

# INTERNATIONAL JOURNAL OF CIVIL ENGINEERING AND TECHNOLOGY (IJCIET)

ISSN 0976 – 6308 (Print)

ISSN 0976 – 6316(Online)

Volume 5, Issue 10, October (2014), pp. 01-08

© IAEME: [www.iaeme.com/Ijciет.asp](http://www.iaeme.com/Ijciет.asp)

Journal Impact Factor (2014): 7.9290 (Calculated by GISI)

[www.jifactor.com](http://www.jifactor.com)

IJCIET

©IAEME

---

## TESTING ACCURACY OF MARITIME DGPS SYSTEM BASED ON LONG-TERM MEASUREMENTS CAMPAIGNS OVER THE YEARS 2006-2014

Capt. PhD.H.Sniegocki<sup>1</sup>, Prof. DSc. PhD. C. Specht<sup>2</sup>, M. Specht<sup>3</sup>

<sup>1</sup>(Associate Professor& Deputy Rector for Maritime Affairs, Faculty of Navigation, Gdynia Maritime University, Gdynia, Poland)

<sup>2</sup>(Professor, Faculty of Navigation, Gdynia Maritime University, Gdynia, Poland)

<sup>3</sup>(Student, Faculty of Civil and Environmental Engineering, Gdansk University of Technology, Gdansk, Poland)

### ABSTRACT

The paper presents a comparative analysis of statistical accuracy (repeatable and predictable) of a maritime DGPS system in three long time measurement campaigns carried out in: 2006, 2009 and the last in May 2014 (0.95 million fixes). In all the above mentioned studies, the measurements were taken at the same Polish reference station – Rozewie and the same location of the measuring receiver. Therefore, the conclusions of the examination can be more general. The results indicate the existence of a direct relationship between the increase in the accuracy of the GPS system and the accuracy of the differential version. They also demonstrated that the system obtained the accuracy of 1-2 m ( $p = 0.95$ ).

**Keywords:** Maritime Navigation, Differential GPS, Position Accuracy, Polish DGPS System.

### I. INTRODUCTION

Today GPS is the main source of position solutions to a wide range of navigational and transportation applications. In 1983 the U.S. President Ronald Reagan announced that civil users would be granted access to Standard Positioning Service (SPS) which broadcasts code signals (C/A – Coarse/Acquisition) at L1 frequency that can be used to determine the time of the position of a receiver once it becomes operational. Global Positioning System standard performances, even after Selective Availability turning off (2<sup>nd</sup> May 2000) [1], could not be accepted for many professional

navigation applications in land, air and maritime transport. Many official defined navigation requirements [2,3,4] which call for high accuracy, availability, reliability and continuity could be fulfilled only by basing on additional GPS solution such as a space-based WAAS (Wide Area Augmentation System), EGNOS (European Geostationary Overlay System) or regional or local augmentation services such as DGPS (Differential GPS) [5,6]. These techniques improve GPS data providing additional information from complementary systems, thereby augmenting both accuracy and quality performances in navigation [7], transport [8] and non-professional navigation applications [9].

