A kinematic campaign to evaluate EGNOS 1046 Maritime Service

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BIOGRAPHIES

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Francisco Javier Pancorbo Garcia, has an M.Sc degree in Electronic and Management Engineering from Universidad Politécnica de Madrid (1997). He is a Program Manager at everis Aerospace and Defense, in charge of the GNSS and Earth Observation areas. He co-authors 1 journal article related to commissioning of Large Telescopes (SPIE 2007).

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Manuel López Martínez is Technology Officer in the European GNSS Agency (GSA), where he is supporting and fostering the adoption of Galileo and EGNOS in maritime, inland waterways and search and rescue applications. He received his PhD in System Engineering and Automation from the University of Seville in 2005, where he obtained permanent position as associate professor at in 2008. He was teaching until he joined the GSA in 2013 as seconded national expert in the Market Development Department.

ABSTRACT

Global Navigation Satellite Systems (GNSSs) have improved the efficiency and accuracy of transportation means. In terms of safety, the European Geostationary Navigation Overlay System (EGNOS) is providing vertical and lateral guidance to civil aviation since 2011. Furthermore, EGNOS can support applications in other sectors such as maritime, railways and road.

The present contribution aims to assess the use of EGNOS for maritime navigation compliant with the International Maritime Organization (IMO) requirements established in its Resolution A.1046 (27) for harbour entrances, harbour approaches and coastal waters: 99.8% of Signal Availability, 99.8% of Service Availability, 99.97% of Service Continuity and 10 m of Horizontal Accuracy.

The study has selected the waters surrounding the Canary Islands, within the south west border of coverage of EGNOS, to perform a kinematic test campaign from 7th November 2018 to 21st April 2019. For this purpose, we installed a geodetic multi-frequency multi-constellation receiver-antenna pair on-board two vessels from the Armed Institute of the Spanish Civil Guard based in Tenerife.

The ESA/UPC GNSS laboratory (gLAB) tool suite has processed the remotely-retrieved GNSS measurements, in conjunction with EGNOS corrections and with cleansed GPS broadcast navigation messages. EGNOS Availability and Continuity have been evaluated within the area comprised between longitudes 13°W to 19°W and latitudes 27°N to 30°N with spatial resolution of 0.1° per 0.1°. The vessel accuracy is evaluated as the difference of coordinates obtained with single-frequency EGNOS solution and the reference trajectory computed with dual-frequency Precise Point Positioning and final orbits from the International GNSS Service.

The EGNOS Maritime Service met all IMO requirements in the geographic area of latitudes northern than 28°N and longitudes eastern than 16°W after reaching a Signal Availability of 99.999%, a Service Availability in 99.90% of the predefined rectangular region, and 1.06 m of Horizontal Accuracy at the 95th percentile. In contrast, the Service Continuity requirement (only required for coastal waters) was met in 62.50% of the predefined region. We conclude that the continuity risk is the most limiting factor for expanding the EGNOS Maritime Service along the coastal waters of Canary Islands, in the EGNOS south-west border of coverage.

INTRODUCTION

The Global Navigation Satellite System (GNSS) has improved the efficiency and accuracy of transportation means. In terms of safety, Augmentation Systems provide vertical and lateral guidance to aircrafts complying with stringent requirements established by the International Civil Aviation Organization [1]. Furthermore, Augmentation Systems can support applications in other transportation sectors such as maritime, railways and road [2].

The potential use of Satellite Based Augmentation System (SBAS) to support new services for maritime applications has been studied in the European [3] and in the North America [4] regions, taking into consideration the requirements of the International Maritime Organization (IMO). In particular, those requirements established in its Resolution A.1046 (27) [5] which are listed in **Table 1** for the self-consistency of this paper.

The coverage offered by a SBAS-based navigation service for maritime applications would enhance the present situation, in which maritime users rely on Differential GNSS (DGNSS) corrections and integrity information for GNSS signals broadcast in real-time by approximately 350 reference stations worldwide distributed that belong to the International Association of Maritime Aids to Navigation and Lighthouse Authorities (IALA) [6].

