INTEGRITY AND CONTINUITY ANALYSIS FOR GPS

QUARTERLY REPORT 2 (APRIL TO JUNE 2026)

Prepared by:	M Copple
Approved by:	M Pattinson
Authorized by:	M Pattinson

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1. INTRODUCTION

1.1. PURPOSE

This document presents the results of the integrity and continuity analysis for GPS against ICAO requirements for the period of April to June 2026. The results have been generated within the frame of the performance monitoring contract awarded to GMV NSL by the CAA. The objectives of the study are to compare the measured performance against the applicable ICAO SARPs in Annex 10 Volume 1 [RD.1], covering the following parameters [AD.1]:

- Accuracy;
- Integrity;
- Continuity;
- Availability.

Assuming fault-free receiver performance conforming to the TSO-C129 specification.

The performance is analysed using raw data recorded at the GMV Nottingham site.

1.2. DOCUMENT OVERVIEW

This document is arranged in the following sections:

- **Section 1**, the current section, is an introduction that describes the purpose, scope and structure of the document;
- **Section 2** introduces the activity, including relevant performance requirements, methodology for assessment and list of assumptions;
- **Section 3** presents the accuracy assessment;
- **Section 4** contains an assessment of the integrity;
- **Section 5** presents the continuity assessment;
- **Section 6** contains an assessment of the availability;
- **Section 7** presents the conclusions.

1.3. REFERENCES

1.3.1. APPLICABLE DOCUMENTS

The following documents, of the exact issue shown, form part of this document to the extent specified herein. Applicable documents are those referenced in the Contract or approved by the Approval Authority. They are referenced in this document in the form [AD.x]:

Table 1-1 Applicable Documents

Ref.	Title	Code	Version	Date
[AD.1]	THE PROVISION OF MONITORING AND ANALYSIS OF GPS SIGNALS IN SPACE –	CONTRACT NO. 1762 (AMENDMENT NO. 15)	-	16/01/26

1.3.2. REFERENCE DOCUMENTS

The following documents, although not part of this document, amplify or clarify its contents. Reference documents are those not applicable and referenced within this document. They are referenced in this document in the form [RD.x]:

Table 1-2 Reference Documents

Ref.	Title	Code	Version	Date
[RD.1]	ICAO SARPS, Annex 10: International Standards and Recommended Practices: Aeronautical Telecommunications, Volume 1: Radio Navigation Aids	-	7th Edition	July 2018
[RD.2]	Global Positioning System Standard Positioning Service Performance Standard	GPS SPS	5th Edition	April 2020
[RD.3]	Reference Set of Parameters for RAIM Availability Simulations', EUROCAE WG-62	-	-	8-9 July 2003
[RD.4]	The International GNSS Service in a changing landscape of Global Navigation Satellite Systems	Journal of Geodesy 83: 191-198		2009

1.4. ACRONYMS

Acronyms used in this document and needing a definition are included in the following table:

Table 1-3 Acronyms

Acronym	Definition
AOD	Age of Data
CAA	Civil Aviation Authority
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution of Precision
IGS	International GNSS Service
NANU	Notice Advisory to Navstar Users
NOTAM	Notice To Airmen
PDOP	Position Dilution Of Precision
RAIM	Receiver Autonomous Integrity Monitoring
SIS	Signal In Space
SPS	Standard Positioning Service
TTA	Time To Alarm
UERE	User Equivalent Range Error
URA	User Range Accuracy
URE	User Range Error
VDOP	Vertical Dilution Of Precision

2. PERFORMANCE REQUIREMENTS AND METHODOLOGY

2.1. PURPOSE

The purpose of the performance monitoring activity [AD.1] is to collect and analyse data on the performance of the GPS Signal In Space (SIS). For this report, the applicable requirements are defined in the ICAO SARPs (Standards and Recommended Practices) contained in Annex 10 to the Convention on International Civil Aviation, Volume 1 Radio Navigation Aids [RD.1].

