



**GLOBAL POSITIONING SYSTEM (GPS)
PERFORMANCE**

JANUARY TO MARCH 2014

QUARTERLY REPORT

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1 INTRODUCTION

1.1 Purpose of Document

This document presents the results of the GPS SPS performance assessment for the period of 1 January 2014 to 31 March 2014. 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 MLGR, which is centrally located in Ireland.

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	Purchase order – Performance Monitoring And Analysis Of GPS Signals 2014	PO 201400257	-	-
AD.2	Outline Proposal to Ordnance Survey Ireland (OSi) in response to Request For Quotation for the provision of GPS performance monitoring services for Irish Aviation Authority (IAA)	OSI-GMAS-PRP	1.0	06/03/14

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 th Edition	Sept 2008
RD.2	Global Positioning System (GPS) Civil Monitoring Performance Specification	DOT-VNTSC-FAA-09-08	-	April 30 th 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

Acronym	Organisation
NOTAM	Notice To Airmen
NSL	Nottingham Scientific Ltd
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
URE	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>The User Range Error (URE) for any healthy satellite for Single-Frequency C/A-Code:</p> <ul style="list-style-type: none"> • ≤ 7.8 m 95% Global Average URE during Normal Operations over all age of data (AODs) • ≤ 6.0 m 95% Global Average URE during Normal Operations at Zero AOD • ≤ 12.8 m 95% Global Average URE during Normal Operations at Any AOD • ≤ 30 m 99.94% Global Average URE during Normal Operations over one year period • ≤ 30 m 99.79% Worst Case Single Point Average URE during Normal Operations over one year period • ≤ 388 m 95% Global Average URE during Extended Operations after 14 Days without Upload. <p>The User Range Rate Error (URRE) for Single-Frequency C/A-Code:</p> <p>≤ 0.006 m/sec 95% Global Average URRE over any 3-second interval during Normal Operations at Any AOD</p> <p>The User Range Acceleration Error (URAE) for Single-Frequency C/A-Code:</p> <p>≤ 0.002 m/sec/sec 95% Global Average URAE over any 3-second interval during Normal Operations at Any AOD</p> <p>The UTC Offset Error for Single-Frequency C/A-Code:</p> <p>≤ 40 nsec 95% Global Average UTCOE during Normal Operations at Any AOD</p>

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

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

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 (MLGR) and Sligo Hospital (SLGO). The locations of these sites are shown in Figure 2-1.

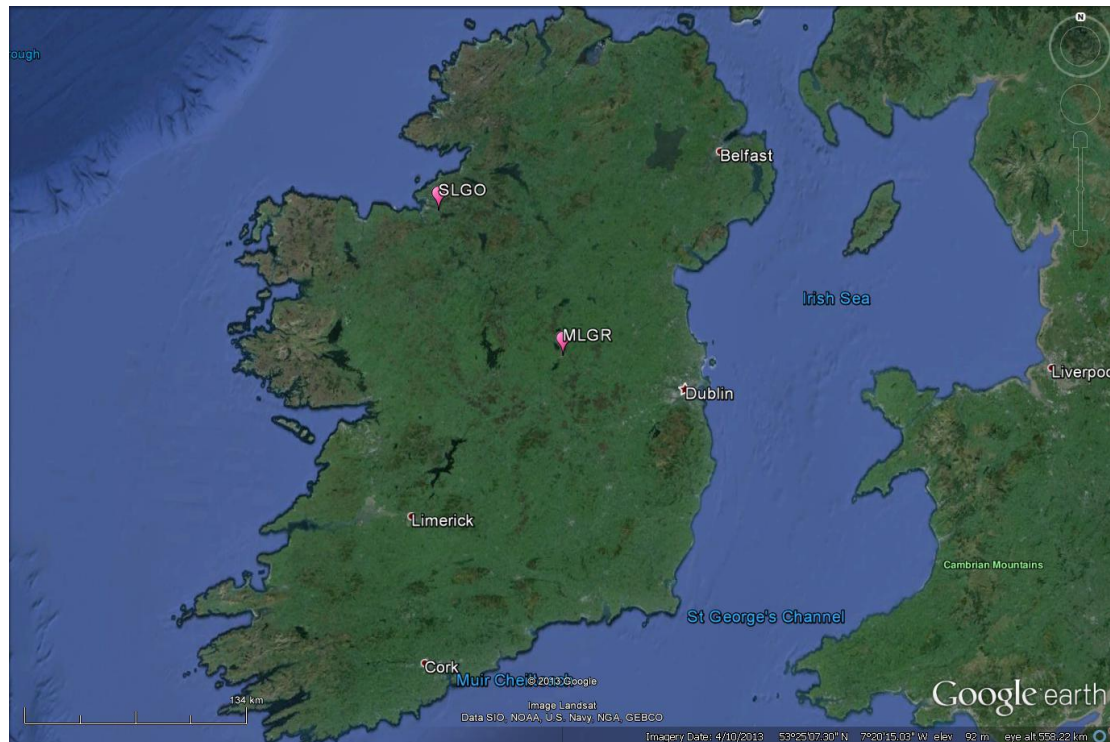


Figure 2-1: Location of Performance Monitoring Stations

MLGR is used as the main site to provide performance monitoring across the whole of Irish airspace and SLGO is used as a back-up in case of problems with MLGR 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.

