BeiDou Navigation Satellite System Ground-based Augmentation Service Interface Control Document

(Version 1.0)

China Satellite Navigation Office

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1 Statement

China Satellite Navigation Office is responsible for the preparation, revision, distribution, and retention of the BeiDou Navigation Satellite System (BDS) Interface Control Documents (hereinafter referred to as ICD), and reserves the rights for final interpretation of this document.

2 Scope

The Ground-based Augmentation System service is one type of the services provided by BDS. This document describes the related information of public service provided by the Ground-based Augmentation System.

3 Overview of the Ground-based Augmentation System

The Ground-based Augmentation System consists of a BDS augmentation station network, a communication network, a data processing and broadcasting system, etc. It provides augmentation service by wide-area augmentation products, regional augmentation products and post-processing high-precision data products, as shown in Table 3-1.

Table 3-1 Service description of BDS Ground-based Augmentation System

Types of service	**Wide-area augmentation service**			**Regional augmentation service**	**Post-processing service**
Supported navigation satellite system	BDS			BDS/GPS/GLONASS	
Service description	Single-frequency pseudorange augmentation service	Single-frequency carrier phase augmentation service	Dual-frequency carrier phase augmentation service	Network RTK service	Post-processing millimeter-level relative baseline measurement service

3.1 Coordinate System

BDS adopts the BeiDou Coordinate System (BDCS) whose definition complies with the standards of the International Earth Rotation and Reference System Service(IERS). The definition is also consistent with that of the China Geodetic Coordinate System 2000(CGCS2000). BDCS and CGCS2000 have the same ellipsoid parameters.

3.2 Time System

The BeiDou Navigation Satellite System Time (BDT) is adopted by the BDS as time reference. BDT adopts the second of the international system of units (SI) as the base unit, and accumulates continuously without leap seconds. The start epoch of BDT is 00:00:00 on January 1, 2006 of Coordinated Universal Time (UTC). BDT connects with UTC via UTC (NTSC), and the deviation of BDT to UTC is maintained within 50 nanoseconds (modulo 1 second).

4 The Augmentation Products Transmission Mode

The Ground-based Augmentation System provides augmentation products whereby the data are encoded and transmitted through mobile communication. For the signal characteristics of mobile communication, please refer to relevant documents and standards.

5 Information Format of Data Product

5.1 Wide-area Augmentation Data Product

5.1.1 Brief Description

The wide-area augmentation data product provided by BDS Ground-based Augmentation System consists of multiple messages, which is encapsulated referring to the RTCM3.2 data format. Each message is encapsulated separately (the message content length is no more than 1023 bytes) and the encapsulation format is shown in Figure 5-1.

Preamble (8 bits)	Reserved (6 bits)	Message Length (10 bits)	Message (≤1023 bytes)	CRC (24 bits)

Figure 5-1 Data Product Encapsulation Diagram

The message structure consists of a fixed preamble, a message length definition, a message, and a 24-bit Cyclic Redundancy Check (CRC). The content of message encapsulation is shown in Table 5-1.

Table 5-1 Message Encapsulation Content

Name	**Length**	**Note**
Preamble	8 bits	Fixed bits “11010011”
Reserved	6 bits	Reserved data field “000000”
Message Length	10 bits	The value is determined by the message content length.
Message*	≤1023 bytes	The message consists of message header and data in data field, with variable length, ranging from 0 to 1023 bytes.
Cyclic Redundancy Check Bit	24 bits	CRC-24Q algorithm
*The message is encapsulated in bits. Fill bits (zeros) must be used to complete the last byte at the end of the message data before the CRC in order to maintain the last byte boundary. Thus, the total number of bytes must be the next full integer if fill bits are needed. For example, 55.125 computed bytes means 56 bytes in total.		

5.1.2 Message Composition

The wide-area augmentation data product provided by BDS Ground-based Augmentation System includes six types of messages: combination of BDS orbit and clock correction message, combination of GPS orbit and clock correction message, ionospheric spherical harmonic model message, ionospheric grid message, BDS satellite code bias message and GPS satellite code bias message. The number and length of each type of messages are shown in Table 5-2.

Table 5-2 Messages of Wide-area Augmentation Data Product

Message Number	Message Type	Message Length (bytes)
1303	Combination of BDS Orbit and Clock Correction Message	8.5+25.625*Ns
1060	Combination of GPS Orbit and Clock Correction Message	8.5+25.625*Ns
1330	Ionospheric Spherical Harmonic Model Message	9.5+2.25*Ni
1331	Ionospheric Grid Message	41.75+1.625*Nt
1302	BDS Code Bias Message	8.375+1.375*Ns+2.375ΣNCB
1059	GPS Code Bias Message	8.375+1.375*Ns+2.375ΣNCB
Note: Ns is the number of BDS/GPS satellites, Ni = (spherical harmonic order +1) * (spherical harmonic degree +1), with a maximum of 128, and Nt is the number of ionospheric grid points, NCB = No. of Code Biases per individual Satellite and ΣNCB is the number of code bias of each GNSS system.		

Each message is as follows:

(1) Combination of BDS orbit and clock correction message: the satellite clock correction and the orbit correction are combined into one message, so as to ensure time consistency between the orbit correction data and the clock correction data. The message consists of message header and data content. The message header is detailed in Table 5-3, and the data content is detailed in Table 5-4.

(2) Combination of GPS orbit and clock correction messages: the satellite clock correction and the orbit correction are combined into one message, so as to ensure time consistency between the orbit correction data and the clock correction data. The message consists of message header and data content. The message header is detailed in Table 5-5, and the data content is detailed in Table 5-6.

(3) Ionospheric spherical harmonic model message: the ionospheric spherical harmonic model is independent from specific satellite navigation systems. This message can be used to

calculate ionospheric delay information, and its message header and data content are detailed in Table 5-7 and Table 5-8, respectively.

(4) Ionospheric grid model is independent from satellite navigation systems. The grid models of BDS and GPS are completely consistent, and the message type is also consistent. The ionosphere information of each grid includes grid vertical delay (dτ) and error index (GIVEI), occupying 13 bits in total. The ionospheric grid model message contains message header and data field. See Table 5-9 for the message header and Table 5-10 for the data field.

(5) BDS code bias message: BDS code bias message contains code bias corrections of the signal components of each BDS satellite. The BDS code bias message contains message header and data field. See Table 5-11 for the message header and Table 5-12 and Table 5-13 for the data content.

(6) GPS code bias message: GPS code bias message contains code bias corrections of the signal components of each BDS satellite. The BDS code bias message contains message header and data field. See Table 5-14 for the message header and Table 5-15 and Table 5-16 for the data content.