2.2. ICAO STANDARDS AND DEFINITIONS

The ICAO Annex 10 Volume 1 Chapter 3 Section 3.7 details the ICAO SARPS for GNSS [RD.1]. Section 3.7.2.4.1 sets the Signal-in-Space (SiS) performance requirements. An important assumption made in this respect is that *"the combination of GNSS elements and a fault-free receiver shall meet the SiS requirements defined in Table 3.7.2.4-1 (located at the end of section 3.7)".* The table below presents the requirements specified for NPA together with the relevant notes.

Horizontal Accuracy 95% (Notes 1 and 3)	Horizontal Alert Limit	Integrity	Time to Alert (Note 3)	Continuity (Note 4)	Availability (Note 5)
220m	556m	1-1x10-7/h	10 s	1-1x10-4/h to 1-1x10-8/h	0.99 to 0.99999

Note 1 *– The 95th percentile values for GNSS position errors are those required for the intended operation at the lowest height above threshold (HAT), if applicable.*

Note 3 *– The accuracy and time–to-alert requirements include the nominal performance of a fault-free receiver.*

Note 4 *– Ranges of values are given for the continuity requirement for NPA operations, as this requirement is dependent upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigational aids. The lower value given is the minimum requirement for areas with low traffic density and airspace complexity.*

Note 5 *– A range of values is given for the availability requirement as these requirements are dependent upon the operational need which is based upon several factors including the frequency of operations, weather environments, the size and duration of outages, availability of alternative navigational aids, radar coverage, traffic density and reversionary operational procedures. The lower values given are the minimum availabilities for which a system is considered to be practical but are not adequate to replace non-GNSS navigation aids. For approach and departure, the higher values given are based upon the availability requirements at airports with a large amount of traffic assuming that operations to or from multiple runways are affected but reversionary operational procedures ensure the safety of the operation.*

Relevant definitions for the performance requirements are provided below.

Horizontal Accuracy

Annex 10 Volume 1 Attachment D section 3.2.1 states: *"GNSS position error is the difference between the estimated position and the actual position. For an estimated position at a specific location, the probability should be at least 95 per cent that the position error is within the accuracy requirement."*

Integrity, Horizontal Alert Limit, Time to Alert

ICAO Annex 10 Volume 1 Attachment D section 3.3.1 states: "*Integrity is a measure of the trust that can be placed in the correctness of the information supplied by the total system. Integrity includes the ability of a system to provide timely and valid warnings to the user (alerts) when the system must not be used for the intended operation (or phase of flight).*" Therefore, integrity is the probability of not using a radiated false guidance signal.

For a loss of integrity to occur, the following conditions must occur simultaneously:

- radiation from the satellite system of a signal, which would result in a derived position error outside the ICAO GNSS NPA Horizontal Alert Limit (HAL), and
- failure to detect and indicate when the ICAO GNSS NPA HALs have been exceeded for a period of time beyond the ICAO GNSS NPA Time-To-Alert (TTA) period.

In this respect, the following points are relevant:

- The GPS SPS [RD.2] incorporates monitoring of the health of the satellites. This monitoring is not at the required probability level nor is it sufficiently prompt to fulfil the ICAO GNSS Horizontal Accuracy and TTA requirements.
- The use of at least a TSO-C129a compliant receiver will be necessary for GPS supported NPAs in accordance with AMC-20-XX. This type of receiver provides "Real-time monitoring" of the derived GPS position by the use of Receiver Autonomous Integrity Monitoring (RAIM).
- The requirements for the integrity contribution of the receiver are specified in document RTCA DO-208, Table 2-1 "GPS Position Integrity Performance Requirements", which is referenced from document TSO-C129a. Table 2-1 sets a minimum detection probability at 0.999.
- The ICAO requirement for integrity for GPS when used to provide a NPA is 1-(1x10-7) per flight hour.
- Taking into account the receiver detection probability of 0.999, there remains an integrity requirement of 1 – (1 x 10-4) per flight hour to be achieved by the remaining parts of the system. These remaining parts include the performance of the SIS and any other real-time monitoring devices in use.