In case there are problems with the data access simultaneously from both MLGR 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 = 1×10^{-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 January 1 to March 31 2014.

Slot	A1	A2	A3	A4	B1	B2	B3	B4	C1	C2	C3	C4
PRN	24	31	8	7	16	25	28	12	29	27	19	17
Slot	D1	D2	D3	D4	E1	E2	E3	E4	F1	F2	F3	F4
PRN	2	1	21	4	20	22	5	18	14	15	13	23

Table 3-1: Baseline constellation in the Reporting Period

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 January 1 to March 31 2014 are shown in the next figure.

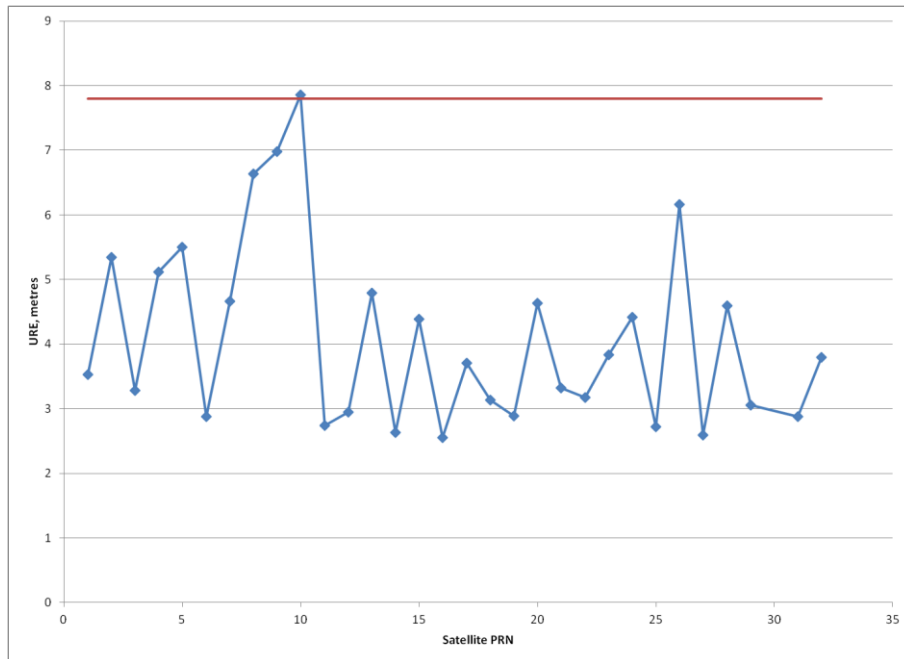


Figure 3-1: Constellation URE (95%) for Reporting Period

It can be seen that the URE (95%) for all but one of the satellites is less than the 7.8m threshold. However, PRN10 has 95% value of 7.86m, which is just above the threshold and could indicate a problem. It is more likely though that this apparent failure is due to high ionospheric residual errors on some of the days (see section 3.3), which would lead to an increase in 95% URE values for all satellites and could be enough to tip certain satellites above the threshold.

The daily constellation RMS URE results in the period January to March 2014 and the 4m threshold are shown in the next figure. Note that ≤ 7.8 m 95% SPS SIS URE performance standard is equivalent to a ≤ 4.0 m RMS SPS SIS URE performance standard [RD.1]. This is also important for the position service availability assessment.

