



**GLOBAL POSITIONING SYSTEM (GPS)  
PERFORMANCE**

**APRIL TO JUNE 2019**

**QUARTERLY REPORT**

	<b>Name – Responsibility</b>	<b>Date</b>	<b>Signature</b>
<b>Prepared by</b>	M Pattinson (NSL)	12/07/19	
<b>Checked by</b>	M Dumville (NSL)	12/07/19	
<b>Authorised by</b>	M Dumville (NSL)	12/07/19	

Total Pages: 32

## Change Record

Issue / Rev.	Date	§ : Change Record	Authors
1.A	12/07/19	First version delivered to OSi for review and comment	M Pattinson

## Table of Contents

<b>1 INTRODUCTION.....</b>	<b>6</b>
1.1 Purpose of Document .....	6
1.2 Document Overview.....	6
1.3 References.....	7
1.3.1 Applicable Documents .....	7
1.3.2 Reference Documents .....	7
1.4 Acronyms.....	7
<b>2 INTRODUCTION.....</b>	<b>9</b>
2.1 Purpose.....	9
2.2 Performance Specification and Definitions .....	9
2.3 Methodology .....	12
2.4 Assumptions .....	15
<b>3 SPS PERFORMANCE .....</b>	<b>17</b>
3.1 Baseline 24-Slot Constellation .....	17
3.2 SPS SIS Accuracy .....	17
3.3 SPS SIS Integrity .....	20
3.4 SPS SIS Continuity.....	20
3.5 SPS SIS Availability.....	20
3.6 PDOP Availability .....	21
3.7 Position Service Availability.....	23
3.8 Positioning Accuracy.....	24
<b>4 NANU ANALYSIS.....</b>	<b>27</b>
<b>5 CONCLUSIONS.....</b>	<b>30</b>

## List of Figures

Figure 2-1: Location of Performance Monitoring Stations .....	13
Figure 3-1: Constellation URE (95%) for Reporting Period .....	18
Figure 3-2: Constellation RMS URE for Reporting Period.....	18
Figure 3-3: Daily PDOP Availability in the Reporting Period .....	22
Figure 3-4: Daily Maximum PDOP Value in the Reporting Period .....	22
Figure 3-5: Daily Horizontal Service Availability Values for Reporting Period .....	23
Figure 3-6: Daily Vertical Service Availability Values for Reporting Period .....	24
Figure 3-7: Daily Horizontal Position Accuracy (95%) for Reporting Period.....	25
Figure 3-8: Daily Vertical Position Accuracy (95%) for Reporting Period .....	25
Figure 3-9: Daily Horizontal Position Accuracy (99.99%) for Reporting Period .....	26
Figure 3-10: Daily Vertical Position Accuracy (99.99%) for Reporting Period .....	26

## List of Tables

Table 1-1: Applicable Documents .....	7
Table 1-2: Reference Documents .....	7
Table 1-3 : Acronyms and Abbreviations .....	8
Table 2-1: SPS Criteria and Specifications .....	11
Table 3-1: Baseline constellation in the Period April to June 2019 .....	17
Table 3-2: Range Error Statistics for Reporting Period .....	19
Table 4-1: Summary of Forecast Scheduled Outages .....	27
Table 4-2: Summary of Actual Scheduled Outages .....	27
Table 4-3: Summary of Cancelled Outages .....	27
Table 4-4: Summary of Forecast and Actual Unscheduled Outages.....	28
Table 4-5: Summary of NANU Statistics for Monitoring Period .....	29
Table 5-1: Summary of Performance .....	31

# 1 INTRODUCTION

## 1.1 Purpose of Document

This document presents the results of the GPS SPS performance assessment for the period of April 2019 to June 2019. The objectives of the performance assessment are to compare the measured performance against US DoD SPS performance specification [RD.1], covering the following parameters:

- SPS SiS Accuracy,
- SPS SiS Integrity,
- SPS SiS Continuity,
- SPS SiS Availability,
- PDOP Availability,
- SPS Position Service Availability and
- SPS Position Service Accuracy.

It also includes NANU analysis and geomagnetic activity.

The performance is analysed according to [AD.1] and [AD.2] using raw data recorded at the OSi site MLG1.

## 1.2 Document Overview

This document is arranged in the following sections:

- **Section 1**, the current section, describes the purpose, scope and structure of the document and lists the reference documents.
- **Section 2** gives an introduction to the activity, including performance specification and assessment methodology and assumptions;
- **Section 3** contains an assessment of performance against GPS SPS performance standards;
- **Section 4** provides an analysis of the NANUs;
- **Section 5** contains the conclusions.

## 1.3 References

### 1.3.1 Applicable Documents

Ref.	Document title	Document reference	Issue	Date
AD.1	Agreement relating to the provision of services pursuant to request for tenders for the provision of GNSS monitoring services	-	-	25/06/19
AD.2				

Table 1-1: Applicable Documents

### 1.3.2 Reference Documents

Ref.	Document title	Document reference	Issue	Date
RD.1	Global Positioning System Standard Positioning Service Performance Standard	GPS SPS	4 <sup>th</sup> Edition	Sept 2008
RD.2	Global Positioning System (GPS) Civil Monitoring Performance Specification	DOT-VNTSC-FAA-09-08	-	April 30 <sup>th</sup> 2009
RD.3	Reference Set of Parameters for RAIM Availability Simulations', EUROCAE WG-62	-	-	8-9 July 2003

Table 1-2: Reference Documents

## 1.4 Acronyms

Acronym	Organisation
AOD	Age Of Data
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
HDOP	Horizontal Dilution Of Precision
IAA	Irish Aviation Authority
IGS	International GNSS Service
NANU	Notice Advisory to Navstar Users
NOTAM	Notice To Airmen
NSL	Nottingham Scientific Ltd

<b>Acronym</b>	<b>Organisation</b>
OSi	Ordnance Survey Ireland
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

Table 1-3 : Acronyms and Abbreviations



## 2 INTRODUCTION

### 2.1 Purpose

The purpose of the performance monitoring activity is to collect and analyse data on the performance of the GPS Signal in Space (SIS) [AD.1]. For this report, the applicable requirements are defined in the Global Positioning System Standard Positioning Service Performance Standard (GPS SPS PS), approved by the US Department of Defence [RD.1].

### 2.2 Performance Specification and Definitions

The applicable performance specifications for the Standard Positioning Service [RD. 1] are as follows:

Criteria	Specifications
SPS SIS Accuracy	<p><b>The User Range Error (URE) for any healthy satellite for Single-Frequency C/A-Code:</b></p> <ul style="list-style-type: none"> <li>• <math>\leq 7.8</math> m 95% Global Average URE during Normal Operations over all age of data (AODs)</li> <li>• <math>\leq 6.0</math>m 95% Global Average URE during Normal Operations at Zero AOD</li> <li>• <math>\leq 12.8</math> m 95% Global Average URE during Normal Operations at Any AOD</li> <li>• <math>\leq 30</math> m 99.94% Global Average URE during Normal Operations over one-year period</li> <li>• <math>\leq 30</math> m 99.79% Worst Case Single Point Average URE during Normal Operations over one-year period</li> <li>• <math>\leq 388</math> m 95% Global Average URE during Extended Operations after 14 Days without Upload.</li> </ul> <p><b>The User Range Rate Error (URRE) for Single-Frequency C/A-Code:</b></p> <p><math>\leq 0.006</math> m/sec 95% Global Average URRE over any 3-second interval during Normal Operations at Any AOD</p> <p><b>The User Range Acceleration Error (URAE) for Single-Frequency C/A-Code:</b></p> <p><math>\leq 0.002</math> m/sec/sec 95% Global Average URAE over any 3-second interval during Normal Operations at Any AOD</p> <p><b>The UTC Offset Error for Single-Frequency C/A-Code:</b></p> <p><math>\leq 40</math> nsec 95% Global Average UTCOE during Normal Operations at Any AOD</p>

