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The Implementation of the EGNOS System to APV-I Precision Approach Operations

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ABSTRACT: First in the Poland tests of the EGNOS SIS (Signal in Space) were conducted on 5th October 2007 on the flight inspection with SPAN (The Synchronized Position Attitude Navigation) technology at the Mielec airfield. This was an introduction to a test campaign of the EGNOS-based satellite navigation system for air traffic. The advanced studies will be performed within the framework of the EGNOS-APV project in 2009. The implementation of the EGNOS system to APV-I precision approach operations, is conducted according to ICAO requirements in Annex 10. Definition of usefulness and certification of EGNOS as SBAS (Satellite Based Augmentation System) in aviation requires thorough analyses of accuracy, integrity, continuity and availability of SIS (Signal in Space). Also, the project will try to exploit the excellent accuracy performance of EGNOS to analyze the implementation of GLS (GNSS Landing System) approaches (Cat I-like approached using SBAS, with a decision height of 200 ft). Location of the EGNOS monitoring station Chelm, located near Polish-Ukrainian border, being also at the east border of planned EGNOS coverage for ECAC states is very useful for SIS tests in this area. According to current EGNOS programmed schedule, the project activities will be carried out with EGNOS system v2.2, which is the version released for civil aviation certification. Therefore, the project will allow demonstrating the feasibility of the EGNOS certifiable version for civil applications.

The following article provides a overview of the performance of EGNOS SIS (PRN 120) as observed at EGNOS 7 days over a period of 168 hours from 19 of November 00:00 until 26 of November 23:59 with a Septentrio PolaRx 2 receiver, during the observed period of 168 hours at EGNOS CHELM. Smoothing was set to 100 seconds.

This First Glance Report is generated with Pegasus 4.2 and presents the following performance characteristics:

- **Sample validity**: Valid samples are all the samples that are present in the data and are not considered to be affected due to logging or processing tool problems
- **Accuracy** statistics: calculated for horizontal and vertical positioning errors separately.
  - For the **measured accuracy**, the samples are taken directly from the horizontal and vertical errors as computed by PEGASUS.
  - For the scaled accuracy, every sample is scaled with a ratio of AL/PL(i) before taking the 95th percentile.
- User **Availability** percentiles for the different PA operations: determined by dividing the number of samples that are available for an operation by the total number of valid samples
- Number of **discontinuity events** within the period: the total number of discontinuity events for a given operation.
- Number of **Integrity** events within the period: the total number of integrity events. The Misleading Information (MI) events are determined based on samples with XPE>XPL. The Hazardous MI (HMI) are counted according to XPE>XAL>XPL for each operation.

All values that exceed a certain required threshold are presented in red.

For more information refer to the FGA Performance algorithms document.

Table 1. SIS Analyze .

Site	[ANALYZE] EGNOS CHELM 7 days						Date	27/11/2008
Location	Lat:	51.130		Lon:	23.480		Alt:	254.70
Receiver	Septentrio PolaRx 2			Soft-ware	Pegasus 4.2		PRN	120
Data set	Duration	Start	Stop	Expected	Total	SBAS Msg	Valid	Valid(%)
1 Hz	168h00	00:00	23:59	604800	604788	604285	604428	**99.94%**
Results per operation								
	Operation	**APV-I**			**APV-II**		**CAT-I**	
	HAL/VAL	40 / 50			40 / 20		40 / 12	
Accuracy (m)								
		Meas.	Scaled	Req.	Meas.	Scaled	Req.	Meas.	Scaled	Req.
HNSE (95%)		**1.71**	6.92	16	1.72	7.03	16	1.72	7.72	16
VNSE (95%)		**1.69**	5.46	20	1.63	2.23	8	1.53	1.60	4
Availability (%)								
Valid EGNOS Solutions	603370	**597696**			510339		62104	
Minimum Required		99%			99%		na	
Availability		**98.886%**			**84.433%**		**10.275%**	
Continuity								
Events		**345**			**3120**		**7838**	
Integrity								
	MI	HMI APV-I			HMI APV-II		HMI CAT-I	
Total	**0**	0			0		0	
Horizontal	**0**	0			0		0	
Vertical	**0**	0			0		0	

Table 2. PL and APV-I statistics .

