SAPA Interface Control Document

Draft Version 1.7

Scottsdale, May 2019

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1. Revision Control

Version	Date modified	Changes/updates
1.0	February 7 2018	- Initial version of ICD proposal including OCB messages only
1.1	March 23 2018	- Follow up of ICD proposal including atmospheric messages
1.2	August 1 2018	- Re-structuring of messages and document layout in accordance with feedback by all partners and collaborators in the SAPA format development
1.3	August 22 2018	- Incorporation of comments from technical board meeting; - Addition of several aspects of message interpretation and integration.
1.4	October 3 2018	- Adjust of HPAC atmosphere data field bounds - Added preface, introduction and carrier phase alignment sections
1.5	November 3 2018	- Added confidentialy note in every page of document
1.6	December 7 2018	- Renamed HPAC Area definition message to Geographic Area Definition - Dropped Special Values representing invalid Satellite Corrections (SF020) and code bias correction (SF029). Range remains the same. - Decreased length of code bias masks by 1 to make them same length as phase bais masks. See SF027 and SF028 - Fixed inconsistency between Number of Grid Points Present (SF039) and Area Latitude Grid Node Count (SF034) and Area Longitude Grid Node Count (SF035). - Fixed Ionosphere Grid Residuals definition (table 6.22 and table 6.32) as data field referenced was incorrect. - Removed end-of-set from Geographic Area Definition Message as it is not required. - Minor spelling and grammar changes - Updated message size calculations due to changes described above
1.6.1	April 9, 2019	- Increased size of SF039 to 7 bits to support more than 63 grid points - Adjusted message size computations for change in SF039
1.6.2	May 15, 2019	- Added offset to large troposphere coefficient (SF048) to match the offset on the small troposphere coefficient (SF045).
1.7	May 17, 2019	- Renamed SF006/SF007 to Solution ID and Solution Processor ID respectively. - Restrict satellite reference datum to be consistent across all messages within a solution ID - Addition of 1 reserved bit to each message header - Specifically define bias track types - Add description on restricting the use of area definition related data to users located within the boundary of the area. - Merged message sub-types for OCB and HPAC messages - Replaced area continuity indicator with an Area Issue of Update to remove ambiguity of reference time - Added implementation details for troposphere height correction, phase windup, yaw attitude and GLONASS leap second handling - Removed unnecessary invalid field values.

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2. Preface

The SAPA format was designed as an open standard to provide the data necessary to support high precision positioning applications using GNSS processing techniques. This document describes message formats, concepts behind field content, the types of data carried, what information various messages convey, as well as methods and algorithms that are necessary for fundamental use of such data.

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3. Acronyms and abbreviations

IODE – Issue of Data Ephemeris

IOU – Issue Of Update

OCB – Orbits, Clocks, and Biases

PRN – Pseudo-Random Noise (used to denote a specific GNSS satellite)

SAPA – Safe And Precise Augmentation

SF – SAPA field(s)

SM – SAPA message(s)

SIOU – Solution IOU

TF – Trasnport layer Field

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4. Introduction

Global Navigation Satellite Systems (GNSS) are satellite-based positioning systems that are currently providing global service 24 hours each day. Systems within GNSS, include, the Global Positioning System (GPS), the GLObal NAvigation Satellite System (GLONASS), Galileo satellite system, the Quasi-Zenith Satellite System (QZSS), and the BeiDou Navigation Satellite System (BDS). Many types of correction services exist to improve the accuracy of these systems. Among these are techniques that emerged from precise positioning approaches that do not require that the end-user also set up some reference GNSS station or network. These systems rely on service providers to gather and process information from numerous real-time sources then broadcast the data to the end user to be used in connection with their own GNSS receiver for the purpose of accurate positioning/navigation realization.

To date there exists no open, industry recognized standard that supports low bandwidth requirements required by some delivery systems while, at the same time, providing standards for integrity for safety of life applications. The SAPA message protocol has been developed with the goal of meeting these requirements.

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5. Application Layer

The Application Layer defines how messages can be applied for different end-user applications. The messages provide in this document are for broadcasting (provider or sending) services, and they are not intended for two-way data links. As such, information is developed centrally by a Service Provider, who has an institutional or commercial interest in providing data that enables end-user applications for precise positioning or navigation.

The use of GNSS data for positioning and navigation has become an essential part of modern countries, their industries, their economy, and their people. Among these are techniques that emerged from precise positioning approaches that do not require that the end-user also set up some reference GNSS station or network. The initial offering of this standard is focused at the numerous applications that exploit such precise positioning approaches. Primarily the application layer for the use of these messages are within the systems exploiting GNSS receivers to produce precise positioning and navigation for real-time applications. The messages of this standard are focused at delivering the information which facilitates those end goals.

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6. Presentation layer

The table below shows the existing message types in the SAPA format design.
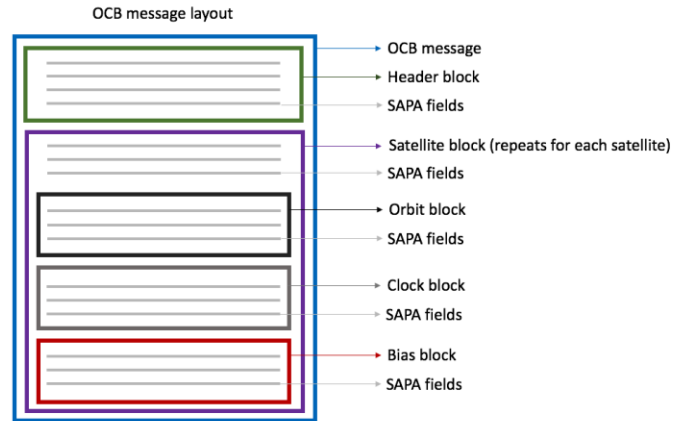
Table 6.1 – Messages types and subtypes in SAPA

Type	Subtype	Message name	Description
0	0	GPS OCB	**GNSS Orbit, Clock, Bias (OCB) messages** These are the messages that carry data for satellite orbits, clocks, biases, and other auxiliary information. Generally speaking, these messages are sufficient to allow global positioning modes that do not require the transmission of atmospheric data.
	1	GLONASS OCB	
	2 to 15	TBD	
1	0	GPS HPAC	**High-precision atmosphere correction (HPAC) messages** These are the messages that contain high-precision atmosphere data, specifically ionospheric and tropospheric correction data. Both ionosphere and troposphere data are transmitted in the same message for each constellation.
	1	GLONASS HPAC	
	2 to 15	TBD	
2	0	GAD	**Geographic Area Definition (GAD) messages** These are the messages used to define geographic areas of data usage. The use of these messages can serve different purposes, including atmospheric data availability and other types of geographical/geometrical aspects of usage of data.
	1 to 15	TBD	
3 to 127	TBD	TBD	TBD

6.1. General message layout

The SAPA messages payload is structured as a composition of different elements. Those elements are listed below:

- SAPA field – The SAPA fields are the most basic element of every SAPA message. They contain, in most cases, a single piece of information;
- Block – A block is a group of related SAPA fields that are often repeated within a message, or simply used to cleanly separate different types of data within a message. In most cases the SAPA fields within a block contain pieces of information that should be used in combination with each other. Blocks can contain other blocks;
- Header – SAPA message headers contain general information about the message that applies to all blocks within that message;
- Message – The SAPA messages (SM) are typically built with one header and one or more blocks, depending on the type of the message.

