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EGNOS Performance Improvement in Southern Latitudes

L. Panagiotopoulou & K. Frangos
Geotopos S.A., Athens, Greece

ABSTRACT: This paper intends to provide results from "EGNOS Performance Improvement in Southern Latitudes" (EPISOL) project. EPISOL is performed by the Greek company GEOTOPOS S.A. under a contract with the European Space Agency (ESA). EPISOL project aims at analysing, testing and validating the European SBAS EGNOS (European Geostationary Navigation Overlay Service) performance, by outpointing advantages and limitations. It has been designed and operated in a very complicated and demanding environment, the Aegean Sea (Greece, Southern Europe), in which a huge amount of commercial and cruise vessel routes are scheduled daily. Technically, EPISOL also exploits the possibility of EGNOS data collection through other means than the direct Signal in Space (SiS), such as SiSNet (Signal in Space through interNet). Results from this project will form a solid basis towards navigation service improvements and safety enhancements for highly demanded maritime applications, providing important information about EGNOS performance at the edge of the system's service area. In this frame, EPISOL includes a significant number of trials and collection of a large amount of data on coasting vessels in the Aegean before and after the operation of EGNOS Ranging and Integrity Monitoring Station (RIMS) in Athens. As EGNOS data analysis illustrates the European SBAS performance, arguably well-established GNSS navigation techniques, such as GPS RTK, offer reference trajectories for direct comparisons on the position domain.

1 INTRODUCTION

EPISOL has been operated in two Phases: Phase 1 in 2008 before Athens RIMS installation and Phase 2 in 2010 after its deployment and integration in EGNOS ground station network. It has been designed and operated in the Aegean Sea to provide important information about EGNOS performance at the edge of the system's service area.

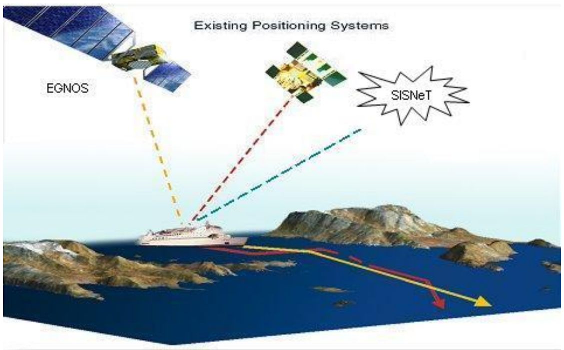


Figure 1: Concept of EPISOL project.

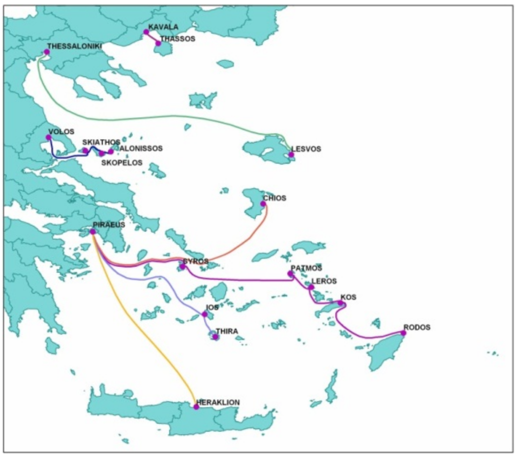
More specifically, EPISOL main objective is the validation of EGNOS relative position accuracy achieved in the Aegean Sea and, in the sequel, the demonstration of alternative methods for redistribution of EGNOS messages in order to overcome EGNOS SiS coverage limitations. In this frame, results from both phases concerning system performance and conclusions for system improvement and future applications in the area, have been drawn.

2 EXPERIMENTS DESIGN

As noted, EGNOS performance is mainly related to the achieved accuracy on the position domain. Therefore, the project has included a significant number of trials and collection of a large amount of data on vessels that sail towards very popular island destinations of the national cabotage, tactically. All routes were carefully chosen in reference with the highly demanding environment of the Aegean Sea and designed for trials in the open sea, as well as for trials for canal, coast and port approach navigation. Additionally, EPISOL analysis presents the achievable system integrity performance in Greece adapting EGNOS standards to International Maritime Organisation (IMO) requirements.

EPISOL analysis also illustrates the continuity of EGNOS SiS and the need to complement with other means of signal transmission. SiSNet combines the powerful capabilities of SBAS navigation and web technologies and thus, EGNOS SiS messages are transmitted via the internet in real time. Figure 1 shows the concept of EPISOL project.

To validate EGNOS performance, the recently established Hellenic Positioning System (HEPOS) has provided GPS RTK reference trajectories with respect to HEPOS network coverage and HEPOS NTRIP RTCM corrections transmission due to the local GPRS network coverage limitations.



Map 1: EPISOL trials in the Aegean Sea.

Considering these limitations and in accordance with the project's demands, Map 1 shows seven routes to famous Greek islands, that cover a major part of the Aegean Sea, selected to carry out EPISOL trials.

3 DATA COLLECTION PLATFORM ARCHITECTURE

EPISOL data collection platform is described in Figure 2:

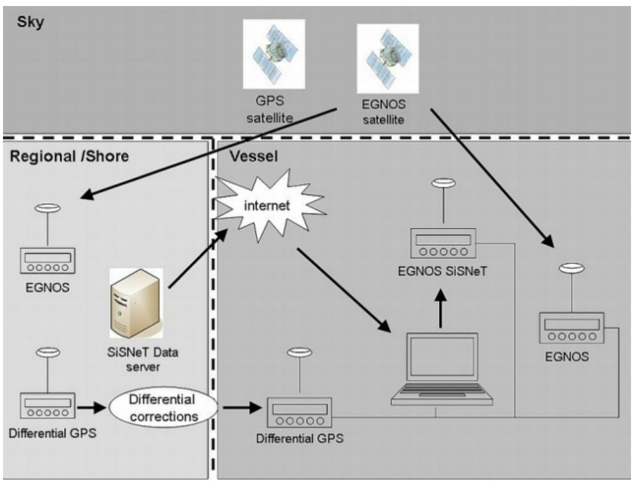


Figure 2: System Architecture.