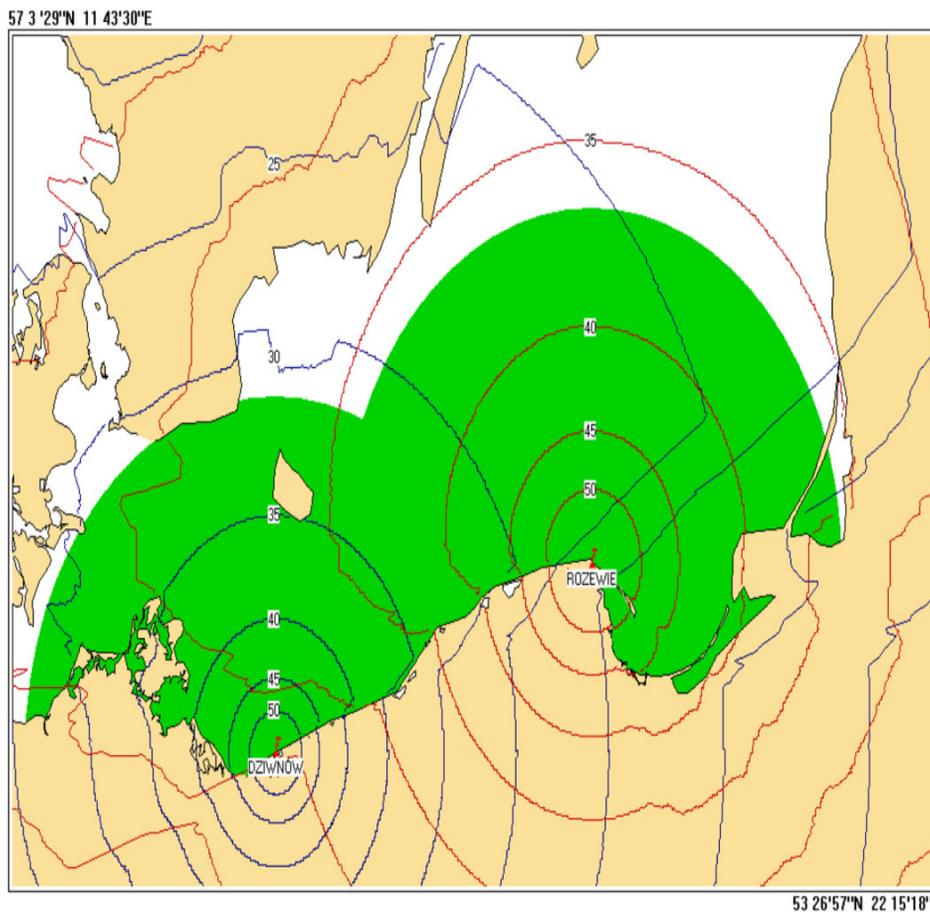
Federal Aviation Administration acquires data quarterly from various research centres to compare real GPS performance [10] to official Performance Standard. Detailed analysis of the accuracy of GPS is also presented in [11]. Analyses clearly show that the achieved position accuracy is better than presented in the standard[1] and grows from year to year. One of the reasons for this situation is the fact that performance standard was published before modernisation of Control and Space Segments.

The improved accuracy in the GPS system results in a change in the accuracy of all augmentation systems such as EGNOS, WAAS and also maritime DGPS. Therefore the systems must be regularly monitored in order to be used in various means of transport. This is especially important in shipping, in port approaching channels where high reliability and availability of position reduce the risk of accident [12]. Equally important factors affecting the accuracy determining the position of the marine DGPS systems are the following: loss of pseudorange correction, its decorrelation effects [13, 14], as well as, solar activity [15]. Integrity is the special feature that distinguishes marine DGPS positioning systems from other systems. Thanks to this special feature, its users obtain information about the status of the system in real time [16].

## **II. METHODS AND MATERIALS**

In 1987 the U.S. Coast Guard Research and Development (R & D) Center demonstrated that differential corrections broadcast to local user equipment improved GPS SPS to a predictable accuracy of 10 meters (2DRMS); inside the coverage area of the correction broadcast [17]. After 2 years (in 1989), the U.S. Coast Guard modified the existing marine radiobeacon located at Montauk Point (New York) to broadcast differential corrections in the RTCM SC-104 format. Montauk Point began the first continuous public DGPS reference station broadcast on August 15, 1990. The station field tests demonstrated that Minimum Shift Keying (MSK) modulation of an existing radiobeacon signal was effective in transmission of RTCM SC-104 format corrections [18]. The RTCM-SC-104 format [19] was developed in future versions: 2.0 (includes DGPS code corrections), 2.1 (supplemented by RTK corrections), 2.2 (supplemented by Glonass data), 2.3 (supplemented by GPS antenna definition), 3.0 (supplemented by networking solutions). Marine radiobeacons, operational in the frequency range of 283.5-325 KHz, were to provide signals according to technical standards form differential GPS transmission [19,20] and performance [21]. As these facilities were highly attractive because of its cheapness and accessibility, differential correction standards were developed by ITU according to their Recommendations. IALA also came out with its guidelines and recommendation for such services. Message format for corrections transmission was developed by Radio Technical Commission for Maritime Services, which is regularly updated. The Polish DGPS system was established by Polish Hydrographic Office in 1994, finally it was made up of two independent maritime reference stations (RS) located in Rozewie and Dziwnow and one control station in Gdynia. Both RS stations equipped with local integrity monitors were remotely controlled by dedicated network. The hardware and software of the system have been entirely modernized in 2009, by replacing L1 code receivers with new two-frequency (L1/L2), as well as, a set of new

technology GNSS antennas. Figure 1 presents the coverage of the Polish DGPS reference stations: Rozewie and Dziwnow covering Polish coastal waters and ports (approximately 200-250 km).



