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Geometrical-Based Navigation System Performance Assessment in the Space Service Volume Using a Multiglobal Navigation Satellite System Methodology

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September 2016

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I would like to express my gratitude to James Miller, Deputy Director of Policy and Strategic Communications within the Space Communications and Navigation Program, for the opportunity to participate in the International Committee on Global Navigation Satellite Systems (GNSS)' efforts to illustrate the benefits to the space user within the Space Service Volume that utilizes a multiple GNSS based methodology.

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Abstract

NASA is participating in the International Committee on Global Navigation Satellite Systems (GNSS) (ICG)’s efforts towards demonstrating the benefits to the space user in the Space Service Volume (SSV) when a multi-GNSS solution space approach is utilized. The ICG Working Group: Enhancement of GNSS Performance, New Services and Capabilities has started a three phase analysis initiative as an outcome of recommendations at the ICG-10 meeting, in preparation for the ICG-11 meeting. The first phase of that increasing complexity and fidelity analysis initiative is based on a pure geometrically-derived access technique. The first phase of analysis has been completed, and the results are documented in this paper.

Introduction

The region of space nearby the Earth is divided into two specific regions, defined as the Terrestrial Service Volume (TSV) and the Space Service Volume (SSV) (Ref. 7). The TSV is defined from the Earth’s surface up to an altitude of 3,000 km, while the SSV is defined from the altitude of 3,000 km to the geostationary altitude of roughly 36,000 km. These two regions of space are illustrated in Figure 1.

Navigation system performance is vastly different in these two regions of space, as many of the GNSS constellations operate at in Medium Earth Orbit (MEO) at an altitude around 20,000 km. Space users in the TSV can expect to observe GNSS satellites with a zenith-facing antenna just as a ground user on the Earth’s surface. However, space users in the SSV will observe dramatically different numbers of GNSS satellites, both dependent on the space user altitude but also its antenna location. At the maximum altitude within the SSV at 36,000 km, space users will not be able to observe GNSS satellites with a zenith-facing antenna, but rather, will be required to observe GNSS satellites with a nadir-facing antenna which have signals crossing over the Earth’s limb (Ref. 1). Figure 2 illustrates a potential space user within the TSV, while Figure 3 illustrates a potential space user within the SSV.

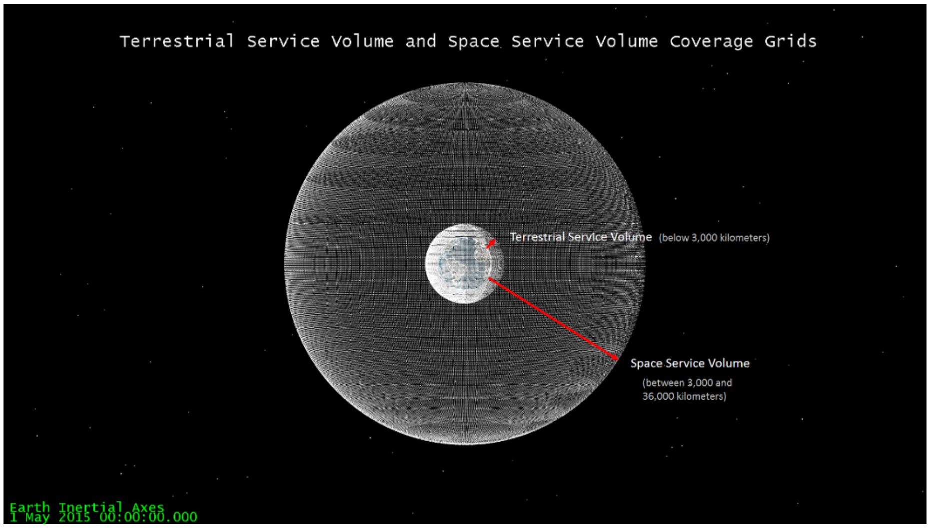


Figure 1.—Earth terrestrial and space service volume regions.

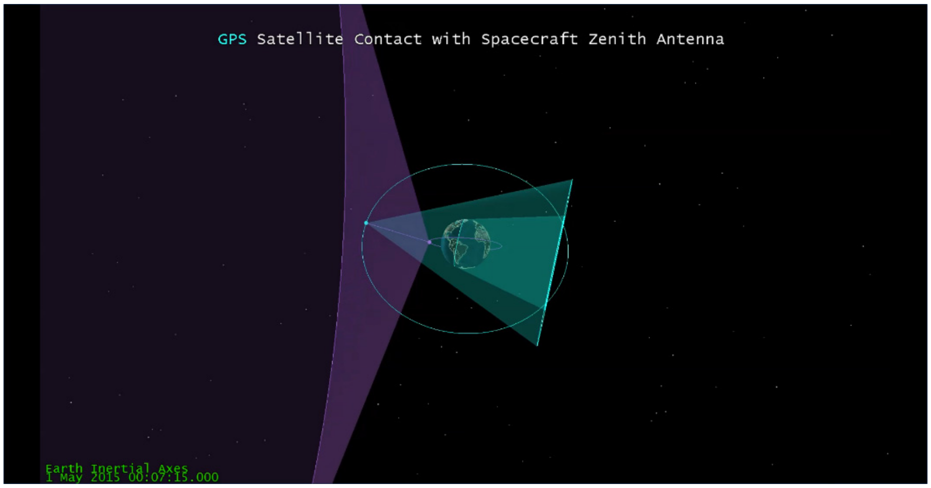


Figure 2.—Space user within terrestrial service volume.

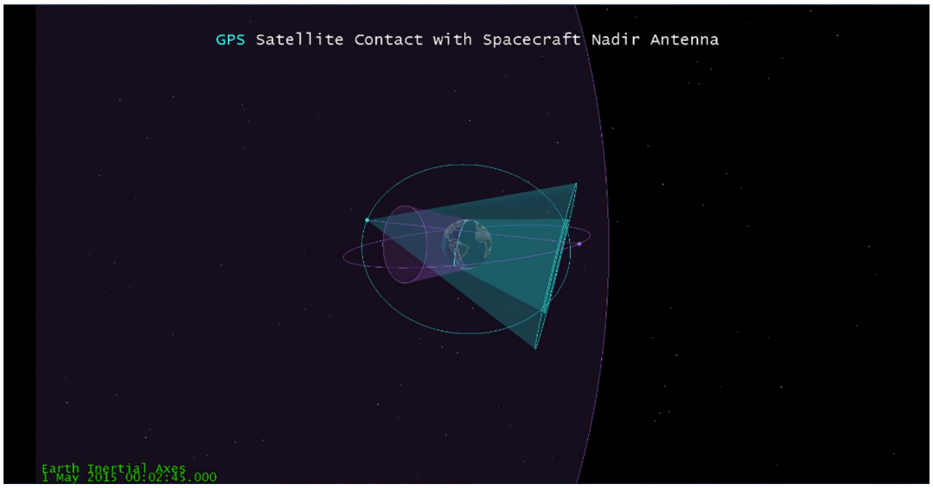


Figure 3.—Space user within the space service volume.

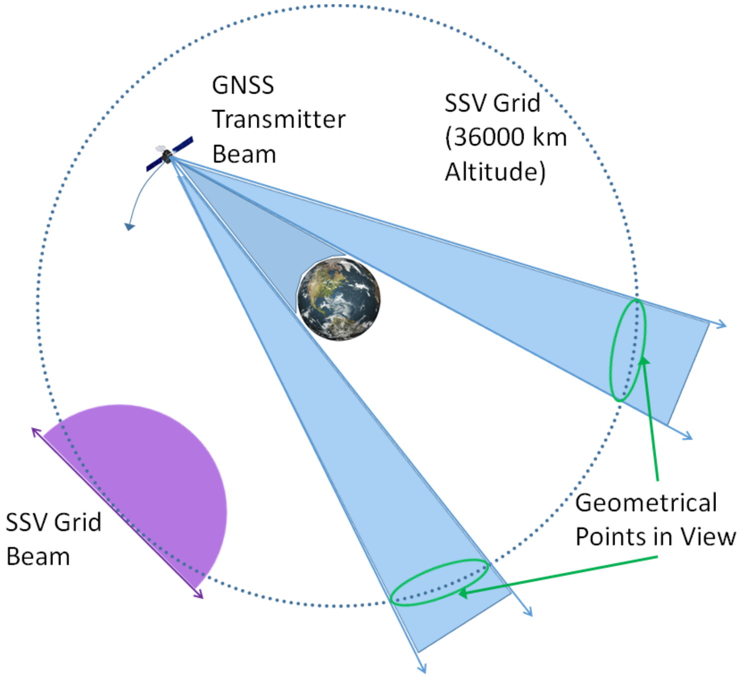


Figure 4.—Geometrical visibility limitations within the space service volume.

The trade space of potential GNSS constellation includes the United States' Global Position System (GPS) (Refs. 5 and 6), European Galileo (Ref. 3), Russian Global Navigation Satellite System (GLONASS) (Ref. 4), Chinese BeiDou (Ref. 2), Indian Regional Navigation Satellite System (IRNSS) (Ref. 8), and the Japanese Quasi-Zenith Satellite System (QZSS) (Ref. 9). The first four of those GNSS systems provide various levels of global coverage, while the last two of those systems only provide regional coverage over Asia. Due to the nature of the main antenna beam of those GNSS constellations being directed nadir, along with the fact that side-lobe antenna performance is unspecified, visibility is restricted to the portion of the antenna beam that extends beyond the Earth blockage, as seen in Figure 4.

That ultimately limits the visible number of spacecraft that can be in view of the space user at the maximum SSV altitude of 36,000 km. The results of this paper summarize the analytical techniques used to derive the visibility Figures of Merit, along with the performance levels of the individual constellations, along with a combined multi-GNSS system performance levels.

Analysis Methodology and Assumptions

The international team within the ICG that assessed the navigation performance of the SSV space user derived an analysis methodology and list of assumptions for their purposes. The GNSS systems considered were either individual GNSS constellations or the overall combination of all six GNSS constellations combined. Geometrical access considerations were also finalized to define when access was considered between a GNSS system spacecraft and a SSV space user. Keplarian orbit propagation and simulation parameters were also finalized, and are provided in Table 1. The orbital elements pertaining to the various GNSS constellations are provided in Appendix A, Tables 5 through 10, which describe the initial conditions used to describe the orbital state of the individual satellites that comprise each GNSS constellation. These parameters are used to generate the simplified Fixed Frame Keplarian orbit propagated position vector, which does not include the nominal Inertial to Fixed Frame transformation terms pertaining to pole wander, nutation, or precession.

