BS ISO 18197:2015

BSI Standards Publication

Space systems — Space based services requirements for centimetre class positioning

...making excellence a habit.™

National foreword

This British Standard is the UK implementation of ISO 18197:2015.

The UK participation in its preparation was entrusted to Technical Committee ACE/68/-/1, Space systems and operations.

A list of organizations represented on this committee can be obtained on request to its secretary.

This publication does not purport to include all the necessary provisions of a contract. Users are responsible for its correct application.

Published by BSI Standards Limited 2015

ISBN 978 0 580 84494 2

ICS 49.140

Compliance with a British Standard cannot confer immunity from legal obligations.

This British Standard was published under the authority of the Standards Policy and Strategy Committee on 31 May 2015.

Amendments/corrigenda issued since publication

Date	Text affected

BS ISO 18197:2015

INTERNATIONAL STANDARD

ISO 18197

First edition
2015-05-01

Space systems — Space based services requirements for centimetre class positioning

Systèmes spatiaux — Exigences de services fondés sur l'espace pour le positionnement de la classe centimètre

Reference number
ISO 18197:2015(E)

Contents

Page

Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

Attention is drawn to the possibility that some of the elements of this document may be the subject of patent rights. ISO shall not be held responsible for identifying any or all such patent rights. Details of any patent rights identified during the development of the document will be in the Introduction and/or on the ISO list of patent declarations received (see www.iso.org/patents).

Any trade name used in this document is information given for the convenience of users and does not constitute an endorsement.

For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 20, *Aircraft and space vehicle*, Subcommittee SC 14, *Space systems and operations*.

Introduction

Nowadays, applications such as civil engineering, automatic farming, traffic control, and disaster monitoring system need centimetre class positioning. This centimetre class positioning is deeply concerned with various fields of our daily life.

Especially the positioning system of applications for the construction and civil engineering, surveying and mapping, and water level measuring for river or ocean, requires certifying the reliability of positioning system. Also, the case of automatic vehicle driving, ship control, and snowplow on the road demands the centimetre class positioning capability which is available in real-time and over wide area.

This International Standard intends to standardize the system requirements and verification criteria for centimetre class positioning over a wide area by broadcasting augmentation data through satellites, in order that we can enhance the availability of related applications and improve our daily life.

The services broadcasting augmentation data through satellite or satellite-based augmentation system (SBAS), such as WAAS, EGNOS, and MSAS, are currently in operation for aviation. This SBAS claims the positioning accuracy of meter level and focuses on high integrity. Also, the SBAS is mainly operated by a state agency for the sake of human life and internationality of aviation.

On the other hand, the services in this International Standard such as precise point positioning (PPP) require the positioning accuracy at centimetre level. There are now a number of providers supplying different sets of PPP corrections. At the same time, this PPP covers different markets such as civil engineering, automatic farming, and automatic driving. PPP began to outpace SBAS for some applications requiring higher precision. Therefore, it is inevitably essential to ensure and certify the reliability of the PPP system.

As stated above, from the viewpoint of benefit, it is clear that PPP services continue to evolve and become more and more sophisticated to match the growing complexity of customer applications.[7] On the other hand, in view of rationale, there have been some great strides in overcoming the convergence time challenge and there are currently some successful real-time PPP applications both academic and commercial.[8] The objective of this International Standard is to establish the space based services by broadcasting the augmentation data for centimetre class positioning over wide area. Also, this International Standard defines the requirements for verification and evaluation of the guarantee of quality of the services, and therefore, this International Standard plays a role of the recognition for the certification of these services as well.

Space systems — Space based services requirements for centimetre class positioning

1 Scope

This International Standard defines the requirements for the wide area centimetre class positioning system by broadcasting augmentation data through satellites as follows.

— Centimetre class positioning

According to the progress of requirements for positioning services such as automatic farming, mapping and others, centimetre class positioning is very useful.

— Wide area positioning

It is quite effective to broadcast augmentation data through satellites for users over wide area such as a square, more than 1,000 km each side, anytime and anywhere. Even if this area is short of data network, additional ground network facilities are not needed. In addition, as ranging signal and augmentation data can be received from satellite broadcasting at the same time, it is unnecessary for user terminals to receive the signal such as transmitted by ground network.

— Real-time property

The user terminals need to resolve the ambiguity in real-time, using augmentation data broadcast from satellites or other means, for the realization of centimetre class positioning. On the other hand, the provider sides have to broadcast augmentation data such that the terminal sides are able to resolve the ambiguity in real-time.

2 Normative references

No normative references cited in this document.

3 Terms and definitions

For the purposes of this document, the following terms and definitions apply.

3.1
fixing
determining the integer number of carrier phase waves when calculating the position by use of carrier phase measurement

Note 1 to entry: This should be distinguished from the case of determining the desired value by convergence of continuous quantities when calculating the position by use of pseudorange measurement.

3.2
sustainability
measurement anomaly at some reference point should make no influence on the augmentation data generation

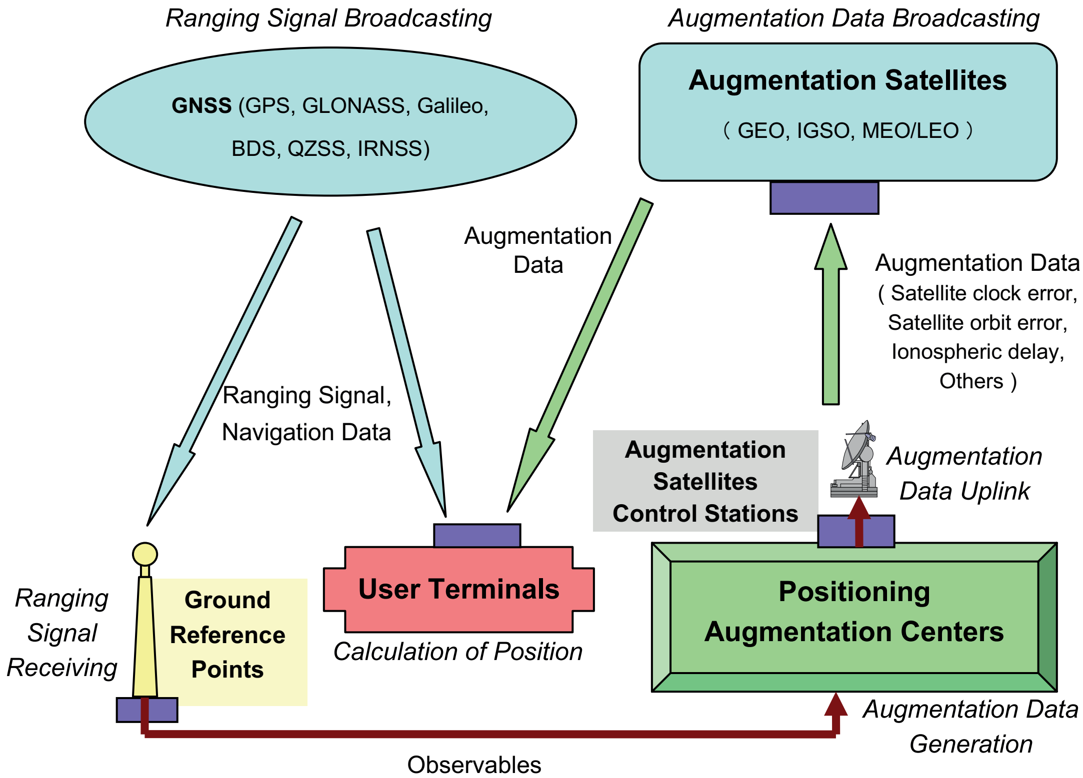
4 Abbreviated terms

BDS	BeiDou Navigation Satellite System
CEP	Circular Error Probable
DOP	Dilution of Precision
ECEF	Earth-Centred Earth-Fixed
ECI	Earth-Centred Inertial
GEO	Geostationary Earth Orbit
GLONASS	Global Navigation Satellite System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
IGSO	Inclined Geosynchronous Satellite Orbit
IOD	Issue Of Data
IRNSS	Indian Regional Navigational Satellite System
ITRF	International Terrestrial Reference Frame
ITS	Intelligent Transportation System
LEO	Low Earth Orbit
MEO	Medium Earth Orbit
NED	North East Down
NRTK	Network Real-Time Kinematics
RTK	Real-Time Kinematics
QZS	Quasi-Zenith Satellite
QZSS	Quasi-Zenith Satellite System

5 Positioning augmentation system overview

5.1 System configuration

Figure 1 shows the typical view of positioning augmentation system of centimetre class. Here, this International Standard does not deal with the ranging signal broadcast from GNSS.



NOTE Bold: facilities, italic: primary functions, normal: signal/data.