Table 5-3 Header Part of BDS Combined Orbit and Clock Correction Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
Message Number	DF002	uint12	12	Message number 1303
BDS Epoch Time	DF649	int20	20	-
SSR Update Interval	DF391	bit(4)	4	-
Multiple Message Indicator	DF388	bit(1)	1	-
Satellite Reference Datum	DF375	bit(1)	1	-
IOD SSR	DF413	uint4	4	-
SSR Provider ID	DF414	uint16	16	-
SSR Solution ID	DF415	uint4	4	-
No. of Satellite	DF387	Uint6	6	-
Total	-	-	68	-

Table 5-4 Satellite Specific Part of BDS Combined Orbit and Clock Correction Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
BDS Satellite ID	DF488	uint6	6	-
BDS IODE	DF541	uint8	8	-
Delta Radial	DF365	int22	22	-
Delta Along-Track	DF366	int20	20	-

Data Field	Data Field Number	Data Type	Number of Bits	Note
Delta Cross-Track	DF367	int20	20	-
Dot Delta Radial	DF368	int21	21	-
Dot Delta Along-Track	DF369	int19	19	-
Dot Delta Cross-Track	DF370	int19	19	-
Delta Clock C0	DF376	int22	22	-
Delta Clock C1	DF377	int21	21	-
Delta Clock C2	DF378	int27	27	-
Total	-	-	205	-

Table 5-5 Header Part of GPS Combined Orbit and Clock Correction Message

Data field	Data field number	Data type	Number of bits	Note
Message Number	DF002	uint12	12	Message number 1060
GPS Epoch Time	DF385	uint20	20	-
SSR Update Interval	DF391	bit(4)	4	-
Multiple Message Indicator	DF388	bit(1)	1	-
Satellite Reference Datum	DF375	bit(1)	1	-
IOD SSR	DF413	uint4	4	-
SSR Provider ID	DF414	uint16	16	-
SSR Solution ID	DF415	uint4	4	-
No. of Satellite	DF387	Uint6	6	-
Total	-	-	68	-

Table 5-6 Satellite Specific Part of GPS Combined Orbit and Clock Correction Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
GPS Satellite ID	DF068	uint6	6	-
GPS IODE	DF071	uint8	8	-
Delta Radial	DF365	int22	22	-
Delta Along-Track	DF366	int20	20	-
Delta Cross-Track	DF367	int20	20	-
Dot Delta Radial	DF368	int21	21	-
Dot Delta Along-Track	DF369	int19	19	-
Dot Delta Cross-Track	DF370	int19	19	-
Delta Clock C0	DF376	int22	22	-
Delta Clock C1	DF377	int21	21	-
Delta Clock C2	DF378	int27	27	-
Total	-	-	205	-

Table 5-7 Header Part of Ionospheric Spherical Harmonic Model Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
Message Number	DF002	uint12	12	Message number 1330
Epoch Time	DF385	uint20	20	Second of week
SSR Update Interval	DF391	bit(4)	4	-
Multiple Message Indicator	DF388	bit(1)	1	-
IOD SSR	DF413	uint4	4	-
SSR Provider ID	DF414	uint16	16	-
SSR Solution ID	DF415	uint4	4	-
Ionospheric Height	DF601	uint7	7	Scale factor is 10,000
Spherical Harmonic Order	DF602	uint4	4	-
Spherical Harmonic Degree	DF603	uint4	4	-
Total	-	-	76	-
Note: The spherical harmonic order in the table is no less than the spherical harmonic degree.				

The data field of ionospheric spherical harmonic model message includes the spherical harmonic coefficient C and the spherical harmonic coefficient S. The coding sequence of the spherical harmonic coefficients C and S shall be in accordance with the sequence of formula (1) matrix (from top to bottom and from left to right):

$$\begin{bmatrix} c_{00} & & & & & & \\ s_{11} & c_{10} & c_{11} & & & & \\ s_{22} & s_{21} & c_{20} & c_{21} & c_{22} & & \\ & \cdots\cdots & & & & & \\ s_{n,n} & \cdots & s_{n,1} & c_{n,0} & c_{n,1} & \cdots & c_{n,n} \end{bmatrix} \quad (1)$$

Where:

c_{ij}, s_{ij} --- Cosine and Sine coefficients corresponding to the order i and the degree j;

n --- Spherical harmonic order of the spherical harmonic model message header.

Note: The spherical harmonic order (set as *n*) is the same as the spherical harmonic degree (set as *m*) in the matrix by default; if *n*>*m*, then from the row *m*, each row has a coefficient of 2*m*+1, that is, the coefficient is $S_{k,m}, S_{k,m-1}, \cdots, S_{k,1}, C_{k,0}, C_{k,1} \cdots, C_{k,m}$, where $m \le k \le n$.

Table 5-8 Data Field of Ionospheric Spherical Harmonic Model Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
Spherical Harmonic Coefficient C	DF604	int18	18	-
Spherical Harmonic Coefficients S	DF605	int18	18	-
Total	-	-	36	-

Table 5-9 Header Part of Ionospheric Grid Model Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
Message Number	DF002	uint12	12	1331
Issue Of Data Ionosphere (IODI)	DF600	uint2	2	-
Ionospheric Grid Point Mask (IGP Mask)	DF606	bit(320)	320	-
Total	-	-	334	-

Table 5-10 Data Field of Ionospheric Grid Model Message

Data Field	Data Field Number	Data Type	Number of Bits	Note
Vertical Delay Correction (dτ)	DF607	bit(9)	9	-
Error Index (GIVEI)	DF608	bit(4)	4	-
Total	-	-	13	-

Table 5-11 Header Part of BDS Satellite Code Bias Message 1302

Data Field	Data Field Number	Data Type	Number of Bits	Note
Message Number	DF002	uint12	12	1302
BDS Epoch Time 1s	DF649	uint20	20	-
SSR Update Interval	DF391	bit(4)	4	-
Multiple Message Indicator	DF388	bit(1)	1	-
IOD SSR	DF413	uint4	4	-
SSR Provider ID	DF414	uint16	16	-
SSR Solution ID	DF415	uint4	4	-
No. of Satellites	DF387	uint6	6	-
Total	-	-	67	-

Table 5-12 Satellite Specific Part of BDS Satellite Code Bias Message 1302

Data Field	Data Field Number	Data Type	Number of Bits	Note
BDS Satellite ID	DF488	uint6	6	-
No. of Code Biases	DF379	uint5	5	-
Total	-	-	11	-