Criteria	Specifications
SPS SIS Integrity	<p><b>The SIS Integrity for Single-Frequency C/A-Code:</b></p> <ul style="list-style-type: none"> <li>• <math>\leq 1 \times 10^{-5}</math> Probability Over Any Hour of the SPS SIS Instantaneous URE Exceeding the NTE Tolerance Without a Timely Alert during Normal Operations</li> </ul> <p><b>The UTCOE Integrity for Single-Frequency C/A-Code:</b></p> <ul style="list-style-type: none"> <li>• <math>\leq 1 \times 10^{-5}</math> Probability Over Any Hour of the SPS SIS Instantaneous UTCOE Exceeding the NTE Tolerance Without a Timely Alert during Normal Operations</li> </ul>
SPS SIS Continuity	<p><b>SPS SIS Unscheduled Failure Interruption Continuity</b></p> <ul style="list-style-type: none"> <li>• <math>\geq 0.9998</math> Probability Over Any Hour of Not Losing the SPS SIS Availability from a Slot Due to Unscheduled Interruption</li> <li>• Given that the SPS SIS is available from the slot at the start of the hour</li> </ul>
SPS SIS Availability	<p><b>SPS SIS Per-Slot Availability</b></p> <ul style="list-style-type: none"> <li>• <math>\geq 0.957</math> Probability that a Slot in the Baseline 24-Slot Configuration will be Occupied by a Satellite Broadcasting a Healthy SPS SIS</li> <li>• <math>\geq 0.957</math> Probability that a Slot in the Expanded Configuration will be Occupied by a Pair of Satellites Each Broadcasting a Healthy SPS SIS</li> </ul> <p><b>SPS SIS Constellation Availability</b></p> <ul style="list-style-type: none"> <li>• <math>\geq 0.98</math> Probability that at least 21 Slots out of the 24 Slots will be Occupied Either by a Satellite Broadcasting a Healthy SPS SIS in the Baseline 24-Slot Configuration or by a Pair of Satellites Each Broadcasting a Healthy SPS SIS in the Expanded Slot Configuration</li> <li>• <math>\geq 0.99999</math> Probability that at least 20 Slots out of the 24 Slots will be occupied either by a Satellite Broadcasting a Healthy SPS SIS in the Baseline 24-Slot Configuration or by a Pair of Satellites Each Broadcasting a Healthy SPS SIS in the Expanded Slot Configuration.</li> <li>• <math>\geq 0.95</math> Probability that the Constellation will have at least 24 Operational Satellites regardless of Whether Those Operational Satellites are Located in Slots or Not.</li> </ul>
PDOP Availability	<ul style="list-style-type: none"> <li>• <math>\geq 98\%</math> global Position Dilution of Precision (PDOP) of 6 or less</li> <li>• <math>\geq 88\%</math> worst site PDOP of 6 or less</li> </ul>
SPS Position Service Availability	<ul style="list-style-type: none"> <li>• <math>\geq 99\%</math> Horizontal Service Availability average location</li> <li>• <math>\geq 90\%</math> Horizontal Service Availability worst-case location</li> <li>• <math>\geq 99\%</math> Vertical Service Availability average location</li> <li>• <math>\geq 90\%</math> Vertical Service Availability worst-case location</li> </ul>

Criteria	Specifications
	<b>With 17 m horizontal and 37 m vertical (SIS only) 95% threshold over 24hours</b>
Positioning Accuracy	<ul style="list-style-type: none"> <li>• ≤ 9 meters 95% All-in-View Global Average Horizontal Error (SIS Only)</li> <li>• ≤ 17 meters 95% All-in-View worst site Horizontal Error (SIS Only)</li> <li>• ≤ 15 meters 95% All-in-View Global Average Vertical Error (SIS Only)</li> <li>• ≤ 37 meters 95% All-in-View worst site Vertical Error (SIS Only)</li> <li>• ≤ 40 nanoseconds time transfer error 95% of time (SIS Only) for Time Transfer Domain Accuracy</li> </ul>

Table 2-1: SPS Criteria and Specifications

The definitions for each of the criteria and the methodology used for assessment are given below. As well as the GPS SPS [RD.1], the GPS civil monitoring performance specification [RD.2] has also been used to help define the methodology for the assessment.

### SPS SIS Accuracy

The SPS SIS accuracy is described in two statistical ways; one way is as the 95th percentile (95%) SPS SIS user range error (URE) at a specified age of data (AOD), the other is as the 95% SPS SIS URE over all AODs. With either statistical expression, the SPS SIS accuracy is also known as the SPS SIS pseudorange accuracy. In this context, “pseudorange” means the full pseudorange data set (i.e., the matched combination of a corrected pseudorange measurement and a pseudorange origin, or equivalently the matched combination of a raw pseudorange measurement and the associated NAV data).

Other accuracy-related SPS SIS performance parameters include the SPS SIS pseudorange rate (velocity) accuracy defined as the 95% SPS SIS pseudorange rate error over all AODs and the SPS SIS pseudorange acceleration (rate rate) accuracy defined as the 95% SPS SIS pseudorange acceleration error over all AODs. These values are not monitored as part of this performance monitoring contract.

### SPS SIS Integrity

The SPS SIS integrity is defined as the trust which can be placed in the correctness of the information provided by the SPS SIS. SPS SIS integrity includes the ability of the SPS SIS to provide timely alerts to receivers when the SPS SIS should not be used for positioning or timing. The SPS SIS should not be used when it is providing misleading signal-in-space information (MSI), where the threshold for “misleading” is a not-to-exceed (NTE) tolerance on the SIS URE. For this SPS PS, the four components of integrity are the probability of a major service failure, the time to alert, the SIS URE NTE tolerance, and the alert (either one or the other of two types of alerts).

- **Probability of a Major Service Failure.** The probability of a major service failure for the SPS SIS is defined to be the probability that the SPS SIS instantaneous URE exceeds the SIS URE NTE tolerance (i.e., MSI) without a timely alert being issued (i.e., unalerted MSI [UMSI]). Alerts generically include both alarms and warnings.
- **Time to Alert.** The time to alert (TTA) for the SPS SIS is defined to be the time from the onset of MSI until an alert (alarm or warning) indication arrives at the receiver's antenna. Real-time alert information broadcast as part of the NAV message data is

defined to arrive at the receiver's antenna at the end of the NAV message subframe which contains that particular piece of real-time alert information.

- **SIS URE NTE Tolerance.** The SPS SIS URE NTE tolerance for a healthy SPS SIS is defined to be 4.42 times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite. The SIS URE NTE tolerance for a marginal SPS SIS is not defined and there is no SIS URE NTE tolerance for an unhealthy SPS SIS.

### **SPS SIS Continuity**

The SPS SIS continuity for a healthy SPS SIS is the probability that the SPS SIS will continue to be healthy without unscheduled interruption over a specified time interval. Scheduled interruptions which are announced at least 48 hours in advance do not contribute to a loss of continuity. Scheduled SPS SIS interruptions are announced by way of the Control Segment issuing a "Notice Advisory to Navstar Users" (NANU). NANUs are similar to the "Notices to Airmen" (NOTAMs) issued regarding scheduled interruptions of ground-based air navigation aids. OCS internal procedures are to issue NANUs for scheduled interruptions at least 96 hours in advance.

### **SPS SIS Availability**

The SPS SIS availability is the probability that the slots in the GPS constellation will be occupied by satellites transmitting a trackable and healthy SPS SIS. For this SPS Performance Standard, there are two components of availability as follows:

- **Per-Slot Availability.** The fraction of time that a slot in the GPS constellation will be occupied by a satellite that is transmitting a trackable and healthy SPS SIS.
- **Constellation Availability.** The fraction of time that a specified number of slots in the GPS constellation

### **PDOP Availability**

PDOP availability is defined as the percentage of time over a specified time interval that the predicted PDOP is less than a specified value for any point within the service volume [RD.1].

### **Position Service Availability**

Position service availability is defined as the percentage of time over a specified time interval that the position accuracy is less than a specified value for any point within the service volume [RD.1].

