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THE COMPARISON OF EGNOS PERFORMANCE AT THE AIRPORTS LOCATED IN EASTERN POLAND

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Abstract

The European Geostationary Navigation Overlay Service (EGNOS) is the first pan-European satellite navigation system. EGNOS makes GPS suitable for safety critical applications such as flying and landing an aircraft. To use EGNOS in aviation the system monitoring and validation in certain localization in needed, as well as official flight procedure design and certification. According to these rules, several GNSS/EGNOS stations located at Polish airfields are currently operational, permanently collecting EGNOS data. The newest monitoring station was established and put into operation at the Polish Air Force Academy in Dęblin in the beginning of 2016.

Dęblin is situated in central-eastern part of Poland (south of Warsaw). Until recently this area was on the edge of official coverage of EGNOS services, especially Safety-of-Life (SoL) service. Latest official documents declare that theoretically the eastern part of Poland is currently fully covered with EGNOS SoL service, however this still needs to be practically confirmed. New station equipped with the newest Javad Delta-3 GNSS receiver will allow to evaluate practical quality of EGNOS in this area.

The article presents preliminary results of EGNOS Safety of Life service performance in Dęblin in comparison to the results obtained in Olsztyn which is situated in north-eastern part of Poland (north of Warsaw). The main parameters characterizing navigational system i.e. accuracy, integrity, continuity and availability were analyzed in detail. The results can be the basis to assess the possibility of implementation of the EGNOS APV approach and landing procedures in Dęblin and Olsztyn.

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Introduction

Present Global Navigation Satellite Systems (GNSS) undergo significant developments and quality improvements. The number of operational GNSS satellites is growing, allowing for new possibilities in positon determination. Although new multi-constellation techniques (LI et al. 2015a, b), using satellites of GPS, GLONASS, BeiDou and Galileo provide reliable and accurate positioning, this kind of solution cannot be used today for safety of life applications, which require certified augmentation system. EGNOS (European Geostationary Navigation Overlay Service) is a Satellite Based Augmentation System (SBAS) developed by the European Space Agency, the European Commission and EUROCONTROL. Currently it augments the US GPS satellite navigation system and makes it suitable for safety critical applications such as flying aircraft (ALLIEN et al. 2009, GRZEGORZEWSKI et al. 2008, GRUNWALD et al. 2016). EGNOS system has also potential use in other applications not related to aviation such as: navigating ships through narrow channels, road and rail transport, agriculture, surveying, etc. (BAKUŁA et al. 2015, FELSKI et al. 2013). ESA watched over the proper development, validation and practical use of EGNOS since 2009. In contrast, EUROCONTROL was responsible for establishing requirements for the users of the system in civil aviation. The task of the European Union was the development of requirements for the other users of the system.

EGNOS supports GPS since 2005 through the transmission of signals via geostationary satellites, derived on a basis of terrestrial network of permanent stations and control centers which supervise the proper operation of the system (ALLIEN et al. 2009). EGNOS currently supports the GPS system by:

– improvement of the positioning accuracy,
– providing information concerning integrity of positioning,
– synchronizing time in which user's position is calculated with UTC time (Coordinated Universal Time).

EGNOS in aviation

Prior to the implementation of EGNOS in aviation, it is necessary to fulfill a number of requirements and adapt to existing international guidelines required by ICAO (International Civil Aviation Organization). The basic premise of validation of EGNOS is to prove that the system can be used in safety of live applications. This is only possible if the EGNOS signal – SIS (Signal-In-Space) over the area covered by the validation procedure meets the international requirements contained in the ESSC (EGNOS System Safety

Case) (*2014 Federal Radionavigation Plan* 2015, FELSKI et al. 2013). On March 2, 2011 the Safety-of-Life (SoL) Service of EGNOS, devoted mainly to aviation users, was officially announced operational (GSA 2015). The EGNOS SoL service provides timing and positioning information improved from the GPS one, adding integrity data to materialize signal-in-space (SiS) performance compliant with aviation requirements defined in the International Civil Aviation Organization (ICAO) Standard and Recommended Practices (SARPS) for SBAS (ICAO 2006).

Integrity is the measure of the trust that can be placed in the correctness of the information supplied by a navigation system. Integrity includes also the ability of the system to provide timely warnings to users when the system should not be used for the intended operation or phase of flight (*2014 Federal Radionavigation Plan* 2015). The integrity monitoring system assures that, in the absence of an integrity alert, the estimated position is within the volume defined by the HPL (Horizontal Protection Level) and VPL (Vertical Protection Level), which are smaller than HAL (Horizontal Alarm Limit) and VAL (Vertical Alarm Limit) respectively (Fig. 1*a*). When any of the protection levels exceeds the alert limit, the integrity monitoring system should warn the user that an operating parameter of a navigation system is out of tolerance (Fig. 1b). Failure to do so constitutes a hazardous condition, which should not occur more frequently than a strict probability specification.

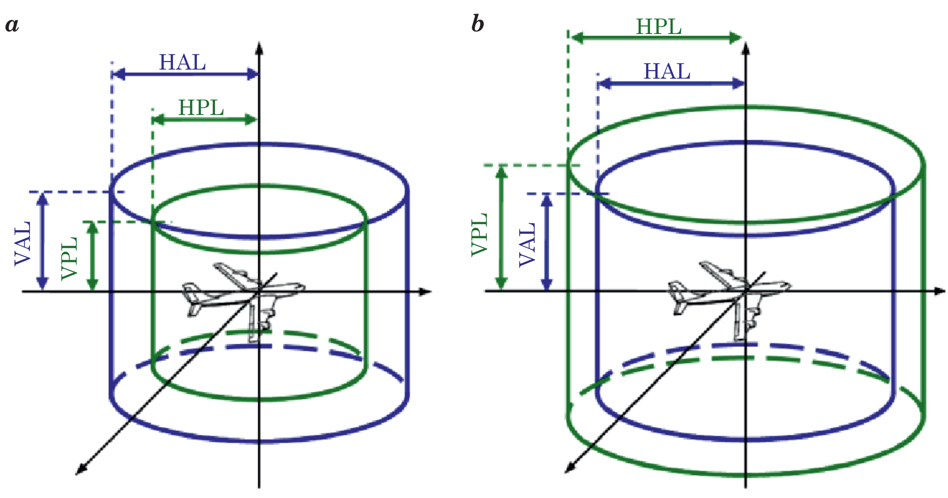


Fig. 1. Relationship between alert and protection levels: *a* – system can be used for the applicable phase of flight, *b* – lost integrity of the navigation system
Source: SALÓS ANDRÉS (2012).