**Fig. 1:** Coverage of the Polish DGPS reference stations: Rozewie and Dziwnow (green areas) and signal strength level lines (in dB/μV/m) Rozewie –red, Dziwnow– blue [22]

Position accuracy in navigation can be defined as a degree of conformance between the estimated or measured position and its true position. Position accuracy can be determined as different types of statistics. They can be calculated in relation to the true values of coordinates (if any) or if the current position is not known, the average position is often used as an approximation to the current position. Both solutions of position must be based upon the same geodetic datum (WGS-84). There are 3 types of solutions [4]:

- Predictable accuracy: The accuracy of a PNT position in comparison to the charted position (true coordinate values).
- Repeatable accuracy: The accuracy which enables the user to return to the position with coordinates measured previously with the same PNT system (mean coordinate values).
- Relative accuracy: The accuracy which enables the user to measure position relative to that of another user of the same PNT system at the same time. Applicable only for two receivers.

The values describing accuracy statistics, commonly used in maritime navigation are: CEP (Circular Error Probable, 2D, p=0.5), SEP (Spherical Error Probable, 3D, p= 0.5) RMS (Root Mean Square, 1D, p= 0.68), DRMS (Distance Root Mean Square, 2D or 3D, p= 0.68) or 2DRMS (Twice Distance Root Mean Square, 2D or 3D, p= 0.95) or 3DRMS (Triple Distance Root Mean Square, 2D or 3D, p=0.997). Detailed explanation of the accuracy measures is presented in [23]. The most common measure of accuracy for marine navigation (2D) is 2DRMS (p=0.95) of the horizontal position errors:

$$2DRMS = 2\sqrt{\sigma_{\phi}^2 + \sigma_{\lambda}^2}, \quad (1)$$

where:

$\sigma_{\phi}$  – latitude standard deviation,  
 $\sigma_{\lambda}$  – longitude standard deviation.

Distribution of position error can be described by Rayleigh probability density functions  $f(x;\sigma)$  and cumulative distribution functions  $F(x)$  as follows:

$$f(x;\sigma) = \frac{x}{\sigma^2} e^{-\frac{x^2}{2\sigma^2}}, \quad F(x) = 1 - e^{-\frac{x^2}{2\sigma^2}}, \quad (2, 3)$$

for,  $x \in [0, \infty)$  where scale parameter  $\sigma$  is defined as:

$$\sigma = \sqrt{\frac{1}{2N} \sum_{i=1}^N x_i^2}, \quad (4)$$

where:

N – number of measurements.

### III. RESULTS

In order to evaluate changes in positioning accuracy characteristics of the DGPS system, three long-term measurement campaigns took place over the years: 2005-2014:

- 1<sup>st</sup> March 2006 (2.187.842 fixes, fix rate 1 Hz).
- 2<sup>nd</sup> July-August 2009 (214.842 fixes, fix rate 1 Hz).
- 3<sup>rd</sup> April-May 2014 (951.698 fixes, fix rate 1 Hz).

