GLOBAL NAVIGATION SATELLITE SYSTEM

GLONASS

Open Service Performance Standard (OS PS)

APPENDIX B
BACKGROUND INFORMATION

Edition 2.2

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B.1 Comments on Global Average and Worst Case Single Point Average SIS URE Calculation Formulae

The SIS URE incorporates space vehicle clock errors and space vehicle orbit erors.

When assessing Global Average SIS URE the empiric formula is used [Kamran Ghassemi and Steven C. Fisher: Performance projections of GPS IIF]:

$$SISURE = \sqrt{(0.98 \cdot \Delta R - c \cdot \Delta T)^2 + \sin^2 \alpha \cdot (\Delta N^2 + \Delta B^2)}\ ,$$

where:

$\Delta R, \Delta N, \Delta B$ are a SV's orbit errors for radius, alongtrack and crosstrack;

ΔT is a SV's clock error;

c is the speed of light in vacuum;

α is the angle between the radial vector of a SV and the range vector to a user.

Sin2 α is usually assumed as 0.0225 for assessment. This value corresponds to α ~ 9°. The computations made to assess the average value of α, for GLONASS and GPS, and for elevation angles of 5 and 15 degrees, show that α is in the interval between 10 and 12 degrees. Computation results are presented in Table
Table B.1.1.

Table B.1.1 — Global average values and values averaged over the territory of Russia for α and its functions for GLONASS and GPS elevation angles of 5 and 15 degrees.

GNSS	Region	Elevation angle, degrees	Averaging				
			Sinα	Cosα	α	Sin$^2\alpha$	Cos$^2\alpha$
GLONASS	Globally	5	0.1975	0.9803	11.3900	0.0390	0.9610
		15	0.1840	0.9829	10.6033	0.0339	0.9661
	Russia	5	0.1932	0.9812	11.1398	0.0373	0.9627
		15	0.1796	0.9837	10.3447	0.0322	0.9678
GPS	Globally	5	0.1900	0.9818	10.9517	0.0361	0.9639
		15	0.1763	0.9843	10.1559	0.0311	0.9689
	Russia	5	0.1930	0.9812	11.1258	0.0372	0.9628
		15	0.1791	0.9838	10.3155	0.0321	0.9679

To assess Worst Case Single Point Average SIS URE the method is used, introduces by the Stanford University to estimate navigation satellite system failures (Liang, 2012). The adjusted formula used to compute Worst Case Single Point Average SIS URE is the following:

$$URE_{WorstCase}(SV_h,t) = \max_{-|\beta|\le\alpha\le|\beta|} [\ \Delta \mathrm{R}(SV_h,t)\cdot\cos(\alpha) - \mathrm{c}\,\Delta \mathrm{T}(SV_h,t) +$$

$$+\sin(\alpha)\cdot\sqrt{\Delta N^2(SV_h,t)+\Delta B^2(SV_h,t)}\,],$$

$$\beta = \arcsin\left(\frac{\sin(90^\circ + \mathrm{mask})\cdot 6731}{25508.2}\right),$$

$$\mathrm{mask} = 5^\circ.$$

B.1.1 illustrates various SIS URE assessment options.

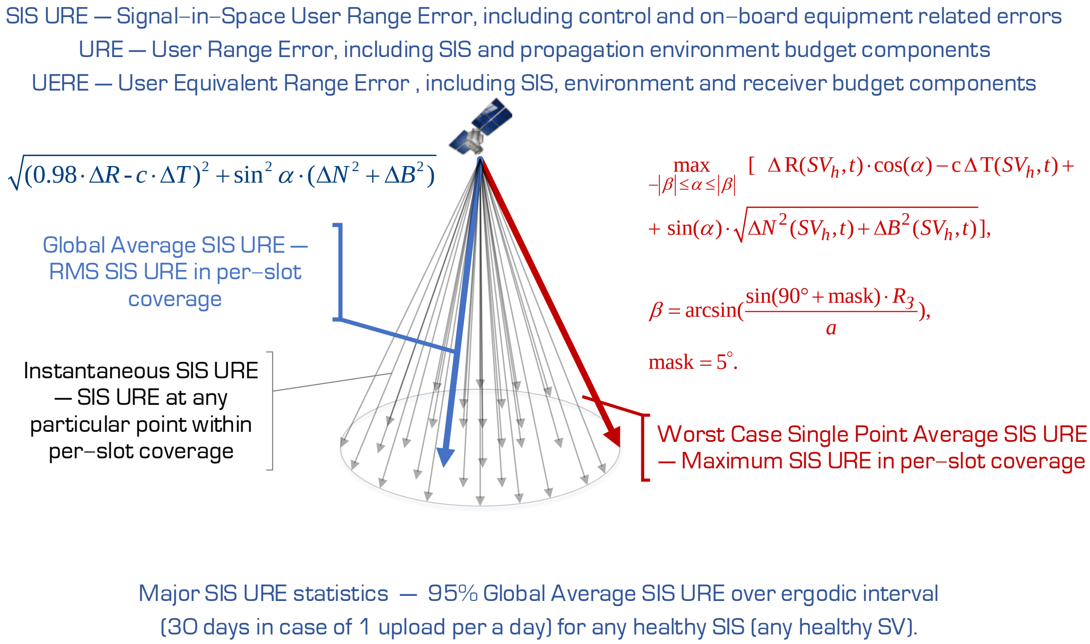


Figure B.1.1 — SIS URE assessment options

B.2 On Variable Increment used for PDOP Availability and Positioning Error Calculation