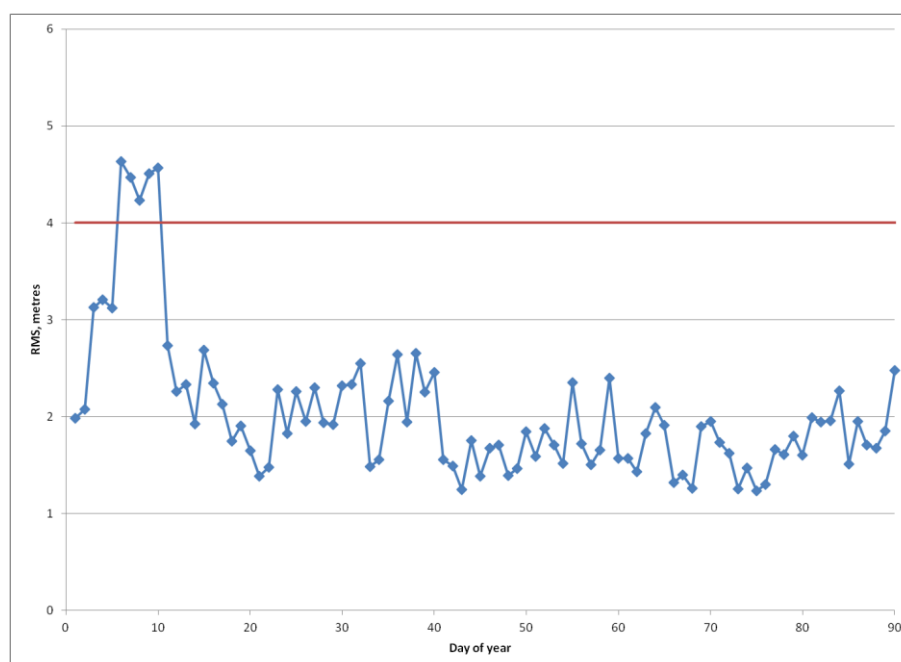


Figure 3-2: Constellation RMS URE for Reporting Period

It can be seen that on most days the RMS values for the monitoring site are less than the threshold (4 metres). However, there is a period from day 6 to day 10 where the daily rms figure is greater than 4m. The reason for this is most likely due to high ionospheric residual error from increased ionospheric activity, as described in more detail in section 3.3.

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 January 1 to March 31 2014 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	0.07	1.85	1.85	3.53	9.90	1984532
2	0.75	2.57	2.45	5.34	11.70	2784009
3	0.34	1.73	1.70	3.29	6.23	2175973
4	0.26	2.49	2.48	5.11	11.40	2578107
5	0.38	2.90	2.87	5.51	12.49	2599551
6	0.99	1.60	1.26	2.88	6.35	1217950
7	-0.16	2.48	2.48	4.66	11.30	2784973
8	1.16	3.14	2.92	6.63	13.56	2726848
9	1.35	3.36	3.08	6.98	15.40	2562855
10	1.89	3.74	3.23	7.86	14.52	2142131
11	0.41	1.41	1.35	2.74	7.12	1818038
12	0.07	1.53	1.53	2.95	8.13	2548707

PRN	Range Error (mean)	Range Error (RMS)	1-sigma	Range Error (95%)	Range Error (max)	Number of Samples
13	0.34	2.48	2.45	4.79	13.15	2618624
14	0.15	1.41	1.40	2.63	6.42	2692029
15	0.53	2.24	2.17	4.39	8.04	2276868
16	0.35	1.39	1.35	2.56	5.81	2610748
17	0.03	1.84	1.84	3.70	8.82	2758289
18	0.20	1.58	1.57	3.14	6.24	2852449
19	0.76	1.52	1.31	2.89	6.71	2370128
20	1.16	2.22	1.89	4.63	11.06	2036496
21	0.46	1.75	1.69	3.32	6.52	2703491
22	0.96	1.72	1.43	3.18	8.25	2802712
23	0.26	2.10	2.08	3.83	11.43	2692311
24	0.19	2.15	2.14	4.41	8.78	2055261
25	0.19	1.44	1.43	2.72	6.51	2336290
26	1.28	3.12	2.84	6.17	11.04	2154561
28	0.16	1.37	1.36	2.59	6.79	2221784
29	0.68	2.23	2.12	4.60	9.68	2810439
31	-0.19	1.47	1.46	2.88	6.65	2767307
32	1.01	1.94	1.65	3.79	9.85	2449653

Table 3-2: Range Error Statistics for Reporting Period

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 ± 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 1×10^{-5} /hr probability for misleading information, 90 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 seven days where satellites have measured URE greater than the threshold value. These are:

- Day 3 (3rd Jan) @ 18:28:09 for 231 seconds

- Day 4 (4th Jan) @ 14:25:56 for 5923 seconds
- Day 6 (6th Jan) @ 11:53:55 for 26306 seconds
- Day 7 (7th Jan) @ 13:36:00 for 24171 seconds
- Day 8 (8th Jan) @ 14:05:38 for 14361 seconds
- Day 9 (9th Jan) @ 13:28:25 for 21023 seconds
- Day 10 (10th Jan) @ 12:56:31 for 20026 seconds
- Day 50 (19th Feb) @ 11:36:57 for 33 seconds

Day 50 has K-index values of 5, indicating increased solar activity. In addition, it is noted from other sources (e.g. <http://www.swpc.noaa.gov/weekly/pdf/prf2002.pdf>) that solar flares and associated coronal mass ejections on 4th and 7th January did cause increased ionospheric activity during the period 6th to 10th January. Re-processing these days with dual frequency data removes the errors. Therefore it is most likely that these failures are due to high ionospheric residual errors rather than SIS errors, else such errors would also be apparent in dual-frequency results. High ionospheric residual errors would also explain the increased daily rms URE values on days 6 to 10 shown in Figure 3-2 and the higher than expected 95% URE values for certain satellites across the monitoring period (Figure 3-1).

