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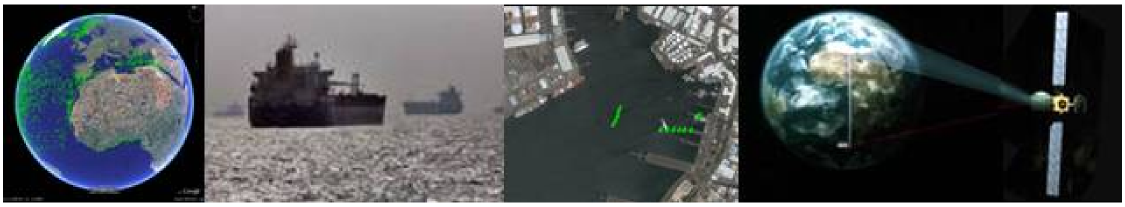

Technical Note TN 3: Vessel Position Simulator

Preparatory Action for Assessment of the Capacity of Spaceborne Automatic Identification System Receivers to Support EU Maritime Policy

DG MARE Service Contract : No MARE/2008/06/ SI2.517298

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2. DEFINITIONS AND ACRONYMS

AIS	Automatic Identification System
VPST	Vessel Position Simulation Tool
LRIT	Long Range Identification and Tracking
SatAIS	Satellite based AIS
MMSI	Maritime Mobile Service Identity (MMSI)

Table 2-1 Definitions and acronyms

3. SCOPE

One of the major issues that currently degrade the applicability of satellite AIS data in certain cases is the relatively low data update rate in most regions of the world. This issue also effects the possibilities of analysing the performance of satellite AIS data by comparing it with data from other sources (such as LRIT data. Since a thorough analysis of the current capabilities of satellite AIS is one of the main objectives of the EU study PASTA MARE, headed by LuxSpace, a vessel prediction tool has been developed under project work package WP2300. This tool will allow the inter- and extrapolation of vessel positions in order to fill up the gaps in the satellite AIS data stream that exist due to the time intervals between the acquisition of a vessel's position by the AIS satellites.

Chapter 4 provides a background on satellite based AIS (SatAIS) and introduces a number issues related to SatAIS for which the simulation tool could be of use. The goals of the system are outlined in chapter 5 while the system requirements are listed in chapter 6. Chapter 7 provides the reader with a functional description of the simulation tool. The development approach is expounded in chapter 8. A detailed outline of the algorithm is given in chapter 9. Chapter 10 provides an overview of the cases in which the simulation algorithm has been used to show the applicability of the tool with the conclusions of the demonstrations provided in chapter 11. Possible improvements for future expansion of the tool are given in chapter 12. Finally chapter 13 gives the overall conclusions from the development phase to the demonstration phase of the vessel position simulation tool (VPST).

4. BACKGROUND

The Automatic Identification System, AIS, is today an integrated part of international maritime activity. The International Maritime Organization's convention for Safety of Life at Sea, mandates almost all ships in international traffic to use the system. Intended as an anti collision system, it gives information about the traffic in the area around every vessel. AIS has also become a tool for monitoring traffic activity. Dynamic information is reported every 2-10 seconds for moving vessels depending on the speed and rate of turn.

Within the past years, several institutions and companies have demonstrated that AIS signals can be effectively received with space born receivers which makes space based AIS (SatAIS) the ideal data source to feature a data service that provides global situational awareness of ship positions, vessel and fleet movements and tracking and maritime traffic density maps.

The major unique and favourable points of AIS compared to other systems are:

- Much more information content than other systems like LRIT (only position and equipment ID provided) thus could unify several or even all other reporting systems
- AIS system will not be switched off so easily as data are important navigation aid for vessel crew
- Spoofing can be detected
- Available on global scale (pole to pole)
- Every ship above 300 tons equipped
- Full vessel tracks can be provided
- Historical data can be made available

As part of the ESA project for maritime security services called MARISS, LuxSpace has gained experience in processing, distributing and analysing satellite AIS data, originating from the six Orbcomm AIS satellites that are currently in orbit. The data AIS data used during the different project phases, which were executed from November 2008 until January 2009, has been retained on the LuxSpace data server and has been used during the development and testing of the vessel position simulation tool.

5. PURPOSE OF THE VESSEL OBJECTIVES SYSTEM GOALS

The purpose of developing a vessel position simulation tool is, as explained in chapter 4, two fold. First of all when tracking vessels it is important to know the vessel position with at maximum a 30 minute time interval between the position updates. The second purpose of a simulation tool is to enable a more convenient way of analysing the performance of satellite based AIS data by predicting all vessel positions in a certain reference area for a specific acquisition time. By comparing the combined number of acquired and simulated SatAIS vessel position inside the reference area with data acquired from other data sources for the specific acquisition time, a measure for the performance of SatAIS data can be established. In other words, the simulation tool will provide a way to optimally synchronize the vessel position data sets from multiple sources for each acquisition moment.

The SatAIS data update interval which has been used as an initial guideline during the development of the VPST is determined in paragraph 5.1 taking the six operational Orbcomm AIS satellites as reference. Paragraph 5.2 focuses on the data analysis and the role that the VPST will play in enhancing the performance. The benefits of a VPST for vessel tracking and early warning systems are further expounded in paragraph 5.3.