### **Positioning Service Accuracy**

Position service accuracy is defined as the statistical difference between position measurements and a surveyed benchmark for any point within the service volume over a specified time interval [RD.1].

## **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 the OSi network of active stations in Ireland. OSi operates a national network of GNSS receiver stations. The network consists of 25 receivers that provide 24-hour availability of dual frequency GPS and GLONASS data. For the purposes of this performance monitoring activity, OSi provides raw data for 2 of these sites to NSL for

processing and analysis. The sites that are used are Mullingar (MLG1) and Sligo Hospital (SLGO). The locations of these sites are shown in Figure 2-1.

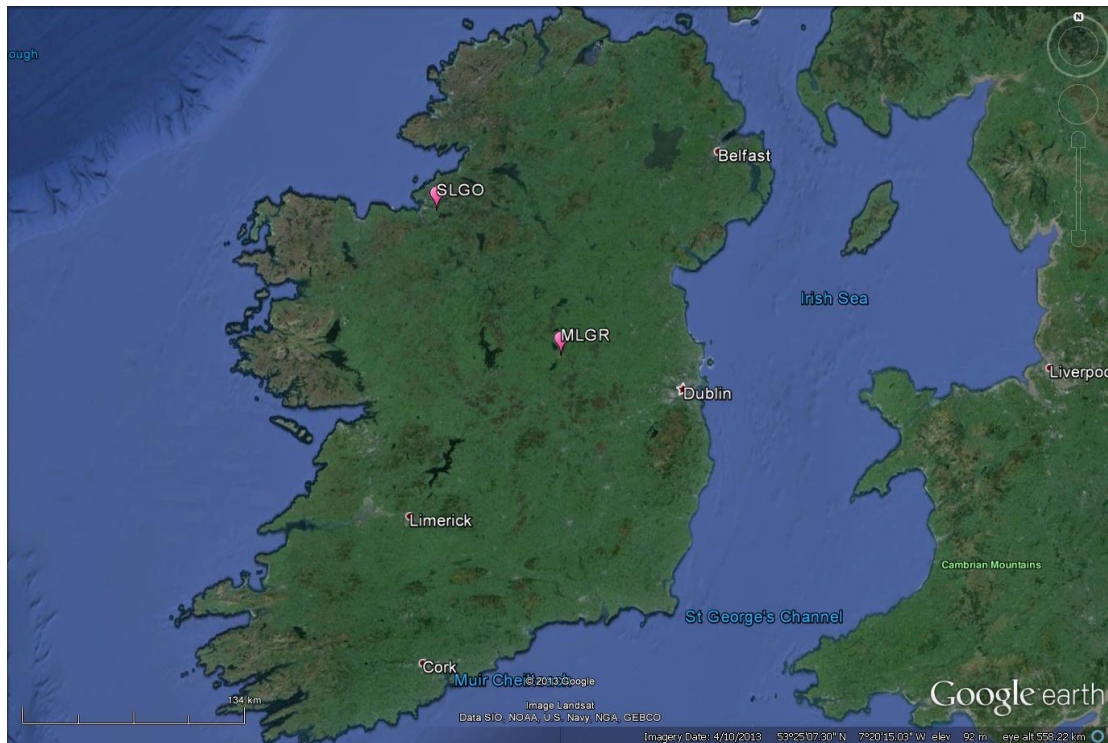


Figure 2-1: Location of Performance Monitoring Stations

In this report, MLG1 is used as the main site to provide performance monitoring across the whole of Irish airspace and SLGO is a back-up in case of problems with MLG1 and to allow cross-checking of performance in the case of anomaly investigations. These sites have been chosen to fulfil the following criteria:

- Centrally located within Ireland in order to ensure monitoring of complete airspace;
- Good data availability and continuity (i.e. avoid sites with historically poor data availability);
- Good measurement quality (i.e. avoid sites with known interference, multipath or sky visibility issues);
- Availability of required observation types and data.

During this period data from MLG1 was continuous and has been used for performance analysis for the whole period.

In case there are problems with the data access simultaneously from both MLG1 and SLGO, data from the EGNOS RIMS station at Cork will be used. The raw observation data is made available through the EGNOS Data Access Server (EDAS) in real-time or via an ftp archive. In addition to the raw data, NANU information is downloaded from the US Coast Guard Navigation Centre website (<http://www.navcen.uscg.gov/?pageName=gpsNanuInfo>). This provides information on the NANUs for scheduled and unscheduled outages during the monitoring period.



The methods for assessing of each of the requirements are described below.

### **SPS SIS Accuracy**

SIS accuracy is assessed through processing and analysis of the raw measurement data. In order to compute the SIS accuracy, the measurements recorded at the GPS receiver are used to compute the instantaneous SIS errors. This is done by computing the difference between computed ranges (based on known receiver location and satellite position) and the corrected measurement, which has satellite and receiver clock biases, group delay, ionospheric and tropospheric errors removed. Once the SIS range errors for every satellite measurement on every epoch have been computed, the per-satellite statistics across the whole period, as well as daily statistics for all satellites combined, are generated.

### **SPS SIS Integrity**

SIS accuracy is assessed through processing and analysis of the raw measurement data. The SIS integrity is assessed by comparing each instantaneous computed SIS error value with a threshold value of  $4.42 \times$  broadcast URA. The number of occasions where the instantaneous URE exceeds the threshold are counted and checked against the expected number of failures.

### **SPS SIS Continuity**

SIS continuity is assessed through analysis of the broadcast navigation messages and the NANU archive. Firstly, the daily broadcast navigation messages are scanned in order to find the time periods for any satellites that do not have healthy navigation messages. These satellites and time periods are then matched against NANU information to see if the outages are scheduled or unscheduled.

The SIS continuity is computed for the baseline 24-slot constellation and is an average value over all slots. The total time that any satellites in the baseline constellation were unhealthy due to an unscheduled outage is divided by the total time in the analysis period and expressed as a percentage. Results are presented for the reporting period and, when available, for the previous year.

### **SPS SIS Availability**

SIS availability is assessed through analysis of the broadcast navigation messages and the NANU archive. Firstly, the daily broadcast navigation messages are scanned in order to find the time periods for any satellites that do not have healthy navigation messages. These satellites and time periods are then matched against NANU information to see if the outages are scheduled or unscheduled.

The SIS availability is computed for the baseline 24-slot constellation as well as for the whole constellation and is an average value over all slots. At each epoch the number of healthy satellites (both in the baseline 24-slot constellation and in total) is counted. Then the following parameters are computed:

- Total time that there are less than 21 healthy satellites in the baseline constellation;
- Total time that there are less than 20 healthy satellites in the baseline constellation;
- Total time that there are less than 24 healthy satellites in the whole constellation.

These parameters are then divided by total time of the analysis and expressed as percentage values. Results are presented for the reporting period and, when available, for the previous year.

It should be noted that in case the baseline 24-slot constellation does not meet requirements, the analysis will be expanded to include pairs of satellites in the expanded slot constellation.

### **PDOP Availability**

PDOP availability is assessed through processing and analysis of the raw measurement data. The PDOP availability is assessed by computing the PDOP for all satellites in view above 5 degrees at the GPS receiver at every epoch (1Hz rate). Each PDOP value is checked against the threshold value of 6 and any failures are counted. The numbers of failures on each day are then used to generate the daily availability value. A separate availability value for each day is computed.

### **Position Service Availability**

Position service availability is assessed through processing and analysis of the raw measurement data. The derivation of the position service availability requirements of 17m (95% horizontal accuracy) and 37m (95% vertical accuracy) for 99% of the time are explained a bit more in section B.3.1 of the GPS SPS [RD.1]. The requirement is based on fulfilling a 1-sigma UERE of 4m, HDOP of 2.1 and VDOP of 4.4. To check this requirement, the following approach is used:

- For each day, compute daily rms SIS error for all satellites combined. This is equivalent to the 1-sigma UERE in the description above;
- On each epoch, multiply daily rms SIS error by HDOP value to compute estimated horizontal accuracy due to SIS error;
- For each epoch, multiply daily rms SIS error by VDOP value to compute estimated vertical accuracy due to SIS error;
- Compute daily availability (%) of estimated horizontal accuracy < 8.5m (1-sigma);
- Compute daily availability (%) of estimated vertical accuracy < 18.5m (1-sigma).
- If daily availability of horizontal accuracy greater than the required threshold, the requirement for horizontal service accuracy is passed;
- If daily availability of vertical accuracy greater than the required threshold, the requirement for vertical service accuracy is passed.