Table 5-13 Code Specific Part of BDS Satellite Code Bias Message 1302

Data field	Data field number	Data type	Number of bits	Note
BDS Signal and Tracking Mode Indicator	DF648	uint5	5	-
Code Bias	DF383	uint14	14	-
Total	-	-	19	-

Table 5-14 Header Part of GPS Satellite Code Bias Message 1059

Data Field	Data Field Number	Data Type	Number of Bits	Note
Message Number	DF002	uint12	12	1059
GPS Epoch Time 1s	DF385	uint20	20	-
SSR Update Interval	DF391	bit(4)	4	-
Multiple Message Indicator	DF388	bit(1)	1	-
IOD SSR	DF413	uint4	4	-
SSR Provider ID	DF414	uint16	16	-
SSR Solution ID	DF415	uint4	4	-
No. of Satellites	DF387	uint6	6	-
Total	-	-	67	-

Table 5-15 Satellite Specific Part of GPS Satellite Code Bias Message 1059

Data Field	Data Field number	Data Type	Number of Bits	Note
GPS Satellite ID	DF068	uint6	6	-
No. of Code Biases	DF379	uint5	5	-
Total	-	-	11	-

Table 5-16 Code Specific Part of GPS Satellite Code Bias Message 1059

Data Field	Data Field Number	Data Type	Number of Bits	Note
GPS Signal and Tracking Mode Indicator	DF380	uint5	5	-
Code Bias	DF383	int14	14	-
Total	-	-	19	-

5.1.3 Basic Frame Structure of Message

The basic frame ftructure of message generally consists of message header and data field, such as the combination of BDS orbit and clock correction message (message number 1303). The message is encapsulated in the form of the message header at the front and the data field at the back. If the data field of a message includes multiple data of the same structure, each data shall be programmed in sequence.

The message header and the data consist of multiple data fields respectively. Each data field is encapsulated according to the defined sequence to form the message header and the data. The programming process is aligned according to the bit.

Structures of combination of BDS orbit and clock correction message, spherical harmonic ionosphere message, ionospheric grid message and BDS code bias message are shown in Figure 5-2, Figure 5-3, Figure 5-4 and Figure 5-5, respectively.

