



Copernicus Climate Change Service



Product User Guide – Metop RO Level 1b Bending Angle Profile FCDRs

- D2.2 - Metop GRAS Bending Angle FCDR Release 3**
- D2.3 - COSMIC IGOR Bending Angle FCDR Release 1**
- D2.4 - CHAMP Black Jack Bending Angle FCDR Release 1**
- D2.5 - GRACE Black Jack Bending Angle FCDR Release 1**

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Contents:

1	INTRODUCTION	2
	1.1 Purpose and Scope	2
	1.2 Structure of this Document	2
	1.3 Acronyms and Abbreviations	3
	1.4 Definitions	4
2	BACKGROUND	6
3	PRODUCT DEFINITION	6
	3.1 Physical Structure	6
	3.2 Product Contents	8
	3.3 File Specifications	10
	3.4 Supplementary files	12
	3.5 File Visualization	13
4	PRODUCT GENERATION	14
	4.1 Data Processing	14
	4.2 Input Data	15
	4.3 Reprocessing procedure	16
5	PRODUCT FEATURES	19
	5.1 Validation	19
	5.2 Applicability	21
6	PRODUCT ACCESS	22
	6.1 Register with the Data Centre	22
	6.2 Order Data	22
7	PRODUCT SUPPORT AND FEEDBACK	23
8	PRODUCT REFERENCING	23
9	ACKNOWLEDGEMENTS	23
10	REFERENCES	24
	APPENDIX 1: Metadata netCDF File	26



List of Figures

- Figure 1 Radio occultation geometry, showing the bending angle α , the impact parameter a , and the straight line tangent altitude (SLTA). Note that α is generally below 1° and is measured in μrad , thus the figure is greatly exaggerated. 5
- Figure 2: Example of GRAS radio occultation measurements for a setting and a rising orbit. 8
- Figure 3: Schematic representation of inputs and outputs of the Yaros v2.0 reprocessing chain for the generation of Level 1b bending angles from GRAS Radio Occultation data. Note that for CHAMP, GRACE, and COSMIC only processing from L1a to L1b is performed. 14
- Figure 4 (O-B)/B statistics of EUMETSAT Metop-A Release 3 - Level 1b Bending Angle FCDR comparison to ERA5 forward propagated bending angles (year 2008) for the Metop-A GRAS data record for Yaros v1.4 and v2.0. Robust systematic uncertainty (right), random uncertainty (middle), outlier distribution (right). 15
- Figure 6: Example of Level 1b bending angle profile collected on 10 July 2012 over the Southern Pacific, the occultating GPS satellite was 08. The high resolution profile is shown, maximum and minimum observed bending angle, as well as the minimum height reached by the profile is also included. 19



List of Tables

Table 1: Missions, temporal coverage and number of occultations	7
Table 2: Measurement data sets of the netCDF and BUFR files of the Release 2 - GRAS Level 1b Bending Angle FCDR. Note, the data sets marked with * are not available in the BUFR files.	9
Table 3: Example of Global attributes of the netCDF files of the RO Level 1b Bending Angle Profile FCDRs. This example is taken from one of the CHAMP files. Global attributes for GRAS files may be slightly different because of more attributes available as shown in Table 4.	9
Table 4: Example of Global attributes of the netCDF files of the RO Level 1b Bending Angle Profile FCDRs. This example is taken from one of the GRAS files.	10
Table 5: File names identifying the Level 1b CHAMP data set in netCDF format.	10
Table 7: File names identifying the Level 1b GRAS data set in BUFR format.	11
Table 9: File names identifying the Level 1b GRAS data set, corresponding to the EPS format.	12
Table 11: File names identifying the RINEX files, corresponding to the RINEX v210 format.	13
Table 12: File names identifying the NAVBIT files.	13



1 INTRODUCTION

1.1 Purpose and Scope

The purpose of this guide is to provide users with detailed information about the Fundamental Climate Data Record (FCDR) of Level 1b radio occultation (RO) bending angles from:

1. Global Navigation Satellite System (GNSS) Receiver for Atmospheric Sounding (GRAS) instrument on Metop-A, Metop-B, and Metop-C – **GRAS Release 3**
2. GPS RO measurements from onboard CHALLENGING Minisatellite Payload (CHAMP) – **CHAMP Release 1**
3. GPS RO measurements from the twin satellite configuration Gravity Recovery and Climate Experiment (GRACE) – **GRACE Release 1**
4. GPS RO measurements from six COSMIC satellites – **COSMIC Release 1**

These datasets are collectively named as RO Level 1b Bending Angle Profile FCDRs. This release was produced with the “wave optics” (fast phase transform) retrieval algorithm implemented in Yaros 2.0 [RD 3], and comprises GRAS data from Metop-A for the period 10/2006–06/2020, from Metop-B for the period 09/2012–06/2020, and from Metop-C for the period 11/2018–06/2020, CHAMP data from 05/2001 to 10/2008, GRACE data from 02/2007 to 11/2017, and COSMIC data from 04/2006 to 04/2020. These data can be regarded as an FCDR, i.e., a long-term data record of well-calibrated and quality-controlled sensor data. This is designed to allow the generation of homogeneous products that are accurate and stable enough for climate monitoring and data assimilation for re-analysis of the recent climate.

The delivery of the RO Level 1b Bending Angle Profile FCDRs including documentation is part of the “Multiannual Agreement for the Provision of Climate Data for the Benefit of the Copernicus Climate Change Service (C3S)”. The FCDRs described in this product user guide will be used for assimilation in ECMWF’s Numerical Weather Prediction (NWP) model-based re-analysis. This FCDR provides a consistent record of bending-angle profile data from which, for example, stratospheric temperature and pressure, and tropospheric temperature, pressure (and to some extent humidity) profiles can be retrieved for climate monitoring.

This guide provides:

1. Specifications of the data record;
2. Scientific details on the generation and definition of the data record;
3. Characteristics and limitations of these products, aiming to assist the users in the decision of whether they can or should use the products of the data record for their applications;
4. Technical details on the format and the ordering of the data record, as well as information on the mechanisms to provide feedback.

1.2 Structure of this Document

This document has the following structure:

- Section 1 Purpose and scope of this product user guide
- Section 2 Background information on the product



Section 3	Definition of the product
Section 4	Generation of the product
Section 5	Product features
Section 6	Product ordering
Section 7	Product support and feedback
Section 8	Product referencing
Section 9	Acknowledgements
Section 10	References
Appendix	Metadata netCDF File

1.3 Acronyms and Abbreviations

The below table lists acronyms and abbreviations used in this document:

Acronym	Meaning
ATBD	Algorithm Theoretical Baseline Document
BUFR	Binary Universal Form for the Representation of meteorological data
C3S	Copernicus Climate Change Service
C/A	Coarse/Acquisition
CDR	Climate Data Record
CDS	Climate Data Store
CF	Climate and Forecast
CODE	Center for Orbit Determination in Europe
DOI	Digital Object Identifier
ECMWF	European Centre for Medium-Range Weather Forecasts
EOP	Earth Orientation Parameters
EPS	EUMETSAT Polar System
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FCDR	Fundamental Climate Data Record
FDF	Flight Dynamics Facility
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GRAS	Global navigation satellite system Receiver for Atmospheric Sounding
GSN	GRAS Support Network
ICRF	International Celestial Reference Frame
IGS	International GNSS Service
ITF	International Terrestrial Reference Frame
LEO	Low Earth Orbit
MDR	Measurement Data Records
MPHR	Main Product Header
NAS	Network Attached Storage



Acronym	Meaning
netCDF	Network Common Data Form
NOAA	National Oceanic and Atmospheric Administration
NRT	Near Real Time
NWP	Numerical Weather Prediction
POD	Precise Orbit Determination
PPF	Product Processing Facility
PRN	Pseudo Random Noise
QC	Quality Control
RINEX	Receiver Independent Exchange
RO	Radio Occultation
ROM SAF	Radio Occultation Meteorology Satellite Application Facility
SNR	Signal to Noise Ratio
SOA	SOLar Activity
SLTA	Straight Line Tangent Altitude
UCAR	University Corporation for Atmospheric Research
UTC	Coordinated Universal Time
VR	Validation Report
WMO	World Meteorological Organisation
YAROS	Yet Another Radio Occultation Software

1.4 Definitions

The following definitions are used throughout the document.

Data levels:

- Level 0 - Reconstructed raw sounding data at full time resolution with all available supplemental instrument information used in subsequent processing included.
- Level 1a - individual occultations full information such as phases and amplitudes, Signal to Noise Ratios (SNRs), as well as all other information e.g. from the Precise Orbit Determination (POD), needed to process it further to Level 1b.
- Level 1b - Level 1a sounding data that have been processed to bending angles and impact parameters, tangent point location, and quality information.

Products types:

- Near Real Time (NRT) - refers to data delivered for Numerical Weather Prediction (NWP) applications and is generally provided within less than 2h 15min (for EUMETSAT GRAS L1B products). This data is available in NRT through EUMETCast, GTS, and from the archive (GRAS GDS Level 1B product).
- Fundamental Climate Data Record - is a well-characterised, long-term data record, usually involving a series of instruments, with potentially changing measurement



approaches, but with overlaps and calibrations sufficient to allow the generation of products that are accurate¹ and stable, in both space and time, to support climate applications. FCDRs are typically calibrated radiances, backscatter of active instruments, or radio occultation bending angles. FCDRs also include the ancillary data used to calibrate them [RD 14].

Statistics:

- Observations minus background departures - refers to departures that are derived using the $(O-B)/B$ [%] quantity. O represents the observed profile, B the background profile (e.g. as taken from ECMWF ERA-Interim [RD 15]). This representation allows a better comparison for the exponentially varying bending angle profiles. B is sometimes not taken from the ECMWF ERA-Interim re-analysis, but from a match of another bending angle observation; then referring to $(O_1-O_2)/O_2$ where O_1 generally denotes the EUMETSAT data and O_2 the other bending angle observation. All profile data validation is based on "thinned" data, meaning that the high resolution profile data (which has > 1000 data points per profile) is thinned to a resolution varying with altitude (higher resolution near the surface of about 150m, to about 300m near 60km). This thinned profile data, comprising 247 data points, is also used in the Near-Real-Time product delivery to NWP users. The high resolution data is though also part of the GRAS Level 1b Bending Angle FCDR [RD 5].

Other:

- Straight Line Tangent Altitude (SLTA): the tangent altitude of the direct Low Earth Orbit (LEO) satellite and the GNSS satellite ray with respect to the Earth WGS84 Ellipsoid; it is generally > 0km, but in the lower troposphere can go to values <- 200km due to the bending of the ray.
- Bending angle: the actual geometry of the limb sounding radio occultation measurement technique is shown in Figure 1. The figure shows the bending angle as the angle between the actual, measured, and the straight line propagation from the GNSS satellite to the LEO satellite. The SLTA altitude is also shown.

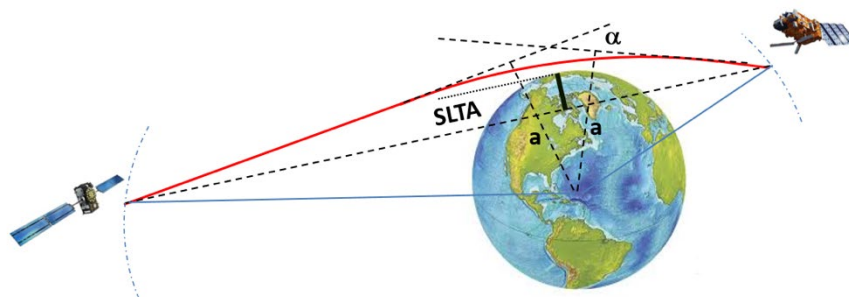


Figure 1 Radio occultation geometry, showing the bending angle α , the impact parameter a , and the straight line tangent altitude (SLTA). Note that a is generally below 1° and is measured in μrad , thus the figure is greatly exaggerated.

¹ Note that this Product User Guide and the Validation Report discuss data quality sometimes in bias and standard deviation terms, which in metrology are called systematic and random uncertainty.



2 BACKGROUND

The radio occultation instruments (GRAS, CHAMP, GRACE, and COSMIC) receive radio signals that are continuously broadcasted by Global Positioning System (GPS) navigation satellites of the GNSS orbiting the Earth, and measures the time delay of the refracted GPS radio signals as the ray signal path skirts the Earth's atmosphere on its way from the transmitting GPS to the receivers on these instruments. This time delay in the received signals can be processed to obtain vertical profiles of atmospheric parameters, such as temperature, pressure and water vapour in the stratosphere and troposphere.

The RO Level 1b Bending Angle Profile FCDRs are EUMETSAT deliverables to the Copernicus Climate Change Service (C3S), which aims at the preparation of consistent inputs for next generation reanalyses project and for climate monitoring. C3S is implemented by the European Centre for Medium-Range Weather Forecasts² (ECMWF) on behalf of the European Commission. Among others, EUMETSAT's contribution to the C3S was the generation of a homogeneous and consistent RO Level 1b Bending Angle Profile FCDRs of bending angles for the time-series of GRAS, CHAMP, GRACE, and COSMIC measurements.

The RO Level 1b Bending Angle profiles FCDRs have been produced employing EUMETSAT's Climate Data Record processing infrastructure.

3 PRODUCT DEFINITION

This chapter provides information on file sizes, file content, file formats, and file names for the RO Level 1b Bending Angle Profile FCDRs.

3.1 Physical Structure

The RO Level 1b Bending Angle Profile FCDRs cover the period from May 2001 till June 2020. It provides bending angle profile data, i.e., data of the angle between the actual, measured, and the straight line propagation from the GNSS satellite to the LEO satellite (see Figure 1), for approximately 8.8 million occultations (excluding the degraded occultations) from the aforementioned instruments. The data record is made available as:

- i) individual occultation profiles in Network Common Data Form (NetCDF) and in the Binary Universal Form for the Representation of meteorological data (BUFR) format [RD 11];
- ii) multiple occultation profiles in EUMETSAT's native EPS format (only for GRAS data). The format of these data is identical to the data provided by the version 5 operational Near Real Time (NRT) stream of the GRAS instruments except for meta-data describing the reprocessing itself [RD 4]. Typically, one multiple occultation product contains all occultations collected in one orbit.

The individual occultation files contain Radio Occultation measurements that are taken whenever one of the GNSS/GPS satellites, as seen from the observing spacecraft, sets or rises behind the Earth's horizon. Typically, a single occultation, covering the neutral atmosphere, lasts up to a few minutes. During a single occultation the line of sight

² <https://www.ecmwf.int/> Link valid 28/12/2018



between the two satellites moves from high altitudes into the troposphere (for setting occultations and vice versa for rising ones), scanning nearly vertically through the atmosphere (the reference location and the actual latitudes / longitudes of the profile are included in the data record). The location of the occultation (which is associated with the point where the straight line connecting the GNSS transmitter with the RO receiver touches the Earth's surface, i.e. SLTA equals 0) depends on the orbit geometry of the satellites being involved in the measurement. This location will typically be located about 3000 km away from the sub-satellite point of the RO receiver. Individual occultations, when being processed to Level 1b, therefore consist of vertical bending-angle profiles, which are more or less randomly distributed over the globe (see Figure 2). Note though that actual locations are driven by the satellites involved in the occultation, thus they "appear" random when looking at a plot with locations over the globe, but they are in fact predictable from the GPS and the receiver satellite orbits. Also, the orbit characteristics of the receiver satellite might lead to sampling around certain local solar times (e.g. for sun-synchronous Metop), thus in this domain, the data is not randomly distributed.