The values of integrity and other fundamental navigation parameters in aviation are highly dependent on the phase of flight. Typical ICAO performance requirements are given in Table 1.

Table 1

Performance requirements for different phases of flight and landing of a civil aircraft

<table>
<tr><th rowspan="3">Aircraft phase of flight</th><th colspan="2">Accuracy</th><th colspan="3">Integrity</th><th colspan="2">Maximum probabilities of failure</th></tr>
<tr><th colspan="2">(2 σ or 95%)</th><th colspan="2">alert limits (4-6σ)</th><th rowspan="2">time to alert</th><th rowspan="2">integrity</th><th rowspan="2">continuity</th></tr>
<tr><th>vertical</th><th>horizontal</th><th>vertical</th><th>horizontal</th></tr>
<tr><td>En-route, Terminal</td><td>N/A</td><td>0.74 – 3.7 km</td><td>N/A</td><td>1.85 – 7.4 km</td><td>5 min – 15 s</td><td>10^{-7}/hr</td><td>10^{-4}/hr</td></tr>
<tr><td>NPA, Initial Approach, Departure</td><td>N/A</td><td>0.22 – 0.74 km</td><td>N/A</td><td>1.85 – 3.7 km</td><td>10–15 s</td><td>10^{-7}/hr</td><td>10^{-4}/hr</td></tr>
<tr><td>LNAV/VNAV</td><td rowspan="3">20 m</td><td>220 m</td><td rowspan="3">50 m</td><td>556 m</td><td rowspan="3">10 s</td><td rowspan="6">$1–2 \cdot 10^{-7}$/ 150 s</td><td rowspan="6">$4–8 \cdot 10^{-6}$/ 15 s</td></tr>
<tr><td>LPV</td><td rowspan="5">16 m</td><td rowspan="5">40 m</td></tr>
<tr><td>APV-I</td></tr>
<tr><td>APV-II</td><td>8 m</td><td>20 m</td><td rowspan="3">6 s</td></tr>
<tr><td>LPV 200</td><td rowspan="2">4 m</td><td>35 m</td></tr>
<tr><td>Precision approach CAT I</td><td>10 m</td></tr>
<tr><td>Precision approach CAT II/III</td><td>< 2.9 m</td><td>< 6.9 m</td><td>5.3 m</td><td>< 17 m</td><td>< 2 s</td><td>$<10^{-9}$/ 150 s</td><td>$<4 \cdot 10^{-6}$/ 15 s</td></tr>
</table>

Source: ICAO (2006), Ene (2009).

To use EGNOS in aviation the system validation in certain localization in needed, as well as official flight procedure design and certification. Today over 150 European airports use EGNOS-based flight procedures (LPV) and it is estimated that by 2018 the number will increase to 440. These procedures provide a cost effective alternative equivalent to conventional ILS CAT I instrument landing procedures. LPV procedures offer similar performance without the need for significant on-site infrastructure installation and maintenance. For these reasons, they are becoming a very valuable navigation aid to small and medium-size airports, increasing safety and accessibility to those aerodromes.

EGNOS performance in eastern Poland

As a part of the preliminary research the quality of EGNOS positioning at new location in the Polish Air Force Academy in Dęblin was analyzed, using data recorded on 02–04.04.2016 (CIEĆKO et al. 2016). In the next step the results from Dęblin were compared with calculations made during the same days in Olsztyn. Developed results are characterized by accuracy, integrity, continuity and availability of GPS/EGNOS positioning. The study aims to test the applicability of the system in safety of life applications with the focus to the procedures which are at least compatible with APV-1. The analyzed data were recorded by the permanent GNSS monitoring stations located in eastern Poland (Dęblin and Olsztyn).

The station at the Polish Air Force Academy in Dęblin was installed in January 2016 and is equipped with the latest Javad Delta-3 (S/N: 02345) multi constellation & multi frequency GNSS receiver and multi frequency GNSS antenna – AT 1675 (S/N: 5480), mounted on a mast on the roof of Air Navigation Department – Figure 2.

Fig. 2. Equipment of permanent GNSS monitoring station in Dęblin

Javad Delta-3 GNSS receiver with 864 channels along with three powerful processors and program memory allows for tracking all current and future satellite signals. Delta-3 is a newly introduced (in 2015), powerful and reliable receiver for high-precision navigation systems it can also operate as a receiver for post-processing, as a Continuously Operating Reference Station (CORS) or portable base station for Real-Time Kinematic (RTK) applications, and as a scientific station collecting information for special studies, such as ionosphere monitoring.

Data from Olsztyn were acquired at a permanent EGNOS monitoring station located at the airport Olsztyn-Dajtki EPOD in northeastern Poland. The observations were recorded on the same days 02–04.04.2016 with a Septentrio AsteRx2e_HDC (S/N: 8512000440) receiver connected to a choke-ring NovAtel ANT-C2GA-TW-N (S/N: 224444) antenna mounted on a specially adapted mast – Figure 3. The selected location had been previously tested for the presence of potential interference of the GNSS signal with signals generated by the communications equipment installed at the airport.

Fig. 3. GNSS equipment installed in the building of the Aeroclub of Warmia and Mazury

Recorded data were elaborated using PEGASUS software, which is a set of tools developed in Matlab environment, allowing for detailed analyses of GNSS data collected from a variety of SBAS and GBAS systems, using positioning models defined in the MOPS (Minimum Operational Performance Standards) documents for aviation. This software uses only the algorithms that are consistent with the relevant RTCA guidelines (RTCA 2013). PEGASUS is used as a basic tool in the monitoring of the EDCN network for applications of APV-1 and LPV-200 procedures (FELSKI et al. 2011, www.eurocontrol 2016). Figure 4 shows the main window of PEGASUS software.

Each of analysed 24-hour sessions is characterized by the same configuration of parameters, compliant with RTCA (RTCA 2013): a minimum topocentric height of satellites at 5 degrees, exclusion from the positioning the ranges to geostationary satellites, data logging interval of 1 second and the use of EGNOS satellite PRN120. The calculation was performed only with the data (valid samples) which were not considered during the registration and processing as invalid. According to the RTCA, the information indicated by the SBAS data analysis software can be described as erroneous because of:

– error log – part of the data has not been registered,
– rejection of the data in the process of filtration,
– due to tuning of the software filters.