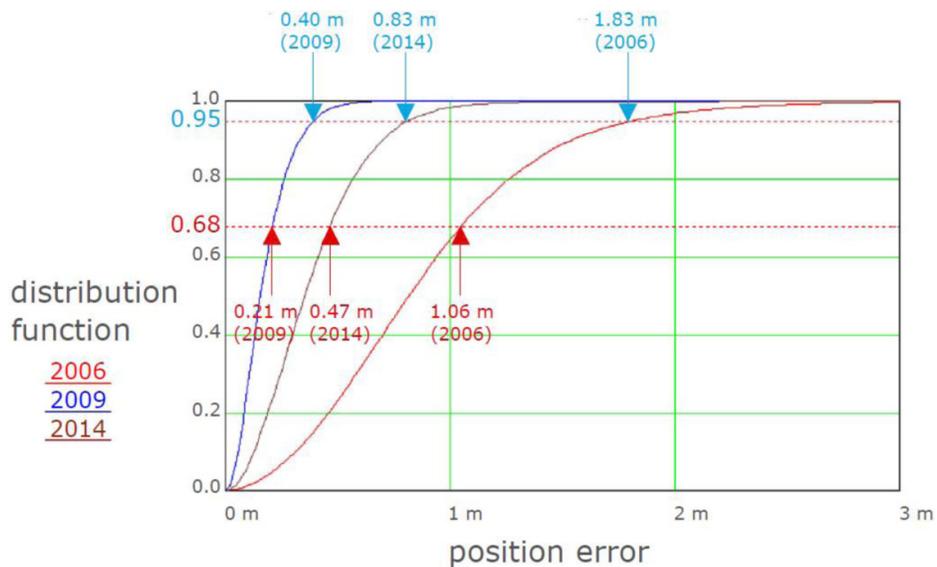
Pseudorange (PRC) corrections type 9-3 [24] broadcast from DGPS reference station Rozewie were received by a single frequency (L1) receiver installed in Gdynia, 40 km from the transmitting MF beacon. These tests were focused on evaluation of horizontal and vertical accuracies of the 3D position. Data files contained position time series in the format of NMEA 0183 standard, GGA referenced to WGS-84 datum ( $a = 6378137.00$  m,  $b = 6356752.314$  m) [25, 26]. The reference point for all campaigns was set in the same place – Port of Gdynia with coordinates:  $B=54^{\circ} 31.75524'$  N,  $L=18^{\circ} 33.57418'$  E,  $H = 68.07$  m. The measured ellipsoidal coordinates were transformed to Gauss-Krueger (X, Y) coordinate system. The Gauss-Krueger projection is a conformal mapping of a reference ellipsoid of the earth onto a plane where the equator and central meridian remain as straight lines and the scale along the central meridian is constant. All other meridians and parallels being complex curves. This projection is presented in [27].

**Table. 1:** The accuracy characteristics (with 1 cm approximation) of the Polish DGPS system based on measurements in 3 campaigns: 2006, 2009, 2014

Type of statistics	DGPS 2014		DGPS 2009		DGPS 2006	
	repeatable accuracy	predictable accuracy	repeatable accuracy	predictable accuracy	repeatable accuracy	predictable accuracy
Number of measurements	951.698 fixes		214.842 fixes		2.187.842 fixes	
RMS ( $\varphi$ ) – latitude	0.37 m	0.40 m	0.12 m	0.13 m	0.78 m	0.81 m
RMS ( $\lambda$ ) – longitude	0.25 m	0.26 m	0.16 m	0.17 m	0.61 m	0.62 m
RMS (h) – height	0.60 m	0.60 m	0.33 m	0.34 m	1.43 m	1.43 m
DRMS(2D)	0.44 m	0.48 m	0.20 m	0.21 m	0.99 m	1.02 m
<b>2DRMS (2D)</b>	<b>0.88 m</b>	<b>0.96 m</b>	<b>0.40 m</b>	<b>0.42 m</b>	<b>1.98 m</b>	<b>2.04 m</b>
DRMS (3D)	0.75 m	0.77 m	0.39 m	0.40 m	1.74 m	1.76 m
<b>calculations directly from population (by sorting errors)</b>						
CEP (2D)	0.33 m	0.36 m	0.16 m	0.16 m	0.78 m	0.83 m
R68 (2D)	0.43 m	0.47 m	0.21 m	0.21 m	1.01 m	1.06 m
<b>R95 (2D)</b>	<b>0.75 m</b>	<b>0.83 m</b>	<b>0.39 m</b>	<b>0.40 m</b>	<b>1.77 m</b>	<b>1.79 m</b>
SEP (3D)	0.55 m	0.59 m	0.29 m	0.38 m	1.35 m	1.39 m
R68 (3D)	0.72 m	0.76 m	0.39 m	0.51 m	1.74 m	1.77 m
R95 (3D)	1.39 m	1.40 m	1.00 m	1.20 m	3.02 m	3.04 m