Continuity

Annex 10 Attachment D section 3.4.1 states: "*Continuity of service of a system is the capability of the system to perform its function without unscheduled interruptions during the intended operation.*" ICAO provides a range of values for continuity; the value used by a specific aerodrome will depend upon several factors including the intended operation, traffic density, complexity of airspace and availability of alternative navigational aids. Guidance on setting this requirement can be found in Annex 10 Volume 1 Attachment D section 3.4.2.3.

It should be noted that the ICAO SARPs for NPA are consistent with those for en-route. In this respect, Annex 10 Volume 1 Attachment D section 3.4.2.1 states: "*For en-route operations, continuity of service relates to the capability of the navigation system to provide a navigation output with the specified accuracy and integrity throughout the intended operation, assuming that it was available at the start of the operation.*"

Therefore, loss of continuity (strictly in the case of SiS, i.e. assuming a fault-free receiver) can be considered to be when the horizontal alert limit cannot be achieved due to an unexpected failure of the GPS service for 10 seconds or more, during a period when RAIM is predicted to be available for a specific operation.

Availability

ICAO Annex 10 Volume 1 Attachment D section 3.5.1 states: "*The availability of GNSS is characterized by the portion of time the system is to be used for navigation during which reliable navigation information is presented to the crew, autopilot, or other system managing the flight of the*

aircraft". Furthermore, Section 3.5.6 states: "The availability of GNSS should be determined through design, analysis and modelling, rather than measurement."

Under normal conditions, availability of the signal from sufficient satellites to support RAIM, a prerequisite for the use of GPS to support an NPA, is predictable and may be assessed in advance of the use of the instrument approach procedure.

2.3. METHODOLOGY

For the performance analysis in this report, raw GPS measurement data from reference stations has been analysed. The primary source of data is continuously operating receivers, installed by GMV at its Nottingham and Harwell offices, which provide a log of 1Hz GNSS measurement data. These are shown in the map below.

Figure 2-1: Location of GMV Monitoring Receivers

As an alternative, data from the EUREF permanent GPS network can be used (as shown in the next figure). The EUREF receivers provide high-rate (1Hz), multi-constellation, multi-frequency GNSS measurements. The data files are accessed via FTP and can be downloaded at GMV NSL before processing with GISMO software. The daily navigation message files are also downloaded from the IGS FTP site and used to provide the navigation data [RD.4].

Figure 2-2: Location of EUREF Sites
(http://www.epncb.oma.be/_networkdata/stationmaps.php)

In this quarter, data from the GMV Nottingham site (NOTT) is used for most of the monitoring period. There was an issue with the NOTT antennas between 14th and 19th May so data from the EUREF site DARE has been used for these days.

2.4. ASSUMPTIONS

For processing the raw data and generating the results, the following assumptions are made:

- Single frequency (L1) processing with C/A code;
- 5-degree elevation mask used;
- Broadcast ionospheric model (Klobuchar) used to remove ionospheric errors;
- RTCA tropospheric model used to remove tropospheric errors;
- Weighted least squares RAIM algorithm used for RAIM prediction (protection level computation) and Fault Detection;
- Probability of missed detection = 0.001 and Probability of false alarm = 1x10-5 for RAIM computations;
- UERE budget (non-SIS components) used in position solution and for RAIM predictions based on the values given below [RD.3]:

Elevation, degrees	Error, metres
5	7.48
10	6.64
15	5.92
20	5.31
30	4.31
40	3.57

Elevation, degrees	Error, metres
50	3.06
60	2.73
90	2.44

- The URA value from the broadcast navigation message is combined with the values in the table to form the total UERE for the observations.

As the actual monitoring is based on the measurements from a single receiver, the following points should be noted:

- Performance monitoring is local to the monitoring station with a coverage area defined by the correlation of the major error sources and the configuration of the constellation.
- The range-domain errors contain the residuals of other error sources other than the SIS range errors, hence the performance statistics generated are conservative.

3. ACCURACY

Accuracy is assessed using the calculated position error between the position solution and the known location of the antenna at the 95th percentile level. The position solution is computed using GPS L1 measurements at a rate of 1 Hz above a 5-degree elevation mask. The horizontal and vertical error distributions for the period April to June 2026 are shown in the following figures for fault-free solutions (i.e. no problems indicated). The samples shown in each figure are in error bins of 1cm and include position errors from all days during the monitoring period.