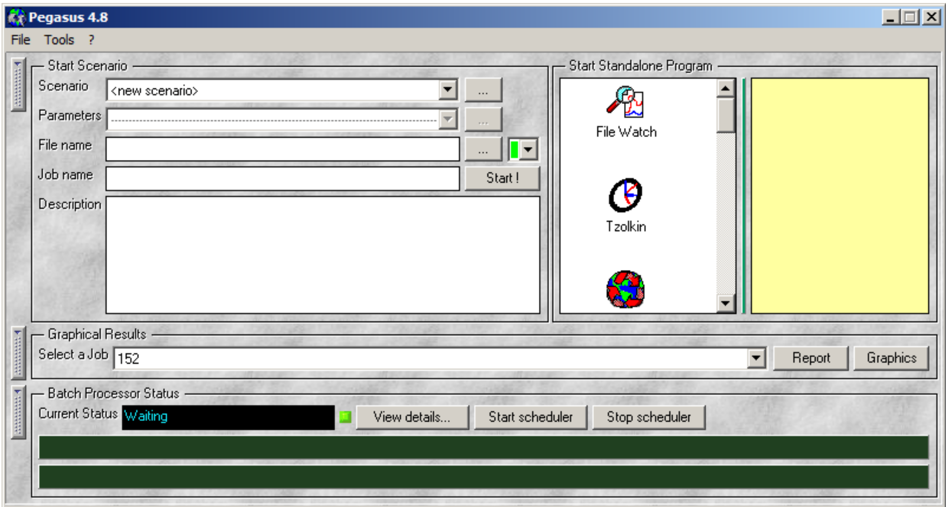


Fig. 4. The main window of PEGASUS software

The GPS/EGNOS positioning accuracy was examined on the basis of the true coordinates of the GNSS station antenna, calculated using data of CORS network belonging to the ASG-EUPOS (part of the European system EUPOS). Figure 5 represents the horizontal deviation from the reference position.

Horizontal positioning error in the three measurement sessions, for both locations shows not large but systematic shift of point clouds to the north. Positioning accuracy in the directions east and west stands at a maximum of about 4 m of the true position in Dęblin and about 2 m in Olsztyn. The maximum northerly error reached approximately 3 m and 2.5 m in Dęblin and Olsztyn respectively, while the south was about 2 m for both locations. From the above analysis, it can be clearly seen that the horizontal positioning accuracy at tested locations meets the requirements for approach APV-1 (HPE<16 m). Almost 100% of analysed epochs (in Olsztyn – 100%) also meet the EGNOS accuracy standard (HPE<3 m) published in GSA 2015. Table 2 contains the numerical values characterizing the accuracy results of the horizontal and vertical error analyses.

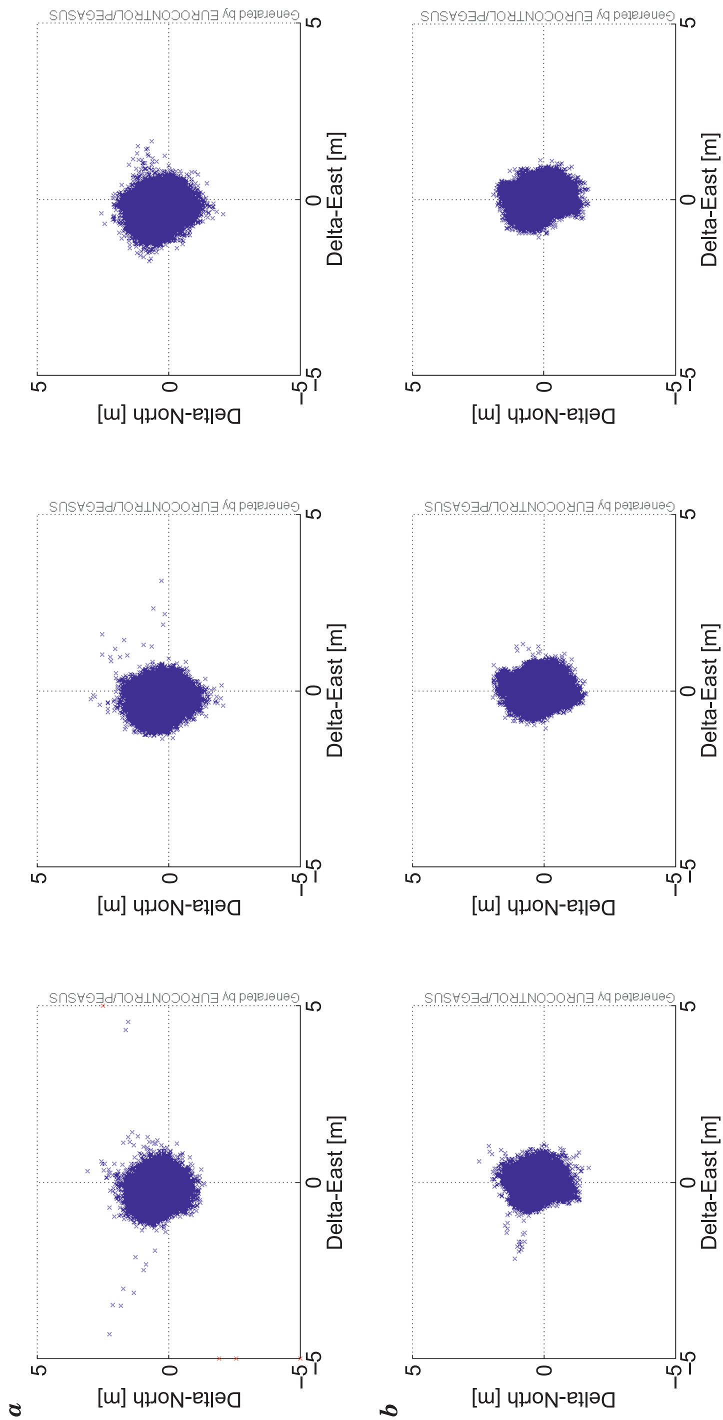


Fig. 5. Horizontal deviation of the GPS/EGNOS positioning for a sessions performed on 02–04.04.2016, *a* – Dęblin, *b* – Olsztyn

Table 2

The accuracy analyses of GPS/EGNOS positioning at Dęblin and Olsztyn airport

Parameter	Day	02.04.2016		03.04.2016		04.04.2016	
		Dęblin	Olsztyn	Dęblin	Olsztyn	Dęblin	Olsztyn
Accuracy	HPE 95% NPA [m]	1.18	0.92	1.12	0.95	1.15	0.98
	HPE 95% APV-1 [m]	1.18	0.92	1.12	0.95	1.15	0.98
	VPE 95% NPA [m]	1.72	1.81	1.89	2.00	1.90	2.06
	VPE 95% APV-1 [m]	1.72	1.81	1.89	2.00	1.90	2.06
	HPE_{max} [m]	23.43	2.52	3.14	2.04	2.57	1.93
	VPE_{max} [m]	48.79	3.25	10.34	4.46	11.46	3.44
	$HPE_{avg.}$ [m]	0.63	0.48	0.56	0.47	0.61	0.50
	$VPE_{avg.}$ [m]	0.73	0.81	0.75	0.87	0.80	0.97
	$HPE_{st.dev.}$ [m]	0.30	0.25	0.30	0.27	0.58	0.27
	$VPE_{st.dev.}$ [m]	0.52	0.54	0.58	0.62	2.34	0.61