5.1 AIS DATA UPDATE INTERVAL

As has previously been stated the AIS data originating from the Orbcomm AIS satellites has been used as input to the development of the VPST. From the Orbcomm data sets also part of the simulation input parameters have been derived as described in paragraph 6.2. The Orbcomm vessel position update rate represents in essence the worst case scenario. All six operational Orbcomm AIS satellites have been launched in the same plane in the same orbit which means that they are following each other in their orbit. Due to this fact the minimum update time interval is rather large due to the single satellite ground track over the Earth with only six sub-satellite points. Moreover, due to the limited onboard dedicated memory capacity of the Orbcomm satellites a filter has been implemented which allows the storage of only one AIS message with the same MMSI per satellite every 5 minutes. This filtering process further complicates synchronization of this data with data from other sources and makes a position simulation tool even more necessary. Nevertheless, the Orbcomm data presents a good starting point for the tool development with the possibility to test the tool's simulation algorithm in real cases. Figure 5.2 depicts the ground track of the six satellites over Europe.

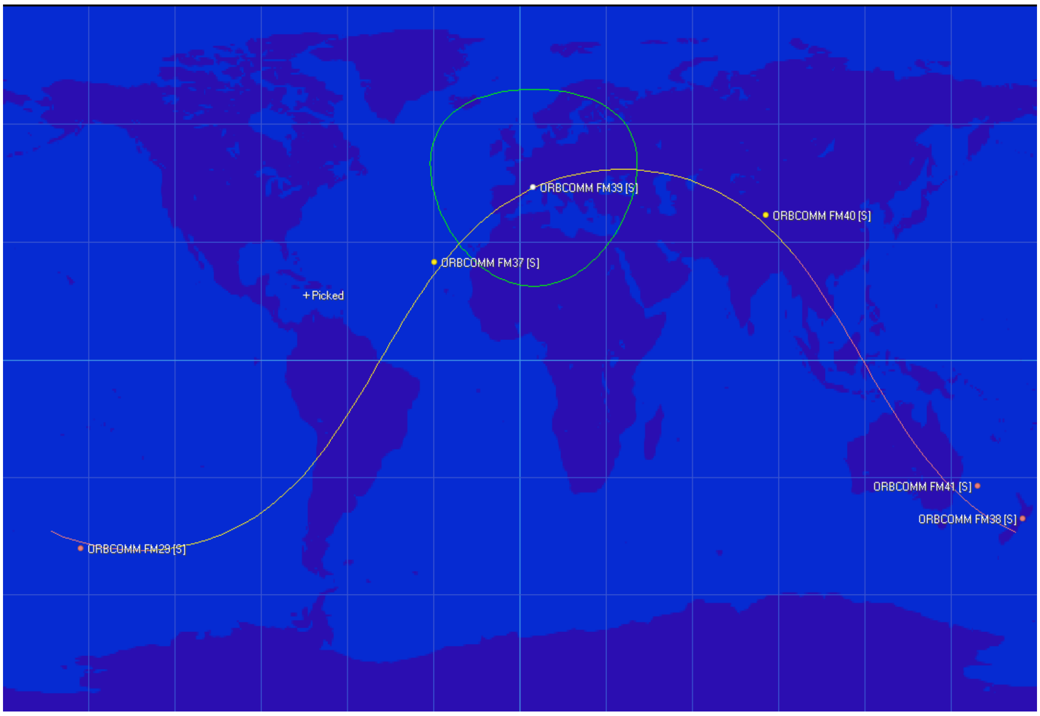


Figure 5-1: Orbcomm satellite ground track

The worst case scenario for the data update interval presents itself for the northern regions. Appendix A provides an overview of the satellite passes during one day for the north of Europe for all six Orbcomm satellites with a minimum elevation of 5 degrees. Form this it can be deduced that the maximum data update time interval at 60 degrees latitude is at maximum 14 hours.

5.2 DATA PERFORMANCE ANALYSIS

The VPST will be used for SatAIS data performance analysis for the following reasons.

- In order to enable data synchronization with other data sources
- In order to fill up the gaps in the AIS data availability for a certain area between the consecutive satellite passes as described in paragraph 5.1, or when AIS messages from a certain time instance have not been received (correctly)

The following case, as represented in figure 5.2, deals with the overlay of satellite AIS data with an image acquired using TerraSAR-X. This case represents in detail the synchronization problem as listed under point one. Since not from every time instance AIS messages have been received a large number of vessel positions detected with SatAIS fall outside the area and timeframe of the TerraSAR-X image. The case of the TerraSAR-X image holds also true for synchronization with data from other data sources such as LRIT. When the performance of SatAIS data is to be analysed a certain geographical area has to be defined within the number of detected vessels is counted for a certain acquisition moment. The course of vessels detected by SatAIS for example five minute later and outside the region subject to the analysis can be simulated to predict their position inside the region analysed. This enhances the resolution of the SatAIS data to a large extend and increases the performance of the data analysis. The accuracy of the simulated vessel position can be high in this case due to the small required time interval between the detected vessel position and the simulated vessel position.

The second point concerns the same issue with data synchronization but addresses more the large time interval between subsequent satellite passes over a certain geographical area. When the vessel positions between the satellite passes can be predicted over a long time span, although the resulting simulated vessel positions will become more inaccurate when the time span between the detected vessel positions and the simulated vessel positions increases, it will evidently further increase the resolution with respect to time of SatAIS data.

Since the SatAIS data performance analysis will mostly use historical data sets that originate from at least a day in the past, the VPST for this application concerns only position interpolation.

5.3 VESSEL TRACKING

In the light of certain applications of SatAIS data for maritime security, the ability to track vessels across international waters is essential. It is important that the detected positions of a vessel do not have large gaps in between with respect to time. Also, in the case of vessel tracking, the future positions of a vessel are of course of importance. Therefore, the VPST will also include vessel position extrapolation with a limited extrapolation time. The most important application of vessel position extrapolation when tracking vessels is the early warning system. This system, which is currently under development by LuxSpace allows the user to receive a warning when a certain condition or state has been reached. This condition is for example the vessel crossing a certain geographical line, entering a certain region, or coming in the proximity of another vessel. It is evident that an effective early warning systems requires the knowledge of vessel positions a certain time in advance. When trading off the estimated accuracy of the vessel position obtained by extrapolation and the required time for which the vessel position should be known in advance, it can be stated that the VPST should be able to extrapolate the vessel's position 3 hours ahead.