TABLE 1.—KEPLARIAN ORBITAL SIMULATION ASSUMPTIONS

Parameter	Value
Initial simulation date and time (UTC)	Jan 1, 2016 12:00:00
Simulation duration (days)	14
Simulation time step (minutes)	1
Earth universal gravitational parameter (m^3/s^2)	3.986004415e14
Pi (Standard Matlab Pi)	3.141592653589793
Spherical Earth radius (km)	6378
Atmospheric radius (km)	50
Geostationary grid altitude (km)	36000
Earth rotation rate (rad/day)	2*pi*1.00273781191135448
Earth rotation angle at reference epoch (rad)	2*pi*0.7790572732640

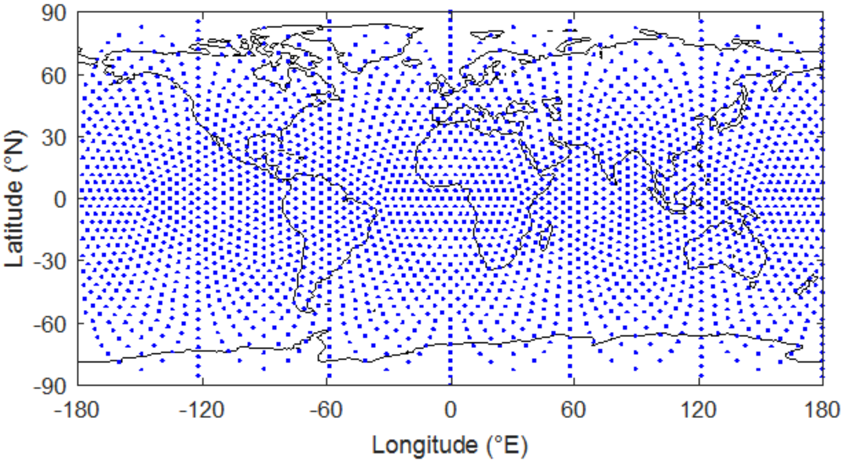


Figure 5.—User grid locations over Earth surface.

An equal area-based grid of points were utilized to represent the Space Service Volume for the purposes of this analysis, as seen in Figure 5. The benefit of using an equal area-based grid of points is that when various Figures of Merit are being calculated, additional processes of de-weighting the results so that they are not biased to regions with many more points are not necessary. Figure 5 illustrates the grid point locations over the spherical Earth surface at an altitude of 36,000 km. The grid has roughly 4° spacing near the Equator, and comprises 2562 points.

For the purposes of this study, access was derived and limited from a purely geometrical basis. Therefore, it is important to understand exactly how access is determined from all input criteria. For this study, two access criteria are considered. First, the space user in the SSV grid needs to be within a specified beamwidth angle of the GNSS transmitter beam. For this criterion, the calculation of the space user angle off the GNSS transmitter boresight vector is dependent on the pointing vector of the GNSS transmitter. For the IRNSS system, this boresight vector is directed to a fixed Earth location of 83° E. 5° N. while all other GNSS systems direct their boresight vector towards the center of Earth location. Second, the GNSS transmitter needs to be within the space user's nadir hemispherical field of view, constrained by the Earth with atmospheric altitude blockage. This is all illustrated further in Figure 6.

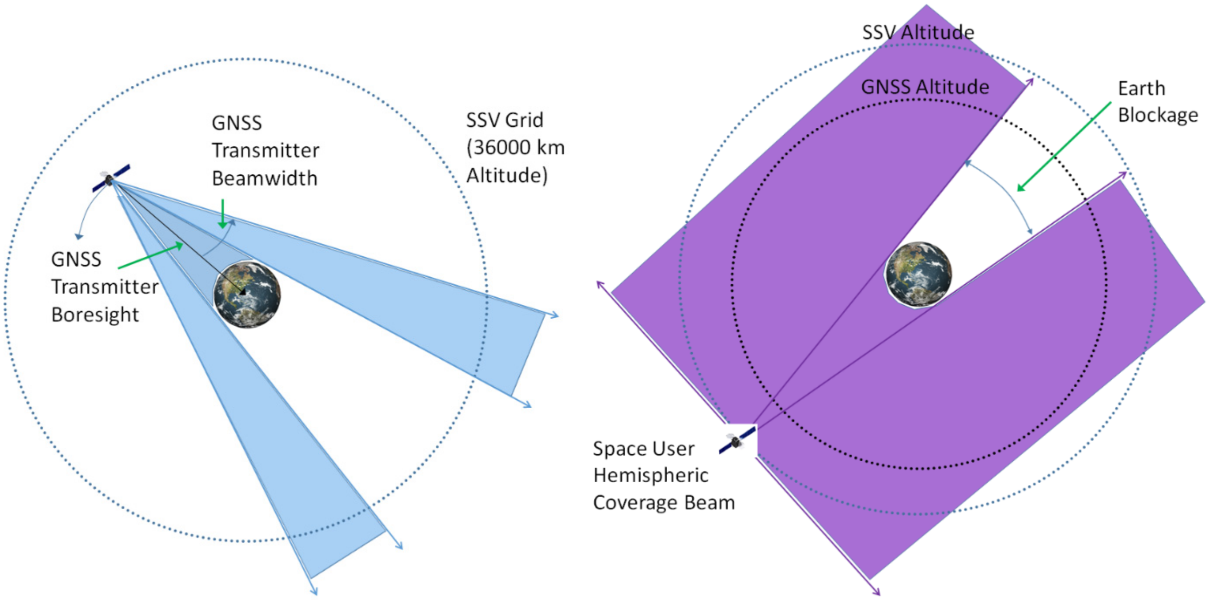


Figure 6.—Geometrical access considerations.

TABLE 2.—GNSS TRANSMITTER BEAMWIDTHS

GNSS constellation	L1 beamwidth, degree	L5 beamwidth, degree
BeiDou	25 (MEO) 19 (GEO/IGSO)	28 (MEO) 22 (GEO/IGSO)
Galileo	20.5	23.5
GLONASS	20	28
GPS	23.5	26
IRNSS	Not Applicable	16
QZSS	22	24

A table of the GNSS transmit beamwidths is provided also in Table 2 for both the L1 (1575.42 MHz) and L5 (1176.45 MHz) frequency bands that the study analyzes against. Note that for the BeiDou constellation, the beamwidth of the defined separately for the satellites in MEO or Geostationary (GEO)/Inclined Geosynchronous Orbit (IGSO). Also, for IRNSS, L1 beamwidth is not applicable, as IRNSS does not transmit the L1 frequency band. It is also important to note that all L5 beamwidths are larger than their constellation's L1 beamwidth, as that will directly impact performance results.

The overall simulation methodology is performed in multiple steps, which are listed below:

1. Propagate orbit position vectors into Earth-Centered Earth-Fixed frame coordinates over scenario time instances.
2. Calculate angle off GNSS boresight vector to all SSV grid points over scenario time instances.
3. Calculate angle off SSV nadir boresight vector to all GNSS orbit positions over scenario time instances.
4. Determine yes/no access using maximum GNSS beamwidth consideration, Earth blockage consideration, and SSV hemispherical beamwidth consideration over scenario time instances for all SSV grid points.
5. Calculate Figures of Merit from access determination over scenario time instances over all SSV grid points.

Access Results

The simulation results that are presented here are the various Figures of Merit calculated in the analysis effort. For this simulation effort, the Figures of Merit are defined as System Availability and Maximum Outage time, with the minimum number of satellites under consideration being either one or four satellites. Since the grid points are defined as having equal area pertaining to each grid point, averaging of performance over the grid points can be done using a pure mean calculation, without additional scale factors needing to be applied. As stated, the constellations being considered are the six individual constellations, as well as a combined multi-GNSS constellation consisting of all individual constellations, at either the L1 or L5 frequency bands, independently. Therefore, a system performance assessment is not, for example, of using the L1 frequency band performance of BeiDou, Galileo, GLONASS, GPS and QZSS combined with the L5 frequency band performance of IRNSS. Finally, for the purpose of IRNSS, which does not support the L1 frequency band, tabulated results are shown as "Not Applicable" (N/A). MO times that are the duration of the scenario, which is the result if the criteria is never met within the scenario duration, are denoted as "Max Scenario Duration (SD)." Table 3 reports the various Figures of Merit for the L1 frequency band, while Table 4 reports the same parameters for the L5 frequency band.

Results in Tables 3 and 4 provided the averaged globalized SSV expected system performance. All system availability metrics that were provided were values that were rounded down to the next lowest tenths decimal place. Maximum outage time is limited to integer numbers of minutes, due to the nature that the simulations were performed on 1 min intervals. Two-dimensional plots of the various Figures of Merit are provided in Appendix B, utilizing the plot format of the SSV grid points shown previously in Figure 5, where the color of the grid point represents the value of the various metrics.

TABLE 3.—L1 SSV SYSTEM PERFORMANCE FIGURES OF MERIT

Figure of Merit	BeiDou	Galileo	GLONASS	GPS	IRNSS	QZSS	All
1 Satellite system availability (%)	97.4	78.5	59.1	90.5	N/A	26.7	99.9
4 Satellite system availability (%)	24.1	1.2	0.5	4.8	N/A	0.8	94.4
1 Satellite maximum outage (minutes)	45	98	134	111	N/A	Max SD	39
4 Satellite maximum outage (minutes)	Max SD	Max SD	Max SD	Max SD	N/A	Max SD	97

TABLE 4.—L5 SSV SYSTEM PERFORMANCE FIGURES OF MERIT

Figure of Merit	BeiDou	Galileo	GLONASS	GPS	IRNSS	QZSS	All
1 Satellite system availability (%)	99.9	93.4	98.3	96.9	36.9	30.5	100
4 Satellite system availability (%)	45.4	4.2	14.5	15.6	0.6	1.5	99.9
1 Satellite maximum outage (minutes)	7	55	35	77	Max SD	Max SD	0
4 Satellite maximum outage (minutes)	644	Max SD	2252	1180	Max SD	Max SD	35

It is also important to understand that these globally averaged metrics are not balanced and uniform over the entire SSV grid latitude and longitude points. The simple example is that for regional constellations, the longitudinal coverage does not exist for large portions of the SSV grid, due to the lack of sources available in view. For global constellations, it was found that the performance varied as a function of latitude, which is illustrated in the figures shown in Appendix B. Here, a counter-intuitive result was observed where polar regions of the SSV grid performed much better than equatorial regions, and so one potential path forward could be to weight the SSV grid points by a spatial importance function, such that more prevalent regions of the SSV grid could be considered as more important in deriving the overall global metrics.