In OS PS SIS Availability, Position Service Availability, and Positioning Error and Time Transfer Error estimation requires averaging of the respective characteristics over the specific segment of surface (or globally). The estimation can be made with the constant increment for longitude and latitude, however, in this case the area, limited by the grid nodes shall be accounted for, as per the following example for SIS Availability estimation:

$$A_{PDOP\_Global} = \frac{\sum_{i,j} A_{PDOP\_Local}(\varphi_i, \lambda_j) \cdot S_{i,j}}{\sum_{i,j} S_{i,j}} = \frac{\sum_{i,j} A_{PDOP\_Local}(\varphi_i, \lambda_j) \cdot (\sin(\varphi_i + \Delta\varphi) - \sin\varphi_i)}{\sum_{i,j} (\sin(\varphi_i + \Delta\varphi) - \sin\varphi_i)},$$

where:

φ_i, λ_j are latitude and longitude of the site;

$\Delta\varphi$ is the increment along the latitude;

A_{local} is the local availability at the site;

$S_{i,j}$ is the elementary area.

Using the constant increment for time and longitude, and the variable increment for latitude is a simpler method to provide for the equality of areas, and thus to directly average the obtained parameters:

$$A_{PDOP\_Global} = \frac{\sum_{\varphi,\lambda} A_{PDOP\_Local}(\varphi, \lambda)}{N_{Sites}}$$

B.3 Background Information on GLONASS Performance Assessment Using Data from IGS Stations

The GLONASS performance can be assessed using measurement data from a globally distributed station networks, e.g. of IGS. However a number of specific features shall be taken into account related to the choice of timescale to which satellite clock is tied and the heterogeneity of station receivers.

According to IGS requirements, the post-processed orbit and clock data is tied to the measurements of P1/P2 receiver class, which are used to directly perform measurements. However this approach is hardly acceptable to GLONASS measurements due to significant systematic errors associated with various receiver types and even with individual items of one and the same type of receivers. It is important, that the IGS analysis center coordinator does not estimate precise satellite clock corrections when computing final solutions. It is predetermined by the significant systematic errors of the code measurements due to the Frequency Division Multiple Access signals. (FigureFigure B.3.1).

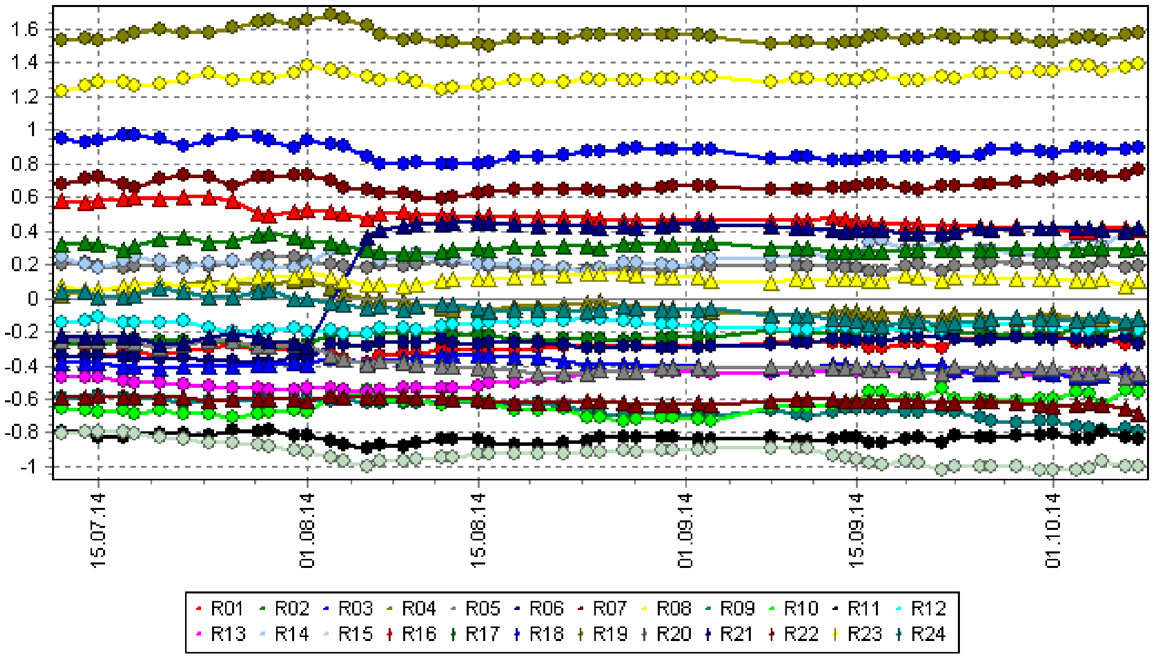


Figure B.3.1 — Systematic errors for measurements by JAVAD receivers, m

These systematic errors are due to the non-linear characteristics of the RF filters, and sometimes they can reach as much as tens of nanoseconds. The absolute receiver calibration is not possible because of the frequency dependent nature of RF filters. That is why the systematic errors are estimated for any receiver relative to an abstract receiver, averaged over the network.

As a rule, receivers of one class are characteristic of the similar delays in the GLONASS channels. The cross-correlation level however is dependent on the manufacturer and/or receiver type, i.e. is hardware and software dependent. In most cases residual cross-correlation biases within one class of receivers do not exceed 1 nsec, which is quite significant value taking into account that the noise error of the post-processed GPS and GLONASS clock corrections reach as much as dozens of picoseconds. The analysis of data from various receiver types and individual items of one and the same receiver type leads to the conclusion that the receivers directly performing P1 and P2 measurements demonstrate insignificant systematic errors of up to 0.5 nsec in GPS channels.