Protection level statistics					
	99%	95%	50%	mean	std deviation
HPL	**34.81**	22.99	10.24	11.89	5.21
VPL	**35.66**	24.43	15.40	16.39	4.67
APV-I Position error statistics					
	Samples	**Mean**	**RMS**	95%	std deviation
HPE	**597696**	1.10	1.16	1.71	0.35
VPE	**597696**	0.76	0.92	1.69	0.51

1 SIGNAL IN SPACE ANALYSIS

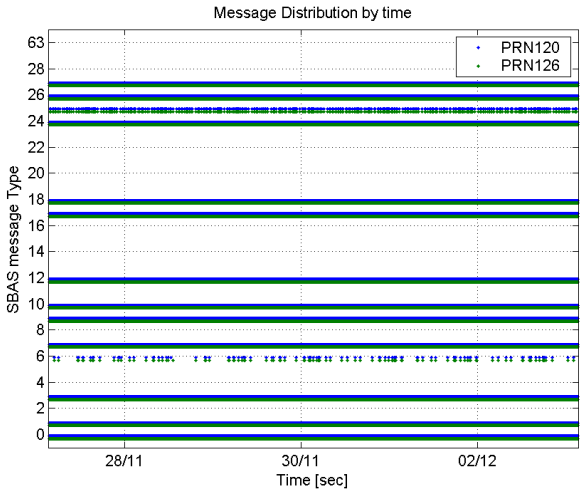


Figure 1. Message Distribution by time.

1.1 *Message Types Distribution*

Table 3. Message type counter .

	PRN 120		**PRN 126**	
SBAS MT	**number**	**%**	**number**	**%**
MT 0	150905	24.97	150839	24.97
MT 1	9396	1.55	9393	1.56
MT 2	0	0.00	0	0.00
MT 3	150865	24.97	150806	24.97
MT 4	0	0.00	0	0.00
MT 5	0	0.00	0	0.00
MT 6	590	0.10	585	0.10
MT 7	9397	1.56	9392	1.55
MT 9	9396	1.55	9393	1.56
MT 10	9396	1.55	9393	1.56
MT 12	3764	0.62	3762	0.62
MT 17	3764	0.62	3763	0.62
MT 18	18819	3.11	18814	3.11
MT 24	150869	24.97	150807	24.97
MT 25	550	0.09	550	0.09
MT 26	82811	13.70	82772	13.70
MT 27	3763	0.62	3763	0.62
MT 28	0	0.00	0	0.00
MT 62	0	0.00	0	0.00
MT 63	0	0.00	0	0.00
Total	604285	100.00	604032	100.00

1.2 *Message Type 6 Analysis*

This figure shows the number of occurrences for consecutive MT6 broadcasts (1, 2, 3, 4 or more repetitions). A normal alert consists of four consecutive MT6 messages, while single occurances indicate CPF switch-overs.

Table 4. Message type 6 repetitions.

Message Type 6 repetitions					
	single	double	3 x	4 x	> 5x
PRN 120	1	0	1	145	1
PRN 126	1	0	1	145	0

2 POSITION SOLUTION ANALYSIS

2.1 *Position errors and Protection levels*

All plots have fixed scales that represent nominal behaviour. When the performance does not fit properly within these scales further detailed investigations are needed.