The aim of the present contribution is to assess the compliance of the European Geostationary Navigation Overlay System (EGNOS), operational since 2009, against IMO requirements. In particular, we used the most demanding requirements in harbour entrances, harbour approaches and coastal waters. In what follows, we refer to as EGNOS 1046 Maritime Service in accordance to the numbering of the IMO Resolution.

The paper is organized as follows. Next section describes the data and experimental setup used. Then, the methodology and the different GNSS processing steps are described in detail. After that, the results of every assessed metric are detailed, including some insights of the GNSS data processing. The paper concludes identifying the geographic area in which the EGNOS 1046 Maritime Service met IMO requirements, identifying the most limiting factor.

Table 1 Requirements of the International Maritime Organization established in its Resolution A.1046 (27) [5]

Parameter	Navigation Phase	
	<i>Ocean Waters</i>	<i>Harbour entrances, harbour approaches and coastal waters</i>
Horizontal Accuracy 95%	100 m	10 m
Signal Availability	99.8%	99.8%
Service Continuity (over 15 min)	n/a	99.97%
Position update rate	2s	2s
Time to Alarm ^a	Maritime Safety Information as soon as practicable	10 s
System coverage	Adequate ^b	Adequate ^b

^a. Generation of integrity warnings in cases of system malfunctions, non-availability or discontinuities

^b. Taking into account the radio frequency environment, the coverage of the system should be adequate to provide position fixing throughout this phase of navigation.

DATA

The study has selected the waters surrounding the Canary Islands to perform the kinematic test with two vessels from the Armed Institute of the Spanish Civil Guard based in Tenerife and depicted in **Figure 1**. The campaign started on 7th November 2018 (DoY 311 of 2018) and finished on 21st April 2019 (DoY 111 of 2019). Due to technical and operational reasons, MT-50 was used until 15th February 2019 (DoY 46 of 2019) and EC2259 from 18th of February 2019 (DoY 49 of 2019) until the end of the data campaign.

Figure 2 depicts the experimental setup necessary to perform the experimental kinematic campaign, which are listed in **Table 2**. A geodetic multi-frequency multi-constellation GNSS Septentrio PolarX5 receiver and a PolaNt-x MF antenna have been installed on-board the two aforementioned vessels, together with the necessary equipment to retrieve its data remotely using a 4G modem.

The other data files involved in the assessment are GPS broadcast navigation files and EGNOS messages. Those have been gathered from public web servers. In particular, the RINEX navigation files are download from the International GNSS Service (IGS) [7], whereas EGNOS differential corrections have been download from the SERENAD Data Server that belongs to National Centre for Space Studies (CNES).

Figure 1: Guardia Civil's vessels used: M-50 "Río Jándula" (left) and EC2259 "Pico del Teide" (right).

Table 2. List of Components installed in the vessels from the Spanish police Guardia Civil

Name	Model	Description
Antenna Septentrio Polan-x MF	13725	Antenna which obtains the RF signal from GNSS satellites.
Septentrio Receiver PolaRx5e	4801021	Receiver that is responsible to collect the data from the antenna.
RF Cable of 30m TNC-m to TNC-m	215702	Cable which connects the receiver to the antenna. 30 m RF cable TNC-m to TNC-m (RG223). Max. attenuation 17 dB @1500 MHz, static bending radius 26 mm, cable diameter 5.3 mm.
Raspberry pi 3 b+	2ABCB-RPI3BP	Management unit responsible to download the GNSS data stored in the receiver and upload it to Dropbox.
Router 4G Alcatel MW40V	MW40V-2AALIB1	Router which allows the management unit to connect to Internet.
Surge Guard	N/A	Multi-socket adaptor where connect the devices of the equipment.
Fan ELUTENG USB	N/A	Small size fan responsible to extract the hot air avoiding thermal variations on the GNSS receiver.
External Battery Zendure A2	ZDA2P33-b	External battery to power the management unit when there is no current from the dock or engines, avoiding data gaps in such transition.
Adapter Battery Charger AUKRU Micro USB 5V 3A	N/A	Socket which keeps the battery connected to the vessel current.
Waterproof Suitcase TecTake	402412	Watertight case modified to contain and protect the equipment, to install it a ventilation and some holes to allow cables.
Flange	N/A	The flange is used to fix the antenna at the top of the vessel pole.