Conclusions and Next Steps

The analysis presented in this paper documents the navigation performance at the maximum altitude within the SSV using individual GNSS constellations and using a combined multi-GNSS constellation at the individual L1 and L5 frequency bands. The results show that no individual constellation can provide the nominal four satellite coverage within the SSV at all points in time. The combination of the six GNSS platforms shows that with the use of the L5 frequency band, 100 percent coverage is possible for a single satellite, while global four satellite coverage is nearly possible, at 99.9 percent. The results are very promising towards meeting the needs of space users in the SSV.

It is important to note that this study was limited to geometrical access considerations, which does not take into account aspects of access pertaining to received signal to noise ratios at the space user. Signal to noise ratio based access also is dependent on the space user receive antenna, in terms of gain profile, and orientation to the spacecraft. Future work will need to take into account minimum signal to noise ratio thresholds to determine is a GNSS spacecraft is visible, which should be derived in terms of initial acquisition of the GNSS signal, as well as on-going tracking of the GNSS signal. Here, acquisition of the GNSS signal is more difficult to perform than on-going tracking of the GNSS signal, and so the signal to noise ratio threshold for acquisition is higher than for tracking. Future work should also recognize the differences in acquisition and tracking of one GNSS constellation signal to another, due to differences in the data rates and code schemes implemented in each constellation's signal format. This implies that a specific signal to noise threshold at one constellation does not mean the same signal to noise threshold for another constellation. Future work should also take advantage of the transmitter side lobe signals, which requires that the GNSS transmitter antenna pattern is known, to increase the number of potential spacecraft in view of the SSV user. Finally, specific user missions should be used in place of a global SSV grid, to allow direct variations in orbital altitude or to focus on specific regions of space to be assessed via these simulation techniques.

Appendix A—Orbital State Definitions

A.1 BeiDou Orbital State Definition

TABLE 5.—BeiDou REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity, ( )	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean anomaly, degree
1	27906137	0.003	55	0	0	225.631
2	27906137	0.003	55	0	0	270.631
3	27906137	0.003	55	0	0	315.631
4	27906137	0.003	55	0	0	0.631
5	27906137	0.003	55	0	0	45.631
6	27906137	0.003	55	0	0	90.631
7	27906137	0.003	55	0	0	135.631
8	27906137	0.003	55	0	0	180.631
9	27906137	0.003	55	120	0	240.631
10	27906137	0.003	55	120	0	285.631
11	27906137	0.003	55	120	0	330.631
12	27906137	0.003	55	120	0	15.631
13	27906137	0.003	55	120	0	60.631
14	27906137	0.003	55	120	0	105.631
15	27906137	0.003	55	120	0	150.631
16	27906137	0.003	55	120	0	195.631
17	27906137	0.003	55	240	0	255.631
18	27906137	0.003	55	240	0	300.631
19	27906137	0.003	55	240	0	345.631
20	27906137	0.003	55	240	0	30.631
21	27906137	0.003	55	240	0	75.631
22	27906137	0.003	55	240	0	120.631
23	27906137	0.003	55	240	0	165.631
24	27906137	0.003	55	240	0	210.631
25	42164200	0.003	0	0	2.204	336.229
26	42164200	0.003	0	0	23.459	336.229
27	42164200	0.003	0	0	54.082	336.229
28	42164200	0.003	0	0	83.582	336.229
29	42164200	0.003	0	0	103.582	336.229
30	42164200	0.003	55	61.445	0	336.229
31	42164200	0.003	55	301.445	0	96.229
32	42164200	0.003	55	181.445	0	216.229

A.2 Galileo Orbital State Definition

TABLE 6.—GALILEO REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity, ( )	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean anomaly, degree
1	29599801.224	0.0000001	56	326.60209225	0	107.1899147499
2	29599801.224	0.0000001	56	326.60209225	0	152.1899147499
3	29599801.224	0.0000001	56	326.60209225	0	197.1899147499
4	29599801.224	0.0000001	56	326.60209225	0	242.1899147499
5	29599801.224	0.0000001	56	326.60209225	0	287.1899147499
6	29599801.224	0.0000001	56	326.60209225	0	332.1899147499
7	29599801.224	0.0000001	56	326.60209225	0	17.1899147499
8	29599801.224	0.0000001	56	326.60209225	0	62.1899147499
9	29599801.224	0.0000001	56	86.60209225	0	122.1899147499
10	29599801.224	0.0000001	56	86.60209225	0	167.1899147499
11	29599801.224	0.0000001	56	86.60209225	0	212.1899147499
12	29599801.224	0.0000001	56	86.60209225	0	257.1899147499
13	29599801.224	0.0000001	56	86.60209225	0	302.1899147499
14	29599801.224	0.0000001	56	86.60209225	0	347.1899147499
15	29599801.224	0.0000001	56	86.60209225	0	32.1899147499
16	29599801.224	0.0000001	56	86.60209225	0	77.1899147499
17	29599801.224	0.0000001	56	206.60209225	0	137.1899147499
18	29599801.224	0.0000001	56	206.60209225	0	182.1899147499
19	29599801.224	0.0000001	56	206.60209225	0	227.1899147499
20	29599801.224	0.0000001	56	206.60209225	0	272.1899147499
21	29599801.224	0.0000001	56	206.60209225	0	317.1899147499
22	29599801.224	0.0000001	56	206.60209225	0	2.1899147499
23	29599801.224	0.0000001	56	206.60209225	0	47.1899147499
24	29599801.224	0.0000001	56	206.60209225	0	92.1890000000

A.3 GLONASS Orbital State Definition

TABLE 7.—GLONASS REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity, ( )	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean anomaly, degree
1	25508200	0.000397	64.16	201.81	28.75	295.76
2	25505500	0.001181	64.64	202.16	229.92	47.69
3	25507000	0.001152	64.47	202.24	242.46	349.96
4	25509600	0.000341	64.49	202.16	229.04	317.62
5	25508200	0.000593	64.15	201.75	71.12	71.67
6	25505600	0.000838	64.14	201.75	134.53	321.03
7	25507100	0.001027	64.48	202.28	239.38	172.44
8	25509600	0.00154	64.48	202.27	282.44	85.43
9	25509000	0.002309	64.93	322.43	13.68	322.87
10	25506000	0.001662	65.73	322.85	160.86	131.88
11	25506000	0.001846	65.34	322.22	357.58	250.24
12	25509100	0.003395	64.93	322.44	167.5	34.48
13	25509000	0.000449	65.33	322.18	95.45	60.38
14	25505900	0.001493	65.71	322.79	163.14	306.41
15	25505700	0.002211	65.71	322.78	345.48	85.17
16	25509300	0.001967	64.91	322.37	149.58	229.88
17	25509600	0.000831	64.79	82.98	220.69	132.36
18	25507100	0.001346	65.06	82.75	338.33	331.94
19	25505300	0.000102	65.28	83.61	167.08	95.28
20	25508100	0.00106	65.29	83.67	344.69	231.89
21	25509600	0.000685	65	82.79	185.84	348.48
22	25507200	0.002793	65.19	82.78	356.75	132.46
23	25505600	0.000142	65.17	82.74	135.86	306.03
24	25508000	0.000779	65.18	82.77	84.59	315.17

A.4 GPS Orbital State Definition

TABLE 8.—GPS REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity, ( )	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean, anomaly, degree
1	26559800	0	55	273.056	0	11.676
2	26559800	0	55	273.056	0	41.806
3	26559800	0	55	273.056	0	161.786
4	26559800	0	55	273.056	0	268.126
5	26559800	0	55	333.056	0	66.356
6	26559800	0	55	333.056	0	94.916
7	26559800	0	55	333.056	0	173.336
8	26559800	0	55	333.056	0	204.376
9	26559800	0	55	333.056	0	309.976
10	26559800	0	55	33.056	0	111.876
11	26559800	0	55	33.056	0	241.556
12	26559800	0	55	33.056	0	339.666
13	26559800	0	55	33.056	0	11.796
14	26559800	0	55	93.056	0	135.226
15	26559800	0	55	93.056	0	167.356
16	26559800	0	55	93.056	0	257.976
17	26559800	0	55	93.056	0	282.676
18	26559800	0	55	93.056	0	35.156
19	26559800	0	55	153.056	0	197.046
20	26559800	0	55	153.056	0	302.596
21	26559800	0	55	153.056	0	333.686
22	26559800	0	55	153.056	0	66.066
23	26559800	0	55	213.056	0	238.886
24	26559800	0	55	213.056	0	334.016
25	26559800	0	55	213.056	0	0.456
26	26559800	0	55	213.056	0	105.206
27	26559800	0	55	213.056	0	135.346

A.5 IRNSS Orbital State Definition

TABLE 9.—IRNSS REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity, ( )	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean anomaly, degree
1	42164200	0.0007	28.1	124.08	0	211.3
2	42164200	0.0007	29.97	303.04	0	32.32
3	42164200	0.0007	4.01	264.62	0	98.963
4	42164200	0.0007	29.98	303.19	0	88.964
5	42164200	0.0007	28.1	124.08	0	267.8
6	42164200	0.0007	5	270	0	42.663
7	42164200	0.0007	5	270	0	139.568
8	42164200	0.0007	42	318.5	0	8.7629
9	42164200	0.0007	42	110	0	235.5129
10	42164200	0.0007	42	290	0	84.5129
11	42164200	0.0007	42	279	0	121.2629

A.6 QZSS Orbital State Definition

TABLE 10.—QZSS REFERENCE EPOCH ORBITAL STATE DEFINITION

Satellite	Semi-major axis, m	Eccentricity,	Inclination, degree	Right ascension, degree	Argument of perigee, degree	Mean anomaly, degree
1	42164169.45	0.075	40	165	270	341.58
2	42164169.45	0.075	40	295	270	211.58
3	42164169.45	0.075	40	35	270	111.58
4	42164169.45	0	0	0	0	47.58