Two individual Septentrio Polarx2e_SBAS GNSS dual frequency (L1/L2) receivers were installed on board. The first receiver was logging SBAS messages transmitted from both PRN 120 and PRN 126 EGNOS geostationary satellites. PRN 120 broadcasts EGNOS Operational Signal which provides the fully tested system service and PRN 126 broadcasts EGNOS Test Signal, including the latest healthy Athens RIMS data in the system's status configuration. Currently, Athens RIMS is gradually integrated in the system network and the latest system status is continuously tested before its official broadcast. The second receiver accessed EGNOS messages exclusively through SiSNet and the SBAS PVT (Position – Velocity – Time) solution was being internally calculated by the receiver's software. In order to avoid lever-arm effects, both receivers were receiving satellite data from one antenna and an antenna splitter was splitting the signal to the receiver antenna ports. Finally, two laptops connected to a 3G/GPRS modem were offering internet access, providing HEPOS RTCM corrections for the reference trajectories and EGNOS messages through SiSNet server when GPRS network was available. The data collection period of Phase 1 opened at early May 2008 and it was closed at mid July 2008, of Phase 2 opened at May 2010 and it was closed at mid October 2010 while in each Phase almost 70 hours of GNSS/SBAS measurements at 1 Hz rate have been recorded.

4 PERFORMANCE ANALYSIS AND EVALUATION

For the scope of this paper, positioning results using EGNOS from three different routes are displayed, considering the criterion of the equal geographical distribution along the Aegean Sea. Thus, the northernmost Route I, the Route G at the central latitudes of the Hellenic sea area and the southernmost Route A are selected. The performance analysis is focused on different evaluation objectives on the position domain. The main objective that is common to all selected routes, is the comparison of the performance of the achieved position accuracy for both EGNOS Operational Signal and EGNOS Test Signal as transmitted from PRN 120 and PRN 126 respectively. The reference trajectory is the provided HEPOS RTK PVT solution, as long as the vessel was sailing within the limits of HEPOS and local GPRS network coverage. All positioning results from the selected data sets are compared with IMO requirements for both accuracy alone and accuracy / integrity, as well.

Table 1: IMO requirements.

Navigation type application	System / Service level parameters			
	Absolute accuracy	Integrity		
	Horizontal (m)	Protection level (m)	Alarm time (sec)	Availability per 30 days (%)
Ocean / Coastal	10	25	10	99.8
Port approach	10	25	10	99.8
Port	1	2.5	10	99.8

Table 1 shows IMO requirements for different types of navigation applications. The system's integrity level is defined from the calculated position protection limits. Positioning results for EGNOS Operational Signal from Phase 1 and from Phase 2 are illustrated in the analysis performance of Route G. Finally, positioning from EGNOS SiSNet is provided and comparisons between EGNOS SiS Test Signal results and the relative SiSNet results are displayed in the analysis performance of Route I.

5 EGNOS POSITIONING IN SOUTH LATITUDES: RESULTS

Route A

Table 2: Route A EGNOS Performance on the position domain.

Route A Heraklio Piraeus	Performance on the position domain VPE EGNOS Test	HPE EGNOS Test	VPE EGNOS	HPE EGNOS
Mean (m)	0.20	2.11	1.05	1.64
Standard Deviation (m)	2.26	3.47	5.29	2.08
2-sigma 95% (m)	4.71	9.05	11.62	5.80
Availability (IMO Req) %	73.0		12.5	

As noted, EGNOS Horizontal Position Errors (HPE) and EGNOS Vertical Position Errors (VPE) that visualize system's accuracy performance are calculated using reference position the RTK PVT solution provided by HEPOS. It is remarked that HEPOS reference position accuracy is perturbed by all factors that influence RTK positioning. However, RTK method (when available) offers considerably, the optimum navigation solution and especially in maritime applications it is ideally used for position error calculations. Table 2 shows system's accuracy performance for both EGNOS Test and Operational Status. The general comment from this Table is that EGNOS Test signal mean values are more than 5 times less than the corresponding values of EGNOS Operational and the standard deviation on the vertical direction (height accuracy performance) is 135% improved. Nevertheless, EGNOS Operational Signal mean values are 25% improved in comparison with the corresponding values of the Test signal and the standard deviation is almost 40% improved horizontally (with relevance to the corresponding RTK solutions).

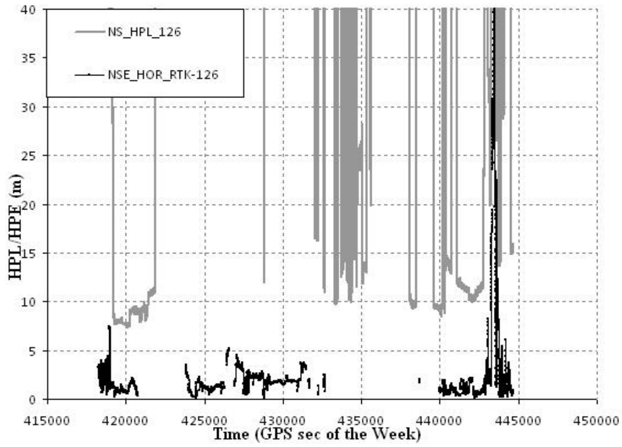


Figure 3: Route A EGNOS Test HPE/HPL time series.

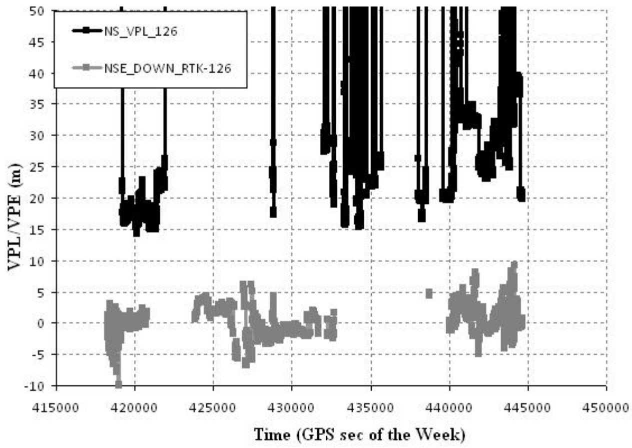


Figure 4: Route A EGNOS Test VPE/VPL time series.