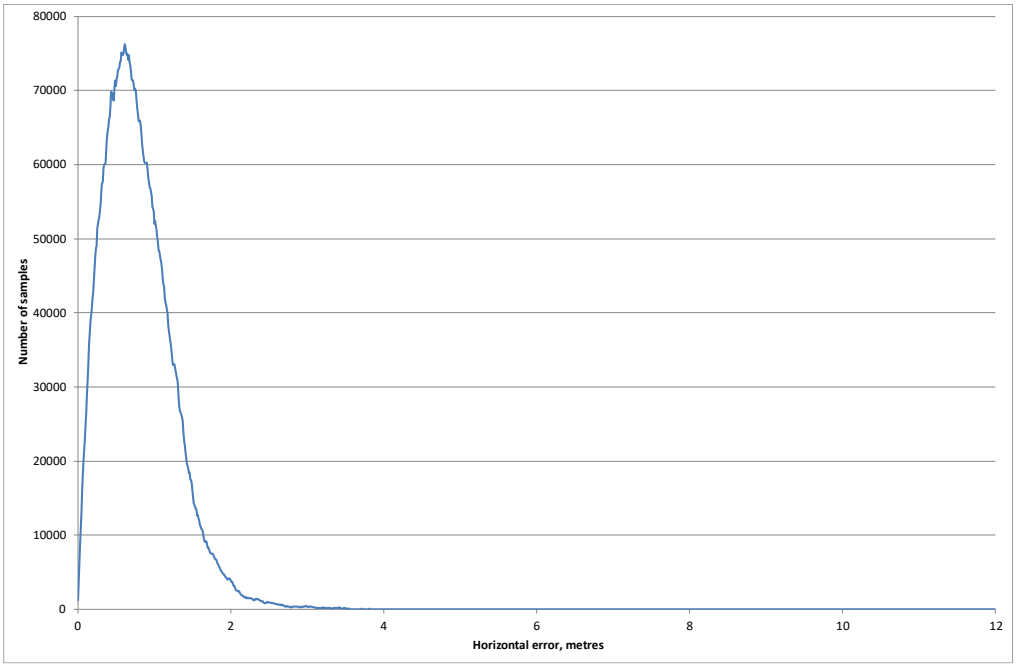

Figure 3-1: Horizontal Error Distribution for Monitoring Period

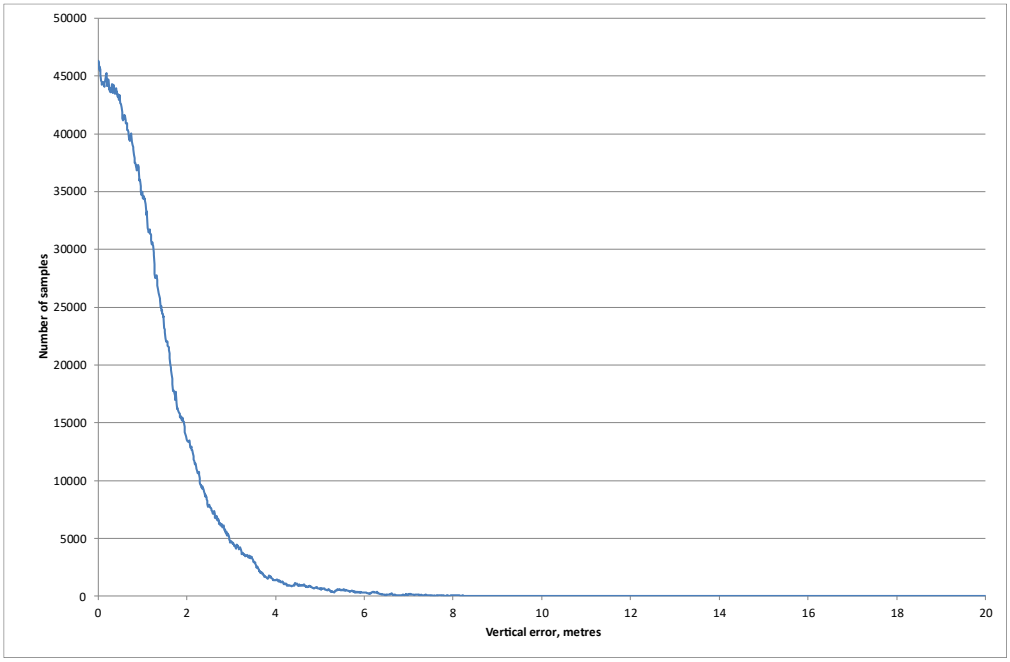

Figure 3-2: Vertical Error Distribution for Monitoring Period

It can be seen that the horizontal errors are most commonly between 0 to 2m.

To better understand the maximum errors, the horizontal error distribution above 3m and the vertical error distribution above 5m are also shown.