Appendix B—Two-Dimensional Figure of Merit Views

B.1 L1 Frequency Band Regional Figures of Merit

B.1.1 BeiDou L1 Frequency Band Regional Figures of Merit

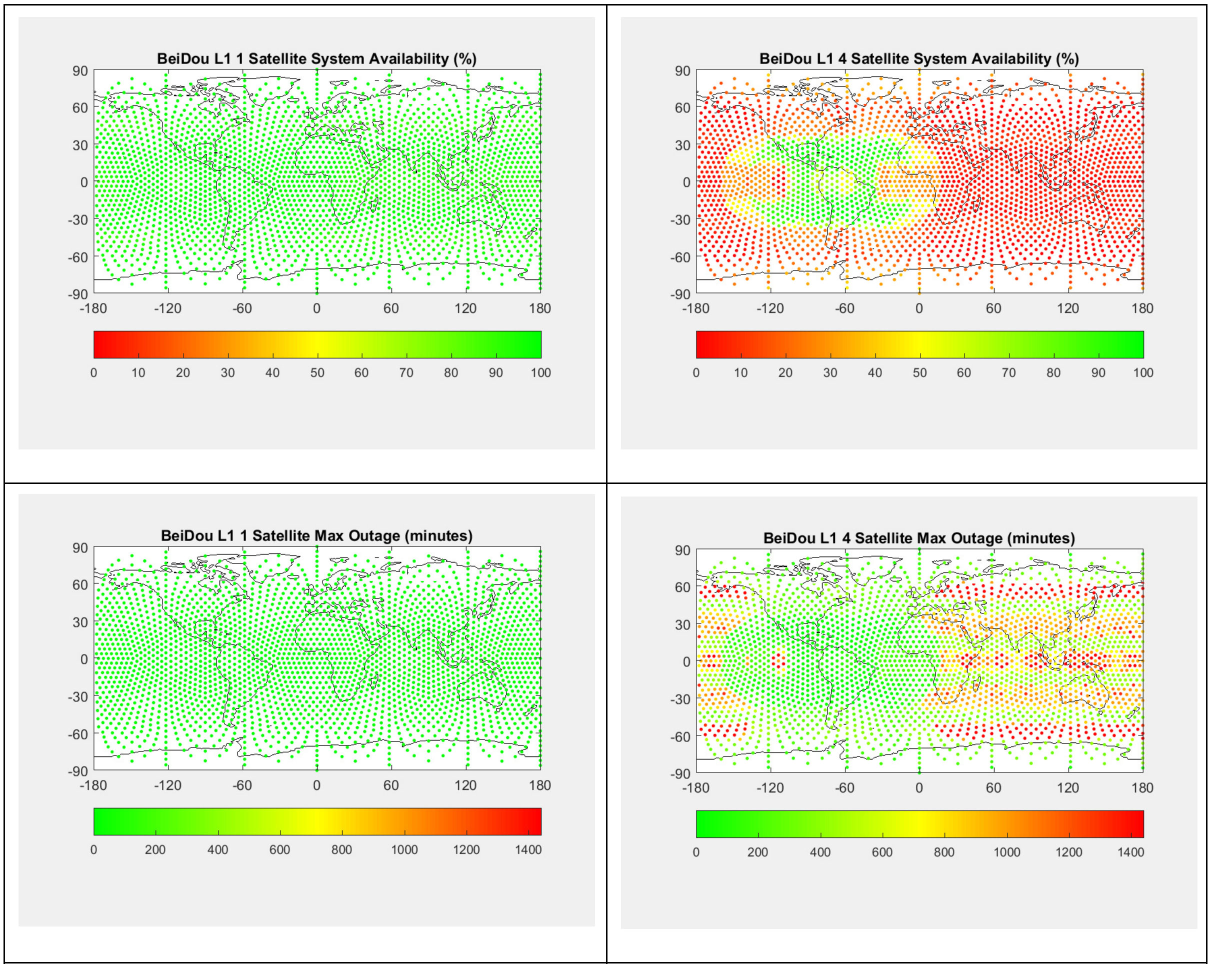


Figure 7.—BeiDou L1 regional figures of merit.

B.1.2 Galileo L1 Frequency Band Regional Figures of Merit

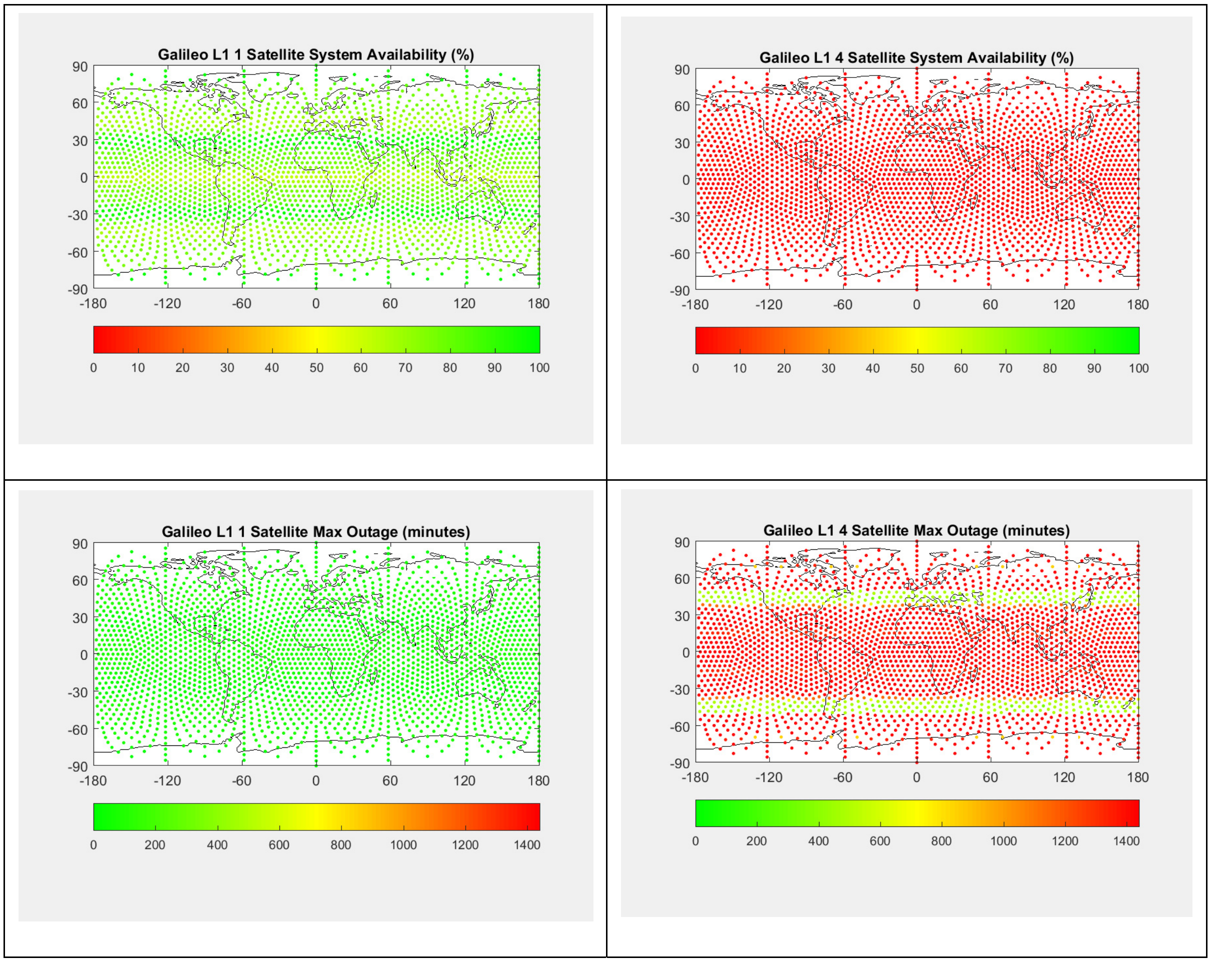


Figure 8.—Galileo L1 regional figures of merit.

B.1.3 GLONASS L1 Frequency Band Regional Figures of Merit

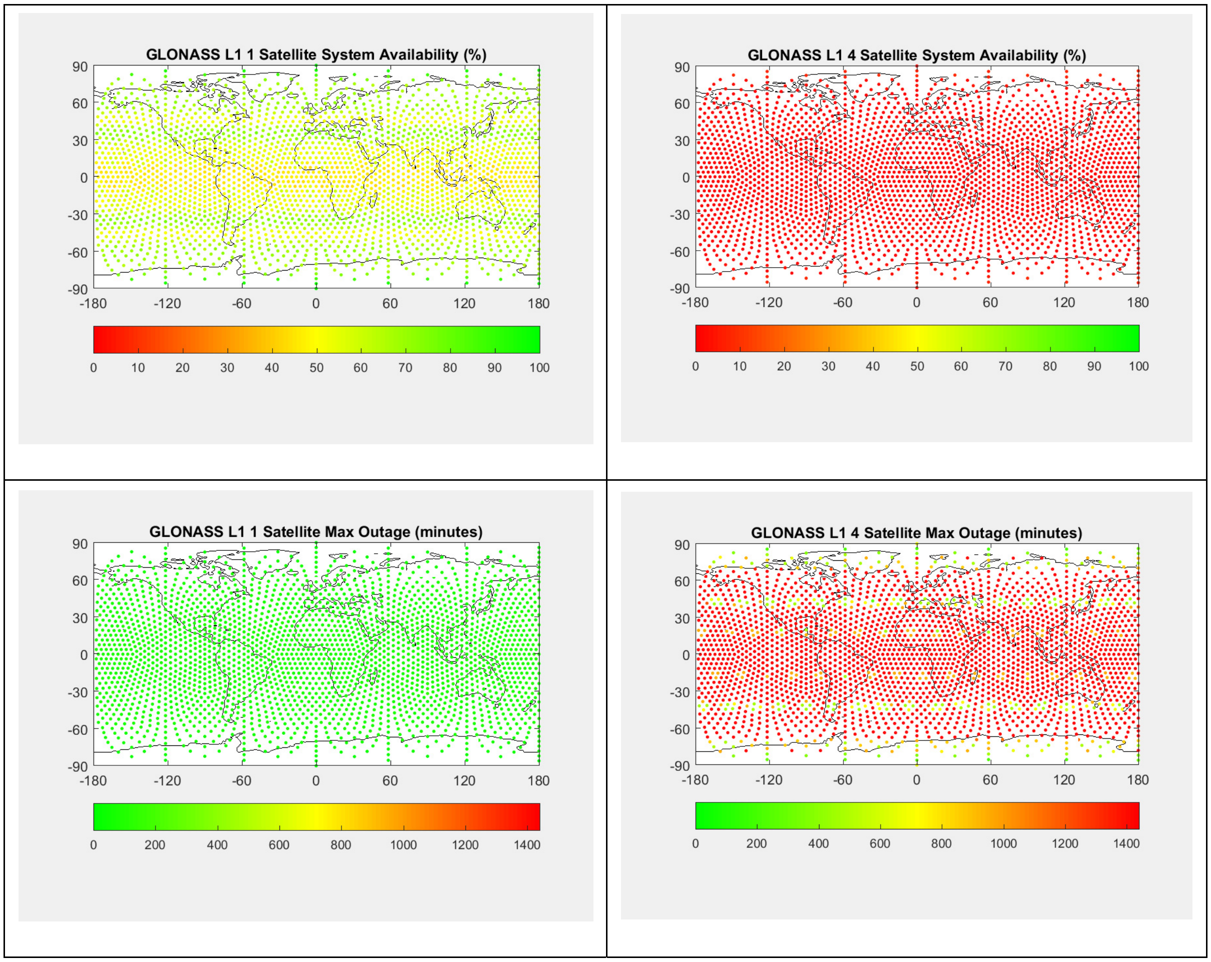


Figure 9.—GLONASS L1 regional figures of merit.