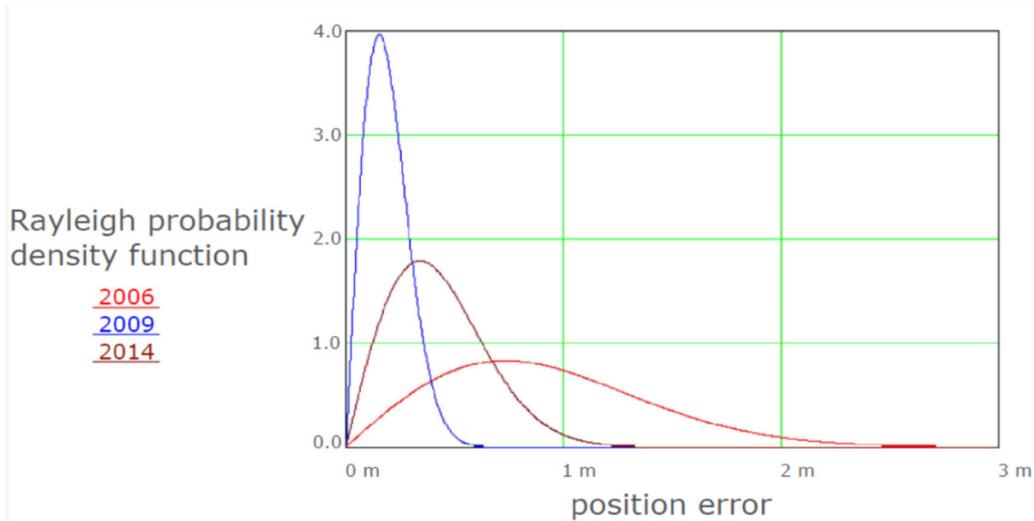
The figure below presents the distribution of error position (predictable accuracy) determined for the years 2006, 2009, 2014. One can conclude that such a large number of measurements guarantees high accuracy of error estimation and their probabilities. It is worth noting that studies conducted in 2006 used the reference station with equipment purchased in 1994. In contrast, studies in 2009 and 2014, used the upgraded in 2009, station equipment.

The most representative measure of the precision horizontal position error was adopted, because the main purpose of maritime DGPS is to render positioning service for marine vessels (2D).



**Fig. 2:** DGPS horizontal position error (relative to true position) distribution function calculated for campaigns in 2006 (right), 2009 (left), 2014 (central)

The distribution of measurement results determining the Rayleigh probability density functions, according to relation (2, 4) for campaigns carried out over the years 2006-2014 is presented in Figure 3.



**Fig. 3:** Probability density function (Rayleigh distribution) for position error of the maritime DGPS

The statistical distribution of position errors shows lack of measurement outliers (40 km off reference station), which presents a very high availability of position with the errors at the level of 1-2 meter. This accuracy is obtained at probability level of 95% for accepted maritime application.

#### IV. DISCUSSION

Similar measurements were taken in the USA, Canada, Brazil [15], Germany [14], and Portugal [13]. Long-term analyses were conducted using data from permanent GPS reference networks in Canada, Brazil, and the United States. Several million observations were processed in this study during the years 1998-2000. Studies focus on large ionospheric gradients near the equatorial anomaly and at subauroral latitudes (associated with the main trough and storm-enhanced densities). Results indicate that DGPS horizontal positioning accuracies are degraded by a factor of 2-5 relative to average values [15]. They showed that the differences in accuracy observed in the years 2009 and 2014 are likely to result from the impact of the solar activity.

The measurements carried out in Germany [14] taken during a voyage of a vessel in the western part of the Baltic Sea show relatively weak DGPS decorrelation effects in time and space over a maximum distance of 214 nm. Archived accuracies were calculated as a (median: 0.98m,  $1\sigma=1.27$  m,  $2\sigma=2.06$  m) and showed that a significant cause of loss of accuracy could be no reception pseudorange corrections (PRC's) from the reference station resulting in jumps of the position error. Polish refereed test analyses, in contrast to studies performed in the dynamics carried out by Schlueter et al.[14]– at variable and long distances from the reference stations – showed no loss of availability of the pseudorange corrections. The reason for this was the relatively short distance to the DGPS station (40 km) resulting in high levels of signal strength (about 52 dB/ $\mu$ V/m) and signal to noise ratio (SNR) – 20 dB. At the Portuguese coast investigations on the DGPS system accuracy spatial and temporal decorrelation were carried out in 2004. Horizontal position error reached 1m, and PRC's deccorelation was estimated as 0.4m/100nm.