The figure below shows a representation of the OCB message (SM 0-0) layout as an example:

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OCB message layout

```
OCB message ─────────────► OCB message
                           Header block
                           SAPA fields

                           Satellite block (repeats for each satellite)
                           SAPA fields

                           Orbit block
                           SAPA fields

                           Clock block
                           SAPA fields

                           Bias block
                           SAPA fields
```

6.2. Continuity controls

The following is a list of existing continuity controls in the SAPA message format:

- Solution Issue of Update (SF005) – Controls when and if different parts of the correction that are sent in separate messages can be combined for processing;
- Solution ID (SF006) – Specifies a unique identier of the current solution which consists of all instances of a correction streams that are generated for a given area of coverage. When a change in the Solution ID is encountered, no guarantee on continuity is provided.
- Solution Processor ID (SF007) – Specifies the instance of the processor being used for generating correction data. When a change in the Solution Processor ID is encounterd, no guarantee on continuity is provided.
- Continuity Indicator (SF015) – Indicates the time over which no discontinuities have occurred. Processor implementation must reset their current state when the time since the last processed (or received) data is greater than the continuity time indicated in this data field;
- IODE Continuity (SF022) - Indicates if there has been a change in the IODE (SF018 and SF019) currently in use for the correction data. In case of a change, user must wait to receive a new IODE, issued after the indicated change. A new IODE must be received before continuing combining correction and broadcast ephemeris data.
- Area Issue of Update (SF068) –Controls when and if area data from different messages can be combined for processing.

6.3. Floating-point numbers conversion

SAPA achieves some of its compression by converting floating-point numbers to integer representations using range and resolution values. The following equation shows how to perform the conversion from encoded (unsigned integer) values to decoded (floating-point numbers) values:

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$V_{decoded} = (V_{encoded} * Res) + Rng_{min}$,

where $V_{decoded}$ is the decoded value that is retrieved after converting the encoded value ($V_{encoded}$) from an integer to a floating-point number. Res is the field resolution, and Rng_{min} is the lower limit of the data field range.

The following equation shows how to perform the conversion from original (to be encoded floating-point numbers) values to encoded (unsigned integer) values:

$V_{encoded} = (V_{original} - Rng_{min}) / Res$,

where $V_{encoded}$ is the encoded integer value that is transmitted in the data field, and $V_{original}$ is the original value (floating-point number) that shall be encoded in the data field.

In the case of invalid or special values, encoders shall directly encode the special value as an unsigned integer. Decoders must check for special values prior to performing the conversion to a floating point number.

6.4. SAPA fields

The following table lists all data field definitions used in the SAPA message format.

Table 6.2 – SAPA fields

ID	Name	# Bits	Range	Resolution	Special values	Notes
SF001	Subtype	4	0 to 15	1	none	Subtypes defined in table 6.1
SF002	Time tag type	1	0 to 1	n/a	0 : SF003 to follow 1 : SF004 to follow	Time type is used to define which SAPA field will be used to represent the time tag of the message. Messages can carry time represented by either SF003 or SF004. See respective field definitions for details.
SF003	GNSS hourly time tag	12	0 to 3599 seconds	1 second	Any values above 3599 seconds must be considered as invalid time tag.	This field provides time tag that is ambiguous within 3599 seconds. A value of 0 seconds means that the time tag at zero minutes and zero seconds of the hour. The hour must be resolved with the assistance of an unambiguous time tag, either received in the SAPA message through SF004, or from another source.
SF004	GNSS full time tag	32	0 to 4,294,967,295 seconds	1 [seconds since January 1st 2010, 00:00:00]	none	The system time of the time tag is the system time of the GNSS constellation transmitted in the present message. I.e., GPS message time tags are in GPS system time, while GLONASS message time tags are in GLONASS system time.
SF005	Solution issue of update (SIOU)	9	0 to 511	1	none	The SIOU controls when and if different parts of the correction that are sent in separate messages can be combined for processing. The SIOU can't change more than once per second. User must assume that SIOU has changed over outages of 510 secs or more even if the SIOU before/after an outage matches. SIOU is a solution-wide indicator and is not specific to any message type or subtype.

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ID	Name	# Bits	Range	Resolution	Special values	Notes
SF006	Solution ID	7	0 to 127	1	none	The solution ID represents the unique identification of the current system, which consists of all instances of a solution that is being generated for a given area of coverage. The different instances of the solution are represented by unique solution processor IDs (SF007).
SF007	Solution processor ID	4	0 to 15	1	none	The solution processor ID indicates the unique ID of the processing instance that has generated the correction data in the message. Each processing instance of the solution must be associated with a unique solution processor ID by the corrections provider.
SF008	Yaw present flag	1	0 to 1	n/a	0 : SF021 not present 1 : SF021 present for all orbit blocks	The yaw present flag indicates whether or not the satellite orbit blocks will contain a yaw value. When set, all blocks will contain the yaw value field (SF021). When not set, none of the orbit will contain the yaw value field (SF021).
SF009	Satellite reference datum	1	0 to 1	1	0: ITRF 1: Provider defined	Reference datum indicator of the satellite orbits. When set to 0 the reference datum is ITRF current epoch, latest realization. When set to 1 the reference datum is defined by the provider. For practical purposes the evolution of current and future ITRFs is below the observable accuracy of real time GNSS systems. NOTE: Service providers must a consistent reference datum for a given Solution ID/Solution processor ID pair.
SF010	End of OCB set (EOS)	1	0 to 1	n/a	0 : more OCB subtype messages to follow 1 : All OCB subtype messages sent	The End of Orbit, Clock, Bias set indicates that all messages of the current type (including all subtypes) for a single epoch.
SF011	GPS satellite mask	34 to 66	Bitmask	Bitmask	Leftmost 2 bits indicate bitmask size to follow: 0 : 32 bits 1 : 44 bits 2 : 56 bits 3 : 64 bits	GPS satellite mask field is composed of two bits that indicate the bitmask size, followed by the bitmask. The bitmask after the 2-bit size defines the IDs and order of GPS satellites in the message. The bitmask position added by 1 is equal to the Pseudo-Random Noise (PRN) ID of a satellite. At least one satellite must be present in the bitmask. Bitmask position 0 is the leftmost bit of the satellite mask, excluding the 2-bits indicating the size of the bitmask.
SF012	GLONASS satellite mask	26 to 65	Bitmask	Bitmask	Leftmost 2 bits indicate bitmask size to follow. 0 : 24 bits 1 : 36 bits 2 : 48 bits 3 : 63 bits	GLONASS satellite mask field is composed of two bits that indicate the bitmask size, followed by the bitmask. The bitmask after the 2-bit size defines the IDs and order of GLONASS satellites in the message. The bitmask position added by 1 is equal to the orbit slot of a satellite. At least one satellite must be present in the bitmask. Bitmask position 0 is the leftmost bit of the satellite mask, excluding the 2-bits indicating the size of the bitmask.
SF013	Do not use (DNU)	1	0 to 1	n/a	0 : Satellite fields present	The primary purpose of the DNU Flag, when set, is to indicate some negative

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ID	Name	# Bits	Range	Resolution	Special values	Notes
					1 : No fields in the associated satellite block will be present	health, negative integrity, poor quality, and other such negative aspects of the satellite and its data. When this flag is set, the remaining fields of this section for this satellite shall not be present. Users must immediately stop using any satellite that has been flagged with a DNU indicator.
SF014	OCB present flags	3	Bitmask	Bitmask	Bit 0 (leftmost) 0 : Orbit block no 1 : Orbit block yes Bit 1 (middle) 0 : Clock block no 1 : Clock block yes Bit 2 (rightmost) 0 : Bias block no 1 : Bias block yes	The OCB present flags field is a bitmask that is used to indicate which combination of orbits, clocks, or biases data blocks are present in the message.
SF015	Continuity indicator	3	0 to 7	n/a	0 : 0 secs 1 : 1 secs 2 : 5 secs 3 : 10 secs 4 : 30 secs 5 : 60 secs 6 : 120 secs 7 : 320 secs	Indicates if there has been a discontinuity in the data accompanied by the indicator. The time values provided here are to be read as: "The data has had no discontinuity within the last X seconds.", where X is the value provided in the special values list of this row. Processor implementation must consider resetting their current state when a data gap (ie. last epoch processed or received) greater than the continuity time has occurred.
SF016	GPS ephemeris type	2	0 to 3	n/a	0 : GPS L1C/A 1 to 3 : TBD	Type of ephemeris being used for GPS corrections.
SF017	GLO ephemeris type	2	0 to 3	n/a	0 : GLO L1C/A 1 to 3 : TBD	Type of ephemeris being used for GLONASS corrections.
SF018	GPS IODE	8	0 to 255	1	none	Issue of data ephemeris (IODE) field that indicates to which GPS broadcast IODE the corrections must be combined with in order to be processed by the user.
SF019	GLO IODE	7	0 to 127	1	none	Issue of data ephemeris (IODE) field that indicates to which GLONASS broadcast IODE the corrections must be combined with in order to be processed by the user.
SF020	Satellite corrections	14	±16.382 m	0.002 m	none	Correction value in unit of meters.
SF021	Satellite yaw	6	0 to 354°	6°	0x3F = invalid	Yaw attitude angle of satellite. The yaw correction is with respect to the satellite frame described in section Satellite Frame Convention
SF022	IODE continuity	3	0 to 7	n/a	0 : 0 secs 1 : 1 secs 2 : 5 secs 3 : 10 secs 4 : 30 secs 5 : 60 secs 6 : 120 secs 7 : 320 secs	Indicates if there has been a change in the IODE (SF018 and SF019) currently in use for the correction data. In case of a change, user must wait to receive a new IODE, issued after the indicated change. A new IODE must be received before continuing combining correction and broadcast ephemeris data. The time values provided here are to be read as: "The data has been generated using the same IODE over the last X seconds.", where X is the value provided in the special values list of this row.
SF023	Fix flag	1	0 to 1	n/a	0 : Float 1 : Fixed	Indicates if the clock solution, in combination with orbits and biases, has