Figure 1 — Typical augmentation satellite system for centimetre class positioning

This typical system is configured mainly by the following components:

a) GNSS;

b) augmentation satellites;

c) augmentation satellites control stations;

d) ground reference points;

e) positioning augmentation centres;

f) user terminals.

Each component is explained below.

5.2 Classification of augmentation satellites

An augmentation satellite broadcasts augmentation data, uplinked from the positioning augmentation centres for users over wide area. Augmentation satellites are classified into the following:

a) geostationary earth orbit satellite (GEO);

b) inclined geosynchronous satellite orbit (IGSO);

c) medium or low earth orbit satellite (MEO/LEO).

The overview and features of various augmentation satellites is shown in Table 1.

Table 1 — Overview and features of various augmentation satellites

No.	Satellites class	Orbit height (km)	Observed time per satellite (hr)	Available region	Features
1	GEO	36 000	24	Restricted to low latitude	Operational with one satellite
2	IGSO	around 36 000	8	Available for low, middle, and high latitude	Several satellites are needed to hand over several times a day for users to receive the signal continuously
3	MEO/LEO	< 36 000	<8	Available for low, middle, and high latitude	A lot of satellites are needed to hand over more frequently for users to receive the signal continuously than IGSO

5.3 Positioning augmentation centres

The augmentation centres make augmentation data using the observation data at the ground reference points. The system sustainability is taken into account when making augmentation data. Some remarks are described below about the functions and conditions, message structure, and user operational support service.

5.3.1 Functions and conditions of the positioning augmentation centres

The functions and conditions of the positioning augmentation centres are as follows.

a) Augmentation data generation

The augmentation centres make augmentation data using the observation data at the ground reference points.

b) Monitoring of operation and measures

The augmentation centres monitor the system operational conditions by analysing data received from augmentation satellites and reference points so as to detect ionosphere disturbance or others. Based on the result, this International Standard should assess the influence on ranging signal or communication link and takes proper measures to recover the situation.

c) Detection of satellite signal anomaly

The augmentation centres calculate the predicted error using observation data at the ground reference points. The signal analysis is provided to specify the malfunction satellite.

5.3.2 Message structure

Figure 2 shows the example of message structure of augmentation data broadcast from the augmentation satellite.

Header	Contents of data	Error Co rrection Code

NOTE The header contains preamble, satellite number, station number, and message number. The contents of data correspond to the corrections, that is, satellite clock error, satellite orbit error, ionospheric delay, the status parameters, and ancillary data, such as those listed in Table F.1. The message format contains the error correction code, such as a cyclic redundancy code, so as to decode the message correctly.

Figure 2 — Message structure

5.3.3 User operational support service

The system should provide useful information for user terminals as follows.

a) Estimation of positioning error.

b) Condition of ionosphere, such as disturbance of ionosphere.

c) Condition of troposphere, such as anomaly of water vapour as caused by local rainfall, resulting in the positioning error due to tropospheric delay mismatch.

5.4 Operation

Some remarks on the operation of positioning augmentation system are as follows.

5.4.1 Simultaneous operation

The centimetre class augmentation data can also be used as the meter class augmentation data at the same time. Therefore, this system enhances the operational variation.

5.4.2 Various fields of application

A variety of industrial fields required for centimetre class positioning is illustrated in Annex G.

6 Requirements for positioning augmentation system

6.1 Requirements for augmentation satellites

Requirements for augmentation satellites of various orbits are described below.

a) Orbit constellation

b) Numbers of satellites

c) Antenna coverage

   This means a part on the earth where the transmission signal from the augmentation satellite can be reached.

d) Transmission signal characteristics

   Over the targeted area, under the condition of the minimum elevation angle of the augmentation satellite, this International Standard establishes the requirements for orbit constellation (satellite number/orbit plane/phase difference between orbit planes).

The examples of orbit constellation of augmentation satellites are shown in Annex D. Corresponding to the respective orbit constellation, the ground track and the antenna coverage are shown in Annex E.

6.2 Requirements for augmentation satellites control stations

Augmentation satellite control stations shall track and control the augmentation satellite so that it might broadcast augmentation data for users correctly. Requirements for satellite control stations are described as follows.

a) Allowable broadcasting latency of augmentation data

The allowable broadcasting latency of augmentation data shall be determined for the following parameters:

Latency from ground reference points to positioning augmentation centre	d1[sec]
Latency from positioning augmentation centre to satellites control station	d2[sec]
Latency from satellites control station to augmentation satellite	d3[sec]
Latency from augmentation satellite to user terminals	d4[sec]
--	
Total latency time	d1+d2+d3+d4 [sec]

For typical example, d1, d2, d3, and d4 are 1 s, 1 s, 2 s, and 2 s, respectively.

b) Switch of augmentation data between satellites

In the case of switching augmentation satellites which broadcast the augmentation data for the prescribed area, the procedure for the handover of the augmentation data between relevant satellites shall be established.

c) Preparation for anomaly in space

The satellites control station shall detect anomaly in space environment or satellite orbits and embed the alert message or disabled satellites data into the broadcasting signal.

6.3 Requirements for ground reference points

The functions and conditions required for ground reference points shall be shown as follows.

a) Requirements for output signal

- Pseudorange
- Carrier phase
- Signal strength

The information such as data acquisition rate cycle slip, multi-path, shall be used as effectiveness criterion for augmentation data generation. The following data can be used for verification of the correctness of augmentation data, which is an optional service that is not necessarily operated by the ground reference point:

- augmentation data;
- positioning results;
- S/N of ranging signal;

— number of ephemeris;

— DOP value

b) Geometrical allocation

— Regular allocation

The ground reference points shall be selected so that they are located regularly or in grid type.

— Irregular allocation

The density of ground reference points varies according to the necessity of the respective regions.

c) Objectives of ground reference points

— Determination of satellite clock error

— Determination of satellite orbit error

— Determination of ionospheric delay

— Determination of tropospheric delay

— Determination of signal biases

— Determination of integer biases

d) Case of distinction between primary and secondary reference points

Augmentation data shall be defined for the primary reference points. But, in some cases, the augmentation data can be made by use of not only primary reference point data, but secondary reference point data.

— Reason for the necessity of secondary reference points

e) Case of improper allocation

The method for application of augmentation data shall be clarified in the following cases.

— Case of positioning over ocean

The case should be remarked where no ground reference points are found in the neighbourhood of the user terminal.

— Case of height difference influence

It should be remarked that augmentation data like tropospheric delay depends on the height above sea level.

f) Location of reference points

The highly accurate location of all the reference points for augmentation data generation shall be clarified beforehand.

The ground reference networks in Japan, Germany, France, Europe, United States, China, Latin America, and the whole world can be referred in Reference [9] to Reference [16], respectively.

6.4 Requirements for positioning augmentation centres

6.4.1 Requirements for some parameters

The following parameters shall be determined for the positioning augmentation centres configuration.

a) Data transmission rate

Each correction value shall be updated by its data transmission rate. The correction value shall be predicted forward using the last correction data. Therefore, the accuracy of the correction value depends on the data transmission rate.

b) Data format

The data format includes the characteristics such as the word size, the word format, the message of fixed or variable length, and the parity algorithm.

c) Allowable data latency

Corrections can be applied for some time by the user because they change slowly. The allowable data latency means the maximum elapsed time between the measurement time of the data used to generate the corrections at the reference points and the measurement time of the data to which the corrections are applied.

6.4.2 Requirements for augmentation information

The following various augmentation data which are generated in positioning augmentation centres shall be uploaded to the augmentation satellite and be broadcast to ground users. Requirement for data volume of respective augmentation data shall be determined. The example of data volume and transmission rate of augmentation data are shown in Annex F.

a) Satellite clock error

This means the difference between the satellite clock time and that predicted by the satellite data.

b) Satellite orbit error

This means the difference between the actual satellite location and the location predicted by the satellite orbital data.

c) Ionospheric delay

This means the signal propagation group delay caused by traversing the paths from the satellite to the ground through the ionosphere.

d) Tropospheric delay

This means the signal propagation delay caused by traversing the paths from the satellite to the ground through the lower atmosphere or the troposphere.

e) Code signal bias

This means the delay of code, or in other words, pseudorange with respect to reference signal.

f) Carrier phase signal bias

This means the delay of carrier phase with respect to reference signal.

6.5 Requirements for user terminals

User terminals shall calculate their positions using augmentation data broadcast from augmentation satellites. Requirements for the use of augmentation data are presented as follows.

6.5.1 Requirements for input parameters

a) Data rate

The data rate shall be defined as the interval between the instant when the user terminal receives the augmentation data broadcast from the augmentation satellite.

b) Format transformation

The format transformation means to convert the binary sequence conveyed on the signal into the physical quantities to generate the augmentation data.

c) Data synchronization

This means the time synchronization at the user terminal between the measurement time of the ranging signal from positioning satellites and the receiving time of the correction data from the augmentation satellite. The synchronous case, though accompanied with time delay, shall result in a high accuracy positioning due to timely matching. The asynchronous case shall immediately derive a positioning result with less accuracy due to timely mismatching.