2.2 *Position solution plots.*

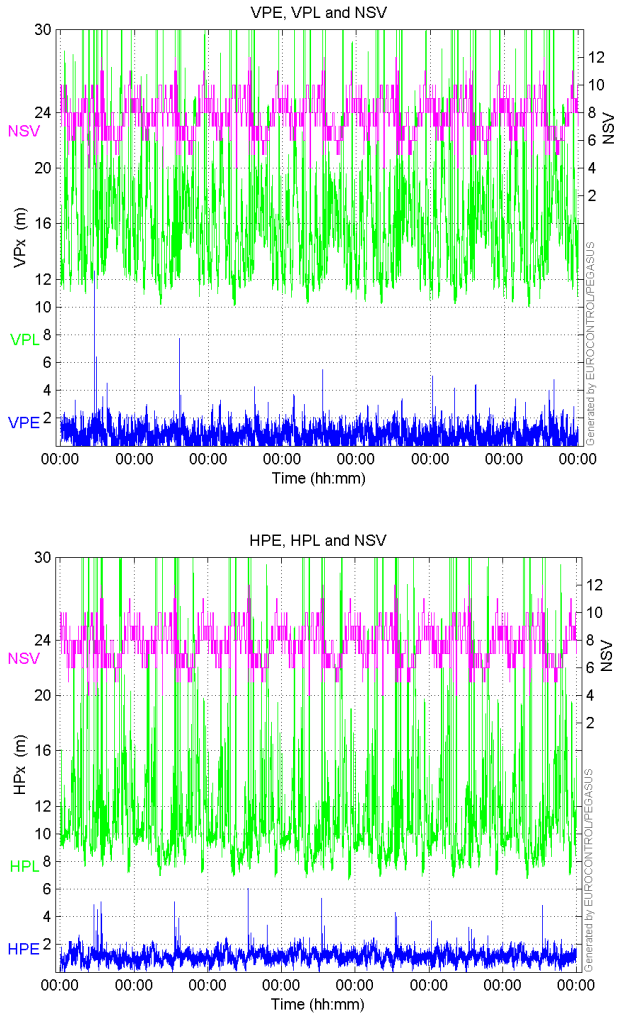


Figure 2,3. Horizontal and vertical Error, Protection Level and NSV over time.

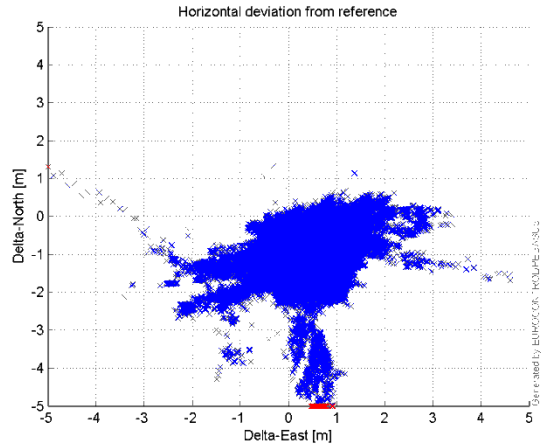


Figure 4. Scatter plot of horizontal deviation from reference position.

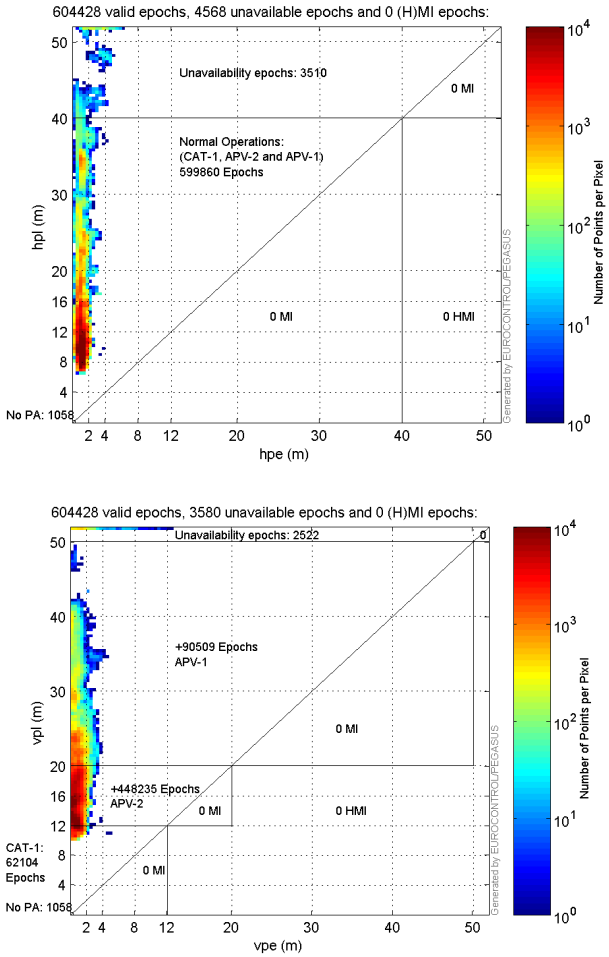


Figure 5, 6. Horizontal and Vertical Stanford graphs.