6. SYSTEM REQUIREMENTS

The system requirements are defined in three sections. The scenarios for which the simulation tool should be applicable, the simulation input parameters the tool should be capable of dealing with and the required output the simulation tool should provide.

6.1 RELEVANT SCENARIOS

The following scenarios can be defined for which requirements have to be defined of what the VPST should be able to handle. These scenarios mainly focus on the presence or absence of landmass which may influence the course of a vessel to a large extend. In addition the vessel traffic density in the area of interest is of importance since a certain distance has to be maintained between vessel positions, detected or simulated.

Scenario 1

Interpolation and extrapolation of vessel positions in open sea with no land mass in the area of interest or close to the simulated vessel tracks. An example case would be an area of interest in the middle of the Atlantic Ocean.

Scenario 2

Interpolation and extrapolation of vessel positions in areas with multiple islands in the area of interest or close to the simulated vessel tracks.

Scenario 3

Interpolation and extrapolation of vessel positions in coastal regions near the main land mass.

Scenario 4

Interpolation and extrapolation of vessel positions in harbour situations.

Scenario 4 will be excluded from the VPST development because it would complicate the algorithm to a very large extend while the results even under the best circumstances, considering the currently available data quality, would be very poo. All scenarios apply to vessel position prediction of single vessels or multiple vessels in a certain area at a specific point in time.

In addition the following requirements have been defined:

- Applicable in every traffic density
- Applicable for vessel course changes in open sea or with a certain accuracy in coastal regions
- Should take into account nearby landmass and should not simulate vessel positions inside 10 km from the coastline.
- The algorithm shall take into account the detected or simulated position of other neighbouring vessels and not simulate a vessel position within 500 meters from an already detected or simulated vessel position. The distance of 500 meters has been defined considering the fact that only AIS messages from class A vessels are currently received and processed. Class A vessels have an average weight of over 300 tons which means that their capability to manoeuvre is limited. Therefore a safety distance of 500 meters is recommendable. Vessel positions should be simulated taking AIS messages from the database in chronological order.

6.2 SIMULATION INPUT REQUIREMENTS

- The main input parameters the VPST should be able to handle are the following

- Data update interval with a maximum value of 14 hours for vessel position interpolation. This can be reduced to ten hours if during testing it becomes clear that the interpolated vessel positions with an offset of 7 hours from a detected vessel position have a very low level of accuracy.
- The VPST has to deal with and use the applicable fields available from AIS messages of types 1,2,3 and 5.
- The VPST has to be able to simulate a vessel's position at a specific moment in time specified by the user as input to the program.
- The VPST has to be able to simulate the position of a vessel in a certain area at a specific moment in time. The time and area parameters are specified by the user and are input to he program.

6.3 SIMULATION OUTPUT REQUIREMENTS

- Simulated vessel positions should be exported to a text file and displayed as graphical output on a map.
- Accuracy of simulated vessel positions should be displayed on the map and indicated in the output text file. This accuracy indication should have at least three grades.
- Every simulated vessel position should be accompanied by the vessel's MMSI, name, shiptype and date and time of the simulated vessel position.
- Interpolate vessel positions within 10 nautical miles of the real position. This holds true for open seas as well as positions near coast lines.
- Simulated vessel positions should not be located on land. A distance of at least 5 kilometers has to be taken into account as the distance between a vessel position and the coast line.
- A distance of 500 meters should be maintained between vessel positions (simulated positions and positions retrieved from the database)
- The algorithm shall be capable of extrapolating vessel positions at least 3 hours ahead

7. FUNCTIONAL DESCRIPTION

The VPST will simulate the position of vessels using extrapolation and interpolation algorithms with the following boundary conditions.

- Vessel positions should be predicted at least 5 kilometres clear of coast lines
- Vessel position should be predicted at least 500 meters away from other vessel positions, simulated or detected

The VPST switches from interpolation to extrapolation when only one vessel position retrieved from the database is located a maximum of 12 hours away from the position to be simulated.
In essence the VPST simulates the vessel positions of all the vessels at a user defined moment in time (simulation time) that have passed through a user defined area during a user defined time interval.
As an example the following can be considered.

- The simulation time is set to 2009-01-10 00:00:00
- The simulation area is defined as (upper latitude: 40, lower latitude: 30, upper longitude: -30, lower longitude: -40)
- The applicable time interval is set to be between 2009-01-08 00:00:00 and 2009-01-12 00:00:00

The VPST will then simulate all the positions of all the vessels at 2009-01-10 00:00:00 that have passed through the simulation area during the applicable time interval. Subsequently, for data analysis purposes, ONLY the simulated vessel positions at 2009-01-10 00:00:00 that are located INSIDE the simualtion area are exported to an output file.

8. DEVELOPMENT APPROACH

The development plan as depicted in figure 8-1, shows that a common approach has been followed during the development of the VPST. First the input parameters, system requirements and quality of available input are analysed. Then the development environment, programming language and program structure are determined. The actual development of the algorithm is broken up in several parts with additional testing in between in order to ensure that the development follows the correct course. The boundary conditions as described in the output requirements in paragraph 6.3 are implemented and tested. The last step consists of the overall testing with relevant scenarios as input in order to test the performance and applicability of the VPST and verify the fulfilment of the requirements.