For the Metop satellites, the multiple occultation files contain RO measurements that are collected during a download from the satellite to a ground receiving stations (e.g., at Svalbard, Norway). Each full-orbit level 0 file covers data collected during a period of ~101 minutes, with the data starting and ending at the edge of the ground station coverage time. Level 0 data was then used to reconstruct GPS observables such as phase and amplitude measurements at the two GPS frequencies, to perform a Precise Orbit Determination (POD), and to derive bending angle profiles from the raw measurements.

For the other RO satellites, the reprocessing was based on Atmospheric excess phase data ("atmPhs") data as provided the University Cooperation for Atmospheric Research (UCAR). This data contains the reconstructed GPS observables as well as results of a POD performed by UCAR. For the processing, reprocessed data sets as available from their website used in the latest available version (for details see <https://www.cosmic.ucar.edu/what-we-do/cosmic-1/data/>; <https://doi.org/10.5065/ZD80-KD74>)

Table 1: Missions, temporal coverage and number of occultations

Mission/satellite	Start	End	# occultation Nominal / Degraded	#occ/day
GRAS/Metop-A	2006/10/27	2020/06/30	2,761,522 / 531,378	659
GRAS/Metop-B	2012/09/29	2020/06/30	1,712,580 / 177,793	668
GRAS/Metop-C	2018/11/17	2020/06/30	355,788 / 32,862	657
CHAMP	2001/05/19	2008/10/05	539,093 / 124,334	246
GRACE	2007/02/28	2017/11/20	448,864 / 71,650	133
COSMIC	2006/04/22	2020/04/25	5,961,727 / 1,693,560	1496

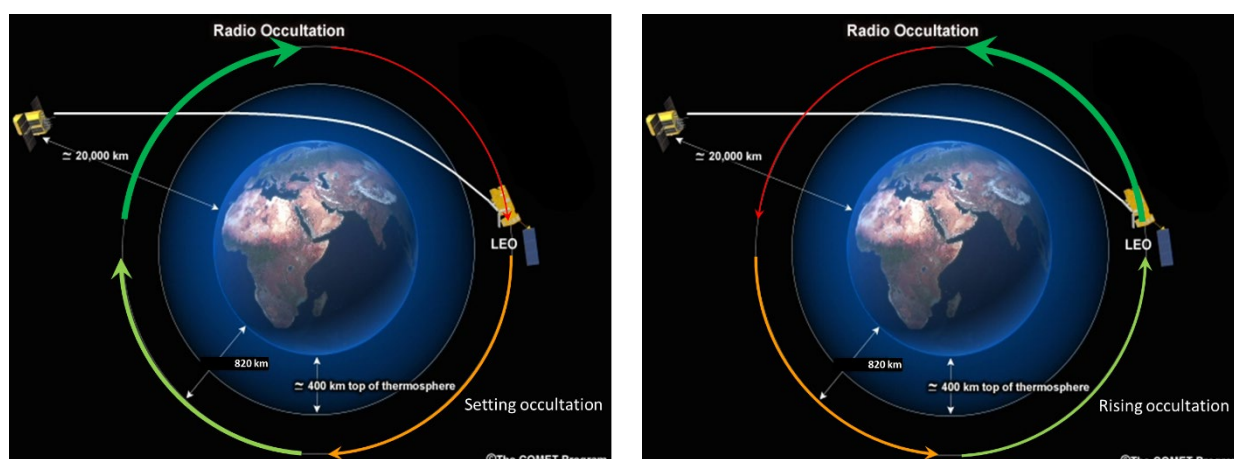


Figure 2: Example of GRAS radio occultation measurements for a setting and a rising orbit.

3.2 Product Contents

The Level 1b netCDF4 files contain information from a single occultation, which include the main variables used in the assimilation process, namely the bending angles (neutral, but also at L1, L2 GPS frequency) over impact parameter, along with information on the measurement time, geo-location of the tangent points, and some quality indicators. In addition, these files contain information on the GPS, RO satellite orbits and clocks, as well as amplitude and phase data at Level 1a. The bending angles are provided at high resolution as well as at a lower/thinned resolution. The vertical levels used for the thinned (and smoothed) bending angle profiles are the same for each occultation with respect to a geo-location based reference frame, and identical to the GRAS ones provided operationally for NWP models in BUFR format. The set of 247 standard vertical levels is used for assimilation purposes; other vertical resolutions can though be generated by the data user by applying suitable thinning and smoothing algorithms to the high resolution data if required. A full list of data and metadata provided in the netCDF files is given in APPENDIX 1.

The Level 1b BUFR files contain information from multiple occultations collected during one full orbit, and comprise the thinned bending angle profiles extracted from the full profiles available in the netCDF4 products. Due to the thinning the final file size or the BUFR files is more than 3 orders of magnitude smaller than those of the netCDF4 files.

The Level 1b native EPS files contain information from multiple occultations collected during one full orbit, and comprise the full profiles available in the netCDF4 products. Nevertheless, these files are just wrappers around the actual netCDF files. The individual netCDF files can be extracted from the EPS file with the help of the EPSar tool. EPSar is a tar-like tool written in plain Perl allowing to list the contents of EPS files, and also to extract some or all netCDF files contained in the EPS file. The most recent version of the EPSar software can be downloaded from <https://github.com/leonid-butenko/epsar>.



Measurement data sets

The files (netCDF and BUFR) comprise of the following measurement data sets that are provided for vertical levels, either at full resolution (can be thousands of data levels) or at thinned resolution (247 levels).

Table 2: Measurement data sets of the netCDF and BUFR files of the Release 2 - GRAS Level 1b Bending Angle FCDR. Note, the data sets marked with * are not available in the BUFR files.

Measurement data set	Long name
azimuth_tp	GNSS->LEO line of sight azimuth angles at tangent points (clockwise against True North)
bangle	Bending angle (ionospheric corrected)
bangle_l1	Bending angle (derived from GPS L1 signals)
bangle_l1	Bending angle (derived from GPS L2 signals)
impact	Impact parameter
impact_height*	Impact height (wrt WGS 84 ellipsoid)
lat_tp	Latitudes for tangent points
lon_tp	Longitudes for tangent points

Global attributes

The files (netCDF) comprise the following global attributes:

Table 3: Example of Global attributes of the netCDF files of the RO Level 1b Bending Angle Profile FCDRs. This example is taken from one of the CHAMP files. Global attributes for GRAS files may be slightly different because of more attributes available as shown in Table 4.

Name	Value
Conventions	CF-1.7
metadata_conventions	Unidata Dataset Discovery v1.0
Product_name	BJxx_1B_CHA_20050130214729Z_20050130214935Z_R_O_20201129223850Z_G04_NN_0100.nc
title	BJxx_1B_CHA_20050130214729Z_20050130214935Z_R_O_20201129223850Z_G04_NN_0100.nc
summary	Champ/BlackJack level 1a/b radio occultation data
keywords	""
history	original generated product (from UCAR/CDAAC atmPhs input)
institution	EUMETSAT
spacecraft	CHA
instrument	BlackJack
product_level	1B
type	BND
mission_type	Global
disposition_mode	Operational
sensing_start_time_utc	2005-01-30 21:47:29.000
sensing_end_time_utc	2005-01-30 21:49:35.980
environment	Offline
references	www.eumetsat.int
doi	Doi:10.15770/EUM_SEC_CLM_0030



Table 4: Example of Global attributes of the netCDF files of the RO Level 1b Bending Angle Profile FCDRs. This example is taken from one of the GRAS files.

Name	Value
Conventions	CF-1.7
metadata_conventions	Unidata Dataset Discovery v1.0
Product_name	GRAS_1B_M03_20200630235238Z_20200630235502Z_N_T_20210113231105Z_G12_NN_0300.nc
title	GRAS_1B_M03_20200630235238Z_20200630235502Z_N_T_20210113231105Z_G12_NN_0300.nc
summary	Metop-C/GRAS level 1a/b radio occultation data
keywords	""
history	original generated product
environment	Offline
references	www.eumetsat.int
doi	Doi:10.15770/EUM_SEC_CLM_0051
product_level	1B
type	BND
mission_type	Global
disposition_mode	Operational
sensing_start_time_utc	2020-06-30 23:52:38.220
sensing_end_time_utc	2020-06-30 23:55:02.787
orbit_start	8552U
orbit_end	8553U
receive_start_time_utc	2020-06-30 23:19:29.000
receive_end_time_utc	2020-07-01 02:45:02.000
receiving_ground_station	SVL
subsetting	NONE
_NCProperties	version=2,netcdf=4.7.1,hdf5=1.10.5

3.3 File Specifications

This section summarizes file format, file naming conventions and data record sizes of the Release 3 - RO Level 1b Bending Angle FCDR. Detailed information on the specification of metadata and variables in the netCDF, BUFR, and EPS files is given in [RD 4].

3.3.1 Individual occultation netCDF files

The filenames of the netCDF4 data files identify the instrument, product level, spacecraft, start sensing time, end sensing time, product type, processing time, and Quality Control (QC) information. Sensing times are actually the start and end time of an occultation. The file naming conventions used for the netCDF4 files are shown in Table 4.

Table 5: File names identifying the Level 1b CHAMP data set in netCDF format.

Naming convention RO Level 1b FCDR -netCDF
<code><instr>_1B_<sat>_<start_time>Z_<end_time>Z_<p>_<d>_<create_time>_<GXX>_<ff>_0x00.nc</code>
Example name Level 1b CHAMP -netCDF
<code>BJxx_1B_CHA_20050130214729Z_20050130214935Z_R_O_20201129223850Z_G04_NN_0100.nc</code>



where:

- <inst> 4-character instrument ID (e.g., GRAS for the GRAS instrument)
- <sat> 3-character satellite ID (e.g., M02 for Metop-A and M01 for Metop-B)
- <start_time> 14-digit sensing start time (e.g., 20150612 22:53:57 UTC on 12 June. 2015)
- <end_time> 14-digit timestamp characterising sensing end time
- <p> 1-character processing mode for Nominal (N), Backlog (B), Reprocessing (R), or Validation (V). Please Note that 'R' is the processing mode for the complete dataset of this data release.
- <d> 1-character disposition mode for Testing (T), Operational (O), Commissioning (C)
- <create_time> 14-digit timestamp characterising product creation time
- <Gxx> 3-character satellite ID of occulting GNSS satellite (e.g., G23 for Pseudo Random Noise 23 of the GPS constellation)
- <ff> 2-character flag field indicating nominal (N) or degraded (D) instrument and processing (e.g., ND for nominal instrument data, but degraded processing)
- <0x00> 4 digit code referring to release number of the FCDR

The netCDF4 files have sizes varying between 1 and 20 Mb per file.

3.3.2 Individual occultation BUFR files

The WMO Binary Universal Form for the Representation of meteorological data (BUFR) format, is a binary format designed to represent any meteorological dataset that employs a continuous binary stream. Please refer to the BUFR format description in [RD 11] for further information.

The filenames of the BUFR data identify the instrument, product level, spacecraft, start sensing time, end sensing time, product type, processing time, and orbit number. The file naming conventions used for the BUFR files are similar to those used for the netCDF files (see sub-section 3.3.1), and are shown in Table 6.

Table 6: File names identifying the Level 1b GRAS data set in BUFR format.

Naming convention RO Level 1b FCDR - BUFR
<instr>_1B_<sat>_<start_time>Z_<end_time>Z_<p>_<d>_<create_time>Z_0x00.bufr
Example name Level 1b GRAS – BUFR
<i>GRAS_xxx_1B_M02_20150612225207Z_20150613003506Z_R_O_20170215052803Z_0300.bufr</i>

The BUFR files contain the occultations collected during one orbit and have a size of about 11 KB MB per file.



3.3.3 Multiple occultation EPS files

The organisation of radio occultation measurements in terms of individual occultations or granules is straightforward, but leads to a large number of data files. This has disadvantages when disseminating large amounts of data or archiving long-term data records. Therefore, EUMETSAT organises GRAS RO data in products covering a full orbit. Technically, the EPS native file format comprises individual granules (or occultations) that are “wrapped” into a single orbit file. At the conceptual level, the wrapping can be understood as using the EPS data format as a data container, similar to .tar or .zip data archives well known from Linux or Unix environments.

The native EPS Data Format consists of a fixed-length ASCII header, followed by one or more data records. Each such data record contains itself a header specifying the record’s type, length, and possibly some additional metadata. In particular, the EPS Data Format consists of the standard Main Product Header (MPHR) common to all EPS products, and one or more Measurement Data Records (MDRs). Each MDR, after its header is removed, is technically a netCDF occultation granule. The individual netCDF files can be extracted from the EPS files with the help of the epsar tool³. Detailed information on the EPS format can be found in [RD 9], although a description providing more details relevant for the reprocessed GRAS RO data is also part of [RD 5].

The filenames of the EPS data files identify the instrument, product level, spacecraft, start sensing time, end sensing time, product type, processing time, and orbit number. The file naming conventions used for native EPS files are the same as for all EPS level 1 data products, and are shown in Table 8.

Table 7: File names identifying the Level 1b GRAS data set, corresponding to the EPS format.

Naming convention Level 1b GRAS - EPS
<code><inst>_xxx_1B_<sat>_<start_time>Z_<stop_time>Z_<p>_<d>_<create_time>Z_0x00</code>
Example name Level 1b GRAS - EPS
<code>GRAS_xxx_1B_M02_20150612225207Z_20150613003506Z_R_O_20170215052803Z_0300</code>

The EPS files have a size varying between 200 and 400 Mb per file.

3.4 Supplementary files

The RO Level 1b Bending Angle Profiles FCDR for GRAS is made available with two supplementary datasets, i.e., the RINEX dataset and the NAVBIT dataset.

The RINEX files contain pseudorange, carrier phase, and amplitude/SNR data of the zenith antenna, and are formatted in standard RINEX v2.10 observation format [RD 21]. One RINEX file is available per day, with a file size of approximately 65 MB per file.

³ The most recent version of the epsar software can be downloaded from <https://github.com/leonid-butenko/epsar> (assessed on 5 December 2018).



Table 8: File names identifying the RINEX files, corresponding to the RINEX v210 format.

Naming convention – GRAS RINEX files
<code><inst>_RNX_1A_<inst>_<start_time>Z_<stop_time>Z_create_time>_YARx_XXXXXXXXXX_0x00</code>
Example name – GRAS RINEX files
<code>GRAS_RNX_1A_M02_20150612225207Z_20150613003506Z_20170215052803Z_YARx_XXXX XXXXXX_0100</code>

The NAVBIT files contain the navigation bit sequences which modulate each of the GPS signals and follow the format described in [RD 17]. One NAVBIT file is available per hour, and has a size of approximately 55 MB per file.

Table 9: File names identifying the NAVBIT files.

Naming convention – NAVBIT files
<code>xxxx_NAB_xx_xxx_<start_time>Z_<stop_time>Z_create_time>_EUMx_MERGNAVBIT_0x00</code>
Example name Level 1b – NAVBIT files
<code>xxxx_NAB_xx_xxx_20191130234442Z_20191202001436Z_20201002144132Z_EUMx_MERG NAVBIT_0100</code>

3.5 File Visualization

The netCDF files can be visualized with the commonly known netCDF viewers and netCDF image processing software. Among others the files can be viewed with HDFview (version 2.13 or later), Ncview (version 2.1.7 or later), Panoply (version 4.7.0 or later), and processed with IDL (version 8.0 or later) and netcdf4-python (version 1.2.4) on python (version 2.6 or later).