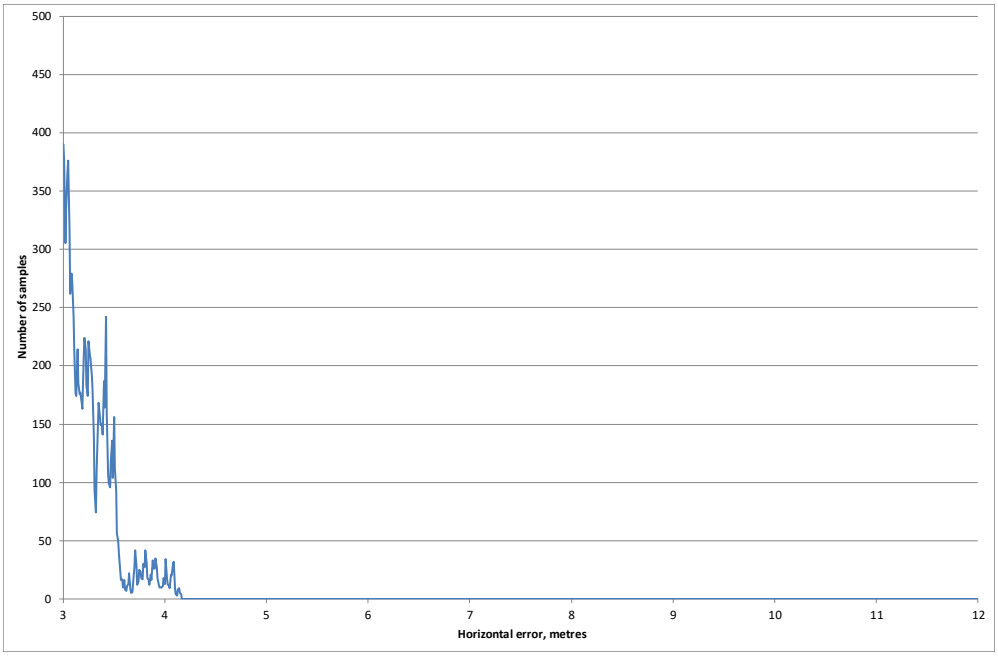

Figure 3-3: Horizontal Error Distribution above 3m for Monitoring Period

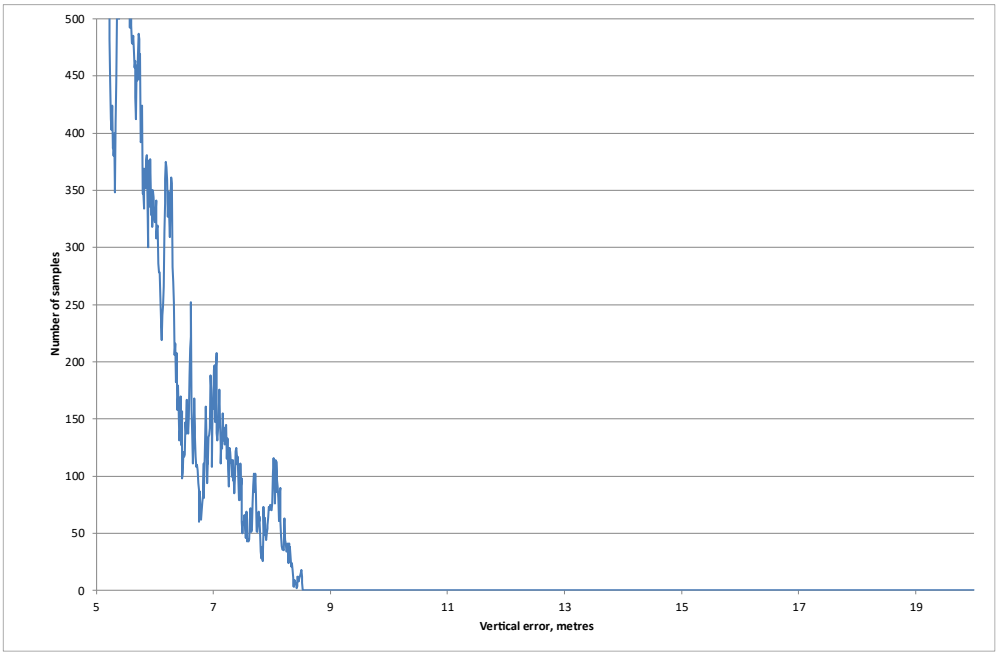

Figure 3-4: Vertical Error Distribution above 9m for Monitoring Period

It is clear from the results that the maximum horizontal errors are well below the accuracy requirement for Non-Precision Approach (220m, 95%). The daily 95th-percentile position errors are also shown to illustrate the fact that the daily performance is also well within the requirement.

