ROEX

The GNSS Radio Occultation Observation Independent Exchange Format

Version 1.00

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ACRONYMS

ASCII	American Standard Code for Information Interchange
BDS	BeiDou Navigation Satellite System
Galileo	Galileo Navigation Satellite System
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IQ	In-phase and Quadrature
IRNSS	Indian Regional Navigation Satellite System
ITRF	International Terrestrial Reference Frame
LEO	Low Earth Orbit Satellite
PRN	Pseudo Random Noise
QZSS	Quasi-Zenith Satellite System
RINEX	Receiver Independent Exchange Format
ROEX	GNSS Radio Occultation Observation Independent Exchange Format
SBAS	Satellite-Based Augmentation System
SNR	Signal-to-Noise Ratio
UTC	Coordinated Universal Time
TAI	International Atomic Time

0 FORWARD

This document specifies the types, composition structure, observations, and data record formats of the GNSS radio occultation observation independent exchange format file.

This document is based on the actual needs of GNSS radio occultation detection applications. It refers to the organizational structure and data record formats of standard data formats, such as the Receiver Independent Exchange Format (RINEX) V4.00, developed by the International GNSS Service (IGS), etc. This document modifies and extends these standards to accommodate the unique characteristics of GNSS radio occultation observations, and designs and establishes the GNSS Radio Occultation Observation Independent Exchange Format (ROEX), supporting the independent exchange and unified processing of GNSS radio occultation observations.

1 BASIC DEFINITIONS

Before providing a detailed introduction to the ROEX format, we need to explain some basic definitions

1.1 Time

The time of the measurement is the receiver time of the received signals. In the observation data file of a multi-GNSS system combination, the header record must include a time system identifier to specify the time system used for all time-related tags (or time parameters) in the file.

1.1.1 Time System Conversions

If the small deviation between time systems is ignored, GLO can take the same value as UTC in the data file, and the relationship between UTC and GPS, GAL, BDT, QZS, and IRN can be expressed by equations (1) to (5):

$$\mathrm{UTC} = \mathrm{GPS} - \Delta t_{\mathrm{LS}_{\mathrm{GPS}}} \tag{1}$$

$$\mathrm{UTC} = \mathrm{GAL} - \Delta t_{\mathrm{LS}_{\mathrm{GAL}}} \tag{2}$$

$$\mathrm{UTC} = \mathrm{BDT} - \Delta t_{\mathrm{LS}_{\mathrm{BDT}}} \tag{3}$$

$$\mathrm{UTC} = \mathrm{QZS} - \Delta t_{\mathrm{LS}_{\mathrm{QZS}}} \tag{4}$$

$$\mathrm{UTC} = \mathrm{IRN} - \Delta t_{\mathrm{LS}_{\mathrm{IRN}}} \tag{5}$$

where:

Δt_{LS_GPS}—— Leap second correction between GPS time and UTC given in the GPS navigation message;
Δt_{LS_GAL}—— Leap second correction between GAL time and UTC given in Galileo navigation messages;
Δt_{LS_BDT}—— Leap second correction between BDT time and UTC given in BDS navigation messages;
Δt_{LS_QZS}—— Leap second correction between QZS time and UTC given in QZSS navigation messages;
Δt_{LS_IRN}—— Leap second correction between IRN time and UTC given in IRNSS navigation messages.

1.2 GNSS Radio Occultation

Limb detection of GNSS satellites by the GNSS Occultation Receiver. GNSS radio occultation events occur when the GNSS occultation receiver tracks GNSSs as the signal path rises or falls through the Earth's atmosphere and ionosphere.

Note 1: By analyzing the phase and amplitude of the occultation signal of the tracked GNSSs recorded by the GNSS occultation receiver, the refractive index, density, air pressure, temperature, humidity of the atmosphere, and the refractive index and electron density of the ionosphere and other elements can be obtained.

Note 2: GNSS occultation receivers can be placed on platforms such as satellites, mountaintops, aircraft, or floatplanes.

1.3 Carrier Phase Observation

The cumulative phase of the GNSS signal carrier is measured by the GNSS occultation receiver tracking the carrier signal.

Note: Locked signal during positioning observation, occultation closed-loop observation, unlocked signal during occultation open-loop observation (ground reconstruction of carrier phase observation).

1.4 SNR

The ratio of the average power of the signal observed by the GNSS occultation receiver to the average power of the noise.

1.5 Close-loop

Tracking loop with feedback system, the feedback system uses the local signal and the real received signal carrier phase and pseudorange difference to calculate the signal frequency and phase, feedback control of the local pseudo-code, and carrier CNC oscillator to generate the local pseudo-codes and carriers.

1.6 Open-loop

Calculate local carrier and pseudo-code phases using dynamics and atmospheric models, and control local pseudo-code and carrier CNC oscillators to generate local pseudo-codes and carriers.

1.7 Open-loop Model Phase

Predicted carrier phase (and pseudo-code phase) for GNSS occultation open-loop tracking using dynamical and atmospheric models, combined with GNSS satellite and GNSS occultation receiver position velocities.

2 GENERAL CONCEPT

2.1 GNSS Occultation Observation Independent Exchange Format File

2.1.1 Document type

The GNSS occultation observation data includes GNSS radio occultation observation data and positioning observation data. This document has developed a special ROEX format for GNSS radio occultation observation data for independent exchange of occultation observation data.

The GNSS occultation observation independent exchange format file is a pure ASCII text file, and the three file types included are as follows:

a) GNSS atmospheric occultation observation[1)] data files (including single-system and multi-system hybrid observation data files), which follow the ROEX atmospheric observation data file format;
b) GNSS ionospheric occultation observation data files, which follow the ROEX ionospheric observation data file format;

2.1.3 Document structure

Each type of GNSS occultation observation independent exchange format file consists of a "header" section, which is a description of the file and data record, and a "data" section, which is used to record the observation data.

2.1.4 Format description method

GNSS occultation observation data independent exchange format file, the format of each line is expressed as oZa.b. When the data type is X, A, I, the data has only oZa part, and when the data type is F, only a.b part.
Where:

a) o: the total amount of data of the same type and format, if default it means only 1 data; if "m" means there are m data;
b) Z: the data type:
   1) X: Any placeholder character (space or non-valid character for additional description);
   2) A: Valid characters;
   3) F: Floating type numbers;
   4) I: Integer type number.
c) a.b: The length of the data, where:
   1) a: Total length of data bits (all valid digits including decimal points);
   2) b: Decimal part length (number of valid digits after the decimal point).

Example:

- **2F8.3:** two consecutive floating-point numbers, each occupying a total of 8 digits, with the decimal part being 3 digits.

2.2 Document Header Section

2.2.1 Basic format

Each line of the header section of the GNSS occultation observation independent exchange format file is a header record. The length of each header record is no more than 80 ASCII characters (columns), of which, 1~60 columns

1)Atmospheric occultation observations in this document refer specifically to neutral atmospheric occultation observations.

are the information part of the header record, and 61~80 columns are the header record identification. The header record identifier has a uniformly specified format and is a description of the content of the information portion of columns 1~60 of the row.

The ROEX file header section contains a description of the global attributes in the mask data file and a list of observation codes.

2.2.2 Arrangement order of header records

The order of the header records in the ROEX format file can be freely arranged except for the following requirements, see Appendix A for an example. The two fixed header records are:

a) “ROEX VERSION/TYPE” should be the first header record in the document;
b) “END OF HEADER” is the last header record.

2.2.3 Handling of unknown items of header record information

When the GNSS occultation observation independent exchange format file is generated, unknown items in the header record information section may be zeroed or left blank, or the entire header record may be left blank. Until the value of the header record or item is obtained, the program that reads the OBS data SNF file may set the default header record or missing item to zero or blank.

2.2.4 Time system identification

The GNSS occultation observation independent exchange format file uses a three-character valid time system identifier to indicate the time system used in the file.

In the observation data file of a single satellite navigation system (BDS, GPS, GLONASS, Galileo, QZSS or IRNSS), the time system identifier is by default the time of that satellite navigation system, and the headers record "TIME OF FIRST OBS" (or "TIME OF FIRST CLO" or "TIME OF FIRST OPE") and "TIME OF LAST OBS" (or "TIME OF LAST CLO" or "TIME OF LAST OPE") may optionally contain the time system identifier; and in the case of BDS/GPS/GLONASS/Galileo/QZSS/ IRNSS multi-satellite navigation system combination observation data files, these two header records must contain the time system identifier, which identifies the time system used for all marked times (or time parameters) in the file.

The time system markers are defined as follows:

a) BDT: BDS Time;
b) GPS: GPS Time;
c) GLO: GLONASS Time;
d) GAL: Galileo Time;
e) QZS: QZSS Time;
f) IRN: IRNSS Time.