2.3 *APV-I Statistics*

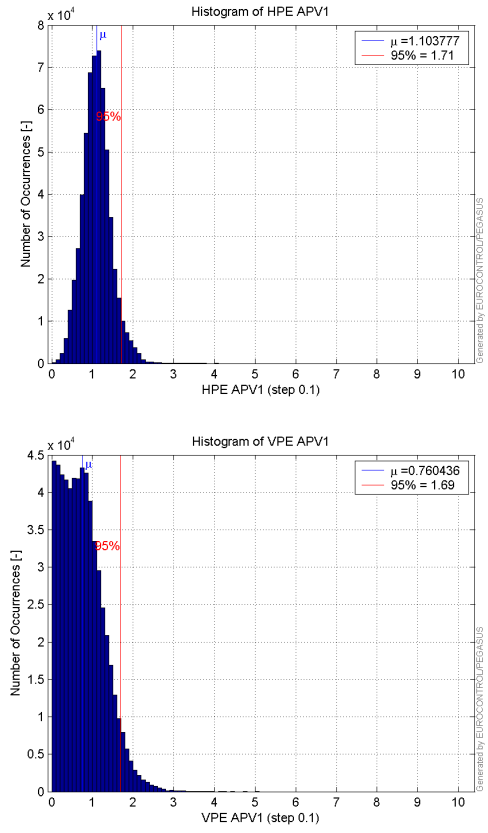


Figure 7,8. Horizontal and Vertical position error distributions (epochs when APV-I available).

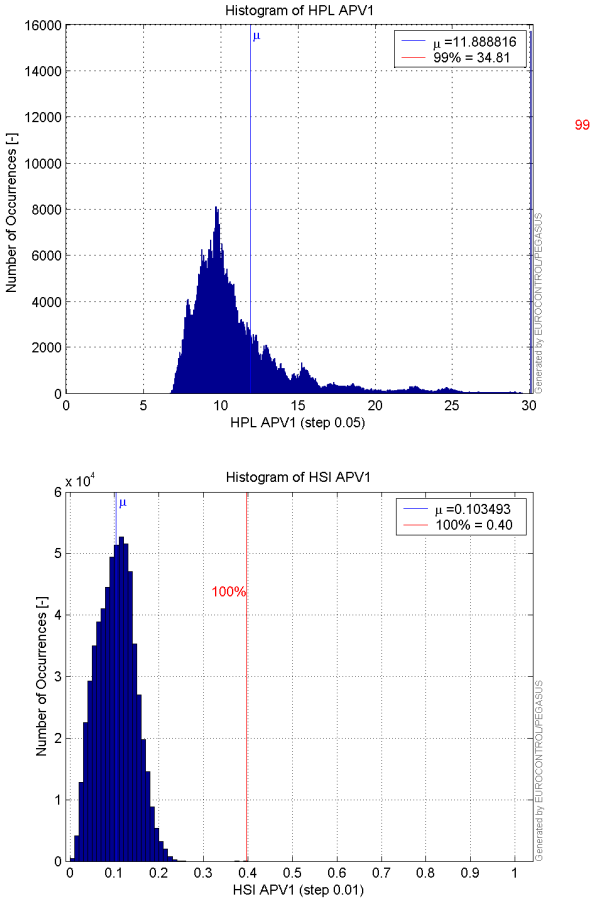


Figure 9,10. Horizontal and Vertical protection level distributions (epochs when APV-I available).