6.5.2 Requirements for the user terminal pre-processing

The user terminal shall follow the procedure as stated below when determining its position using augmentation data so that it can use the conventional RTK positioning calculation method. That is, the adjusted data C1PRC[sv,rv], P2PRC[sv,rv], L1CPC[sv,rv], and L2CPC[sv,rv] shall be defined below where “sv” and “rv” mean the satellite and the approximate position of the user terminal, respectively. Then, both C1PRC[sv,rv] and P2PRC[sv,rv] correspond to the pseudorange correction at reference, or Formula (8.19) in Reference [4] while both L1CPC[sv,rv] and L2CPC[sv,rv] correspond to the phase correction at reference, or Formula (8.20) in Reference [4]. According to Reference [4], applying the above adjusted data to the measurement data at the user terminal shall yield the high accuracy positioning.

The value of augmentation data for the user location can be determined as follows.

— CLKs[sv]: Satellite clock error

— C1Bs[sv]: C1 signal bias of satellite transmitter

— P2Bs[sv]: P2 signal bias of satellite transmitter

— L1Bs[sv]: L1 signal bias of satellite transmitter

— L2Bs[sv]: L2 signal bias of satellite transmitter

— ORB[sv](=(ORBr[sv], ORBa[sv], ORBc[sv])): Satellite orbit error vector

where

ORBr[sv] is the radial component of satellite orbit error vector;

ORBa[sv] is the along-track component of satellite orbit error vector;

ORBc[sv] is the cross-track component of satellite orbit error vector

— ION[sv, rv]: slant total electron content, or integrated electron density along the propagation of a radio signal in the ionosphere, multiplied by 40,3, and divided by (f1 • f2) at the same time.

  — f1: L1 signal frequency

  — f2: L2 signal frequency

Positioning calculation is shown as follows. Using the above augmentation data, make the adjusted data of the user, or C1PRC[sv, rv], P2PRC[sv, rv], L1CPC[sv, rv], and L2CPC[sv, rv] at the user approximate position.

— C1PRC[sv, rv] = – CLKs[sv] – C1Bs[sv] + ORB[sv] · rac[sv, rv] + μ · ION[sv, rv]

— P2PRC[sv, rv] = – CLKs[sv] – P2Bs[sv] + ORB[sv] · rac[sv, rv] + η · ION[sv, rv]

— L1CPC[sv, rv] = – CLKs[sv] – L1Bs[sv] + ORB[sv] · rac[sv, rv] – μ · ION[sv, rv]

— L2CPC[sv, rv] = – CLKs[sv] – L2Bs[sv] + ORB[sv] · rac[sv, rv] – η · ION[sv, rv]

where

rdl[sv] Radial vector

alt[sv] Along-track vector

crt[sv] Cross-track vector

los[sv, rv] Line-of-sight unit vector

rd[sv, rv] = rdl[sv] · los[sv, rv]

at[sv, rv] = alt[sv] · los[sv, rv]

ct[sv, rv] = crt[sv] · los[sv, rv]

rac[sv, rv] = (rd[sv, rv], at[sv, rv], ct[sv, rv])

— μ = 120/154: Ratio of frequency

— η = 154/120: Inverse ratio of frequency

And C1, P2, L1, and L2 signals are described as follows. The C1 signal, or the C/A-code transmitted on the L1 carrier, is generated at a chipping rate of 1,023 Mbps. The corresponding wavelength of one chip is about 300 m. The P2 signal, or the P-code transmitted on the L1 and L2 carrier, is generated at a chipping rate of 10,23 Mbps. The corresponding wavelength of one chip is about 30 m. The L1 signal, containing both the C/A-code and the P-code, is transmitted at a frequency of 1 575,42 MHz. The L1 wavelength is about 19,05 cm. The L2 signal, containing only the P-code, is transmitted at a frequency of 1 227,60 MHz. The L2 wavelength is about 29,31 cm.

It can be considered that there are three cases where two frequencies are selected among three frequencies L1, L2, and L5.

a) Case of two frequencies (L1, L2)

  — f1: L1 signal frequency

  — f2: L2 signal frequency

  — μ = 120/154

  — η = 154/120

b) Case of two frequencies (L1, L5)

  — f1: L1 signal frequency

  — f5: L5 signal frequency

  — μ = 115/154

  — η = 154/115

— P2 → C5

— L2 → L5

c) Case of two frequencies (L2, L5)

— f2: L2 signal frequency

— f5: L5 signal frequency

— $\mu = 115/120$

— $\eta = 120/115$

— C1 → P2

— P2 → C5

— L1 → L2

— L2 → L5

6.5.3 Requirements for user terminal output

User terminals are required to output the position and velocity data of the user location and provide the precise measurement time. Such navigation and time data can be utilized for various applications.

a) navigation data such as position, velocity;

b) time information.

6.6 Requirement for processing

The process of augmentation data generation and position calculation shall require the following mathematical models and physical constants.

6.6.1 Requirement for mathematical models

a) Coordinate system and its transformation

— ECEF coordinate system

It is convenient to represent the positions and velocities of terrestrial objects in ECEF coordinates or with latitude, longitude, and altitude. ITRF is a specific realization of ECEF frame.

— ECI coordinate system

This non-rotating system can describe the equations of orbital motion in space in more simple form.

— NED coordinate system

This system is a geographical coordinate system for representing the position along the northern axis, the eastern axis, and the vertical axis.

b) Time system

— GPS time system

— Other time system

c) Satellite position calculation

d) Geoid model

e) Helmert transformation

f) Tidal displacement of the ground reference points

g) Phase wind-up effect

h) Representation of ionosphere

— Slant range model

The ionospheric delay is obtained for each pair of the satellite and the ground reference point. This ionospheric delay can be high accurately estimated.

— Grid point model

The vertical ionospheric delay is specified per reference point or pair of some latitude and some longitude. The accuracy of this ionospheric delay would be less than the slant range model as noted above.

— Ionospheric correction model

This ionospheric delay is modelled using ionospheric parameters contained in the navigation data. In detail, refer to Figure 20-4 of Reference[3]. It is said that the use of this model would provide at least a 50 % reduction in the positioning error due to ionospheric propagation effects.

— Spherical functional model

This ionospheric delay can be calculated from the surface electron density of the layer, which is represented on a global scale as formulated by the spherical harmonic functions, or the Legendre functions. The coefficients of the spherical functions are obtained in GIM (Global Ionosphere Maps) files provided by CODE, one of the Analysis Centers of IGS. For details, refer to Reference [5].

6.6.2 Requirement for physical constants

a) Ratio of circumference: 3,141 592 653 589 8 (rad)

b) Earth rotational rate: 7,292 115e-5 (rad/s)

c) Earth-centred gravitational constant: 3,986 004 418 e14 (m^3/s^2)

d) Earth equatorial radius: 6,378,137 (m)

e) Flatness: 1/298.257 223 563

f) Speed of light: 299,792,458 (m/s)

For other physical constants, refer to Reference [1] to Reference [3].

7 Requirements for verification and evaluation

This International Standard is supposed to be used for space based services by broadcasting the augmentation data for centimetre class positioning over wide area. Therefore, this International Standard defines the requirements for verification and evaluation of the guarantee of quality of the services. Also, this International Standard also plays a role of the recognition for the certification of the services.

Verification and evaluation shall be prepared as follows (see Figure 3). First, this International Standard draws up the verification and evaluation plan. Then, the International Standard studies the various factors affecting the positioning, and selects the verification conditions. After that, the International Standard establishes the evaluation criteria for positioning accuracy and convergence rate. Finally, the International Standard sets the verification methods by use of statistical process or estimation process.

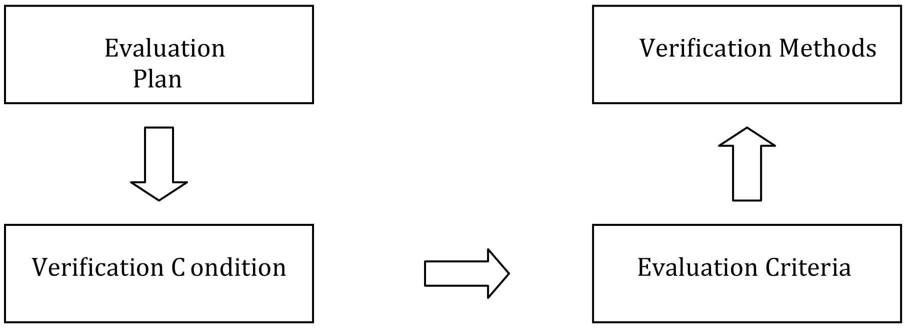


Figure 3 — Methodology for verification and evaluation

7.1 Evaluation plan

To carry out the verification and evaluation, this International Standard refers to the requirements for evaluation plan including procedure, items, data, and so on.