Figure 2: Experimental set up used in the kinematic data collection that has been installed on the vessels from Guardia Civil (top left): A GNSS antenna in the pole (top right), and waterproof suitcase (bottom left) containing the GNSS receiver, a 4G router and other necessary equipment (bottom right).

METHODOLOGY

Once the data collection was completed, the first step of the GNSS data processing was to cleanse the navigation RINEX files following the methodology presented in [8], removing potential errors and inconsistencies from different sources. The removed errors include, for instance, data-logging errors and/or hardware/software bugs, losses of navigation messages, different transmission time, among others. In contrast, the EGNOS files are already consolidated by CNES and did not require further processing.

The second step consists in the evaluation of the Availability and Continuity of the EGNOS Maritime Service following a fault-free receiver approach. That is, a receiver that is assumed to be in continuous signal tracking, without cycle-slips, all GPS navigation data and EGNOS corrections available, and no environmental effects. We investigated the performance of the EGNOS Maritime Service where the rover receiver has navigated. That is, the area comprised between longitudes 13°W to 19°W and latitudes 27°N to 30°N, in the south west border of coverage of the current EGNOS service area.

The third step is the accuracy and integrity assessment of the vessel trajectory. For this purpose, we have computed a reference trajectory using the Precise Point Positioning (PPP) technique [9] and final orbits from IGS. The error of the vessel is evaluated as the difference in the coordinates obtained with single-frequency EGNOS maritime solution and those obtained with the dual-frequency ionospheric-free PPP solution.

We have used the ESA/UPC GNSS laboratory (gLAB) tool suite [10] as the main software to perform the calculations. The SBAS maritime template in gLAB has been used, changing the satellite elevation mask from 5 to 7.5 degrees. Notice that in **Table 1** no requirements on the Alarm Limits (ALs) based on SBAS Protection Levels (PLs) are indicated. Therefore, the Horizontal and Vertical Alarm Limits (HAL and VAL) have been disabled in gLAB by taking a huge value of 100 km. In contrast, and according to IALA [11] we set the Dilution of Precision (DOP) mask to exclude epochs with geometries PDOP ≥ 6 and HDOP ≥ 4 , to ensure that the position information can be reliably used for navigation purposes. The Service Continuity is computed using a fixed window of 15 minutes as Continuity Time Interval (CTI) according to the IALA guidelines [12].

RESULTS

The EGNOS Maritime Service met the IMO requirement of Signal in Space (SiS) Availability of 99.8%. According to **Table 3**, the individual satellites in Geosynchronous Equatorial Orbit (GEO) broadcasting EGNOS messages already achieved such requirement. A simultaneous data gap of 8 s was observed in the SiS of the satellites PRN123 and PRN136, which gives rise to a combined signal availability of 99.999% of the time.

In terms of Availability and Continuity, Figure 3 depicts the performance of the EGNOS Maritime Service in its south west border of coverage using a resolution of 1° per 1°. The results are depicted without applying any kind of interpolation strategy to avoid any artefact or smoothing. The maps evidence that the assessment in the region comprising the Canary Islands is challenging because the current EGNOS exhibits a spatial gradient in performance.

Table 3. EGNOS SIS outages occurred from 07/11/2018 to 21/04/2019

Geostationary PRN	Days	Data Gaps (s)	Availability (%)
123	165	2862	99.98
136	165	1359	99.99
123 and 136	165	8	99.999

Figure 3. EGNOS performance at its south west border of coverage. Left plot shows the service availability with the DOP mask activated and right plots shows the service continuity using a fixed window of 15 minutes.