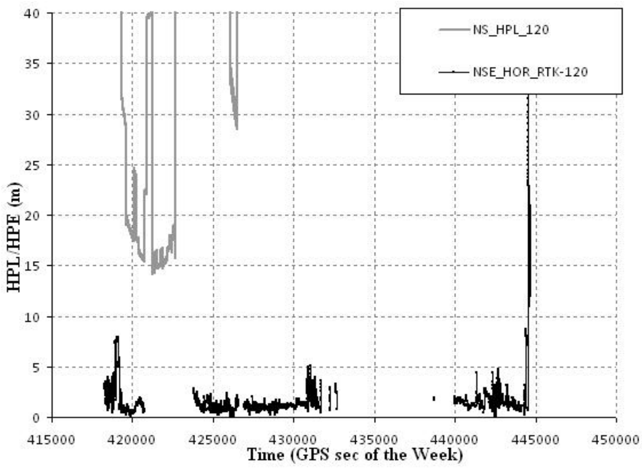


Figure 5: Route A EGNOS Operational HPE/HPL time series.

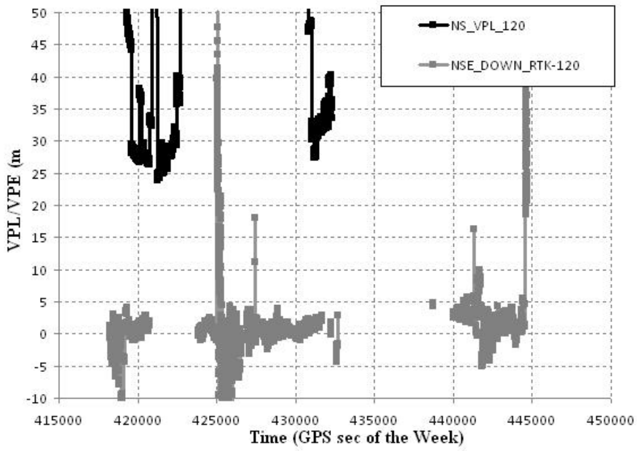
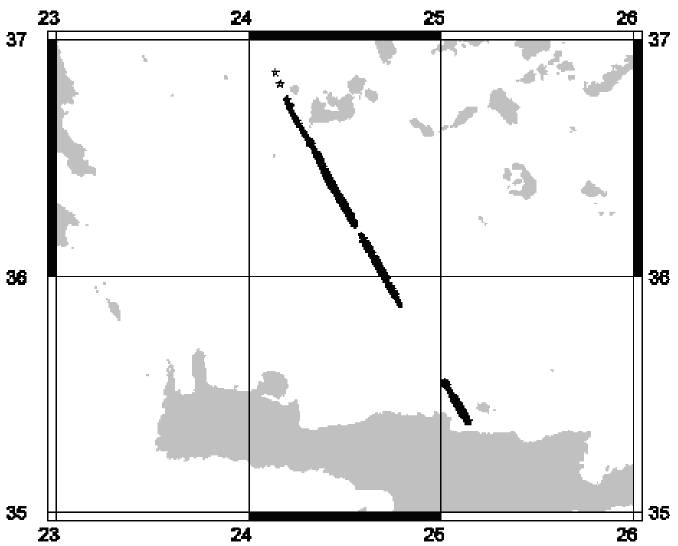
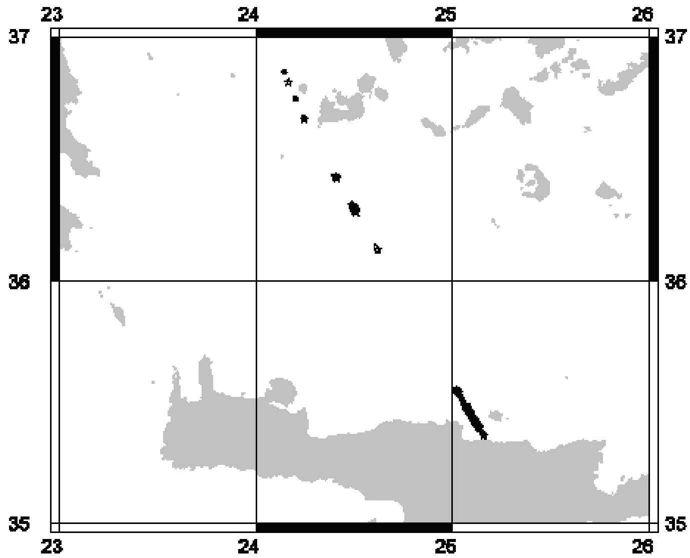


Figure 6: Route A EGNOS Test VPE/VPL time series.