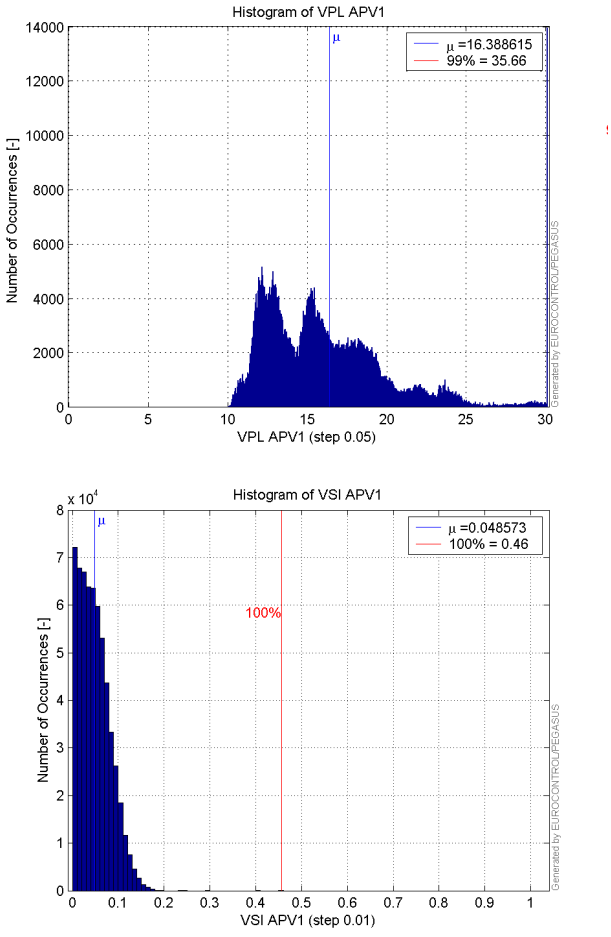


Figure 11,12. Horizontal and Vertical Safety Index distributions (epochs when APV-I available).

2.4 *Integrity*

In case of a (potential) Misleading Information situation, this section will provide a list of all the epochs where there was an xPE/xPL ratio of more than 1 (real MI) or more than 0.75 (near MI).

2.4.1 *Integrity events*

There are no Integrity events in the data. The maximum Horizontal PL/PE ratio is 0.397273 and the maximum Vertical PL/PE ratio is 0.455981

The following table represents the most extreme epochs: Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values.

Table 5, 6. Highest xPE/xPL ratio, Lowest xPL values and Highest xPE values.

extremes							
	Epoch	HPE	HPL	HPE/HPL	VPE	VPL	VPE/VPL
max normHor	175329	3.59359	9.04564	0.39727	1.51378	10.8631	0.13935
max normVer	175331	0.16034	8.86431	0.01809	5.03754	11.0477	0.45598
max HPE	565906	6.07277	60.2411	0.10081	-1.57755	35.1706	0.04485
max VPE	385129	4.89637	52.9584	0.09246	-12.6208	140.124	0.09007
min HPL	78769	1.22757	6.67681	0.18386	0.71793	11.5757	0.06202
min VPL	287957	0.97835	6.78061	0.14429	0.06461	10.0249	0.00645

	HPE	HPL	HPE/HPL	VPE	VPL	VPE/VPL
extremes	6.07277	6.67681	0.397273	-12.6208	10.0249	0.455981

2.5 *Cumulative Density Function*

The Cumulative Density Function (CDF) gives a good indication of the quality of the data in terms of over-bounding. Especially the trend towards lower probabilities becomes clear. The graphs should be read as follows:

- The Red dashed line indicates the ideal trend
- The vertical axis indicates the probabilities, the more data is available, the lower the graphs continue
- The horizontal axis indicates the quality of over-bounding.

- The data points are strictly not allowed to exceed the red-dashed line.
  - However at the start they normally tend to exceed it, and this is acceptable as long as this is only for a small area at the beginning
- The steeper the trend of the data-points, the better.
  - A clear downward trend gives confidence that the over-bounding is sufficient.
  - A clear trend towards exceeding the reference (red-dashed) line is an indication of non over-bounding.
  - In case the trend is parallel and close to the reference, further investigation such as EVT is recommended.
  - A change(s) of the trend suggests that multiple system modes are present in the data. For detailed analysis these should be separated.