The observed gradient in performance over the Canary Islands required the use of a finer resolution. **Figure 4** depicts the area comprised between longitudes 13°W to 19°W and latitudes 27°N to 30°N, where every square pixel represents 0.1° per 0.1°. The top row depicts the Availability assessment, whereas the bottom row shows the Continuity assessment. The left column shows the values at the individual cells and the right column, its compliance against the most demanding requirements of IMO in terms of harbour entrances, harbour approaches and coastal waters. In order to give a quantitative result, we draw a rectangular region surrounding the Canary Islands, in which we evaluate the results numerically.

Figure 4 indicates that the EGNOS Maritime Service met the IMO requirement of 99.8% of Availability in 99.90% of the predefined rectangular region. In contrast, the bottom row depicts how the EGNOS Maritime Service only met the Continuity requirement of 99.97% in a smaller area of 62.50% of the predefined region. Obviously, the use of a more refined area (e.g., waters within 12 nautical miles of the coast) would lead to different percentage results. Irrespectively of the area chosen, **Figure 4** shows that the most stringent IMO requirements in terms of continuity in coastal waters (note that ocean waters do not have a continuity requirement) are met in latitudes north of 28.5°N and longitudes east of 16.5°W.

Figure 4. Zoom of Figure 3 at Canary Islands with a finer grid of 0.1° per 0.1°. Left column shows the service availability (top row) and continuity (bottom row) and right column shows its compliance with IMO requirement of 99.8% and 99.97% respectively.

The intersection of the previously depicted maps of Service Availability and Service Continuity yields the Service Coverage map, shown in **Figure 5**. That is, Service Coverage is defined as the region in which it is simultaneously achieved a Service Availability of 99.8% and Service Continuity of 99.97%. This occurs by latitudes northern than +28 degrees and longitudes eastern than -16 degrees. By comparing the Service Coverage results with **Figure 4**, it can be seen that the region in which the Service Coverage meets simultaneously the two IMO requirements coincides with the Service Continuity. That is, the Service Availability does not impose a limitation on the coverage.

The analysis of the root cause of the lack of continuity in the EGNOS Maritime Service falls out of the scope of the present contribution. However, the authors performed a further analysis dedicated to identify whether the cause could be attributable to values of Horizontal and Positioning Dilution of Precision larger than the specified thresholds ($PDOP \geq 6$ and $HDOP \geq 4$) or to the unavailability of Ionospheric Corrections present in the EGNOS messages. **Figure 6** and **Figure 7** reveal the mean HDOP and PDOP values were respectively under 4 and 6 and that the availability of ionosphere corrections was over 99.8% of the time. This result suggests that the cause resides somewhere else.

Figure 5. EGNOS Maritime Service Coverage map, defined as the simultaneous intersection maps of Availability over 99.8% and Continuity over 99.7%.

Figure 6. Dilution of Precision maps: Positioning DOP (left) and Horizontal DOP (right).

The last part of the present study finishes with the assessment of the accuracy and integrity of the EGNOS Maritime Service. For that purpose, the two aforementioned vessels MT-50 and EC2259 have been navigating around the Canary Islands of Tenerife, La Palma and La Gomera, see **Figure 9**. During the kinematic data collection campaign, the most demanding phase of the navigation requirements of **Table 1** has been assessed. Indeed, the bottom panels of **Figure 9** depict several harbour entrances, harbour approaches and navigation in coastal waters.

Figure 7. Availability of Ionosphere Corrections in the Canary Islands during the kinematic campaign.

Figure 8. Aggregated trajectories for the MT-50 and EC2259 vessels from 7/11/2018 to 21/04/2019.