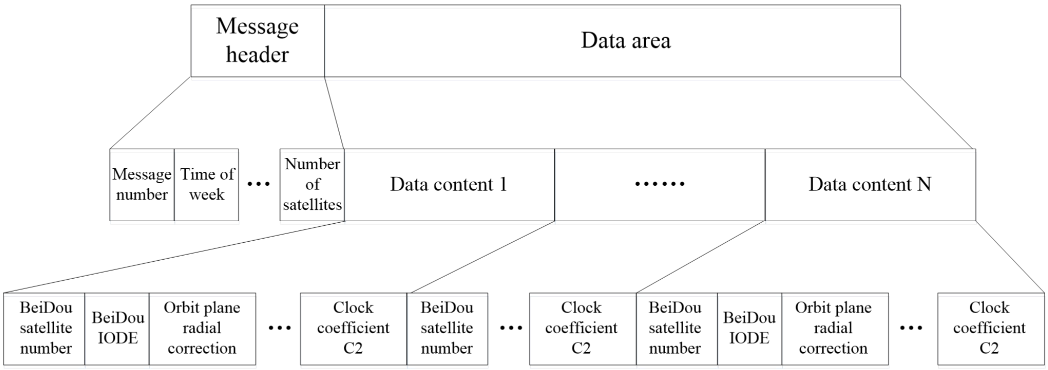

Figure 5-2 Structure of BDS Combined Orbit and Clock Correction Message

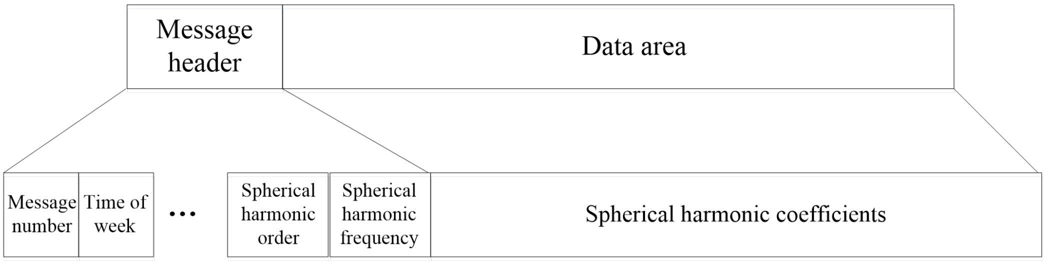

Figure 5-3 Structure of Ionosphere Spherical Harmonic Message

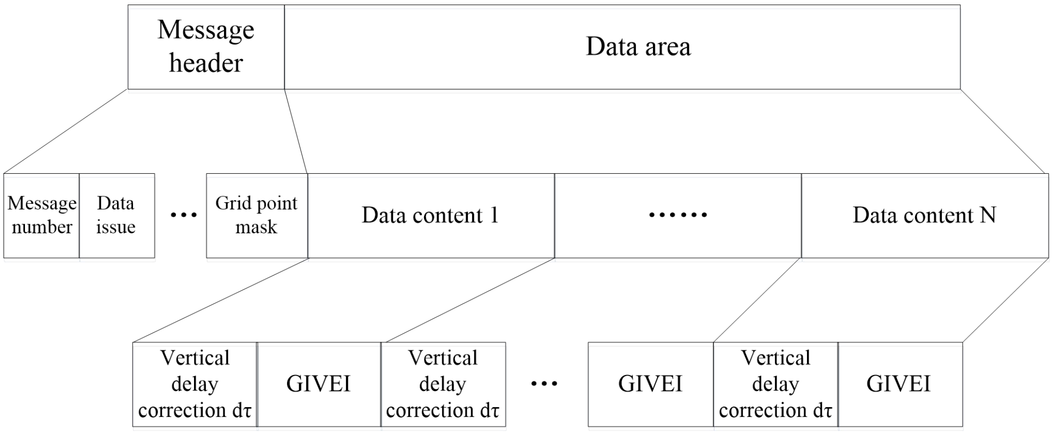

Figure 5-4 Structure of Ionosphere Grid Message

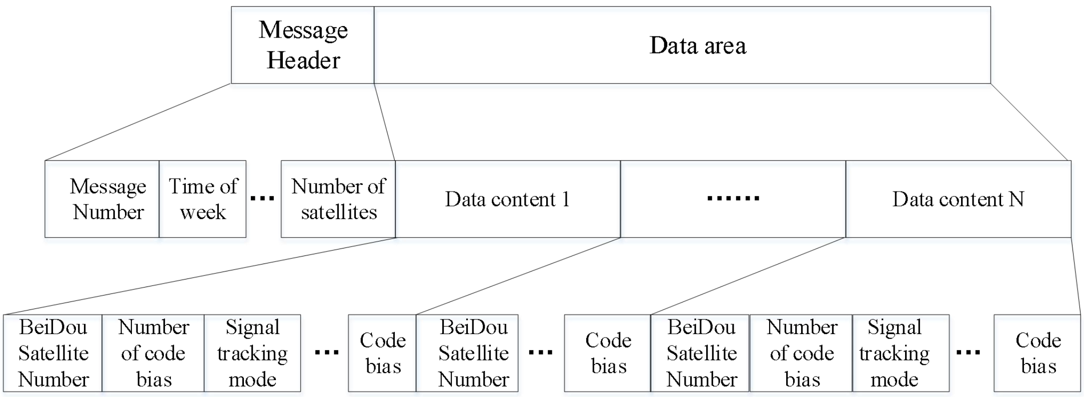

Figure 5-5 Structure of BDS Code Bias Message

5.1.4 Data Description

The data types involved in this standard are shown in Table 5-17.

Table 5-17 Data type

Data type	Description	Scope	Note
bit(N)	bit field	0 or 1, each bit	-
intN	N bit 2's complement integer	$\pm(2^{N-1}-1)$	-2^{N-1} indicates invalid data, N=8~38
uintN	N bit unsigned integer	0～2^N-1	N=2～36
Note: ±X represents the range of -X ~ +X. MSB is 0 for positive numbers and 1 for negative numbers The rest of the bits are the number's magnitude. Negative zero is not used.			

5.1.5 Data Field

The data field is the data that may be used in each message. The definition of each data field for the wide-area augmentation data product is shown in Table 5-18.

Table 5-18 Definition Table of Data Fields

Field Number	Field Name	Range	Scale Factor	Data Type	Note
DF002	Message Number	0～4095	-	uint12	Mark of different messages.
DF068	GPS Satellite ID	1～32	1	uint6	Represent GPS satellite number.
DF071	GPS IODE	-	1	uint8	IODE value of broadcast ephemeris used for calculation of correction
DF365	Delta Radial	±209.7151m	$1*10^{-4}$m	int22	Radial orbit correction for broadcast ephemeris.
DF366	Delta Along-Track	±209.7148m	$4*10^{-4}$m	int20	Along-track orbit correction for broadcast ephemeris.
DF367	Delta Cross-Track	±209.7148m	$4*10^{-4}$m	int20	Cross-track orbit correction for broadcast ephemeris.
DF368	Dot Delta Radial	±1.048575m/s	0.001mm/s	int21	Velocity of radial orbit correction for broadcast ephemeris.
DF369	Dot Delta Along-Track	±1.048572m/s	0.004mm/s	int19	Velocity of along-track orbit correction for broadcast ephemeris.
DF370	Dot Delta Cross-Track	±1.048572m/s	0.04mm/s	int19	Velocity of cross-track orbit correction for broadcast ephemeris.

Field Number	Field Name	Range	Scale Factor	Data Type	Note
DF375	Satellite Reference Datum	0～1	N/A	bit(1)	Orbit corrections refer to satellite reference datum: 0 - ITRF 1 - Regional.
DF376	Delta Clock C_0	±209.7151m	0.1mm	int22	C_0 polynomial coefficient for correction of broadcast satellite clock. The reference time t_0 is Epoch Time (DF385) plus ½ SSR Update Interval. The reference time t_0 for SSR Update Interval "0" is Epoch Time.
DF377	Delta Clock C_1	±1.048575m/s	0.001mm/s	int21	C_1 polynomial coefficient for correction of broadcast satellite clock. See notes on reference time t_0 of DF376.
DF378	Delta Clock C_2	±1.34217726 m/s^2	0.00002 mm/s^2	int27	C_2 polynomial coefficient for correction of broadcast satellite clock. See notes on reference time t_0 of DF376.
DF380	GPS Signal and Tracking Mode Identifier	0～31	1	uint5	Indicator to specify the GPS signal and tracking mode: 0 - L1 C/A 1- L1 P 2- L1 Z-tracking and similar (AS on) 3 - Reserved 4 - Reserved 5 - L2 C/A 6 - L2 L1(C/A)+(P2-P1) (semi-codeless) 7 - L2 L2C (M) 8 - L2 L2C (L) 9 - L2 L2C (M+L) 10 - L2 P 11 - L2 Z-tracking and similar (AS on) 12 - Reserved 13 - Reserved 14 - L5 I 15 - L5 Q >15 - Reserved.

Field Number	Field Name	Range	Scale Factor	Data Type	Note
DF385	GPS Epoch Time	0～604799s	1s	uint20	Full seconds since the beginning of the GPS week.
DF387	No. of Satellites	0～63	1	uint6	Total number of satellites included in the message.
DF388	Multiple Message Indicator	0～1	1	bit(1)	Indicator for transmitting messages with the same Message Number and Epoch Time: 0 - last message of a sequence 1 - multiple message transmitted.
DF391	SSR Updated Interval	0～15	1	bit(4)	0 - 1 s 1 - 2 s 2 - 5 s 3 - 10 s 4 - 15 s 5 - 30 s 6 - 60 s 7 - 120 s 8 - 240 s 9 - 300 s 10 - 600 s 11 - 900 s 12 - 1800 s 13 - 3600 s 14 - 7200 s 15 - 10800 s In order to allow synchronous operation for multiple GNSS services, the SSR Update Intervals for all SSR parameters start at time 00:00:00 of the GPS time scale.
DF413	IOD SSR	0～15	1	uint4	A change of issue of data SSR is used to indicate a change in the SSR generating configuration, which may be relevant for rover operation.

Field Number	Field Name	Range	Scale Factor	Data Type	Note
DF414	SSR Provider ID	0～65535	1	uint16	SSR provider ID is provided by RTCM on request to identify an SSR service. The Provider ID shall be globally unique. Providers should contact “rtcm.org”.
DF415	SSR Solution ID	0～15	1	uint4	SSR solution ID indicates different SSR services of one SSR provider.
DF541	BDS IODE	0～255	1	uint8	In order to ensure correct and unique matching with the broadcast ephemeris, the BDS differential correction message uses the customized IODE generation algorithm. The algorithm of broadcast ephemeris IODE calculation is as follows: IODE (t_{oc}/720) Mod 240.
DF549	BDS Epoch Time	0～604799s	1s	uint20	Full seconds since the beginning of the BDS week.
DF600	Issue of Data, Ionosphere (IODI)	0～3	1	uint2	The user should ensure that the IODI of used grid is consistent with to the one in the relevant message before providing a vertical delay to the model.
DF601	Ionospheric Height	0～128×104m	104m	uint7	DF 601 is ionospheric height and it is 450000 m by default.
DF602	Spherical Harmonic Order	0～15	1	uint4	The maximum order is 15.
DF603	Spherical Harmonic Degree	0～15	1	uint4	The maximum degree is 15.
DF604	Spherical Coefficient C	0～2048	2-6	int18	The spherical harmonic coefficient C is divided by 64 when decoding.
DF605	Coefficient S	0～2048	2-6	int18	The spherical harmonic coefficient S is divided by 64 when decoding.