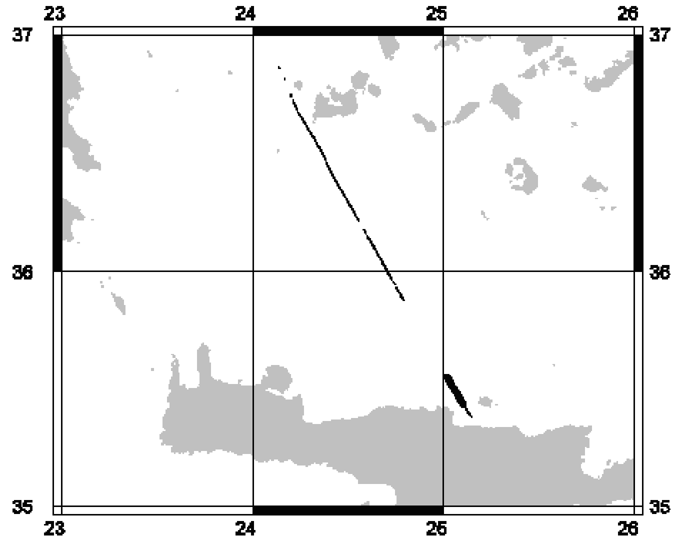
Figures 3-6 show the time series of EGNOS HPE and VPE along with the Horizontal Protection Limits (HPL) and the Vertical Protection Limits (VPL). Figures 3 and 4 correspond to the EGNOS Test signal time series plots. On Figure 3 the grey dotted line represent the HP limit and the black dot represents the horizontal position error whereas, on Figure 4 the black dotted line represents the VP limit and the grey dots represent the vertical position error. Respectively, Figures 5 and 6 correspond to the EGNOS Operational signal time series plots. It is evident that EGNOS Test signal offers larger time spans of protection limits than EGNOS Operational. Therefore and in accordance with Table 1 concerning IMO requirements for different navigation modes, EGNOS Test delivers significantly better results. Maps 2 and 3 show dynamic plots for EGNOS Operational and Test respectively, corresponding to IMO requirements for accuracy alone. Simple dots are the epochs where HPE is more than 10m, small circles represent epochs where HPE is less than 10m (requirements for ocean, coastal and port approach navigation), while star shapes are epochs that correspond to HPE less than 1m (port navigation).



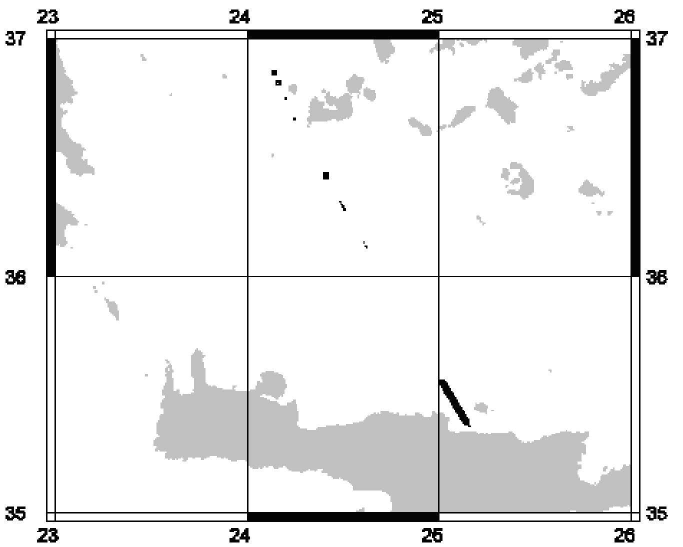
Map 2: Route A EGNOS Operational plot for IMO accuracy requirements.



Map 3: Route A EGNOS Test plot for IMO accuracy requirements.



Map 4: Route A EGNOS Operational plot for both accuracy and integrity IMO requirements.



Map 5: Route A EGNOS Test plot for both accuracy and integrity IMO requirements.

Accordingly, Maps 4 and 5 are dynamic plots for EGNOS Operational and EGNOS Test respectively, that correspond to IMO requirements for both accuracy and integrity on different navigation modes. Simple dots represent positions where Horizontal Position Limit value is larger than 25meters. Square shapes are epochs at which the position horizontal limit is less than 25 meters and horizontal position error is less than 10 meters at the same time, conditions that cover IMO requirements for open sea, coastal and port approach navigation. Star shapes represent epochs where HPL is less than 2.5m and Horizontal Position Error is less than 1 meter at the same time. According to Figures 3 and 5 this route has not had positioning results where HPE is less than 1 meters and HPL is less than 2.5 meters at the same time, conditions required for port navigation. However, as shown on Maps 2 and 3, both Test and Operational Signal HPE results meet the IMO requirements for port navigation.

Route G

Table 3: Route G / Phase 1 and 2 EGNOS Performance on the position domain.

Skiathos Volos	Performance on the position domain							
	VPE EGNOS TEST		HPE EGNOS TEST		VPE EGNOS		HPE EGNOS	
Phase	1	2	1	2	1	2	1	2
Average (m)	1.26	0.27	0.89	1.20	1.22	0.30	2.82	2.23
Standard Deviation (m)	2.30	1.56	0.63	0.63	8.88	3.76	15.95	5.21
2-sigma 95% (m)	5.86	3.39	2.47	2.47	18.99	7.22	34.72	12.65
Availability (IMO Req) %	89	98	89	98	16	41	16	41

EGNOS positioning results from Route G have been selected to outline the system's performance improvements on the position domain between the two Phases of the project. Table 3 shows the basic statistics of the results. VPE EGNOS Test mean values is more than 4.5 times improved in Phase 2, whereas the HPE EGNOS Test mean values are 25% improved as well. The VPE EGNOS Test standard deviation is 33% improved in Phase 2 and HPE EGNOS Test standard deviation is on the same level for both phases. Accordingly, VPE EGNOS Operational mean values are extremely improved in Phase 2, whereas the corresponding standard deviation is almost 60% improved as well. Finally, HPE EGNOS Operational mean values are almost on the same level in both phases, when the standard deviation is almost 3 times improved in Phase 2.

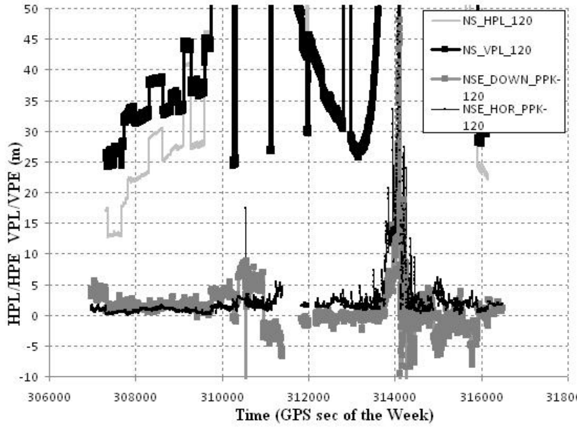


Figure 7: Route G Phase 1 EGNOS Operational HPE/HPL and VPE/VPL time series.