7.1.1 Evaluation procedure

a) Sampling

b) Hypothesis, verification, and criterion

c) Estimation of incorrectness rate

d) Verification of fitting rate

7.1.2 Evaluation items

a) Accuracy evaluation of augmentation data

b) Verification of augmentation data

c) Accuracy evaluation of positioning result

7.1.3 Data

a) Observation raw data

b) Pre-processed data

c) Real-time output data

d) Post-processed data

7.1.4 Evaluation matters

a) Evaluation of fix rate

b) Evaluation of data available period, or the time elapsed after augmentation data was generated, as the period available for augmentation data are limited after this data are generated

c) Anomaly detection and reliability

d) Distinction between horizontal and vertical errors

7.1.5 Time of verification

a) Pre-flight verification

— Advanced verification

b) In-orbit verification

— Real-time verification

— Anomaly detection

7.2 Verification conditions

This International Standard refers to the requirements for verification conditions such as period, place, satellite constellation, the number and allocation of reference points, the state of ionosphere, transmission delay of augmentation data, and characteristics of users.

7.2.1 Period

a) Annual change

— Effects of sunspot activity

b) Seasonal differences

— Effects of ionosphere and troposphere

c) Daily change

7.2.2 Place

a) Flat area

b) Urban area

— Effect of satellite invisibility

c) Mountainous area

— Effect of height

d) Ocean area

e) Accuracy guarantee over wide area

7.2.3 Satellites

a) Orbit constellation

b) Satellite visibility

c) State of transmitted signal

7.2.4 Reference points

a) Number of reference points

b) Allocation of reference points

c) Separation between reference points

7.2.5 Augmentation data

a) Temporal availability

b) Spatial availability

- Based on reference points

- Based on grids

c) Effect of transmission delay

7.2.6 Positioning objects

a) Stationary objects

b) Mobile objects

- Effect of multi-path

7.3 Evaluation criteria

According to the objective of verification and evaluation, this International Standard states the requirements for evaluation criteria including accuracy and convergence rate of augmentation data and positioning results.

7.3.1 Accuracy and convergence of augmentation data

This International Standard evaluates the estimation accuracy, convergence rate, and separation of augmentation data such as clock error, signal bias, ionospheric delay, and others.

7.3.2 Accuracy and convergence of positioning results

For positioning results, this International Standard evaluates statistical value and convergence rate of bias error or offset, random error or standard deviation, CEP (circular error probable), and RMS (root mean square).

7.4 Verification methods

This International Standard describes optimal estimation or verification methods for objects of interest under various conditions.

7.4.1 Estimation process

Evaluate observation data and processed data.

a) Average, standard deviation

b) Minimal root mean square estimation

   This International Standard defines the following estimation process, evaluating the fundamental performances of antennas and receivers used for the verification of augmentation system.

a) Zero baseline verification

   This International Standard verifies by using antenna splitter with baseline length zero, so that the quantities of satellite orbit error, ionospheric delay, tropospheric delay, multi-path, and antenna offset shall be cancelled and only the receiver error remains.

b) Antenna calibration

This International Standard specifies the calibration of the antenna offset and its phase centre variation.

c) Antenna swapping verification

This International Standard verifies positioning accuracy verification by swapping two antennas in order to cancel horizontal and vertical bias error.

7.4.2 Verification method

Compare the processed results with the designated results.

a) Hypothesis, verification, significance level

b) Use of various statistical distributions

This International Standard shows the verification process below.

a) Verification of bias

For the verification of baseline length zero, judge the bias error of the receiver. An example of the bias error judgment by t-distribution verification is shown in Annex A.

b) Verification of device specification

For the verification of baseline length zero, estimate the noise level of the receiver. An example of the receiver specification estimation by chi-squared-distribution verification is shown in Annex B.

c) Verification of dependence on place or time

Evaluate the dependence of the positioning result on area or time zone. An example of the area and time zone dependence by F-distribution verification is shown in Annex C.

d) Verification method on the testing field

1) Procedure of evaluation of the positioning result

— Park the vehicle on the testing field.

— Calculate the positioning result of the vehicle by the method of interest.

— On the other hand, estimate the observation data at the vehicle's approximate location by using the real observation data of three reference points in the neighbourhood of the vehicle. Using this estimated observation data, calculate the positioning result by the method of network RTK, or in short, NRTK.

— Evaluate the positioning result by the method of interest, regarding the positioning result by the NRTK method as nearly correct.

— The criterion on positioning accuracy shall be based on the required accuracy for the respective application shown in Table G.1.

2) Procedure of evaluation of the relative positioning result

— Move the vehicle to the point from the point where the vehicle was parked on the testing field. The difference between the above two points can be correctly measured.

— Calculate the positioning result of the vehicle by the method of interest.

— Evaluate the relative positioning result by the method of interest by comparing the difference of the positioning result with that of the conventionally measured data.

— The criterion on positioning accuracy shall be based on the required accuracy for the respective application shown in Table G.1.

e) Verification method in the driving field

a) Procedure of evaluation of the positioning accuracy of the reference points along the driving route

— Select the reference points in the neighbourhood of the vehicle's driving route. The positioning result of these reference points can be obtained by the surveying method.

— Calculate the positioning result of these reference points in the time zone of the vehicle's driving by the method of interest.

— Evaluate the method of interest by comparing the positioning result by the method of interest with the positioning result by the surveying method, where the latter can be regarded as correct.

— The criterion on positioning accuracy shall be based on the required accuracy for the respective application shown in Table G.1.

b) Procedure of evaluation of the positioning result under various environments

— Drive the vehicle in the outer field under various environments such as city area, mountains, seaside, and highway with a variety of vehicle speed, satellite elevation and weather condition.

— Calculate the positioning result of the vehicle by the method of interest.

— At the same time, calculate the positioning result by the NRTK method along the driving route.

— Evaluate the positioning result by the method of interest, regarding the positioning result by the NRTK method as nearly correct. Then, we can evaluate the positioning accuracy of the method of interest under various environments.

— The criterion on positioning accuracy shall be based on the required accuracy for the respective application shown in Table G.1.

7.4.3 Research for the cause of malfunction

Execute the estimation and verification process in order to find out the cause of malfunction. The following data shall be provided to users as user support operational information, if necessary:

a) ionosphere anomaly;

b) precipitable water vapour anomaly;

c) multi-path;

d) antenna mismatch.

Annex A
(informative)

Verification calculation of bias

An example of the bias error judgment by t-distribution verification is shown below.

Let δ and s be the arithmetic average and standard deviation of experimental data, respectively, with the degree of freedom 60. If Formula (A.1) holds, then the hypothesis “delta = 0” shall not be rejected at the confidence level 95 %. That is, no bias error shall be verified at the confidence level 95 %.

$$\delta < s \times t(60{,}0.05) \approx s \times 2{,}00 \qquad \text{(A.1)}$$

Here, this International Standard assumes the confidence level as 0,95 and the degree of freedom (= points * sets * sections) as 60.

— t-distribution

Normalized data of the size n sampled from population is governed by t-distribution of degree of freedom n-1 as depicted in Figure A.1.