In Table 2 the accuracy test results are expressed as HPE 95%, and VPE 95% shown separately for the use in NPA and APV-1. The value of HPE 95% NPA and VPE 95% NPA corresponds to measurement epochs, which satisfy the requirements of the NPA – namely HPL<556 m. HPE 95% APV-1 is to include only the epochs that satisfy HPL<40 m and VPE 95% APV-1 corresponds to epochs for which VPL<50 m – see Table 1. For each of analysed sessions, the positioning accuracy of NPA corresponds to that obtained for an APV-1 approach. The results of horizontal (HPE 95%<1.2 m) and vertical (VPE 95%<2.1 m) accuracy at both airfields meet the requirements for the use of EGNOS in aviation. The interesting fact is that horizontal positioning was slightly better in Olsztyn, while vertical was better in Dęblin.

The integrity of positioning is mainly expressed through the Protection Levels (PL) and their relationship with accuracy (OLIVEIRA et al. 2009, TIBERIUS, ODIJK 2008). Stanford diagrams presented in Figures 6–8 show the results of horizontal and vertical calculation carried out on the basis of three measurement sessions collected on 02–04.04.2016 in Dęblin and Olsztyn.

Test results presented above show that a total of 13 epochs (13 epochs in Dęblin, 0 epochs in Olsztyn) were not available for both the horizontal and vertical approach APV-1 (HPL <40 m, VPL<50 m). The factor SI – safety index (the ratio of XPE/XPL) for the analysed data reaches low values, which indicates proper function of the integrity algorithm at both stations. Generally, the HPL values are at a satisfactory level of less than 30 m and VPL values are less than 40 m.

Table 3 shows the results of the availability analysis based on the same period of observations made on 02–04.04.2016. The analysed values were: the SIS (Signal In Space) availability, NPA operational availability and APV-1 operational availability.

a

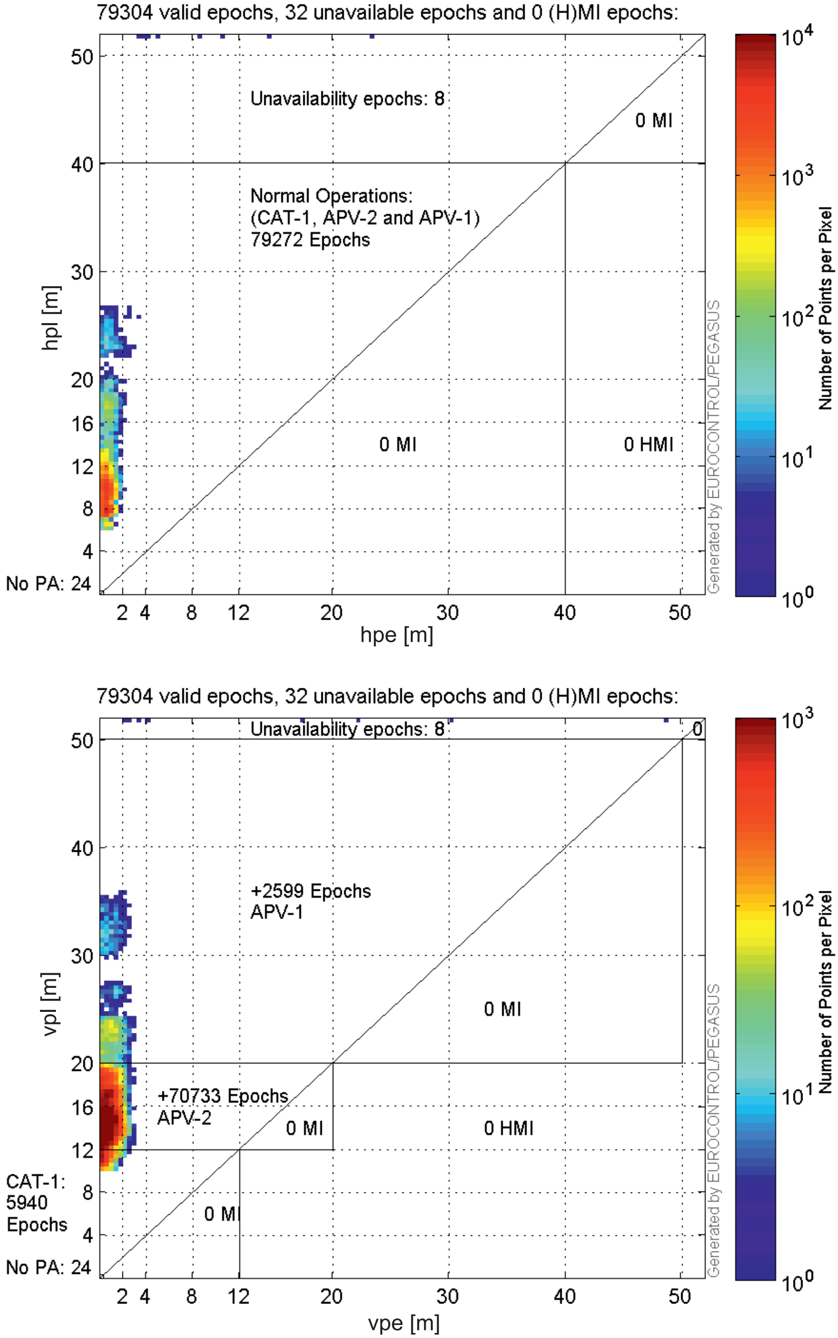
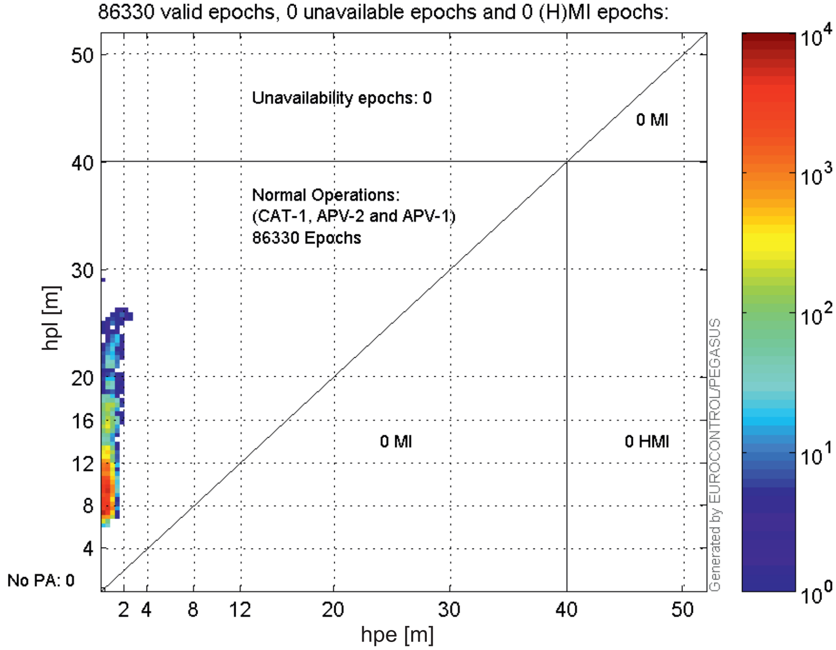
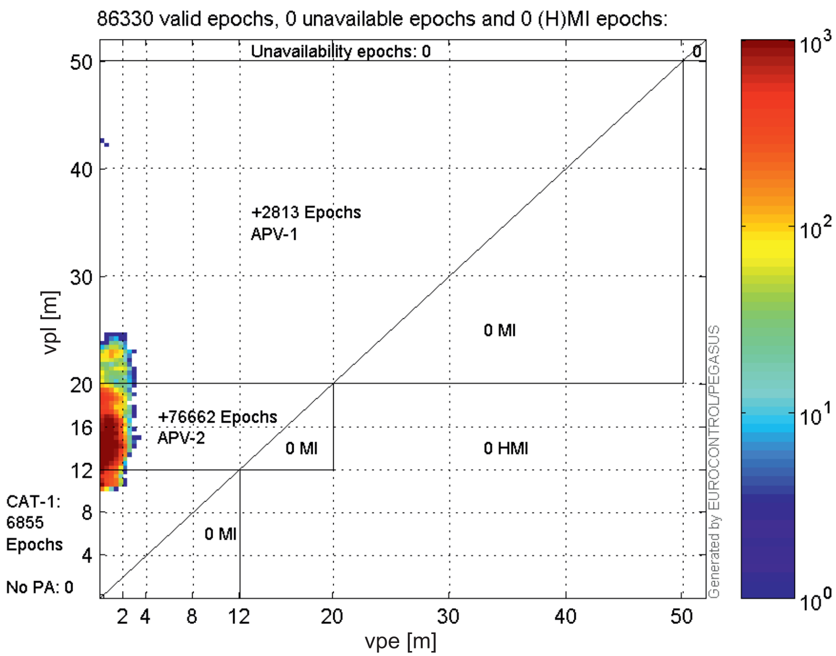