Unlike IGS which uses a static receiver calibration (assuming all P1/P2 receivers are identical), this OS PS recommends a dynamic receiver calibration to be performed over an interval of about 2 weeks. This approach can be employed for both GPS and GLONASS measurements. It is important that due to using the two-week long interval for estimation of systematics of the distributed station network, the obtained data does not have influence on either onboard clock stability estimation, or GPS-GLONASS system time difference.

Thus, the direct use of the post-processed and the broadcast GLONASS satellite clock corrections, unlike GPS, results in some averaged estimation of clock data as seen by an average user with several types of receivers. However the direct use of the post-processed and the broadcast GLONASS satellite clock corrections does not enable the GLONASS broadcast clock performance assessment; hence it cannot be used for assessment of GLONASS performance parameters.

It is obvious that the ground command and control facilities which are used to predict and upload satellite clock data, are also subject to the systematic errors. As the independent performance monitoring system does not have access to the physical timescale of the GLONASS Command and Control Subsystem, the residual errors of the broadcast satellite clock data and the post-processed satellite clock corrections are used to reference the post-processed satellite clock corrections to the broadcast satellite clock data. These data is processed over an interval of 24 days, i.e. over 3 cycles of the GLONASS satellite ground track repetition. Ideally, such referencing of data shall be made once over a long interval of time. However the analysis of the observed differences between the broadcast and the post-processed clock corrections over a long interval demonstrates that the systematics of the ground control facilities varies the same way as that of most of the operating receivers. This can result from the hardware or software modernization or reset, temperature sensitivity, etc. That is why it is recommended to regularly correlate the systematic errors of the broadcast and the post-processed data over some longtime interval divisible by the satellite ground track repeatability period. The smaller correlation interval results in the increased “noise” of the clock prediction error related systematics. The larger interval is also not advisable because of the need to respond to systematics fluctuations.

The special feature is the invalidity of the GLONASS SVs health status generated by some types of IGS receivers. It is known that some receivers falsely generate RINEX files, e.g. Leica outputs all GLONASS SVs as healthy in ALL–IN–VIEW mode; some GLONASS receivers generate frame start time with 3 hour offset; etc. Due to the great variety of receivers using various converters for raw data, the generation of the valid GLONASS SVs health status is sometimes difficult, which results in estimation errors.

Building the own globally distributed network of stations equipped with several items of single class receivers can substantially help to resolve the issue.

Alternatively, the more affordable option for independent monitoring services can be promotion in the ICG of the idea to generate files incorporating the full set of navigation message digital data along with the RINEX files. The GRIL format used in JAVAD and Topcon receivers can serve as an example. The significant amount of such receivers currently in use within the IGS network can facilitate building the sub–network of receivers capable of providing the maximum set of data.

B.4 On the Term “Integrity” and the Difference between “Integrity” and “Probability of a Major Service Failure”

According to ICAO, integrity is a measure of the trust which can be placed in the correctness of the information supplied by the total system. It includes the ability of the system to alert the user when the system should not be used for the intended operation (alert) within a prescribed time period (time–to–alert).

To ensure that the position error is acceptable, an alert limit is defined that represents the largest position error allowable for a safe operation. The position error cannot exceed this alert limit without annunciation. The system can degrade so that the error is larger than the 95th percentile but within the monitor limit.

GNSS SIS integrity requirement of the navigation system for a single aircraft to support en–route, terminal, initial approach, non–precision approach and departure is assumed to be 1×10^{-5} per hour with time–to–alert of 5 min, 15 sec and 10 sec depending on operation (for en–route, en–route terminal and NPA, respectively).

For satellite–based navigation systems, the signal–in–space in the en–route environment simultaneously serves a large number of aircraft over a large area, and the impact of a system integrity failure on the air traffic management system will be greater than with traditional navigation aids. The performance requirements are therefore more demanding.

The SIS URE Major Service Failure is defined as an event over a specified time interval during which a SV health indication in the navigation message is false, that is the instantaneous SIS URE exceeds the tolerance limit without a timely indication of unhealthy SV being issued. In fact the Probability of a Major Service Failure for CSA SIS is defined as a percentage of time over the specified time interval when the GLONASS CSA SIS URE exceeds 70 m for any healthy SV. In contrast to integrity this characteristic lacks such component as the time to alert, and the not–to–exceed tolerance is made not on the position accuracy but on the SIS URE.

B.5 SIS URE relation to AOD and Onboard AFS Stability (Allan Variance)

This OS PS approaches SIS URE irrespective of age of data (AOD) – the metric used to characterize the age of the navigation message data being transmitted by a SV. However AOD is the most tangible characteristic as the GLONASS URE and the CSA SIS accuracy vary noticeably as a function of the time since upload.

Below is the description of the SIS URE as a function of time since upload and AOD within this interval. Currently clock/ephemeris data is uploaded 1 to 3 times daily which is predetermined by the regional nature of the GLONASS Command and Control Subsystem facilities.

Clock/ephemeris data relation to AOD is determined by satellite AFS stability and satellite clock/ephemeris prediction model accuracy. This section provides typical examples for clock/ephemeris data relation to AOD based on real data.

B.5.1 provides the Allan Variance for the GLONASS AFS based on 23 day measurement interval.