2.3 Data Section

2.3.1 Recording rules of observation data

The rules for recording the observation data are as follows:

a) The first line of each ephemeris record includes the observation time, the number of satellites, the receiver clock bias, and other information, starting with the symbol “>”;

b) Each (row) of observation data records below the epoch line starts with the satellite system and number *snn*, the specific identifier and number are defined in Table 1. the next row starts with the observation type and observation information of the same observation data record;

c) For atmospheric occultation observation data files, the signs "START OF OBS CLO" and "END OF OBS CLO" should be used to indicate the beginning and end of closed-loop observation records, and the signs "START OF OBS OPE" and "END OF OBS OPE" should be used to indicate the beginning and end of open-loop observation records, respectively;

d) For ionospheric occultation observation data files, the end-of-file marker "END OF HEADER" is immediately followed by the observation data record.

Tab.1 Satellite system identifier and number definition

Satellite Systems	System identifier (s)	Satellite number (nn)
BDS	C	PRN code of the system's observed satellite
GPS	G	
Galileo	E	
IRNSS	I	
GLONASS	R	The slot number of the frequency segment of the satellite system
SBAS	S	Its PRN code minus 100 (e.g., SBAS satellite PRN 120 is represented as S20)
QZSS	J	PRN code minus two digits of a fixed value
Note: For LEX/L6D of QZSS system with centimeter-level enhancement service, the fixed value is 192; for L1-SAIF/L1S with sub-meter-level enhancement service, the fixed value is 182; for L6E with centimeter-level enhancement experiment, the fixed value is 202; for L5S used for positioning technology verification, the snn and PRN codes correspond to: J02 (PRN196), J03 (PRN200), and J07 (PRN197).		

3 GNSS ATMOSPHERIC OCCULTATION OBSERVATION INDEPENDENT EXCHANGE FORMAT FILE

3.1 Overview

Each GNSS atmospheric occultation observation data file contains data for a single occultation event observation period only. The header section of the data file describes the global properties of that atmospheric occultation event, and the data section is the observation data record of that atmospheric occultation event.

3.2 Document Header Section

3.2.1 Components

The file header of GNSS atmospheric occultation observation data file consists of several header records from "REX VERSION/TYPE" to "END OF HEADER", and a typical file header composition is shown in Fig. 1.

The observation code in the header record is used to identify the type of observation in the data record in the data section, as defined in 3.2.2, and the correspondence with the observation is defined in 3.2.2. The specific format of the header record is defined in 3.2.3.

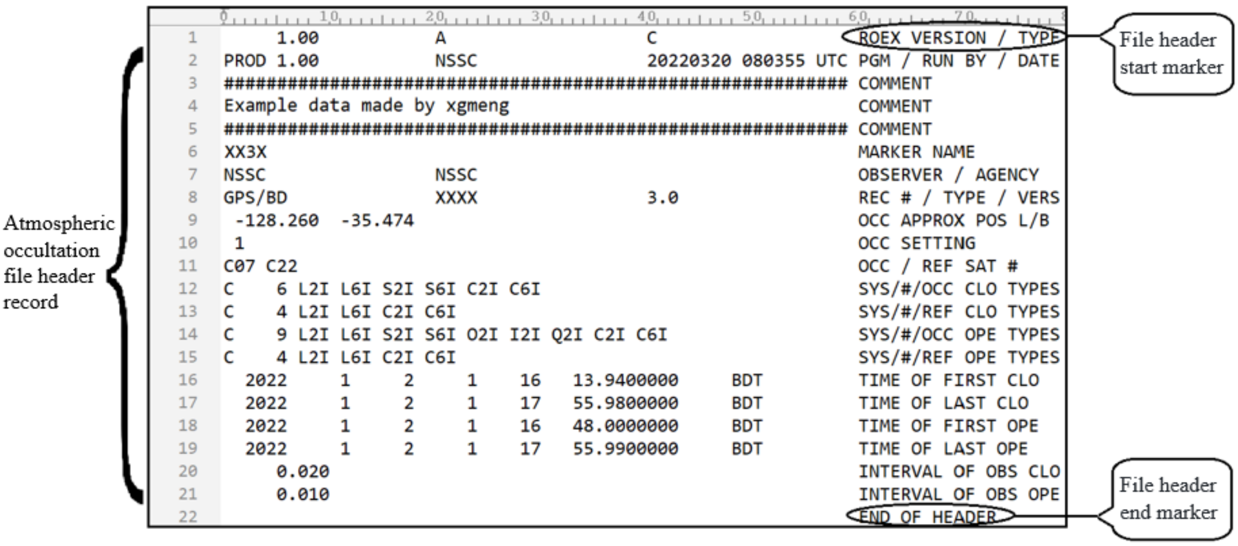


Fig.1 The composition of the header section of a typical atmospheric occultation observation data file

3.2.2 Observation Code

The header section of the GNSS atmospheric occultation data file uses observation codes to identify the different observations and their attributes, the list of observation codes is shown in Table 2.:

a) t: the observation type:

1) L: Carrier phase;

2) S:SNR;

3) C: pseudo-range;

4) O: Open-loop model phase;

5) I: Open-loop I circuit;

6) Q: Open-loop Q circuit.

b) n: band/frequency with the value of 1, 2, ⋯, 8;

c) a: Properties, the tracking mode or channel (e.g., I, Q, etc.). Observation code for a combined code (e.g. M+L) or combined channel (e.g. I+Q) tracking mode with the attribute identifier "X".

Note: I and Q in the observation type denote the isotropic and quadrature correlation results of the local signal in open-loop tracking, while I and Q in the attribute denote the isotropic and quadrature modulated components of the GNSS transmit signal.

Tab. 2 Observation code

System	Frequency Band	Frequency MHz	Channel/Ranging Code	Observation code					
				Carrier Phase	SNR	pseudo-range	Open-loop model phase	Open-loop I circuit	Open-loop Q circuit

BDS	B1 (BDS-2/3 Signal)	1561.098	I (B1I Signal)	L2I	S2I	C2I	O2I	I2I	Q2I
			Q	L2Q	S2Q	C2Q	O2Q	I2Q	Q2Q
			I+Q	L2X	S2X	C2X	O2X	I2X	Q2X
	B1C (BDS-3 Signal)	1575.42	Data	L1D	S1D	C1D	O1D	I1D	Q1D
			Pilot	L1P	S1P	C1P	O1P	I1P	Q1P
			Data+Pilot	L1X	S1X	C1X	O1X	I1X	Q1X
	B1A (BDS-3 Signal)	1575.42	Data	L1S	S1S	C1S	O1S	I1S	Q1S
			Pilot	L1L	S1L	C1L	O1L	I1L	Q1L
			Data+Pilot	L1Z	S1Z	C1Z	O1Z	I1Z	Q1Z
	B2a (BDS-3 Signal)	1176.45	Data	L5D	S5D	C5D	O5D	I5D	Q5D
			Pilot	L5P	S5P	C5P	O5P	I5P	Q5P
			Data+Pilot	L5X	S5X	C5X	O5X	I5X	Q5X
	B2 (BDS-2 Signal)	1207.140	I (B2I Signal)	L7I	S7I	C7I	O7I	I7I	Q7I
			Q	L7Q	S7Q	C7Q	O7Q	I7Q	Q7Q
			I+Q	L7X	S7X	C7X	O7X	I7X	Q7X
	B2b (BDS-3 Signal)	1207.140	Data	L7D	S7D	C7D	O7D	I7D	Q7D
			Pilot	L7P	S7P	C7P	O7P	I7P	Q7P
			Data+Pilot	L7Z	S7Z	C7Z	O7Z	I7Z	Q7Z
	B2(B2a +B2b) (BDS-3 Signal)	1191.795	Data	L8D	S8D	C8D	O8D	I8D	Q8D
			Pilot	L8P	S8P	C8P	O8P	I8P	Q8P
			Data+Pilot	L8X	S8X	C8X	O8X	I8X	Q8X
	B3 (BDS-2/3 Signal)	1268.52	I	L6I	S6I	C6I	O6I	I6I	Q6I
			Q	L6Q	S6Q	C6Q	O6Q	I6Q	Q6Q
			I+Q	L6X	S6X	C6X	O6X	I6X	Q6X
	B3A (BDS-3 Signal)	1268.52	Data	L6D	S6D	C6D	O6D	I6D	Q6D
			Pilot	L6P	S6P	C6P	O6P	I6P	Q6P
			Data+Pilot	L6Z	S6Z	C6Z	O6Z	I6Z	Q6Z
GPS	L1	1575.42	C/A	L1C	S1C	C1C	O1C	I1C	Q1C
			L1C(D)	L1S	S1S	C1S	O1S	I1S	Q1S
			L1C(P)	L1L	S1L	C1L	O1L	I1L	Q1L
			L1C(D+P)	L1X	S1X	C1X	O1X	I1X	Q1X
			P (AS invalid)	L1P	S1P	C1P	—	—	—
			Z- Tracking and Similar Computing (AS valid)	L1W	S1W	C1W	—	—	—
			Y	L1Y	S1Y	C1Y	O1Y	I1Y	Q1Y