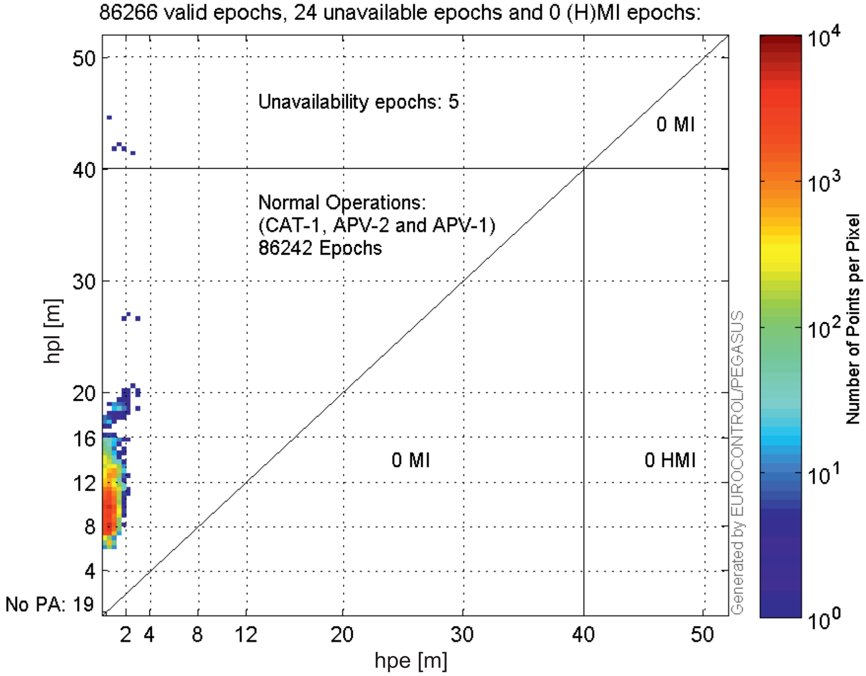
Fig. 6. Stanford diagrams generated for 02.04.2016: *a* – Dęblin, *b* – Olsztyn

b


86330 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
0 MI
Normal Operations:
(CAT-1, APV-2 and APV-1)
86330 Epochs
0 MI
0 HMI
No PA: 0
hpl [m]
hpe [m]
Generated by EUROCONTROL/PEGASUS
Number of Points per Pixel


86330 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
0
+2813 Epochs
APV-1
0 MI
+76662 Epochs
APV-2
0 MI
0 HMI
0 MI
CAT-1:
6855
Epochs
No PA: 0
vpl [m]
vpe [m]
Generated by EUROCONTROL/PEGASUS
Number of Points per Pixel