4 PRODUCT GENERATION

This chapter gives a high-level overview of how the data record was produced and describes the used input and auxiliary data, the processing software, and the setup of the reprocessing facility. The software used to perform the reprocessing is EUMETSAT’s reference RO processor, also referred to as Yaros (Yet another radio occultation processor). We note that Yaros provides the reference implementation of all operational RO processing at EUMETSAT; for example, the operational GRAS processor is a re-implementation of Yaros, adapted to the operational needs in EUMETSAT’s EPS ground segment. A schematic overview of the RO processing setup used for the reprocessing is shown in Figure 3; the individual input data and processing steps are described in more detail in the following sections.

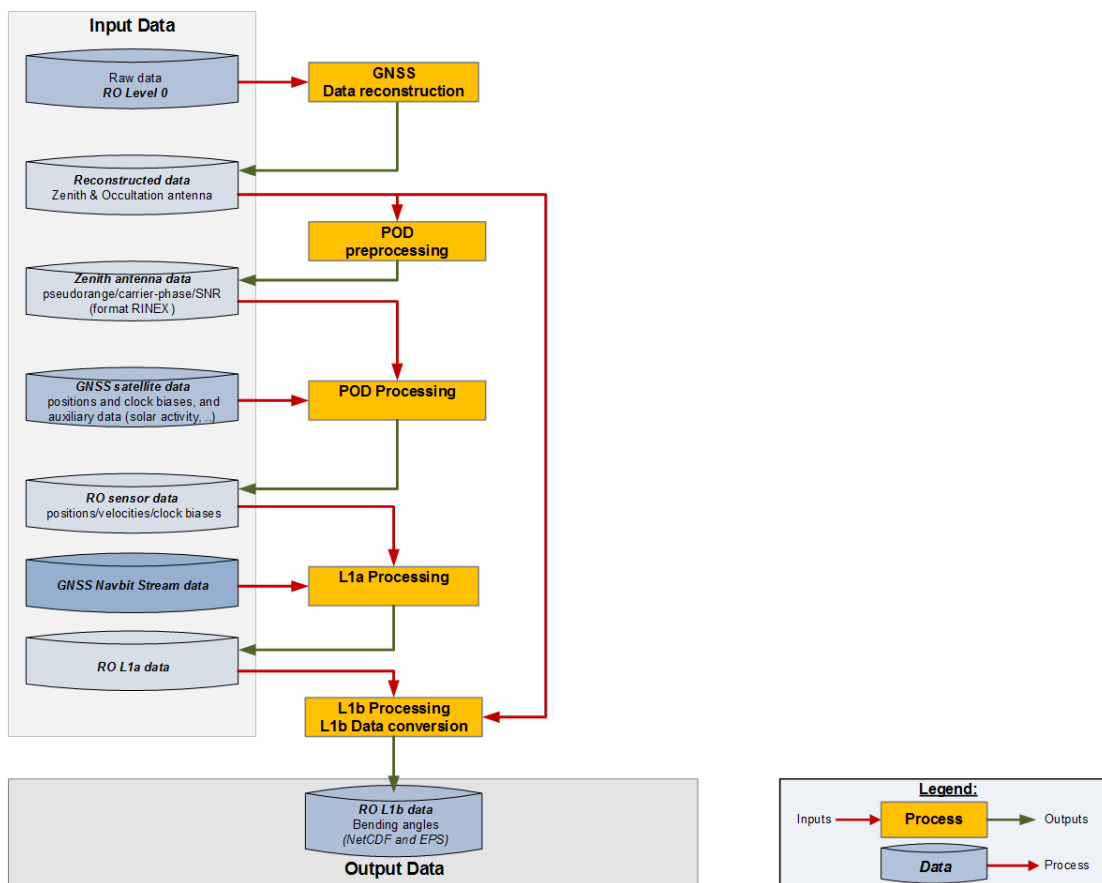


Figure 3: Schematic representation of inputs and outputs of the Yaros v2.0 reprocessing chain for the generation of Level 1b bending angles from GRAS Radio Occultation data. Note that for CHAMP, GRACE, and COSMIC only processing from L1a to L1b is performed.

4.1 Data Processing

A general introduction on the principles of RO sounding can be found in, e.g., [RD 11] and [RD 12]. The reprocessing of the GRAS RO data is based on a “wave optics” (fast phase transform) retrieval algorithm, it is not using, but presenting the next upgrade for the operational NRT GRAS processing as to be introduced early 2021. The improvement of the processing between early operational GRAS data and the reprocessed data set described in this document is shown in Figure 4.

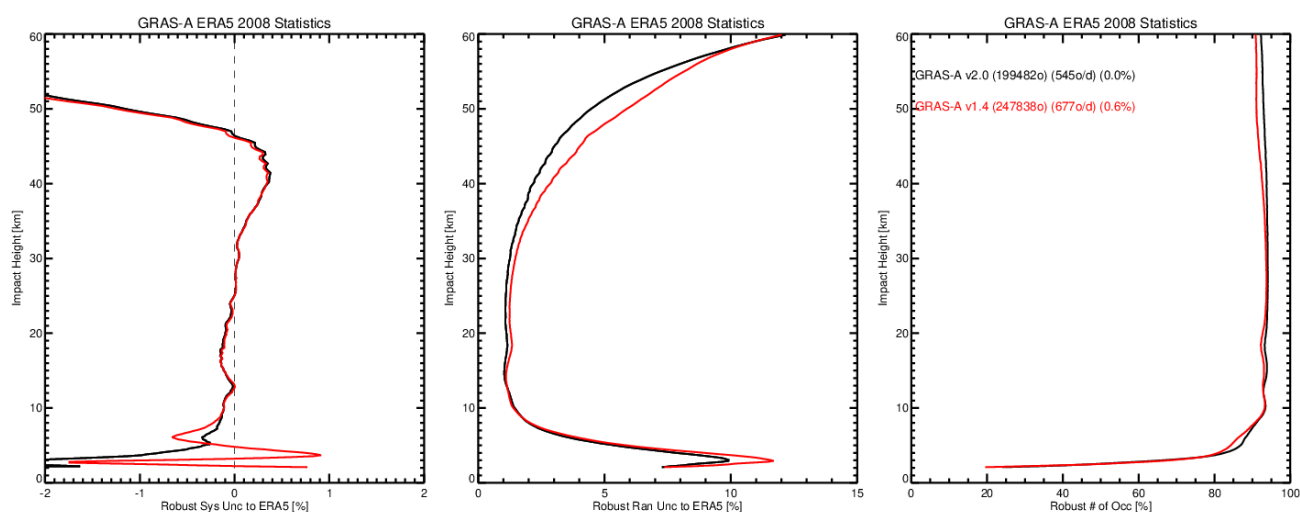


Figure 4 (O-B)/B statistics of EUMETSAT Metop-A Release 3 - Level 1b Bending Angle FCDR comparison to ERA5 forward propagated bending angles (year 2008) for the Metop-A GRAS data record for Yaros v1.4 and v2.0. Robust systematic uncertainty (right), random uncertainty (middle), outlier distribution (right).

Compared to the previous Release 2 (Yaros processing version 1.4), the Release 3 (v2.0), shows a different systematic uncertainty at lower tropospheric altitudes (see Figure 4, left) and lower random uncertainties (see Figure 4, middle). The quality of the data is also better than for v1.4 (see Figure 4, right), albeit there are also fewer occultations per day available (at least for Metop-A).

4.2 Input Data

The Level 0 data from GRAS are used as the prime input data for the processing. These Level 0 data are downloaded from the satellite once per orbit over Svalbard and since January 2011 partially over McMurdo. The files are stored as orbit dumps, generally containing all the data starting from the last dumped data at the Svalbard ground station to all data collected up to the next dump, in the EUMETSAT Data Centre.

For this Release 3 - GRAS Level 1b Bending Angle Profile FCDR data generation, Level 0 GRAS data was obtained from the EUMETSAT Data Centre for the reprocessing period.

For the Release 1 - 3rd party (CHAMP, GRACE, COSMIC) 1b Bending Angle Profile FCDR data generation, the reprocessing was based on Atmospheric excess phase data ("atmPhs") data as provided by the University Cooperation for Atmospheric Research (UCAR). This data contains the reconstructed GPS observables as well as results of a POD performed by UCAR (see details at <https://www.cosmic.ucar.edu/what-we-do/cosmic-1/data/>).

4.2.1 Auxiliary Data

The auxiliary data consists of five elements: GPS navigation bits, GPS clock, GPS orbits, solar magnetic flux and Earth orientation, manoeuvre history. Each of these is described in the sections that follow.



4.2.1.1 GPS navigation bits

Navigation bit sequences are necessary to allow the correct reconstruction of the signal carrier phases when the receiver is in open-loop tracking mode. This auxiliary data files have been generated by EUMETSAT taking data from different sources and generating a merged dataset ([RD 15] provides more details on the process). The products contain the navigation bit sequences which modulate each of the GPS signals, and follow the format described in [RD 17].

4.2.1.2 GPS orbit/clock data

GPS orbits and clocks are not estimated in the framework of the re-processing. They were downloaded from the CODE Analysis Centre at the Astronomical Institute at the University of Bern (AIUB) which is a Global Analysis Center to the International GNSS Service (IGS). See [RD 18] for further details and DOI.

4.2.1.3 Solar flux and Earth Orientation Parameters

The Earth Orientation Parameters (EOP) file contains time series of coefficients necessary to allow the full transformation between the International Terrestrial Reference Frame (ITRF) and the International Celestial Reference Frame (ICRF). The file `finals2000a.data` is downloaded from the 'IERS Rapid Service Prediction Center for Earth Orientation Parameters' [RD 19]; its format is defined in [RD 20].

The file containing Solar Activity (SOA) information, like the Solar Flux, is necessary for the POD function to correctly model forces impacting the satellite motion due to solar activity (in particular solar radiation drag). The file is provided by the EPS Flight Dynamics Facility (FDF) facility, which in turn uses space weather data made available by National Oceanic and Atmospheric Administration (NOAA).

4.2.1.4 Manoeuvre history

The LEO manoeuvre history is necessary to take into account all the manoeuvres applied to the Metop satellites. It is provided internally from the EPS FDF in ASCII format.

4.3 Reprocessing procedure

As shown in Figure 3, the processing of Level 0 raw radio occultation data to Level 1b vertical bending-angle profiles can be broken down into 5 major processing steps. This section summarizes the processing steps of the GRAS processor.

Step 1 - Level 0 Reconstruction

This step involves the extraction of typical GNSS observables, i.e., carrier phase, pseudorange, signal amplitude and/or Signal-to-Noise Ratio (SNR) data, from the level 0 raw data of the RO receiver. For GRAS, the reconstruction of these GNSS observables requires significant processing from a very low, instrument level representation of the measurements. Step 1 results in reconstructed data from the zenith antenna (which is used for POD), and from the velocity and anti-velocity viewing occultation antennas.

Step 2 - Precise Orbit Determination pre-processing

The GRAS receiver is unique in that it does not provide common GPS observables such as pseudorange, carrier phase and amplitude (or Signal-to-Noise Ratios, SNRs) directly; they instead have to be reconstructed from the lower level 0 data contents. After the



reconstruction of these observables for the zenith antenna data, pseudorange, carrier phase and SNR data are interpolated to a 1 Hz temporal resolution. They are then formatted into the Receiver Independent Exchange (RINEX) v2.10 standard GPS observation format. The RINEX format definition can be found in [RD 21].

Step 3 - Precise Orbit Determination

In this step, the precise orbit positions and velocities of the centre of mass of the Metop-A and Metop-B satellites carrying the GRAS receiver are determined from the RINEX files generated in step 2. In addition, the clock bias of the GRAS receiver with respect to the GPS system time is also estimated at each epoch. Precise positions and clock biases of the GNSS satellites are needed for performing this step. The latter are auxiliary data available from [RD 18]. In addition, the yaw-steering attitude of the Metop satellite is modelled. The POD processing is based on a commercial off-the-shelf (COTS) software package, which is fed by driver scripts and configuration templates from Yaros. For GRAS, EUMETSAT uses an adapted version of the NAPEOS suite as POD processor [RD 23]. Step 3 results in precise positions, velocities, and clock biases of the Metop-A and Metop-B satellites carrying the RO receiver.

Step 4 - L1a processing

This step processes the reconstructed GNSS data as measured by the occultation antenna, using information derived in the previous steps, i.e., the precise orbit and clock bias data from the GNSS and the LEO satellites and GNSS measurements from the occultation antennas. The processing of the reconstructed GNSS data aims at extracting all data relevant for individual occultation events. Precise orbit data from both the occulting GNSS satellite and the Metop satellite are used to apply geometric corrections, as are the centre of mass to Antenna reference point and antenna phase corrections. Finally, excess carrier phases are calculated. Clock errors of the receiver are compensated for by applying the GNSS and GRAS clock corrections computed in Step 3, a process known as zero-differencing [RD 24]. Finally, an initial georeferencing information (i.e., the location of the occultation as well as the centre and radius of curvature which will later be used in the level 1b processing) is calculated along with quality control and diagnostic data. Note that for GRAS, multiple measurement modes occur at the same time (e.g., single or dual frequency closed loop measurements at a sampling rate of 50 Hz, as well as single frequency open loop data measured at 1 kHz). This multi-mode multi-rate data set is converted into a single 50 Hz measurement time series for each GPS frequency. This data combination consists of merging of the closed and open loop data, rewriting the observations with respect to a common phase model. The modulation of the observed GNSS signals due to the navigation data transmitted by GPS satellites is also removed from the measurements using the GNSS Navigation Bits. Finally, the data is up-sampled and filtered. The processing applied to GRAS carrier phase is similar to procedures described in the literature (e.g., [RD 25]), but with the necessary adaptations to the GRAS data characteristic. Step 4 results in Level 1a georeferenced and differenced carrier phases, amplitude/SNR, and pseudoranges, as well as diagnostic data. This information is stored in a single file per occultation.

Step 5 - L1b processing

In Step 5, the final step, vertical bending-angle profiles are generated. These profiles are provided as a function of the impact parameter. Apart from "high resolution" profiles, a thinned variant providing data on a standard set of impact level heights is also generated for each occultation. The GRAS processing is based on the Full Spectrum



Inversion (FSI) wave optics algorithm [RD 26], accompanied by a time-domain radio-holographic filtering [RD 27] applied of the signal preparation.

Bending-angle profiles derived independently from the two different carrier frequencies are down sampled, slightly (over a height interval of 200 m) smoothed, and eventually combined using a linear combination [RD 28] to form a neutral atmospheric bending-angle profile. As part of this process, missing data on GPS frequency L2 in the mid and lower troposphere is extrapolated from higher up using a model-based extrapolation method [RD 29, RD 30]; a second order correction of the usual linear combination of bending angles is also applied.