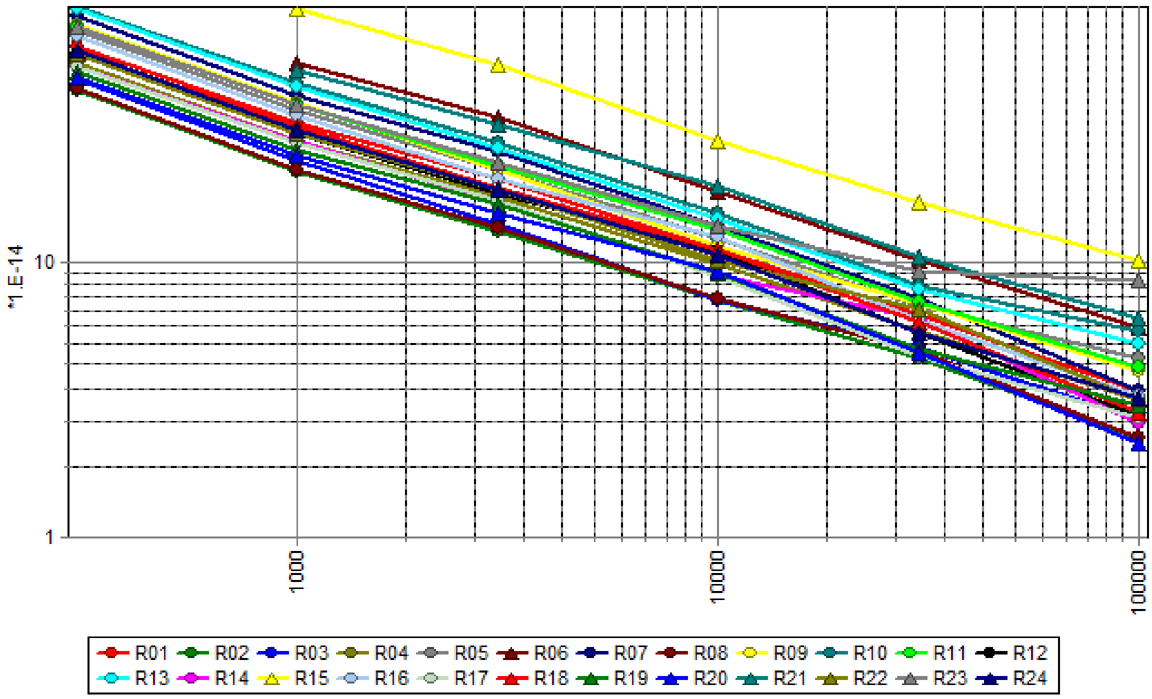


Figure B.5.1 — Allan Variance for GLONASS AFS

The diagram shows that the average one day stability of GLONASS AFS is 5–6 · 10^{-14}, which results in 0.7 to 1.2 m contribution to URE budget depending on the upload scenario.

The SIS URE relation to AOD was estimated over 24–hour and 15–day interval. The broadcast ephemeris and clock data was assessed against the post processed ephemeris and clock data.

The first step of analysis included estimation of SIS URE over a 24–hour interval with a 30 min increment. The obtained SIS URE values were consecutively averaged for 0.1 … 24 hour. The estimation results are provided on B.5.2, the average SIS URE for the constellation as a function of AOD is provided on B.5.3.