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 two unscheduled outages. The first affected PRN9, which is not part of the baseline constellation, but the second one affected PRN01 which is part of the baseline constellation, and hence impacted the continuity. The total outage time for this event was 1.77hrs, giving a continuity figure of 99.997%

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 60.07 hours. This is equivalent to an average of 0.9988 over all slots in the 24-slot constellation, and satisfies SPS SIS Per-slot Availability standard (≥ 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.

- ≥ 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;
- ≥ 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.

- ≥ 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 (PDOP < 6) calculated at the site for all healthy satellites above 5 degrees elevation during the period January 1 to March 31 2014.

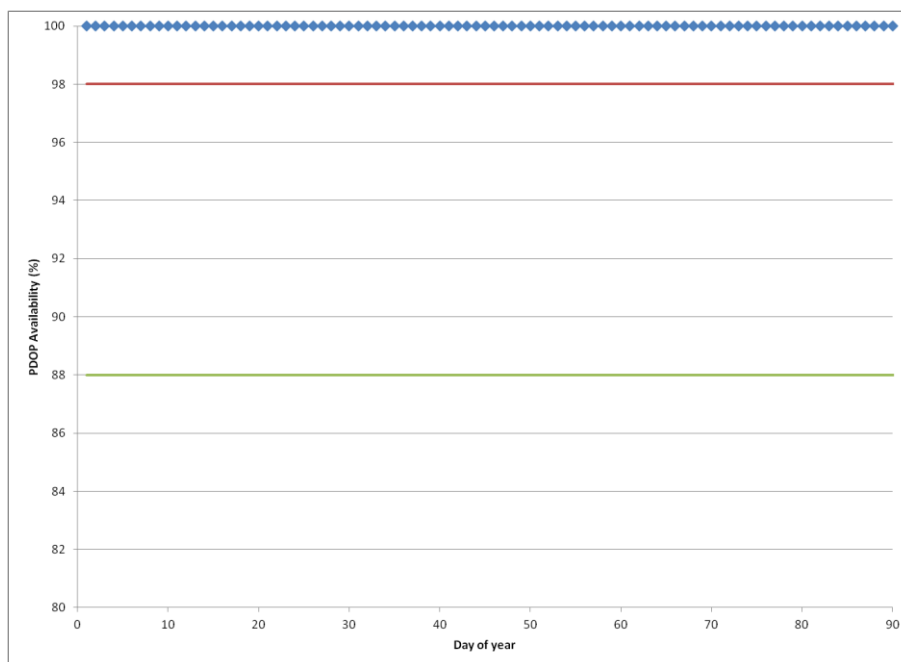


Figure 3-3: Daily PDOP Availability in the Reporting Period

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.

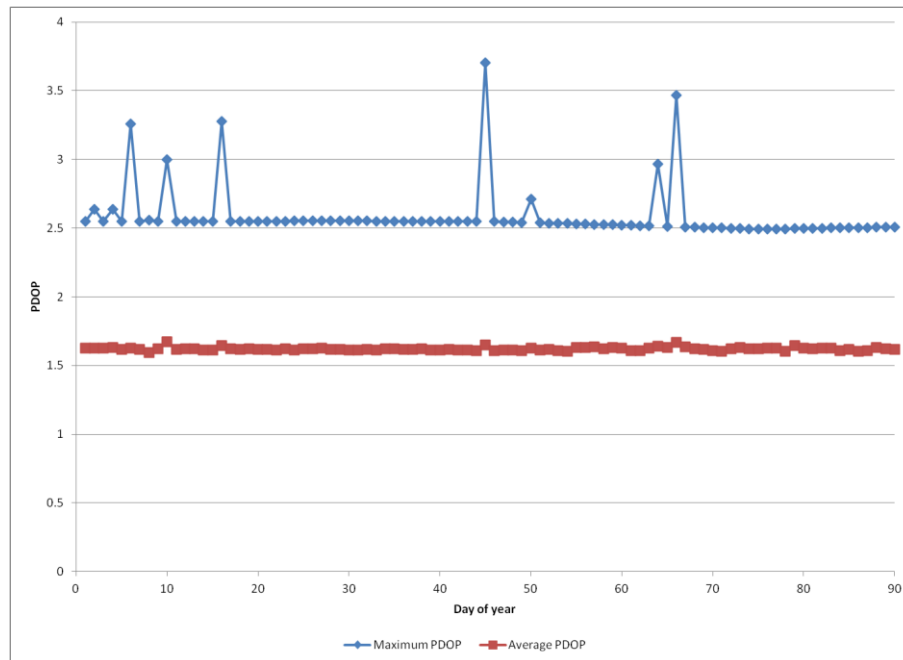


Figure 3-4: Daily Maximum PDOP Value in the Reporting Period

The daily PDOP values can be used to identify specific days that have different performance from the others. The first thing that can be seen is that the maximum PDOP is always well below 6 and most days have very similar maximum and average values. There are some days that have higher maximum values but these days can be explained by individual satellites outages notified by NANU (e.g. days 16, 45, 64, 66) or the receiver losing track of a satellite for a few seconds and leaving a slightly higher DOP for a few seconds.