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ID	Name	# Bits	Range	Resolution	Special values	Notes
						been generated using fixed ambiguities or float ambiguities.
SF024	User range error (URE)	3	0 to 7	n/a	0 : unknown 1 : 0.01m 2 : 0.02m 3 : 0.05m 4 : 0.1m 5 : 0.3m 6 : 1.0m 7 : > 1.0m	Indicates the expected range error of the combined OCB corrections. Value 0 means that there is no known value for this field. Value 7 means that the URE is greater than 1.0 m and corrections can still be used when proper considerations about the uncertainty of the corrections are made.
SF025	GPS phase bias mask	7 or 12	bitmask	bitmask	Leftmost bit indicates bitmask size to follow: 0 : 6 bits 1 : 11 bits Bit #'s left to right (excluding size bit) 0 : L1C phase bias 1 : L2W phase bias 2 : L2L phase bias 3 to 10 : spare phase biases	Indicates which phase bias types are present in the GPS satellite bias corrections block.
SF026	GLONASS phase bias mask	6 or 10	bitmask	bitmask	Leftmost bit indicates bitmask size to follow: 0 : 5 bits 1 : 9 bits Bit #'s left to right (excluding size bit) 0 : L1C phase bias 1 : L2C phase bias 2 to 8 : spare phase biases	Indicates which phase bias types are present in the GLONASS satellite bias corrections block.
SF027	GPS code bias mask	7 or 12	bitmask	bitmask	Leftmost bit indicates bitmask size to follow: 0 : 6 bits 1 : 11 bits Bit #'s left to right (excluding size bit) 0 : C1C code bias 1 : C2W code bias 2 : C2L code bias 3 to 10 : spare code biases	Indicates which code bias types are present in the GPS satellite bias corrections block.
SF028	GLONASS code bias mask	6 or 10	bitmask	bitmask	Leftmost bit indicates bitmask size to follow: 0 : 5 bits 1 : 9 bits Bit #'s left to right (excluding size bit) 0 : C1C code bias 1 : C2C code bias 2 to 8 : spare code biases	Indicates which code bias types are present in the GLONASS satellite bias corrections block.
SF029	Code bias correction	11	±20.46 m	0.02 m	none	Satellite bias correction value in unit of meters.
SF030	Area Count	5	1 to 32	1	none	Number of areas to follow in the data block section of the current message.
SF031	Area ID	8	0 to 255	1	none	Area identifier of the geographic area being defined, must be unique within a Solution (SF006)
SF032	Area reference latitude	11	±90.00 north degrees	0.1 degrees	none	The northern most latitude of the area being defined
SF033	Area reference longitude	12	±180.00 east degrees	0.1 degrees	none	The western most longitude of the area being defined.

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ID	Name	# Bits	Range	Resolution	Special values	Notes
SF034	Area latitude grid node count	3	1 to 8	1	none	The number of grid points that exist in the north-south direction beginning at the reference latitude (SF032).
SF035	Area longitude grid node count	3	1 to 8	1	none	The number of grid points that exist in the west-east direction beginning at the reference longitude (SF033).
SF036	Area latitude grid node spacing	5	0.1 to 3.2 degrees	0.1 degrees	none	The spacing between the grid nodes in the north-south direction
SF037	Area longitude grid node spacing	5	0.1 to 3.2 degrees	0.1 degrees	none	The spacing between the grid nodes in the west-east direction
SF039	Number of grid points present	7	0 to 127	1	none	Number of grid points present in the grid blocks of the message. When grids not present as indicated by SF040 within the same message, this data field may be ignored.
SF040	Poly/Grid block present indicator	2	0 to 2	1	0 : None present 1 : Poly block present 2 : Poly/grid block present	Indicates the presence of the polynomial and grid blocks within the message. As the polynomial and grid blocks are cumulative, grids cannot be present without polynomials.
SF041	Troposphere equation type	3	0 to 7	1	See notes	Indicates the residual zenith troposphere delay polynomial model used. The coefficients are stored in the same order as they appear below ($T_{00}, T_{01}, T_{10}, T_{11}$). Models for each SF041 value: $0 : T_{00}$ $1 : T_{00} + T_{01}(\phi - \phi_0) + T_{10}(\lambda - \lambda_0)$ $2 : T_{00} + T_{01}(\phi - \phi_0) + T_{10}(\lambda - \lambda_0) + T_{11}(\phi - \phi_0)(\lambda - \lambda_0)$ 3 to 7 : TBD
SF042	Troposphere quality	3	0 to 7	1	0 : unknown 1 : <=0.010m 2 : <=0.020m 3 : <=0.040m 4 : <=0.080m 5 : <=0.160m 6 : <=0.320m 7 : > 0.320m	The field represents the quality of the complete interpolated troposphere model (average, polynomial, and grid when applicable) in units of meters at zenith (1σ).
SF043	Area average vertical hydrostatic delay	8	±0.508m	0.004 m	None	The average vertical hydrostatic delay (reduced to a reference height of 0 m on the ellipsoid) within the area offset from 2.3m
SF044	Troposphere polynomial coefficient size indicator	1	0 to 1	1	0: Troposphere small coefficient block is used 1: Troposphere large coefficient block is used	Indicates whether the small or large troposphere polynomial coefficients block is used
SF045	Small troposphere coefficient T00	7	±0.252 m	0.004 m	None	The small size coefficient of the troposphere zenith delay polynomial offset by 0.252m.
SF046	Small troposphere coefficient T10/T01	7	±0.063 m/degree	0.001 m / degree	None	The small size coefficient of the troposphere zenith delay polynomial.
SF047	Small troposphere coefficient T11	9	±0.0510 m/degree^2	0.0002 m /degree^2	None	The small size coefficient of the troposphere zenith delay polynomial.