### **Positioning Service Accuracy**

In order to check the position service accuracy, the raw measurements recorded at the GPS receiver are used to compute a user position solution on every epoch (1Hz). The computed positions are then compared against the known position of the receiver in order to generate horizontal and vertical position errors. Statistics for 95% error value, 99.99% error value etc. are then computed separately for each day and checked against the thresholds.

## **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 iono model (Klobuchar) used to remove ionospheric errors;
- RTCA trop 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 =  $1 \times 10^{-5}$  for RAIM computations;
- UERE budget (non-SIS components) used in position solution and for RAIM predictions are given below [RD.4]:

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

#### 3.1 Baseline 24-Slot Constellation

The SPS SIS performance standard is largely based on the GPS baseline 24-slot constellation, which consists of 24 slots in six orbital planes with four slots per plane. It is important to identify the baseline constellation to act as reference to subsequent data processing and analysis. The following table shows the satellite PRN in each slot for the baseline constellation for the period April to June 2019.

Slot	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
PRN	24	31	30	7	B1/B5	25	28	12	29	27	8	17
Slot	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4
PRN	2	D2/D5	21	6	3	10	5	20	32	F2/F5	9	23

Table 3-1: Baseline constellation in the Period April to June 2019

#### 3.2 SPS SIS Accuracy

In addition to the specifications in Table 2-1, the Conditions and Constraints for SPS SIS URE Accuracy specification [RD.1] are:

- For any healthy SPS SIS
- Neglecting single-frequency ionospheric delay model errors
- Including group delay time correction (TGD) errors at L1
- Including inter-signal bias (P(Y)-code to C/A-code) errors at L1

The statistics presented here are based on the same sample rate for positioning (1Hz). It should be noted that the computed range errors (in addition to SIS errors) contain residual errors local to the monitoring antenna (multipath, tropospheric and ionospheric). The URE Accuracy (95th percentile) values of each satellite for the period April to June 2019 are shown in the next figure.

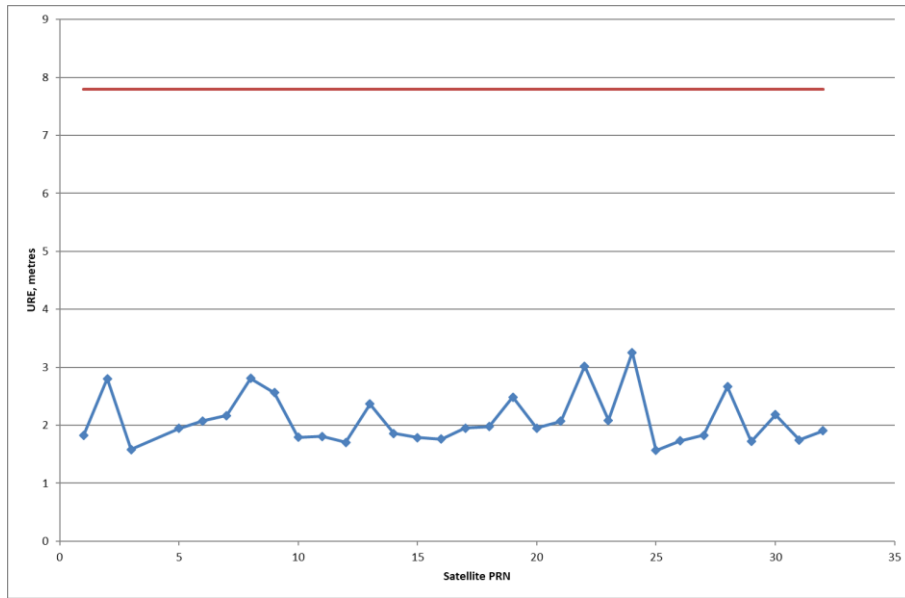


Figure 3-1: Constellation URE (95%) for Reporting Period

It can be seen that the URE (95%) for all satellites is below the 7.8m threshold. The daily constellation RMS URE results in the period April to June 2019 and the 4m threshold are shown in the next figure. Note that  $\leq 7.8$  m 95% SPS SIS URE performance standard is equivalent to a  $\leq 4.0$  m RMS SPS SIS URE performance standard [RD.1]. This is also important for the position service availability assessment.

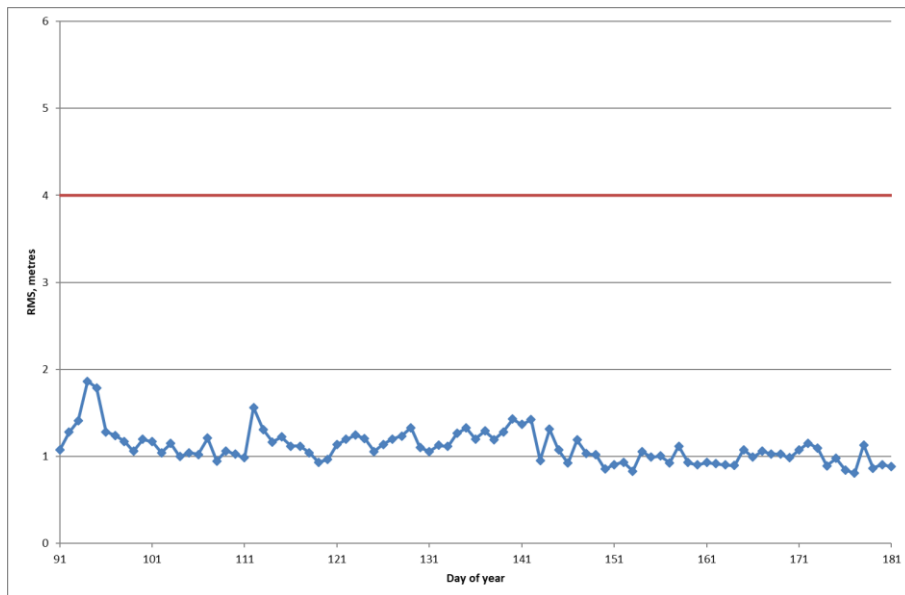


Figure 3-2: Constellation RMS URE for Reporting Period

It can be seen that the RMS values are below the threshold (4 metres) on all days. As well as the 95% and rms URE statistics, additional URE statistics are computed, including mean, 1-sigma and maximum values. Although not strictly required for the performance

specification, these values can be useful for anomaly investigation. The range error statistics (in metres) for the period April to June 2019 are given in the table below.

PRN	Range Error (mean)	Range Error (RMS)	1-sigma	Range Error (95%)	Range Error (max)	Number of Samples
1	-0.05	0.92	0.92	1.82	4.01	2284454
2	1.09	1.48	1.00	2.80	4.35	2915400
3	-0.20	0.84	0.81	1.58	5.17	2472607
5	0.55	1.06	0.91	1.95	3.75	2632931
6	0.56	1.06	0.90	2.08	3.49	2772487
7	0.37	1.16	1.10	2.17	3.87	2846858
8	0.43	1.41	1.35	2.81	6.68	2528438
9	0.90	1.30	0.94	2.56	4.04	2580724
10	-0.36	0.93	0.86	1.79	3.98	2860484
11	0.43	0.92	0.81	1.81	5.07	2049498
12	-0.19	0.86	0.83	1.70	6.57	2568738
13	0.63	1.24	1.07	2.37	4.17	2280916
14	0.36	0.92	0.85	1.86	10.59	2905056
15	0.09	0.91	0.91	1.79	3.95	2422989
16	0.51	0.91	0.75	1.76	6.55	2637771
17	0.20	0.96	0.94	1.95	4.63	2906950
18	0.23	0.98	0.95	1.98	5.87	2088246
19	1.14	1.38	0.78	2.49	4.39	2838942
20	0.63	1.03	0.81	1.95	4.06	2845947
21	0.81	1.12	0.78	2.07	5.47	2846214
22	1.57	1.79	0.85	3.02	5.57	2453150
23	0.56	1.10	0.94	2.08	8.67	2740555
24	0.05	1.64	1.64	3.26	6.85	2117471
25	-0.02	0.83	0.83	1.57	5.11	2321344
26	0.21	0.87	0.85	1.73	4.28	2501157
27	0.47	0.92	0.79	1.83	4.30	2384857
28	0.64	1.38	1.22	2.67	6.20	2943469
29	-0.10	0.88	0.87	1.72	6.38	2715525
30	0.83	1.23	0.90	2.18	3.68	2724920
31	-0.42	0.89	0.79	1.75	4.75	2742262
32	-0.58	1.00	0.81	1.90	44.91	2839496

Table 3-2: Range Error Statistics for Reporting Period

Overall, the measured SIS accuracy meets the requirements during this monitoring period.