B.1.4 GPS L1 Frequency Band Regional Figures of Merit

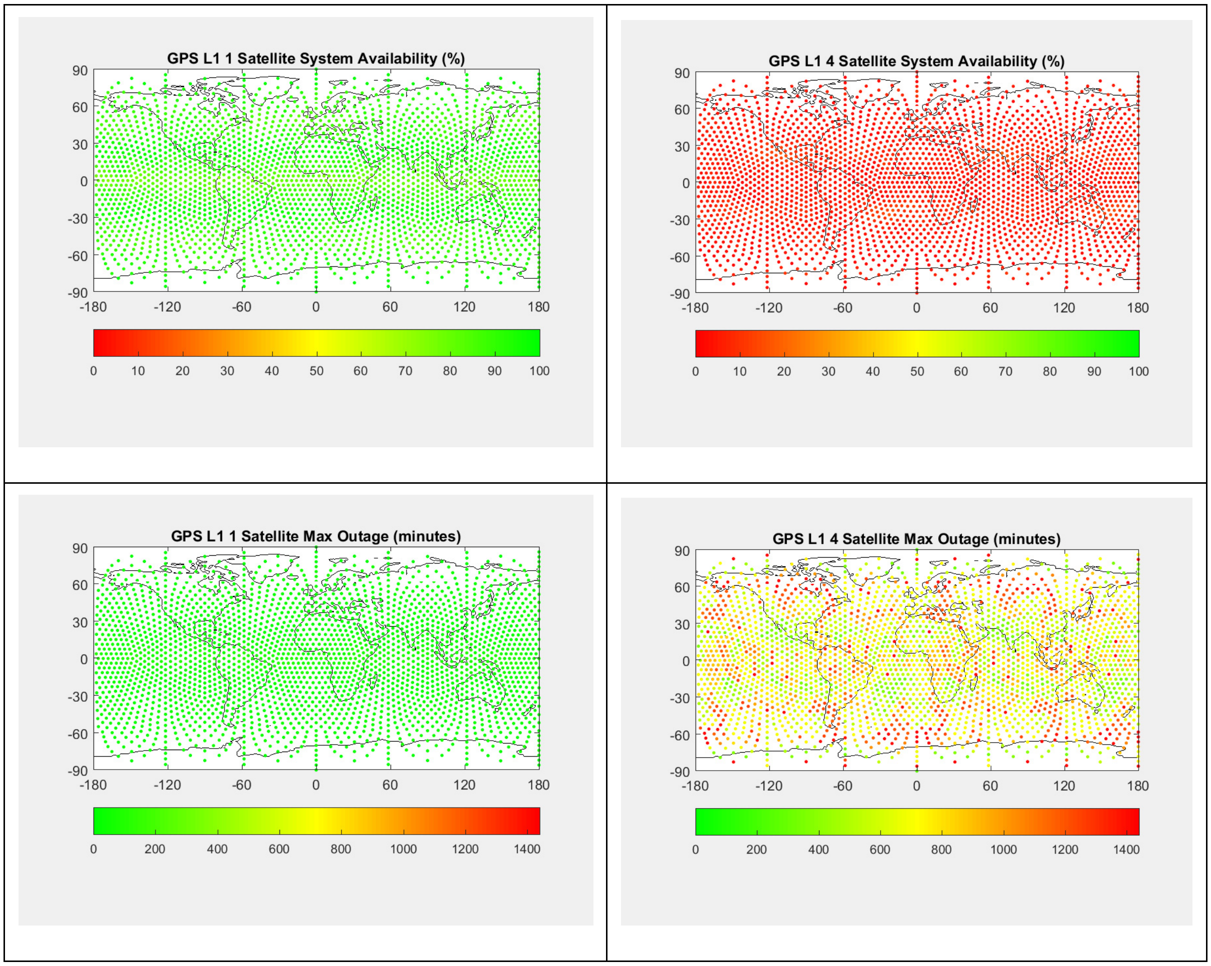


Figure 10.—GPS L1 regional figures of merit.

B.1.5 QZSS L1 Frequency Band Regional Figures of Merit

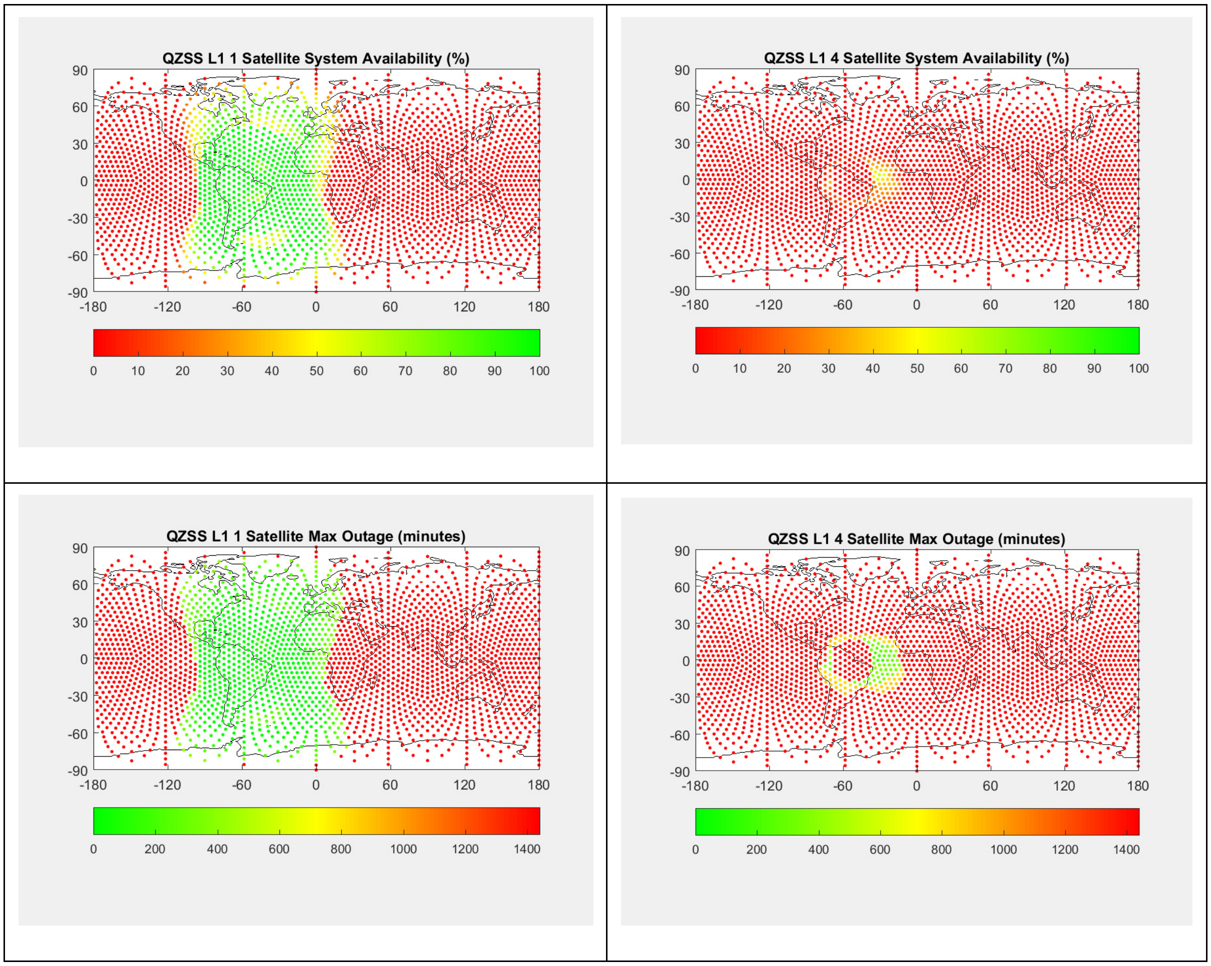


Figure 11.—QZSS L1 regional figures of merit.