			M	L1M	S1M	C1M	O1M	I1M	Q1M
			Uncoded	L1N	S1N	—	—	—	—
	L2	1227.60	C/A	L2C	S2C	C2C	O2C	I2C	Q2C
			L1(C/A) +(P2-P1) (Semi-Uncoded)	L2D	S2D	C2D	O2D	I2D	Q2D
			L2C(M)	L2S	S2S	C2S	O2S	I2S	Q2S
			L2C(L)	L2L	S2L	C2L	O2L	I2L	Q2L
			L2C(M+L)	L2X	S2X	C2X	O2X	I2X	Q2X
			P (AS invalid)	L2P	S2P	C2P	—	—	—
			Z- Tracking and Similar Computing (AS valid)	L2W	S2W	C2W	—	—	—
			Y	L2Y	S2Y	C2Y	O2Y	I2Y	Q2Y
			M	L2M	S2M	C2M	O2M	I2M	Q2M
			Uncoded	L2N	S2N	—	—	—	—
	L5	1176.45	I	L5I	S5I	C5I	O5I	I5I	Q5I
			Q	L5Q	S5Q	C5Q	O5Q	I5Q	Q5Q
			I+Q	L5X	S5X	C5X	O5X	I5X	Q5X
GLONASS	G1	1602+k×9 /16(k= -7～+12)	C/A	L1C	S1C	C1C	O1C	I1C	Q1C
			P	L1P	S1P	C1P	O1P	I1P	Q1P
	G1a	1600.995	L1OCd	L4A	S4A	C4A	O4A	I4A	Q4A
			L1OCp	L4B	S4B	C4B	O4B	I4B	Q4B
			L1OCd+L1OCp	L4X	S4X	C4X	O4X	I4X	Q4X
	G2	1246+k× 7/16	C/A	L2C	S2C	C2C	O2C	I2C	Q2C
			P	L2P	S2P	C2P	O2P	I2P	Q2P
	G2a	1248.06	L2CSI	L6A	S6A	C6A	O6A	I6A	Q6A
			L2OCp	L6B	S6B	C6B	O6B	I6B	Q6B
			L2CSI+L2OCp	L6X	S6X	C6X	O6X	I6X	Q6X
	G3	1202.025	I	L3I	S3I	C3I	O3I	I3I	Q3I
			Q	L3Q	S3Q	C3Q	O3Q	I3Q	Q3Q
			I+Q	L3X	S3X	C3X	O3X	I3X	Q3X
Galileo	E1	1575.42	A PRS	L1A	S1A	C1A	O1A	I1A	Q1A
			B OS data	L1B	S1B	C1B	O1B	I1B	Q1B
			C OS pilot	L1C	S1C	C1C	O1C	I1C	Q1C
			B+C	L1X	S1X	C1X	O1X	I1X	Q1X
			A+B+C	L1Z	S1Z	C1Z	O1Z	I1Z	Q1Z
	E5a	1176.45	I F/NAV OS	L5I	S5I	C5I	O5I	I5I	Q5I
			Q No Data	L5Q	S5Q	C5Q	O5Q	I5Q	Q5Q
			I+Q	L5X	S5X	C5X	O5X	I5X	Q5X
	E5b	1207.140	I I/NAV OS/CS/SoL	L7I	S7I	C7I	O7I	I7I	Q7I

			Q No Data	L7Q	S7Q	C7Q	O7Q	I7Q	Q7Q
			I+Q	L7X	S7X	C7X	O7X	I7X	Q7X
	E5(E5a +E5b)	1191.795	I	L8I	S8I	C8I	O8I	I8I	Q8I
			Q	L8Q	S8Q	C8Q	O8Q	I8Q	Q8Q
			I+Q	L8X	S8X	C8X	O8X	I8X	Q8X
	E6	1278.75	A PRS	L6A	S6A	C6A	O6A	I6A	Q6A
			B C/NAV CS	L6B	S6B	C6B	O6B	I6B	Q6B
			C No Data	L6C	S6C	C6C	O6C	I6C	Q6C
			B+C	L6X	S6X	C6X	O6X	I6X	Q6X
			A+B+C	L6Z	S6Z	C6Z	O6Z	I6Z	Q6Z
SBAS	L1	1575.42	C/A	L1C	S1C	C1C	O1C	I1C	Q1C
	L5	1176.45	I	L5I	S5I	C5I	O5I	I5I	Q5I
			Q	L5Q	S5Q	C5Q	O5Q	I5Q	Q5Q
			I+Q	L5X	S5X	C5X	O5X	I5X	Q5X
QZSS	L1	1575.42	C/A	L1C	S1C	C1C	O1C	I1C	Q1C
			C/B	L1E	S1E	C1E	O1E	I1E	Q1E
			L1C(D)	L1S	S1S	C1S	O1S	I1S	Q1S
			L1C(P)	L1L	S1L	C1L	O1L	I1L	Q1L
			L1C(D+P)	L1X	S1X	C1X	O1X	I1X	Q1X
			L1S/L1-SAIF	L1Z	S1Z	C1Z	O1Z	I1Z	Q1Z
			L1Sb	L1B	S1B	C1B	O1B	I1B	Q1B
	L2	1227.60	L2C(M)	L2S	S2S	C2S	O2S	I2S	Q2S
			L2C(L)	L2L	S2L	C2L	O2L	I2L	Q2L
			L2C(M+L)	L2X	S2X	C2X	O2X	I2X	Q2X
	L5	1176.45	I	L5I	S5I	C5I	O5I	I5I	Q5I
			Q	L5Q	S5Q	C5Q	O5Q	I5Q	Q5Q
			I+Q	L5X	S5X	C5X	O5X	I5X	Q5X
			L5S(I)	L5D	S5D	C5D	O5D	I5D	Q5D
			L5S(Q)	L5P	S5P	C5P	O5P	I5P	Q5P
			L5S(I+Q)	L5Z	S5Z	C5Z	O5Z	I5Z	Q5Z
	L6	1278.75	L6D	L6S	S6S	C6S	O6S	I6S	Q6S
			L6P	L6L	S6L	C6L	O6L	I6L	Q6L
			L6(D+P)	L6X	S6X	C6X	O6X	I6X	Q6X
			L6E	L6E	S6E	C6E	O6E	I6E	Q6E
			L6(D+E)	L6Z	S6Z	C6Z	O6Z	I6Z	Q6Z
IRNSS	L5	1176.45	A SPS	L5A	S5A	C5A	O5A	I5A	Q5A
			B RS(D)	L5B	S5B	C5B	O5B	I5B	Q5B
			C RS(P)	L5C	S5C	C5C	OL5C	I5C	Q5C
			B+C	L5X	S5X	C5X	O5X	I5X	Q5X
	S	2492.028	A SPS	L9A	S9A	C9A	O9A	I9A	Q9A

			B RS(D)	L9B	S9B	C9B	O9B	I9B	Q9B
			C RS(P)	L9C	S9C	C9C	O9C	I9C	Q9C
			B+C	L9X	S9X	C9X	O9X	I9X	Q9X

3.2.3 Format of the Header Section

The format of the header part of the GNSS atmospheric occultation observation data file is shown in Table 3.

Tab. 3 GNSS atmospheric occultation observation data file header format

Header record identification (columns 61-80)	Descriptions	Format
ROEX VERSION / TYPE	- Format Version: 1.00 - File Type ("A": Atmospheric occultation observation file) - Satellite System Code: "C": BDS "G": GPS "R": GLONASS "E": Galileo "J": QZSS "S": SBAS "I": IRNSS "M": Multi-system (the occultation and reference stars are different satellite navigation systems)	F9.2,11X, A1,19X, A1,19X
PGM / RUN BY / DATE	- Generate the program name of the current file - Generate the institution name of the current file - Time of file generation The file generation time format is defined as follows: yyyymmdd hhmmss zone where yyyy is 4-digit year, mm is 2-digit month, dd is 2-digit day, hh is 2-digit hour, mm is 2-digit minute, ss is 2-digit second. zone is time zone (3–4-character code, UTC is recommended, if local time is unknown, then mark zone as LCL).	A20, A20, A20
*** COMMENT**	Comment line	A60
MARKER NAME	Name of measurement marker point (carrier)	A60
OBSERVER / AGENCY	Name of observer/institution	A20, A40
REC # / TYPE / VERS	Receiver number, model, and version (Version: such as the version of the receiver's built-in software)	3A20
*** OCC APPROX POS L/B**	- Approximate position of the occultation event, expressed in longitude/latitude Unit: degree Coordinate frames are recommended for ITRF	2(1X, F8.3),42X
*** OCC AZIM RANGE**	- The azimuth range of the occultation observation, in order, is the starting azimuth, the ending azimuth Unit: degree	2(1X, F8.3),42X