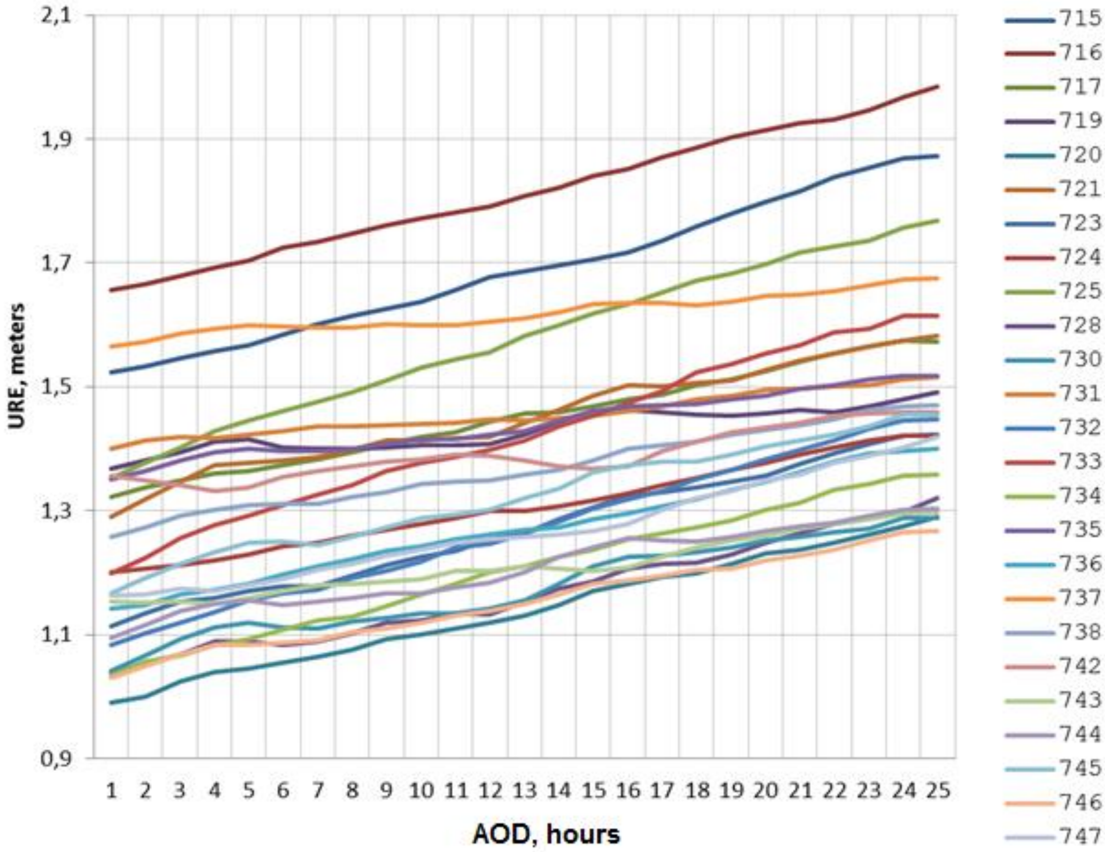


Figure B.5.2 — UERE as a Function of Time Since Upload

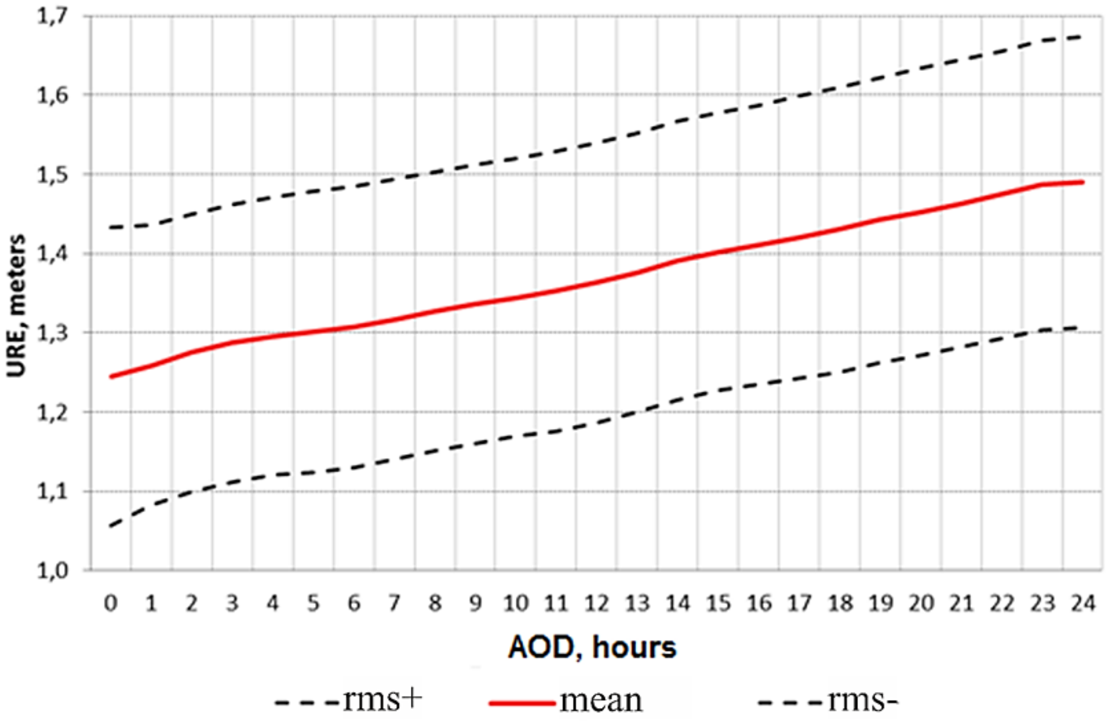


Figure B.5.3 — URE as a function of AOD, averaged for the constellation

The second step of analysis included estimation of SIS URE over a 15–day interval with a 6–hour increment. The labor–intensive estimation process resulted in selection of this 6–hour increment, as it is close to a half of a satellite period. The similar approach was followed as that for a 24–hour estimation interval above. The estimation results are provided on B.5.4 and B.5.5.