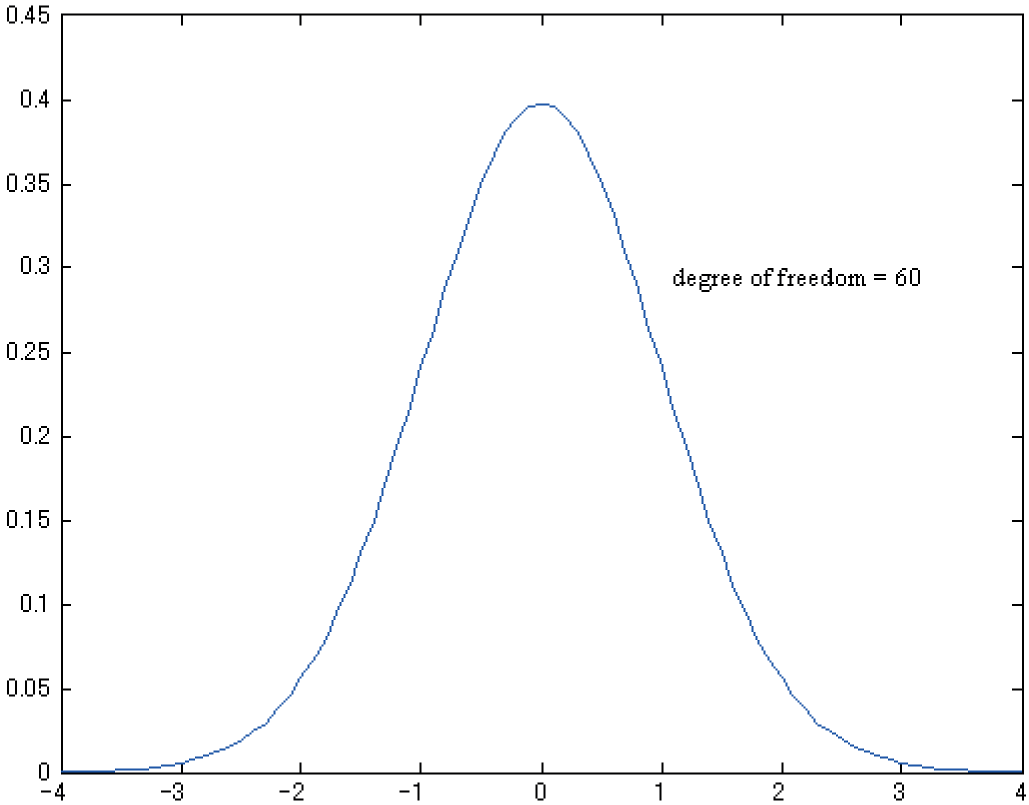


Figure A.1 — t-distribution

Annex B
(informative)

Verification calculation of device specification

An example of the receiver specification estimation by chi-squared-distribution verification is shown below.

Let s and σ be the standard deviation of experimental data and device specification, respectively, with the degree of freedom 60. If Formula (B.1) holds, then the hypothesis "$s < \sigma$" shall not be rejected at the confidence level 95 %. That is, the device specification shall be verified at the confidence level 95 %.

$$s < \sigma \times \sqrt{\frac{\chi^2(60,0.05)}{60}} \approx \sigma \times 1,15 \quad \text{(B.1)}$$

Here, this International Standard assumes the confidence level as 0,95 and the degree of freedom (= points * sets * sections) as 60.

— chi -square-distribution

Normalized data of the size n sampled from population is governed by t-distribution of degree of freedom n-1 as depicted in Figure A.1. Let S be the square sum of sampled data of the size n from normal population, and divide S by population variance square of sigma, which would be governed by chi-squared-distribution of degree of freedom n-1 as depicted in Figure B.1.

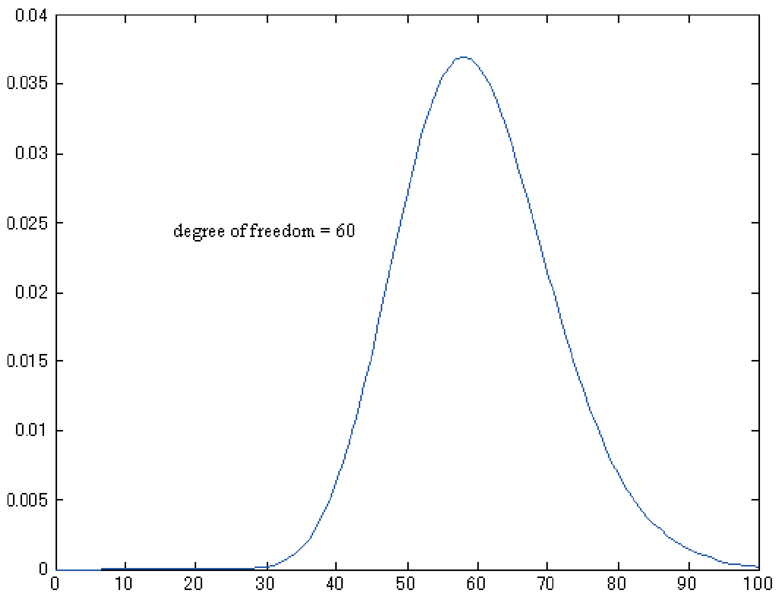


Figure B.1 — chi -square-distribution

Annex C
(informative)

Verification calculation of dependence on place or time

An example of the area and time zone dependence by F-distribution verification is shown below.

Let *sx* and *sy* be the two standard deviations of experimental data, with the degree of freedom 60 and 60, respectively. If Formula (C.1) holds, then the hypothesis that the two experimental data sampled from normal population is equivalent or "σx = σy" shall not be rejected at the confidence level 95 %. That is, the dependence on place or time shall be verified at the confidence level 95 %.

$$0{,}60 \approx \frac{1}{F_{60}^{60}(0{,}025)} < \frac{sx^2}{sy^2} < F_{60}^{60}(0{,}025) \approx 1{,}67 \quad \text{(C.1)}$$

Here, this International Standard assumes the confidence level as 0,95 and the degree of freedom (= points * sets * sections) as 60.

— F-distribution

The ratio of variance of two data, each sampled from population of the same standard deviation, is governed by F-distribution of degree of freedom (nx-1, ny-1) as depicted in Figure C.1.

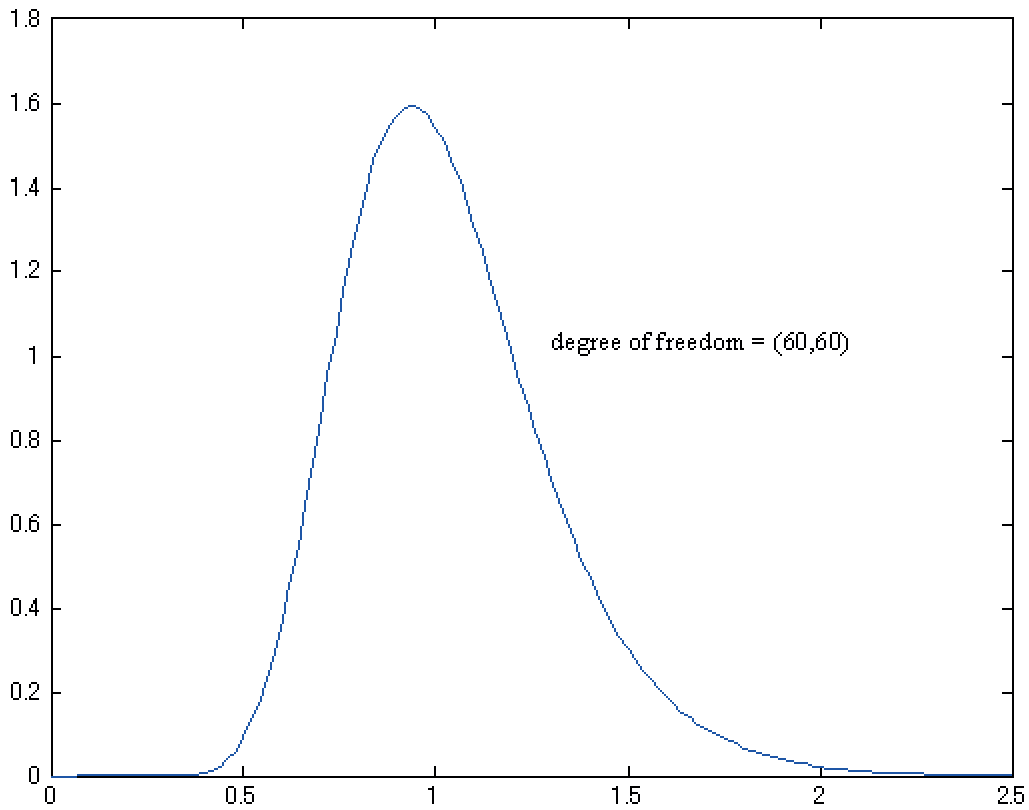


Figure C.1 — F-distribution

Annex D
(informative)

Orbit constellation for augmentation satellites

Table D.1 shows the typical examples to clarify the differences of orbit height and required number of augmentation satellites.

Table D.1 — Example of orbit constellation of augmentation satellites

No.	Inclination (°)	Orbit period (hr)	Orbit height (km)	Approximate observable time per each satellite (hr)	Sat. number	Orbit plane number	Sat. number per each orbit plane	Phase difference between orbit planes (°)	Remarks
1	0	24	35 863	24	1	1	1	0,0°	GEO
2	45	24	35 863	8	3	3	1	multiple of 120,0° ≤ 240,0°	IGSO
3	45	12	20 232	4	6	3	2	multiple of 60,0° ≤ 120,0°	MEO (GPS sat.)
4	45	8	13 929	2	12	4	3	multiple of 30,0° ≤ 90,0°	MEO (Molniya sat.)
5	45	6	10 385	1,5	16	4	4	multiple of 22,5° ≤ 67,5°	MEO
6	45	4	6 415	1	24	6	4	multiple of 15,0° ≤ 75,0°	MEO
7	45	1,9	1 400	0.5	48	6	8	multiple of 7,5° ≤ 37,5°	LEO

Annex E
(informative)

Ground track and antenna coverage of augmentation satellite

Figure E.1 to Figure E.7 shows the ground track (blue line) and the antenna coverage (red line), corresponding to the respective orbit constellation in Annex D. Here, the antenna coverage depicts the moment when the ground trajectory of the satellite is located at the north edge, setting the eccentricity as zero and the elevation larger than 45°.