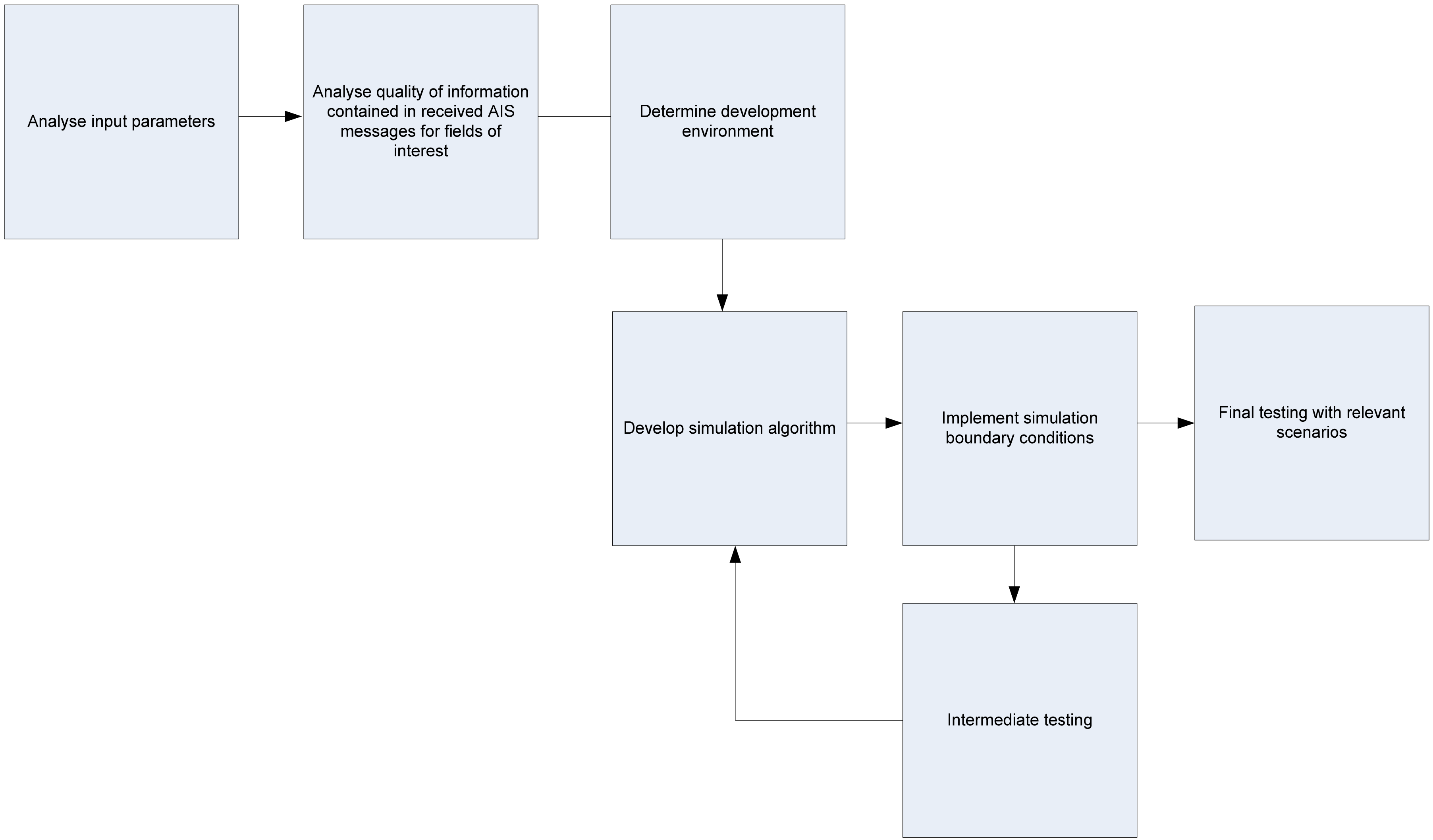


Figure 8-1: Development approach

8.1 AVAILABLE VESSEL INFORMATION

User ID	MMSI number
Rate of turn ROTAIS	±127 (–128 (80 hex) indicates not available, which should be the default). Coded by ROTAIS =4.733 SQRT(ROTINDICATED) degrees/min ROTINDICATED is the Rate of Turn (720 degrees per minute), as indicated by an external sensor. +127 = turning right at 720 degrees per minute or higher; –127 = turning left at 720 degrees per minute or higher 0...+ 126 = turning right at up to 708 degrees per minute or higher; 0...-126 = turning left at up to 708 degrees per minute or higher Values between 0 and 708 degrees/min coded by ROTAIS =4.733 SQRT(ROTsensor) degrees/min where ROTsensor is the Rate of Turn as input by an external Rate of Turn Indicator. ROTAIS is rounded to the nearest integer value. + 127 = turning right at more than 50/30s (No TI available) -127 = turning Left at more than 50/30s (No TI available) –128 (80 hex) indicates no turn information available (default).
SOG	Speed over ground in 1/10 knot steps (0-102.2 knots) 1 023 = not available, 1 022 = 102.2 knots or higher.
Longitude	Longitude in 1/10 000 min (±180 degrees, East =positive (as per 2´s complement), West =negative(as per 2´s complement). 181 degrees (6791AC0 hex) = not available = default)
Latitude	Latitude in 1/10 000 min (±90 degrees, North =positive (as per 2´s complement), South =negative (as per 2´s complement), 91 degrees (3412140 hex) = not available = default)
COG	Course over ground in 1/10°(0-3599). 3600 (E10 hex) = not available = default; 3 601 – 4 095 should not be used.
True Heading	Degrees (0-359) (511 indicates not available = default).