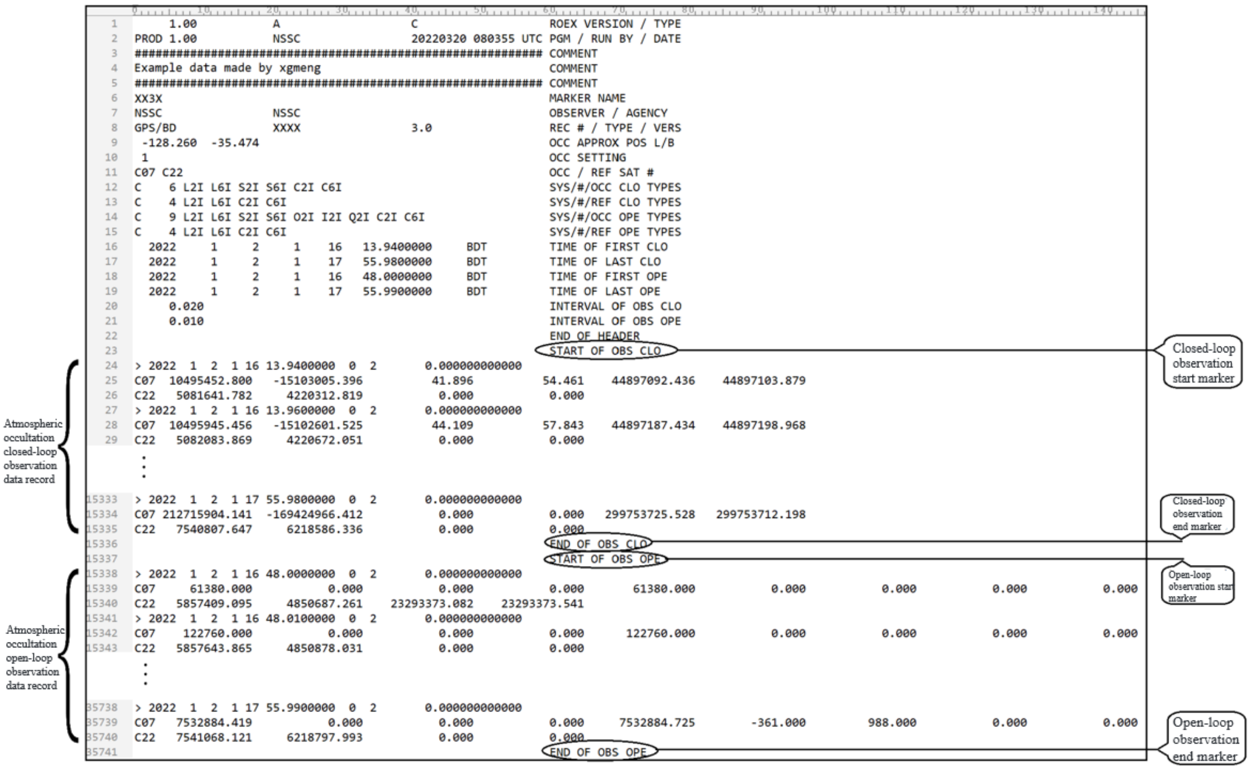
*** OCC ELEV RANGE**	- The altitude angle range of the occultation observation, in order, is the starting altitude angle, the ending altitude angle Unit: degree	2(1X, F8.3),42X
OCC SETTING	Up or down masking star marker (0: up; 1: down)	I2,58X
OCC / REF SAT #	- Occultation satellite system(C/G/E/R/J/S/I) - Occultation Satellite Number - Reference Star Satellite System(C/G/E/R/J/S/I) - Reference Star Satellite Number	A1, I2,2X, A1, I2,52X
SYS/#/OCC CLO TYPES	- Satellite System (C/G/E/R/J/S/I) - Number of distinct observations of closed-loop occultation in the atmosphere - Atmospheric Closed Loop Occultation Observation Quantity Indicator: Observation type, frequency band, attribute If more than 13 observations: use continuation line to solve	A1, 2X, I3, 13(1X, A3) 6X,13(1X, A3)
SYS/#/REF CLO TYPES	- Satellite System (C/G/E/R/J/S/I) - Number of distinct observations of closed-loop occultation in the atmosphere - Atmospheric Closed Loop Occultation Observation Quantity Indicator: Observation type, frequency band, attribute If more than 13 observations: use continuation line to solve	A1, 2X, I3, 13(1X, A3) 6X,13(1X, A3)
SYS/#/OCC OPE TYPES	- Satellite System (C/G/E/R/J/S/I) - Number of distinct observations of open-loop occultation sat. - Atmospheric Open-loop Occultation Observation Quantity Indicator: Observation type, frequency band, attribute If more than 13 observations: use continuation line to solve	A1, 2X, I3, 13(1X, A3) 6X,13(1X, A3)
SYS/#/REF OPE TYPES	- Satellite System (C/G/E/R/J/S/I) - Number of distinct observations of open-loop reference sat. - Atmospheric Open-loop Occultation Observation Quantity Indicator: Observation type, frequency band, attribute If more than 13 observations: use continuation line to solve	A1, 2X, I3, 13(1X, A3) 6X,13(1X, A3)
***INTERVAL OF OBS CLO**	- Atmospheric occultation closed-loop observation interval (s)	F10.3
***INTERVAL OF OBS OPE**	- Atmospheric occultation open-loop observation interval (s)	F10.3
TIME OF FIRST CLO	- The time of the first atmospheric closed-loop occultation observation record: Year (4 digits) month, day, hour, minute (2 digits each) seconds - time system: BDT (=BDS time system) GLO (=UTC time system) GAL (=Galileo time system) GPS (=GPS time system) QZS (=QZSS time system) IRN (=IRNSS time system) The time system should be given in the combined GNSS document Default value: Separate BDS file, with BDT time system	 I6, 4I6, F13.7, 5X, A3

	Separate GPS file, time system for GPS Separate Galileo file, with GAL time system Separate GLONASS file, with GLO time system Separate QZSS file, with QZS time system Separate IRNSS file, with IRN time system	
***TIME OF LAST CLO**	- Time of the last closed-loop occultation observation of the atmosphere: Year (4 digits) month, day, hour, minute (2 digits each) seconds - time system: Same as "TIME OF FIRST CLO"	I6, 4I6, F13.7, 5X, A3
TIME OF FIRST OPE	- Time of the last closed-loop occultation observation of the atmosphere: Year (4 digits) month, day, hour, minute (2 digits each) seconds - time system: Same as "TIME OF FIRST CLO"	I6, 4I6, F13.7, 5X, A3
***TIME OF LAST OPE**	- Time of the last closed-loop occultation observation of the atmosphere: Year (4 digits) month, day, hour, minute (2 digits each) seconds - time system: Same as "TIME OF FIRST CLO"	I6, 4I6, F13.7, 5X, A3
***RCV CLOCK OFFS APPL**	- Whether real-time receiver clock bias is performed 1: Yes; 0: No; Default: no modification required	I6
***LEAP SECONDS**	-leap second Δt_LS (Corresponding system ephemeris broadcast) -Leap seconds before and after the new leap seconds take effect (instantaneously) Δt_LSF - Week count for new leap seconds to take effect WN_LSF (Continuous weekly count) - Number of days in the week when the new leap second is in effect DN 0 if unknown or leave blank Mix file for leap second information for UTC versus BDT	I6, I6, I6, I6
END OF HEADER	the last record in the header	60X
Note: Data records marked with "*" are optional.		