We note that EUMETSAT applies a wave optics retrieval over the entire vertical range of the profile; bending-angle profiles therefore do not exhibit changes in their error characteristics due to a transition between wave and geometrical optics processing. On the other hand, the high resolution bending angles resulting from the FSI still exhibits several 1000 data points, with some of them very closely spaced to each other. In order to reduce the number of data points to a manageable (and meaningful) level, the high resolution profiles are further interpolated to a set of 247 standard levels between the surface and 60 km (impact) altitude. As part of the interpolation, they are also smoothed with an altitude and latitude dependent local regression filter [RD 31; RD 32]. Based on input received from operational users at the time when the operational wave optics was introduced, the smoothing in this last filtering step is tuned towards providing error statistics similar to those obtained from the geometrical optics processing in earlier versions of EUMETSAT's operational processor in the stratosphere, but allows for higher resolutions in the troposphere.

Each occultation is processed independently and saved as a Level 1b netCDF file. In a final step, all occultations belonging to one orbit dump (approx. 100 minutes) are wrapped into an EPS format file. Therefore, Step 5 results in level 1b data stored in EPS files (one file per orbit), where each granule contains data from a single occultation. Apart from level 1b data, these products also include all level 1a and POD data as required to (re-) process the occultation in question.



5 PRODUCT FEATURES

This chapter gives a high-level overview of the scientific data available in the RO Level 1b Bending Angle Profile FCDRs files. In addition, a summary is provided of the technical and scientific assessments made to validate the released data.

The data record is global, covers the latitude from 90° S to 90° N. The Metop satellites have a polar, sun-synchronous orbit with 14.2 orbits per day. Depending on the availability of the GPS satellites more than 700 occultations per day per satellite can be retrieved prior to quality control. Figure 6 shows a typical GRAS bending-angle profile, both for the observation on the L1, L2 GPS frequencies (C/A and P2 respectively), as well as the neutral one and for comparison a climatological reference. The other RO instruments are on non-sun synchronous orbits, and generally have more variability regarding the available number of orbits or occultations per day.

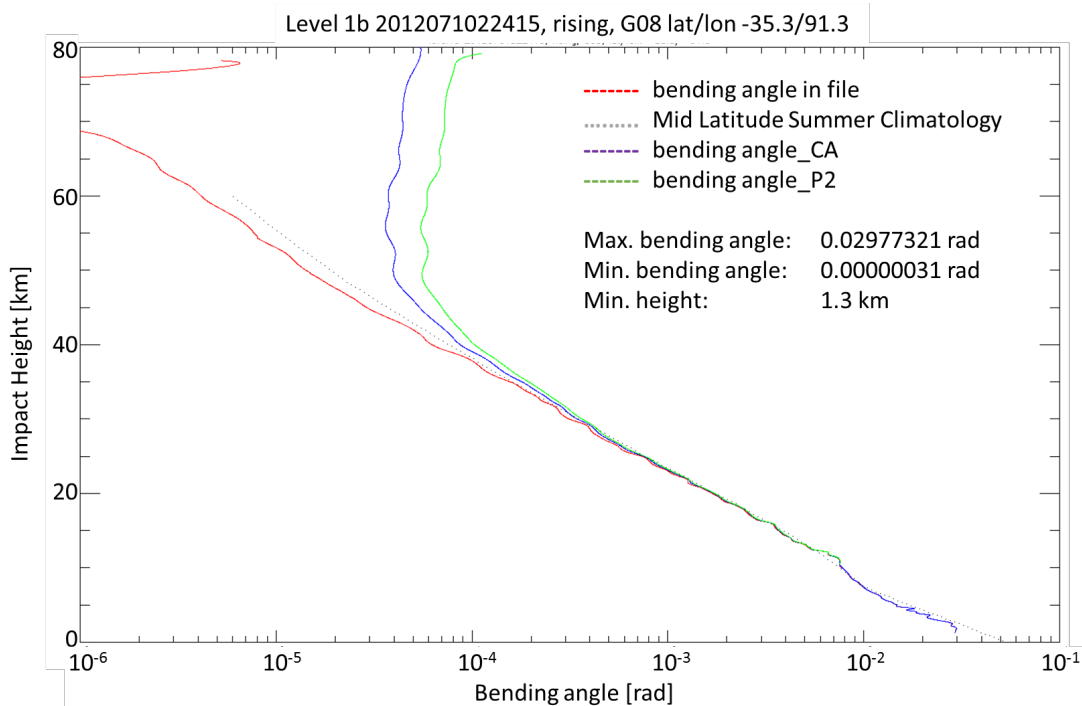


Figure 5: Example of Level 1b bending angle profile collected on 10 July 2012 over the Southern Pacific, the occultating GPS satellite was 08. The high resolution profile is shown, maximum and minimum observed bending angle, as well as the minimum height reached by the profile is also included.

5.1 Validation

This section summarizes the work done to validate the data record technically and scientifically, as well as the main feedback provided by beta-users of the data records. The full details of the validation work are described in the Validation Report (VR) [RD 1]. Please note there is no official reference document that provides requirements for the



reprocessed Level 1b bending angle product, NRT requirements⁴ though serve as a guideline [RD 32].

The technical quality of the RO Level 1b Bending Angle FCDR has been assessed with the following checks:

- Basic checks of the data record, ensuring all the products are present and readable and that the metadata available is complete and consistent with the re-processing system configuration;
- Basic monitoring of the geophysical information in the products to ensure that they are within the ranges expected;
- Analysis of non-nominal or degraded measurements and the effectiveness of internal product flags in identifying them;
- Monitoring of signal-to-noise levels and tracking states of the receiver in order to ensure that measurement data as provided by the instrument is fit-for-use; occultations not meeting this requirement are labelled as degraded.

The scientific quality of the FCDR has been assessed with the following analyses:

1. **Global analysis:** in this analysis data sets are compared with each other globally, using the ERA5 re-analysis as “reference”⁵.
2. **Match-up evaluation:** pairs FCDR data processed by EUMETSAT with the same data processed by another centre (direct match-ups). For direct matching, it is assured that only the same occultations are compared.

Results of the validations for each of the FCDRs are summarised below.

The GRAS FCDR Release 3 data show generally consistent data quality for the entire data record, similar to what was already found in the Releases. It is shown in [RD 1] that Release 3 GRAS data show similar quality in systematic uncertainties and better quality in random uncertainties compared to the previous Release against ERA5 data. Though the overall number of occultations are slightly lower compared to the previous release, there are more data in the troposphere and lower stratosphere in Release 3 compared to the previous version. The data also show very similar quality for the both rising and setting occultations which was not the case for the previous release. All three GRAS instruments show consistent behavior, the absolute systematic uncertainties are less than a percent above the boundary layer and below 50 km and random uncertainties less than 10% in these altitudes (except for the low latitudes). These results qualify the release 3 GRAS data superior to the Release 2 and warrants the use in climate applications. Nonetheless, some issues will be further investigated, for example, the lower number of Metop-A occultations, which could be manifested by one or more bugs in the processing software.

Comparison of the CHAMP against ERA5 show similar to GRAS comparison, but slightly higher systematic and random uncertainties. Comparison of the FCDR and UCAR versions

⁴ See e.g., Prospects of the EPS GRAS Mission For Operational Atmospheric Applications, J-P Luntama et al., Bulletin of the American Meteorological Society, December 2008, Vol. 89, No. 12.

⁵ Note that even though a re-analysis is using the same assimilation software version for the complete data set, it is not a “reference” of the true atmospheric state, but serves here as a commonly used reference. See the Validation Report [RD 1] for more information.



against ERA5 shows similar systematic uncertainties for both datasets, however a slightly higher random uncertainty in the FCDR is observed which can be attributed to the higher number of observations in the FCDR, especially in the lower troposphere. Random uncertainties in the UCAR data show a step like feature at around 20 km altitude which can be attributed to the change from Geometric to Wave Optics computation around this altitude. This feature is not prominent in the FCDR. A few step like feature in the random uncertainties of the FCDR data are visible mainly from 30 to 40 km, which could be arising from imperfection in the smoothing procedure and could be revisited in a future release. Overall, the results indicate that the FCDR has similar quality to the UCAR version.

Similarly, GRACE FCDR data show very similar agreement compared to the UCAR post processed data. Systematic uncertainties stay close to zero for almost all altitudes (except for above 50 km and in the boundary layer) and for the whole time period. Random uncertainties higher up are lower compared to CHAMP, as GRACE has a more accurate clock. Uncertainties are similar for setting and rising occultations and for also for different latitude bands. Random uncertainties are increasing slightly towards the end of the mission for low latitude observations. Overall, the results indicate that the FCDR has similar quality to the UCAR version.

Similarly, COSMIC FCDR data were also compared to the v2013 UCAR reprocessing data. The systematic uncertainties at higher altitudes agree better than those between CHAMP, and GRACE. Lower altitudes low latitudes also agree to about 5km down, while for CHAMP, GRACE this was more about 7km. A time-series analysis shows systematic uncertainties are close to zero during the analyses periods. Random uncertainties stay close to 5% irrespective of setting or rising occultation except in June and October 2006, the reason is currently unknown. The June artefact seems to be correlated with an increase in random uncertainties primarily at high latitudes. Except these, the FCDR shows similar quality to the data currently available from UCAR.

5.2 Applicability

Radio occultation data are well known for being self calibrated, weather independent, and SI traceable; most importantly, they do not require any kind of external calibration before being used in any application. These are the main reasons why RO data are used as anchor observations in NWP data assimilation. Prime application areas are therefore data assimilation and climate monitoring.

5.2.1 Limitations

Although the monitoring and validation described in [RD 1] has shown the reprocessed data is of consistently high quality over the entire campaign period, the following limitations are mentioned which will be addressed in future versions of the EUMETSAT RO processing:

- Due to the focus on operational NWP applications in the original development of the wave optics processing capability (and the initial version of the reprocessing primarily being understood as a backward extension of the operational GRAS data into the past), the smoothing of bending angles is mostly carried out as part of the thinning towards the standard set of 247 operational levels. Therefore, high resolution



bending-angle profiles may exhibit noise related features to a larger degree than the thinned profiles.

- The number of degraded profiles for Metop-A is higher than expected; a detailed analysis and possibly an update of the data set is underway.

6 PRODUCT ACCESS

Access to the data record is granted to all users without charge. The data can be accessed in two manners:

- 1 The data are accessible via the Copernicus Climate Data Store (CDS) and are available from the Copernicus Climate Change Service (C3S) website: <https://climate.copernicus.eu>.
- 2 The data are accessible via the EUMETSAT Data Centre after accepting the EUMETSAT Data Policy [RD 8]. To access the data from EUMETSAT, you need to register with the EUMETSAT Data Centre. When registered, you can order the data through a written request send to EUMETSAT's helpdesk.

6.1 Register with the Data Centre

To register with the EUMETSAT Data Centre:

- 1 Register in the EUMETSAT EO-Portal (<https://eoportal.eumetsat.int/>) by clicking on the New User – Create New Account tab;
- 2 After finalization 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 Login and subscribe to the Data Centre Service by going to the Service Subscription Tab and selecting Data Centre Service. Follow instructions issued from the web page to add needed information.

6.2 Order Data

The data record described in this product user guide can also be ordered via the EUMETSAT User Service Helpdesk in Darmstadt, Germany. Please send a written request to this helpdesk, email ops@eumetsat.int, indicating the data record that you want to order including its Digital Object Identifier (DOI) numbers:

- 10.15770/EUM_SEC_CLM_0051 - Metop GRAS Bending Angle FCDR Release 3
- 10.15770/EUM_SEC_CLM_0031 - COSMIC IGOR Bending Angle FCDR Release 1
- 10.15770/EUM_SEC_CLM_0030 - CHAMP Black Jack Bending Angle FCDR Release 1
- 10.15770/EUM_SEC_CLM_0032 - GRACE Black Jack Bending Angle FCDR Release 1

If you have more questions or support issues, please contact the User Service Helpdesk directly via e-mail: ops@eumetsat.int



7 PRODUCT SUPPORT AND FEEDBACK

For enquiries or feedback concerning the product described in this product user guide, the CDS offers Help & Support functionality. Alternatively, the user can contact the EUMETSAT User Service Helpdesk by email: ops@eumetsat.int.

8 PRODUCT REFERENCING

The product's filename provides a unique identifier for each product, which is also given in the *title* global attribute of the netCDF files. The data record described in this product user guide has a unique DOI, which is also given in the *doi* global attribute of each netCDF file. Please note that the DOI is not included in the BUFR and native files.

9 ACKNOWLEDGEMENTS

Precise GPS ephemerides used for preparing this data record have been obtained from the Center for Orbit Determination in Europe at the Astronomical Institute of the University of Bern (AIUB). The support of this institution is gratefully acknowledged. UCAR is greatly acknowledged for providing the Atmospheric excess phase data for the CHAMP, GRACE, and COSMIC missions.



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APPENDIX 1: Metadata netCDF File

List of variables names of the netCDF format.

```
netcdf BJxx_1B_CHA_20080919215735Z_20080919215902Z_R_O_20201130035617Z_G04_NN_0100 {
// global attributes:
    string :Conventions = "CF-1.7" ;
    string :metadata_conventions = "Unidata Dataset Discovery v1.0" ;
    string                                     :product_name
"BJxx_1B_CHA_20080919215735Z_20080919215902Z_R_O_20201130035617Z_G04_NN_0100.nc" ;
    string                                     :title
"BJxx_1B_CHA_20080919215735Z_20080919215902Z_R_O_20201130035617Z_G04_NN_0100.nc" ;
    string :summary = "Champ/BlackJack level 1a/b radio occultation data"
;
    string :doi = "10.15770/EUM_SEC_CLM_0030" ;
    string :history = "original generated product (from UCAR/CDAAC atmPhs
input)" ;
    string :institution = "EUMETSAT" ;
    string :references = "www.eumetsat.int" ;
    string :environment = "Offline" ;
    string :keywords = "" ;
    string :spacecraft = "CHA" ;
    string :instrument = "BlackJack" ;
    string :product_level = "1B" ;
    string :type = "BND" ;
    string :mission_type = "Global" ;
    string :disposition_mode = "Operational" ;
    string :sensing_start_time_utc = "2008-09-19 21:57:35.000" ;
    string :sensing_end_time_utc = "2008-09-19 21:59:02.980" ;
    :_NCProperties = "version=2,netcdf=4.7.1,hdf5=1.10.5" ;

group: status {

group: satellite {
    variables:
        double epoch_time_utc ;
        string epoch_time_utc:units = "seconds since 2000-01-01 00:00:00" ;
        string epoch_time_utc:long_name = "Epoch time in UTC of the orbital
elements and the orbit state vector" ;
        epoch_time_utc:missing_value = NaN ;
        double semi_major_axis ;
        string semi_major_axis:units = "m" ;
        string semi_major_axis:long_name = "Semi major axis of the orbit at
epoch time" ;
        semi_major_axis:missing_value = NaN ;
        double eccentricity ;
        string eccentricity:long_name = "Eccentricity of the orbit at epoch
time" ;
        eccentricity:missing_value = NaN ;
        double inclination ;
        string inclination:units = "degrees" ;
        string inclination:long_name = "Inclination of the orbit at epoch
time" ;
        inclination:missing_value = NaN ;
        double perigee_argument ;
        string perigee_argument:units = "degrees" ;
        string perigee_argument:long_name = "Argument of perigee of the orbit
at epoch time" ;
        perigee_argument:missing_value = NaN ;
        double right_ascension ;
        string right_ascension:units = "degrees" ;
        string right_ascension:long_name = "Right ascension of the orbit at
epoch time" ;
        right_ascension:missing_value = NaN ;
        double mean_anomaly ;
```



```

        string mean_anomaly:units = "degrees" ;
        string mean_anomaly:long_name = "Mean anomaly of the orbit at epoch
time" ;
        mean_anomaly:missing_value = NaN ;
    double x_position ;
        string x_position:units = "m" ;
        string x_position:long_name = "X position of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        x_position:missing_value = NaN ;
    double y_position ;
        string y_position:units = "m" ;
        string y_position:long_name = "Y position of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        y_position:missing_value = NaN ;
    double z_position ;
        string z_position:units = "m" ;
        string z_position:long_name = "Z position of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        z_position:missing_value = NaN ;
    double x_velocity ;
        string x_velocity:units = "m/s" ;
        string x_velocity:long_name = "X velocity of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        x_velocity:missing_value = NaN ;
    double y_velocity ;
        string y_velocity:units = "m/s" ;
        string y_velocity:long_name = "Y velocity of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        y_velocity:missing_value = NaN ;
    double z_velocity ;
        string z_velocity:units = "m/s" ;
        string z_velocity:long_name = "Z velocity of the orbit state vector
in the orbit frame at ascending node [EARTH+FIXED]" ;
        z_velocity:missing_value = NaN ;
    double earth_sun_distance_ratio ;
        string earth_sun_distance_ratio:long_name = "Ratio of current Earth-
Sun distance to Mean Earth-Sun distance" ;
        earth_sun_distance_ratio:missing_value = NaN ;
    double location_tolerance_radial ;
        string location_tolerance_radial:units = "m" ;
        string location_tolerance_radial:long_name = "Nadir Earth location
tolerance radial" ;
        location_tolerance_radial:missing_value = NaN ;
    double location_tolerance_crosstrack ;
        string location_tolerance_crosstrack:units = "m" ;
        string location_tolerance_crosstrack:long_name = "Nadir Earth
location tolerance cross-track" ;
        location_tolerance_crosstrack:missing_value = NaN ;
    double location_tolerance_alongtrack ;
        string location_tolerance_alongtrack:units = "m" ;
        string location_tolerance_alongtrack:long_name = "Nadir Earth
location tolerance along-track" ;
        location_tolerance_alongtrack:missing_value = NaN ;
    double yaw_error ;
        string yaw_error:units = "degrees" ;
        string yaw_error:long_name = "Yaw attitude bias" ;
        yaw_error:missing_value = NaN ;
    double roll_error ;
        string roll_error:units = "degrees" ;
        string roll_error:long_name = "Roll attitude bias" ;
        roll_error:missing_value = NaN ;
    double pitch_error ;
        string pitch_error:units = "degrees" ;
        string pitch_error:long_name = "Pitch attitude bias" ;
        pitch_error:missing_value = NaN ;
    double subsat_latitude_start ;