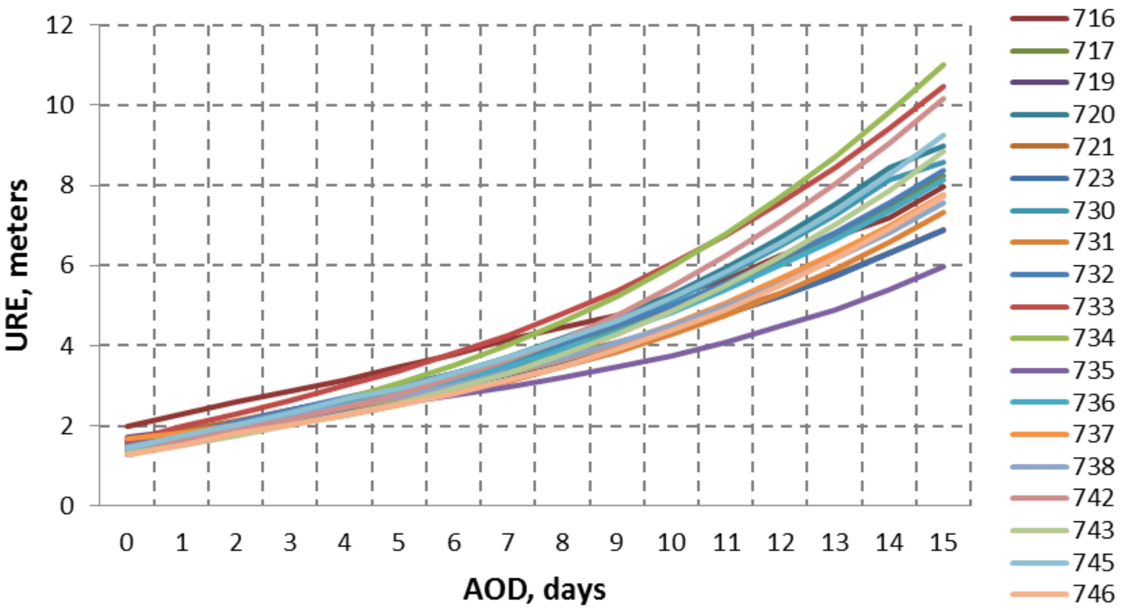


Figure B.5.4 —SIS URE as a function of AOD

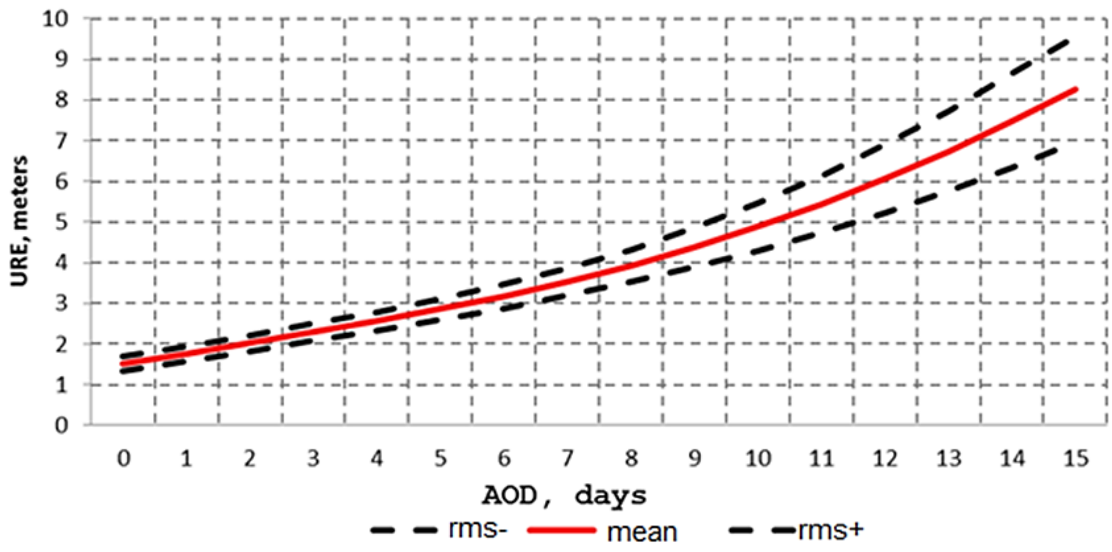
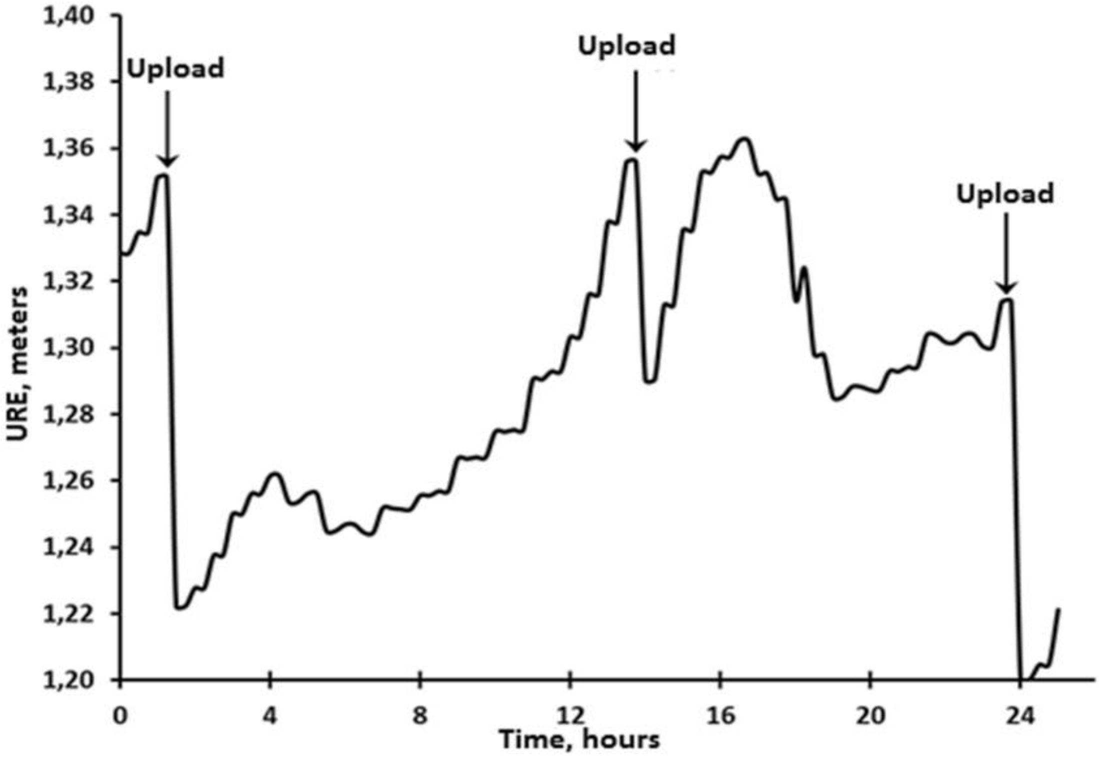


Figure B.5.5 – SIS URE as a funcion of AOD, averaged for the constellation

B.5.6 demonstrates examples of the Global Average SIS URE as a function of time since upload over a 24–hour interval.