Field Number	Field Name	Range	Scale Factor	Data Type	Note
DF606	Ionospheric Grid Point Mask (IGP Mask)	-	-	bit(320)	DF606 provides the observed ionospheric grid point conditions. Each grid point corresponds to one bit, while MSB is equivalent to the grid point with ID=1, the second bit is equivalent to the grid point with ID=2......, and LSB is equivalent to the grid point with ID=320. The information part only transmits the data information of the valid grid points, i.e., when there are m 1's before the n^{th} bit, the ionospheric information of the grid point is located at the (m+1)th value. If there is ionospheric grid point data with ID=n in the following data, the corresponding bit (nth bit) should be 1, otherwise it should be 0, the position 0 is reserved, and the sum of all the bits being 1 is the total number Nt of the valid grid points.
DF607	Vertical Delay Correction (dτ)	0～63.875m	0.125m	bit(9)	Represent the vertical delay correction of the ionospheric grid point.
DF608	Error Index (GIVEI)	0～15	-	bit(4)	Describe the accuracy of grid ionospheric delay correction and is characterized by the grid ionosphere vertical error index (GIVEI).
DF548	BDS Signal and Tracking Mode Identifier	0～31	1	uint5	Indicator to specify the BDS signal and tracking mode: 0- B1I 1- B1Q 2- B1X

Field Number	Field Name	Range	Scale Factor	Data Type	Note
					3 - Reserved 4 - Reserved 5 - B2I 6 - B2Q 7 - B2X 8 - Reserved 9 - Reserved 10 - B3I 11 - B3Q 12 - B3X >13 - Reserved.

5.1.6 The Solution Algorithm

See Appendixes for the wide-area augmentation algorithm.

5.2 Regional Augmentation Data Product Format

The regional augmentation data products provided by GAS consist of multiple messages, including 4 messages: RTK reference station ARP message, GPS MSM4 message, BDS MSM4 message and GLONASS MSM5 message. The number and length of each message are shown in Table 5-19.

Table 5-19 Regional Augmentation Data Product Message

Message Number	Message Type	Number of Bytes
1005	RTK Reference Station ARP Message	19
1074	GPS MSM4	169+Ns*(18+49*Nsig)
1085	GLONASS MSM5	169+Ns*(36+64*Nsig)
1124	BDS MSM4	169+Ns*(18+49*Nsig)
Note: Ns represents the number of BDS/GPS/GLONASS satellites, and Nsig represents the number of transmitted signal types.		

All messages of the regional augmentation data product are the same as the massages with corresponding number in RTCM3.2. See the encapsulation format, message format and data field in RTCM3.2.

5.3 Post-processing High-precision Data Product Format

The post-processing high-precision service does not provide corresponding data products for users. The users upload the observation data, and the service platform processes the data and then provides the service.

6 Abbreviations

ARP	Antenna Reference Point
BDCS	BeiDou Coordinate System
BDS	BDS Navigation Satellite System
BDT	BeiDou Navigation Satellite System Time
CGCS2000	China Geodetic Coordinate System 2000
CRC	Cyclic Redundancy Check
DF	Data Field
EOP	Earth Orientation Parameter
ERP	Earth Rotation Parameter
GAS	Ground-based Augmentation System
GIVE	Grid Ionospheric Vertical Error
GIVEI	Grid Ionospheric Vertical Error Index
GNSS	Global Navigation Satellite System
GLONASS	Global Navigation Satellite System
GPS	Global Positioning System
ICD	Interface Control Document
ID	Identification
IERS	International Earth Rotation and Reference System Service
IOD	Issue Of Data
IODE	Issue Of Data Ephemeris
IODI	Issue of Data Ionosphere
ITRF	International Terrestrial Reference Frame
IONEX	IONospheric Map Exchange Format
ITRS	International Terrestrial Reference System
MSB	Most Significant Bit
MSM	Multiple Signal Messages
NTSC	National Time Service Center

PDOP	Position Dilution Of Precision
RINEX	Receiver INdependent EXchange format
RMS	Root Mean Square
RTCM	Radio Technical Commission for Maritime Services
RTK	Real Time Kinematic
SSR	State Space Representation
TOW	Time of Week
UTC	Coordinated Universal Time

Annex Wide-area Differential User Terminal Solution Method

1 Orbit Correction Message

The orbit correction message contains the parameters for orbit corrections δO in radial, along-track and cross-track component. These orbit corrections are used to compute a satellite position correction δX, to be combined with satellite position $X_{broadcast}$, calculated from broadcast ephemeris. The sign definition of the correction is

$$X_{orbit} = X_{broadcast} - \delta X \tag{A-1}$$

Where:

X_{orbit}——satellite position corrected by SSR orbit correction message (m)

$X_{broadcast}$——satellite position computed according to corresponding GNSS ICD from broadcast ephemeris parameter set identified by IOD/IODE in SSR orbit correction message (m)

δX——satellite position correction (m)

The satellite position correction δX is computed according to (A-2) ~ (A-5)

$$e_{along} = \frac{\dot{r}}{|\dot{r}|} \tag{A-2}$$

$$e_{cross} = \frac{r \times \dot{r}}{|r \times \dot{r}|} \tag{A-3}$$

$$e_{radial} = e_{along} \times e_{cross} \tag{A-4}$$

$$\delta X = \begin{bmatrix} e_{radial} & e_{along} & e_{cross} \end{bmatrix} \delta O \tag{A-5}$$

Where:

$r = X_{broadcast}$——satellite position vector calculated by broadcast ephemeris

$\dot{r} = \dot{X}_{broadcast}$—satellite velocity vector calculated by broadcast ephemeris

e_i—direction unit vector, $i = \{radial, along, cross\}$

δO—orbit correction vector

The complete orbit correction vector δO is computed from the individual correction terms and their velocities (A-6):

$$\delta O = \begin{bmatrix} \delta O_{radial} \\ \delta O_{along} \\ \delta O_{cross} \end{bmatrix} + \begin{bmatrix} \delta \dot{O}_{radial} \\ \delta \dot{O}_{along} \\ \delta \dot{O}_{cross} \end{bmatrix} (t - t_0) \tag{A-6}$$

Where:

t ——the current observation epoch time (s)

t_0 ——reference time obtained from SSR orbit correction message (s)

$\delta O_i, \delta \dot{O}_i$ ——orbit correction terms from SSR orbit message, i = {radial, along, cross}

The reference time for the velocity term is computed from the GNSS epoch time plus half the SSR update interval. Exception is SSR update interval "0", which uses the GNSS epoch time as reference time.