B.1.6 Cumulative Multi-GNSS L1 Frequency Band Regional Figures of Merit

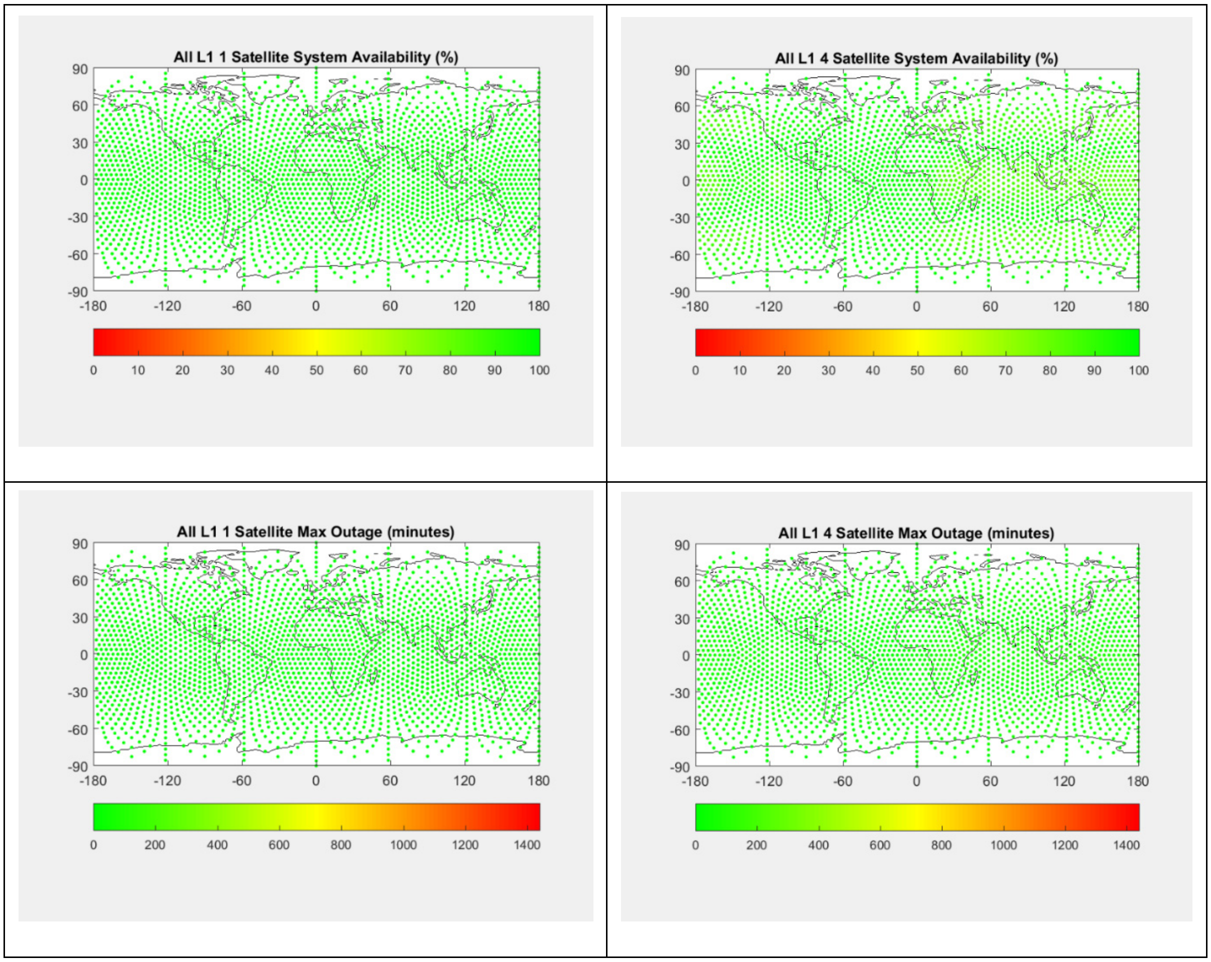
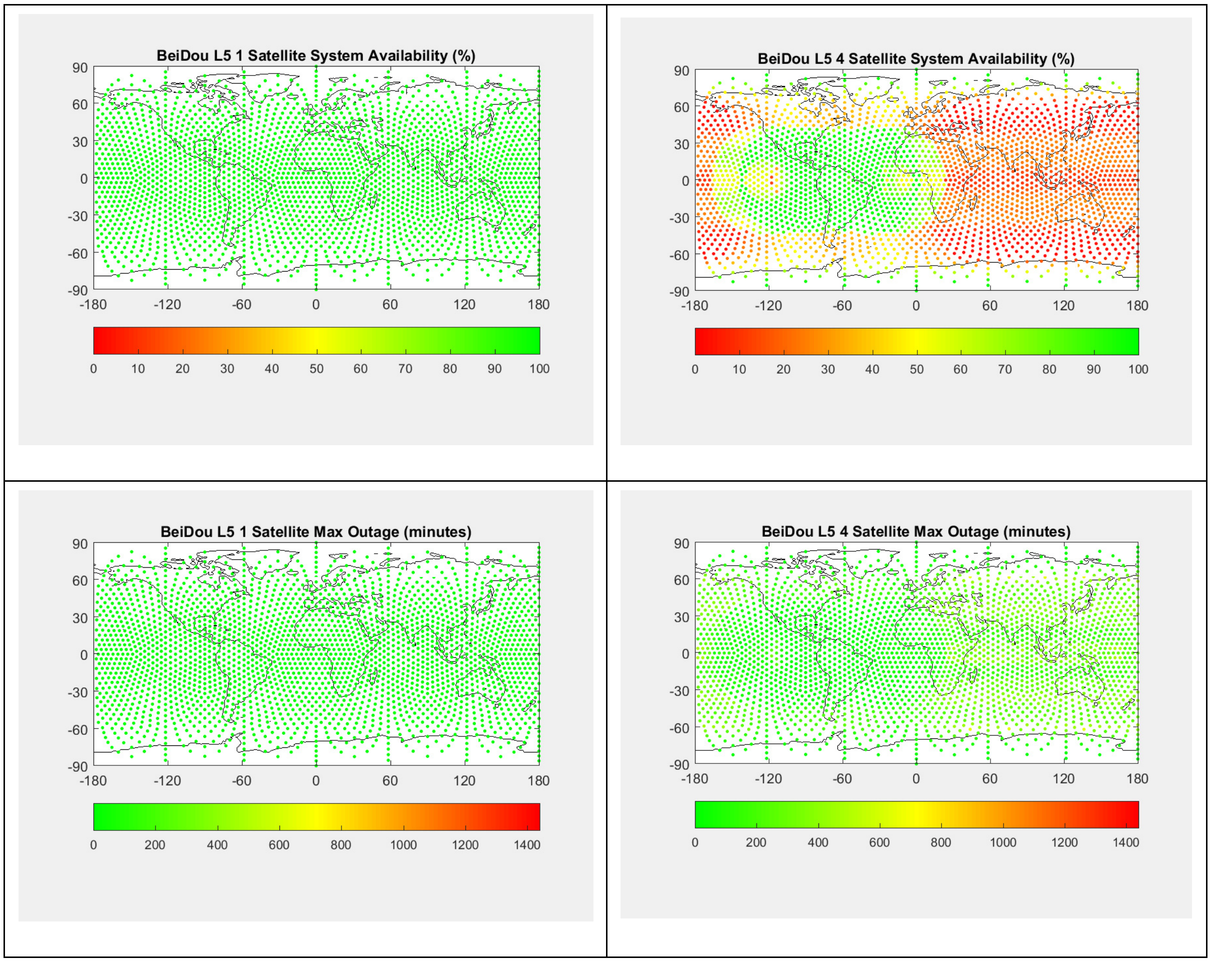


Figure 12.—Cumulative multi-GNSS L1 regional figures of merit.

B.2 L5 Frequency Band Regional Figures of Merit

B.2.1 BeiDou L5 Frequency Band Regional Figures of Merit


BeiDou L5 1 Satellite System Availability (%)

BeiDou L5 4 Satellite System Availability (%)

BeiDou L5 1 Satellite Max Outage (minutes)

BeiDou L5 4 Satellite Max Outage (minutes)

Figure 13.—BeiDou L5 regional figures of merit.