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 January 1 to March 31 2014 are shown in the following figures.

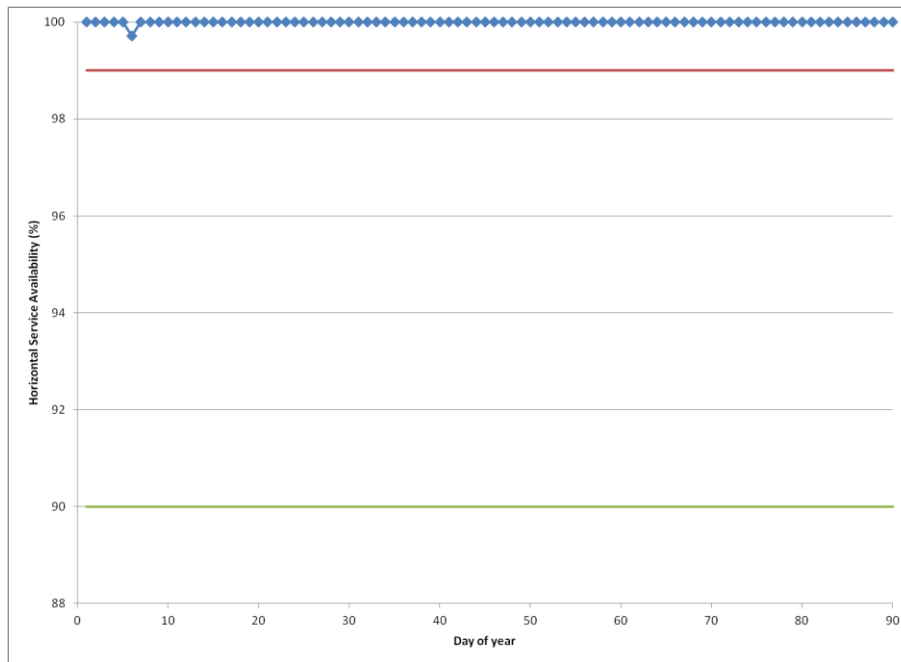


Figure 3-5: Daily Horizontal Service Availability Values for Reporting Period

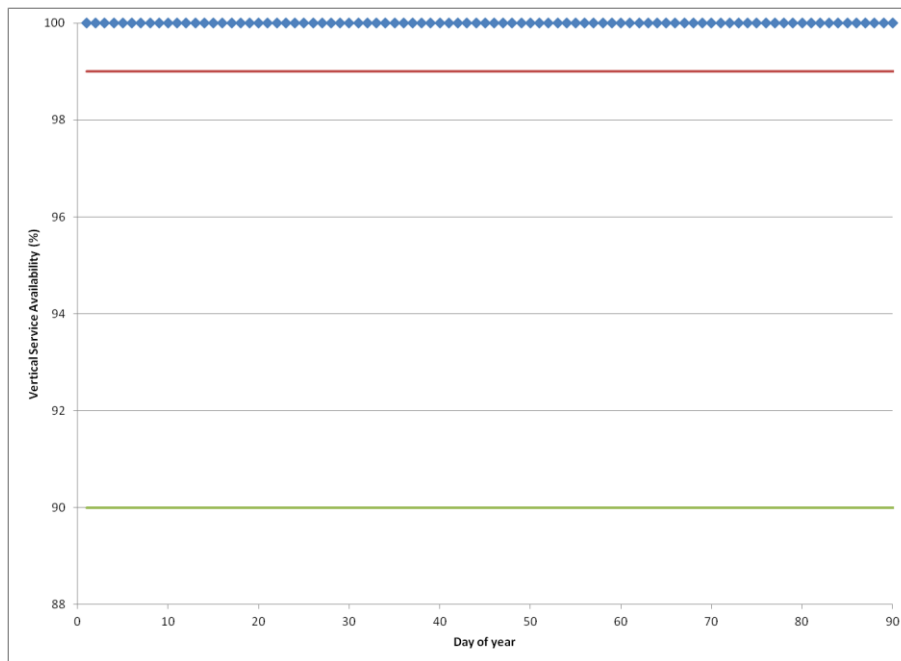


Figure 3-6: Daily Vertical Service Availability Values for Reporting Period

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 January 1 to March 31 2014 are shown in the following figures.