Table 4 summarizes the results of the kinematic evaluation using the 95th percentiles, whereas **Table 5** in the appendix details each navigation day. The kinematic campaign totals over 12 million epochs, which is more than 148 days. However, the protection levels have been computed using the integrity information contained in the SBAS messages, whereas the navigation errors are evaluated with respect to the reference trajectory computed with PPP. It can be seen that the horizontal and vertical errors of the EC2259 vessel are worse than those of the MT50. The reason explaining this deterioration is that the upper part of the pole where the GNSS antenna was installed in the second vessel had more antennae and other equipment in than the first vessel. In contrast, the horizontal and vertical protection levels are more similar, indicating that the geometry of the satellites is comparable.

Figure 9. Zoom of Figure 8 for some selected days.

The navigation errors in the horizontal component of the two vessels is 1.15 m, after aggregating more than twelve million epochs. Therefore, the EGNOS Maritime Service met the IMO requirement of 10 m of horizontal accuracy at the 95th percentile. It might be surprising the large values observed in the Protection Levels of both components. The reason is that in the maritime processing a conservative bound of 8 m is used to bound the degradation of the fast and long term corrections with respect to time. The values of the PL could be lowered by taking account the values present in SBAS Message Type 10, as it is currently done in the Aviation domain [13] processing.

Table 4. Aggregated results of the accuracy and integrity of the vessels in terms of Horizontal and Vertical Positioning Error (HPE and VPE) and Horizontal and Vertical Protection Levels (HPL and VPL). The values are expressed in meters and in form of 95th percentiles.

VESSEL	EPOCHS (s)	95th HPE (m)	95th HPL (m)	95th VPE (m)	95th VPL (m)
MT-50	8473010	1.06	68.35	1.34	139.90
EC2259	4355145	1.29	67.29	1.49	140.42
ALL	12828155	1.15	67.89	1.39	140.03

CONCLUSIONS

Our study concludes with the observation that EGNOS Maritime Service met all IMO requirements in the geographic area of latitudes north of 28°N and longitudes east of 15.5°W. The continuity risk is, by far, the most limiting factor for expanding the EGNOS Maritime Service along the coastal waters of Canary Islands, in the EGNOS south-west border of coverage.

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APPENDIX

Table 5. Detailed results of the kinematic assessment. For each navigation day (ID), it can be read the name of the vessel, the number of epochs in seconds, the travelled distance (in metres) and the 95th percentile value of the horizontal and vertical positioning error and the corresponding protection levels (in metres).

ID	Vessel	Year	DoY	Epochs (s)	Distance (m)	HPE (m)	HPL (m)	VPE (m)	VPL (m)
1	MT-50	2018	311	86400	3036	1.48	66.15	1.55	139.68
2	MT-50	2018	312	86400	3542	1.10	65.35	1.44	147.57
3	MT-50	2018	313	86400	4101	0.94	66.27	1.25	137.99
4	MT-50	2018	314	86400	4717	0.75	65.77	1.07	135.91
5	MT-50	2018	315	86400	3634	1.40	70.00	1.58	140.93
6	MT-50	2018	316	86400	3694	1.29	65.97	1.95	139.45
7	MT-50	2018	317	86400	3429	1.35	69.61	1.50	139.49
8	MT-50	2018	318	86400	3182	1.11	67.64	1.45	135.90
9	MT-50	2018	319	86400	10585	1.55	67.38	1.47	139.17
10	MT-50	2018	320	86400	3441	0.89	65.87	1.34	136.68
11	MT-50	2018	321	86384	4588	0.90	67.42	1.45	139.08
12	MT-50	2018	322	86400	6323	0.82	71.74	1.59	142.71
13	MT-50	2018	323	86400	5196	1.22	68.12	1.53	138.60
14	MT-50	2018	324	86400	3388	0.84	67.49	1.24	137.94
15	MT-50	2018	325	86400	4067	1.05	68.95	1.53	139.40
16	MT-50	2018	326	86400	2925	0.85	68.24	1.28	138.46
17	MT-50	2018	327	86400	2970	1.11	73.70	1.41	156.85
18	MT-50	2018	328	86400	2598	0.94	71.75	1.40	154.22
19	MT-50	2018	329	86400	2147	0.89	66.52	1.34	139.38
20	MT-50	2018	330	86400	1926	1.23	69.02	1.53	138.77
21	MT-50	2018	331	86400	2621	1.12	68.34	1.45	135.26