Table 8-1 Available vessel information

The information contained in these AIS message fields as listed in table 8-1 are taken directly from the database. After reviewing of the available data in the LuxSpace database it has been decided that, since the value of the ROT does not provide additional information due to the fact that the value is in most cases 0 or -128, this parameter shall not be taken as input to the VPST.

8.2 PROGRAMMING ENVIRONMENT

The selected programming environment is Java of Sun Microsystems because of the following reasons:

- Flexible programming language
- Cross operating platform compatibility
- Automated memory management
- Easy database interaction
- Java swing applications makes easy user interface programming possible

8.3 AVAILABLE TOOL STRUCTURE

In order to provide a way to visualize vessel positions and vessel movements LuxSpace has recently developed an application tool. The application allows users to make a selection of vessels according to a specific timeframe, geographical region or MMSI and display the vessel tracks on a geographical map. The application has been programmed in the Java programming language and features a vast number of possibilities to integrate additional program features and add-ons. The application has been specifically designed to allow for future program expansion. Hence, this user application has been chosen to form the basis for the implementation of the vessel simulation algorithm. It will provide the environment to display the results of the VPST and analyse them in a convenient way. Moreover, the application already features the mapping vectors that define the contours of the land mass thereby providing already one of the boundary conditions for the position simulation algorithm. Figure 8.2 depicts a screen shot of the user interface of the application.

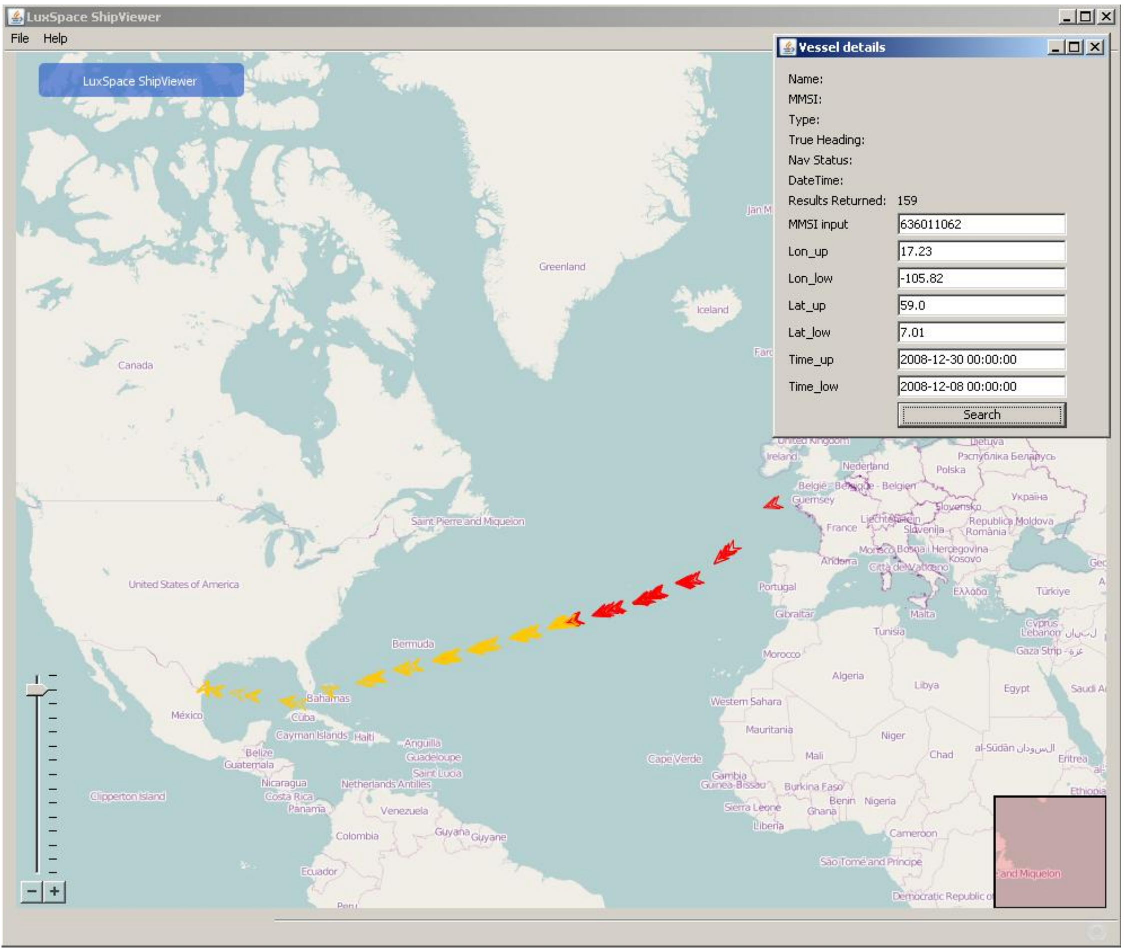


Figure 8-2: LuxSpace ShipViewer

The user application allows users to select a certain geographical region and a certain time interval for which the vessel positions should be retrieved from the database and plotted on the geographical map interface. In addition it allows for the user input of one specific MMSI to allow users to display the track on one single vessel.

In order to adapt the application to host the VPST the input possibility of the simulation date and time should be added with in addition the possibility to only plot simulated vessel positions on the map interface.