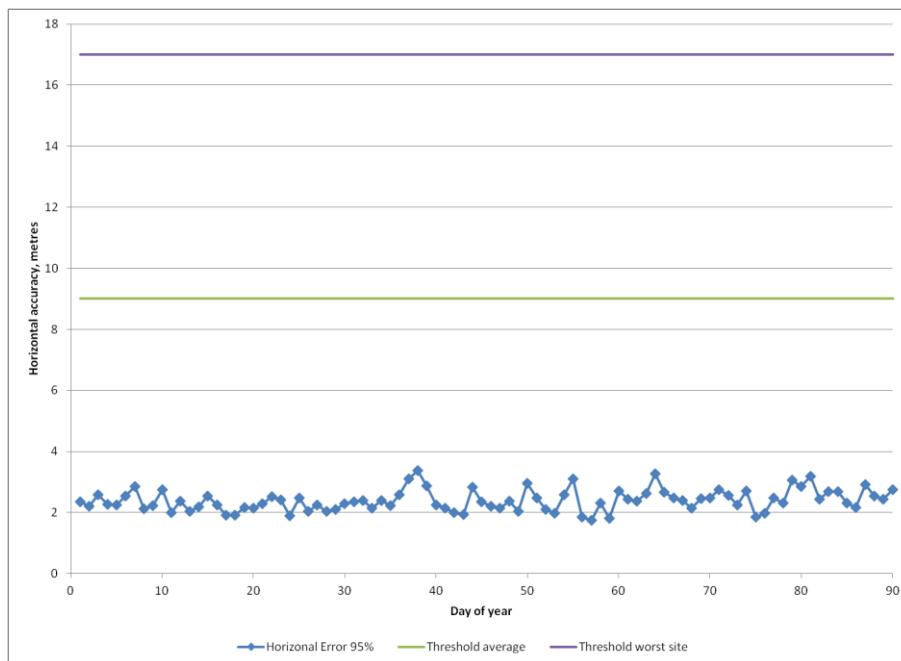


Figure 3-7: Daily Horizontal Position Accuracy (95%) for Reporting Period

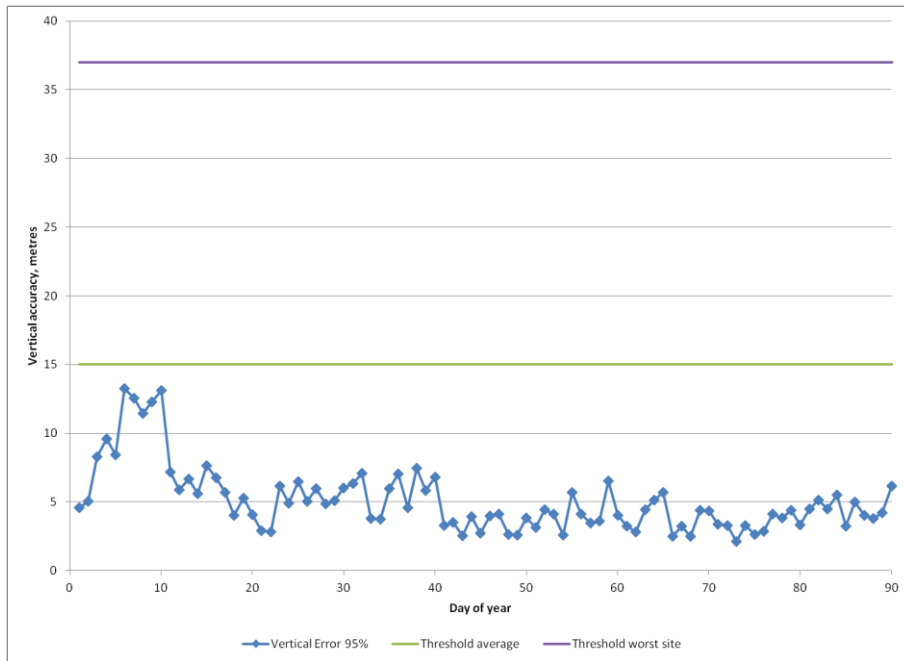


Figure 3-8: Daily Vertical Position Accuracy (95%) for Reporting Period

It can be seen that the daily horizontal accuracy values are all well 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.