3.3 Data Section

3.3.1 Components

The data part of the GNSS atmospheric occultation observation data file consists of the observation start and end marks and the observation data record. The typical data part is shown in Figure 2. The observation data record consists of the observation time and the corresponding observation amount.




```
     1.00            A                   C                   ROEX VERSION / TYPE
PROD 1.00            NSSC                20220320 080355 UTC PGM / RUN BY / DATE
############################################################ COMMENT
Example data made by xgmeng                                  COMMENT
############################################################ COMMENT
XX3X                                                         MARKER NAME
NSSC                 NSSC                                    OBSERVER / AGENCY
GPS/BD               XXXX                3.0                 REC # / TYPE / VERS
  -128.260  -35.474                                          OCC APPROX POS L/B
  1                                                          OCC SETTING
C07 C22                                                      OCC / REF SAT #
C     6 L2I L6I S2I S6I C2I C6I                              SYS/#/OCC CLO TYPES
C     4 L2I L6I C2I C6I                                      SYS/#/REF CLO TYPES
C     9 L2I L6I S2I S6I O2I I2I Q2I C2I C6I                  SYS/#/OCC OPE TYPES
C     4 L2I L6I C2I C6I                                      SYS/#/REF OPE TYPES
  2022     1     2     1    16   13.9400000     BDT          TIME OF FIRST CLO
  2022     1     2     1    17   55.9800000     BDT          TIME OF LAST CLO
  2022     1     2     1    16   48.0000000     BDT          TIME OF FIRST OPE
  2022     1     2     1    17   55.9900000     BDT          TIME OF LAST OPE
     0.020                                                   INTERVAL OF OBS CLO
     0.010                                                   INTERVAL OF OBS OPE
                                                             END OF HEADER
                                                             START OF OBS CLO
> 2022  1  2  1 16 13.9400000  0  2       0.000000000000
C07  10495452.800   -15103005.396       41.896         54.461    44897092.436    44897103.879
C22   5081641.782     4220312.819        0.000          0.000
> 2022  1  2  1 16 13.9600000  0  2       0.000000000000
C07  10495945.456   -15102601.525       44.109         57.843    44897187.434    44897198.968
C22   5082083.869     4220672.051        0.000          0.000
 ⋮
> 2022  1  2  1 17 55.9800000  0  2       0.000000000000
C07 212715904.141  -169424966.412        0.000          0.000   299753725.528   299753712.198
C22   7540807.647     6218586.336        0.000          0.000
                                                        END OF OBS CLO
                                                        START OF OBS OPE
> 2022  1  2  1 16 48.0000000  0  2       0.000000000000
C07      61380.000           0.000        0.000          0.000       61380.000           0.000           0.000           0.000           0.000
C22   5857409.095     4850687.261   23293373.082   23293373.541
> 2022  1  2  1 16 48.0100000  0  2       0.000000000000
C07     122760.000           0.000        0.000          0.000      122760.000           0.000           0.000           0.000           0.000
C22   5857643.865     4850878.031        0.000          0.000
 ⋮
> 2022  1  2  1 17 55.9900000  0  2       0.000000000000
C07    7532884.419           0.000        0.000          0.000     7532884.725        -361.000         988.000           0.000           0.000
C22   7541068.121     6218797.993        0.000          0.000
                                                        END OF OBS OPE
```

Fig. 2 Example of the data component of an atmospheric occultation observation data file

3.3.2 Observation time

The observation time is the time scale information of the observation in the GNSS atmospheric occultation observation data file. In the data logging section of the GNSS atmospheric occultation observation data file, the observation time should be recorded before each set of observation data.

3.3.3 Types of the observations

The GNSS atmospheric occultation observation includes the following types,

a) Carrier phase: one of the basic observation quantities in the GNSS atmospheric occultation observation data file, which is used to calculate the additional phase of the GNSS occultation. The carrier phase observations recorded in the GNSS occultation observation data file should be recorded in full weeks (the recorded value may contain fractional parts). The carrier phase half-periods observed by square receivers (for GPS only) should also be converted to full-period records and identified with the corresponding observation code (see 3.2.2).

b) SNR: one of the basic observation quantities in the GNSS atmospheric occultation observation data file, reflecting the amplitude information of GNSS occultation observation. The SNR observations recorded in the GNSS occultation data file should be recorded in units of V/V.

c) Pseudorange: It is recorded in the GNSS atmospheric occultation observation data file as an additional observation quantity. The pseudo-range observations are derived from the time difference between the receiver reception time and the GNSS satellite signal emission time and are mainly used in the occultation processing to calculate the GNSS satellite position at that time by calculating the GNSS satellite signal emission time. The pseudo-range observations recorded in the GNSS occultation observation data file are in meters.

d) Open-loop model phase: one of the basic observation quantities in the GNSS atmospheric occultation data file, used to reconstruct the open-loop carrier phase observations on the ground together with the open-loop IQ. The open-loop model phase observations recorded in the GNSS occultation data file are in units of weeks.

e) Open-loop I-way and open-loop Q-way: one of the basic observation quantities in the GNSS atmospheric occultation observation data file, used to reconstruct the open-loop carrier phase observation quantities on the ground together with the open-loop model phase. The open-loop I-way and open-loop Q-way observations recorded in the GNSS occultation data file are dimensionless.

3.3.4 Order of the observations

The header record "SYS/#/OCC CLO TYPES" (or "SYS/#/REF CLO TYPES" or "SYS/#/REF OPE TYPES") in the file header section of the GNSS atmospheric occultation observation data file SYS/#/OCC OPE TYPES" or "SYS/#/REF OPE TYPES") is a description of the type of observation in the observation data record of this file. In the data section of the file, all observations for each GNSS satellite for each epoch shall be recorded in the order of the observation code in the corresponding header record.

3.3.5 Definition of the data section format

The data section format definitions of the GNSS atmospheric occultation observation data files are shown in Table 4.

Tab. 4 GNSS atmospheric occultation observation data file - data part format

Record identification (61-80 columns)	Descriptions	Format
START OF OBS CLO	The next line begins with a record of closed-loop observations of atmospheric occultations	A60
END OF OBS CLO	Closed-loop observation of atmospheric occultation ends	A60
START OF OBS OPE	The next line starts to record open-loop observations for atmospheric occultations	A60
END OF OBS OPE	Atmospheric occultation open-loop observation ends	A60
*** COMMENT**	Comment line	A60
---	Epoch records - Record identifier: > epoch: -year (4 digits) -month, day, hour, minute (2-digits each) -second - Epoch symbols: 0: Normal 1: Power outage or power failure between the current epoch and the previous epoch >1: Incident (The incident situation is shown in Table 5) - Number of satellites observed in the current year - (reservation) - receiver clock bias (unit: s, optional) - Altitude of occultation tangent point (unit: m, optional)	 A1, 1X, I4, 4(1X, I2), F11.7, 2X, I1, I3, 6X, F15.12, F12.3
---	The epoch flag is 0 or 1 to start recording observations as follows:	

	- Satellite number - Observations Example: C08 328960404.711 -238484692.530 356.471 237.651 For each observation type, the observation will be repeated in the record: The order of the closed-loop occultation observations is the same as the order of the observation types given in the header record "SYS/#/OCC CLO TYPES"; The order of the closed-loop reference star observations is the same as the order of the observation types given in the header record "SYS/#/REF CLO TYPES"; The order of the open-loop occultation observations is the same as the order of the observation types given in the header record "SYS/#/OCC OPE TYPES"; The order of the open-loop reference star observations is the same as the order of the observation types given in the header record "SYS/#/REF OPE TYPES". The record is repeated for GNSS satellites where occultations (or as reference satellites) were observed in the current epoch. The length of this record is based on the number of observation types for that type of GNSS satellite. Missing observations are indicated by 0.0 or a space. The phase value of the overflow fixed format F14.3 should be adjusted to match the record format (e.g. by adding or subtracting 109).	A1, I2 m(F14.3,2X)
Note: Data records marked with "*" are optional.		

3.3.6 Epoch flag

The description of epoch flag events in the data section of the GNSS atmospheric occultation observation data file is shown in Table 5.

A flag greater than 1 indicates an event. The events with flag 4~5 indicate that header records can be inserted for description, and the value originally used to record the "number of satellites" represents the number of header records to be inserted below, which is 0 when no header records are inserted, and the maximum number of header records that can be inserted is 999. If the event does not contain a calendar record, the area of the calendar record is left blank.

Tab. 5 Epoch flag incident in the data section

Epoch flag	Incident Description
2	Reservation
3	Reservation
4	The header record will be inserted later
5	Other incidents (e.g., temporary insertion of an epoch moment record, which is under the same time system as the observation time)

4 GNSS IONOSPHERIC OCCULTATION OBSERVATION INDEPENDENT

EXCHANGE FORMAT FILE

4.1 Overview

Each GNSS ionospheric occultation observation data file contains data for a single occultation event observation period only. The header section of the data file describes the global properties of the ionospheric occultation event, and the data section is the observation data record of the ionospheric occultation event.

4.2 Document Header Section

4.2.1 Components

The header of GNSS ionospheric occultation observation data file consists of several header records from "REX VERSION/TYPE" to "END OF HEADER", and a typical file header composition is shown in Fig. 3.

The observation code in the header record is used to identify the type of observation in the data record in the data section, as defined in 3.2.2, and the correspondence with the observation is defined in 3.2.2. The specific format of the header record is defined in 4.2.3.