The results of presented accuracy carried out in Poland[28,29], the USA, Canada, Brazil[15], Germany [14], and Portugal [13] show that the GNSS positioning solution accuracy has been

significantly better than the required by IALA 10 m in more than 95% of the samples. It is very important that the adoption of a nominal accuracy of IALA DGPS marine for 2 m ( $p = 0.95$ ) results in an official extension of the application of this system to other maritime activities as for example, hydrography and exploration of marine resources.

## **V. CONCLUSIONS**

DGPS-based reference stations transmitting signals at frequencies 283.5-325 kHz, are today the primary positioning system used for navigation in coastal waters, port approaches, VTS and AIS systems. Polish DGPS surveys conducted over the years indicated that this system provides sub-meter position accuracy. The statistical distribution of position errors shows lack of measurement outliers, which demonstrate very high availability of position errors at the level of 1 meter. A significant increase in determining accuracy of the position observed in the years 2009 and 2010 to 2006 shows that the technical advancement of the DGPS reference station equipment has a significant impact on accuracy.

Research shows that improving the accuracy of the position of the GPS system results in an increase in accuracy of the systems of differential. The differences in the statistics of the position accuracy data observed in 2014 and 2009 prove the conclusions of [15] concerning the effect of solar activity in 2014 to be correct.

## **REFERENCES**

- [1] *Global Positioning System Standard Positioning Service Performance Standard 4<sup>th</sup> Edition*, United States of America Department of Defense, 2008.
- [2] *General Lighthouse Authorities Radio Navigation Plan*, General Lighthouse Authorities of the United Kingdom and Ireland, 2007.
- [3] *European Radio Navigation Services – Development of the European Union Navigation Plan*, Helios Technology Ltd, 2004.
- [4] *2012 Federal Radionavigation Plan*, United States of America Department of Defense, United States of America Department of Homeland Security, United States of America Department of Transportation 2012.
- [5] *EGNOS Service Definition Document – Open Service (EGNOS SDD OS)*, Directorate-General for Energy and Transport (European Commission), Revision 2.0, 2013.
- [6] *Global Positioning System Wide Area Augmentation System (WAAS) Performance Standard 1<sup>st</sup> Edition*, United States of America Department of Transportation, Federal Aviation Administration, 2008.
- [7] Ciećko A., Oszczak B., Oszczak S., *Determination of Accuracy and Coverage of Permanent Reference Station DGPS/RTK in Gdynia*, Proceedings of the 7<sup>th</sup> Bilateral Geodetic Meeting Italy-Poland, Reports on Geodesy, No.2(65), 2003, pp. 45-51.
- [8] Koc W., Specht C., Chrostowski P., *Application Effects of Continuous Satellite Measurements of Railway Lines*, Proceedings of the 12<sup>th</sup> International Conference and Exhibition – Railway Engineering 2013, 2013.
- [9] Specht M., Szot T., *Accuracy Analysis of GPS Sport Receivers in Dynamic Measurements*, Annual of Navigation, No. 19(1), 2012, pp. 165-176.
- [10] William J. Hughes Technical Center NSTB/WAAS T&E Team, *Global Positioning System (GPS) Standard Positioning Service (SPS) Performance Analysis Report*, FAA GPS Product Team, 2000-2010.
- [11] Bailey B.K., *GPS Modernization Update & Program Plans*, Proceedings of the 13<sup>th</sup> Meeting of National Space-Based Positioning, Navigation, and Timing Advisory Board, 2014.