2 Clock Correction Message

The clock correction message contains the parameters to compute the clock correction δC applied to the broadcast satellite clock. The polynomial representation describes the clock differences for a certain time period. The sign definition of the corrections is:

$$t_{satellite} = t_{broadcast} - \frac{\delta C}{c} \tag{A-7}$$

Where:

$t_{satellite}$ ——satellite time corrected by SSR clock correction message (s)

$t_{broadcast}$ ——satellite time computed according to corresponding GNSS ICD from broadcast clock parameters identified by IOD/IODE of corresponding SSR orbit correction message(s)

δC ——the value of the clock obtained from the SSR clock correction message, in meters (m)

c ——the speed of light in meters per second (m/s).

δC clock correction obtained from SSR clock correction message

$$\delta C = C_0 + C_1(t - t_0) + C_2(t - t_0)^2 \tag{A-8}$$

Where:

t ——the current observation epoch time (s)

t_0 ——reference time obtained from SSR clock correction message(s)

C_i ——polynomial coefficients from SSR clock correction message, $i = \{0, 1, 2\}$

The reference time for the polynomial terms is computed from the GNSS epoch time plus half the SSR update interval. Exception is SSR update interval “0”, which uses the epoch time as reference time.

Note: the relativity correction has to be applied to compute $t_{broadcast}$. The relativistic correction term Δt_T is (A-9):

$$\Delta t_T = -\frac{2r \cdot \dot{r}}{c^2} \tag{A-9}$$

Where:

Δt_T ——relativistic correction term

r , $\dot{r}$ ——the vectors computed from broadcast ephemeris

Satellite clocks are determined by ionospheric free signals derived from observations used by the service provider. Such observations are affected by delays introduced in the satellite hardware (code biases). For SSR, the selection of signals used to generate the satellite clock corrections and the treatment of code biases are left to the service provider. The service provider shall ensure a consistent transmission of clock and code bias parameters. A rover must then consistently apply the code biases and clock corrections.

3 Ionospheric Delay Correction

3.1 Spherical Harmonic Model

In the ionospheric spherical harmonic model, the calculation method of ionospheric delay $(T_{iono}(t))_{Lx}$ on the L_x oblique path is shown in formula (A-10, A-11):

$$(T_{iono}(t))_{1x} = \gamma_{1x}F(t)\sum_{n=0}^{n_{\max}}\sum_{m=0}^{M}\tilde{p}_{nm}(\sin\phi_{pp}(t))(\tilde{C}_{nm}\cos(m\cdot s)+\tilde{S}_{nm}\sin(m\cdot s)) \quad \text{(A-10)}$$

Where:

$$\gamma_{Lx} = 40.3\cdot 10^{16}/f_x^2 \quad \text{(A-11)}$$

Where:

$(T_{iono}(t))_{Lx}$—value of ionospheric delay in oblique path, in meters (m)

f_x—carrier frequency of the signal L_x

$F(t)$—mapping function

$n_{\max}$—the highest order of the spherical harmonic expansion

M—spherical harmonic expansion degree, M=min (n, $m_{\max}$)

$m_{\max}$—the highest degree of the spherical harmonic expansion

$\tilde{P}_{nm}$— the normalized n-order m-degree Legendre function

$\phi_{pp}(t)$—latitude value of the pierce point of ionosphere (diurnal geomagnetic coordinate system), in radians (rad)

$\tilde{C}_{nm}$—cosine function coefficient of ionosphere

$\tilde{S}_{nm}$—sine function coefficient of ionosphere

s—the daily solidity of the puncture point, in radians (rad)

The calculation method of mapping function $F(t)$ is shown in formula (A-12):

$$F(t) = 1/\sqrt{1-\left(\frac{a\cos El(t)}{a+H_{iono}}\right)^2} \quad \text{(A-12)}$$

Where:

$El(t)$—the elevation angle between the user and satellite, in radians (rad)

a—equatorial radius defined by ITRS, in meters (m)

H_{iono}—altitude of the ionosphere above the earth, in meters (m), and it is 450000 m by default

The calculation method of the normalized Legendre function $\widetilde{P}_{nm}$ is shown in formula (A-13):

$$\widetilde{P}_{nm}(x) = \mathrm{MC}(n, m) \cdot P_{nm}(x) \qquad \text{(A-13)}$$

Where:

$$P_{nm}(x) = (1 - x^2)^{\frac{m}{2}} \frac{1}{2^n} \sum_{k=0}^{L} \frac{(-1)^k}{(n-k)!} \frac{(2n-2k)!}{(n-m-2k)!} x^{n-m-2k}$$

k∈N, L=int[(n-m)/2]

$$\mathrm{MC}(n, m) = \sqrt{\frac{(n-m)!(2n+1)(2-\delta_{0m})}{(n+m)!}}$$

δ_{0m}——Kronecker δ function

n, m, x——input parameter

The conversion relation between the pierce point of the earth fixed geosynthetic system and the sun fixed geosynthetic system is shown in formulas (A-14) and (A-15):

Given the simplified Julian day *mjd* at the observed epoch, the location latitude and longitude of the pierce point ϕ_{pp}, λ_{pp} ; sun fixed geosynthetic latitude and longitude φ, s , $pole2 = -1.267$, $pole1 = 1.40$, $sunlon = \pi - (mjd - (\text{int})mjd) \times 2\pi$.

$$\begin{bmatrix} r_0 \\ r_1 \\ r_2 \end{bmatrix} = R_3(pole2) R_2(\frac{\pi}{2} - pole1) R_3(-pole2) rtmp \qquad \text{(A-14)}$$

$$\begin{bmatrix} sunr_0 \\ sunr_1 \\ sunr_2 \end{bmatrix} = R_3(pole2) R_2(\frac{\pi}{2} - pole1) R_3(-pole2) surtmp \qquad \text{(A-15)}$$