One interesting point to note is that the maximum range error for PRN32 is very large in this period at 44.91m. However, it does not trigger any large position errors or alerts in the

processing and performance checks. The large error occurs on 4<sup>th</sup> April and last for around 5 seconds. Earlier on this day has been an outage (announced by NANU) where the satellite was set unhealthy in the navigation message. Some hours after the end of the outage we get navigation messages which appear to be degraded as they cause large errors. However, the URA value in the nav message is set to 64, which indicates it is poor quality, and so this satellite is down-weighted in the position solution and does not cause an error. It should be noted though that any user receivers that did not down-weight the satellite according to the broadcast URA value would have suffered a larger position error.

### 3.3 SPS SIS Integrity

In addition to the specifications in Table 2-1, the Conditions and Constraints for SPS SIS Integrity performance [RD.1] are:

- For any healthy SPS SIS;
- SPS SIS URE NTE tolerance defined to be  $\pm 4.42$  times the upper bound on the URA value corresponding to the URA index "N" currently broadcast by the satellite;
- Given that the maximum SPS SIS instantaneous URE did not exceed the NTE tolerance at the start of the hour;
- Worst case for delayed alert is 6 hours;
- Neglecting single-frequency ionospheric delay model errors.

Based on the requirement of  $1 \times 10^{-5}$ /hr probability for misleading information, 91-day period and a 31-satellite constellation, the maximum number of events expected is 0.67.

On every epoch throughout the monitoring period, the instantaneous measured URE for each satellite has been compared against a threshold of 4.42 times the upper value of the URA index. The number of URE values above the threshold has been recorded and is checked against the expected number.

From the analysis there are no epochs where the threshold is exceeded. Therefore, this requirement is passed.

### 3.4 SPS SIS Continuity

In addition to the specifications in Table 2-1, the Conditions and Constraints for SPS SIS Continuity performance [RD.1] are:

- Calculated as an average over all slots in the 24-slot constellation, normalized annually;
- Given that the SPS SIS is available from the slot at the start of the hour.

During this reporting period there were 38 unscheduled events but only four that affected the baseline constellation, totalling 1.35 hrs. Therefore, the continuity in this period was 99.99%, which is above the requirement of 99.98%.

### 3.5 SPS SIS Availability

In addition to the specifications in Table 2-1, the Conditions and Constraints for SPS SIS Availability performance [RD.1] are:

- Calculated as an average over all slots in the 24-slot constellation, normalized

annually;

- Applies to satellites broadcasting a healthy SPS SIS which also satisfy the other performance standards in this SPS Performance Standard.

The total period (in this monitoring period) in which satellites from the baseline 24-satellite constellation broadcast an unhealthy SIS was 24.5 hours. This is equivalent to an average of 0.999 over all slots in the 24-slot constellation and satisfies SPS SIS Per-slot Availability standard ( $\geq 0.957$ ).

The minimum number of the baseline constellation satellites broadcasting healthy SPS SIS was 23, greater than the specifications of 20 and 21. Hence, performance during the monitoring period was measured at the 100% level, satisfying the Performance Standard as specified below.

- $\geq 0.98$  Probability that at least 21 Slots out of the 24 Slots will be Occupied Either by a Satellite Broadcasting a Healthy SPS SIS in the Baseline 24-Slot Configuration or by a Pair of Satellites Each Broadcasting a Healthy SPS SIS in the Expanded Slot Configuration;
- $\geq 0.99999$  Probability that at least 20 Slots out of the 24 Slots will be occupied either by a Satellite Broadcasting a Healthy SPS SIS in the Baseline 24-Slot Configuration or by a Pair of Satellites Each Broadcasting a Healthy SPS SIS in the Expanded Slot Configuration.

The minimum number of operational satellites broadcasting healthy messages in this reporting period was 29. This represents performance at the 100% level, satisfying the Performance Standard as specified below.

- $\geq 0.95$  Probability that the Constellation has at least 24 operational satellites regardless of whether the operational satellites are located in the baseline slots.

### 3.6 PDOP Availability

In addition to the specifications in Table 2-1, the Conditions and Constraints for PDOP performance [RD.1] are:

- Defined for position solution meeting the representative user conditions and operating within the service volume over any 24-hour interval;
- Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message.

The following plot shows the daily PDOP availability ( $\text{PDOP} < 6$ ) calculated at the site for all healthy satellites above 5 degrees elevation during the period April to June 2019.

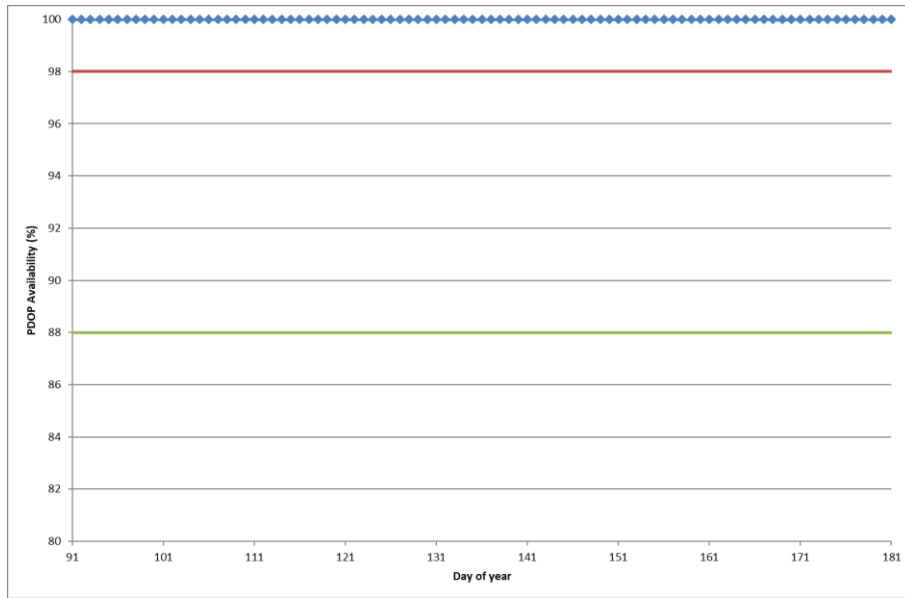


Figure 3-3: Daily PDOP Availability in the Reporting Period

It can be seen that the daily PDOP availability values are all above the thresholds of 98% (global average) and 88% (worst site). Therefore, the PDOP availability fulfils the requirements.

In addition, the daily mean and maximum PDOP values are displayed for the same period.