```



```

        string subsat_latitude_start:units = "degrees_north" ;
        string subsat_latitude_start:long_name = "Latitude of sub-satellite
point at start of the product" ;
        subsat_latitude_start:missing_value = NaN ;
        double subsat_longitude_start ;
        string subsat_longitude_start:units = "degrees_east" ;
        string subsat_longitude_start:long_name = "Longitude of sub-
satellite point at start of the product" ;
        subsat_longitude_start:missing_value = NaN ;
        double subsat_latitude_end ;
        string subsat_latitude_end:units = "degrees_north" ;
        string subsat_latitude_end:long_name = "Latitude of sub-satellite
point at end of the product" ;
        subsat_latitude_end:missing_value = NaN ;
        double subsat_longitude_end ;
        string subsat_longitude_end:units = "degrees_east" ;
        string subsat_longitude_end:long_name = "Longitude of sub-satellite
point at end of the product" ;
        subsat_longitude_end:missing_value = NaN ;
        double leap_second_time_utc ;
        string leap_second_time_utc:units = "seconds since 2000-01-01
00:00:00" ;
        string leap_second_time_utc:long_name = "UTC time of occurrence of a
leap second in this product (0: no leap second)" ;
        leap_second_time_utc:missing_value = NaN ;
        short leap_second_value ;
        string leap_second_value:units = "s" ;
        string leap_second_value:long_name = "Value of leap second in product
(1, 0, or -1)" ;
        leap_second_value:missing_value = -32768s ;
    } // group satellite

group: instrument {
    // group attributes:
        string :onboard_sw_version = "unknown" ;
    } // group instrument

group: processing {
    variables:
        double creation_time_utc ;
        string creation_time_utc:units = "seconds since 2000-01-01 00:00:00"
;
        string creation_time_utc:long_name = "Start time of product creation
in UTC" ;
        creation_time_utc:missing_value = NaN ;

    // group attributes:
        string :processor_name = "YAROS" ;
        string :processor_version = "2.0" ;
        string :processing_mode = "NRT" ;
        string :format_version = "14.0" ;
        string :source = "" ;
        string :baseline = "0100" ;
        string :idb_version = "" ;
        string :processing_centre = "TCE1" ;
        string :generating_facility = "YAR" ;
    } // group processing
} // group status

group: data {
    group: occultation {
        dimensions:
            xyz = 3 ;
        variables:

```



```

    string occultation_prn ;
        string occultation_prn:long_name = "PRN of the occulting GNSS
satellite" ;
        string occultation_prn:missing_value = "" ;
    string occultation_type ;
        string occultation_type:long_name = "Occultation type (rising or
setting)" ;
        string occultation_type:missing_value = "" ;
    string gnss_system ;
        string gnss_system:long_name = "GNSS system (one of GPS, Galileo,
Glonass, Beidou, or QZSS)" ;
        string gnss_system:missing_value = "" ;
    string reference_prn ;
        string reference_prn:long_name = "PRN of the occulting GNSS
satellite" ;
        string reference_prn:missing_value = "" ;
    double slta_georef ;
        string slta_georef:units = "m" ;
        string slta_georef:long_name = "Reference SLTA for georeferencing" ;
        slta_georef:missing_value = NaN ;
    int utc_georef_absdate ;
        string utc_georef_absdate:units = "days since 2000-01-01 00:00:00.00"
;
        string utc_georef_absdate:long_name = "Reference UTC time for
georeferencing (for SLTA = 0 km)" ;
        utc_georef_absdate:missing_value = -2147483648 ;
    double utc_georef_abstime ;
        string utc_georef_abstime:units = "seconds since 00:00:00.00" ;
        string utc_georef_abstime:long_name = "Reference UTC time for
georeferencing (for SLTA = 0 km)" ;
        utc_georef_abstime:missing_value = NaN ;
    int gps_georef_absdate ;
        string gps_georef_absdate:units = "days since 2000-01-01 00:00:00.00"
;
        string gps_georef_absdate:long_name = "Reference GPS time for
georeferencing (for SLTA = 0 km)" ;
        gps_georef_absdate:missing_value = -2147483648 ;
    double gps_georef_abstime ;
        string gps_georef_abstime:units = "seconds since 00:00:00.00" ;
        string gps_georef_abstime:long_name = "Reference GPS time for
georeferencing (for SLTA = 0 km)" ;
        gps_georef_abstime:missing_value = NaN ;
    double longitude ;
        string longitude:units = "degrees_east" ;
        string longitude:long_name = "Longitude of reference location" ;
        longitude:missing_value = NaN ;
    double latitude ;
        string latitude:units = "degrees_north" ;
        string latitude:long_name = "Latitude of reference location" ;
        latitude:missing_value = NaN ;
    double azimuth_north ;
        string azimuth_north:units = "degrees" ;
        string azimuth_north:long_name = "GNSS -> LEO line of sight azimuth
angle at reference location (clockwise against True North)" ;
        azimuth_north:missing_value = NaN ;
    double r_curve ;
        string r_curve:units = "m" ;
        string r_curve:long_name = "Radius of curvature for reference
location" ;
        r_curve:missing_value = NaN ;
    double r_curve_centre(xyz) ;
        string r_curve_centre:units = "m" ;
        string r_curve_centre:long_name = "Centre of curvature position in
Earth centred inertial coordinates for reference location" ;
        r_curve_centre:missing_value = NaN ;
    double r_curve_centre_fixed(xyz) ;

```



```

        string r_curve_centre_fixed:units = "m" ;
        string r_curve_centre_fixed:long_name = "Centre of curvature position
in Earth fixed coordinates for reference location" ;
        r_curve_centre_fixed:missing_value = NaN ;
        double undulation ;
        string undulation:units = "m" ;
        string undulation:long_name = "EGM96 undulation at reference
location" ;
        undulation:missing_value = NaN ;
        double longitude_rec ;
        string longitude_rec:units = "degrees_east" ;
        string longitude_rec:long_name = "Receiver longitude for reference
location" ;
        longitude_rec:missing_value = NaN ;
        double latitude_rec ;
        string latitude_rec:units = "degrees_north" ;
        string latitude_rec:long_name = "Receiver latitude for reference
location" ;
        latitude_rec:missing_value = NaN ;
        double altitude_rec ;
        string altitude_rec:units = "m" ;
        string altitude_rec:long_name = "Receiver altitude for reference
location (above ellipsoid)" ;
        altitude_rec:missing_value = NaN ;
        double position_rec(xyz) ;
        string position_rec:units = "m" ;
        string position_rec:long_name = "Receiver antenna position in Earth
centred inertial coordinates for reference location" ;
        position_rec:missing_value = NaN ;
        double velocity_rec(xyz) ;
        string velocity_rec:units = "m/s" ;
        string velocity_rec:long_name = "Receiver antenna velocity in Earth
centred inertial coordinates for reference location" ;
        velocity_rec:missing_value = NaN ;
        double position_rec_fixed(xyz) ;
        string position_rec_fixed:units = "m" ;
        string position_rec_fixed:long_name = "Receiver antenna position in
Earth fixed coordinates for reference location" ;
        position_rec_fixed:missing_value = NaN ;
        double velocity_rec_fixed(xyz) ;
        string velocity_rec_fixed:units = "m/s" ;
        string velocity_rec_fixed:long_name = "Receiver antenna velocity in
Earth fixed coordinates for reference location" ;
        velocity_rec_fixed:missing_value = NaN ;
        double velocity_rec_fixed_bfr(xyz) ;
        string velocity_rec_fixed_bfr:units = "m/s" ;
        string velocity_rec_fixed_bfr:long_name = "Receiver antenna inertial
velocity in Earth fixed coordinates for reference location (for WMO BUFR" ;
        velocity_rec_fixed_bfr:missing_value = NaN ;
        double longitude_gns ;
        string longitude_gns:units = "degrees_east" ;
        string longitude_gns:long_name = "GNSS longitude for reference
location" ;
        longitude_gns:missing_value = NaN ;
        double latitude_gns ;
        string latitude_gns:units = "degrees_north" ;
        string latitude_gns:long_name = "GNSS latitude for reference
location" ;
        latitude_gns:missing_value = NaN ;
        double altitude_gns ;
        string altitude_gns:units = "m" ;
        string altitude_gns:long_name = "GNSS altitude for reference location
(above ellipsoid)" ;
        altitude_gns:missing_value = NaN ;
        double position_gns(xyz) ;
        string position_gns:units = "m" ;

```



```

        string position_gns:long_name = "GNSS transmitter position in Earth
centred inertial coordinates for reference location" ;
        position_gns:missing_value = NaN ;
        double velocity_gns(xyz) ;
        string velocity_gns:units = "m/s" ;
        string velocity_gns:long_name = "GNSS transmitter velocity in Earth
centred inertial coordinates for reference location" ;
        velocity_gns:missing_value = NaN ;
        double position_gns_fixed(xyz) ;
        string position_gns_fixed:units = "m" ;
        string position_gns_fixed:long_name = "GNSS transmitter position in
Earth fixed coordinates for reference location" ;
        position_gns_fixed:missing_value = NaN ;
        double velocity_gns_fixed(xyz) ;
        string velocity_gns_fixed:units = "m/s" ;
        string velocity_gns_fixed:long_name = "GNSS transmitter velocity in
Earth fixed coordinates for reference location" ;
        velocity_gns_fixed:missing_value = NaN ;
        double velocity_gns_fixed_bfr(xyz) ;
        string velocity_gns_fixed_bfr:units = "m/s" ;
        string velocity_gns_fixed_bfr:long_name = "GNSS transmitter inertial
velocity in Earth fixed coordinates for reference location (for WMO BUFR)" ;
        velocity_gns_fixed_bfr:missing_value = NaN ;
        double azimuth_antenna ;
        string azimuth_antenna:units = "degrees" ;
        string azimuth_antenna:long_name = "Antenna azimuth angle for
reference location" ;
        azimuth_antenna:missing_value = NaN ;
        double zenith_antenna ;
        string zenith_antenna:units = "degrees" ;
        string zenith_antenna:long_name = "Antenna zenith angle for reference
location" ;
        zenith_antenna:missing_value = NaN ;
        string pod_method ;
        string pod_method:long_name = "Method used to perform Precise Orbit
Determination (POD)" ;
        string pod_method:missing_value = "" ;
        string phase_method ;
        string phase_method:long_name = "Method used to perform carrier phase
differencing" ;
        string phase_method:missing_value = "" ;
        string retrieval_method ;
        string retrieval_method:long_name = "Method used to perform level 1b
(bending angle) retrieval" ;
        string retrieval_method:missing_value = "" ;

    // group attributes:
        string :title = "Champ/BlackJack level 1a/b data" ;
    } // group occultation

group: receiver {

    group: satellite {
        dimensions:
            xyz = 3 ;
        variables:
            double centre_of_mass(xyz) ;
            string centre_of_mass:units = "m" ;
            string centre_of_mass:long_name = "Centre of mass (in S/C
coordinates)" ;
            centre_of_mass:missing_value = NaN ;
            double antenna_phase_centre(xyz) ;
            string antenna_phase_centre:units = "m" ;
            string antenna_phase_centre:long_name = "Antenna phase centre (in S/C
coordinates)" ;
            antenna_phase_centre:missing_value = NaN ;

```



```

double antenna_orientation(xyz) ;
    string antenna_orientation:units = "m" ;
    string antenna_orientation:long_name = "Antenna orientation (unit
vector perpendicular to antenna plane in S/C coordinates)" ;
    antenna_orientation:missing_value = NaN ;

// group attributes:
    string :satellite = "Champ" ;
    string :satellite_id_eum = "CHA" ;
    string :satellite_id_sp3 = "L06" ;
    string :satellite_id_nssdc = "2000-039B" ;
    string :satellite_id_norad = "26405" ;
} // group satellite

group: orbit {

    group: centre_of_mass {
        dimensions:
            xyz = 3 ;
            t = 10 ;
        variables:
            int utc_absdate(t) ;
                string utc_absdate:units = "days since 2000-01-01 00:00" ;
                string utc_absdate:long_name = "Epochs (full days) in UTC" ;
                utc_absdate:missing_value = -2147483648 ;
            double utc_abstime(t) ;
                string utc_abstime:units = "seconds since 00:00:00" ;
                string utc_abstime:long_name = "Epochs (seconds since last
midnight) in UTC" ;
                utc_abstime:missing_value = NaN ;
            double position(t, xyz) ;
                string position:units = "m" ;
                string position:long_name = "Satellite position in TOD
reference frame" ;
                position:missing_value = NaN ;
            ubyte orbit_predicted(t) ;
                string orbit_predicted:long_name = "True if orbits are
predicted (instead of estimated)" ;
                orbit_predicted:missing_value = 255UB ;
            ubyte manoeuvre(t) ;
                string manoeuvre:long_name = "True if satellite undergoes a
manoeuvre" ;
                manoeuvre:missing_value = 255UB ;

// group attributes:
                string :title = "Champ precise orbit (centre of mass) in TOD
reference frame" ;
                string :institution = " EUM" ;
                string :coordinate_system = "TOD" ;
                string :orbit_type = "FIT" ;
                :std_base_pv_sp3 = 0. ;
                :std_base_clock_sp3 = 0. ;
                string :comments_1_sp3 = "" ;
                string :comments_2_sp3 = "          This SP3 was created with
Yaros" ;
                string :comments_3_sp3 = "          using raw orbit data." ;
                string :comments_4_sp3 = "" ;
                string :satellite_id_sp3 = "L06" ;
                :accuracy_exponent_sp3 = 0 ;
            } // group centre_of_mass

    group: antenna_phase_centre {
        dimensions:
            xyz = 3 ;
            t = 10 ;
        variables:

```



```

int utc_absdate(t) ;
    string utc_absdate:units = "days since 2000-01-01 00:00" ;
    string utc_absdate:long_name = "Epochs (full days) in UTC" ;
    utc_absdate:missing_value = -2147483648 ;
double utc_abstime(t) ;
    string utc_abstime:units = "seconds since 00:00:00" ;
    string utc_abstime:long_name = "Epochs (seconds since last
midnight) in UTC" ;
    utc_abstime:missing_value = NaN ;
double position(t, xyz) ;
    string position:units = "m" ;
    string position:long_name = "Satellite position in TOD
reference frame" ;
    position:missing_value = NaN ;
ubyte orbit_predicted(t) ;
    string orbit_predicted:long_name = "True if orbits are
predicted (instead of estimated)" ;
    orbit_predicted:missing_value = 255UB ;
ubyte manoeuvre(t) ;
    string manoeuvre:long_name = "True if satellite undergoes a
manoeuvre" ;
    manoeuvre:missing_value = 255UB ;

    // group attributes:
    string :title = "Champ precise orbit (BlackJack setting
antenna phase centre) in TOD reference frame" ;
    string :institution = " EUM" ;
    string :coordinate_system = "TOD" ;
    string :orbit_type = "FIT" ;
    :std_base_pv_sp3 = 0. ;
    :std_base_clock_sp3 = 0. ;
    string :comments_1_sp3 = "" ;
    string :comments_2_sp3 = "          This SP3 was created with
Yaros" ;
    string :comments_3_sp3 = "          using raw orbit data." ;
    string :comments_4_sp3 = "" ;
    string :satellite_id_sp3 = "L06" ;
    :accuracy_exponent_sp3 = 0 ;
} // group antenna_phase_centre
} // group orbit
} // group receiver

group: transmitter {

    group: satellite {
        dimensions:
            xyz = 3 ;
        variables:
            double centre_of_mass(xyz) ;
                string centre_of_mass:units = "m" ;
                string centre_of_mass:long_name = "Centre of mass (in S/C
coordinates)" ;
                centre_of_mass:missing_value = NaN ;
            double antenna_phase_centre(xyz) ;
                string antenna_phase_centre:units = "m" ;
                string antenna_phase_centre:long_name = "Antenna phase centre (in S/C
coordinates)" ;
                antenna_phase_centre:missing_value = NaN ;
            double antenna_orientation(xyz) ;
                string antenna_orientation:units = "m" ;
                string antenna_orientation:long_name = "Antenna orientation (unit
vector perpendicular to antenna plane in S/C coordinates)" ;
                antenna_orientation:missing_value = NaN ;
            ubyte satellite_in_eclipse ;
                string satellite_in_eclipse:long_name = "True if GNSS satellite is
in eclipse during the occultation" ;

```



```

        satellite_in_eclipse:missing_value = 255UB ;

// group attributes:
    string :satellite = "G034" ;
    string :satellite_block = "BLOCK IIA" ;
    string :satellite_clock = "Rb" ;
    string :satellite_prn = "G04" ;
    string :satellite_id_sp3 = "G04" ;
    string :satellite_id_nssdc = "1993-068A" ;
    string :satellite_id_norad = "22877" ;
} // group satellite

group: orbit {

    group: centre_of_mass {
        dimensions:
            xyz = 3 ;
            t = 10 ;
        variables:
            int utc_absdate(t) ;
                string utc_absdate:units = "days since 2000-01-01 00:00" ;
                string utc_absdate:long_name = "Epochs (full days) in UTC" ;
                utc_absdate:missing_value = -2147483648 ;
            double utc_abstime(t) ;
                string utc_abstime:units = "seconds since 00:00:00" ;
                string utc_abstime:long_name = "Epochs (seconds since last
midnight) in UTC" ;
                utc_abstime:missing_value = NaN ;
            double position(t, xyz) ;
                string position:units = "m" ;
                string position:long_name = "Satellite position in TOD
reference frame" ;
                position:missing_value = NaN ;
            ubyte orbit_predicted(t) ;
                string orbit_predicted:long_name = "True if orbits are
predicted (instead of estimated)" ;
                orbit_predicted:missing_value = 255UB ;
            ubyte manoeuvre(t) ;
                string manoeuvre:long_name = "True if satellite undergoes a
manoeuvre" ;
                manoeuvre:missing_value = 255UB ;

// group attributes:
                string :title = "GPS transmitter precise orbit (centre of
mass) in TOD reference frame" ;
                string :institution = " EUM" ;
                string :coordinate_system = "TOD" ;
                string :orbit_type = "FIT" ;
                :std_base_pv_sp3 = 0. ;
                :std_base_clock_sp3 = 0. ;
                string :comments_1_sp3 = "" ;
                string :comments_2_sp3 = "                This SP3 was created with
Yaros" ;
                string :comments_3_sp3 = "                using raw orbit data." ;
                string :comments_4_sp3 = "" ;
                string :satellite_id_sp3 = "G04" ;
                :accuracy_exponent_sp3 = 0 ;
    } // group centre_of_mass

    group: antenna_phase_centre {
        dimensions:
            xyz = 3 ;
            t = 10 ;
        variables:
            int utc_absdate(t) ;
                string utc_absdate:units = "days since 2000-01-01 00:00" ;

```



```

        string utc_absdate:long_name = "Epochs (full days) in UTC" ;
        utc_absdate:missing_value = -2147483648 ;
    double utc_abstime(t) ;
        string utc_abstime:units = "seconds since 00:00:00" ;
        string utc_abstime:long_name = "Epochs (seconds since last
midnight) in UTC" ;
        utc_abstime:missing_value = NaN ;
    double position(t, xyz) ;
        string position:units = "m" ;
        string position:long_name = "Satellite position in TOD
reference frame" ;
        position:missing_value = NaN ;
    ubyte orbit_predicted(t) ;
        string orbit_predicted:long_name = "True if orbits are
predicted (instead of estimated)" ;
        orbit_predicted:missing_value = 255UB ;
    ubyte manoeuvre(t) ;
        string manoeuvre:long_name = "True if satellite undergoes a
manoeuvre" ;
        manoeuvre:missing_value = 255UB ;

    // group attributes:
        string :title = "GNSS transmitter precise orbit (antenna
phase centre) in TOD reference frame" ;
        string :institution = " EUM" ;
        string :coordinate_system = "TOD" ;
        string :orbit_type = "FIT" ;
        :std_base_pv_sp3 = 0. ;
        :std_base_clock_sp3 = 0. ;
        string :comments_1_sp3 = "" ;
        string :comments_2_sp3 = "          This SP3 was created with
Yaros" ;
        string :comments_3_sp3 = "          using raw orbit data." ;
        string :comments_4_sp3 = "" ;
        string :satellite_id_sp3 = "G04" ;
        :accuracy_exponent_sp3 = 0 ;
    } // group antenna_phase_centre
} // group orbit
} // group transmitter

group: earth_orientation_parameters {
    dimensions:
        t = 8 ;
    variables:
        int utc_absdate(t) ;
            string utc_absdate:units = "days since 2000-01-01 00:00" ;
            string utc_absdate:long_name = "Epochs (full days) in UTC" ;
            utc_absdate:missing_value = -2147483648 ;
        double utc_abstime(t) ;
            string utc_abstime:units = "seconds since 00:00:00" ;
            string utc_abstime:long_name = "Epochs (seconds since last midnight)
in UTC" ;
            utc_abstime:missing_value = NaN ;
        double xp(t) ;
            string xp:units = "rad" ;
            string xp:long_name = "x component of polar motion" ;
            xp:missing_value = NaN ;
        double yp(t) ;
            string yp:units = "rad" ;
            string yp:long_name = "y component of polar motion" ;
            yp:missing_value = NaN ;
        double ut1_utc(t) ;
            string ut1_utc:units = "s" ;
            string ut1_utc:long_name = "Difference between Universal Time (UT1)
and Coordinated Universal Time (UTC)" ;
            ut1_utc:missing_value = NaN ;

```



```

        double dX(t) ;
            string dX:units = "rad" ;
            string dX:long_name = "dX wrt IAU2000A Nutation, Free Core Nutation
NOT Removed" ;
            dX:missing_value = 0. ;
        double dY(t) ;
            string dY:units = "rad" ;
            string dY:long_name = "dY wrt IAU2000A Nutation, Free Core Nutation
NOT Removed" ;
            dY:missing_value = 0. ;
        ubyte flag_predicted(t) ;
            string flag_predicted:long_name = "Estimated (0) or Predicted (1)
flag for polar motion values" ;
            flag_predicted:missing_value = 255UB ;
        double LOD(t) ;
            string LOD:units = "ms" ;
            string LOD:long_name = "Length of Day (difference between the
astronomically determined duration of the day and 86400)" ;
            LOD:missing_value = NaN ;

        // group attributes:
            string :title = "Earth orientation parameters" ;
            string :model = "2000A" ;
            string :filename = "finals2000A.data" ;
    } // group earth_orientation_parameters

group: level_1a {
    variables:
        int utc_start_absdate ;
            string utc_start_absdate:units = "days since 2000-01-01 00:00:00.00"
;
            string utc_start_absdate:long_name = "Start (reference) UTC time for
all observation epochs / date" ;
            utc_start_absdate:missing_value = -2147483648 ;
        double utc_start_abstime ;
            string utc_start_abstime:units = "seconds since 00:00:00.00" ;
            string utc_start_abstime:long_name = "Start (reference) UTC time for
all observation epochs / time" ;
            utc_start_abstime:missing_value = NaN ;
        int gps_start_absdate ;
            string gps_start_absdate:units = "days since 2000-01-01 00:00:00.00"
;
            string gps_start_absdate:long_name = "Start (reference) GPS time for
all observation epochs / date" ;
            gps_start_absdate:missing_value = -2147483648 ;
        int gps_start_absdate ;
            string gps_start_absdate:units = "days since 2000-01-01 00:00:00.00"
;
            string gps_start_absdate:long_name = "Start (reference) GPS time for
all observation epochs / date" ;
            gps_start_absdate:missing_value = -2147483648 ;
        double gps_start_abstime ;
            string gps_start_abstime:units = "seconds since 00:00:00.00" ;
            string gps_start_abstime:long_name = "Start (reference) GPS time for
all observation epochs / time" ;
            gps_start_abstime:missing_value = NaN ;

        // group attributes:
            string :title = "Champ/BlackJack level 1a data" ;

group: combined {
    dimensions:
        t = 4400 ;
        xyz = 3 ;
        codes = 2 ;
    variables:

```



```

string codes(codes) ;
    string codes:long_name = "GNSS codes being tracked" ;
    string codes:missing_value = "" ;
double frequencies(codes) ;
    string frequencies:units = "Hz" ;
    string frequencies:long_name = "Frequencies of GNSS codes/signals
being tracked" ;
    frequencies:missing_value = NaN ;
double dtime(t) ;
    string dtime:units = "seconds since 2008-09-19 21:57:35.00" ;
    string dtime:long_name = "Measurement epoch" ;
    dtime:missing_value = NaN ;
double slta(t) ;
    string slta:units = "m" ;
    string slta:long_name = "Straight line tangent altitude" ;
    slta:missing_value = NaN ;
double r_receiver(t, xyz) ;
    string r_receiver:units = "m" ;
    string r_receiver:long_name = "Receiver position in Earth centred
inertial coordinates" ;
    r_receiver:missing_value = NaN ;
double v_receiver(t, xyz) ;
    string v_receiver:units = "m/s" ;
    string v_receiver:long_name = "Receiver velocity in Earth centred
inertial coordinates" ;
    v_receiver:missing_value = NaN ;
double r_transmitter(t, xyz) ;
    string r_transmitter:units = "m" ;
    string r_transmitter:long_name = "Transmitter position (retarded) in
Earth centred inertial coordinates" ;
    r_transmitter:missing_value = NaN ;
double v_transmitter(t, xyz) ;
    string v_transmitter:units = "m/s" ;
    string v_transmitter:long_name = "Transmitter velocity (retarded) in
Earth centred inertial coordinates" ;
    v_transmitter:missing_value = NaN ;
double zenith_antenna(t) ;
    string zenith_antenna:units = "degrees" ;
    string zenith_antenna:long_name = "Antenna zenith angle (in S/C
coordinates)" ;
    zenith_antenna:missing_value = NaN ;
double azimuth_antenna(t) ;
    string azimuth_antenna:units = "degrees" ;
    string azimuth_antenna:long_name = "Antenna azimuth angle (in S/C
coordinates)" ;
    azimuth_antenna:missing_value = NaN ;
double samplerate ;
    string samplerate:units = "Hz" ;
    string samplerate:long_name = "Measurement sample rate" ;
    samplerate:missing_value = NaN ;
double i_1c(t) ;
    string i_1c:units = "V" ;
    string i_1c:long_name = "In-phase component I of L1 C/A carrier phase
measurements with navigation bits demodulated" ;
    i_1c:missing_value = NaN ;
double q_1c(t) ;
    string q_1c:units = "V" ;
    string q_1c:long_name = "Quadrature component Q of L1 C/A carrier
phase with navigation bits demodulated" ;
    q_1c:missing_value = NaN ;
double exphase_1c_nco(t) ;
    string exphase_1c_nco:units = "m" ;
    string exphase_1c_nco:long_name = "L1 C/A carrier NCO excess phase"
;
    exphase_1c_nco:missing_value = NaN ;
double exphase_1c(t) ;