a



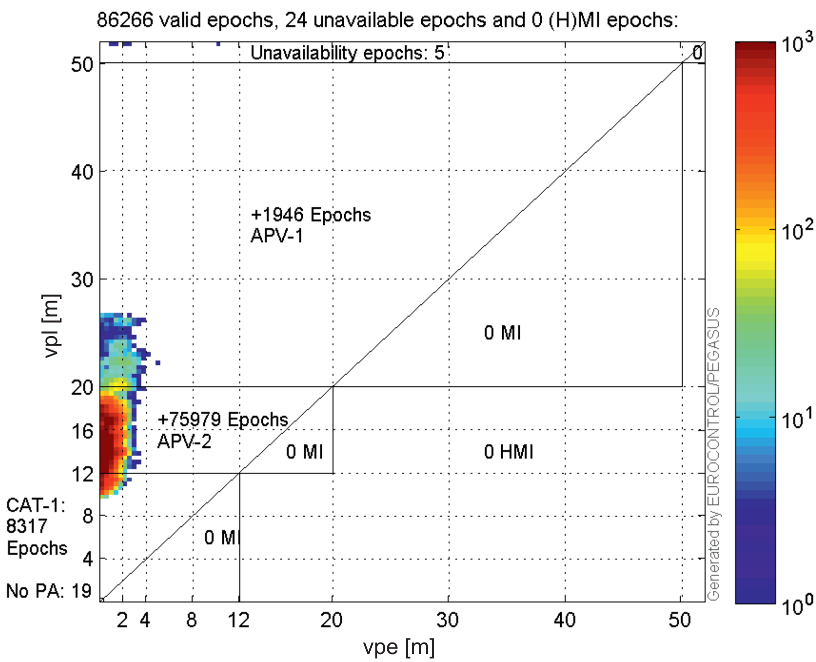
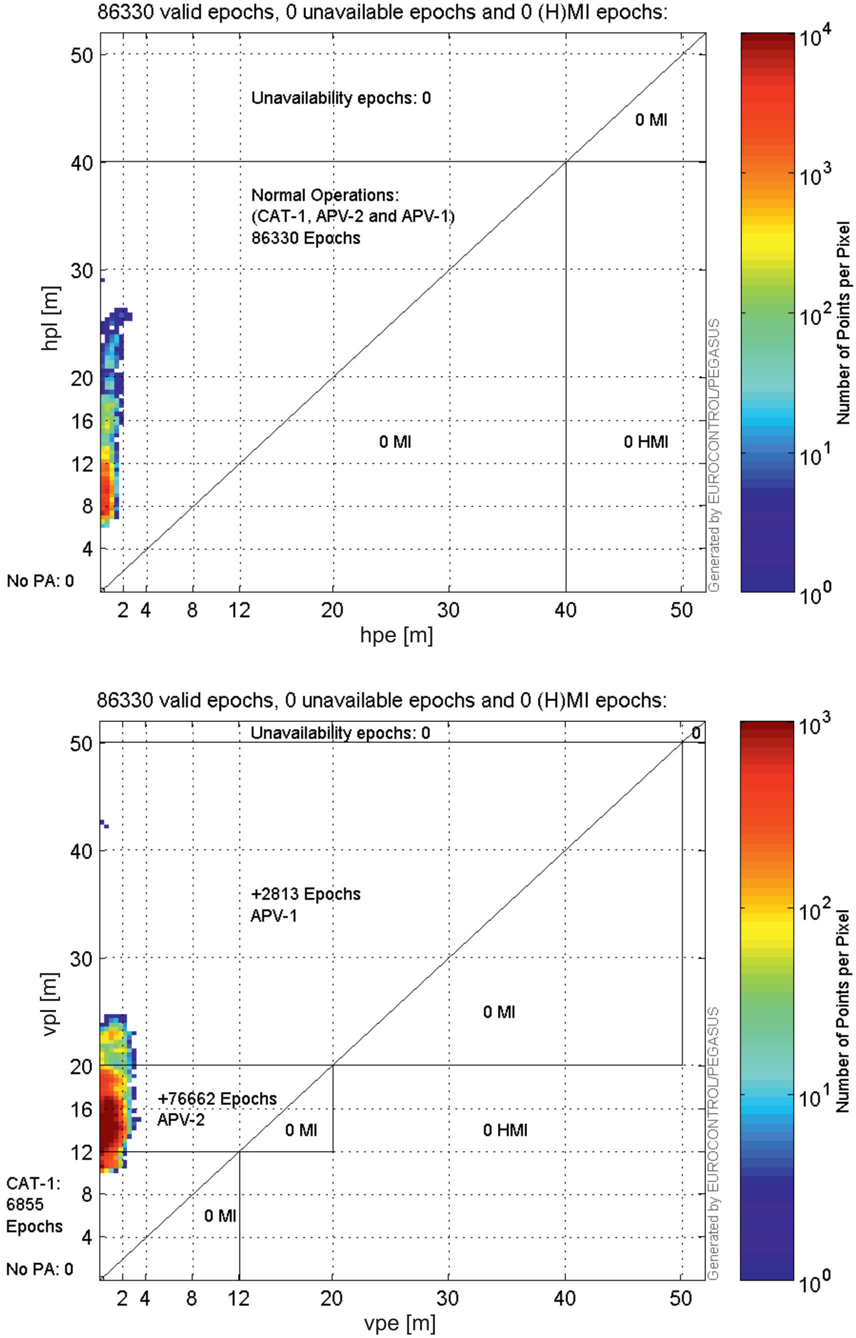


Fig. 7. Stanford diagrams generated for 03.04.2016: *a* – Dęblin, *b* – Olsztyn

b


86330 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
0 MI
Normal Operations:
(CAT-1, APV-2 and APV-1)
86330 Epochs
0 MI
0 HMI
No PA: 0
hpl [m]
hpe [m]
Generated by EUROCONTROL/PEGASUS
Number of Points per Pixel
86330 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
0
+2813 Epochs
APV-1
0 MI
+76662 Epochs
APV-2
0 MI
0 HMI
0 MI
CAT-1:
6855
Epochs
No PA: 0
vpl [m]
vpe [m]
Generated by EUROCONTROL/PEGASUS
Number of Points per Pixel