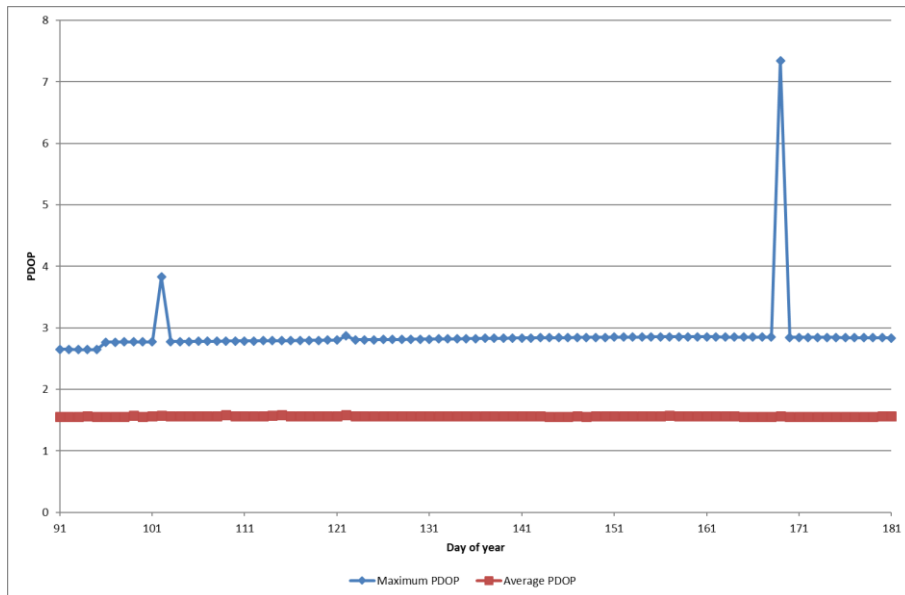


Figure 3-4: Daily Maximum PDOP Value in the Reporting Period

The daily PDOP values can be used to identify specific days that have different performance from the others. It can be seen that on almost all days the maximum PDOP is well below 6. There is one day where the PDOP is 7 but this appears to be due to a local tracking problem at MLG1 where the number of satellites drops to just 4 satellites for a few epochs. It is suspected this is due to local interference because the problem is not observed at SLGO,

and the satellites on which tracking is lost are the lowest elevation satellites, which would have lowest C/N0 and would be affected first by interference. This is likely to be due to local interference.

### 3.7 Position Service Availability

In addition to the specifications in Table 2-1, the Conditions and Constraints for Service Availability performance [RD.1] are:

- 17 meters horizontal (SIS only) 95% threshold;
- 37 meters vertical (SIS only) 95% threshold;
- Defined for position solution meeting representative user conditions and operating within the service volume over any 24-hour interval;
- Based on using only satellites transmitting standard code and indicating “healthy” in the broadcast navigation message.

The computation of these values is detailed in section 2.2.

The daily horizontal and vertical service availabilities for the period April to June 2019 are shown in the following figures.

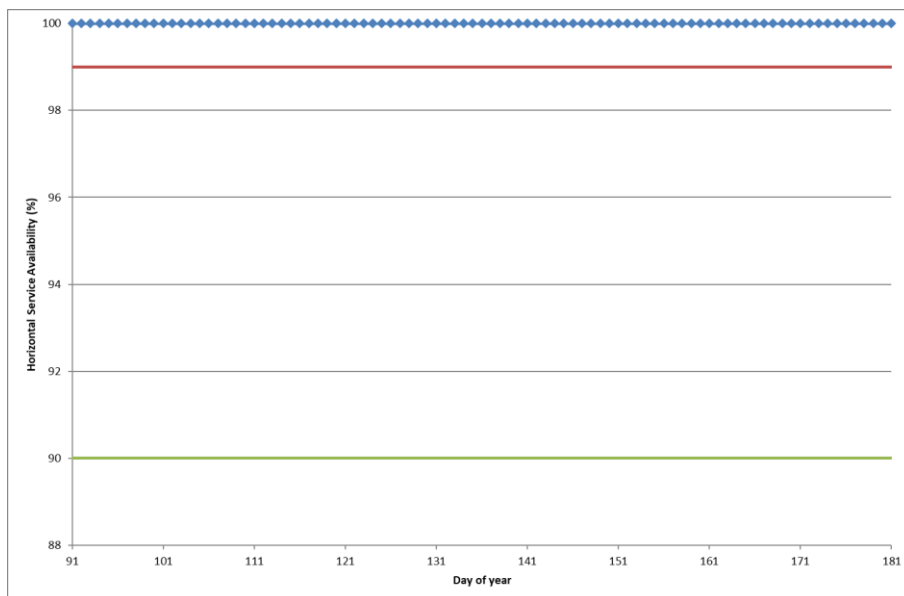


Figure 3-5: Daily Horizontal Service Availability Values for Reporting Period

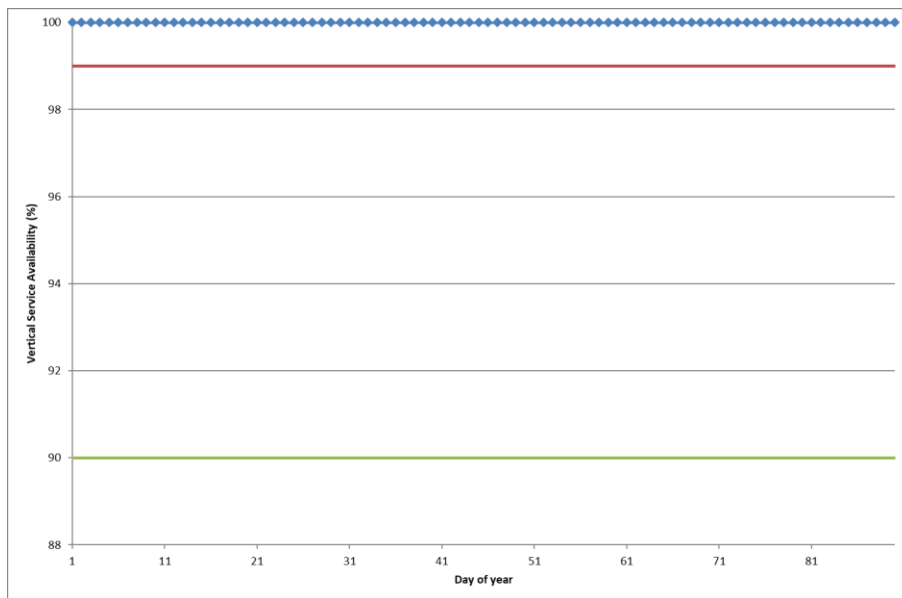


Figure 3-6: Daily Vertical Service Availability Values for Reporting Period

These plots show the horizontal and vertical availability are well above the thresholds of 99% (global average) and 90% (worst site) for the reporting period. Therefore, the position service availability fulfils the requirements.

### 3.8 Positioning Accuracy

In addition to the specifications in Table 2-1, the Conditions and Constraints for Positioning Accuracy performance [RD.1] are:

- Defined for position solution meeting the representative user conditions;
- Standard based on a measurement interval of 24 hours averaged over all points within the service volume.

For this monitoring activity it should be noted that the position accuracy is assessed through analysis of real data at a single point, rather than through service volume analysis.

The daily horizontal and vertical accuracy values (95%) for the period April to June 2019 are shown in the following figures.