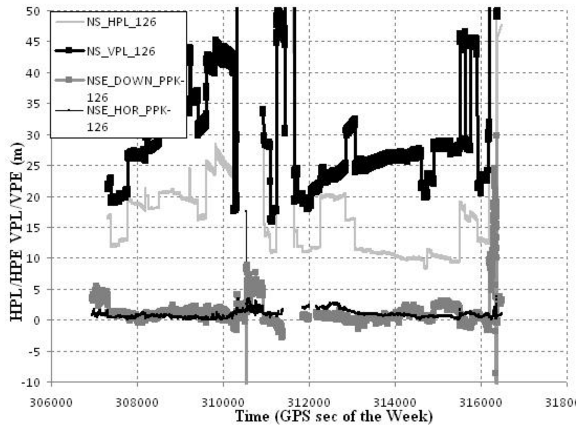


Figure 8: Route G Phase 1 EGNOS Test HPE/HPL and VPE/VPL time series.

Figures 7 and 8 display the horizontal and vertical position errors along with the horizontal and vertical protection limits time series charts in Phase 1. Figure 7 corresponds to the HPE-HPL / VPE-VPL performance through time as provided from EGNOS Operational signal and Figure 8 corresponds to the HPE-HPL / VPE-VPL time series of EGNOS Test signal.

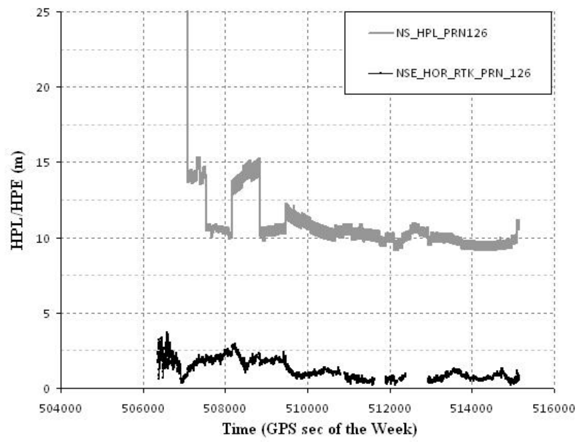


Figure 9: Route G Phase 2 EGNOS Test HPE/HPL time series.

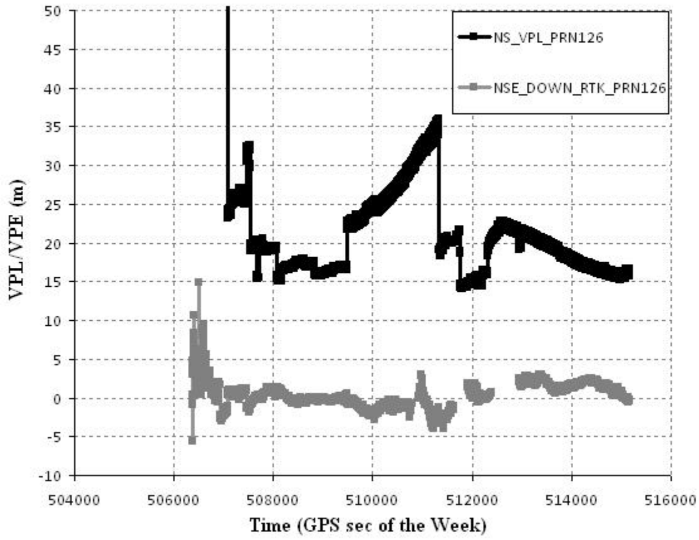


Figure 10: Route G Phase 2 EGNOS Test VPE/VPL time series.

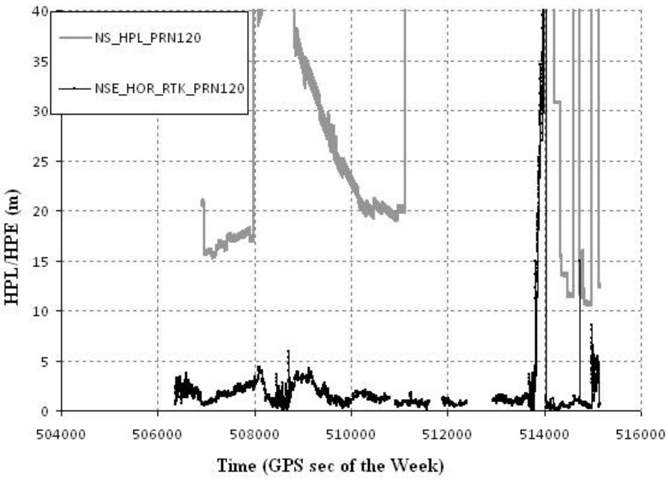


Figure 11: Route G Phase 2 EGNOS Operational HPE/HPL time series.