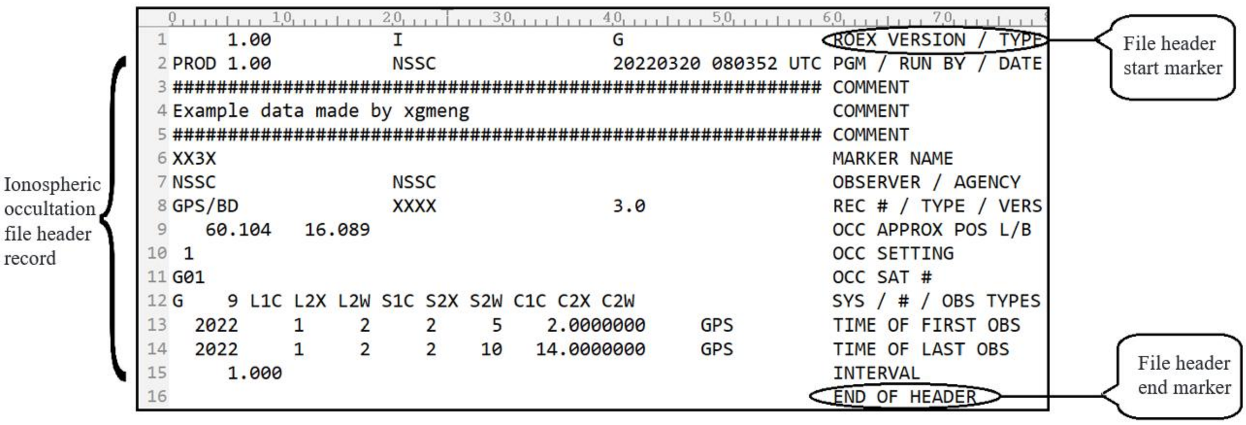


Fig. 3 Example of the composition of the header section of an ionospheric occultation observation data file

4.2.2 Observation Code

The header of the GNSS ionospheric occultation observation data file uses observation codes to identify the different observation quantities and their attributes. The only three types of observations in the GNSS ionospheric occultation observation data file are carrier phase, SNR, and pseudorange, and their observation codes are the same as defined in 3.2.2.

4.2.3 Format of the Header Section

The format of the header section of the GNSS ionospheric occultation observation data file is shown in Table 6.

Tab. 6 GNSS ionospheric occultation observation data file header format

Header record identification (61-80 columns)	Descriptions	Format
ROEX VERSION / TYPE	- Format Version:1.00 - File Type ("I": Ionospheric occultation observation data file) - Satellite System Code: "C": BDS "G": GPS "R": GLONASS "E": Galileo "J": QZSS "I": IRNSS "S": SBAS	F9.2,11X, A1,19X, A1,19X
* COMMENT	Comment line	A60
MARKER NAME	Measurement marker point (carrier) name	A60
OBSERVER / AGENCY	Name of observer/institution	A20, A40
REC # / TYPE / VERS	Receiver number, model, and version (Version: e.g. version of the receiver's built-in software)	3A20
* OCC APPROX POS L/B	- Approximate position of ionospheric occultation events, expressed in longitude/latitude Unit: degree Coordinate frame suggested for ITRF	2(1X, F8.3),42X
OCC SETTING	Ascending or descending occultation flags (0: Ascending;1: descending.)	I2,58X
OCC SAT#	- Ionospheric occultation satellite system(C/G/E/R/J/S/I) - Ionospheric occultation satellite number	A1, I2,57X
SYS / # / OBS TYPES	- Satellite Systems(C/G/E/R/J/S/I) - For the different number of observations of this satellite system- Observed quantity descriptors: Observation type, frequency band, attributes If there are more than 13 observations: use the continuation solution.	A1, 2X, I3, 13(1X, A3) 6X,13(1X, A3)
*INTERVAL	- Observation interval(s)	F10.3
TIME OF FIRST OBS	- Time of the first observation record: Year (4 digits) Month, day, hour, minute (2 digits each) Seconds - Time System: BDT (=BDS Time System) GLO (=UTC Time System) GAL (=Galileo Time System) GPS (=GPS Time System) QZS (=QZSS Time System) IRN (=IRNSS Time System) Default: BDS File, Time System BDT GPS File, Time System GPS Galileo File, Time System GAL GLONASS File, Time System GLO	 I6, 4I6, F13.7, 5X, A3

	QZSS File, Time System QZS IRNSS File, Time System 为 IRN	
***TIME OF LAST OBS**	- Time of final observation record: Year (4 digits) Month, day, hour, minute (2 digits each) Seconds - Time System: Same as the "TIME OF FIRST OBS" record	 I6, 4I6, F13.7, 5X, A3
***RCV CLOCK OFFS APPL**	- Whether real-time receiver clock bias correction is performed 1: Yes;0: No; Default: No correction required	I6
***LEAP SECONDS**	-leap second Δt_{LS} (Corresponding system ephemeris broadcast) -Leap seconds before and after the new leap seconds take effect (instantaneously) Δt_{LSF} - Week count for new leap seconds to take effect WN_LSF (Continuous weekly count) - Number of days in the week when the new leap second is in effect DN 0 if unknown or leave blank Mix file for leap second information for UTC versus BDT	I6, I6, I6, I6
END OF HEADER	The last record in the header section	60X
Note: Data records marked with "*" are optional.		

4.3 Data Section

4.3.1 Components

The data section of the GNSS ionospheric occultation data file consists of ionospheric occultation observation data records, see Figure 4. ionospheric occultation data records include observation times and corresponding observation quantities.

```
     1.00           I                   G                   ROEX VERSION / TYPE
PROD 1.00           NSSC                20220320 080352 UTC PGM / RUN BY / DATE
############################################################ COMMENT
Example data made by xgmeng                                 COMMENT
############################################################ COMMENT
XX3X                                                        MARKER NAME
NSSC                NSSC                                    OBSERVER / AGENCY
GPS/BD              XXXX                3.0                 REC # / TYPE / VERS
   60.104   16.089                                          OCC APPROX POS L/B
 1                                                          OCC SETTING
G01                                                         OCC SAT #
G    9 L1C L2X L2W S1C S2X S2W C1C C2X C2W                  SYS / # / OBS TYPES
  2022     1     2     2     5    2.0000000     GPS         TIME OF FIRST OBS
  2022     1     2     2    10   14.0000000     GPS         TIME OF LAST OBS
     1.000                                                  INTERVAL
                                                            END OF HEADER
> 2022  1  2  2  5  2.0000000  0  1       0.000000000000
G01     184648.824      -152331.483       42793.249        105.619         137.777          47.483     24573976.039     24573985.201     24573983.785
> 2022  1  2  2  5  3.0000000  0  1       0.000000000000
G01     206170.813      -135561.126       59563.631        104.905         148.568          51.365     24578070.071     24578081.420     24578080.593
> 2022  1  2  2  5  4.0000000  0  1       0.000000000000
G01     227703.156      -118782.668       76342.086        107.180         148.979          53.031     24582167.204     24582179.273     24582179.250
> 2022  1  2  2  5  5.0000000  0  1       0.000000000000
G01     249245.865      -101996.158       93128.611        104.773         159.969          55.798     24586266.714     24586278.698     24586279.488
  ⋮
> 2022  1  2  2 10 14.0000000  0  1       0.000000000000
G01    7312631.186      5401940.140     5597064.888        228.070         406.801         209.720     25930385.218     25930396.410     25930397.303
```

Ionospheric occultation observation data record

Fig.4 Example of the data component of the ionospheric occultation observation data file

4.3.2 Observation time of the data section

The observation time is the time scale information of the mesoscopic measurements in the data section of the GNSS ionospheric occultation observation data file. In the data logging section of the GNSS ionospheric occultation observation data file, the observation moment should be recorded before each set of observation data.

4.3.3 Types of the observations

The only three observation quantities in the GNSS ionospheric occultation observation data file are carrier phase, SNR, and pseudorange, and the meaning of their observation quantities is the same as 3.3.3.

4.3.4 Order of the observations

The header record "SYS / # / OBS TYPES" in the header section of the GNSS ionospheric occultation observation data file is a description of the observation data record of the file. The header record should first be labeled with the satellite system identifier, followed by the number of observations observed by that type of satellite and the corresponding list of observation codes. In the data section of the file, all observations for each satellite under each calendar element should be recorded in the order of the list of observation codes in the corresponding header record.

4.3.5 Format of the data section

The data section format definitions of the GNSS ionospheric occultation observation data files are shown in Table 7.

Tab. 7 GNSS ionospheric occultation observation file - data part format

Record identification (61-80 columns)	Descriptions	Format
* COMMENT	Comment line	A60
---	Epoch records - Record identifier: > epoch: -year (4 digits) -month, day, hour, minute (2-digits each) -second - Epoch symbols: 0: normal 1: Power outage or power failure between the current epoch and the previous epoch >1: Incident (The incident situation is shown in Table 5) - Number of satellites observed in the current year -(reservation) - receiver clock bias (unit: s, optional)	 A1, 1X, I4, 4(1X, I2), F11.7, 2X, I1, I3, 6X, F15.12
---	The epoch flag is 0 or 1 to start recording observations as follows: - Satellite number - Observations Example: C14 -280917.930 281675.672 260.114 374.822 For each observation type, the observations will be repeated in the record (in the same order as given in the header record "SYS / # / OBS TYPES"). Only one GNSS satellite with ionospheric occultation is observed and recorded in the current ephemeris. The length of this record depends on the number of ionospheric occultation observation types. Missing observations are indicated by 0.0 or a space.	 A1, I2 m (F14.3, 2X)

	The phase value of the overflow fixed format F14.3 should be adjusted to match the record format (e.g. by adding or subtracting 109).	
Note: Data records marked with "*" are optional.		