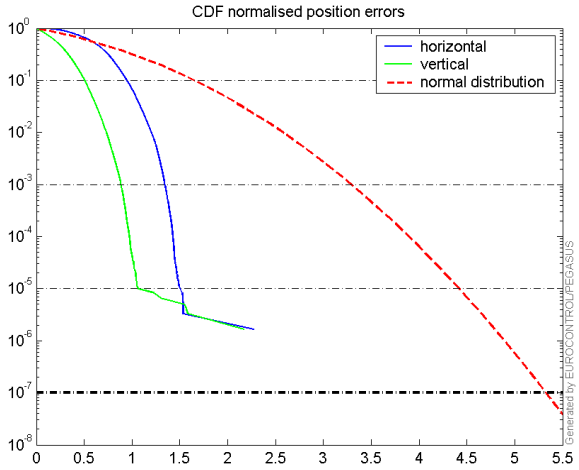


Figure 13. Horizontal and Vertical Position over-bounding in CDF.

2.6 *Continuity*

This section will provide a list of all the discontinuity events. In case there are more than 20 discontinuity events the tables are filtered to a maximum table length of 20. In case there still too many independent events, the table will not be displayed and further investigation is recommended.

The following table presents the discontinuity performance in more detail.

- All discontinuities regardless of duration (same as in firstglance)
- Long discontinuities lasting 3 or more seconds
- Independent discontinuities, lasting 3 or more seconds and after continuously available period of 15 or more seconds
- P(disc.): Continuity Risk determined by multiplying the continuity risk per epoch with 15 seconds
- P(slide): Continuity Risk determined with sliding window of 15 seconds

Table 7. Discontinuity in detail.

Discontinuity events					
	Valid	APV-1	APV-2	CAT-1	APV-35m
All	10	345	3120	7838	745
Long	9	40	173	257	49
Independent	7	27	103	67	27
P(disc.)	0.00017	0.00068	0.00303	0.01618	0.00069
P(slide)	0.00021	0.00206	0.01723	-9.35643	0.00371

2.7 *Discontinuity events for Position Solution*

Table 8. The following table presents all Position discontinuity events.

Position discontinuity events			
#	Epoch	duration	stable period
1	379453	34	33493
2	387656	219	8169
3	387879	25	4
4	416940	160	29036
5	484425	171	67325
6	484600	84	4
7	70570	160	28709
8	109514	1	38784
9	201129	44	4466
10	242862	160	41689

3 RANGE DOMAIN ANALYSIS

3.1 *Signal quality and PRN Status*

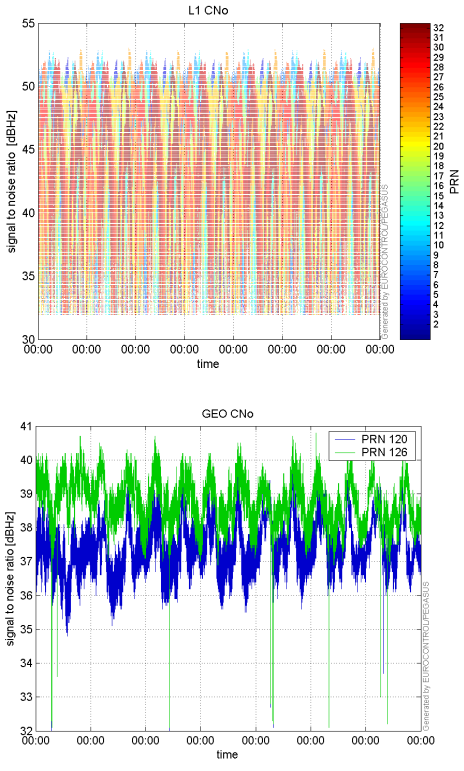


Figure 14, 15. Signal to Noise ratio.

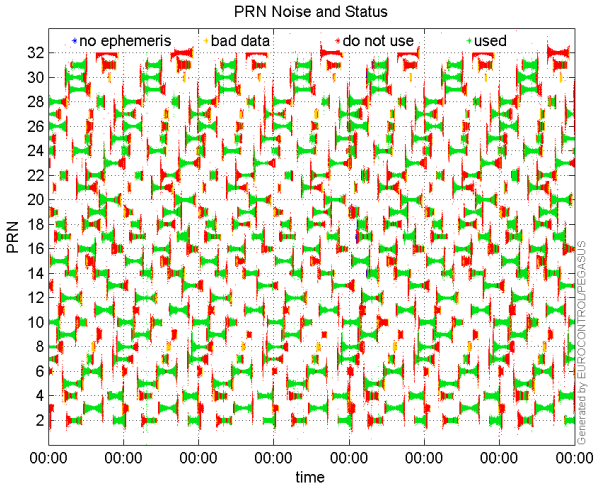


Figure 16. PRN Noise and Status.