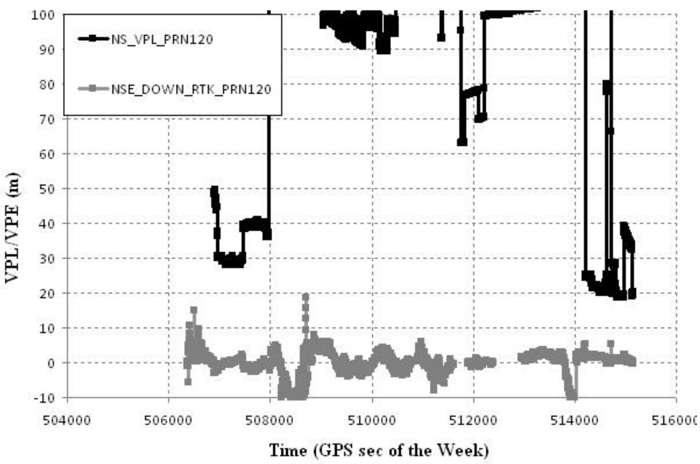
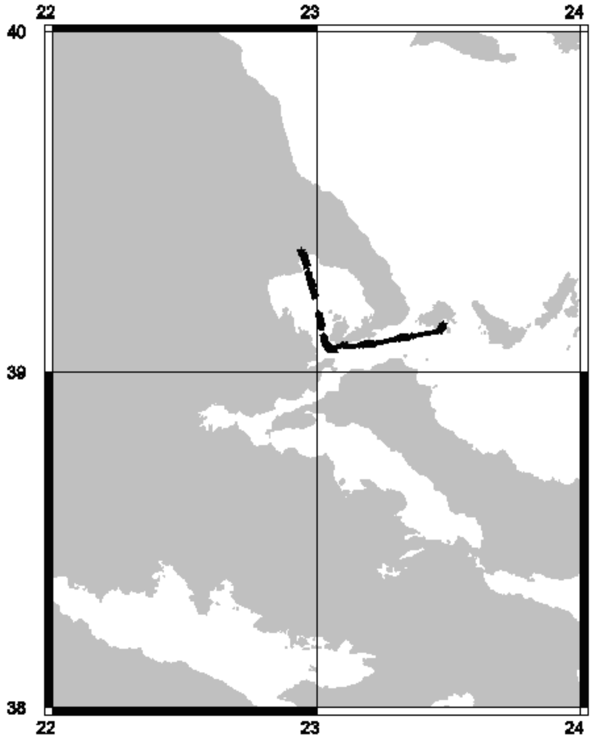
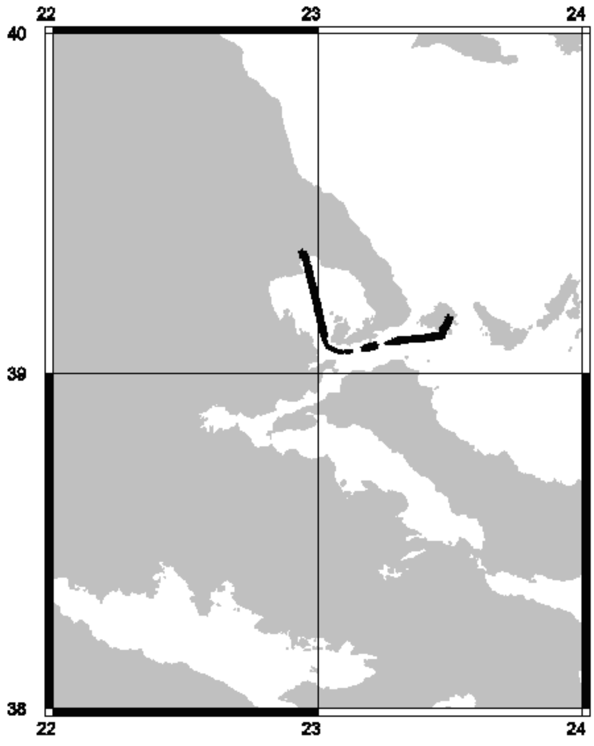


Figure 12: Route G Phase 2 EGNOS Operational VPE/VPL time series.

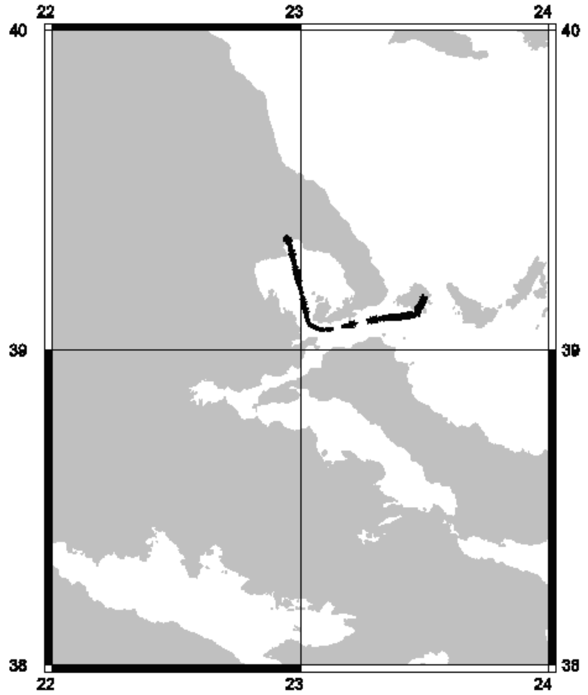
Accordingly, Figures 9-12 display the horizontal and vertical position errors along with the horizontal and vertical protection limits time series charts in Phase 2 Figures 9 and 10 show HPE-HPL and VPE-VPL diagrams of EGNOS Test, respectively. In the same manner, Figures 11 and 12 show the HPE-HPL and VPE-VPL diagrams of EGNOS Operational Signal. Comparing the integrity performance between the Operational and Test signal, it is obvious that system's integrity performance is enhanced after the installation and deployment of Athens RIMS.



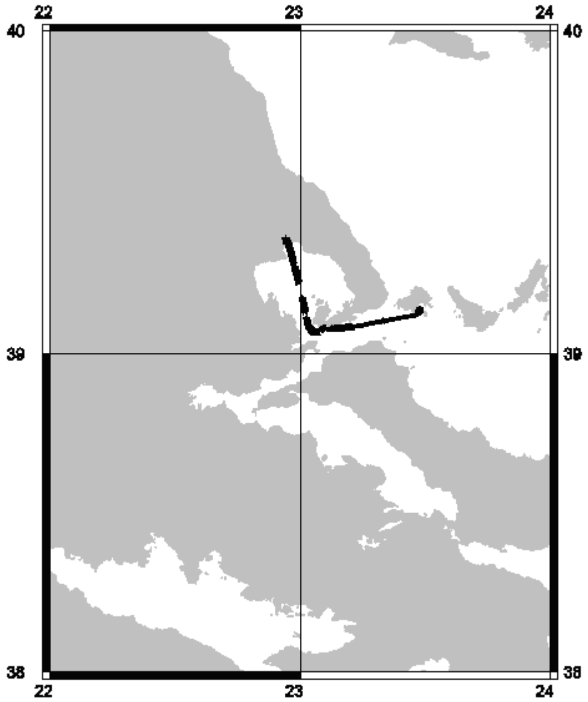
Map 6: Route G Phase 1 EGNOS Operational plot for IMO accuracy requirements.