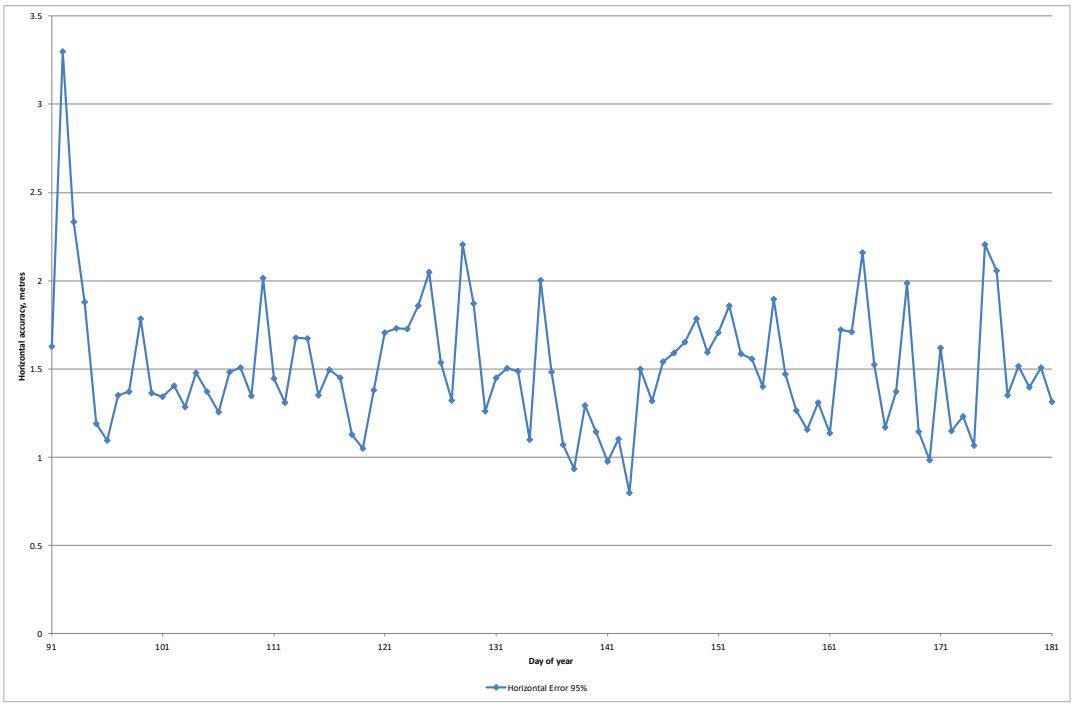

Figure 3-5: Horizontal Position Accuracy (95%) for Monitoring Period

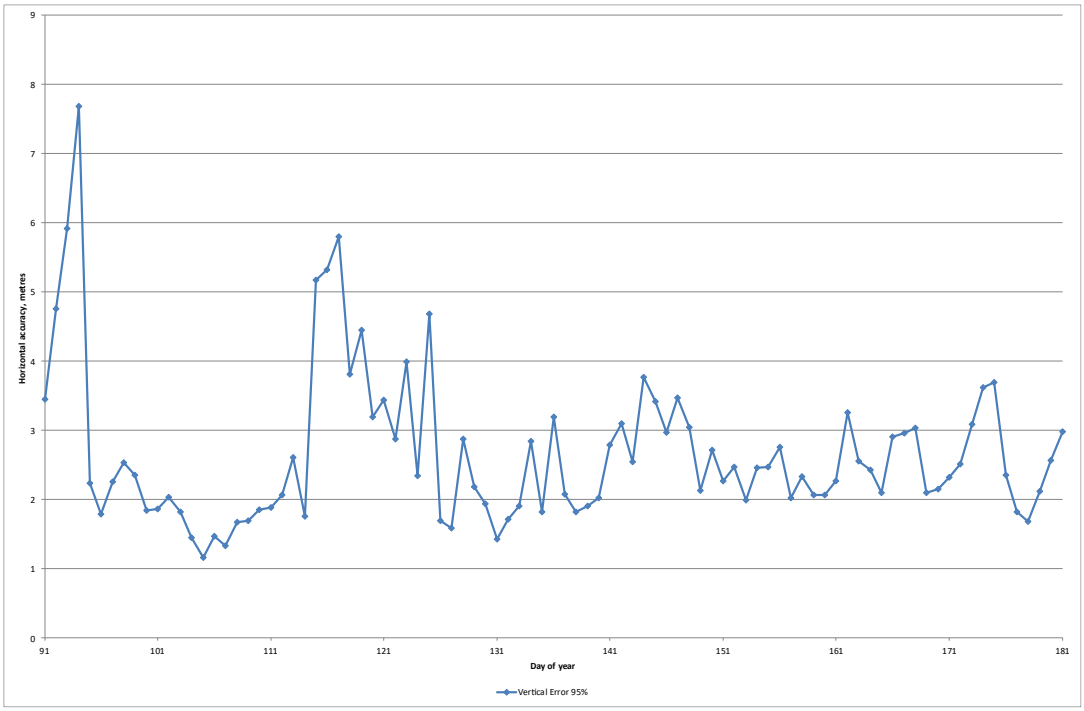

Figure 3-6: Vertical Position Accuracy (95%) for Monitoring Period

4. INTEGRITY

The approach taken here is as stated in Section 1.2, with the integrity data generated based on the known positions of the antennas. The basic assumption made is that the receiver is fault-free and that its integrity function has a probability of missed detection (Pmd) of 0.001. The process adopted here first involves mapping the ICAO requirements to the period under investigation to enable the determination of compliance with ICAO requirements. Given the Pmd of 0.001 and that the integrity risk for NPA is specified as $1x10^{-7}$ per hour, the SiS probability of failure is determined as $1x10^{-4}$ per hour. Because of the effect of dynamics and/or contextual factors on aircraft attitude, it is assumed that there are 3600 independent measurements in any given hour. This translates to a probability of failure of $2.78x10^{-8}$ per sample. Therefore, for the period analysed (i.e. 7776000 samples) the maximum allowable number of failures is 0.22.

The next step is to compare the positioning solutions as determined from the measurements and the known position of the antenna. The resulting position errors are then compared to the alert limit for NPA. Finally, the number of violations (the cases where the position errors are larger than the alert limit) is compared to the maximum allowable number of failures (i.e. 0.22). It is on this basis that compliance (or non-compliance) with ICAO's integrity requirements has been determined. It should be noted that this is a relatively simple approach as it does not account for the uncertainties in the quantities being compared, particularly in the case of position solutions and the coordinates of the antennas. However, as the alert limit is large compared to the normal level of positioning error it is a reasonable approximation.