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ID	Name	# Bits	Range	Resolution	Special values	Notes
SF048	Large troposphere coefficient T00	9	±1.020 m	0.004 m	None	The large size coefficient of the troposphere zenith delay polynomial offset by 0.252m
SF049	Large troposphere coefficient T10/T01	9	±0.255 m/degree	0.001 m / degree	None	The large size coefficient of the troposphere zenith delay polynomial.
SF050	Large troposphere coefficient T11	11	±0.2046 m/degree^2	0.0002 m / degree^2	None	The large size coefficient of the troposphere zenith delay polynomial.
SF051	Troposphere residual field size	1	0 to 1	1	0: Troposphere small residual is used 1: Troposphere large residual is used	Troposphere residual field size indicator.
SF052	Small troposphere residual zenith delay	6	±0.124 m	0.004 m	0x3F = invalid	The small size troposphere residual zenith delay.
SF053	Large troposphere residual zenith delay	8	±0.508 m	0.004 m	0xFF = invalid	The large size troposphere residual zenith delay.
SF054	Ionosphere equation type	3	0 to 7	1	See notes	Indicates the slant ionosphere delay polynomial model used. The coefficients are stored in the same order as they appear below ($C_{00}, C_{01}, C_{10}, C_{11}$). Models for each SF054 value: 0 : C_{00} 1 : $C_{00} + C_{01}(\phi - \phi_0) + C_{10}(\lambda - \lambda_0)$ 2 : $C_{00} + C_{01}(\phi - \phi_0) + C_{10}(\lambda - \lambda_0) + C_{11}(\phi - \phi_0)(\lambda - \lambda_0)$ 3 - 7 : TBD
SF055	Ionosphere quality	4	0 to 15	1	0 Unknown 1 <=0.03 TECU 2 <=0.05 TECU 3 <=0.07 TECU 4 <=0.14 TECU 5 <=0.28 TECU 6 <=0.56 TECU 7 <=1.12 TECU 8 <=2.24 TECU 9 <=4.48 TECU 10 <=8.96 TECU 11 <=17.92 TECU 12 <=35.84 TECU 13 <=71.68 TECU 14 <=143.36 TECU 15 >143.36 TECU	The model quality of the interpolated ionosphere model (1σ). The indicator represents the combined accuracy of the polynomial, and when present, grid model.
SF056	Ionosphere polynomial coefficient size indicator	1	0 to 1	1	0: Ionosphere small coefficient block is used 1: Ionosphere large coefficient block is used	Indicates whether the small or large ionosphere polynomial coefficients block is used

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ID	Name	# Bits	Range	Resolution	Special values	Notes
SF057	Small ionosphere coefficient C00	12	±81.88 TECU	0.04 TECU	None	The small size coefficient of the ionosphere slant delay polynomial.
SF058	Small ionosphere coefficient C10/C01	12	±16.376 TECU/degree	0.008 TECU / degree	None	The small size coefficient of the ionosphere slant delay polynomial.
SF059	Small ionosphere coefficient C11	13	±8.190 TECU/degree²	0.002 TECU / degree²	None	The small size coefficient of the ionosphere slant delay polynomial.
SF060	Large ionosphere coefficient C00	14	±327.64 TECU	0.04 TECU	None	The large size coefficient of the ionosphere slant delay polynomial.
SF061	Large ionosphere coefficient C10/C01	14	±65.528 TECU/degree	0.008 TECU / degree	None	The large size coefficient of the ionosphere slant delay polynomial.
SF062	Large ionosphere coefficient C11	15	±32.766 TECU/degree²	0.002 TECU / degree²	None	The large size coefficient of the ionosphere slant delay polynomial.
SF063	Ionosphere residual field size	2	0 to 3	1	0: Ionosphere small residual is used 1: Ionosphere medium residual is used 2: Ionosphere large residual is used 3: Ionosphere extra large residual is used	Ionosphere residual field size indicator.
SF064	Small ionosphere residual slant delay	4	±0.28 TECU	0.04 TECU	0xF = invalid	The small size ionosphere residual slant delay.
SF065	Medium ionosphere residual slant delay	7	±2.52 TECU	0.04 TECU	0x7F = invalid	The medium size ionosphere residual slant delay.
SF066	Large ionosphere residual slant delay	10	±20.44 TECU	0.04 TECU	0x3FF = invalid	The large size ionosphere residual slant delay.
SF067	Extra large ionosphere residual slant delay	14	±327.64TECU	0.04 TECU	0x3FFF = invalid	The extra large size ionosphere residual slant delay.
SF068	Area Issue of Update (AIOU)	4	0 to 15	1	None	The AIOU controls when and if messages may be combined with the GAD messages described in SM 2. The AIOU cannot change more than once per 30 seconds. User must assume that an AIOU has changed over outages of 450 seconds or more even if the AIOU before and after the outage matches.

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ID	Name	# Bits	Range	Resolution	Special values	Notes
SF069	Reserved	N	N/A	N/A	N/A	Reserved bits may be used to extend existing messages in the future. Reserved bits should be set to zero, until defined in future versions of the ICD.

6.5. SAPA Messages

SAPA Messages are provided on a per constellation basis. For each constellation data field definitions which are a function of constellation are marked with a **. These data fields must be treated consistently throughtout the message. All other data fields are consistent across all constellations.

6.5.1. Orbit, Clock, Bias (OCB) messages - SM 0-0/0-1

The following table describes the overall layout of the SM 0-0/0-1:

Table 6.3 – Overall layout of SAPA message 0-0/0-1

Block	Name	Definition	Size (bits)
Header Block (SM 0-0)	Message sub-type	SF001	4
	Time tag type	SF002	1
	Time tag	SF003 or SF004	12 or 32
	Solution ID	SF006	7
	Solution processor ID	SF007	4
	Solution issue of update (SIOU)	SF005	9
	End of set	SF010	1
	Reserved	SF069	1
	Yaw present flag	SF008	1
	Satellite reference datum	SF009	1
	Ephemeris type**	SF016 or SF017	2
	Satellite mask**	SF011 or SF012	26 to 66
Satellite block (SM 0-0)	Satellite block	Table 6.4	Variable (Repeated for each satellite)

The following tables describe the satellite, clock, and bias blocks present in SM 0-0/0-1. The satellite block repeats for every satellite present in the satellite mask (SF011/SF012).

Table 6.4 – Message 0-0/0-1 satellite block

Block	Name	Definition	Size (bits)
Satellite block (SM 0-0)	Do not use (DNU)	SF013	1
	OCB present flags	SF014	3
	Continuity indicator	SF015	3
	Orbit block	Table 6.5	50 or 56

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Block	Name	Definition	Size (bits)
	Clock block	Table 6.6	20
	Bias block**	Table 6.7 or Table 6.8	Variable size

Table 6.5 – Message 0-0/0-1 orbit block

Block	Name	Definition	Size (bits)
Orbit block (SM 0-0)	IODE**	SF018 or SF019	8 or 7
	Orbit radial correction	SF020	14
	Orbit along-track correction	SF020	14
	Orbit cross-track correction	SF020	14
	Satellite yaw	SF021	0 or 6

Table 6.6 – Message 0-0/0-1 clock block

Block	Name	Definition	Size (bits)
Clock block (SM 0-0)	IODE continuity	SF022	3
	Clock correction	SF020	14
	User range error	SF024	3

Table 6.7 – Message 0-0 GPS bias block

Block	Name	Definition	Size (bits)
Bias block (SM 0-0)	GPS phase bias mask**	SF025	7 or 12
	Phase bias block	Table 6.9	18 per phase bias type (Repeated for each bias)
	GPS code bias mask**	SF027	7 or 12
	Code bias correction	SF029	11 per code bias type (Repeated for each bias)

Table 6.8 – Message 0-1 GLONASS bias block

Block	Name	Definition	Size (bits)
Bias block (SM 0-1)	GLONASS phase bias mask**	SF026	6 or 10
	Phase bias block	Table 6.9	18 per phase bias type (Repeated for each bias)
	GLONASS code bias mask**	SF028	6 or 10
	Code bias correction	SF029	11 per code bias type (Repeated for each bias)

Table 6.9 – Message 0-0/0-1 phase bias block

Block	Name	Definition	Size (bits)
Phase Bias block (SM 0-0)	Fix flag	SF023	1
	Continuity indicator	SF015	3
	Phase bias correction	SF020	14 per phase bias type

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6.5.2. High Precision Atmosphere Correction (HPAC) message - SM 1-0/1-1

The following table describes the overall layout of the SM 1-0/1-1:

Table 6.10 – Overall layout of SAPA message 1-0/1-1

Block	Name	Definition	Size (bits)
Header Block (SM 1-0)	Message sub-type	SF001	4
	Time tag type	SF002	1
	Time tag	SF003 or SF004	12 or 32
	Solution ID	SF006	7
	Solution processor ID	SF007	4
	Solution issue of update (SIOU)	SF005	9
	Reserved	SF069	1
	Area issue of update	SF068	4
	Area count	SF030	5
Atmosphere Block (SM 1-0)	Atmosphere block	Table 6.11	Variable (Repeated for each area)

Table 6.11 – Message 1-0/1-1 HPAC atmosphere data block

Block	Name	Definition	Size (bits)
Atmosphere Block (SM 1-0)	Area data block	Table 6.12	21
	Troposphere data block	Table 6.13	Variable
	Ionosphere data block	Table 6.16	Variable

The following tables describe the HPAC area data block, troposphere and ionosphere blocks present in SM 1-0/1-1. The blocks repeat for every area present in SM 1-0/1-1.

