths for the relative spectral response function" ;
SRF_wavelengths:units = "um" ;
SRF_wavelengths:add_offset = 0. ;
SRF_wavelengths:scale_factor = 0.0001 ;
ubyte scanline_map_to_origl1bfile(y) ;
scanline_map_to_origl1bfile:_FillValue = 255UB ;
scanline_map_to_origl1bfile:long_name = "Indicator of original file" ;
scanline_map_to_origl1bfile:description = "Indicator for mapping each line to its corresponding original
level 1b file. See global attribute 'source' for the filenames. 0 corresponds to 1st listed file, 1 to 2nd file." ;
short scanline_origl1b(y) ;
scanline_origl1b:_FillValue = -32767s ;
scanline_origl1b:long_name = "Original_Scan_line_number" ;
scanline_origl1b:description = "Original scan line numbers from corresponding l1b records" ;
ushort x(x) ;

```



```

ushort y(y) ;
string channel(channel) ;
short u_independent_Ch1(y, x) ;
    u_independent_Ch1:_FillValue = -32767s ;
    u_independent_Ch1:units = "Reflectance" ;
    u_independent_Ch1:coordinates = "longitude latitude" ;
    u_independent_Ch1:long_name = "independent uncertainty per pixel for channel 1" ;
    u_independent_Ch1:valid_max = 10000LL ;
    u_independent_Ch1:valid_min = 10LL ;
    u_independent_Ch1:add_offset = 0. ;
    u_independent_Ch1:scale_factor = 1.e-05 ;
short u_independent_Ch2(y, x) ;
    u_independent_Ch2:_FillValue = -32767s ;
    u_independent_Ch2:units = "Reflectance" ;
    u_independent_Ch2:coordinates = "longitude latitude" ;
    u_independent_Ch2:long_name = "independent uncertainty per pixel for channel 2" ;
    u_independent_Ch2:valid_max = 10000LL ;
    u_independent_Ch2:valid_min = 10LL ;
    u_independent_Ch2:add_offset = 0. ;
    u_independent_Ch2:scale_factor = 1.e-05 ;
short u_independent_Ch3a(y, x) ;
    u_independent_Ch3a:_FillValue = -32767s ;
    u_independent_Ch3a:units = "Reflectance" ;
    u_independent_Ch3a:coordinates = "longitude latitude" ;
    u_independent_Ch3a:long_name = "independent uncertainty per pixel for channel 3a" ;
    u_independent_Ch3a:valid_max = 10000LL ;
    u_independent_Ch3a:valid_min = 10LL ;
    u_independent_Ch3a:add_offset = 0. ;
    u_independent_Ch3a:scale_factor = 1.e-05 ;
short u_structured_Ch1(y, x) ;
    u_structured_Ch1:_FillValue = -32767s ;
    u_structured_Ch1:units = "Reflectance" ;
    u_structured_Ch1:coordinates = "longitude latitude" ;
    u_structured_Ch1:long_name = "structured uncertainty per pixel for channel 1" ;
    u_structured_Ch1:valid_max = 10000LL ;
    u_structured_Ch1:valid_min = 10LL ;
    u_structured_Ch1:add_offset = 0. ;
    u_structured_Ch1:scale_factor = 1.e-05 ;
short u_structured_Ch2(y, x) ;
    u_structured_Ch2:_FillValue = -32767s ;
    u_structured_Ch2:units = "Reflectance" ;
    u_structured_Ch2:coordinates = "longitude latitude" ;
    u_structured_Ch2:long_name = "structured uncertainty per pixel for channel 2" ;
    u_structured_Ch2:valid_max = 10000LL ;
    u_structured_Ch2:valid_min = 10LL ;
    u_structured_Ch2:add_offset = 0. ;
    u_structured_Ch2:scale_factor = 1.e-05 ;
short u_structured_Ch3a(y, x) ;
    u_structured_Ch3a:_FillValue = -32767s ;
    u_structured_Ch3a:units = "Reflectance" ;
    u_structured_Ch3a:coordinates = "longitude latitude" ;
    u_structured_Ch3a:long_name = "structured uncertainty per pixel for channel 3a" ;
    u_structured_Ch3a:valid_max = 10000LL ;
    u_structured_Ch3a:valid_min = 10LL ;
    u_structured_Ch3a:add_offset = 0. ;
    u_structured_Ch3a:scale_factor = 1.e-05 ;
short u_common_Ch1(y, x) ;

```