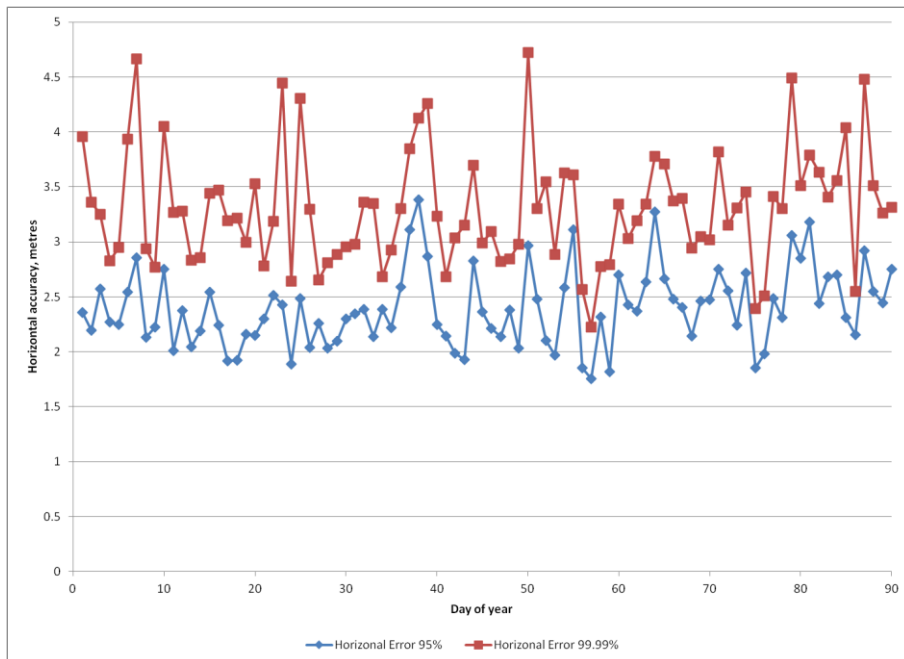


Figure 3-9: Daily Horizontal Position Accuracy (99.99%) for Reporting Period

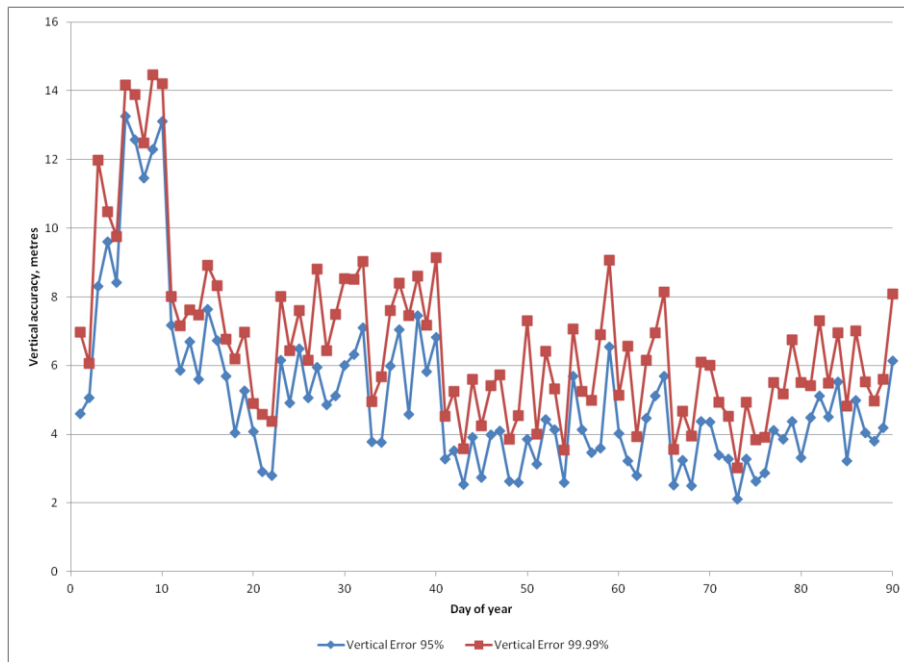


Figure 3-10: Daily Vertical Position Accuracy (99.99%) for Reporting Period

It can be seen that for vertical accuracy the 99.99% values generally follow the same pattern as the 95% values.

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.

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2014001	19	FCSTDV	9	2015	10	815	12	C3
2014003	22	FCSTDV	16	1700	17	500	12	E2
2014005	16	FCSTDV	35	1530	36	330	12	B1
2014006	1	FCSTMX	34	1600	35	400	12	D2
2014008	21	FCSTDV	38	1245	39	45	12	D3
2014010	16	FCSTDV	42	1515	43	315	12	B1
2014013	16	FCSTRESCD	49	1515	50	315	12	2014010
2014012	2	FCSTDV	45	920	45	2120	12	D1
2014015	6	FCSTUUFN	52	1430	UFN	N/A	UFN	C6
2014017	8	FCSTDV	58	30	58	1230	12	A3
2014021	5	FCSTDV	64	0	64	1200	12	E3
2014022	17	FCSTDV	66	322	66	1522	12	C4
2014029	24	FCSTDV	79	300	79	1500	12	A1