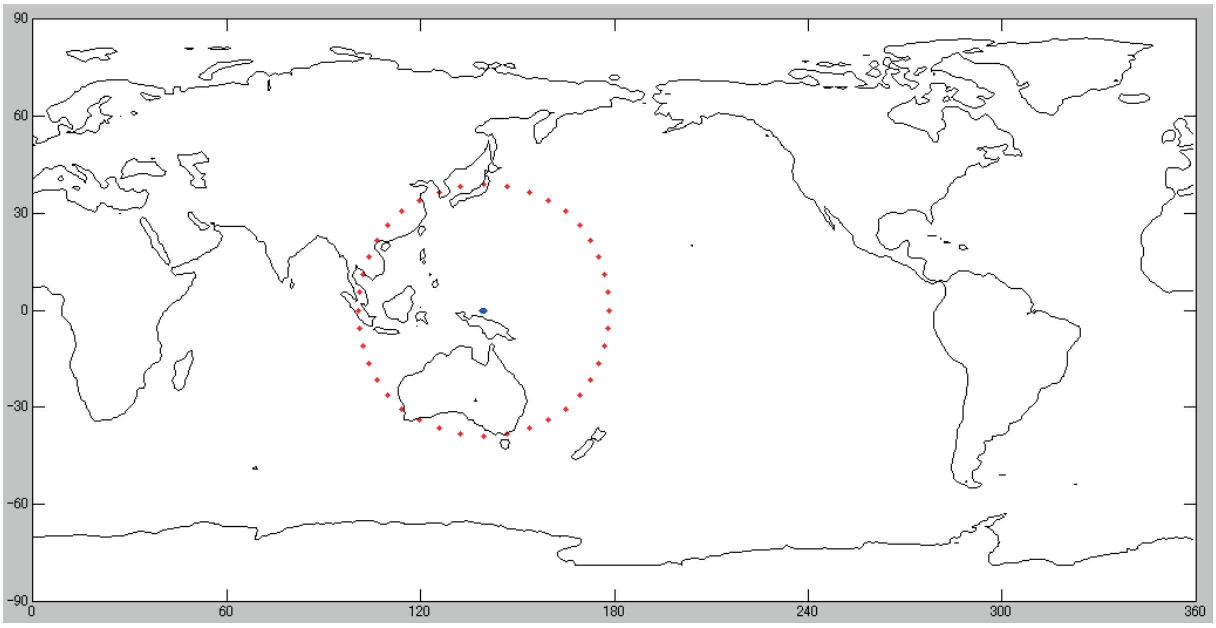


Figure E.1 — Ground track and antenna coverage of augmentation satellite (No.1 GEO)

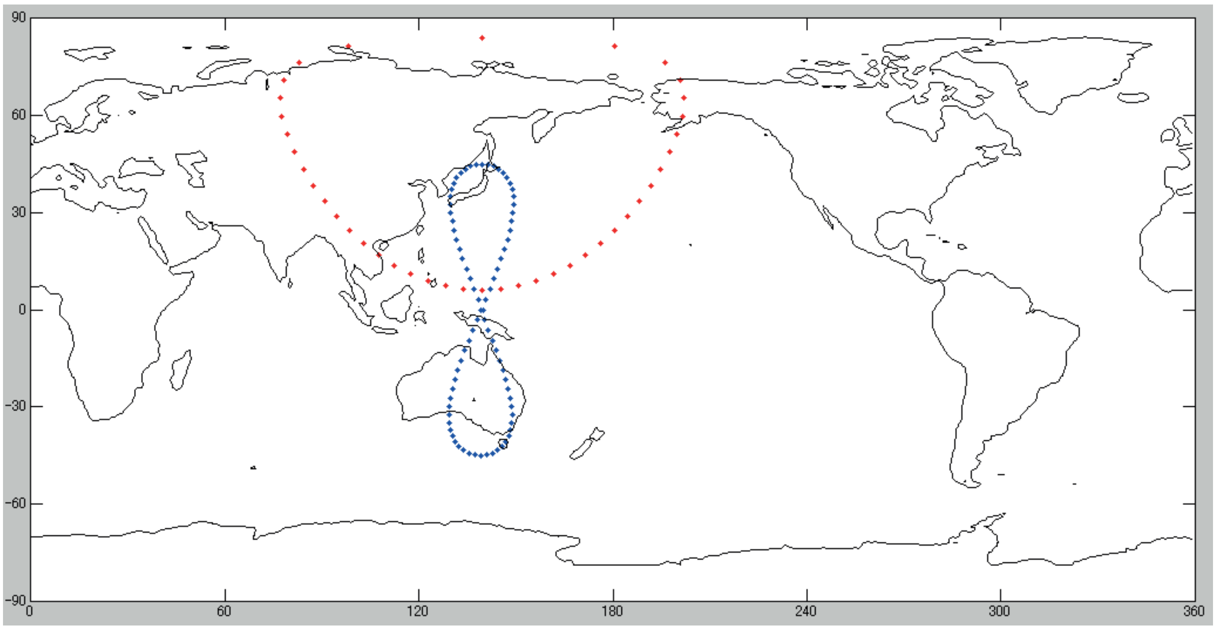


Figure E.2 — Ground track and antenna coverage of augmentation satellite (No.2 IGSO)

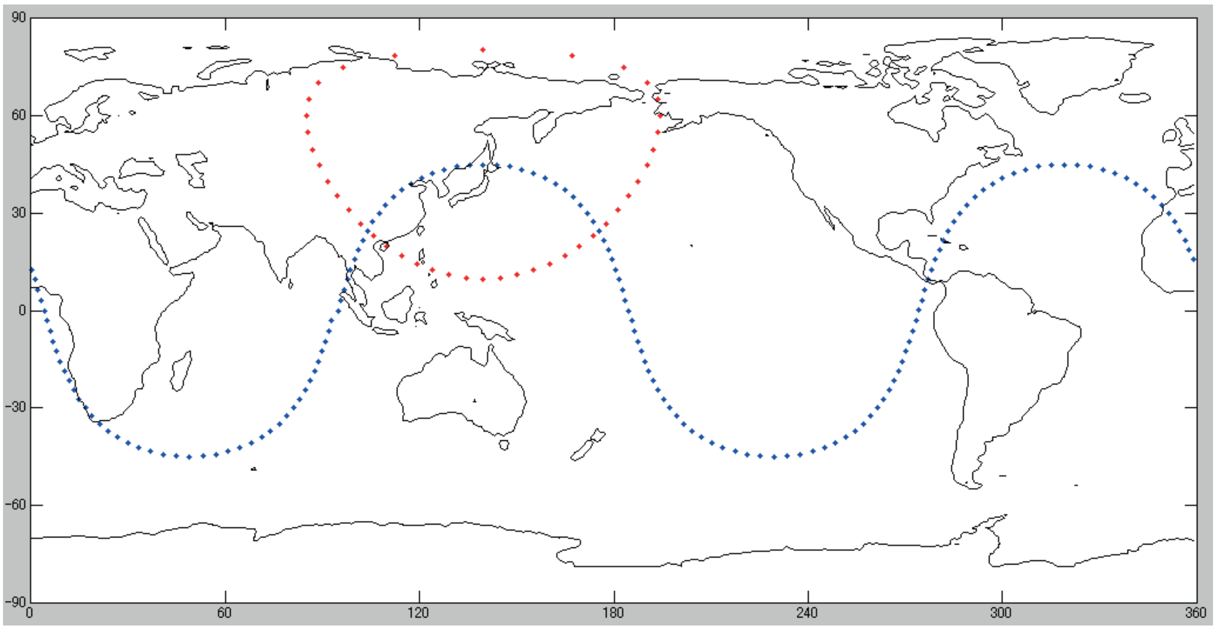


Figure E.3 — Ground track and antenna coverage of augmentation satellite (No.3 MEO)