Where:

$$rtmp = \begin{bmatrix} \cos\phi_{pp}\cos\lambda_{pp} & \cos\phi_{pp}\sin\lambda_{pp} & \sin\phi_{pp} \end{bmatrix}^T$$

$$surtmp = \begin{bmatrix} \cos(sunlon) & \sin(sunlon) & 0 \end{bmatrix}^T$$

$$R_3(pole2) = \begin{bmatrix} \cos(pole2) & \sin(pole2) & 0 \\ -\sin(pole2) & \cos(pole2) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_3(-pole2) = \begin{bmatrix} \cos(pole2) & \sin(pole2) & 0 \\ -\sin(-pole2) & \cos(-pole2) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_2(\frac{\pi}{2}-pole1)=\begin{bmatrix}\cos(\frac{\pi}{2}-pole1) & 0 & -\sin(\frac{\pi}{2}-pole1)\\ 0 & 1 & 0\\ \sin(\frac{\pi}{2}-pole1) & 0 & \cos(\frac{\pi}{2}-pole1)\end{bmatrix}$$

For the calculation of longitude and latitude of lower pierce point of sun fixed geomagnetic coordinate system, see formulas (A-16) ~ (A-20).

$$\varphi = \tan^{-1}\frac{r_2}{\sqrt{r_0^2 + r_1^2}} \tag{A-16}$$

$$sumlon = \tan^{-1}\frac{r_1}{r_0} \tag{A-17}$$

$$lons = \tan^{-1}\frac{sunr_1}{sunr_0} \tag{A-18}$$

$$lon = smlon - lons \tag{A-19}$$

$$s = \begin{Bmatrix} lon + 2\pi & lon<0 \\ lon & lon \geq 0 \end{Bmatrix} \tag{A-20}$$

Where:

r_0, r_1, r_2, $sunr_1$, $sunr_2$ are calculated from equations (A-14) and (A-15)

φ —latitude of lower pierce point of earth fixed geomagnetic coordinate system, in radians (rad)

s —longitude of lower pierce point of earth fixed geomagnetic coordinate system, in radians (rad)

3.2 Spherical harmonic cosine coefficient model

The ionospheric delay can be calculated according to the ionospheric error correction coefficient when the pseudorange is calculated by single-frequency users.

The ionospheric pierce point coordinates should be obtained to calculate the ionospheric delay. In the ITRS coordinate system, the calculation method of the ionosphere pierce point latitude $\phi_{pp}(t)$ is shown in formula (A-21), and the calculation method of the ionosphere pierce point longitude $\lambda_{pp}(t)$ is shown in formula (A-22):

$$\phi_{pp}(t) = \sin^{-1}\left\{\sin\phi_r \cos\psi_{pp}(t) + \cos\phi_r \sin\psi_{pp}(t)\cos Az(t)\right\} \tag{A-21}$$

$$\lambda_{pp}(t) = \lambda_r + \tan^{-1}\left(\frac{\sin\psi_{pp}(t)\sin Az(t)}{\cos\psi_{pp}(t)\cos\phi_r - \sin\psi_{pp}(t)\cos Az(t)\sin\phi_r}\right) \tag{A-22}$$

Where:

$\phi_{pp}(t)$ —latitude of the pierce point of ionosphere, in radians (rad)

ϕ_r —latitude of the user receiver in the ITRS coordinate system, in radians (rad)

$\psi_{pp}(t)$ —the earth's central angle between the user position and the earth projection of the pierce point, in radians (rad)

Az —azimuth angle between user receiver and satellite, in radians (rad)

$\lambda_{pp}(t)$ —longitude of the pierce point of ionosphere, in radians (rad)

λ_r —longitude of the user receiver in the ITRS coordinate system, in radians (rad)

$\psi_{pp}(t)$ is calculated in formula (A-23)

$$\psi_{pp}(t) = \frac{\pi}{2} - El(t) - \sin^{-1}\left(\frac{a}{a + H_{iono}} \cdot \cos El(t)\right) \qquad \text{(A-23)}$$

Where:

$El(t)$ —the elevation angle between the user and satellite, in radians (rad)

a —equatorial radius defined by ITRS, in meters (m)

H_{iono} —altitude of the ionosphere above the earth, in meters (m), and it is 450000 m by default

3.3 Grid Model

(1) Ionospheric Grid Information

The information of each ionospheric grid point (IGP) consists of the vertical delay at grid point (dτ) and its error index (GIVEI), occupying 13 bits altogether.

(2) Grid Number

The ionospheric grid covers 70 to 145 degrees east longitude and 7.5 to 55 degrees north latitude. This area is divided into 320 grids of 5×2.5 degrees. The definition of ionospheric grid point (IGP) numbers less than or equal to 160 is listed in Table A-1.

Table A-1 Definition of Grid Points (No. 1～160)

Latitude	**Longitude**															
	70	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**	**145**
55	10	20	30	40	50	60	70	80	90	100	110	120	130	140	150	160
50	9	19	29	39	49	59	69	79	89	99	109	119	129	139	149	159
45	8	18	28	38	48	58	68	78	88	98	108	118	128	138	148	158
40	7	17	27	37	47	57	67	77	87	97	107	117	127	137	147	157

Latitude	Longitude															
	70	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**	**145**
35	6	16	26	36	46	56	66	76	86	96	106	116	126	136	146	156
30	5	15	25	35	45	55	65	75	85	95	105	115	125	135	145	155
25	4	14	24	34	44	54	64	74	84	94	104	114	124	134	144	154
20	3	13	23	33	43	53	63	73	83	93	103	113	123	133	143	153
15	2	12	22	32	42	52	62	72	82	92	102	112	122	132	142	152
10	1	11	21	31	41	51	61	71	81	91	101	111	121	131	141	151

When IGP≤160, the corresponding longitudes and latitudes are (A-24):

$$L = 70 + INT((IGP - 1)/10) \times 5$$
$$B = 5 + (IGP - INT((IGP - 1)/10) \times 10) \times 5 \quad \text{(A-24)}$$

Where:

L —longitude, in degrees (°)

$INT(*)$ —round down

IGP—grid number

B —latitude, in degrees (°)

The definition of ionospheric grid points numbers more than 160 is shown in Table A-2.