```

u_common_Ch1: FillValue = -32767s ;
u_common_Ch1: units = "percent" ;
u_common_Ch1: coordinates = "longitude latitude" ;
u_common_Ch1: long_name = "common uncertainty per pixel for channel 1" ;
u_common_Ch1: valid_max = 1000LL ;
u_common_Ch1: valid_min = 1LL ;
u_common_Ch1: add_offset = 0. ;
u_common_Ch1: scale_factor = 0.001 ;
short u_common_Ch2(y, x) ;
    u_common_Ch2: FillValue = -32767s ;
    u_common_Ch2: units = "percent" ;
    u_common_Ch2: coordinates = "longitude latitude" ;
    u_common_Ch2: long_name = "common uncertainty per pixel for channel 2" ;
    u_common_Ch2: valid_max = 1000LL ;
    u_common_Ch2: valid_min = 1LL ;
    u_common_Ch2: add_offset = 0. ;
    u_common_Ch2: scale_factor = 0.001 ;
short u_common_Ch3a(y, x) ;
    u_common_Ch3a: FillValue = -32767s ;
    u_common_Ch3a: units = "percent" ;
    u_common_Ch3a: coordinates = "longitude latitude" ;
    u_common_Ch3a: long_name = "common uncertainty per pixel for channel 3a" ;
    u_common_Ch3a: valid_max = 1000LL ;
    u_common_Ch3a: valid_min = 1LL ;
    u_common_Ch3a: add_offset = 0. ;
    u_common_Ch3a: scale_factor = 0.001 ;
short u_independent_Ch3b(y, x) ;
    u_independent_Ch3b: FillValue = -32767s ;
    u_independent_Ch3b: units = "K" ;
    u_independent_Ch3b: coordinates = "longitude latitude" ;
    u_independent_Ch3b: valid_max = 15000LL ;
    u_independent_Ch3b: valid_min = 1LL ;
    u_independent_Ch3b: long_name = "independent uncertainty per pixel for channel 3b" ;
    u_independent_Ch3b: add_offset = 0. ;
    u_independent_Ch3b: scale_factor = 0.001 ;
short u_independent_Ch4(y, x) ;
    u_independent_Ch4: FillValue = -32767s ;
    u_independent_Ch4: units = "K" ;
    u_independent_Ch4: coordinates = "longitude latitude" ;
    u_independent_Ch4: valid_max = 15000LL ;
    u_independent_Ch4: valid_min = 1LL ;
    u_independent_Ch4: long_name = "independent uncertainty per pixel for channel 4" ;
    u_independent_Ch4: add_offset = 0. ;
    u_independent_Ch4: scale_factor = 0.001 ;
short u_independent_Ch5(y, x) ;
    u_independent_Ch5: FillValue = -32767s ;
    u_independent_Ch5: units = "K" ;
    u_independent_Ch5: coordinates = "longitude latitude" ;
    u_independent_Ch5: valid_max = 15000LL ;
    u_independent_Ch5: valid_min = 1LL ;
    u_independent_Ch5: long_name = "independent uncertainty per pixel for channel 5" ;
    u_independent_Ch5: add_offset = 0. ;
    u_independent_Ch5: scale_factor = 0.001 ;
short u_structured_Ch3b(y, x) ;
    u_structured_Ch3b: FillValue = -32767s ;
    u_structured_Ch3b: units = "K" ;
    u_structured_Ch3b: coordinates = "longitude latitude" ;

```

```

u_structured_Ch3b:valid_max = 15000LL ;
u_structured_Ch3b:valid_min = 1LL ;
u_structured_Ch3b:long_name = "structured uncertainty per pixel for channel 3b" ;
u_structured_Ch3b:add_offset = 0. ;
u_structured_Ch3b:scale_factor = 0.001 ;
short u_structured_Ch4(y, x) ;
    u_structured_Ch4:_FillValue = -32767s ;
    u_structured_Ch4:units = "K" ;
    u_structured_Ch4:coordinates = "longitude latitude" ;
    u_structured_Ch4:valid_max = 15000LL ;
    u_structured_Ch4:valid_min = 1LL ;
    u_structured_Ch4:long_name = "structured uncertainty per pixel for channel 4" ;
    u_structured_Ch4:add_offset = 0. ;
    u_structured_Ch4:scale_factor = 0.001 ;
short u_structured_Ch5(y, x) ;
    u_structured_Ch5:_FillValue = -32767s ;
    u_structured_Ch5:units = "K" ;
    u_structured_Ch5:coordinates = "longitude latitude" ;
    u_structured_Ch5:valid_max = 15000LL ;
    u_structured_Ch5:valid_min = 1LL ;
    u_structured_Ch5:long_name = "structured uncertainty per pixel for channel 5" ;
    u_structured_Ch5:add_offset = 0. ;
    u_structured_Ch5:scale_factor = 0.001 ;
short u_common_Ch3b(y, x) ;
    u_common_Ch3b:_FillValue = -32767s ;
    u_common_Ch3b:units = "K" ;
    u_common_Ch3b:coordinates = "longitude latitude" ;
    u_common_Ch3b:valid_max = 15000LL ;
    u_common_Ch3b:valid_min = 1LL ;
    u_common_Ch3b:long_name = "common uncertainty per pixel for channel 3b" ;
    u_common_Ch3b:add_offset = 0. ;
    u_common_Ch3b:scale_factor = 0.001 ;
short u_common_Ch4(y, x) ;
    u_common_Ch4:_FillValue = -32767s ;
    u_common_Ch4:units = "K" ;
    u_common_Ch4:coordinates = "longitude latitude" ;
    u_common_Ch4:valid_max = 15000LL ;
    u_common_Ch4:valid_min = 1LL ;
    u_common_Ch4:long_name = "common uncertainty per pixel for channel 4" ;
    u_common_Ch4:add_offset = 0. ;
    u_common_Ch4:scale_factor = 0.001 ;
short u_common_Ch5(y, x) ;
    u_common_Ch5:_FillValue = -32767s ;
    u_common_Ch5:units = "K" ;
    u_common_Ch5:coordinates = "longitude latitude" ;
    u_common_Ch5:valid_max = 15000LL ;
    u_common_Ch5:valid_min = 1LL ;
    u_common_Ch5:long_name = "common uncertainty per pixel for channel 5" ;
    u_common_Ch5:add_offset = 0. ;
    u_common_Ch5:scale_factor = 0.001 ;
short channel_correlation_matrix_independent(channel, channel) ;
    channel_correlation_matrix_independent:_FillValue = -32768s ;
    channel_correlation_matrix_independent:long_name = "Channel_correlation_matrix_independent_effects" ;
    channel_correlation_matrix_independent:units = "1" ;
    channel_correlation_matrix_independent:valid_min = "-10000" ;
    channel_correlation_matrix_independent:valid_max = "10000" ;

```