Table 6.12 – Message 1-0/1-1 HPAC area data block

Block	Name	Definition	Size (bits)
Area Data Block (SM 1-0)	Area ID	SF031	8
	Number of grid points present	SF039	7
	Tropo blocks indicator	SF040	2
	Iono blocks indicator	SF040	2

The HPAC troposphere data blocks are only present if one or both Tropo blocks indicator bits are turned on. It is made up of the troposphere block, troposphere polynomial coefficient block and troposphere grid block.

Table 6.13 – Message 1-0/1-1 HPAC troposphere data block

Block	Name	Definition	Size (bits)
Troposphere Polynomial Coefficient Block (SM 1-0)	Troposphere equation type	SF041	3
	Troposphere quality	SF042	3

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Block	Name	Definition	Size (bits)
(Present if tropo blocks indicator = 1 or 2)	Area average vertical hydrostatic delay	SF043	8
	Troposphere polynomial coefficient size indicator	SF044	1
	Troposphere polynomial coefficients	SF044 = 0 see table 6.14 SF044 = 1 see table 6.15	Variable
Troposphere Grid Block (SM 1-0) (Present if tropo blocks indicator = 2)	Troposphere residual field size	SF051	1
	Troposphere grid residuals	SF051 = 0 : SF052 SF051 = 1 : SF053	SF051 = 0: NGridPts * 6 SF051 = 1: NGridPts * 8

The HPAC troposphere small coefficient blocks are only present if the Troposphere polynomial coefficient size indicator is set to 0. The equation type is defined from SF041 – Troposphere Equation Type.

Table 6.14 – Message 1-0/1-1 HPAC troposphere small coefficient block

Block	Name	Definition	Size (bits)
Troposphere Small Coefficients Block (SM 1-0)	Troposphere coefficient T00 (SF041 models 0, 1 or 2)	SF045	7
	Troposphere coefficient T01 (SF041 models 1 or 2)	SF046	0 or 7
	Troposphere coefficient T10 (SF041 models 1 or 2)	SF046	0 or 7
	Troposphere coefficient T11 (SF041 model 2)	SF047	0 or 9

The HPAC troposphere large coefficient blocks are only present if the Troposphere polynomial coefficient size indicator is set to 1. The equation type is defined from SF041 – Troposphere Equation Type.

Table 6.15 – Message 1-0/1-1 HPAC troposphere large coefficient block

Block	Name	Definition	Size (bits)
Troposphere Large Coefficients Block (SM 1-0)	Troposphere coefficient T00 (SF041 models 0, 1 or 2)	SF048	9
	Troposphere coefficient T01 (SF041 models 1 or 2)	SF049	0 or 9
	Troposphere coefficient T10 (SF041 models 1 or 2)	SF049	0 or 9
	Troposphere coefficient T11 (SF041 model 2)	SF050	0 or 11

The HPAC ionosphere data blocks are only present if one or both Iono blocks indicator bits are turned on. It is made up of the ionosphere block and the ionosphere satellite block.

Table 6.16 – Message 1-0/1-1 HPAC ionosphere data block

Block	Name	Definition	Size (bits)
Ionosphere Block (SM 1-0) (Present if iono blocks indicator = 1 or 2)	Ionosphere equation type	SF054	3
	Satellite Mask**	SF011 or SF012	26 to 66
Ionosphere Satellite Block (SM 1-0) (Present if iono blocks indicator = 1 or 2)	Ionosphere Satellite Block	Table 6.17	Variable (Repeated for all satellites)

The HPAC ionosphere satellite block consists of the satellite polynomial block, the satellite coefficients block and ionosphere satellite grid block. The satellite block is repeated for all satellites enabled in the satellite Mask of SM 1-0/1-1.

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Table 6.17 – Message 1-0/1-1 HPAC ionosphere satellite block

Block	Name	Definition	Size (bits)
Ionosphere Satellite Polynomial Block (SM 1-0) (Present if tropo blocks indicator = 1 or 2)	Ionosphere quality	SF055	4
	Ionosphere polynomial coefficient size indicator	SF056	1
Ionosphere Satellite Coefficient Block (SM 1-0)	Ionosphere satellite polynomial coefficients	SF056 = 0 see table 6.18 SF056 = 1 see table 6.19	Variable
Ionosphere Grid Block (SM 1-0)	Ionosphere residual field size	SF063	2
	Ionosphere grid residuals	SF063 = 0 : SF064 SF063 = 1 : SF065 SF063 = 2 : SF066 SF063 = 3 : SF067	SF063 = 0: NGridPts * 4 SF063 = 1: NGridPts * 7 SF063 = 2: NGridPts * 10 SF063 = 3: NGridPts * 14

The HPAC ionosphere small coefficient blocks are only present if the Ionosphere polynomial coefficient size indicator is set to 0. The equation type is defined from SF054 – Ionosphere Equation Type.

Table 6.18 – Message 1-0/1-1 HPAC ionosphere small coefficient block

Block	Name	Definition	Size (bits)
Ionosphere Small Coefficients Block (SM 1-0)	Ionosphere coefficient C00 (SF054 models 0, 1 or 2)	SF057	12
	Ionosphere coefficient C01 (SF054 models 1 or 2)	SF058	0 or 12
	Ionosphere coefficient C10 (SF054 models 1 or 2)	SF058	0 or 12
	Ionosphere coefficient C11 (SF054 model 2)	SF059	0 or 13

The HPAC ionosphere large coefficient blocks are only present if the Ionosphere polynomial coefficient size indicator is set to 1. The equation type is defined from SF054 – Ionosphere Equation Type.

Table 6.19 – Message 1-0/1-1 HPAC ionosphere large coefficient block

Block	Name	Definition	Size (bits)
Ionosphere Large Coefficients Block (SM 1-0)	Ionosphere coefficient C00 (SF054 models 0, 1 or 2)	SF060	14
	Ionosphere coefficient C01 (SF054 models 1 or 2)	SF061	0 or 14
	Ionosphere coefficient C10 (SF054 models 1 or 2)	SF061	0 or 14
	Ionosphere coefficient C11 (SF054 model 2)	SF062	0 or 15

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6.5.3. Geographic Area Definition (GAD) message - SM 2-0

The following table describes the overall layout of the SM 2-0:

Table 6.20 – Overall layout of SAPA message 2-0

Block	Name	Definition	Size (bits)
Header Block (SM 2-0)	Message sub-type	SF002	4
	Solution ID	SF006	7
	Solution processor ID	SF007	4
	Solution issue of update (SIOU)	SF005	9
	Area issue of update (AIOU)	SF068	4
	Reserved	SF069	1
	Area count	SF030	5
Area Definition Block (SM 2-0)	Area definition block	Table 6.21	49 per area (Repeated for all areas)

The following table describe the area definition block present in SM 2-0. The area definition block repeats for every area present in a solution.

Table 6.21 – Overall layout of SAPA message 2-0

Block	Name	Definition	Size (bits)
Area Definition Block (SM 2-0)	Area ID	SF031	8
	Area reference latitude	SF032	11
	Area reference longitude	SF033	12
	Area latitude grid node count	SF034	3
	Area longitude grid node count	SF035	3
	Area latitude grid node spacing	SF036	5
	Area longitude grid node spacing	SF037	5

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7. Transport layer

The transport layer defines the frame architecture for sending or receiving SAPA messages. The purpose of defining this layer is to ensure that SAPA messages can be properly *decoded* by applications.

The structure of the frame format is shown in the table below.