8.4 ALGORITHM DEVELOPMENT PLAN

At first the algorithm itself takes for one single vessel taking only one position before and after the simulated position into account with all relevant AIS message parameters. Then the boundary conditions are developed and added sequentially to the simulation algorithm

Based on speed of the vessel in the first position and second position the possible area where the vessel can be located is determined. Then the most probable position is determined. After application of the boundary conditions, in the event that the most probable position does not seem to be correct, the next most probable location is determined inside the possible vessel location area by moving the vessel in the most direction which is most probable and applying the boundary conditions again. The boundary conditions taken into account, as previously described, are:

- Vessel positions should be predicted at least 5 kilometres clear of coast lines
- Vessel position should be predicted at least 500 meters away from other vessel positions, simulated or detected

8.5 TEST AND VALIDATION PLAN

One of the main difficulties with respect to the development of a VPST is currently the scarce availability of vessel position information from other sources than SatAIS. This at least is true during the development of the simulation algorithm during the first phase of the PASTA MARE project. During the course of the project data from other sources will be collected, such as coastal based AIS and LRIT data so that the functionalities and reliability of the simulation tool can be enhanced. For the development of the algorithm only SatAIS from January has been used.

Using SatAIS data alone for validation of the algorithm is difficult due to the fact that the main purpose of the algorithm is to simulate vessel positions during time intervals when no SatAIS data is available. Moreover, the time interval between available SatAIS messages from every unique MMSI is too large to simulate an already detected vessel position in order to verify the accuracy of the simulation. In other words when an already detected vessel position is simulated the other available SatAIS messages to use as input to the simulation algorithm fall outside the maximum range of 12 hours (it is assumed that the detected positions from each of the six Orbcomm satellites in one batch obtained during one pass are located so closely together that they can be seen as one position. Predicting positions in between a batch would not make sense). Figure 8.3 demonstrates this issue.

Until more vessel position data from other data sources becomes available within the project, the performance of the VPST is verified visually by analysing the results of the demonstrations and determining what the ideal track of the vessel would be. When interpolating a position in most cases it can be seen when plotted on a map, which track the vessel has followed most likely. It can then be verified whether the simulated positions are located on this track. The demonstrations in chapter 10 provide evidence of this approach. Obviously this approach does not provide conclusive evidence to determine the accuracy of the VPST to a large extend. This can only be done when current SatAIS data is obtained and data from other sources is provided as reference.

9. ALGORITHM OUTLINE

9.1 VESSEL POSITION SIMULATION ALGORITHM

The following sections describe the outline of the vessel position simulation algorithm. The description follows the whole processing line from the initial user input to the final plotting of the simulated positions and the output of the simulated vessel data.

9.1.1 STEP 1 – PROCESS USER INPUT

In step 1 of the algorithm the user input is collected and processed. The simulation parameters are set up including the simulation area and simulation date and time. This also includes the information whether the user intends to simulate the position of all vessels in a certain area at a certain moment in time or only the position of one vessel at a certain moment in time.

9.1.2 STEP 2 – RETREIVE VESSEL DATA

In step 2 of the algorithm a connection is established with the database and the applicable AIS messages are retrieved in accordance with the simulation parameters.
The COG is provided in knots/hour which is equal to nautical miles/hour. Every vessel position with applicable data is stored in memory.

9.1.3 STEP 3 – COLLECT MMSI NUMBERS

A list of unique MMSI's is constructed in order to determine all the vessels for which a simulated position has to be provided.

9.1.4 STEP 4 – SELECT VESSEL DATA INPUT

In step 4 of the algorithm the actual data input for the algorithm is selected from the vessel information collected in step 2. In the current version of the algorithm only two vessel positions are used as input for interpolation and one position in case of position extrapolation. Since the update intervals between vessel positions acquired from SatAIS rather large no significant improvement was detected when more positions were used for inter and

extrapolation. In fact, in many cases, the performance of the algorithm degraded when taking more than two positions into account as input.
The positions as input to the algorithm for interpolation are defined as follows:

- (ϕ_b, λ_b), position with time stamp before the simulation time (t_{sim}), not more than 12 hours before
- (ϕ_a, λ_a), position with time stamp after the simulation time (t_{sim}), not more than 12 hours after

where φ represents the latitude and λ represents the longitude of a position.

When no position can be found in the database with a time stamp less than 12 hours away from the simulation time no simulation is possible. When only one position is found the simulated position is extrapolated from the one position found.

In addition the time difference is calculated between t_{sim} and the timestamps of (ϕ_b, λ_b) and (ϕ_a, λ_a), indicated as Δt_b and Δt_a respectively (in seconds).
The other parameters are evidently indicated as:
Speed over ground: SOG_b and SOG_a (in knots/hour)
True Heading: H_b and H_a (in degrees)

9.1.5 STEP 5 – CALCULATE POSSIBLE POSITIONS

Step 5 consists of the following points:

- Convert SOG_b and SOG_a to nautical miles/second
- One degree difference in latitude equals 60 nautical miles
- One degree difference in longitude 60*cos(latitude)

<u>Interpolation</u>

The core of the interpolation algorithm is formed by the following equations:

$$\varphi_b^{'} = \varphi_b + ((((SOG_b \cdot \Delta t_b \cdot 0.00000027) + (0.5 * ((SOG_a - SOG_b)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \cos(\mathrm{H}_1 \cdot 0.0175)) \cdot 0.0167)$$

$$\lambda_b^{'} = \lambda_b + ((((SOG_b \cdot \Delta t_b \cdot 0.00000027) + (0.5*((SOG_a - SOG_b)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \sin(\mathrm{H}_1 \cdot 0.0175)) \cdot (0.0167/\cos(\varphi_b \cdot 0.0175)))$$

$$\varphi_a^{'} = \varphi_a - ((((SOG_a \cdot \Delta t_a \cdot 0.00000027) + (0.5*((SOG_b - SOG_a)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \cos(\mathrm{H}_2 \cdot 0.0175)) \cdot 0.0167)$$

$$\lambda_a^{'} = \lambda_a + ((((SOG_a \cdot \Delta t_a \cdot 0.00000027) + (0.5*((SOG_b - SOG_a)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \sin(\mathrm{H}_2 \cdot 0.0175)) \cdot (0.0167/\cos(\varphi_a \cdot 0.0175)))$$

With all parameters as previously defined

The final simulated vessel position is then subsequently determined from $(\phi_b^{'}\lambda_b^{'})$ and $(\phi_a^{'}\lambda_a^{'})$ taking into account Δt_b and Δt_a . This is done by calculating a ratio that indicates the influence $(\phi_b^{'}\lambda_b^{'})$ and $(\phi_a^{'}\lambda_a^{'})$ each have on the simulated vessel position $(\phi_{sim}, \lambda_{sim})$ for specific simulation time t_{sim} .