B.2.2 Galileo L5 Frequency Band Regional Figures of Merit

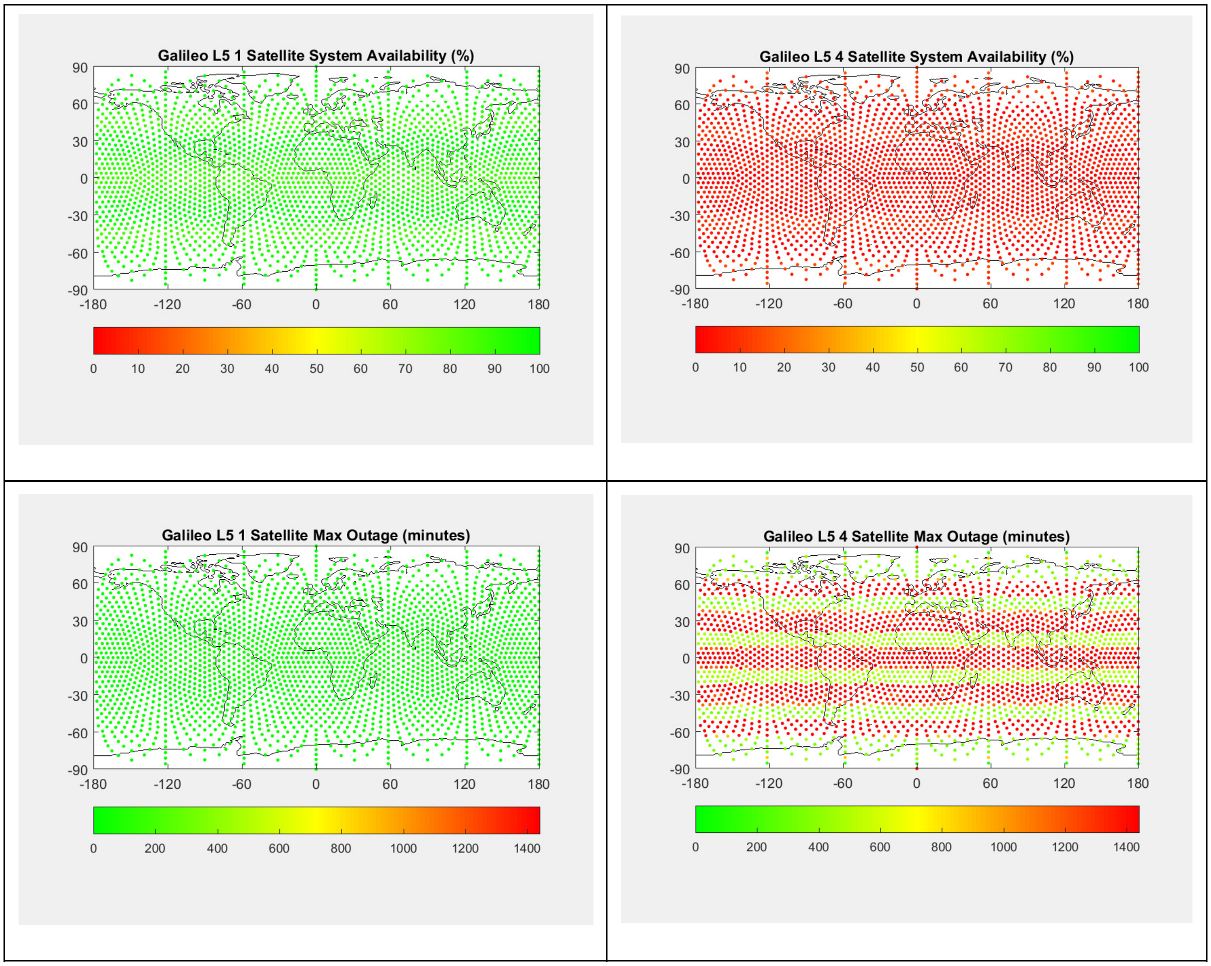
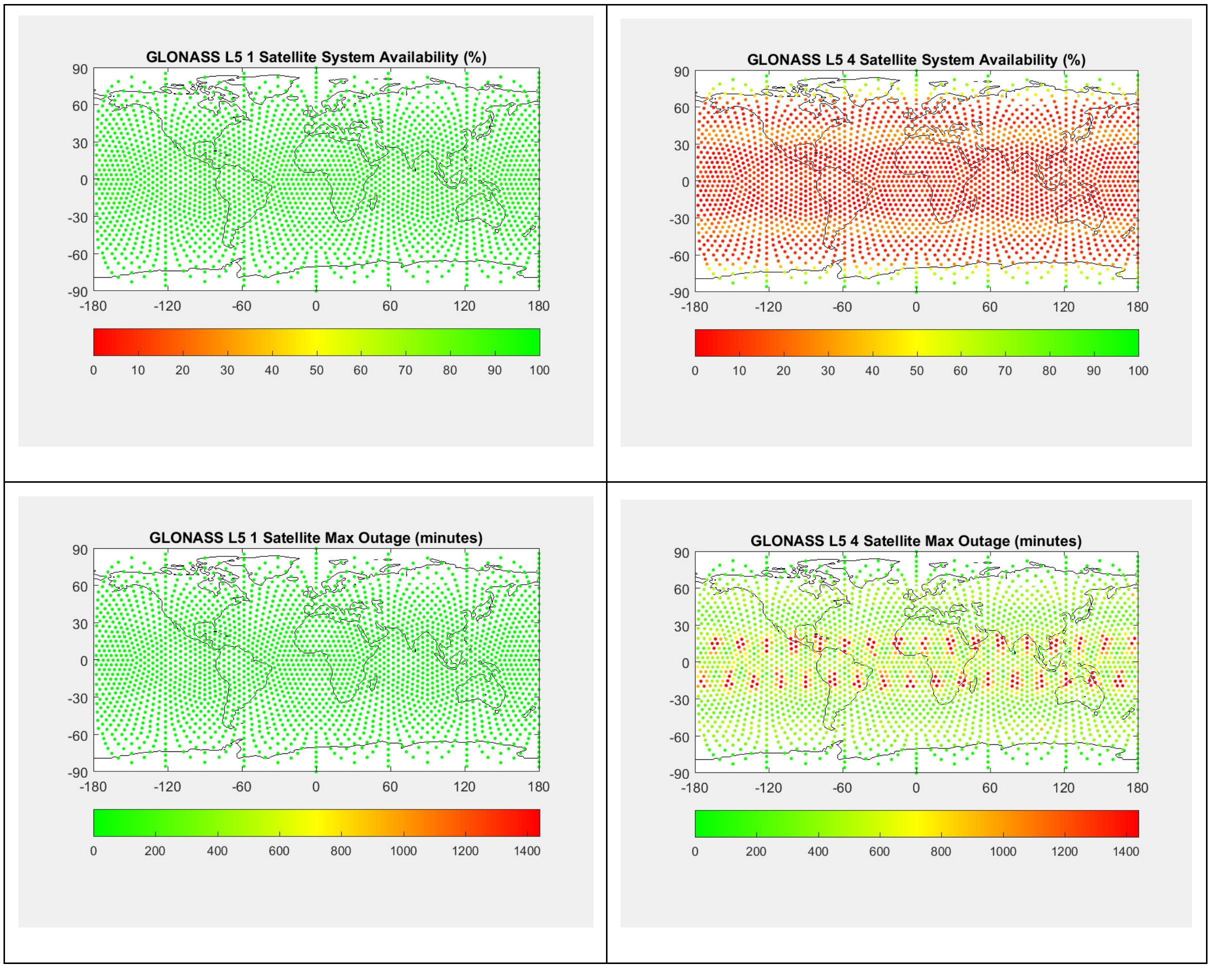


Figure 14.—Galileo L5 regional figures of merit.

B.2.3 GLONASS L5 Frequency Band Regional Figures of Merit


GLONASS L5 1 Satellite System Availability (%)

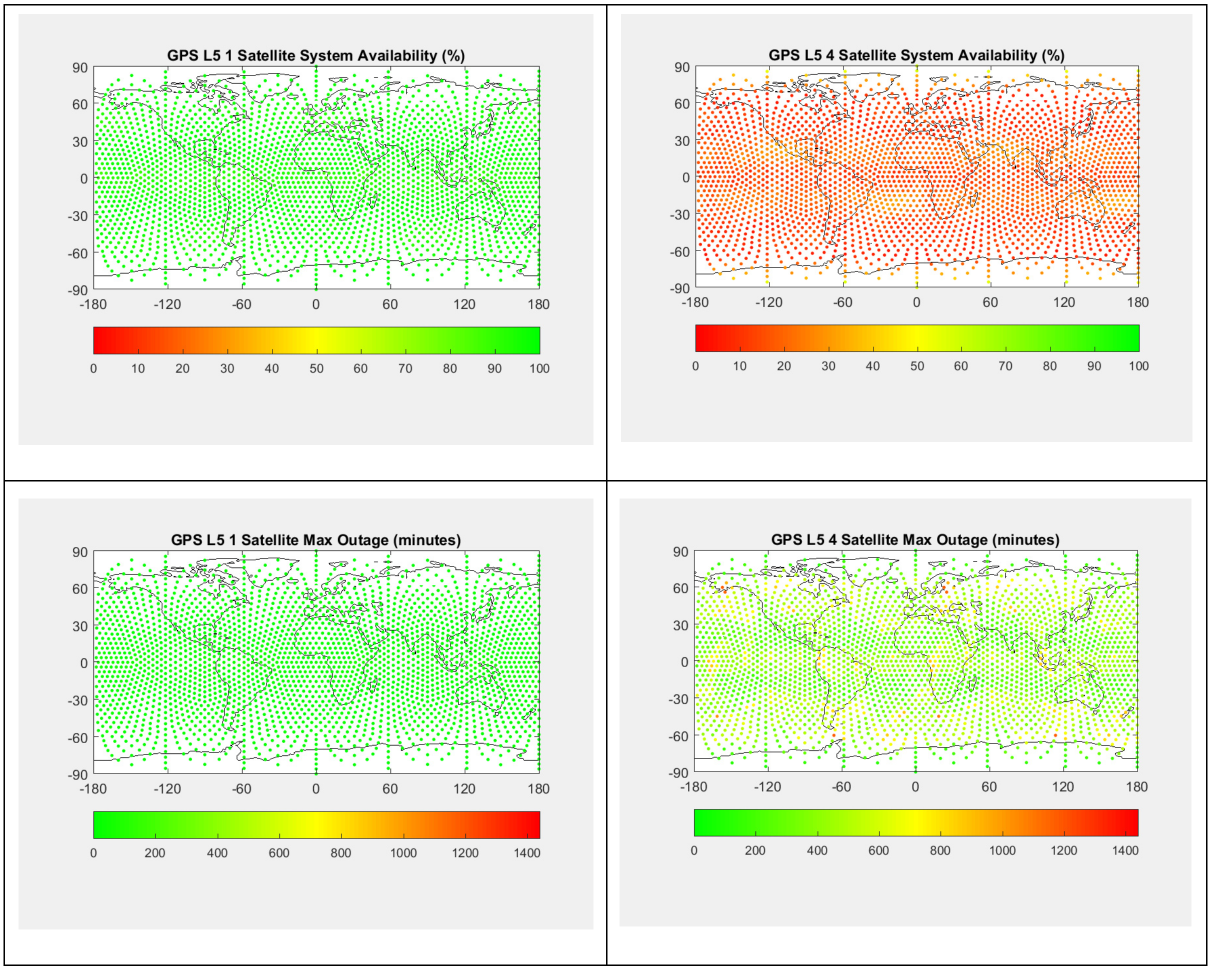
GLONASS L5 4 Satellite System Availability (%)

GLONASS L5 1 Satellite Max Outage (minutes)

GLONASS L5 4 Satellite Max Outage (minutes)

Figure 15.—GLONASS L5 regional figures of merit

B.2.4 GPS L5 Frequency Band Regional Figures of Merit


GPS L5 1 Satellite System Availability (%)

GPS L5 4 Satellite System Availability (%)

GPS L5 1 Satellite Max Outage (minutes)

GPS L5 4 Satellite Max Outage (minutes)

Figure 16.—GPS L5 regional figures of merit.