Table 7.1 – Message frame format

ID	Name	# Bits	Range	Resolution	Special values	Notes
TF001	Preamble	8	n/a	n/a	115 : This is the only valid value that can be used for the SAPA message frame preamble.	Various notations for the preamble value: Binary: 01110011_2 Decimal: 115_{10} Hexadecimal: 0x73
TF002	Message type	7	0 to 127	1	none	Types defined in table 6.1
TF003	Payload length	10	1 to 1024	1 byte	none	Size of the payload length, which must be at least 1 byte long
TF004	Encryption and/or authentication flag (EAF)	1	0 to 1	n/a	0 : No encryption or authentication is applied to any portion of the message frame and/or payload 1: The message payload is encrypted and/or authenticated.	When applied, encryption and/or authentication is present in the message payload section (TF007).
TF005	Message CRC type	2	0 to 3	1	0: CRC-8-CCITT 1: CRC-16-CCITT 2: CRC-24-Radix-64 3: CRC-32-CCITT	This field indicates what type of CRC is used in the message. Table 7.2 describes details of each option.
TF006	Frame CRC	4	n/a	n/a	n/a	Byte-by-byte 4-bit CRC calculated from TF002 through TF005. A 4-bit 0x0 filler (4 bits) is added to the right of the rightmost bit of the TF002-TF005 bit sequence (20 bits). Therefore, a 24-bit sequence is used in the CRC computation. This is done in order to allow byte alignment of the buffer used for the CRC computation. The parameters of this CRC-4 are: a. Polynomial = 0x09 b. Initialized at zero c. Input is reflected. d. Output is reflected. e. Zero XOR on output.
TF007	Message payload	8 to 8192	n/a	n/a	n/a	Message payload, containing encoded message – supported messages are defined in the Presentation Layer section of this document. If the encoded message length is not byte-aligned, fill bits must be inserted to match the payload length declared in the message frame (TF003).
TF008	Message CRC	8 to 32	n/a	n/a	n/a	CRC computed using all bits from TF002 to TF007. The type and size of CRC used is defined in TF005. If EAF (TF004) is set to one, CRC computation is done with encrypted payload.

Table 7.2 – SAPA message CRC types

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TF005 value	CRC type	Notes
0	CRC-8-CCITT	An unsigned 8-bit CRC using a polynomial of 0x07U. Pre-computation initialization: None. Post-computation inclusion: None.
1	CRC-16-CCITT	An unsigned 16-bit CRC using a polynomial of 0x1021U. Pre-computation initialization: None. Post-computation inclusion: None.
2	CRC-24-Radix-64	An unsigned 24-bit CRC using a polynomial of 0x864CFBU. Pre-computation initialization: None. Post-computation inclusion: None.
3	CRC-32-CCITT	An unsigned 32-bit CRC using a polynomial of 0x04C11DB7U. Pre-computation initialization: 0xFFFFFFFFU. Post-computation inclusion: Result XORed with 0xFFFFFFFFU.

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8. Implementation Details

General guidelines and notes about using and implementing the SAPA message format are described below.

8.1. Numerical Constants

Table 8.0 – SAPA numerical constants

Constant	Description	Value	Unit
c	Speed of light	299792458.0	m/s
π	Circular constant "pi"	3.1415926535898	unitless

8.2. Reference Datum

SF009 is used to define the datum of the satellite coordinates provided in SAPA message. Over the past decades updates to ITRF have become stable at close to the mm level. Therefore, it is not necessary to define the exact realization of ITRF used in the SAPA message format. The epoch of the positions computed using the SAPA message format will always be in the current epoch as provided in the message.

Service providers may choose to broadcast SAPA messages in non-ITRF datums. In this case users must consult the service providers to establish the reference datum.

8.3. Broadcast Ephemeris

All references to broadcast ephemeris refer to the following versions of interface documents:

Table 8.1 – SAPA Constellation ICD

Constellation	Document
GPS	IS-GPS-200H
GLONASS	Version 5.1

SAPA OCB messages are combined with the corresponding value obtained from the satellite broadcast message. The IODE is used to uniquely identify the broadcast ephemeris used in the expansion. Any deviation from the standard broadcast ephemeris implementations described in the documents above will directly impact the final accuracy of the system.

8.4. Message Flexibility

This standard is designed to allow for flexibility in how service providers broadcast the messages to optimize bandwidth. Below are several guidelines which should be followed:

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1) GNSS OCB messages (SM 0) contain an OCB present indicator (SF014) which allows service providers to independently send clocks, biases and orbits if desired. This allows for data rates to be optimized based on the rate of change of each parameter.

2) HPAC Atmosphere correction messages (SM 1) should only broadcast troposphere parameters for a singleconstellation. Service providers can take advantage of the Troposphere blocks indicator field (SF040) to indicate whether the troposphere block is present in the SM 1 message. If multiple troposphere models are broadcast for a single epoch, it is expected that the user utilize the latest received troposphere model. Additional service providers can choose to send polynomial only, or grid plus polynomial corrections depending on accuracy requirements.

3) Geographic Area Definition Message (SM 2) provides flexibility to allow for optimizing area size based on service requirements.

4) Several messages included reserved bits which in the future may be used to extend message content at the end of the payload. Therefore, decoder implmentations should not use payload length to indicate where they stop decoding.

8.5. Message Size Calculations

Table 8.2 – SAPA message size calculations

Type	Subtype	Message name	Nominal Size Calculation (bits)	
0	0/1	GPS OCB (SM 0-0)/ GLONASS OCD (SM 0-1)	HeaderBlock	$31 + Tb + MNsc$
			OrbitBlock	$Op * (Iod+42 + Yp * 6)$
			ClockBlock	$Cp * 20$
			BiasBlock	$Bp * (MNPb + Npb*18 + MNCb + Ncb * 11)$
			Total	HeaderBlock + $(7 + Dnu * (OrbitBlock + ClockBlock + BiasBlock)) * NSc$
1	0/1	GPS HPAC (SM 1-0) / GLONASS HPAC (SM 1-0)	HeaderBlock	$31 + Tb$
			AreaDataBlock	22
			TropDataBlock	$15 + Tpc + Tgp * (1 + Tgr * NGp)$
			IonoDataBlock	$3 + MNsc + (5 + Ipc + Igp * (2 + Igr * NGp)) * Nsa$
			Total	HeaderBlock + NAreas * (AreaDataBlock + Tp * TropDataBlock + Ip * IonoDataBlock)
2	0	Geographic Area Definition (SM 2-0)	Total	$30 + 47 * NAreas$

Tb   Number of bits used in the time tag (12 or 32). See SF003/SF004
MNsc   Mask size as defined in SF011/SF012 for constellation (including expansion bits)
Iod   Number of bits for the IODE. See SF018 and SF019.
Op   0 when orbit block is not present, 1 when orbit block is present
Yp   0 when yaw is not present, 1 when yaw is present
Cp   0 when clock block is not present, 1 when clock block is present
Bp   0 when bias block is not present, 1 when bias block is present
MNpb   Max Number of phase biases. See SF025/SF026.
Npb   Number of phase biases present.
MNcb   Max Number of code biases. See SF027/SF028.
Ncb   Number of code biases present.
Dnu   0 when satellite should not be used, 1 otherwise

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Nsc   Number of satellites present for constellation within the solution
Tpc   Number of bits for the troposphere polynomial coefficient block:

	Troposphere Eq Type		
	0	1	2
Troposphere Small Coefficients Block	7	21	30
Troposphere Large Coefficients Block	9	27	38

Tgp   0 when troposphere grid block is not present, 1 when troposphere grid block is present
Tgr   Troposphere grid bits, 6 or 8 if "Troposphere residual field size" (SF051) is 0 or 1 respectively.
Ipc   Number of bits for the ionosphere polynomial coefficient block:

	Ionosphere Eq Type		
	0	1	2
Ionosphere Small Coefficients Block	12	36	49
Ionosphere Large Coefficients Block	14	42	57

Igp   0 when ionosphere grid block is not present, 1 when ionosphere grid block is present
Igr   Ionosphere grid bits, 4, 7, 10 or 14 if "Ionosphere residual field size" (SF064) is 0, 1, 2 or 3 respectively.
Tp   0 when troposphere data block is not present, 1 when troposphere data block present
Ip   0 when ionosphere data block is not present, 1 when ionosphere data block present
NAreas Number of areas within the solution
NSa   Number of satellites visible in area
NGp   Number of grid points in area

8.6. Satellite and User Dependent Biases

In order to facilitate ambiguity resolution, it is necessary that satellite biases are consistent between all satellites of a satellite system and a specific frequency. Parameters provided with the SAPA message format must be free from satellite signal dependent biases other than those provided in the system dependent code and phase bias data fields.