Extrapolation

The core of the interpolation algorithm is formed by the following equations:

When (ϕ_a, λ_a) is extrapolated:

$$\varphi_{sim} = \varphi_a - ((((SOG_a \cdot \Delta t_a \cdot 0.00000027) + (0.5*((SOG_b - SOG_a)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \cos(\mathrm{H}_2 \cdot 0.0175)) \cdot 0.0167)$$

$$\lambda_{sim} = \lambda_a + ((((SOG_a \cdot \Delta t_a \cdot 0.00000027) + (0.5*((SOG_b - SOG_a)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \sin(\mathrm{H}_2 \cdot 0.0175)) \cdot (0.0167/\cos(\varphi_a \cdot 0.0175)))$$

when (ϕ_a, λ_a) is extrapolated:

$$\varphi_{sim} = \varphi_b + ((((SOG_b \cdot \Delta t_b \cdot 0.00000027) + (0.5 * ((SOG_a - SOG_b)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \cos(\mathrm{H}_1 \cdot 0.0175)) \cdot 0.0167)$$

$$\lambda_{sim} = \lambda_b + ((((SOG_b \cdot \Delta t_b \cdot 0.00000027) + (0.5 * ((SOG_a - SOG_b)/((\Delta t_b - \Delta t_a) \cdot 0.00000027)) \cdot (\Delta t_b \cdot 0.00000027)^2)) \cdot \sin(\mathrm{H}_1 \cdot 0.0175)) \cdot (0.0167 / \cos(\varphi_b \cdot 0.0175)))$$

9.1.6 STEP 6 – CALCULATE DISTANCE TRAVELED

The combined distance from $(\phi_b \lambda_b)$ to $(\phi_{sim}, \lambda_{sim})$ to $(\phi_a \lambda_a)$ is calculated. This distance is then compared to the total distance that the vessel could travel during time $\Delta t_b + \Delta t_a$ with the highest SOG (SOG_b or SOG_a). If the comparison is false, which means that the distance that the simulated vessel would travel from $(\phi_b \lambda_b)$ to $(\phi_a \lambda_a)$ is larger than the total distance possible at the highest SOG the simulated vessel position is flagged as position with low accuracy (as in the case of position extrapolation).

9.2 APPLICATION OF BOUNDARY CONDITIONS

9.2.1 STEP 7 – VERIFY SIMULATED POSITION LOCATED OFF-LAND

The contours of the landmass of each continent and island has been saved as polygons made up of the geographical coordinates of the coastline. For each simulated vessel position it is possible to verify whether it is located inside one of these polygons or not. In addition, the distance between the simulated position and the closest geographical coordinate of the polygon can easily be determined. Both actions are accomplished using build-in classes of the programming language java. The requirement is, as stated in paragraph 6.3, that a simulated vessel position is located at least 5 kilometres of the coast of the nearest landmass. When the simulated position is determined to be located inside the polygon the following steps are followed:

step 1 – determine which position, $(\phi_b' \lambda_b')$ or $(\phi_a' \lambda_a')$, is located inside the polygon or that both are located inside the polygon

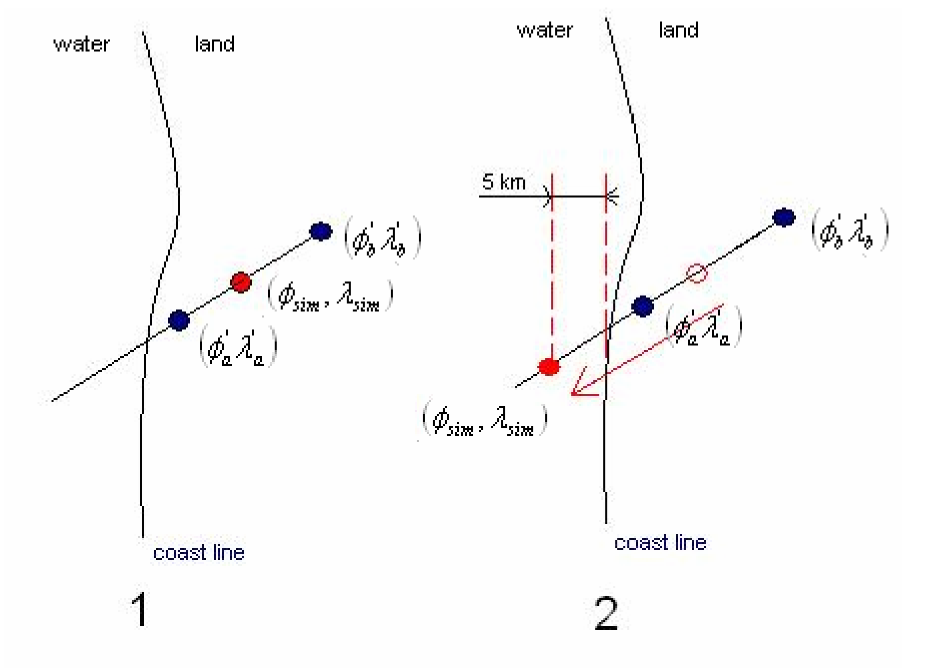
step 2 – if both positions are located inside the polygon, determine which of the two positions is located closest to the edge of the polygon step 3 – if both positions are located inside the polygon, the simulated position $(\phi_{sim}, \lambda_{sim})$ is moved over the line between $(\phi_b^{'} \lambda_b^{'})$ and $(\phi_a^{'} \lambda_a^{'})$ in the direction of the position located closest to the edge of the polygon or towards the position that is located outside the polygon. The simulated position $(\phi_{sim}, \lambda_{sim})$ is then subsequently moved along this line until it is located 5 kilometres from the edge of the polygon