```

channel_correlation_matrix_independent:description = "Channel error correlation matrix for independent
effects";
channel_correlation_matrix_independent:add_offset = 0.;
channel_correlation_matrix_independent:scale_factor = 0.0001;
short channel_correlation_matrix_structured(channel, channel);
channel_correlation_matrix_structured:_FillValue = -32768s;
channel_correlation_matrix_structured:long_name = "Channel_correlation_matrix_structured_effects";
channel_correlation_matrix_structured:units = "1";
channel_correlation_matrix_structured:valid_min = "-10000";
channel_correlation_matrix_structured:valid_max = "10000";
channel_correlation_matrix_structured:description = "Channel error correlation matrix for structured
effects";
channel_correlation_matrix_structured:add_offset = 0.;
channel_correlation_matrix_structured:scale_factor = 0.0001;
short channel_correlation_matrix_common(channel, channel);
channel_correlation_matrix_common:_FillValue = -32768s;
channel_correlation_matrix_common:long_name = "Channel_correlation_matrix_structured_effects";
channel_correlation_matrix_common:units = "1";
channel_correlation_matrix_common:valid_min = "-10000";
channel_correlation_matrix_common:valid_max = "10000";
channel_correlation_matrix_common:description = "Channel error correlation matrix for common effects"
;

channel_correlation_matrix_common:add_offset = 0.;
channel_correlation_matrix_common:scale_factor = 0.0001;
float lookup_table_BT(lut_size, channel);
lookup_table_BT:_FillValue = NaNf;
lookup_table_BT:description = "Lookup table to convert radiance to brightness temperatures";
float lookup_table_radiance(lut_size, channel);
lookup_table_radiance:_FillValue = NaNf;
lookup_table_radiance:description = "Lookup table to convert brightness temperatures to radiance";
float cross_element_correlation_coefficients(delta_x, channel);
cross_element_correlation_coefficients:_FillValue = NaNf;
cross_element_correlation_coefficients:long_name = "cross_element_correlation_coefficients";
cross_element_correlation_coefficients:description = "Correlation coefficients per channel for scanline
correlation";
float cross_line_correlation_coefficients(delta_y, channel);
cross_line_correlation_coefficients:_FillValue = NaNf;
cross_line_correlation_coefficients:long_name = "cross_line_correlation_coefficients";
cross_line_correlation_coefficients:description = "Correlation coefficients per channel for inter scanline
correlation";

// global attributes:
:Conventions = "CF-1.6";
:licence = "This dataset is released for use under CC-BY licence
(https://creativecommons.org/licenses/by/4.0/) and was developed in the EC FIDUCEO project \"Fidelity and Uncertainty
in Climate Data Records from Earth Observations\". Grant Agreement: 638822." ;
:writer_version = "2.0.0";
:institution = "University of Reading";
:title = "0.3Bet version of AVHRR Fundamental Climate Data Records";
:source =
"NSS.GHRR.NH.D88286.S2149.E2335.B0026162.GC,NSS.GHRR.NH.D88286.S2331.E0124.B0026263.WI";
:history = "";
:references = "CDF_FCDR_File Spec";
:comment = "This version is a 0.3Bet one and does not contain the final complete uncertainty model
though many error effects have been included." ;
:template_key = "AVHRR";
:sensor = "AVHRR";

```

```
:platform = "NOAA11" ;  
:software_version = "0.3Bet" ;  
:Ch3a_Ch3b_split_file = "FALSE" ;  
:Ch3a_only = "FALSE" ;  
:Ch3b_only = "TRUE" ;  
:UUID = "f18c7c65-af89-4d6e-93ac-328f95a5a8ae" ;
```