Table 4-1: Summary of Forecast Scheduled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2014002	19	FCSTSUMM	9	2058	10	250	5.866667	2014001
2014004	22	FCSTSUMM	16	1741	16	2245	5.066667	2014003
2014009	1	FCSTSUMM	34	1616	34	2132	5.266667	2014006
2014011	21	FCSTSUMM	38	1302	38	1840	5.633333	2014008
2014016	16	FCSTSUMM	49	1556	49	2213	6.283333	2014013
2014014	2	FCSTSUMM	45	941	45	1507	5.433333	2014012
2014019	6	DECOM	52	1501	52	2200	6.983333	2014015
2014020	8	FCSTSUMM	58	101	58	631	5.5	2014017
2014023	5	FCSTSUMM	64	14	64	758	7.733333	2014021
2014024	17	FCSTSUMM	66	355	66	946	5.85	2014022
2013030	24	FCSTSUMM	79	314	79	854	5.666667	2014029

Table 4-2: Summary of Actual Scheduled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Ref
2014007	16	FCSTCANC	35	1530	N/A	N/A	2014005

Table 4-3: Summary of Cancelled Outages

NANU	PRN	Type	Start day	Start Time	Stop day	Stop time	Outage (hours)	Ref
2014025	9	UNUSUFN	66	1508	N/A	N/A	N/A	A5
2014026	9	UNUSABLE	66	1508	66	1548	0.7	2014025
2014027	1	UNUSUFN	73	502	N/A	N/A	N/A	D2
2014028	1	UNUSABLE	73	502	73	648	1.766667	2014027

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.

	Q1 2014
hrs	2160
total forecast downtime (all)	132.00
total forecast downtime (baseline)	132.00
total actual scheduled downtime (all)	65.28
total actual scheduled downtime (baseline)	58.30
Scheduled satellite outage events (all)	11
Scheduled satellite outage events (baseline)	10
Unscheduled satellite outage events (all)	2
Unscheduled satellite outage events (baseline)	1
Total actual unscheduled downtime (all)	2.47
Total actual unscheduled downtime (baseline)	1.77
Total actual downtime (all)	67.75
Total actual downtime (baseline)	60.07
Availability (all)	99.899
Availability (baseline)	99.884
Continuity (baseline)	99.997

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.

There were two unscheduled outages in this reporting period. The first affected PRN9, which is not part of the baseline constellation, but the second one affected PRN01 which is part of the baseline constellation, and hence impacted the continuity.

From analysis of the broadcast navigation messages it can be seen that all occurrences of unhealthy satellites were linked with NANUs. As well as the outages listed above, PRN30 was launched on 21st February 2014 but remained unhealthy (no USABINIT NANU sent) for the rest of the monitoring period.

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) ≤ 7.8 m 95%	One SV > 7.8m All the rest <7m	Yes. Failure most likely due to high ionospheric errors and not SIS errors.
SPS SIS rms	≤ 4 m	Not all days <4m	Yes. Failures most likely due to high ionospheric errors and not SIS errors.
SPS SIS Integrity	The SIS Integrity $\leq 1 \times 10^{-5}$ Probability Over Any Hour (<0.7 events per quarter)	Events on 8 days	Yes. Failures most likely due to high ionospheric errors and not SIS errors.
SPS SIS Continuity	≥ 0.9998 Probability Over Any Hour	99.997% (one unscheduled outage on baseline)	Yes
SPS SIS Availability	SPS SIS Per-Slot Availability <ul style="list-style-type: none"> • ≥ 0.957 SPS SIS Constellation Availability <ul style="list-style-type: none"> • ≥ 0.98 Probability that at least 21 Slots out of the 24 Slots will be healthy • ≥ 0.99999 Probability that at least 20 Slots out of the 24 Slots will be healthy • ≥ 0.95 Probability that the Constellation will have at least 24 Operational Satellites 	1) 99.9% per-Slot Availability 2) 100% Constellation Availability 3) 100% probability that the number of operational satellite is larger than 24.	Yes

Criteria	Specifications	Measured Performance	Passed
PDOP Availability	<ul style="list-style-type: none"> • $\geq 98\%$ global PDOP of 6 or less • $\geq 88\%$ worst site PDOP of 6 or less 	>99.8% availability on all days	Yes
SPS Position Service Availability	<ul style="list-style-type: none"> • $\geq 99\%$ Horizontal Service Availability average location • $\geq 90\%$ Horizontal Service Availability worst-case location • $\geq 99\%$ Vertical Service Availability average location • $\geq 90\%$ Vertical Service Availability worst-case location 	100% availability on all days	Yes
Positioning Accuracy	<ul style="list-style-type: none"> • ≤ 9 meters 95% All-in-View Global Average Horizontal Error (SIS Only) • ≤ 17 meters 95% All-in-View worst site Horizontal Error (SIS Only) • ≤ 15 meters 95% All-in-View Global Average Vertical Error (SIS Only) • ≤ 37 meters 95% All-in-View worst site Vertical Error (SIS Only) 	1) <4 metres 95% Horizontal Error at the IGS site 2) <14 metres 95% Vertical Error at the IGS 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 except the SIS accuracy, SIS rms and the SIS integrity. However, preliminary analysis shows that this apparent non-conformance is most likely due to high solar activity leading to increased ionospheric residual errors.

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