Map 7: Route G Phase 1 EGNOS Test plot for IMO accuracy requirements.

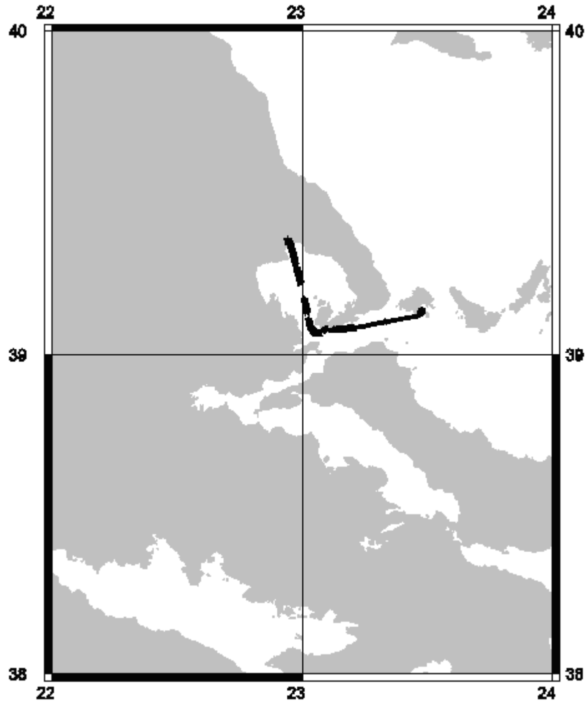


Map 8: Route G Phase 2 EGNOS Operational plot for IMO accuracy requirements.

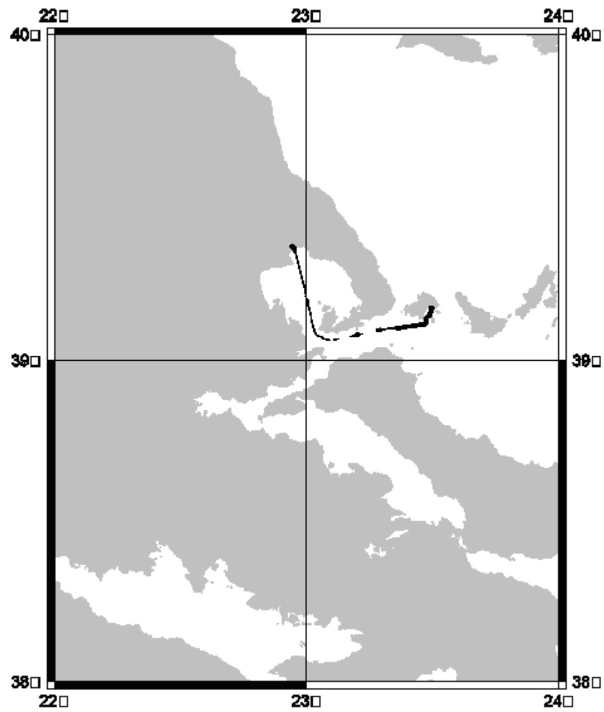


Map 9: Route G Phase 2 EGNOS Test plot for IMO accuracy requirements.

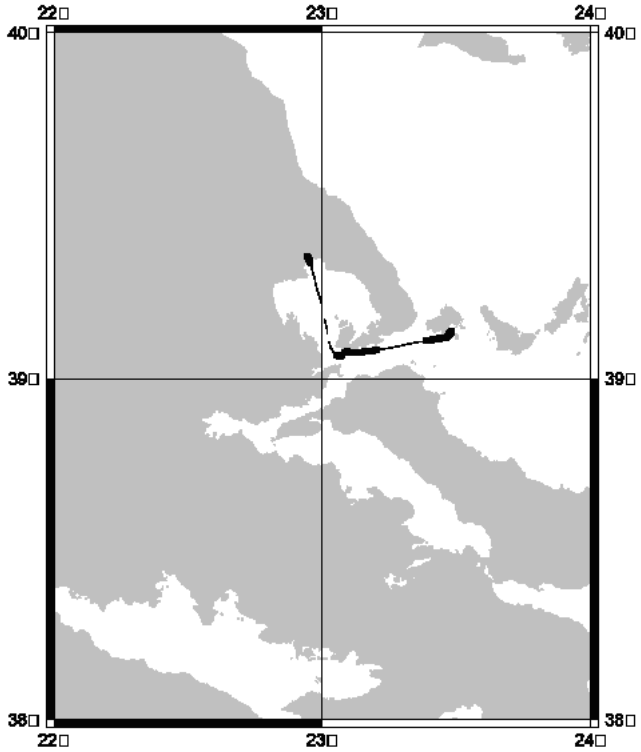
Maps 6-9 are the IMO requirements plots for accuracy alone and correspond to EGNOS Test and EGNOS Operational signal performance for both Phase 1 and Phase 2. Same, Maps 10-13 are the IMO requirements plots for both accuracy and integrity for EGNOS Test and EGNOS Operational signal performance, accordingly. A close examination of Map 13 shows that the system performance improvement in both accuracy and integrity during Phase 2 is even clearer.