```



```

        string exphase_1c:units = "m" ;
        string exphase_1c:long_name = "L1 C/A carrier excess phase phase
including I/Q contributions" ;
        exphase_1c:missing_value = NaN ;
    double phase_1c_nco(t) ;
        string phase_1c_nco:units = "m" ;
        string phase_1c_nco:long_name = "L1 C/A carrier NCO phase" ;
        phase_1c_nco:missing_value = NaN ;
    double phase_1c(t) ;
        string phase_1c:units = "m" ;
        string phase_1c:long_name = "L1 C/A carrier phase phase including I/Q
contributions" ;
        phase_1c:missing_value = NaN ;
    double snr_1c(t) ;
        string snr_1c:units = "V/V" ;
        string snr_1c:long_name = "Signal-to-Noise-Ratio of L1 C/A carrier
phase measurements" ;
        snr_1c:missing_value = NaN ;
    double slta_1c_min ;
        string slta_1c_min:units = "m" ;
        string slta_1c_min:long_name = "Minimum SLTA of L1 C/A carrier phase
data" ;
        slta_1c_min:missing_value = NaN ;
    double slta_1c_max ;
        string slta_1c_max:units = "m" ;
        string slta_1c_max:long_name = "Maximum overall SLTA of L1 C/A
carrier phase data" ;
        slta_1c_max:missing_value = NaN ;
    double slta_1c_continuous ;
        string slta_1c_continuous:units = "m" ;
        string slta_1c_continuous:long_name = "Lowest SLTA without gaps (SNR
drops) of L1 C/A carrier phase data" ;
        slta_1c_continuous:missing_value = NaN ;
    double snr_1c_mean ;
        string snr_1c_mean:units = "V/V" ;
        string snr_1c_mean:long_name = "Mean Signal-to-Noise-Ratio
(amplitude) of L1 C/A carrier phase measurements (SLTA > 60 km)" ;
        snr_1c_mean:missing_value = NaN ;
    double exphase_1c_noise ;
        string exphase_1c_noise:units = "m" ;
        string exphase_1c_noise:long_name = "Mean phase noise of L1 C/A
carrier excess phase measurements (SLTA > 60 km)" ;
        exphase_1c_noise:missing_value = NaN ;
    double i_2w(t) ;
        string i_2w:units = "v" ;
        string i_2w:long_name = "In-phase component I of L2 P carrier phase
measurements with navigation bits demodulated" ;
        i_2w:missing_value = NaN ;
    double q_2w(t) ;
        string q_2w:units = "v" ;
        string q_2w:long_name = "Quadrature component Q of L2 P carrier phase
with navigation bits demodulated" ;
        q_2w:missing_value = NaN ;
    double exphase_2w_nco(t) ;
        string exphase_2w_nco:units = "m" ;
        string exphase_2w_nco:long_name = "L2 P carrier NCO excess phase" ;
        exphase_2w_nco:missing_value = NaN ;
    double exphase_2w(t) ;
        string exphase_2w:units = "m" ;
        string exphase_2w:long_name = "L2 P carrier excess phase phase
including I/Q contributions" ;
        exphase_2w:missing_value = NaN ;
    double phase_2w_nco(t) ;
        string phase_2w_nco:units = "m" ;
        string phase_2w_nco:long_name = "L2 P carrier NCO phase" ;
        phase_2w_nco:missing_value = NaN ;

```



```

double phase_2w(t) ;
    string phase_2w:units = "m" ;
    string phase_2w:long_name = "L2 P carrier phase phase including I/Q
contributions" ;
    phase_2w:missing_value = NaN ;
double snr_2w(t) ;
    string snr_2w:units = "V/V" ;
    string snr_2w:long_name = "Signal-to-Noise-Ratio of L2 P carrier
phase measurements" ;
    snr_2w:missing_value = NaN ;
double slta_2w_min ;
    string slta_2w_min:units = "m" ;
    string slta_2w_min:long_name = "Minimum SLTA of L2 P carrier phase
data" ;
    slta_2w_min:missing_value = NaN ;
double slta_2w_max ;
    string slta_2w_max:units = "m" ;
    string slta_2w_max:long_name = "Maximum overall SLTA of L2 P carrier
phase data" ;
    slta_2w_max:missing_value = NaN ;
double slta_2w_continuous ;
    string slta_2w_continuous:units = "m" ;
    string slta_2w_continuous:long_name = "Lowest SLTA without gaps (SNR
drops) of L2 P carrier phase data" ;
    slta_2w_continuous:missing_value = NaN ;
double snr_2w_mean ;
    string snr_2w_mean:units = "V/V" ;
    string snr_2w_mean:long_name = "Mean Signal-to-Noise-Ratio
(amplitude) of L2 P carrier phase measurements (SLTA > 60 km)" ;
    snr_2w_mean:missing_value = NaN ;
double exphase_2w_noise ;
    string exphase_2w_noise:units = "m" ;
    string exphase_2w_noise:long_name = "Mean phase noise of L2 P carrier
excess phase measurements (SLTA > 60 km)" ;
    exphase_2w_noise:missing_value = NaN ;

// group attributes:
    string :title = "Champ/BlackJack level 1a data (combined closed and
open loop measurements)" ;
} // group combined
} // group level_1a

group: level_1b {
    variables:
        int utc_start_absdate ;
            string utc_start_absdate:units = "days since 2000-01-01 00:00:00.00"
;
            string utc_start_absdate:long_name = "Start (reference) UTC time for
all observation epochs / date" ;
            utc_start_absdate:missing_value = -2147483648 ;
        double utc_start_abstime ;
            string utc_start_abstime:units = "seconds since 00:00:00.00" ;
            string utc_start_abstime:long_name = "Start (reference) UTC time for
all observation epochs / time" ;
            utc_start_abstime:missing_value = NaN ;
        int gps_start_absdate ;
            string gps_start_absdate:units = "days since 2000-01-01 00:00:00.00"
;
            string gps_start_absdate:long_name = "Start (reference) GPS time for
all observation epochs / date" ;
            gps_start_absdate:missing_value = -2147483648 ;
        double gps_start_abstime ;
            string gps_start_abstime:units = "seconds since 00:00:00.00" ;
            string gps_start_abstime:long_name = "Start (reference) GPS time for
all observation epochs / time" ;
            gps_start_abstime:missing_value = NaN ;

```



```

// group attributes:
    string :title = "Champ/BlackJack level 1b data (neutral atmosphere)"
;

group: high_resolution {
    dimensions:
        z = 3466 ;
        signals = 2 ;
    variables:
        string signals(signals) ;
            string signals:long_name = "GNSS signals being used" ;
            string signals:missing_value = "" ;
        double frequencies(signals) ;
            string frequencies:units = "Hz" ;
            string frequencies:long_name = "Frequencies of GNSS codes/signals
being tracked" ;
            frequencies:missing_value = NaN ;
        double impact(z) ;
            string impact:units = "m" ;
            string impact:long_name = "Impact parameter" ;
            impact:missing_value = NaN ;
        double impact_height(z) ;
            string impact_height:units = "m" ;
            string impact_height:long_name = "Impact height (wrt WGS 84
ellipsoid)" ;
            impact_height:missing_value = NaN ;
        double bangle(z) ;
            string bangle:units = "rad" ;
            string bangle:long_name = "Bending angle (ionospheric corrected)" ;
            bangle:missing_value = NaN ;
        double bangle_l1(z) ;
            string bangle_l1:units = "rad" ;
            string bangle_l1:long_name = "Bending angle (L1)" ;
            bangle_l1:missing_value = NaN ;
        double bangle_l2(z) ;
            string bangle_l2:units = "rad" ;
            string bangle_l2:long_name = "Bending angle (L2)" ;
            bangle_l2:missing_value = NaN ;
        double bangle_l4(z) ;
            string bangle_l4:units = "rad" ;
            string bangle_l4:long_name = "Bending angle (L4 = L1 - L2,
extrapolated)" ;
            bangle_l4:missing_value = NaN ;
        double bangle_sdev(z) ;
            string bangle_sdev:units = "rad" ;
            string bangle_sdev:long_name = "Bending angle (ionospheric corrected)
estimated standard deviation" ;
            bangle_sdev:missing_value = NaN ;
        double bangle_l1_sdev(z) ;
            string bangle_l1_sdev:units = "rad" ;
            string bangle_l1_sdev:long_name = "Bending angle (L1) estimated
standard deviation" ;
            bangle_l1_sdev:missing_value = NaN ;
        double bangle_l2_sdev(z) ;
            string bangle_l2_sdev:units = "rad" ;
            string bangle_l2_sdev:long_name = "Bending angle (L2) estimated
standard deviation" ;
            bangle_l2_sdev:missing_value = NaN ;
        double bangle_l1_renyi_entropy(z) ;
            string bangle_l1_renyi_entropy:units = "rad" ;
            string bangle_l1_renyi_entropy:long_name = "Bending angle (L1) local
Renyi entropy" ;
            bangle_l1_renyi_entropy:missing_value = NaN ;
        double bangle_l2_renyi_entropy(z) ;
            string bangle_l2_renyi_entropy:units = "rad" ;

```



```

        string bangle_l2_renyi_entropy:long_name = "Bending angle (L2) local
Renyi entropy" ;
        bangle_l2_renyi_entropy:missing_value = NaN ;
    double lat_tp(z) ;
        string lat_tp:units = "degrees_north" ;
        string lat_tp:long_name = "Latitudes for tangent points" ;
        lat_tp:missing_value = NaN ;
    double lon_tp(z) ;
        string lon_tp:units = "degrees_east" ;
        string lon_tp:long_name = "Longitudes for tangent points" ;
        lon_tp:missing_value = NaN ;
    double azimuth_tp(z) ;
        string azimuth_tp:units = "degrees" ;
        string azimuth_tp:long_name = "GNSS->LEO line of sight azimuth angles
at tangent points (clockwise against True North)" ;
        azimuth_tp:missing_value = NaN ;
    double dtime_mean(z) ;
        string dtime_mean:units = "seconds since 2008-09-19 21:57:35.00" ;
        string dtime_mean:long_name = "Mean measurement epoch (used for
georeferencing only)" ;
        dtime_mean:missing_value = NaN ;
    double doppler_l1_max ;
        string doppler_l1_max:units = "Hz" ;
        string doppler_l1_max:long_name = "Maximum instantaneous Doppler
(L1)" ;
        doppler_l1_max:missing_value = NaN ;
    double doppler_rate_l1_max ;
        string doppler_rate_l1_max:units = "Hz/s" ;
        string doppler_rate_l1_max:long_name = "Maximum instantaneous
Doppler rate (L1)" ;
        doppler_rate_l1_max:missing_value = NaN ;
    double doppler_accel_l1_max ;
        string doppler_accel_l1_max:units = "Hz/s^2" ;
        string doppler_accel_l1_max:long_name = "Maximum instantaneous
Doppler acceleration (L1)" ;
        doppler_accel_l1_max:missing_value = NaN ;
    double exdoppler_l1_max ;
        string exdoppler_l1_max:units = "Hz" ;
        string exdoppler_l1_max:long_name = "Maximum instantaneous excess
Doppler (L1)" ;
        exdoppler_l1_max:missing_value = NaN ;
    double exdoppler_rate_l1_max ;
        string exdoppler_rate_l1_max:units = "Hz/s" ;
        string exdoppler_rate_l1_max:long_name = "Maximum instantaneous
excess Doppler rate (L1)" ;
        exdoppler_rate_l1_max:missing_value = NaN ;
    double exdoppler_accel_l1_max ;
        string exdoppler_accel_l1_max:units = "Hz/s^2" ;
        string exdoppler_accel_l1_max:long_name = "Maximum instantaneous
excess Doppler acceleration (L1)" ;
        exdoppler_accel_l1_max:missing_value = NaN ;
    double doppler_l2_max ;
        string doppler_l2_max:units = "Hz" ;
        string doppler_l2_max:long_name = "Maximum instantaneous Doppler
(L2)" ;
        doppler_l2_max:missing_value = NaN ;
    double doppler_rate_l2_max ;
        string doppler_rate_l2_max:units = "Hz/s" ;
        string doppler_rate_l2_max:long_name = "Maximum instantaneous
Doppler rate (L2)" ;
        doppler_rate_l2_max:missing_value = NaN ;
    double doppler_accel_l2_max ;
        string doppler_accel_l2_max:units = "Hz/s^2" ;
        string doppler_accel_l2_max:long_name = "Maximum instantaneous
Doppler acceleration (L2)" ;
        doppler_accel_l2_max:missing_value = NaN ;

```



```

double exdoppler_l2_max ;
    string exdoppler_l2_max:units = "Hz" ;
    string exdoppler_l2_max:long_name = "Maximum instantaneous excess
Doppler (L2)" ;
    exdoppler_l2_max:missing_value = NaN ;
double exdoppler_rate_l2_max ;
    string exdoppler_rate_l2_max:units = "Hz/s" ;
    string exdoppler_rate_l2_max:long_name = "Maximum instantaneous
excess Doppler rate (L2)" ;
    exdoppler_rate_l2_max:missing_value = NaN ;
double exdoppler_accel_l2_max ;
    string exdoppler_accel_l2_max:units = "Hz/s^2" ;
    string exdoppler_accel_l2_max:long_name = "Maximum instantaneous
excess Doppler acceleration (L2)" ;
    exdoppler_accel_l2_max:missing_value = NaN ;
double bangle_upper_resid_mean ;
    string bangle_upper_resid_mean:units = "rad" ;
    string bangle_upper_resid_mean:long_name = "Bending angle
(ionospheric corrected) residual - 60-80km robust mean" ;
    bangle_upper_resid_mean:missing_value = NaN ;
double bangle_upper_resid_sdev ;
    string bangle_upper_resid_sdev:units = "rad" ;
    string bangle_upper_resid_sdev:long_name = "Bending angle
(ionospheric corrected) residual - 60-80km robust standard deviation" ;
    bangle_upper_resid_sdev:missing_value = NaN ;
double impact_top ;
    string impact_top:units = "m" ;
    string impact_top:long_name = "Highest impact parameter (ionospheric
corrected)" ;
    impact_top:missing_value = NaN ;
double impact_l1_top ;
    string impact_l1_top:units = "m" ;
    string impact_l1_top:long_name = "Highest impact parameter (L1)" ;
    impact_l1_top:missing_value = NaN ;
double impact_l2_top ;
    string impact_l2_top:units = "m" ;
    string impact_l2_top:long_name = "Highest impact parameter (L2)" ;
    impact_l2_top:missing_value = NaN ;
double impact_bot ;
    string impact_bot:units = "m" ;
    string impact_bot:long_name = "Lowest impact parameter (ionospheric
corrected)" ;
    impact_bot:missing_value = NaN ;
double impact_l1_bot ;
    string impact_l1_bot:units = "m" ;
    string impact_l1_bot:long_name = "Lowest impact parameter (L1)" ;
    impact_l1_bot:missing_value = NaN ;
double impact_l2_bot ;
    string impact_l2_bot:units = "m" ;
    string impact_l2_bot:long_name = "Lowest impact parameter (L2)" ;
    impact_l2_bot:missing_value = NaN ;
double ic_tec ;
    string ic_tec:units = "m^-3" ;
    string ic_tec:long_name = "Total electron content estimated in
ionospheric correction" ;
    ic_tec:missing_value = NaN ;
double ic_bangle_diff_slope ;
    string ic_bangle_diff_slope:long_name = "Bending angle difference fit
slope estimated in ionospheric correction" ;
    ic_bangle_diff_slope:missing_value = NaN ;
double ic_bangle_diff_offset ;
    string ic_bangle_diff_offset:long_name = "Bending angle difference
fit offset estimated in ionospheric correction" ;
    ic_bangle_diff_offset:missing_value = NaN ;
double signal_cutoff_l1_slta ;
    string signal_cutoff_l1_slta:units = "m" ;