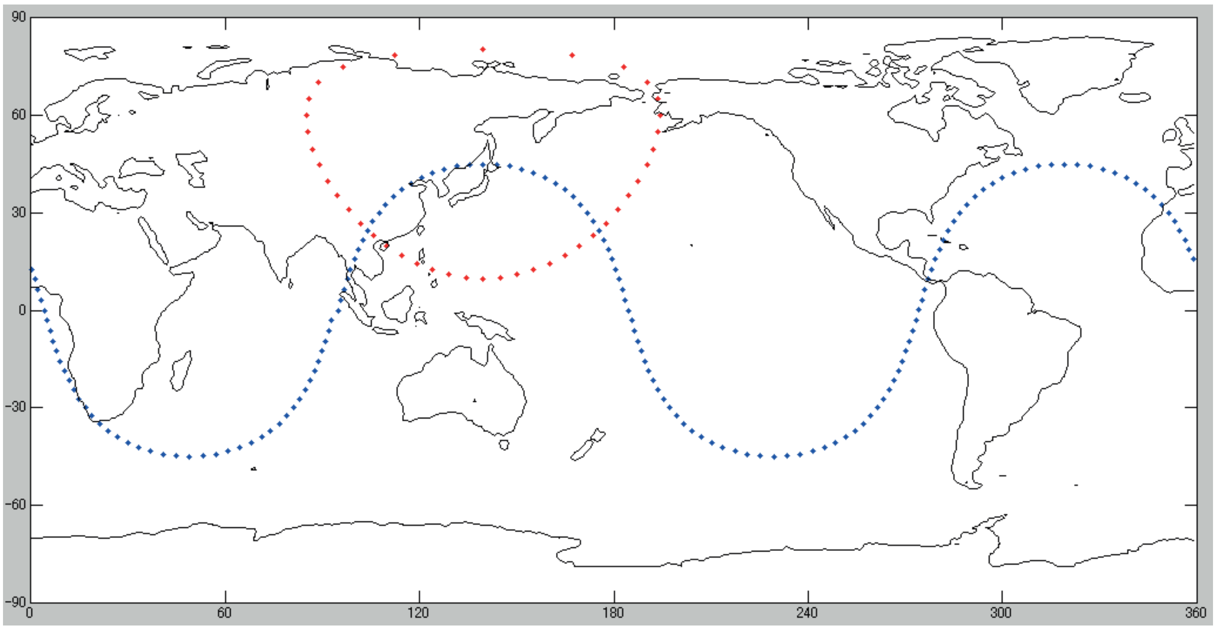


Figure E.4 — Ground track and antenna coverage of augmentation satellite (No.4 MEO)

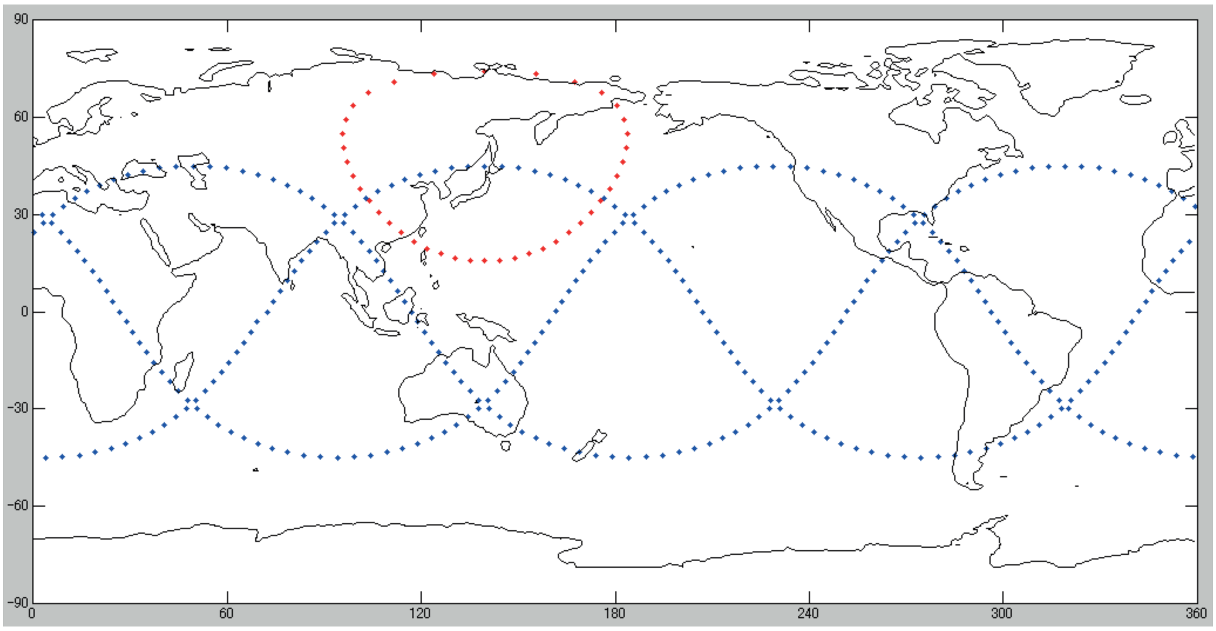


Figure E.5 — Ground track and antenna coverage of augmentation satellite (No.5 MEO)

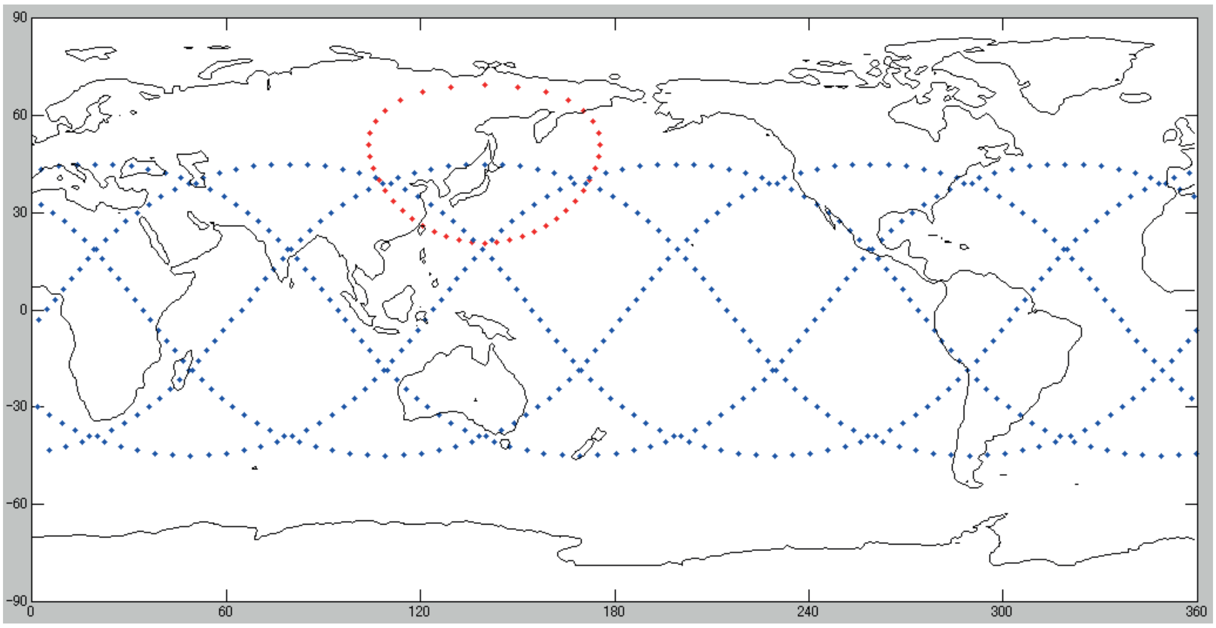


Figure E.6 — Ground track and antenna coverage of augmentation satellite (No.6 MEO)

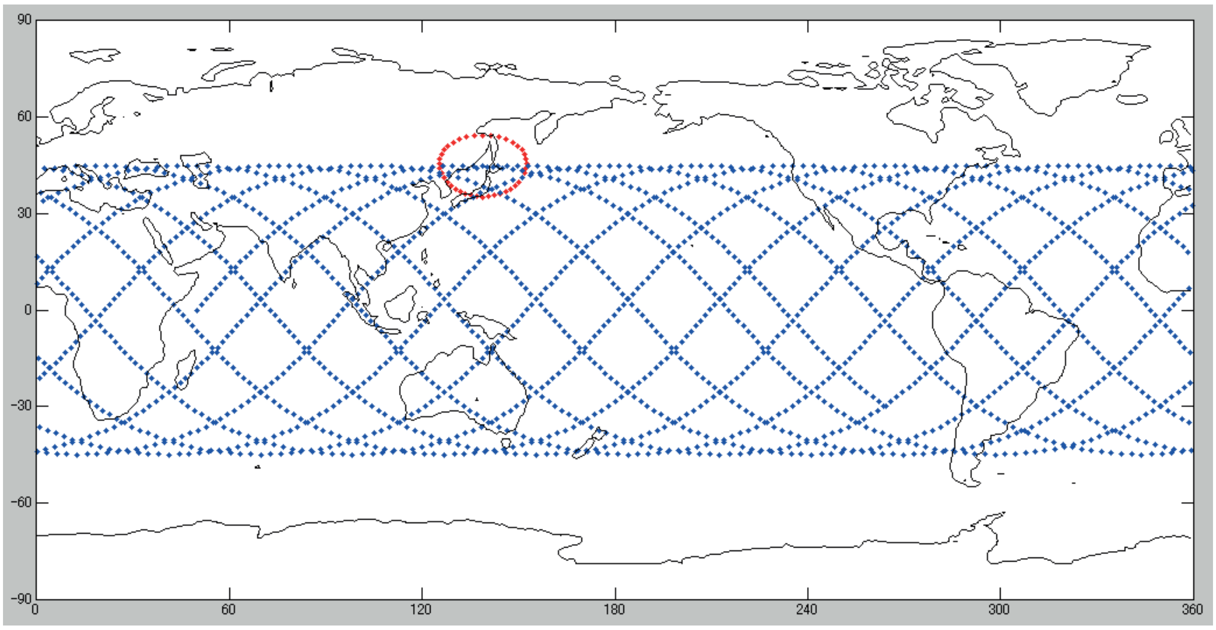


Figure E.7 — Ground track and antenna coverage of augmentation satellite (No.7 LEO)

Annex F
(informative)

Data volume and transmission rate of augmentation data

Table F.1 shows the example of data volume and transmission rate of augmentation data.