a

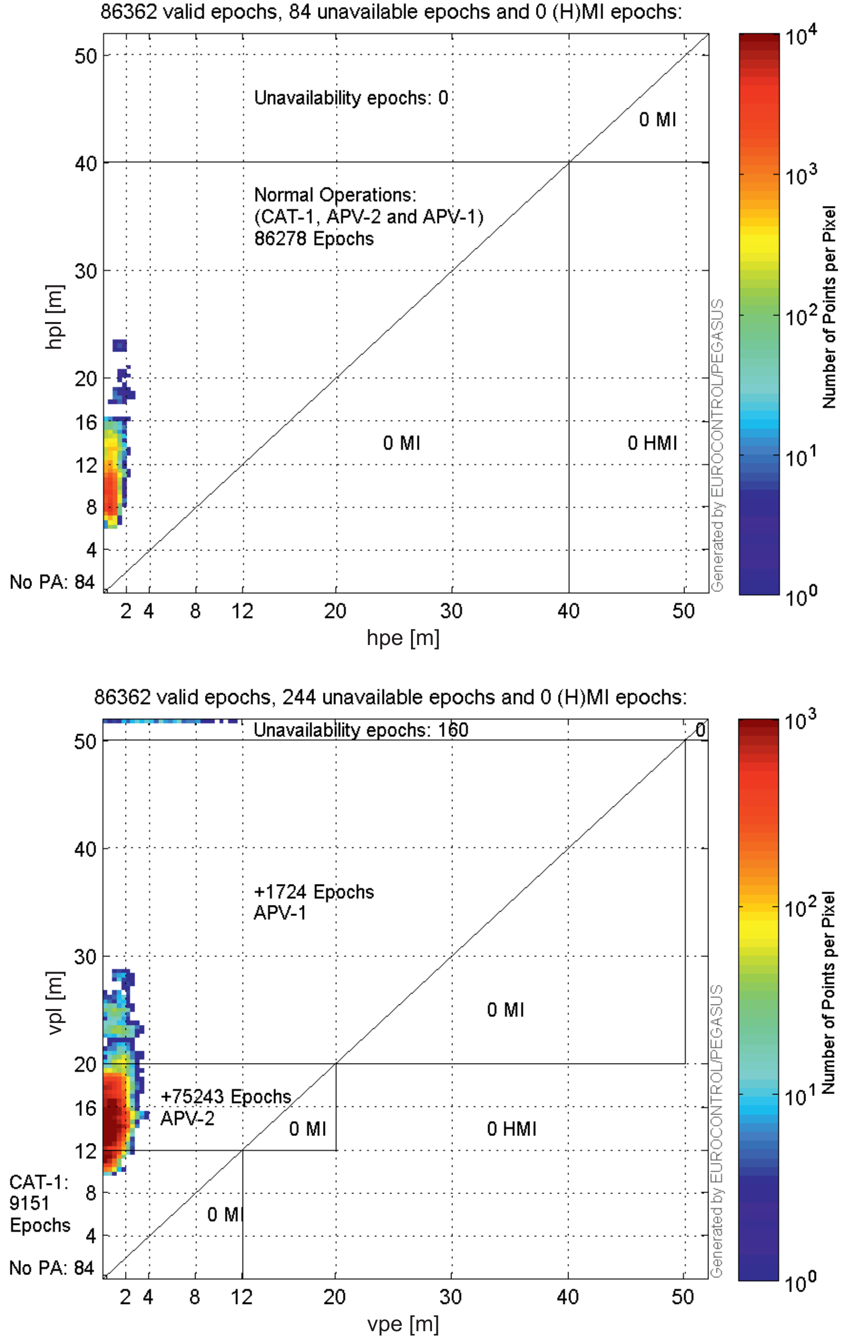


Fig. 8. Stanford diagrams generated for 04.04.2016: *a* – Dęblin, *b* – Olsztyn

b

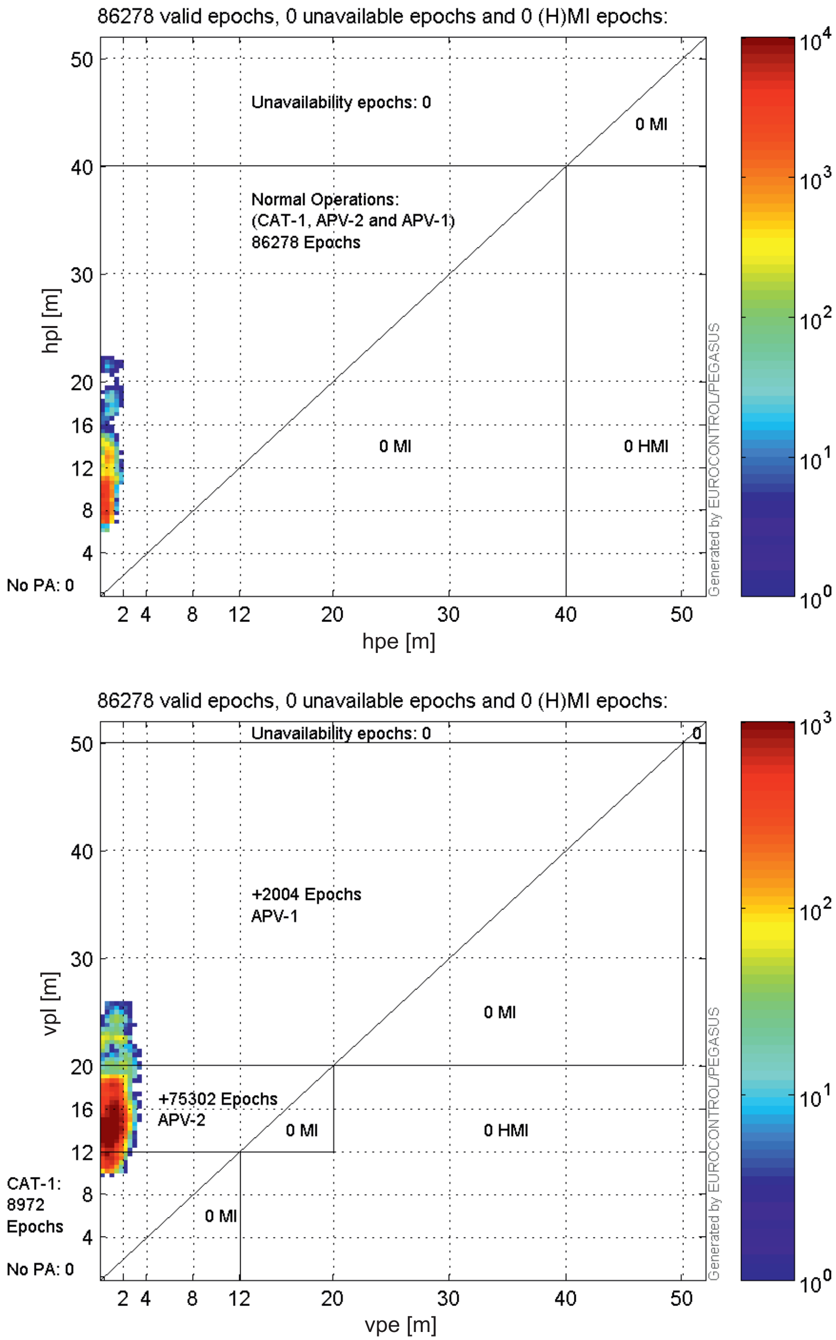

86278 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
0 MI
Normal Operations:
(CAT-1, APV-2 and APV-1)
86278 Epochs
0 MI
0 HMI
No PA: 0
hpl [m]
hpe [m]
Number of Points per Pixel
Generated by EUROCONTROL/PEGASUS
86278 valid epochs, 0 unavailable epochs and 0 (H)MI epochs:
Unavailability epochs: 0
+2004 Epochs
APV-1
0 MI
+75302 Epochs
APV-2
0 MI
0 HMI
0 MI
CAT-1:
8972
Epochs
No PA: 0
vpl [m]
vpe [m]
Number of Points per Pixel
Generated by EUROCONTROL/PEGASUS

Table 3

The availability analysis results obtained on 02–04.04.2016

Parameter	Day	02.04.2016		03.04.2016		04.04.2016	
		Dęblin	Olsztyn	Dęblin	Olsztyn	Dęblin	Olsztyn
Availability	signal availability	1	1	1	1	1	1
	NPA operational availability	0.999697	0.999813	0.999780	0.999889	0.998588	0.998611
	APV-1 operational availability	0.999697	0.999813	0.999720	0.999876	0.996736	0.998611

The availability of EGNOS signal throughout the test period is very close to 100%. Operational availability of EGNOS NPA and APV-1 reaches the value of around 0.999 in both examined locations, which meets the official requirements of the application in the APV-1 approach (the result of better than 99%).