APPENDIX A: EXAMPLE OF GNSS RADIO OCCULTATION OBSERVATION INDEPENDENT EXCHANGE FORMAT FILE

A.1 Example of BDS atmospheric occultation observation data file

An example of the BDS atmospheric occultation observation data file is shown in Figure A.1.

A.2 Example of GPS atmospheric occultation observation data file

An example of the GPS atmospheric occultation observation data file is shown in Figure A.2.

A.3 Example of BDS/GPS hybrid atmospheric occultation observation data file

An example of the BDS/GPS hybrid atmospheric occultation observation data file is shown in Figure A.3.

A.4 Example of BDS ionospheric occultation observation data file

An example of the BDS ionospheric occultation observation data file is shown in Figure A.4.

A.5 Example of GPS ionospheric occultation observation data file

An example of the GPS ionospheric occultation observation data file is shown in Figure A.5

```
     1.00           A                   C                   ROEX VERSION / TYPE
PROD 1.00           NSSC                20220320 080355 UTC PGM / RUN BY / DATE
############################################################ COMMENT
Example data made by xgmeng                                 COMMENT
############################################################ COMMENT
XX3X                                                        MARKER NAME
NSSC                NSSC                                    OBSERVER / AGENCY
GPS/BD              XXXX                3.0                 REC # / TYPE / VERS
 -128.260  -35.474                                          OCC APPROX POS L/B
 1                                                          OCC SETTING
C07 C22                                                     OCC / REF SAT #
C    6 L2I L6I S2I S6I C2I C6I                              SYS/#/OCC CLO TYPES
C    4 L2I L6I C2I C6I                                      SYS/#/REF CLO TYPES
C    9 L2I L6I S2I S6I O2I I2I Q2I C2I C6I                  SYS/#/OCC OPE TYPES
C    4 L2I L6I C2I C6I                                      SYS/#/REF OPE TYPES
  2022     1     2     1    16    13.9400000     BDT        TIME OF FIRST CLO
  2022     1     2     1    17    55.9800000     BDT        TIME OF LAST CLO
  2022     1     2     1    16    48.0000000     BDT        TIME OF FIRST OPE
  2022     1     2     1    17    55.9900000     BDT        TIME OF LAST OPE
     0.020                                                  INTERVAL OF OBS CLO
     0.010                                                  INTERVAL OF OBS OPE
                                                            END OF HEADER
                                                            START OF OBS CLO
> 2022  1  2  1 16 13.9400000  0  2       0.000000000000
C07  10495452.800   -15103005.396          41.896          54.461    44897092.436    44897103.879
C22   5081641.782     4220312.819           0.000           0.000
> 2022  1  2  1 16 13.9600000  0  2       0.000000000000
C07  10495945.456   -15102601.525          44.109          57.843    44897187.434    44897198.968
C22   5082083.869     4220672.051           0.000           0.000
 ⋮
> 2022  1  2  1 17 55.9800000  0  2       0.000000000000
C07 212715904.141  -169424966.412           0.000           0.000   299753725.528   299753712.198
C22   7540807.647     6218586.336           0.000           0.000
                                                            END OF OBS CLO
                                                            START OF OBS OPE
> 2022  1  2  1 16 48.0000000  0  2       0.000000000000
C07      61380.000           0.000           0.000           0.000       61380.000           0.000           0.000           0.000           0.000
C22   5857409.095     4850687.261     23293373.082     23293373.541
> 2022  1  2  1 16 48.0100000  0  2       0.000000000000
C07     122760.000           0.000           0.000           0.000      122760.000           0.000           0.000           0.000           0.000
C22   5857643.865     4850878.031           0.000           0.000
 ⋮
> 2022  1  2  1 17 55.9900000  0  2       0.000000000000
C07   7532884.419           0.000           0.000           0.000     7532884.725        -361.000         988.000           0.000           0.000
C22   7541068.121     6218797.993           0.000           0.000
                                                            END OF OBS OPE
```

Fig.A.1 Example of BDS atmospheric occultation

ROEX Version 1.00

```
     1.00          A                   G                   ROEX VERSION / TYPE
PROD 1.00          NSSC                20220320 080353 UTC PGM / RUN BY / DATE
########################################################## COMMENT
Example data made by xgmeng                                COMMENT
########################################################## COMMENT
XX3X                                                       MARKER NAME
NSSC               NSSC                                    OBSERVER / AGENCY
GPS/BD             XX3X                3.0                 REC # / TYPE / VERS
  -99.486  -11.789                                         OCC APPROX POS L/B
 1                                                         OCC SETTING
G04 G06                                                    OCC / REF SAT #
G    9 L1C L2X L2W S1C S2X S2W C1C C2X C2W                 SYS/#/OCC CLO TYPES
G    6 L1C L2X L2W C1C C2X C2W                             SYS/#/REF CLO TYPES
G   12 L1C L2X S1C S2X O1C I1C Q1C O2X I2X Q2X C1C C2X     SYS/#/OCC OPE TYPES
G    4 L1C L2X C1C C2X                                     SYS/#/REF OPE TYPES
  2022     1     2     1    22    2.0000000     GPS        TIME OF FIRST CLO
  2022     1     2     1    23   39.9800000     GPS        TIME OF LAST CLO
  2022     1     2     1    22   47.0000000     GPS        TIME OF FIRST OPE
  2022     1     2     1    23   39.9900000     GPS        TIME OF LAST OPE
     0.020                                                 INTERVAL OF OBS CLO
     0.010                                                 INTERVAL OF OBS OPE
                                                           END OF HEADER
                                                           START OF OBS CLO
> 2022  1  2  1 22  2.0000000  0  2       0.000000000000
G04  -2650761.979    -1695665.294    -833828.435        665.648          0.000          0.000    28932019.538    29079868.426    29079868.426
G06   8143335.081     6324610.927    6251147.673    20799565.000    20799576.079    20799576.375
> 2022  1  2  1 22  2.0200000  0  2       0.000000000000
G04  -2650083.462    -1728913.294    -833493.464        667.229          0.000          0.000    28932148.989    29079868.426    29079868.426
G06   8143829.757     6324996.391    6251533.135          0.000          0.000          0.000
 .
 .
 .
> 2022  1  2  1 23 39.9600000  0  2       0.000000000000
G04 -97284889.604   -41267253.013  -26554364.189          0.000         21.663          0.000   299609717.352   299609855.879   299609737.189
G06  10699552.761     8316468.783    8243005.533          0.000          0.000          0.000
> 2022  1  2  1 23 39.9800000  0  2       0.000000000000
G04 -97399977.604   -41300501.013  -26587612.189          0.000         19.762          8.526   299609717.352   299609855.879   299609737.189
G06  10700101.192     8316896.132    8243432.881          0.000          0.000          0.000
                                                           END OF OBS CLO
                                                           START OF OBS OPE
> 2022  1  2  1 22 47.0000000  0  2       0.000000000000
G04    -57544.000      -16624.000          0.000          0.000     -57544.000          0.000           0.000      -16624.000           0.000           0.000           0.000           0.000
G06   9284815.409     7214076.073   21016781.317   21016792.386
> 2022  1  2  1 22 47.0100000  0  2       0.000000000000
G04   -115088.000      -33248.000          0.000          0.000    -115088.000          0.000           0.000      -33248.000           0.000           0.000           0.000           0.000
G06   9285075.622     7214278.836          0.000          0.000
 .
 .
 .
> 2022  1  2  1 23 39.9800000  0  2       0.000000000000
G04  -4112388.161    -4060011.618          0.000         14.871   -4112388.627       -339.000         -73.000    -4060011.336        -233.000        1153.000           0.000           0.000
G06  10700101.192     8316896.132          0.000          0.000
> 2022  1  2  1 23 39.9900000  0  2       0.000000000000
G04  -4112061.642    -4059756.203          0.000         12.468   -4112061.398         65.000        1714.000    -4059756.352         637.000        -873.000           0.000           0.000
G06  10700375.411     8317109.811          0.000          0.000
                                                           END OF OBS OPE
```