Table A-2 Definition of Grid Points (No.161～320)

Latitude	Longitude															
	70	**75**	**80**	**85**	**90**	**95**	**100**	**105**	**110**	**115**	**120**	**125**	**130**	**135**	**140**	**145**
52.5	170	180	190	200	210	220	230	240	250	260	270	280	290	300	310	320
47.5	169	179	189	199	209	219	229	239	249	259	269	279	289	299	309	319
42.5	168	178	188	198	208	218	228	238	248	258	268	278	288	298	308	318
37.5	167	177	187	197	207	217	227	237	247	257	267	277	287	297	307	317
32.5	166	176	186	196	206	216	226	236	246	256	266	276	286	296	306	316
27.5	165	175	185	195	205	215	225	235	245	255	265	275	285	295	305	315
22.5	164	174	184	194	204	214	224	234	244	254	264	274	284	294	304	314
17.5	163	173	183	193	203	213	223	233	243	253	263	273	283	293	303	313
12.5	162	172	182	192	202	212	222	232	242	252	262	272	282	292	302	312
7.5	161	171	181	191	201	211	221	231	241	251	261	271	281	291	301	311

When IGP > 160, the corresponding longitudes and latitudes are (A-25):

$$L = 70 + INT((IGP - 161)/10) \times 5$$
$$B = 2.5 + (IGP - 160 - INT((IGP - 161)/10) \times 10) \times 5 \quad \text{(A-25)}$$

Where:

L —longitude, in degrees (°)

$INT(*)$ —round down

IGP—grid number

B —latitude, in degrees (°)

(3) Issue of Data Ionosphere (IODI)

IODI occupies 2 bits, which represents an effective range of 0~3. The IODI changes each time the IGP mask changes. The user should ensure that the IODI of all bands agree and that they agree with the IODI in IGP before applying the vertical delays to the model.

(4) Vertical Delay Parameter of Ionosphere

dτi is the vertical ionosphere delay at the i^{th} grid point, expressed in scale factor of 0.125 in meters. The effective range of dτi is between 0 to 63.625 meters. IGP is not monitored when the value of dτi is 111111110 (=63.750meters). dτi is not available when its value is 111111111 (=63.875meters).

Making use of the ionospheric correction at grid points, the users compute the ionospheric correction for the intersection point of ionosphere and direction from user to observed satellite by interpolation and correct the observed pseudorange. The reference altitude of ionosphere is 450000 m.

(5) Grid Ionospheric Vertical Error Index (GIVEI)

The grid ionosphere vertical error (GIVE) describes the delay correction accuracy at ionosphere grid points and is indicated with GIVEI, which is composed of 4 bits, as shown in Table A-3.

Table A-3 GIVEI Definitions

GIVEI	GIVE (meters)
0	0.3
1	0.6
2	0.9
3	1.2
4	1.5
5	1.8

GIVEI	GIVE (meters)
6	2.1
7	2.4
8	2.7
9	3.0
10	3.6
11	4.5
12	6.0
13	9.0
14	15.0
15	45.0

(6) Suggestions on User Grid Ionospheric Correction Algorithm

The user can select effective data of the grid points adjacent to or nearby the observed intersection point with $d\tau_i$ and GIVEI to design the model and compute the delay correction for ionospheric pierce point (IPP) by interpolation.

As long as there are at least three grid points surrounding the user IPP available and effective, the IPP ionospheric delay can be calculated from the vertical ionospheric delay of these effective grid points through the bilinear interpolation algorithm. The guiding fitting algorithm is shown in formula (A-26):

$$Ionodelay_p = \frac{\sum_{i=1}^{4} \omega_i \times VTEC_i}{\sum_{i=1}^{4} \omega_i} \tag{A-26}$$

Where:

$Ionodelay_p$ —value of vertical ionospheric delay at the user's pierce point, in meters (m)

$\omega_i (i = 1 \sim 4)$ —weight of distance between IPP and the four grids

$VTEC_i (i = 1 \sim 4)$ —value of vertical ionospheric delay of the grids around the user's pierce point, in meters (m)

ω_i The calculation method of is shown in formula (A-27) ~ (A-32):

$$\omega_1 = (1 - x_p) \times (1 - y_p) \tag{A-27}$$

$$\omega_2 = x_p \times (1 - y_p) \tag{A-28}$$

$$\omega_3 = x_p y_p \tag{A-29}$$

$$\omega_4 = (1 - x_p) \times y_p \tag{A-30}$$

Where:

$$x_p = \frac{\lambda_p - \lambda_1}{\lambda_2 - \lambda_1} \quad \text{(A-31)}$$

$$y_p = \frac{\phi_p - \phi_1}{\phi_4 - \phi_1} \quad \text{(A-32)}$$

Where:

(φ_p, λ_p) —latitude and longitude of the geographic location of the ionospheric pierce point corresponding to the user receiver and a satellite connection, in degree (°)

$(\varphi_i, \lambda_i, i = 1 \sim 4)$ —location of the four grids around the user's pierce point

The position relation between the user's pierce point and the four grid points around it is shown in Figure A-1.

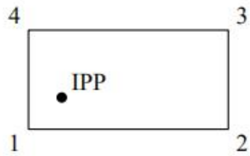

Figure A-1 User IPP and Grid Points

The calculated vertical ionospheric delay $Ionodelay_p$ of the user's pierce point can be used to calculate the ionospheric delay $(T_{iono}(t))_{Lx}$ on the oblique path of L_x, as shown in formula (A-33):

$$(T_{iono}(t))_{Lx} = \gamma_{Lx} \times F(t) \times Ionodelay_p \quad \text{(A-33)}$$

Where:

$(T_{iono}(t))_{Lx}$ —value of ionospheric delay in oblique path, in meters (m)

γ_{Lx} —square of the ratio of L_x frequency to L1 frequency

$F(t)$ —mapping function

Where, the calculation method of mapping function $F(t)$ is shown in formula (A-34):

$$F(t) = 1 / \sqrt{1 - \left(\frac{a \cos El(t)}{a + H_{iono}} \right)^2} \quad \text{(A-34)}$$

Where:

$El(t)$ —the elevation angle between the user and satellite, in radians (rad)

a —equatorial radius defined by ITRS, in meters (m)

H_{iono} —altitude of the ionosphere above the earth, in meters (m), and it is 450000 m by default

4 Satellite Code Bias Correction

Due to the different tracking modes of satellite signals, each observation is subject to a code bias related to signal tracking modes. In order to realize precise positioning performance, when different signals at different frequencies are processed, the code bias of each observation should first be corrected, and the correction method is shown in formula (A-35):

$$\tilde{l}_{sig} = l_{sig} + bias_{sig} \tag{A-35}$$

Where：

$\tilde{l}_{sig}$ ——pseudorange observation of signal sig after code bias correction, in meters (m)

$\tilde{l}_{sig}$ ——raw pseudorange observation of signal sig, in meters (m)

$bias_{sig}$ ——satellite code biases of the corresponding signal, in meters (m)

Users can get the satellite code bias corrections of different pseudorange observations based on DF548 and DF380, and the corrections should be added to the corresponding raw pseudorange observations.