Instanteneous Global Average URE for SV R06, m

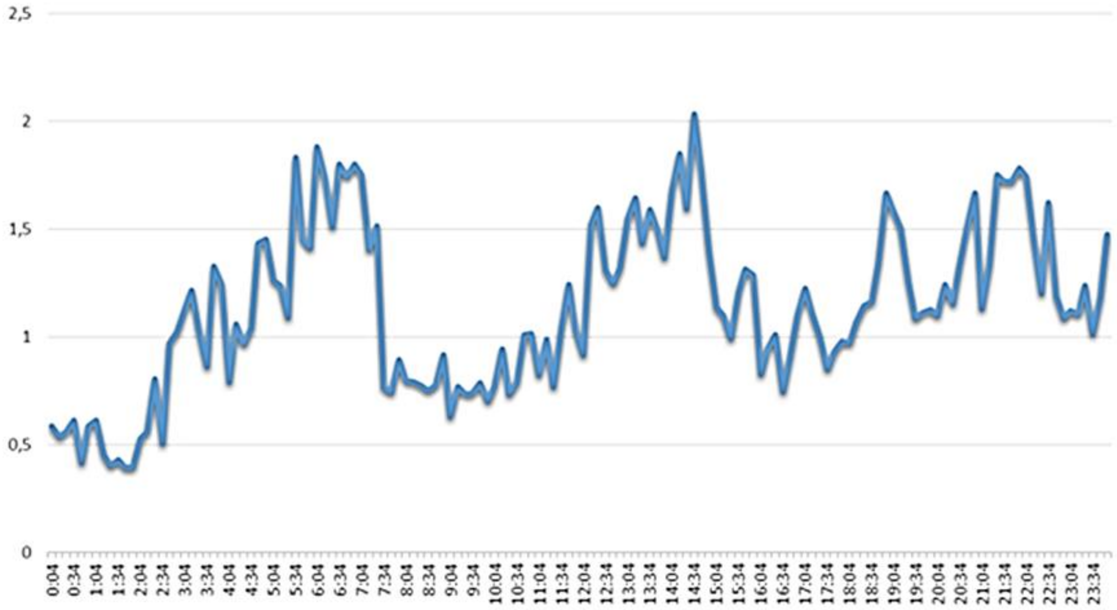


Figure B.5.6 — Examples, demonstrating instantaneous Global Average SIS URE as a function of AOD over a 24–hour interval

B.6 Examples of Error Budget induced by the Propagation Environment and UE

This OS PS addresses performance parameters assigned to the SV and Command and Control Subsystems. The user positioning accuracy is predetermined by many factors including the following most influential budget components:

- SIS URE which includes only those pseudorange data set error budget components assigned to the GLONASS SV and Control Subsystems (orbit determination and time synchronization errors within the mission segment and on-board equipment related errors). We use the term SIS URE for better understanding,
- Ionosphere error and troposphere error contributions,
- Reception error contributions (multipath) and receiver noise error contributions.

The positioning error including its horizontal and vertical components as well as time transfer error component can be as per the following formulae:

$$PE = PDOP \cdot UERE,$$

$$HPE = HDOP \cdot UERE,$$

$$VPE = VDOP \cdot UERE,$$

$$TCE = TDOP \cdot UERE,$$

where:

PE is a positioning error,

HPE is a horizontal positioning error,

VPE is a vertical positioning error;

TCE — is a User Time Error referred to the system timescale;

UERE is a user equivalent range error computed as per the following formula:

$$UERE^2 = URE^2 + UEE^2$$

$$URE^2 = SIS\ URE^2 + UAE^2$$

where

SIS URE is a Signal-in-Space User Range Error. The SIS URE includes only those pseudorange data set error budget components assigned to the GLONASS Space Vehicle Subsystem and the Command and Control Subsystem.

UAE — user atmosphere error, including those pseudorange data set budget components assigned to the propagation environment which is different for single frequency, dual frequency, and triple frequency receivers, employing or excluding meteorological parameters.

URE is a User Range Error, including SIS and propagation environment budget components;

UEE is a User Equipment Error (pseudorange inaccuracy due to the receiver).

For reference the GLONASS UERE budgets for various types of receivers are shown in B.6.1. These are given for illustration purposes only and are not subject of this OS PS.

Table B.6.1 — UERE Budget

Error Source	UERE Contribution Single Frequency Receiver (m)	UERE Contribution Dual Frequency Receiver (m)
Receiver Noise	2.57	8.0
Multipath	7.28	7.28
Troposphere	0.2	0.2
Ionosphere	8.5	–
Ephemeris	0.5	0.5
Clock	3.2	3.2
Total System UERE	9.1	8.5

B.7 PDOP Distribution Estimation

Using equations in B.6 the positioning error can be computed if SIS URE is known (available or obtained). To accomplish this, the current value of the respective DOP shall be known. The DOP value can be obtained as a result of SIS monitoring or based on the analysis data for the GLONASS nominal constellation. B.7.1, B.7.2 illustrates the HDOP and VDOP results for the GLONASS nominal constellation and for the constellation missing 1 and 2 mean SVs.