3.2 *Normalised range error*

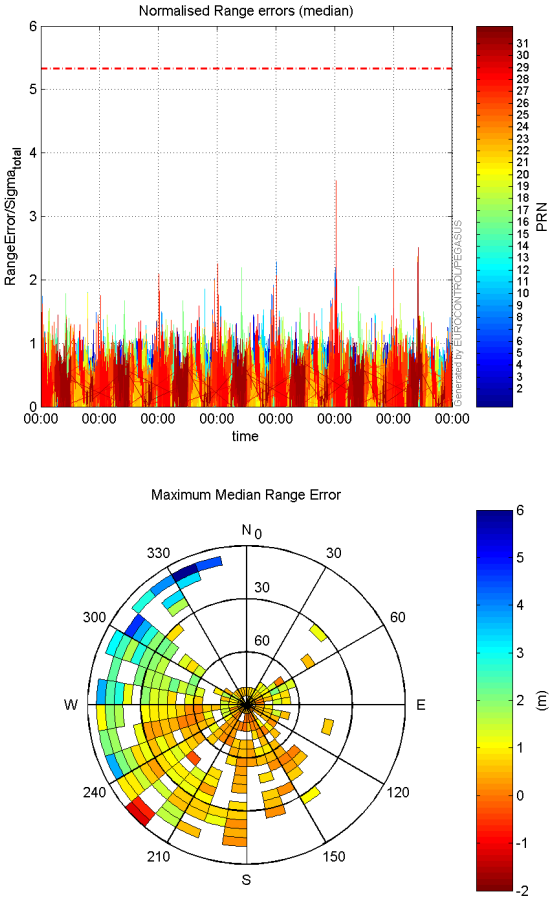
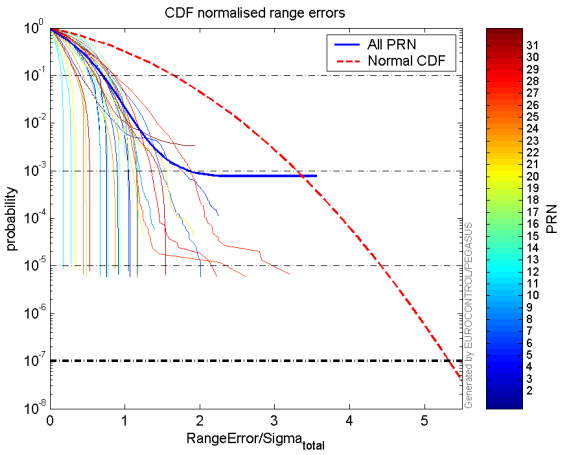


Figure 17, 18. Normalised range errors.



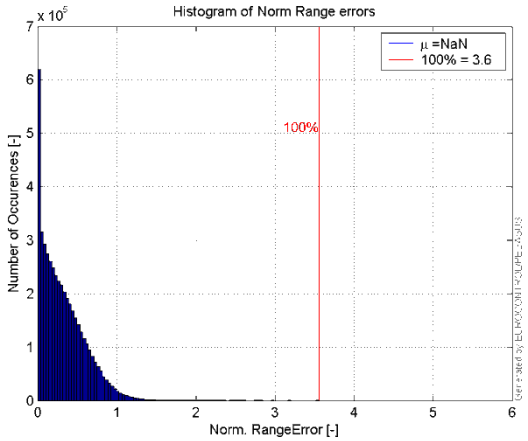


Figure 19, 20. Normalised range errors histogram and CDF.

4 CONCLUSION

From a GNSS applications point of view (GPS assisted in Europe by EGNOS) special importance parameters recorded by the receiver are: availability and continuity. Carried out measuring session shows that the EGNOS system in the current development phase isn't meeting requirements put for air applications. The preliminary assessment of the EGNOS system doesn't let categorize it as meeting APV requirements at the border of the EGNOS service.