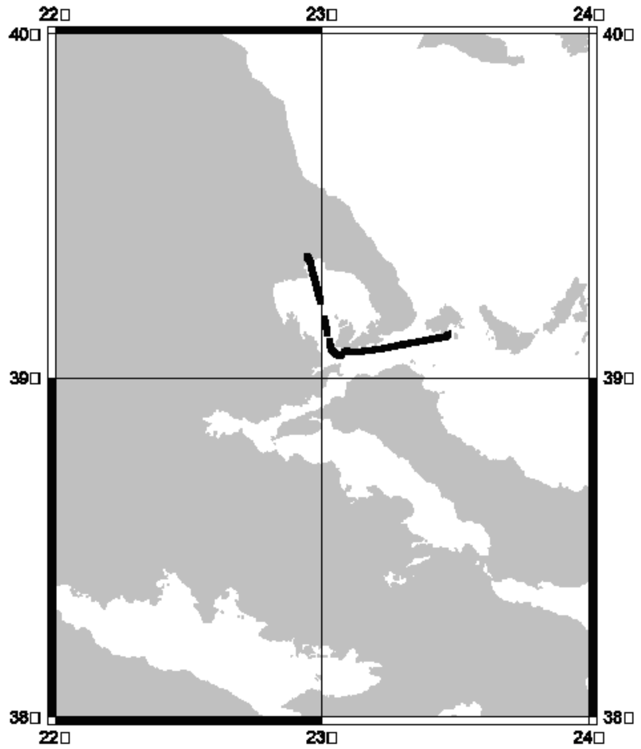
Map 10: Route G Phase 1 EGNOS Operational plot for both accuracy and integrity IMO requirements.



Map 11: Route G Phase 1 EGNOS Test plot for both accuracy and integrity IMO requirements.



Map 12: Route G Phase 2 EGNOS Operational plot for both accuracy and integrity IMO requirements.



Map 13: Route G Phase 2 EGNOS Test plot for both accuracy and integrity IMO requirements.

Route I

Table 4: Route I - EGNOS SiS and SiSNet Performance on the position domain.

Thasos Kavala	Performance on the position domain							
	VPE EGNOS TEST		HPE EGNOS TEST		VPE EGNOS		HPE EGNOS	
Phase	SiS	SiS NeT	SiS	SiS NeT	SiS	SiS NeT	SiS	SiS NeT
Average (m)	0.13	0.47	1.12	0.47	8.60	1.01	3.63	1.53
Standard Deviation (m)	3.99	4.00	1.54	1.76	11.90	2.96	4.27	0.81
2-sigma 95% (m)	8.12	8.48	4.20	3.98	32.40	6.93	12.16	3.14
Availability (IMO Req) %	97	97	97	97	15	N/C*	15	N/C*

(*N/C – Not Computed)

EGNOS performance analysis in the European south latitudes includes performance comparisons between SiS and SiSNet, aiming at the evaluation of alternative means of receiving EGNOS messages than the direct satellite signal reception. Table 4 is displaying SiS and SiSNet performance on the position domain. It is obvious that EGNOS Test for both message reception methodologies perform alike on the vertical position direction, whereas small differentiations are observed on the horizontal position accuracy. It is also evident, that the levels of the position accuracy for EGNOS Operational are extremely improved using SiSNet, however protection limits for EGNOS SiSNet Operational were not available. For this reason Figures 13 and 14 display the horizontal and vertical position errors along with the horizontal and vertical protection limits time series charts, for EGNOS SiS Test signal alone and EGNOS SiSNet Test signal alone, respectively.

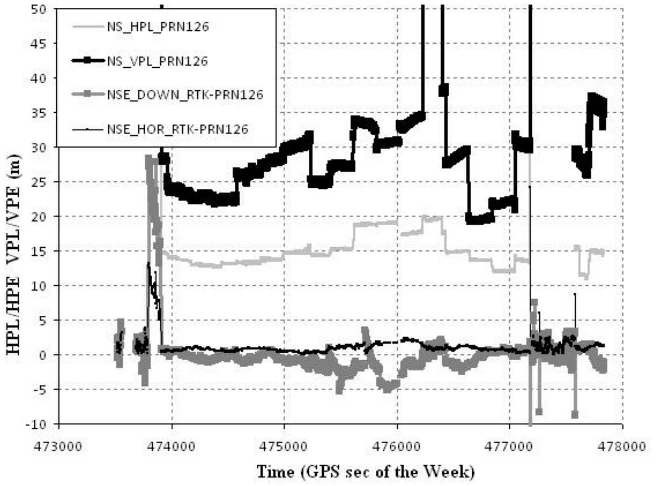


Figure 13: Route I EGNOS SiS Test HPE/HPL and VPE/VPL time series.

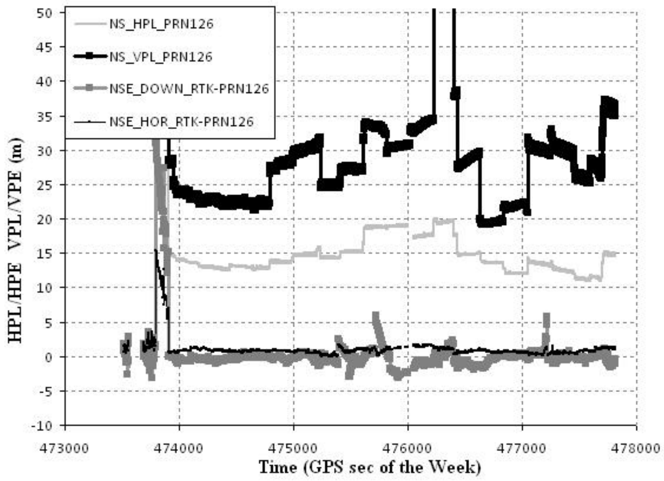


Figure 14: Route I EGNOS SiSNeT Test HPE/HPL VPE/VPL time series.

6 CONCLUSIONS

EPISOL is a project mainly concentrated on the performance analysis of the position domain. Namely, it is focused on the position accuracy and integrity that can be achieved using EGNOS for maritime applications. As the project has taken place in two Phases, before and after Athens RIMS deployment, using SiSNet as the alternative means for EGNOS messages reception, the most important conclusion drawn by the analysis results is the significant system improvement after the RIMS deployment. Actually, and since RIMS data are gradually integrated into the system's new configuration, it is anticipated that EGNOS accuracy and integrity performance at the south latitudes, shall further be improved at the time of the complete integration of the RIMS in the system's network. Moreover, it has been proved that EGNOS SiSNet could equally replace SiS reception in environments and under conditions that SiS reception is not available. Finally, it has been shown that even under the current configuration status, EGNOS can be used as the primer navigation system for many maritime applications meeting IMO requirements for sea navigation.

ACKNOWLEDGEMENTS

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