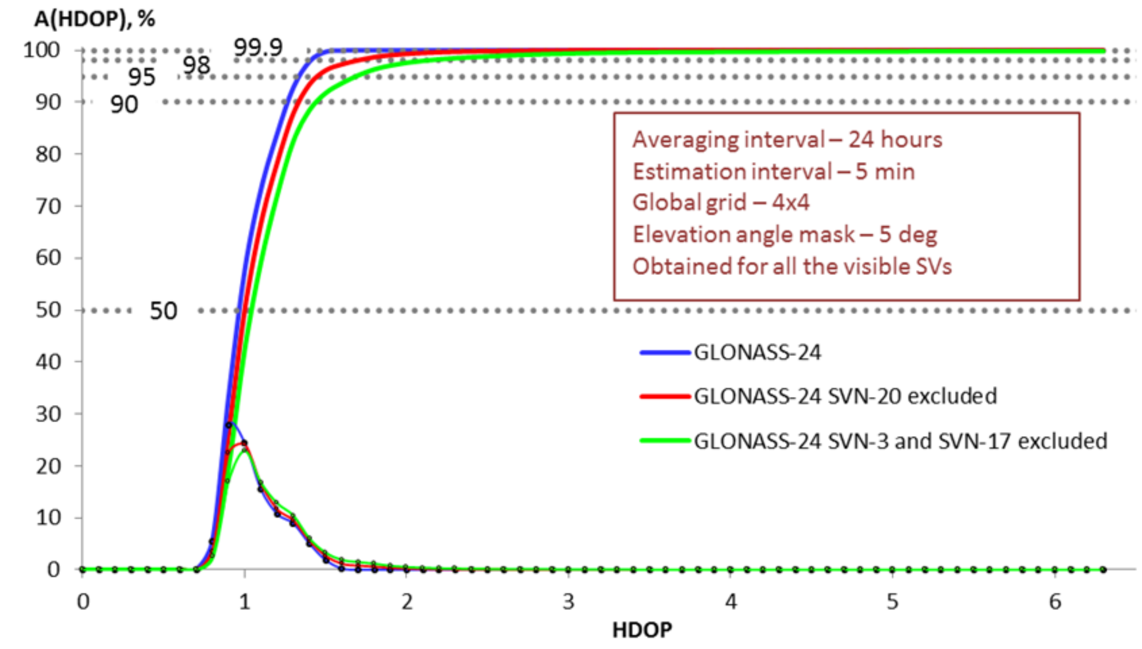


Figure B.7.1 — HDOP for GLONASS Constellation of 24, 23, and 22 SVs

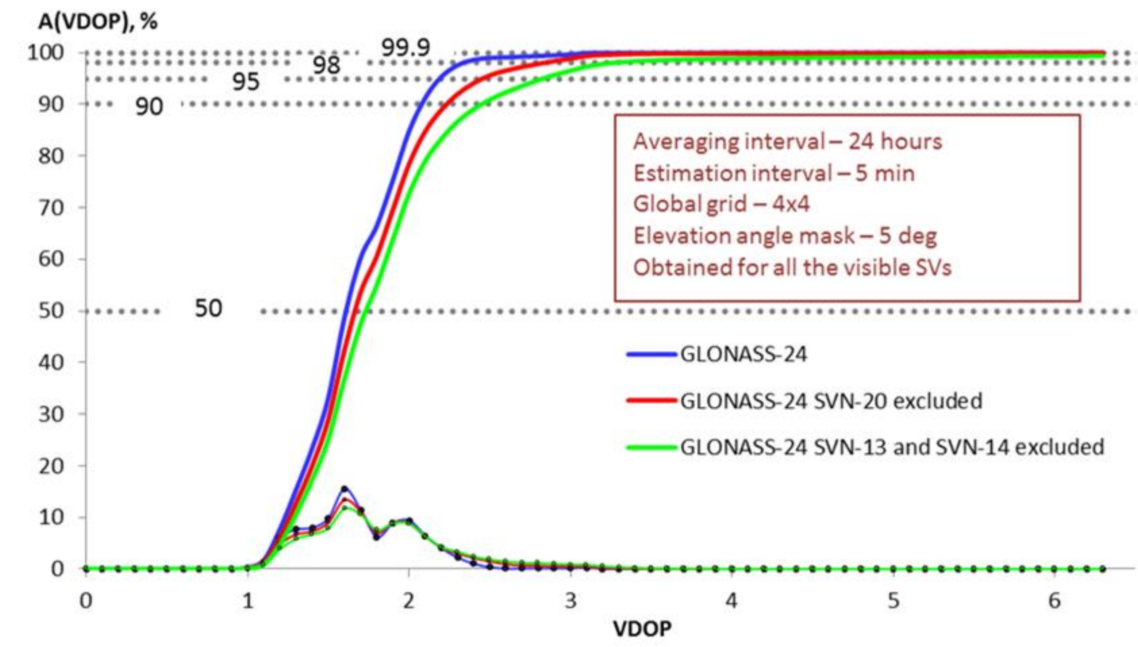


Figure B.7.2 —VDOP for GLONASS Constellation of 24, 23, and 22 SVs

The mean SVs are chosen as those, whose failures will result in the mean values of HDOP and VDOP. Similarly, it is possible to choose the worst SVs, whose failure will result in the worst (largest) HDOP and VDOP values.

In addition to the global distribution, HDOP and VDOP distribution can be estimated for any site including the worst site – that is the site with the largest local HDOP and VDOP for 24–hour interval (Table B.7.1).

Table B.7.1 — HDOP and VDOP for GLONASS Constellation of 24, 23, and 22 SVs

Constellation	Worst* HDOP	Worst* VDOP	Mean** HDOP	Mean** VDOP
	99.90%			
GLONASS–24	~1.50	~2.00	~1.55	~3.05
GLONASS–23	~2.95	~3.40	~2.65	~4.35
GLONASS–22	>6	>6	>6	>6
	99.00%			
GLONASS–24	~1.54	~2.00	~1.45	~2.50
GLONASS–23	~2.80	~3.20	~1.90	~3.05
GLONASS–22	>6	>6	~2.60	~4.40
	98.00%			
GLONASS–24	~1.45	~2.00	~1.40	~2.35
GLONASS–23	~2.55	~3.10	~1.70	~2.85
GLONASS–22	>6	>6	~2.10	~3.25
	90.00%			
GLONASS–24	~1.40	~1.95	~1.25	~2.05
GLONASS–23	~2.05	~2.50	~1.32	~2.25
GLONASS–22	~2.90	~3.15	~1.40	~2.45

* The worst SV and the worst site.
** The mean SV and the global distribution.

The estimation of the positioning error by multiplying URE and the respective mean DOP represents some generalized performance characteristic and does not fully reflect the real distribution of performance.

It is more advisable to translate instantaneous SIS URE for any site and for any healthy SV into positioning errors by projecting ephemeris and clock errors on the site–to–SV line–of–sight.