ID	Vessel	Year	DoY	Epochs (s)	Distance (m)	HPE (m)	HPL (m)	VPE (m)	VPL (m)
22	MT-50	2018	332	86400	3265	1.10	67.66	1.37	138.52
23	MT-50	2018	333	86400	2961	1.38	70.51	1.21	140.47
24	MT-50	2018	334	86400	65755	0.94	68.46	1.35	136.12
25	MT-50	2018	335	86400	2565	1.03	71.62	1.46	141.81
26	MT-50	2018	336	86400	2650	0.85	70.48	1.30	139.42
27	MT-50	2018	337	86400	3514	0.83	72.25	1.34	135.40
28	MT-50	2018	338	86400	3419	0.86	74.90	1.04	146.61
29	MT-50	2018	339	86400	3327	0.69	69.56	1.14	138.80
30	MT-50	2018	340	86400	3330	1.00	72.74	1.42	140.45
31	MT-50	2018	341	86400	2792	1.03	75.13	1.38	144.78
32	MT-50	2018	342	86400	2699	1.19	72.51	1.80	147.72
33	MT-50	2018	343	86400	2401	1.25	72.28	1.78	138.32
34	MT-50	2018	344	86400	3060	1.01	71.02	1.19	154.20
35	MT-50	2018	345	86400	3052	1.00	67.15	1.15	137.28
36	MT-50	2018	346	86400	3036	1.08	69.65	1.44	138.76
37	MT-50	2018	347	71199	2987	1.15	68.16	1.26	144.11
38	MT-50	2018	349	86400	4302	1.29	70.38	1.40	137.50
39	MT-50	2018	350	86400	3624	0.95	68.83	1.35	141.49
40	MT-50	2018	351	86400	3402	0.83	68.44	1.49	145.19
41	MT-50	2018	352	86400	2979	0.75	71.44	1.50	171.82
42	MT-50	2018	353	86400	3064	0.86	71.87	1.24	143.24
43	MT-50	2018	354	86400	2967	0.82	66.35	1.20	156.08
44	MT-50	2018	355	86400	2919	0.64	71.98	1.15	145.10
45	MT-50	2018	356	86400	2535	0.75	71.77	1.52	139.15
46	MT-50	2018	357	86400	5030	1.11	66.79	1.32	154.14
47	MT-50	2018	358	86400	5328	0.75	68.89	1.54	139.91
48	MT-50	2018	359	76055	3698	1.06	65.01	1.35	143.46
49	MT-50	2018	360	86400	2530	1.19	71.34	1.49	139.51
50	MT-50	2018	361	86400	2603	1.01	72.69	1.35	137.97
51	MT-50	2018	362	86400	2923	1.15	68.91	1.38	137.11
52	MT-50	2018	363	86400	2778	1.12	76.34	1.46	139.31
53	MT-50	2018	364	86400	2206	1.10	75.23	1.28	143.66
54	MT-50	2018	365	86400	3282	1.14	74.71	1.15	183.78
55	MT-50	2019	1	86400	3753	0.87	63.57	1.54	142.00
56	MT-50	2019	2	86400	3157	0.95	64.90	1.27	143.20
57	MT-50	2019	3	86400	2699	0.92	63.47	1.31	138.09
58	MT-50	2019	4	86400	2513	1.16	68.78	1.50	140.55
59	MT-50	2019	5	86400	2549	1.07	63.81	1.29	142.20
60	MT-50	2019	6	86400	4074	1.33	66.19	1.34	142.82
61	MT-50	2019	7	86400	3608	0.70	68.81	1.17	141.07
62	MT-50	2019	8	86400	2868	0.78	64.85	1.26	142.07
63	MT-50	2019	9	86400	2421	0.82	69.09	1.14	142.43
64	MT-50	2019	11	32280	1042	1.42	110.87	1.85	211.35
65	MT-50	2019	12	86400	3005	1.06	69.47	1.21	143.13
66	MT-50	2019	13	86400	3531	0.82	65.01	1.25	143.12
67	MT-50	2019	14	86400	3985	1.11	70.56	1.13	141.64
68	MT-50	2019	15	86400	2969	0.86	65.40	1.14	140.73
69	MT-50	2019	16	86400	2498	1.22	68.64	1.47	136.08
70	MT-50	2019	17	86400	3005	0.69	69.63	1.04	142.21
71	MT-50	2019	18	86400	3334	0.77	64.20	1.13	140.14