The distributions of horizontal and vertical errors for the period April to June 2026 were shown in Section 3. It was seen that the horizontal errors were usually around 0 to 1m with a maximum value of less than 8m. As there are no horizontal position errors that are well below 556m, the integrity requirement was therefore met during the monitoring period.

5. CONTINUITY

The continuity in the monitoring period is computed as:

$$continuity = 1 - \frac{CTI}{MTBF}$$

Where CTI is the continuity time interval (1hr in this case),

MTBF is the mean time between failures, which is computed as the total monitoring time divided by the number of failure events.

A failure event is counted as any period lasting more than 10 seconds where:

- HPL cannot be computed (i.e. <5 satellites in view above elevation mask);
- Computed HPL > Alert Limit (i.e. 556m);
- Computed horizontal position error > Alert Limit;
- Any combination of the above.

It should be noted that continuity only considers failures due to unscheduled events, and so any periods of high HPL, for example, that have previously been notified through a NANU are not counted as a failure for continuity. During the monitoring period of April to June 2026, the following potential failure events were observed.

Start Date	Start Time	Outage Duration (secs)	Reason for Outage	Comments
04/04/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.
18/04/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.
24/04/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.
21/04/2026	06:04:35	2	Bad HPL (# of SV dropped to 4)	SNR on all satellites start dropping a few seconds before the satellites drop out of the solution. SNR quickly return to normal levels and satellites return to the solution after two seconds, not seen at other sites. Likely to be local interference.
22/04/2026	15:27:02	5	1 second of bad HPL followed by 4 seconds of No solution (<4 SVs)	SNR on all satellites start dropping a few seconds before the satellites drop out of the solution. SNR quickly return to normal levels and satellites return to the solution after four seconds, not seen at other sites. Likely to be local interference.
02/05/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.

Start Date	Start Time	Outage Duration (secs)	Reason for Outage	Comments
12/05/2026	13:47:08	5	No solution (<4 SVs)	SNR's on all satellites start dropping a few seconds before the satellites drop out of the solution. SNR quickly return to normal levels and satellites return to the solution after five seconds, not seen at other sites. Likely to be local interference.
30/05/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.
13/06/2026	23:59:59	1	No solution (<4 SVs)	Issue with navigation data file meaning no messages available to be used on this epoch (they had timed out). It is a file issue rather than a GPS system issue.

Table 5-1: Summary of Outages during Monitoring Period

Nine potential outages were detected in this monitoring period. Six of them last for no more than 1 second and these outages seem to be due to a specific issue with navigation message file logs rather than being GPS system events.

Further analysis indicates that the other three short events were caused by local interference. Therefore, the continuity was 100%, which meets the requirement in this period.

6. AVAILABILITY

The availability in the monitoring period is computed as:

$$availability = \frac{MTBO}{MTBO + MTTR}$$

Where MTBO is the mean time between outages, calculated as the total monitoring time divided by the number of outage events, and MTTR is the mean time to restore, which is computed as total outage time divided by the number of outage events.

As in the continuity analysis, outages are identified and used to compute the MTBO and MTTR figures. The difference in this case is that availability includes outages due to both scheduled and unscheduled outages. Based on the outages listed in Table 5-1, during this period there were no system outages lasting more than 10 seconds and therefore the availability is 100%. This is consistent with the availability requirements specified in Section 2.2.

7. CONCLUSIONS

The GPS performance has been assessed against the ICAO requirements for the period from April to June 2026.

- Accuracy
  - Horizontal accuracy checked against the threshold of 220m.
  - 95% horizontal accuracy <5m on each day.
  - The accuracy requirement was met.
- Integrity
  - Horizontal error checked against the alert limit of 556m.
  - Maximum horizontal errors <8m.
  - The integrity requirement was met.
- Continuity
  - The results were checked for outages (<5 satellites, position error > alert limit, protection level > alert limit).
  - No relevant system outages identified.
  - Continuity was 100%, therefore the requirement was met.
- Availability
  - The results were checked for outages (<5 satellites, position error > alert limit, protection level > alert limit).
  - No system outages identified.
  - Availability was 100%, therefore the requirement was met.

END OF DOCUMENT