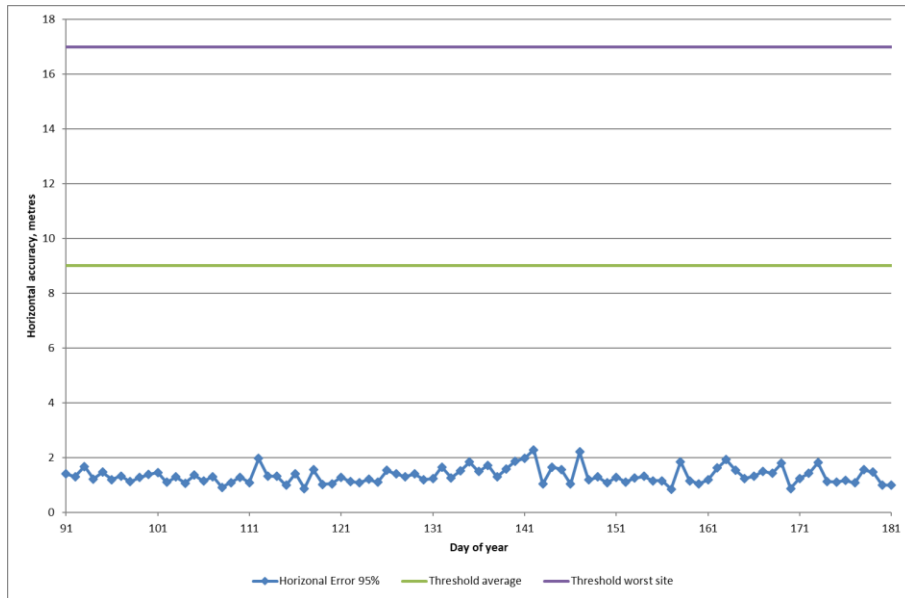


Figure 3-7: Daily Horizontal Position Accuracy (95%) for Reporting Period

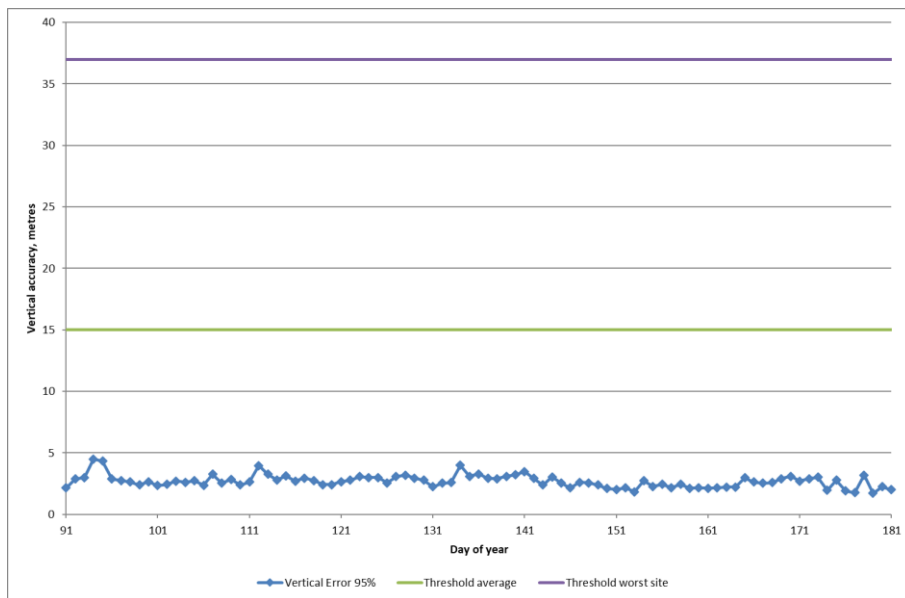


Figure 3-8: Daily Vertical Position Accuracy (95%) for Reporting Period

It can be seen that the daily horizontal accuracy values are all below the thresholds of 9m (global average) and 17m (worst site).

Also, the daily vertical accuracy values are well below the thresholds of 15m (global average) and 37m (worst site).

In addition, the daily position accuracy values at the 99.99% level are shown for the same period.

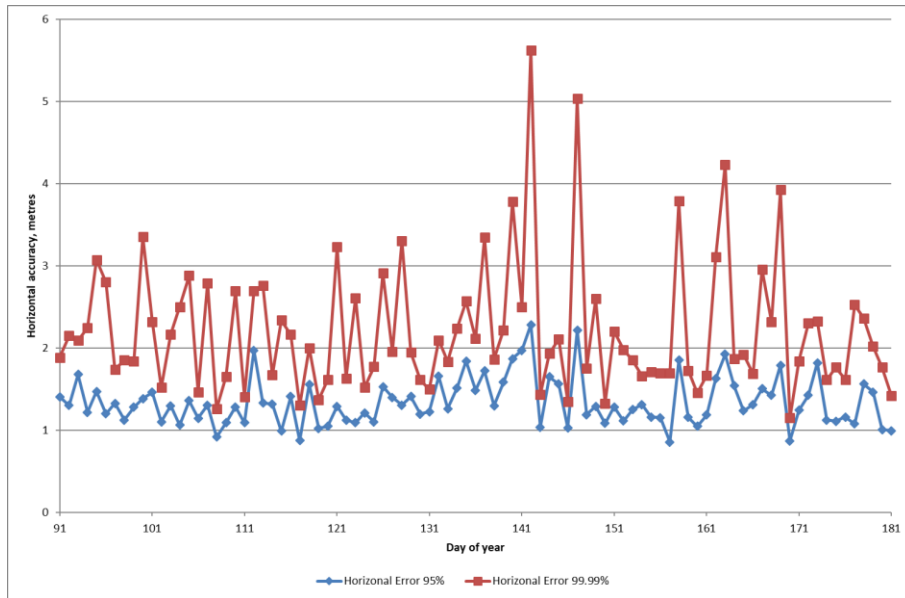


Figure 3-9: Daily Horizontal Position Accuracy (99.99%) for Reporting Period

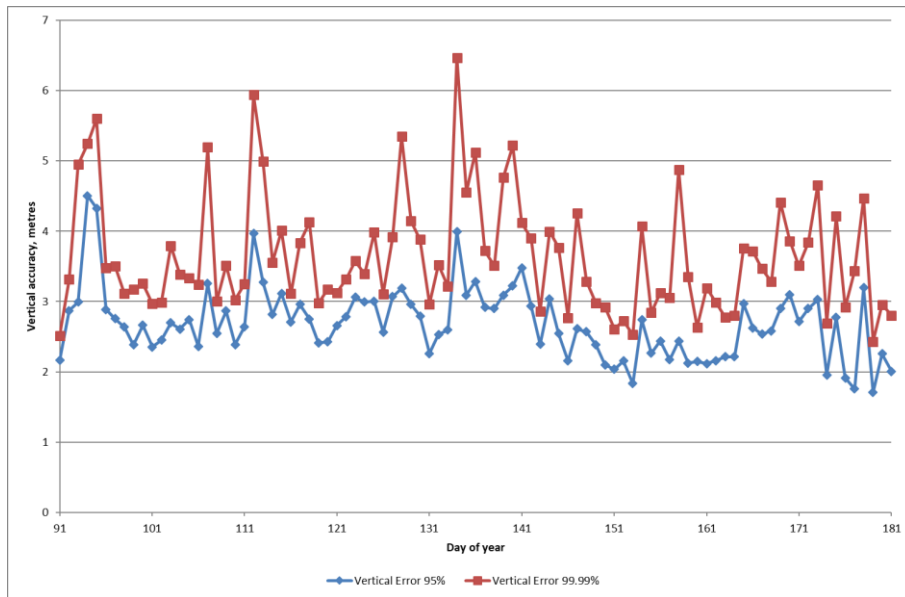


Figure 3-10: Daily Vertical Position Accuracy (99.99%) for Reporting Period

It can be seen that generally the 99.99% values generally follow the same pattern as the 95% values and are not significantly larger.

## 4 NANU ANALYSIS

NANU information is downloaded from the US Coast Guard Navigation Centre website (<http://www.navcen.uscg.gov/?pageName=gpsNanuInfo>). Summaries of the forecast and actual outages for scheduled and unscheduled events are given below. NANUs that affect the baseline constellation are highlighted in green. NANUs that affect one satellite of an expended slot in the baseline constellation are highlighted in purple.