Dependent on the users hardware specifications, it may be necessary to model receiver dependent biases such as:

- Receiver quarter cycle carrier phase shifts
- GLONASS inter-frequency biases
- Inter-System clock biases

8.7. GNSS Satellite Clock Calculation

SAPA OCB messages (SM 0) contains the parameters for clock correction δC. This correction is combined with the broadcast satellite clock t_b to form the corrected satellite clock t_s:

$$t_s = t_b - \frac{\delta C}{c}$$

where c is the speed of light constant.

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Relativistic effects must be applied for all constellations, except for GLONASS, where relativistic effect is already accounted for in the broadcast clock parameter. The relativistic clock correction for GPS is:

$$\delta t_r = -\frac{2\,\boldsymbol{r}\cdot\dot{\boldsymbol{r}}}{c^2}$$

8.8. GNSS Satellite Orbit Calculation

SAPA OCB message (SM 0) contains the parameters for orbit correction $\delta\boldsymbol{O}$ in radial, along-track and cross-track component. These corrections are transformed to a satellite position correction $\delta\boldsymbol{X}$ to be combined with the broadcast satellite position $\boldsymbol{X}_b$ to form the corrected satellite nominal antenna phase center position $\boldsymbol{X}_{orb}$:

$$\boldsymbol{X}_{orb} = \boldsymbol{X}_b - \delta\boldsymbol{X}$$

The satellite position correction $\delta\boldsymbol{X}$ is computed according to:

$$\boldsymbol{e}_{along} = \frac{\dot{\boldsymbol{r}}}{|\dot{\boldsymbol{r}}|}$$

$$\boldsymbol{e}_{cross} = \frac{\boldsymbol{r}\times\dot{\boldsymbol{r}}}{|\boldsymbol{r}\times\dot{\boldsymbol{r}}|}$$

$$\boldsymbol{e}_{radial} = \boldsymbol{e}_{along}\times\boldsymbol{e}_{cross}$$

$$\delta\boldsymbol{X} = \begin{bmatrix}\boldsymbol{e}_{radial} & \boldsymbol{e}_{along} & \boldsymbol{e}_{cross}\end{bmatrix}\cdot\delta\boldsymbol{O}$$

$\boldsymbol{r} = \boldsymbol{X}_b$ satellite broadcast position vector

$\dot{\boldsymbol{r}} = \dot{\boldsymbol{X}}_b$ satellite broadcast velocity vector

$\boldsymbol{e}_i$ direction unit vector, $i = \{radial, along, cross\}$

Satellite orbits are in the reference frame defined in SF009. See section 8.2 for further details.

8.9. GNSS Satellite Bias Calculation

SAPA OCB message (SM 0) contains parameters for bias correction for various track types. These biases shall be subtracted from the raw pseudorange and carrier phase measurements for the corresponding track types.

GLONASS biases are aligned to a theoretical zero bias receiver.

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8.10. SAPA Geographic Area Definition Message Implementation Details

The area definition message (SM 2) defines the geographic validity regions, grid layout and polynomial expansion point for the atmosphere model data (SM 1). These are shown in the figure below
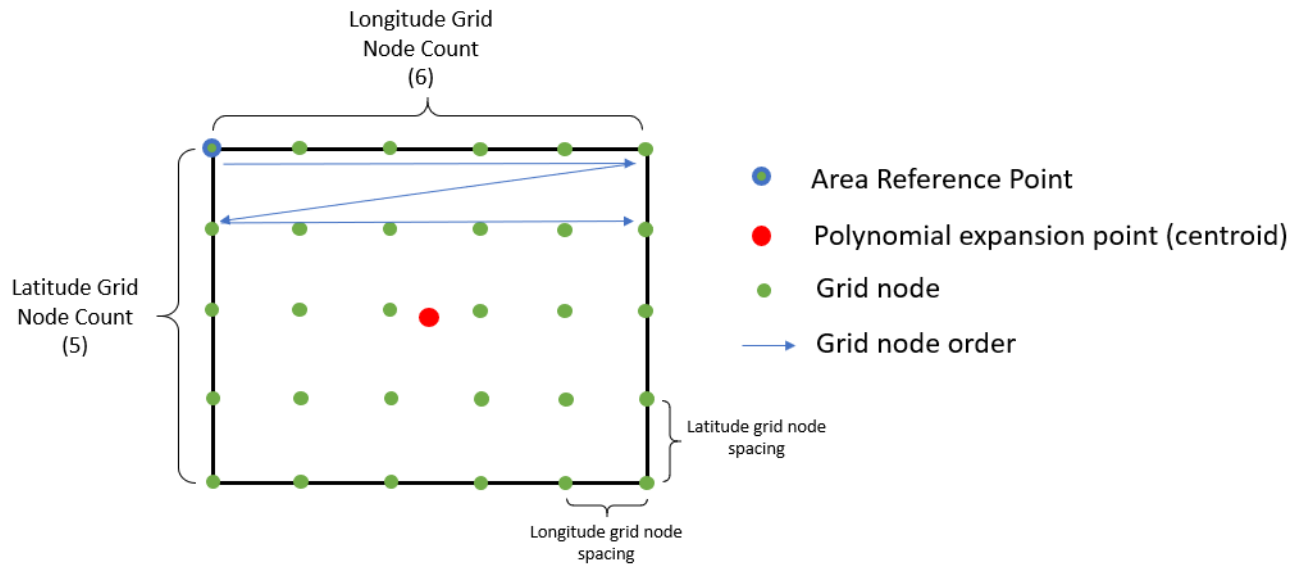
Users select the appropriate geographic area based on approximate receiver position. The user position must be located inside of the area definition for the data to be used. This is to ensure safe and consistent interpolation of both polynomial and gridded data. Below are examples showing availability of atmosphere data with respect to various configurations.

✕ Area related data unavailable

✔ Area related data available
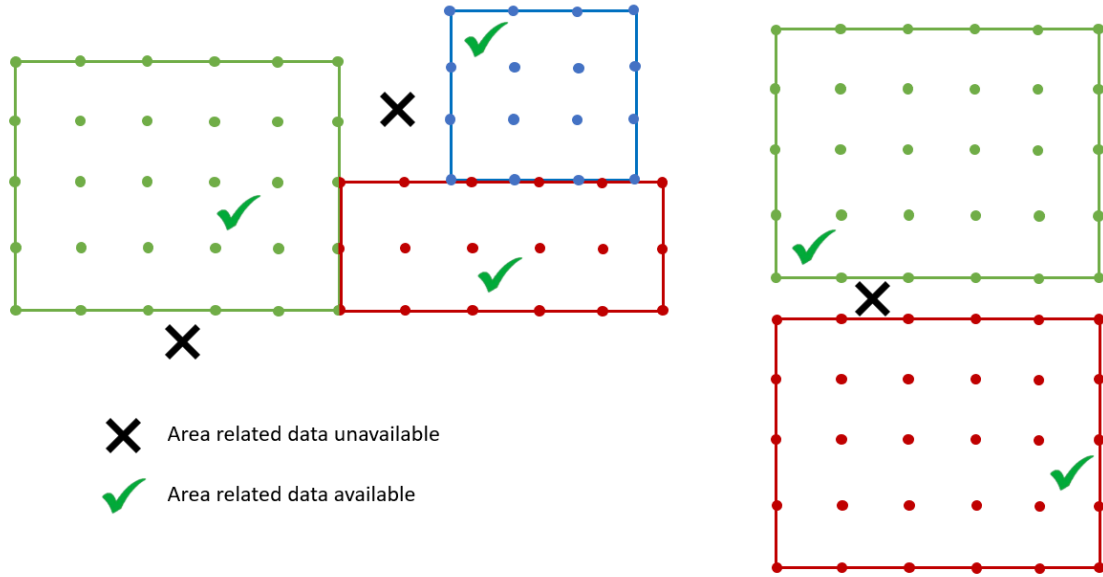
Due to the curvature of the earth, the SM 2 area definition messages are not suited for arctic navigation and should not be used above +/- 85 degrees latitude.