ID	Vessel	Year	DoY	Epochs (s)	Distance (m)	HPE (m)	HPL (m)	VPE (m)	VPL (m)
72	MT-50	2019	19	86400	2696	0.95	67.49	1.06	135.34
73	MT-50	2019	20	86400	2302	0.99	68.97	1.02	140.67
74	MT-50	2019	21	86400	2870	0.78	67.30	1.03	142.23
75	MT-50	2019	22	86078	3213	1.22	63.48	1.33	134.21
76	MT-50	2019	23	86400	3190	1.00	64.62	1.25	136.38
77	MT-50	2019	24	86400	3194	1.19	64.04	1.14	136.73
78	MT-50	2019	25	86400	2664	1.00	70.34	1.30	151.69
79	MT-50	2019	26	86400	2082	1.06	66.73	1.12	139.20
80	MT-50	2019	27	86400	2662	0.88	68.07	1.24	142.90
81	MT-50	2019	28	86400	3007	0.78	64.27	1.17	138.61
82	MT-50	2019	29	86400	3027	0.78	66.77	1.28	138.17
83	MT-50	2019	30	86400	3262	0.86	65.99	1.00	135.80
84	MT-50	2019	31	86400	2280	1.42	68.74	1.25	135.61
85	MT-50	2019	32	86400	2383	0.89	66.59	1.23	137.08
86	MT-50	2019	33	86400	4158	1.01	67.13	1.40	137.38
87	MT-50	2019	34	86400	4102	1.31	65.69	1.42	132.50
88	MT-50	2019	35	86400	20204	1.21	66.34	1.35	138.76
89	MT-50	2019	36	86400	92646	0.99	66.48	1.22	139.55
90	MT-50	2019	37	86400	71077	1.32	67.17	1.62	139.59
91	MT-50	2019	38	86400	3631	1.16	65.43	1.61	127.67
92	MT-50	2019	39	86400	15246	1.35	65.70	1.40	135.68
93	MT-50	2019	40	86400	63255	0.97	64.60	0.97	126.92
94	MT-50	2019	41	86400	68228	1.60	66.74	1.39	133.89
95	MT-50	2019	42	86400	88927	1.34	64.15	1.32	132.11
96	MT-50	2019	43	86400	2208	1.22	67.62	1.04	135.31
97	MT-50	2019	44	86400	2384	1.37	67.81	1.21	134.04
98	MT-50	2019	45	86400	4439	0.93	76.78	1.20	187.07
99	MT-50	2019	46	86400	3549	1.84	67.44	1.44	135.23
100	EC2259	2019	49	11674	677	0.86	55.31	1.01	112.84
101	EC2259	2019	50	86400	4147	1.18	67.69	1.28	133.14
102	EC2259	2019	51	65300	2198	1.33	64.41	1.22	132.40
103	EC2259	2019	52	86400	28987	1.13	65.99	1.67	133.34
104	EC2259	2019	53	86400	3761	1.61	66.00	1.47	133.59
105	EC2259	2019	54	86400	63388	1.38	68.06	1.57	143.53
106	EC2259	2019	55	86400	4314	1.41	69.28	1.44	135.95
107	EC2259	2019	56	86400	36487	0.91	68.34	1.30	137.66
108	EC2259	2019	57	86400	42522	0.88	66.58	1.13	127.96
109	EC2259	2019	58	86400	2898	1.36	66.28	1.43	139.99
110	EC2259	2019	59	86400	54826	1.27	67.18	1.78	142.78
111	EC2259	2019	60	86400	2549	1.21	70.38	1.67	133.33
112	EC2259	2019	61	86400	3399	1.20	66.90	1.55	139.20
113	EC2259	2019	62	86400	3081	1.32	65.94	1.61	138.56
114	EC2259	2019	63	86400	2400	1.62	68.73	1.59	134.57
115	EC2259	2019	64	86400	2231	1.15	69.48	1.48	143.10
116	EC2259	2019	65	86400	48029	1.15	66.55	1.55	138.32
117	EC2259	2019	66	86400	58382	1.14	67.42	1.57	143.79
118	EC2259	2019	67	86400	2417	1.41	65.40	1.66	147.24
119	EC2259	2019	68	86400	2621	1.42	66.84	1.57	139.93
120	EC2259	2019	69	86400	2197	1.01	66.74	1.43	137.43
121	EC2259	2019	70	86400	2127	1.25	66.60	1.52	134.76