- [12] Smolarek L., Sniegocki H., *Risk Modelling for Passages in Approach Channel*, Mathematical Problems in Engineering, Vol. 2013, 2013.
- [13] Monteiro L. S., Moore T., Hill C., *What is the accuracy of DGPS?*, Proceedings of the 61<sup>st</sup> Annual Meeting of The Institute of Navigation, pp. 805-817.
- [14] Schlueter S., Minkwitz D., Hirrl A., *Investigations of Decorrelation Effects on the Performance of DGNSS Systems in the Baltic Sea*, Proceedings of the 5<sup>th</sup> ESA Workshop on Satellite Navigation Technologies and European Workshop on GNSS Signals and Signal Processing (NAVITEC), 2010, pp. 1-7.
- [15] Skone S., El-Gizawy M., Shrestha S. M., *Analysis of differential GPS performance for marine users during solar maximum*, Radio Science, Vol. 39, Issue 1, 2004, pp. RS1S17.
- [16] Ober P. B., *RSIM-Based Integrity Monitoring for DGNSS*, Proceedings of the 2002 National Technical Meeting of The Institute of Navigation, 2002, pp. 467-473.
- [17] Pietraszewski D., Spalding J., Viehweg C., Luft L., *U.S. Coast Guard Differential GPS Navigation Field Test Finding*, NAVIGATION: Journal of the Institute of Navigation, Vol. 35, No. 1, 1988, pp. 55-72.
- [18] Pianka D., Pietraszewski D., Poppe M., Ruane M., *Medium Frequency DGPS Data Link*, Proceedings of the 4<sup>th</sup> International Technical Meeting of the Satellite Division of The Institute of Navigation, 1991, pp. 845-854.
- [19] *RTCM Recommended Standards for Differential GNSS (Global Navigation Satellite Systems) Service*, Version 3.0, RTCM Paper 30-2004/SC104-STD, 2004.
- [20] *International Technical characteristics of differential transmissions for GNSS from maritime radio beacons in the frequency band 283.5-315 kHz in Region 1 and 285-325 kHz in Regions 2 and 3*, ITU Recommendation M.823-3, 2006.
- [21] *Recommendation on the Performance and Monitoring of DGNSS Services in the Frequency Band 283.5 – 325 kHz*, IALA Recommendation R-121, 2004.
- [22] Specht C., Nowak A., Felski A., et al., *Analysis of the Availability and Reliability of Differential GPS System*, Research Project of the Committee for Scientific Research, Polish Academy of Sciences, No. 8 T12E02521, 2000-2003.
- [23] *GPS Position Accuracy Measures*, NovAtel –Positioning Leadership, APN-029 Revision 1, 2003.
- [24] Enge P., Young D., Sheynblat L., Westfall B., *DGPS/Radiobeacon Field Trials Which Compare Type 1 and Type 9 Messaging*, Proceedings of the 49<sup>th</sup> Annual Meeting of The Institute of Navigation, 1993, pp. 671-680.
- [25] *Department of Defense World Geodetic System 1984, Its Definition and Relationships with Local Geodetic Systems 3<sup>rd</sup> Edition*, NIMA Technical Report TR8350.2, 2000.
- [26] Merrigan M.J., Swift E.R., Wong R.F., Saffel J.T., *A Refinement to the World Geodetic System 1984 Reference Frame*, Proceedings of the 15<sup>th</sup> International Technical Meeting of the Satellite Division of The Institute of Navigation, 2002, pp. 1519–1529.
- [27] Deakin R.E., Hunter M.N., Karney C.F.F., *The Gauss-Krueger Projection*, Proceedings of the 23<sup>rd</sup> Victorian Regional Survey Conference, 2010.
- [28] Specht C., *Accuracy and coverage of the modernized Polish Maritime differential GPS System*, Advances in Space Research, Vol. 47, Issue 2, 2011, pp. 221-228.
- [29] Specht C., *DGPS and EGNOS Systems in Hydrographic Survey – Accuracy Analyses at the Polish Sea Area*, Hydroacoustics, Vol. 10, 2007, pp. 193-198.
- [30] A. A. Makhloof, “Ellipsoidal Approximation for Topographic-Isostatic Masses Effects on Airborne and Satellite Gravity Gradiometry”, *International Journal of Civil Engineering & Technology (IJCIET)*, Volume 4, Issue 6, 2013, pp. 145 - 159, ISSN Print: 0976 – 6308, ISSN Online: 0976 – 6316.