Table F.1 — Example of data volume and transmission rate of augmentation data

No.	Data	Resolution (mm)	Range (m)	Bit number (b)	Sat. number	Grid number	Sum. of bit number (b)	Renewal period (s)	Transmission rate (bps)
1	Satellite clock error	0,5	±50	18	14	—	252	5	50
2	Satellite orbit error	0,5	±50	18 × 3	14	—	756	30	25
3	Ionospheric delay	0,5	±120	19	14	160	42 560	30	1 419
4	Tropospheric delay	0,5	±4	14	—	160	2 240	30	75
5	Code signal bias	5,0	±20	13 × 2	14	—	364	30	12
6	Carrier phase signal bias	0,5	±20	17 × 2	14	—	476	30	16
7	Quality indicator	—	—	32	14	—	448	30	15
8	Others (IOD, message number, version)	—	—	—	—	—	—	—	30
	Summation	—	—	—	—	—	—	—	1 642

Annex G
(informative)

Applications required for centimetre accuracy positioning

Table G.1 shows the application required for centimetre class positioning. For the respective industrial field, set the requirement for accuracy, real-time property and reliability, for example.

Table G.1 — Applications required for centimeter class positioning

No.	Field	Contents of application	Required accuracy	Real–time property	Reliability
1	Automatic farming	High-value crop cultivation	5 cm	Necessary	Normal
2	Civil engineering architecture	Construction based on information technology	2 cm to 3 cm	Necessary	High
3	Natural disasters	Earthquake detection Tsunami measurement	2 cm to 3 cm	Necessary	High
4	Surveying	Static survey	1 cm to 2 cm	Unnecessary	High
5	Mobile mapping	Mapping Mobile survey	5 cm	Unnecessary	Normal
6	Snowplow	Determination of precise position of working vehicles	5 cm	Necessary	High
7	Intelligent Transportation System (ITS)	Automatic driving	5 cm	Necessary	High

Bibliography

[1] World Geodetic System 1984: NATIONAL IMAGERY AND MAPPING AGENCY TECHNICAL REPORT 8350.2, Third Edition, 2000

[2] Conventions I.E.R.S. 2010: IERS Technical Note No. 36, IERS Conventions Centre, 2010[3] I S - GPS-200F: Navstar GPS Space Segment/Navigation User Segment Interfaces, 2011

[3] IS-GPS-200F: Navstar GPS Space Segment/Navigation User Segment Interfaces, 2011

[4] Hofmann-Wellenhof B., Lichtenegger H., Collins J. Global Positioning System - Theory and Practice, Fifth. Springer, revised edition, 2001

[5] Schaer S. How to use CODE's Global Ionosphere Maps. AIUB, 1997

[6] RTCM 10402.3: RECOMMENDED STANDARDS FOR DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICE – VERSION 2.3, RTCM SPECIAL COMMITTEE NO.104, 2001

[7] Murfin Tony Look, No Base-Station! — Precise Point Positioning (PPP), GPS World, March 20, 2013

[8] Schrock G. Feature: After RTK — Part 1. Professional Surveyor Magazine, **Vol. 32**, 2012

[9] http://www.gsi.go.jp/

[10] http://www.sapos.de/

[11] http://rgp.ign.fr/

[12] http://www.epncb.oma.be/

[13] http://geodesy.noaa.gov/CORS/

[14] http://www.igs.org/presents/poland2012/

[15] http://www.igs.org/presents/poland2012/posters.htm

[16] http://igscb.jpl.nasa.gov/

[17] Walker J.G. Satellite Constellations, Journal of the British Interplanetary Society, Vol.37, 559-571, 1984

[18] EUPOS – European Position Determination System. *Technical Standards*. Revised 2nd Edition, 2008[19] M.Sahmoudi, and etc., U-SBAS: A Universal multi-SBAS Standard to ensure Compatibility, Interoperability and Interchangeability, NAVITEC, 2010

[20] Wübbena G., Schmitz M., Bagge A. PPP-RTK: Precise Point Positioning Using State-Space Representation in RTK Networks. ION GNSS, 2005

[21] Geng J. Rapid Re-convergence in Real-time Precise Point Positioning with Ambiguity Resolution. ION GNSS, 2009

[22] Laurichesse D., Mercier F., Berthias J.P. Real-time PPP with undifferenced integer ambiguity resolution, experimental results. ION GNSS, 2010

[23] GLOBAL POSITIONING SYSTEM WIDE AREA AUGMENTATION SYSTEM (WAAS) PERFORMANCE STANDARD, DOT&FAA, 2008.10.31

[24] RTCM STANDARD 10403.2: DIFFERENTIAL GNSS (GLOBAL NAVIGATION SATELLITE SYSTEMS) SERVICES — VERSION 3, RTCM SPECIAL COMMITTEE NO.104, 2013.2.1

ICS 49.140

Price based on 31 pages

This page deliberately left blank

British Standards Institution (BSI)

BSI is the national body responsible for preparing British Standards and other standards-related publications, information and services.

BSI is incorporated by Royal Charter. British Standards and other standardization products are published by BSI Standards Limited.

About us

We bring together business, industry, government, consumers, innovators and others to shape their combined experience and expertise into standards -based solutions.

The knowledge embodied in our standards has been carefully assembled in a dependable format and refined through our open consultation process. Organizations of all sizes and across all sectors choose standards to help them achieve their goals.

Information on standards

We can provide you with the knowledge that your organization needs to succeed. Find out more about British Standards by visiting our website at bsigroup.com/standards or contacting our Customer Services team or Knowledge Centre.

Buying standards

You can buy and download PDF versions of BSI publications, including British and adopted European and international standards, through our website at bsigroup.com/shop, where hard copies can also be purchased.

If you need international and foreign standards from other Standards Development Organizations, hard copies can be ordered from our Customer Services team.

Subscriptions

Our range of subscription services are designed to make using standards easier for you. For further information on our subscription products go to bsigroup.com/subscriptions.

With **British Standards Online (BSOL)** you'll have instant access to over 55,000 British and adopted European and international standards from your desktop. It's available 24/7 and is refreshed daily so you'll always be up to date.

You can keep in touch with standards developments and receive substantial discounts on the purchase price of standards, both in single copy and subscription format, by becoming a **BSI Subscribing Member**.

PLUS is an updating service exclusive to BSI Subscribing Members. You will automatically receive the latest hard copy of your standards when they're revised or replaced.

To find out more about becoming a BSI Subscribing Member and the benefits of membership, please visit bsigroup.com/shop.

With a **Multi-User Network Licence (MUNL)** you are able to host standards publications on your intranet. Licences can cover as few or as many users as you wish. With updates supplied as soon as they're available, you can be sure your documentation is current. For further information, email bsmusales@bsigroup.com.

Revisions

Our British Standards and other publications are updated by amendment or revision.

We continually improve the quality of our products and services to benefit your business. If you find an inaccuracy or ambiguity within a British Standard or other BSI publication please inform the Knowledge Centre.

Copyright

Useful Contacts:

Customer Services
Tel: +44 845 086 9001
Email (orders): orders@bsigroup.com
Email (enquiries): cservices@bsigroup.com

Subscriptions
Tel: +44 845 086 9001
Email: subscriptions@bsigroup.com

Knowledge Centre
Tel: +44 20 8996 7004
Email: knowledgecentre@bsigroup.com

Copyright & Licensing
Tel: +44 20 8996 7070
Email: copyright@bsigroup.com

BSI Group Headquarters

389 Chiswick High Road London W4 4AL UK

bsi.

...making excellence a habit.™