```



```

        string signal_cutoff_l1_slta:long_name = "L1a postprocessing signal
cut-off SLTA (L1)" ;
        signal_cutoff_l1_slta:missing_value = NaN ;
        double signal_cutoff_l2_slta ;
        string signal_cutoff_l2_slta:units = "m" ;
        string signal_cutoff_l2_slta:long_name = "L1a postprocessing signal
cut-off SLTA (L2)" ;
        signal_cutoff_l2_slta:missing_value = NaN ;
        double impact_rate_mesosphere ;
        string impact_rate_mesosphere:units = "m/s" ;
        string impact_rate_mesosphere:long_name = "Mesospheric (> 50 km)
neutral impact parameter descent/ascent rate" ;
        impact_rate_mesosphere:missing_value = NaN ;
        double impact_rate_troposphere ;
        string impact_rate_troposphere:units = "m/s" ;
        string impact_rate_troposphere:long_name = "Tropospheric (< 5 km)
neutral impact parameter descent/ascent rate" ;
        impact_rate_troposphere:missing_value = NaN ;

        // group attributes:
        string :title = "High resolution bending angle retrieval" ;
    } // group high_resolution

group: thinned {
    dimensions:
        z = 247 ;
        signals = 2 ;
    variables:
        string signals(signals) ;
        string signals:long_name = "GNSS signals being used" ;
        string signals:missing_value = "" ;
        double frequencies(signals) ;
        string frequencies:units = "Hz" ;
        string frequencies:long_name = "Frequencies of GNSS codes/signals
being tracked" ;
        frequencies:missing_value = NaN ;
        double impact(z) ;
        string impact:units = "m" ;
        string impact:long_name = "Impact parameter" ;
        impact:missing_value = NaN ;
        double impact_height(z) ;
        string impact_height:units = "m" ;
        string impact_height:long_name = "Impact height (wrt WGS 84
ellipsoid)" ;
        impact_height:missing_value = NaN ;
        double bangle(z) ;
        string bangle:units = "rad" ;
        string bangle:long_name = "Bending angle (ionospheric corrected)" ;
        bangle:missing_value = NaN ;
        double bangle_l1(z) ;
        string bangle_l1:units = "rad" ;
        string bangle_l1:long_name = "Bending angle (L1)" ;
        bangle_l1:missing_value = NaN ;
        double bangle_l2(z) ;
        string bangle_l2:units = "rad" ;
        string bangle_l2:long_name = "Bending angle (L2)" ;
        bangle_l2:missing_value = NaN ;
        double bangle_l4(z) ;
        string bangle_l4:units = "rad" ;
        string bangle_l4:long_name = "Bending angle (L4 = L1 - L2,
extrapolated)" ;
        bangle_l4:missing_value = NaN ;
        double bangle_sdev(z) ;
        string bangle_sdev:units = "rad" ;
        string bangle_sdev:long_name = "Bending angle (ionospheric corrected)
estimated standard deviation" ;

```



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        bangle_sdev:missing_value = NaN ;
    double bangle_l1_sdev(z) ;
        string bangle_l1_sdev:units = "rad" ;
        string bangle_l1_sdev:long_name = "Bending angle (L1) estimated
standard deviation" ;
        bangle_l1_sdev:missing_value = NaN ;
    double bangle_l2_sdev(z) ;
        string bangle_l2_sdev:units = "rad" ;
        string bangle_l2_sdev:long_name = "Bending angle (L2) estimated
standard deviation" ;
        bangle_l2_sdev:missing_value = NaN ;
    double bangle_l1_renyi_entropy(z) ;
        string bangle_l1_renyi_entropy:units = "rad" ;
        string bangle_l1_renyi_entropy:long_name = "Bending angle (L1) local
Renyi entropy" ;
        bangle_l1_renyi_entropy:missing_value = NaN ;
    double bangle_l2_renyi_entropy(z) ;
        string bangle_l2_renyi_entropy:units = "rad" ;
        string bangle_l2_renyi_entropy:long_name = "Bending angle (L2) local
Renyi entropy" ;
        bangle_l2_renyi_entropy:missing_value = NaN ;
    double lat_tp(z) ;
        string lat_tp:units = "degrees_north" ;
        string lat_tp:long_name = "Latitudes for tangent points" ;
        lat_tp:missing_value = NaN ;
    double lon_tp(z) ;
        string lon_tp:units = "degrees_east" ;
        string lon_tp:long_name = "Longitudes for tangent points" ;
        lon_tp:missing_value = NaN ;
    double azimuth_tp(z) ;
        string azimuth_tp:units = "degrees" ;
        string azimuth_tp:long_name = "GNSS->LEO line of sight azimuth angles
at tangent points (clockwise against True North)" ;
        azimuth_tp:missing_value = NaN ;
    double dtime_mean(z) ;
        string dtime_mean:units = "seconds since 2008-09-19 21:57:35.00" ;
        string dtime_mean:long_name = "Mean measurement epoch (used for
georeferencing only)" ;
        dtime_mean:missing_value = NaN ;
    double doppler_l1_max ;
        string doppler_l1_max:units = "Hz" ;
        string doppler_l1_max:long_name = "Maximum instantaneous Doppler
(L1)" ;
        doppler_l1_max:missing_value = NaN ;
    double doppler_rate_l1_max ;
        string doppler_rate_l1_max:units = "Hz/s" ;
        string doppler_rate_l1_max:long_name = "Maximum instantaneous
Doppler rate (L1)" ;
        doppler_rate_l1_max:missing_value = NaN ;
    double doppler_accel_l1_max ;
        string doppler_accel_l1_max:units = "Hz/s^2" ;
        string doppler_accel_l1_max:long_name = "Maximum instantaneous
Doppler acceleration (L1)" ;
        doppler_accel_l1_max:missing_value = NaN ;
    double exdoppler_l1_max ;
        string exdoppler_l1_max:units = "Hz" ;
        string exdoppler_l1_max:long_name = "Maximum instantaneous excess
Doppler (L1)" ;
        exdoppler_l1_max:missing_value = NaN ;
    double exdoppler_rate_l1_max ;
        string exdoppler_rate_l1_max:units = "Hz/s" ;
        string exdoppler_rate_l1_max:long_name = "Maximum instantaneous
excess Doppler rate (L1)" ;
        exdoppler_rate_l1_max:missing_value = NaN ;
    double exdoppler_accel_l1_max ;
        string exdoppler_accel_l1_max:units = "Hz/s^2" ;

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        string  exdoppler_accel_l1_max:long_name = "Maximum instantaneous
excess Doppler acceleration (L1)" ;
        exdoppler_accel_l1_max:missing_value = NaN ;
        double doppler_l2_max ;
        string  doppler_l2_max:units = "Hz" ;
        string  doppler_l2_max:long_name = "Maximum instantaneous Doppler
(L2)" ;
        doppler_l2_max:missing_value = NaN ;
        double doppler_rate_l2_max ;
        string  doppler_rate_l2_max:units = "Hz/s" ;
        string  doppler_rate_l2_max:long_name = "Maximum instantaneous
Doppler rate (L2)" ;
        doppler_rate_l2_max:missing_value = NaN ;
        double doppler_accel_l2_max ;
        string  doppler_accel_l2_max:units = "Hz/s^2" ;
        string  doppler_accel_l2_max:long_name = "Maximum instantaneous
Doppler acceleration (L2)" ;
        doppler_accel_l2_max:missing_value = NaN ;
        double exdoppler_l2_max ;
        string  exdoppler_l2_max:units = "Hz" ;
        string  exdoppler_l2_max:long_name = "Maximum instantaneous excess
Doppler (L2)" ;
        exdoppler_l2_max:missing_value = NaN ;
        double exdoppler_rate_l2_max ;
        string  exdoppler_rate_l2_max:units = "Hz/s" ;
        string  exdoppler_rate_l2_max:long_name = "Maximum instantaneous
excess Doppler rate (L2)" ;
        exdoppler_rate_l2_max:missing_value = NaN ;
        double exdoppler_accel_l2_max ;
        string  exdoppler_accel_l2_max:units = "Hz/s^2" ;
        string  exdoppler_accel_l2_max:long_name = "Maximum instantaneous
excess Doppler acceleration (L2)" ;
        exdoppler_accel_l2_max:missing_value = NaN ;
        double bangle_upper_resid_mean ;
        string  bangle_upper_resid_mean:units = "rad" ;
        string  bangle_upper_resid_mean:long_name = "Bending angle
(ionospheric corrected) residual - 60-80km robust mean" ;
        bangle_upper_resid_mean:missing_value = NaN ;
        double bangle_upper_resid_sdev ;
        string  bangle_upper_resid_sdev:units = "rad" ;
        string  bangle_upper_resid_sdev:long_name = "Bending angle
(ionospheric corrected) residual - 60-80km robust standard deviation" ;
        bangle_upper_resid_sdev:missing_value = NaN ;
        double impact_top ;
        string  impact_top:units = "m" ;
        string  impact_top:long_name = "Highest impact parameter (ionospheric
corrected)" ;
        impact_top:missing_value = NaN ;
        double impact_l1_top ;
        string  impact_l1_top:units = "m" ;
        string  impact_l1_top:long_name = "Highest impact parameter (L1)" ;
        impact_l1_top:missing_value = NaN ;
        double impact_l2_top ;
        string  impact_l2_top:units = "m" ;
        string  impact_l2_top:long_name = "Highest impact parameter (L2)" ;
        impact_l2_top:missing_value = NaN ;
        double impact_bot ;
        string  impact_bot:units = "m" ;
        string  impact_bot:long_name = "Lowest impact parameter (ionospheric
corrected)" ;
        impact_bot:missing_value = NaN ;
        double impact_l1_bot ;
        string  impact_l1_bot:units = "m" ;
        string  impact_l1_bot:long_name = "Lowest impact parameter (L1)" ;
        impact_l1_bot:missing_value = NaN ;
        double impact_l2_bot ;

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        string impact_l2_bot:units = "m" ;
        string impact_l2_bot:long_name = "Lowest impact parameter (L2)" ;
        impact_l2_bot:missing_value = NaN ;
    double ic_tec ;
        string ic_tec:units = "m^-3" ;
        string ic_tec:long_name = "Total electron content estimated in
ionospheric correction" ;
        ic_tec:missing_value = NaN ;
    double ic_bangle_diff_slope ;
        string ic_bangle_diff_slope:long_name = "Bending angle difference fit
slope estimated in ionospheric correction" ;
        ic_bangle_diff_slope:missing_value = NaN ;
    double ic_bangle_diff_offset ;
        string ic_bangle_diff_offset:long_name = "Bending angle difference
fit offset estimated in ionospheric correction" ;
        ic_bangle_diff_offset:missing_value = NaN ;
    double signal_cutoff_l1_slta ;
        string signal_cutoff_l1_slta:units = "m" ;
        string signal_cutoff_l1_slta:long_name = "L1a postprocessing signal
cut-off SLTA (L1)" ;
        signal_cutoff_l1_slta:missing_value = NaN ;
    double signal_cutoff_l2_slta ;
        string signal_cutoff_l2_slta:units = "m" ;
        string signal_cutoff_l2_slta:long_name = "L1a postprocessing signal
cut-off SLTA (L2)" ;
        signal_cutoff_l2_slta:missing_value = NaN ;
    double impact_rate_mesosphere ;
        string impact_rate_mesosphere:units = "m/s" ;
        string impact_rate_mesosphere:long_name = "Mesospheric (> 50 km)
neutral impact parameter descent/ascent rate" ;
        impact_rate_mesosphere:missing_value = NaN ;
    double impact_rate_troposphere ;
        string impact_rate_troposphere:units = "m/s" ;
        string impact_rate_troposphere:long_name = "Tropospheric (< 5 km)
neutral impact parameter descent/ascent rate" ;
        impact_rate_troposphere:missing_value = NaN ;

    // group attributes:
        string :title = "Thinned bending angle retrieval" ;
        string :thinner_method = "Local polynomial regression with z-
dependent (sine-squared) variable bandwidth on 247 standard impact height levels" ;
    } // group thinned
} // group level_1b
} // group data

group: quality {
    variables:
        ubyte snr_l1_ok ;
            string snr_l1_ok:long_name = "True if upper level (SLTA > 60 km) mean
C/A carrier phase SNR > 200 V/V" ;
            snr_l1_ok:missing_value = 255UB ;
        ubyte snr_l2_ok ;
            string snr_l2_ok:long_name = "True if upper level (SLTA > 60 km) mean
P2 carrier phase SNR > 50 V/V" ;
            snr_l2_ok:missing_value = 255UB ;
        ubyte gns_orbit_ok ;
            string gns_orbit_ok:long_name = "True if GNSS orbit estimates are
available" ;
            gns_orbit_ok:missing_value = 255UB ;
        ubyte gns_clock_ok ;
            string gns_clock_ok:long_name = "True if GNSS clock error estimates
are available" ;
            gns_clock_ok:missing_value = 255UB ;
        ubyte rec_orbit_ok ;
            string rec_orbit_ok:long_name = "True if receiver orbit estimates are
available" ;

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        rec_orbit_ok:missing_value = 255UB ;
    ubyte rec_clock_ok ;
        string rec_clock_ok:long_name = "True if receiver clock error
estimates are available" ;
        rec_clock_ok:missing_value = 255UB ;
    ubyte ol_data_used ;
        string ol_data_used:long_name = "True if open loop data was used in
retrieval" ;
        ol_data_used:missing_value = 255UB ;
    ubyte overall_quality_flag ;
        string overall_quality_flag:long_name = "'\0\' if retrieval is ok" ;
        overall_quality_flag:missing_value = 255UB ;
    ubyte overall_quality_ok ;
        string overall_quality_ok:long_name = "True if retrieval is ok" ;
        overall_quality_ok:missing_value = 255UB ;
    ubyte high_resolution_ok ;
        string high_resolution_ok:long_name = "True if high resolution
retrieval is ok" ;
        high_resolution_ok:missing_value = 255UB ;
    ubyte thinned_ok ;
        string thinned_ok:long_name = "True if thinned retrieval is ok" ;
        thinned_ok:missing_value = 255UB ;
    ubyte bangle_bias_ok ;
        string bangle_bias_ok:long_name = "True if upper level (60 - 80 km)
mean bending angle is ok" ;
        bangle_bias_ok:missing_value = 255UB ;
    ubyte bangle_sdev_ok ;
        string bangle_sdev_ok:long_name = "True if upper level (60 - 80 km)
bending angle residual standard deviation is ok" ;
        bangle_sdev_ok:missing_value = 255UB ;
    ubyte iono_corr_ok ;
        string iono_corr_ok:long_name = "True if ionospheric correction is
ok" ;
        iono_corr_ok:missing_value = 255UB ;
    ubyte impact_top_ok ;
        string impact_top_ok:long_name = "True if uppermost impact parameter
height is ok" ;
        impact_top_ok:missing_value = 255UB ;
    ubyte impact_bot_ok ;
        string impact_bot_ok:long_name = "True if lowermost impact parameter
height is ok" ;
        impact_bot_ok:missing_value = 255UB ;
    ubyte impact_l1_top_ok ;
        string impact_l1_top_ok:long_name = "True if uppermost L1 impact
parameter height is ok" ;
        impact_l1_top_ok:missing_value = 255UB ;
    ubyte impact_l1_bot_ok ;
        string impact_l1_bot_ok:long_name = "True if lowermost L1 impact
parameter height is ok" ;
        impact_l1_bot_ok:missing_value = 255UB ;
    ubyte impact_l2_top_ok ;
        string impact_l2_top_ok:long_name = "True if uppermost L2 impact
parameter height is ok" ;
        impact_l2_top_ok:missing_value = 255UB ;
    ubyte impact_l2_bot_ok ;
        string impact_l2_bot_ok:long_name = "True if lowermost L2 impact
parameter height is ok" ;
        impact_l2_bot_ok:missing_value = 255UB ;
    ubyte signal_cutoff_done ;
        string signal_cutoff_done:long_name = "True if deep occultation
signal cut-off was done." ;
        signal_cutoff_done:missing_value = 255UB ;

    // group attributes:
        string :title = "Champ/BlackJack level 1a/b quality" ;
} // group quality

```



}



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