Fig.A.2 Example of GPS atmospheric occultation observation

```
     1.00           A                   M                   ROEX VERSION / TYPE
PROD 1.00           NSSC                20220320 080355 UTC PGM / RUN BY / DATE
########################################################### COMMENT
Example data made by xgmeng                                 COMMENT
########################################################### COMMENT
SIMU                                                        MARKER NAME
NSSC                NSSC                                    OBSERVER / AGENCY
GPS/BD              SIMU                1.0                 REC # / TYPE / VERS
 -123.274  -41.922                                          OCC APPROX POS L/B
 1                                                          OCC SETTING
C10 G06                                                     OCC / REF SAT #
C    6 L2I L6I S2I S6I C2I C6I                              SYS/#/OCC CLO TYPES
G    4 L1C L2X C1C C2X                                      SYS/#/REF CLO TYPES
C    9 L2I L6I S2I S6I O2I I2I Q2I C2I C6I                  SYS/#/OCC OPE TYPES
G    4 L1C L2X C1C C2X                                      SYS/#/REF OPE TYPES
  2022     1     2     1    14   59.1000000     BDT         TIME OF FIRST CLO
  2022     1     2     1    16   29.9800000     BDT         TIME OF LAST CLO
  2022     1     2     1    15   32.0000000     BDT         TIME OF FIRST OPE
  2022     1     2     1    16   29.9900000     BDT         TIME OF LAST OPE
     0.020                                                  INTERVAL OF OBS CLO
     0.010                                                  INTERVAL OF OBS OPE
                                                            END OF HEADER
                                                            START OF OBS CLO
> 2022  1  2  1 14 59.1000000  0  2       0.000000000000
C10  11683651.857   -26015104.118         788.815        133.653    44698704.515    44845270.328
G06   3546981.253     2973275.515           0.000           0.000
> 2022  1  2  1 14 59.1200000  0  2       0.000000000000
C10  11684231.056   -26017039.633         790.054        302.437    44698815.682    44698801.690
G06   3547359.341     2973582.742           0.000           0.000
 .
 .
 .
> 2022  1  2  1 16 29.9800000  0  2       0.000000000000
C10 197734976.379 -168208947.882           2.686           7.399   299628706.144   299715838.521
G06   5441153.517     4512445.530           0.000           0.000
                                                            END OF OBS CLO
                                                            START OF OBS OPE
> 2022  1  2  1 15 32.0000000  0  2       0.000000000000
C10     61380.000           0.000           0.000           0.000       61380.000           0.000           0.000           0.000           0.000
G06   4192070.008     3497462.925    22973562.099    22973562.465
> 2022  1  2  1 15 32.0100000  0  2       0.000000000000
C10    122760.000           0.000           0.000           0.000      122760.000           0.000           0.000           0.000           0.000
G06   4192273.414     3497628.209           0.000           0.000
 .
 .
 .
> 2022  1  2  1 16 29.9900000  0  2       0.000000000000
C10   7542726.365           0.000          14.230           0.000     7542726.212        1546.000       -2239.000           0.000           0.000
G06   5441381.092     4512630.453           0.000           0.000
                                                            END OF OBS OPE
```

Fig.A.3 Example of BDS/GPS hybrid atmospheric occultation

ROEX Version 1.00

```
     1.00           I                   C                   ROEX VERSION / TYPE
PROD 1.00           NSSC                20220320 080353 UTC PGM / RUN BY / DATE
############################################################ COMMENT
Example data made by xgmeng                                 COMMENT
############################################################ COMMENT
XX3X                                                        MARKER NAME
NSSC                NSSC                                    OBSERVER / AGENCY
GPS/BD              XXXX                3.0                 REC # / TYPE / VERS
 -111.077    0.087                                          OCC APPROX POS L/B
 1                                                          OCC SETTING
C12                                                         OCC SAT #
C    6 L2I L6I S2I S6I C2I C6I                              SYS / # / OBS TYPES
  2022     1     2     1    18   58.0000000     BDT         TIME OF FIRST OBS
  2022     1     2     1    34   36.0000000     BDT         TIME OF LAST OBS
     1.000                                                  INTERVAL
                                                            END OF HEADER
> 2022  1  2  1 18 58.0000000  0  1       0.000000000000
C12    104381.266      431902.972         227.957         414.671    26473866.440    26473875.157
> 2022  1  2  1 18 59.0000000  0  1       0.000000000000
C12    126544.789      449912.650         226.037         431.841    26478123.299    26478129.205
> 2022  1  2  1 19  0.0000000  0  1       0.000000000000
C12    148737.697      467946.197         225.735         432.885    26482385.305    26482389.572
> 2022  1  2  1 19  1.0000000  0  1       0.000000000000
C12    170915.080      485967.135         225.915         431.621    26486644.074    26486647.827
  .
  .
  .
> 2022  1  2  1 34 36.0000000  0  1       0.000000000000
C12  21542279.626    18337844.498         157.656          64.275    30609773.802    30609788.483
```

Fig.A.4 Example of BDS ionospheric occultation observation data file

```
     1.00            I                   G                   ROEX VERSION / TYPE
PROD 1.00            NSSC                20220320 080352 UTC PGM / RUN BY / DATE
############################################################ COMMENT
Example data made by xgmeng                                  COMMENT
############################################################ COMMENT
XX3X                                                         MARKER NAME
NSSC                 NSSC                                    OBSERVER / AGENCY
GPS/BD               XXXX                3.0                 REC # / TYPE / VERS
   60.104   16.089                                           OCC APPROX POS L/B
 1                                                           OCC SETTING
G01                                                          OCC SAT #
G    9 L1C L2X L2W S1C S2X S2W C1C C2X C2W                   SYS / # / OBS TYPES
  2022     1     2     2     5    2.0000000     GPS          TIME OF FIRST OBS
  2022     1     2     2    10   14.0000000     GPS          TIME OF LAST OBS
     1.000                                                   INTERVAL
                                                             END OF HEADER
> 2022  1  2  2  5  2.0000000  0  1       0.000000000000
G01     184648.824     -152331.483      42793.249       105.619         137.777          47.483    24573976.039    24573985.201    24573983.785
> 2022  1  2  2  5  3.0000000  0  1       0.000000000000
G01     206170.813     -135561.126      59563.631       104.905         148.568          51.365    24578070.071    24578081.420    24578080.593
> 2022  1  2  2  5  4.0000000  0  1       0.000000000000
G01     227703.156     -118782.668      76342.086       107.180         148.979          53.031    24582167.204    24582179.273    24582179.250
> 2022  1  2  2  5  5.0000000  0  1       0.000000000000
G01     249245.865     -101996.158      93128.611       104.773         159.969          55.798    24586266.714    24586278.698    24586279.488
  ⋮

> 2022  1  2  2 10 14.0000000  0  1       0.000000000000
G01    7312631.186     5401940.140    5597064.888       228.070         406.801         209.720    25930385.218    25930396.410    25930397.303
```

Fig.A.5 Example of GPS ionospheric occultation observation data file

APPENDIX B: FILE NAMING

GNSS radio occultation observation independent exchange format file naming is recommended by the carrier name, receiver name, data start time, data duration, data type, and file suffix, etc., the file naming rules are as follows:

Mission_Payload_StartTime_Duration _DataType.Format.Compression

The character length of each field is fixed, separated by "_", and the last two fields "Format" and "Compression" are separated by "." between "Format" and "Compression". If the data length is insufficient, it is filled with 0. The description of each subparagraph in the file name is shown in Table 1.

Note: File naming is not strictly part of the GNSS occultation observation data exchange format definition, users can follow the ROEX data format definitions according to business needs.

Tab. B.1 Description of each sub-item in the file naming

Description items	Name	Necessary	Format
Mission	Name of the mission (or spacecraft)	Yes	4-character marker e.g.: FY3D means Fengyun-3D satellite
Payload	GNSS occultation receiver name	Yes	4-character marker e.g.: GNOS denotes the name of the GNSS occultation receiver on the FY3D satellite
StartTime	Data start time	Yes	Marked with 14 characters in the format YYYYMMDDHHMMSS, where YYYY means 4-digit year, MM means 2-digit month, DD means 2-digit day, and HHMMSS means the measurement start time

			(hour, minute, second). e.g.: 20210408121121 means the data start time is 12:11:21 on April 8, 2021. Time system using the file header identification of the time system
Duration	Data duration	Yes	5-characters marker, unit in seconds Padding with zeros on the left side of the insufficient part e.g.: 00090 means the data duration is 90 seconds
DataType	Data Type	Yes	Mark with 2 characters in the format SF S: Satellite System Identifier F: Data types (A: atmospheric occultation observations; I: ionospheric occultation observations; P: positioning observations) details: CA=BDS Atm. Obs. GA=GPS Atm. Obs. RA=GLONASS Atm. Obs. EA=Galileo Atm. Obs. JA=QZSS Atm. Obs. SA=SBAS Atm. Obs. IA=IRNSS Atm. Obs. MA=Mixed Atm. Obs. CI=BDS Ion. Obs. GI=GPS Ion. Obs. RI=GLONASS Ion. Obs. EI=Galileo Ion. Obs. JI=QZSS Ion. Obs. SI=SBAS Ion. Obs. II=IRNSS Ion. Obs. CP=BDS Pos. Obs. GP=GPS Pos. Obs. RP=GLONASS Pos. Obs. EP=Galileo Pos. Obs. JP=QZSS Pos. Obs. SP=SBAS Pos. Obs. IP=IRNSS Pos. Obs. MP=Mixed Pos. Obs. Where, Atm. Obs.: Atmospheric Observation; Ion. Obs.: Ionospheric Observation; Pos. Obs.: Positioning Observation.
Format	Data file format	Yes	3-character marker, ROX (or rox) in ROEX format.
Compression	Compression method for data files	No	2-3-character markers e.g.: gz: gzip compression method; zip: bzip2 compression method.