8.11. Ionosphere Slant Delay Calculation

SM 1 contains parameters for correcting for the ionosphere slant delay for each signal frequency. The slant delay for a given satellite is computed as:

$$\delta I_{CP}^{i} = -40.3 \times \frac{10^{-16}}{f_j^2} \cdot (I_P^i + I_G^i)$$

$$\delta I_{PR}^{i} = 40.3 \times \frac{10^{-16}}{f_j^2} \cdot (I_P^i + I_G^i)$$

where

δI_{CP}^{i} slant ionosphere delay of satellite i, for the carrier phase measurement, in units of meters

δI_{PR}^{i} slant ionosphere delay of satellite i, for the pseudorange measurement, in units of meters

I_P^i slant ionosphere delay evaluated for the polynomial for satellite i, in units of TECU

I_G^i interpolated residual slant ionosphere delay interpolated from the gridded residuals for satellite i in units of TECU.

In the case where no grid information is present, I_G^i is assumed to be zero.

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Grid Interpolation:

A bi-linear grid interpolation is used to interpolate the residual slant delay for the requested user position.

$$I_G^i = \sum_{k=1}^{4} W_k I_{G_k}^i$$

Where

W_k is the weight applied to the grid point k

$I_{G_k}^i$ is the residual slant ionosphere delay for satellite i at grid point k in units of TECU.

Polynomial Evaluation:

The slant ionosphere delay is evaluated for the user location based on distance from the area's centroid latitude (ϕ_c)and longitude (λ_c) and approximate user latitude (ϕ_u) and longitude (λ_u):

$$I_P^i = f_p(\delta\phi, \delta\lambda)$$

where

$$\delta\phi_p = \phi_u - \phi_c$$
$$\delta\lambda_p = \lambda_u - \lambda_c$$

ϕ_u latitude of the user in units of degrees

ϕ_c area centroid latitude in units of degrees

λ_u longitude of the user in units of degrees

λ_c area centroid longitude in units of degrees

f_p is the polynomial representation of the ionosphere slant delay, as given by data field SF054:

$0 : I_P^i = C_{00}$
$1 : I_P^i = C_{00} + C_{01}(\phi_c - \phi_0) + C_{10}(\lambda_c - \lambda_0)$
$2 : I_P^i = C_{00} + C_{01}(\phi_c - \phi_0) + C_{10}(\lambda_c - \lambda_0) + C_{11}(\phi_c - \phi_0)(\lambda_c - \lambda_0)$
3 - 7 : place holders for future polynomial representations

8.12. Troposphere Delay Calculation

SM 1 contains parameters for correcting for the troposphere zenith delay. The slant delay for a given satellite is computed as:

$$\delta T^i = \overline{T_h^z} \cdot m_h(\epsilon_i) + (T_P + T_G) \cdot m_{nh}(\epsilon_i)$$

Where

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δT^i is the troposphere slant delay for satellite i at the user's location

$\overline{T_h^z}$ is the average zenith hydrostatic delay for the given area referenced to a zero ellipsoidal height (WGS-84)

$m_h(\epsilon_i)$ is the hydrostatic mapping function defined in Niell (1996) for the satellite elevation angle (ϵ_i)

$m_{nh}(\epsilon_i)$ is the non-hydrostatic mapping function defined in Niell (1996) for the satellite elevation angle (ϵ_i)

T_G is the residual troposphere zenith delay for station interpolated from the grid points, in units of meters.

T_P^i is the residual troposphere zenith delay for satellite i interpolated obtained from the polynomial expansion, in units of meters.

Grid Interpolation:

A bi-linear grid interpolation is used to interpolate the residual slant delay for the requested user position.

$$T_G = \sum_{k=1}^{4} W_k T_{G_k}$$

Where

W_k is the weight applied to the grid point k

T_{G_k} is the residual troposphere zenith delay for ionosphere delay at grid point k in units of TECU.

Polynomial Evaluation:

The troposphere zenith delay is evaluated for the user location based on distance from the area's centroid latitude (ϕ_c) and longitude (λ_c) and approximate user latitude (ϕ_u) and longitude (λ_u):

$$T_P = f_p(\delta\phi, \delta\lambda)$$

where

$$\delta\phi_p = \phi_u - \phi_c$$
$$\delta\lambda_p = \lambda_u - \lambda_c$$

ϕ_u latitude of the user in units of degrees

ϕ_c area centroid latitude in units of degrees

λ_u longitude of the user in units of degrees

λ_c area centroid longitude in units of degrees

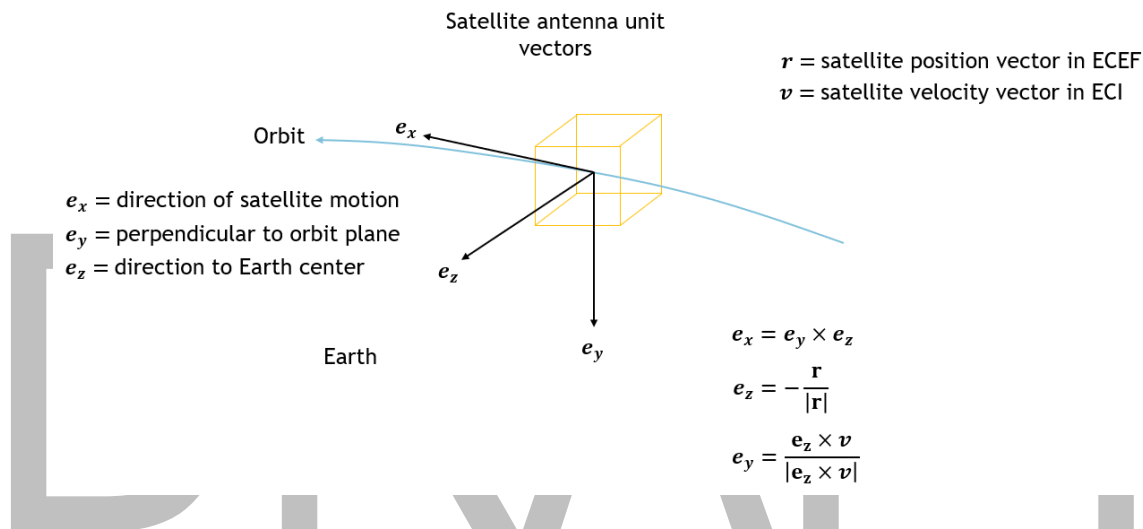f_p is the polynomial representation of the troposphere residual zenith delay, as given by data fields SF041:

$0 : T_P = T_{00}$

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$$1 : T_P = T_{00} + T_{01}(\phi_c - \phi_0) + T_{10}(\lambda_c - \lambda_0)$$
$$2 : T_P = T_{00} + T_{01}(\phi_c - \phi_0) + T_{10}(\lambda_c - \lambda_0) + T_{11}(\phi_c - \phi_0)(\lambda_c - \lambda_0)$$
3 - 7 : place holders for future polynomial representations

8.13. Satellite Frame Convention

If the yaw angle is not provided, the satellite yaw angle should be considered zero. The nominal satellite phase windup is computed according to Wu et al. (1993). The satellite frame used for yaw computations is a satellite fixed frame defined as follows:

Satellite antenna unit vectors

r = satellite position vector in ECEF
v = satellite velocity vector in ECI

Orbit

e_x = direction of satellite motion
e_y = perpendicular to orbit plane
e_z = direction to Earth center

Earth

$$e_x = e_y \times e_z$$
$$e_z = -\frac{r}{|r|}$$
$$e_y = \frac{e_z \times v}{|e_z \times v|}$$

8.14. Modeling Conventions

The table below lists references for the standard error models which must be applied at the rover in order to achieve full accuracy:

Error Source	Reference Document
Solid Earth Tides	IERS (2010)
Phase Windup	Wu et al. (1993)
Shapiro	Ashby (2003)
Sagnac	Ashby (2003)
Troposphere Mapping Function	Niell (1996)

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SAPCORDA

9. References

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