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2019043	32	FCSTDV	94	945	94	2145	12	F1
2019049	32	FCSTDV	99	930	99	2130	12	F1
2019050	22	FCSTDV	102	810	102	2010	12	E6
2019057	3	FCSTDV	109	845	109	2045	12	E1
2019062	1	FCSTMX	114	1730	116	1730	48	D2
2019066	7	FCSTDV	122	1545	123	345	12	A4
2019080	30	FCSTDV	157	1220	158	20	12	A3

Table 4-1: Summary of Forecast Scheduled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2019047	32	FCSTSUMM	94	1016	94	1142	1.433333	2019043
2019054	32	FCSTSUMM	99	941	99	1404	4.383333	2019049
2019059	22	FCSTSUMM	102	829	102	1432	6.05	2019050
2019061	3	FCSTSUMM	109	912	109	1430	5.3	2019057
2019064	1	FCSTSUMM	114	1856	115	1727	22.5166667	2019062
2019067	7	FCSTSUMM	122	1604	122	2305	7.0166667	2019066
2019083	30	FCSTSUMM	157	1222	157	1723	5.0166667	2019080

Table 4-2: Summary of Actual Scheduled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Ref
-	-	-	-	-	-	-	-

Table 4-3: Summary of Cancelled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2019046	18	UNUNOREF	91	1402	91	1404	0.033333333	NA
2019048	18	UNUNOREF	94	1352	94	1353	0.016666667	NA
2019051	18	UNUNOREF	97	1348	97	1350	0.033333333	NA
2019052	18	UNUNOREF	97	1353	97	1355	0.033333333	NA
2019053	18	UNUNOREF	99	1329	99	1331	0.033333333	NA
2019055	18	UNUNOREF	100	1318	100	1319	0.016666667	NA
2019056	18	UNUNOREF	100	1321	100	1322	0.016666667	NA
2019058	18	UNUNOREF	101	1326	101	1327	0.016666667	NA
2019060	18	UNUNOREF	107	1313	107	1314	0.016666667	NA

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2019063	18	UNUNOREF	115	1636	115	1637	0.016666667	NA
2019065	18	UNUNOREF	117	1526	117	1527	0.016666667	NA
2019068	18	UNUNOREF	123	1455	123	1458	0.05	NA
2019069	18	UNUNOREF	125	1503	125	1506	0.05	NA
2019070	18	UNUNOREF	127	1534	127	1536	0.033333333	NA
2019071	18	UNUNOREF	128	1519	128	1521	0.033333333	NA
2019072	18	UNUNOREF	128	1522	128	1524	0.033333333	NA
2019073	18	UNUNOREF	129	1530	129	1533	0.05	NA
2019074	18	UNUNOREF	132	1522	132	1524	0.033333333	NA
2019075	18	UNUNOREF	136	1750	136	1751	0.016666667	NA
2019076	18	UNUNOREF	137	1444	137	1446	0.033333333	NA
2019077	18	UNUNOREF	148	1547	148	1550	0.05	NA
2019078	18	UNUNOREF	149	1456	149	1459	0.05	NA
2019079	18	UNUNOREF	151	1411	151	1413	0.033333333	NA
2019081	18	UNUNOREF	152	1409	152	1410	0.016666667	NA
2019082	18	UNUNOREF	153	1404	153	1405	0.016666667	NA
2019084	18	UNUNOREF	158	1531	158	1532	0.016666667	NA
2019085	3	UNUNOREF	158	1600	158	1601	0.016666667	NA
2019086	3	UNUNOREF	159	1600	159	1601	0.016666667	NA
2019087	18	UNUNOREF	162	1523	162	1524	0.016666667	NA
2019088	18	UNUNOREF	164	1508	164	1509	0.016666667	NA
2019089	18	UNUNOREF	166	1433	166	1434	0.016666667	NA
2019090	2	UNUSUFN	174	1350	NA	NA	NA	D1
2019091	2	UNUSABLE	174	1350	174	1503	1.2166667	2019090
2019092	18	UNUNOREF	174	1948	174	1949	0.016666667	NA
2019093	29	UNUNOREF	175	1628	175	1634	0.1	NA
2019094	13	UNUSUFN	175	1818	NA	NA	NA	F6
2019095	13	UNUSABLE	175	1818	175	1838	0.333333	2019094
2019096	18	UNUNOREF	176	2009	176	2010	0.016666667	NA
2019097	18	UNUNOREF	176	2012	176	2013	0.016666667	NA
2019098	18	UNUNOREF	178	1941	178	1942	0.016666667	NA

Table 4-4: Summary of Forecast and Actual Unscheduled Outages

The constellation availability and continuity figures for the baseline constellation, and for all satellites, based on the NANU information are shown in the following table. Note that for continuity and availability, the baseline constellation is not affected if at least one of the satellites in an expended slot is healthy, i.e. an outage on one of the satellites in an expended slot does not affect the statistics for the baseline constellation.

	Q2 2019
hrs	2184
<b>total forecast downtime (all)</b>	120.00
<b>total forecast downtime (baseline)</b>	60.00
<b>total actual scheduled downtime (all)</b>	50.28
<b>total actual scheduled downtime (baseline)</b>	23.15
<b>Scheduled satellite outage events (all)</b>	7

<b>Scheduled satellite outage events (baseline)</b>	5
<b>Unscheduled satellite outage events (all)</b>	38
<b>Unscheduled satellite outage events (baseline)</b>	4
<b>Total actual unscheduled downtime (all)</b>	2.57
<b>Total actual unscheduled downtime (baseline)</b>	1.35
<b>Total actual downtime (all)</b>	52.85
<b>Total actual downtime (baseline)</b>	24.50
<b>Availability (all)</b>	99.922
<b>Availability (baseline)</b>	99.953
<b>Continuity (baseline)</b>	99.996

Table 4-5: Summary of NANU Statistics for Monitoring Period

From the results it can be seen that the forecast downtime was greater than the actual downtime. Also, the actual scheduled downtime periods were within the time period described in the forecast NANUs.

## 5 CONCLUSIONS

The following table summarises the measured performance against the specification.

Criteria	Specifications	Measured Performance	Passed
SPS SIS Accuracy	The User Range Error (URE) $\leq 7.8$ m 95%	All SVs < 7.8m	Yes.
SPS SIS rms	$\leq 4$ m	All days <4m	Yes.
SPS SIS Integrity	The SIS Integrity $\leq 1 \times 10^{-5}$ Probability Over Any Hour (<0.7 events per quarter)	No SIS events	Yes
SPS SIS Continuity	$\geq 0.9998$ Probability Over Any Hour	99.99% (four unscheduled outages on baseline)	Yes
SPS SIS Availability	SPS SIS Per-Slot Availability <ul style="list-style-type: none"> <li><math>\geq 0.957</math></li> </ul> SPS SIS Constellation Availability <ul style="list-style-type: none"> <li><math>\geq 0.98</math> Probability that at least 21 Slots out of the 24 Slots will be healthy</li> <li><math>\geq 0.99999</math> Probability that at least 20 Slots out of the 24 Slots will be healthy</li> <li><math>\geq 0.95</math> Probability that the Constellation will have at least 24 Operational Satellites</li> </ul>	1) 99.9% per-Slot Availability  2) 100% Constellation Availability  3) 100% probability that the number of operational satellite is larger than 24.	Yes
PDOP Availability	<ul style="list-style-type: none"> <li><math>\geq 98\%</math> global PDOP of 6 or less</li> <li><math>\geq 88\%</math> worst site PDOP of 6 or less</li> </ul>	>99.8% availability on all days	Yes

Criteria	Specifications	Measured Performance	Passed
SPS Position Service Availability	<ul style="list-style-type: none"> <li>• <math>\geq 99\%</math> Horizontal Service Availability average location</li> <li>• <math>\geq 90\%</math> Horizontal Service Availability worst-case location</li> <li>• <math>\geq 99\%</math> Vertical Service Availability average location</li> <li>• <math>\geq 90\%</math> Vertical Service Availability worst-case location</li> </ul>	100% availability on all days	Yes
Positioning Accuracy	<ul style="list-style-type: none"> <li>• <math>\leq 9</math> meters 95% All-in-View Global Average Horizontal Error (SIS Only)</li> <li>• <math>\leq 17</math> meters 95% All-in-View worst site Horizontal Error (SIS Only)</li> <li>• <math>\leq 15</math> meters 95% All-in-View Global Average Vertical Error (SIS Only)</li> <li>• <math>\leq 37</math> meters 95% All-in-View worst site Vertical Error (SIS Only)</li> </ul>	1) $<3$ metres 95% Horizontal Error at the site, 2) $<5$ metres 95% Vertical Error at the site	Yes

Table 5-1: Summary of Performance

From the table it can be seen that the measured performance is within the required values for all requirements.

**End of Document**