ID	Vessel	Year	DoY	Epochs (s)	Distance (m)	HPE (m)	HPL (m)	VPE (m)	VPL (m)
122	EC2259	2019	71	86400	32176	0.94	69.34	1.30	131.16
123	EC2259	2019	72	86400	2102	1.13	69.52	1.48	140.76
124	EC2259	2019	73	86400	2394	0.90	66.15	1.21	143.07
125	EC2259	2019	74	86400	216181	1.26	68.29	2.02	145.58
126	EC2259	2019	75	86400	73649	1.29	70.09	1.70	135.42
127	EC2259	2019	76	86400	255143	1.23	69.48	1.88	138.77
128	EC2259	2019	77	86400	2988	0.84	64.86	1.15	122.16
129	EC2259	2019	78	86400	2956	1.71	65.61	1.63	124.22
130	EC2259	2019	79	86400	3299	0.81	67.43	1.22	126.44
131	EC2259	2019	80	86400	3804	1.87	70.36	1.56	132.43
132	EC2259	2019	81	86400	3789	1.48	69.78	1.29	125.60
133	EC2259	2019	82	86400	3925	0.93	68.40	1.35	127.46
134	EC2259	2019	94	47031	2101	2.44	73.03	1.68	151.88
135	EC2259	2019	95	86400	44151	1.60	67.12	1.57	152.49
136	EC2259	2019	96	86400	3608	1.73	67.83	1.59	146.40
137	EC2259	2019	97	86400	42836	1.09	65.57	1.43	149.28
138	EC2259	2019	98	86400	2119	0.84	65.24	1.28	139.19
139	EC2259	2019	99	86400	2293	0.88	69.87	1.30	148.18
140	EC2259	2019	100	86039	2640	1.49	67.13	1.71	139.99
141	EC2259	2019	101	86400	2399	1.49	65.80	1.30	138.89
142	EC2259	2019	102	86400	2590	1.35	66.75	1.36	144.61
143	EC2259	2019	103	86400	2445	1.52	66.80	1.78	145.03
144	EC2259	2019	104	86400	3239	1.18	67.00	1.48	147.58
145	EC2259	2019	105	86400	6411	1.17	69.55	1.65	142.85
146	EC2259	2019	106	86400	5972	1.03	66.64	1.38	144.06
147	EC2259	2019	107	86400	4826	1.22	66.18	2.08	147.15
148	EC2259	2019	108	86400	3367	0.97	64.83	1.07	145.49
149	EC2259	2019	109	86400	2570	0.93	68.21	1.27	164.88
150	EC2259	2019	110	86400	2015	1.00	66.19	1.30	148.41
151	EC2259	2019	111	86400	2082	0.99	67.18	1.59	143.89