In performed studies continuity parameter was also examined. All discontinuity events for NPA and APV-1 were analysed. In the case of NPA variant for the calculation all measurement epochs with a NPA solution (HPL<556 m) were taken into consideration. APV-1 variant includes all the epochs for which HPL<40 m and VPL<50 m. Table 4 presents the results of analysis of the continuity of the EGNOS system in the considered period.

Table 4

The results of the continuity analysis on 02–04.04.2016

Parameter	Day	02.04.2016		03.04.2016		04.04.2016	
		Dęblin	Olsztyn	Dęblin	Olsztyn	Dęblin	Olsztyn
Continuity	All NPA discontinuity events	–	–	–	–	–	–
	All APV–1 discontinuity events	–	–	–	–	1	–
	Long NPA discontinuity events	–	–	–	–	–	–
	Long APV–1 discontinuity events	–	–	–	–	1	–

The only event of loss of continuity was observed in Dęblin in the third measurement session (04.04.2016). It concerns the use of EGNOS in the APV-1 approach only. With these results, it is advisable to perform experiments based on data from longer periods, or to perform permanent monitoring of continuity of the EGNOS system at certain location.

Conclusion

The results of performed analyses and comparisons are preliminary ones and indicate initial quality assessment of GPS/EGNOS positioning in the airfields located at Polish Air Force Academy in Dęblin and Aeroclub in Olsztyn. These analyses were possible due to the newly established GNSS/EGNOS monitoring stations equipped with proper GNSS receivers. The quality of basic positioning parameters such as: accuracy, integrity, continuity and availability was analysed in detail. Achieved, preliminary results indicate good trends of EGNOS development for the use in air navigation in eastern Europe. In the analysed period, just a few events exceeding the limit values of quality were observed, but the overall results are at a satisfactory level. Attained, good values of positioning parameters prove that the EGNOS system upgrades that were made in recent years translate into the possibility of obtaining good accuracy, integrity, availability and continuity also in the eastern Poland. However, the research carried out on the basis of just 3 days of observation in 2 locations, do not constitute a final assessment of the GPS/EGNOS quality in eastern Poland. According to the authors, there should be continuous monitoring of the EGNOS performance in the area of the eastern Poland, prior to practical implementation of procedures in accordance with APV-1 in that region.

References

2014 Federal Radionavigation Plan. 2015. Department of Defense, Department of Homeland Security, and Department of Transportation. Springfield, Virginia.

Allien A., Taillander C., Capo C. 2009. *User Guide For EGNOS Application Development*. European Space Agency, Paris.

Bakuła M., Przestrzelski P., Kaźmierczak R. 2015. *Reliable technology of centimeter GPS/GLONASS surveying in forest environments*. Geoscience and Remote Sensing, 53(2): 1029–1038.

Ciećko A., Grunwald G., Ćwiklak J., Popielarczyk D., Templin T. 2016. *EGNOS performance monitoring at newly established GNSS station in Polish Air Force Academy*. SGEM2016 Conference Proceedings, 2(2): 239–246, doi: 10.5593/SGEM2016/B22/S09.031.

Ene A. 2009. *Utilization of Modernized Global Navigation Satellite Systems for Aircraft-Based Navigation Integrity*. PhD Thesis, Department of Aeronautics, Stanford University.

EUROCONTROL – Driving excellence in ATM performance. www.eurocontrol.int/articles/pegasus (access: 2.05.2016).

Felski A., Nowak A. 2013. *On EGNOS Monitoring in Local Conditions*. Artificial Satellites, 48(2): 85–92.

Felski A., Nowak A., Woźniak T. 2011. *Accuracy and Availability of EGNOS – Results of Observations*. Artificial Satellites, 46: 111–118.

Grunwald G., Bakuła M., Ciećko A., Kaźmierczak R. 2016. *Examination of GPS/EGNOS integrity in north-eastern Poland*. IET Radar, Sonar & Navigation. The Institution of Engineering and Technology, 10(1): 114–121, doi: 10.1049/iet-rsn.2015.0053.

GRZEGORZEWSKI M., CIEĆKO A., OSZCZAK S., POPIELARCZYK D. 2008. *Autonomous and EGNOS Positioning Accuracy Determination of Cessna Aircraft on the Edge of EGNOS Coverage.* Proceedings of the 2008 National Technical Meeting of the Institute of Navigation – NTM, p. 407–410.

International Standards and Recommended Practices (SARPS). 2006. Annex 10 to the Convention on International Civil Aviation, Aeronautical Telecommunications, Vol. I, Radio Navigation Aids', 6th Edition, International Civil Aviation Organization (ICAO).

LI X., GE M., DAI X., REN X., FRITSCHE M., WICKERT J., SCHUH H. 2015a. *Accuracy and reliability of multi-GNSS real-time precise positioning: GPS, GLONASS, BeiDou, and Galileo*. J. Geod., 89: 607–635, doi: 10.1007/s00190-015-0802-8.

LI X., ZHANG X., REN X., FRITSCHE M., WICKERT J., SCHUH H. 2015b. *Precise positioning with current multi-constellation Global Navigation Satellite Systems: GPS, GLONASS, Galileo and BeiDou*. Scientific Reports, 5(8328): 1–14, doi: 10.1038/srep08328.

Minimum Operational Performance Standards for Airborne Equipment Using Global Positioning System/Wide Area Augmentation System. 2013. Radio Technical Committee for Aeronautics. Doc. DO-229D.

OLIVEIRA J., TIBERIUS C. 2009. *Quality Control in SBAS: Protection Levels and Reliability Levels.* The Journal of Navigation, 62: 509–522.

Safety of Life Service Definition Document. v. 3.0. 2015. GSA – European Global Navigation Satellite Systems Agency.

SALÓS ANDRÉS C.D. 2012. *Integrity monitoring applied to the reception of GNSS signals in urban environments*. PhD Thesis, Toulouse University.

TIBERIUS C., ODIJK D. 2008. *Does the HPL bound the HPE?* NAVITEC. Proceedings of NaviTec'08 workshop, ESA-Estec, Noordwijk.