B.2.5 IRNSS L5 Frequency Band Regional Figures of Merit

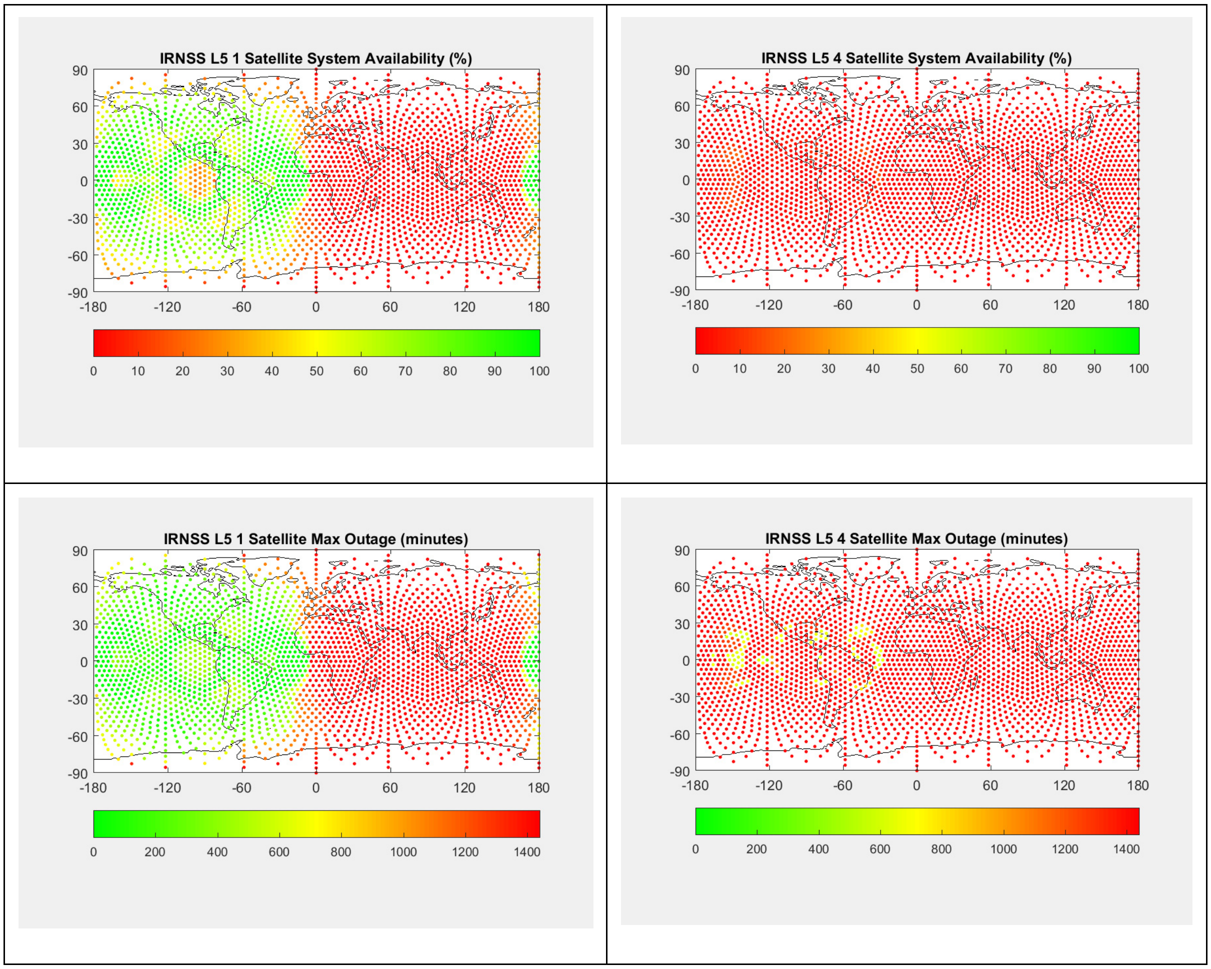
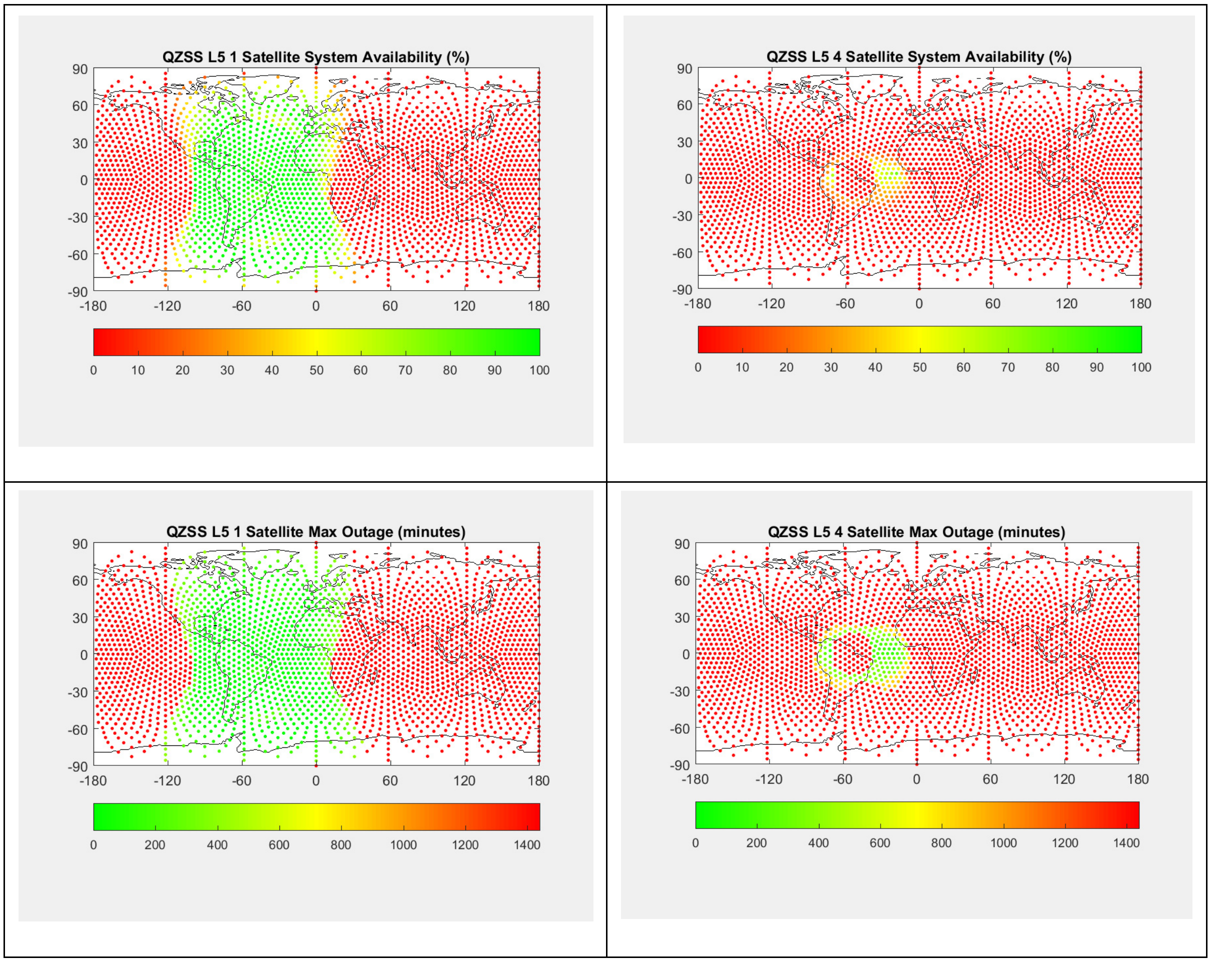


Figure 17.—IRNSS L5 regional figures of merit.

B.2.6 QZSS L5 Frequency Band Regional Figures of Merit



QZSS L5 1 Satellite System Availability (%)

QZSS L5 4 Satellite System Availability (%)

QZSS L5 1 Satellite Max Outage (minutes)

QZSS L5 4 Satellite Max Outage (minutes)

Figure 18.—QZSS L5 regional figures of merit.

B.2.7 Cumulative Multi-GNSS L5 Frequency Band Regional Figures of Merit

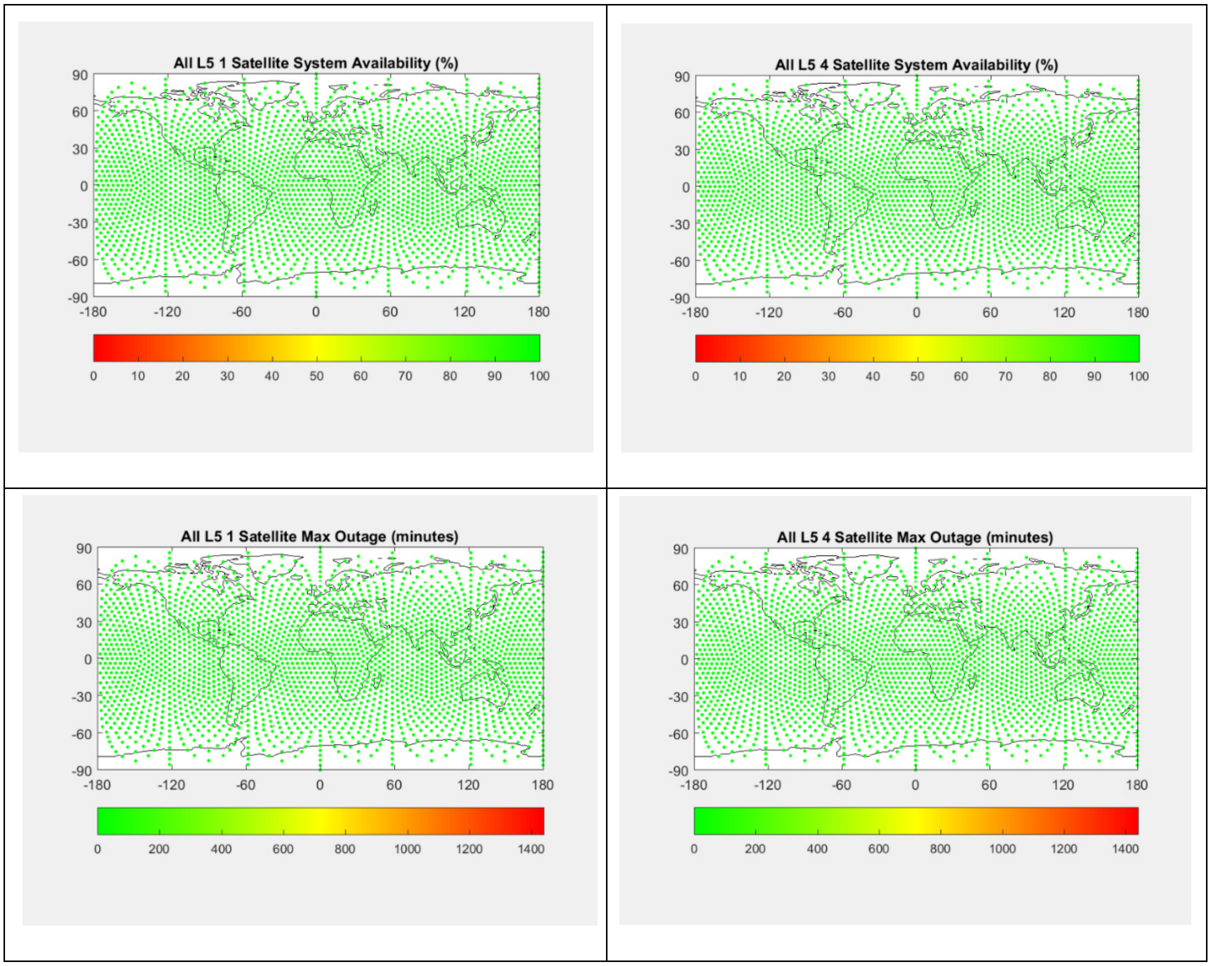


Figure 19.—Cumulative multi-GNSS L5 regional figures of merit.

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