When the distance between the edge of the polygon and the simulated position is less than 5 kilometres the following steps are followed:

Step 1 – determine if one of the positions, $(\phi_b^{'} \lambda_b^{'})$ or $(\phi_a^{'} \lambda_a^{'})$, is located inside the polygon

Step 2 – if one of the positions is located inside the polygon, the simulated position is moved over the line between $(\phi_b^{'} \lambda_b^{'})$ and $(\phi_a^{'} \lambda_a^{'})$ towards the point located outside the polygon or the point located farthest away from the polygon until the distance of the polygon is equal to 5 kilometres.

The following figures demonstrate an example of the previously described scheme in $(\phi_b^{'} \lambda_b^{'})$ and $(\phi_a^{'} \lambda_a^{'})$ case are located both inside the polygon (landmass):



::

Figure 9-1: Correct simulated position with boundary condition

:

9.2.2 STEP 8 – VERIFY DISTANCE BETWEEN SIMULATED POSITIONS

The minimum required distance between vessel positions (simulated or retrieved from the database) has been set to 500 meters. When the simulated vessel position is located closer than 500 meters to another vessel position the vessel position is moved along the line between $(\phi_b^{'}\lambda_b^{'})$ and $(\phi_a^{'}\lambda_a^{'})$ towards the point ($(\phi_b^{'}\lambda_b^{'})$ or $(\phi_a^{'}\lambda_a^{'})$) that is closest to the simulated position until the distance to the other vessel position is calculated to be 500 meters. Than the same position verification with respect to other vessel positions is performed again. If it is determined that the new simulated position is again within the range of 500 meters of another vessel the orginally simulated position is subsequently moved along the line between $(\phi_b^{'}\lambda_b^{'})$ and $(\phi_a^{'}\lambda_a^{'})$ towards the point ($(\phi_b^{'}\lambda_b^{'})$ or $(\phi_a^{'}\lambda_a^{'})$) that is farthest away to the simulated position.

The following figures demonstrate an example of the previously described scheme

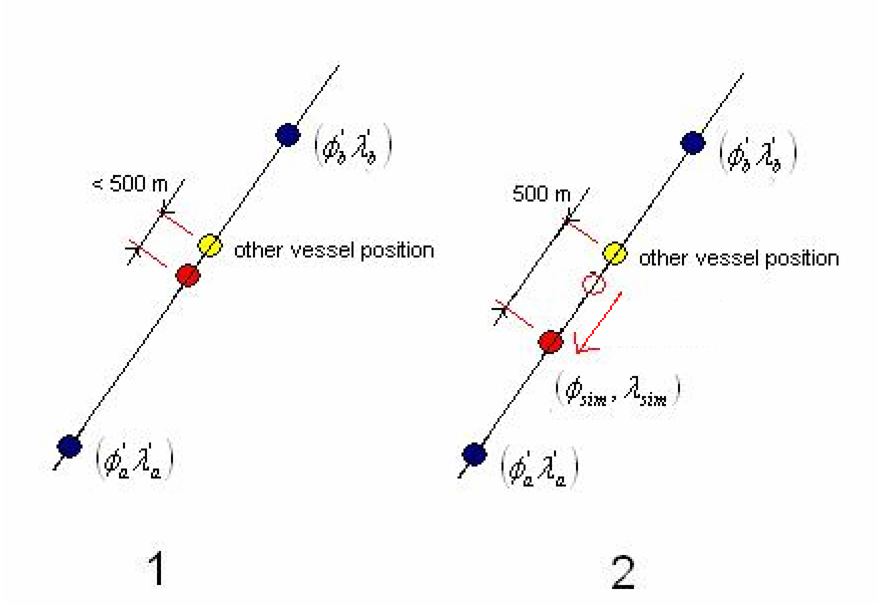


Figure 9-2: Correct simulated position with boundary condition

9.3 OUTPUT OF SIMULATED DATA

The following sections expounds the way in which the simulation results are exported to screen and file.

9.3.1 STEP 9 – PLOT SIMULATED POSITIONS AND PRINT DATA

The vessel positions that have been simulated with the VPST are plotted on the geographical map of the user application that has been described in paragraph 8.3. The vessel positions retrieved from the database including the positions that have been considered as input to the simulation algorithm can be included in the same plot. The data of the simulated vessels, of which table 10-1 is an example, is printed in a .txt file on the user's computer for further reference. The contents of this file can be used for further analysis of the performance SatAIS data.

10. DEMONSTRATIONS

The test parameters are defined as derived from the system requirements. Applicable test cases are defined and described. Subsequently the tests and test results are elaborated upon.

10.1 DEMONSTRATION OBJECTIVES

The test parameters will be taking all AIS parameters into account leaving out the ROT because of reasons explained. The demonstrations are performed in order to show that the vessel positions that can be simulated with the VPST follow the line the vessel is most likely expected to follow. In the figures that are included as a result of the demonstrations the positions that have been interpolated have been marked with a **green** nametag. The positions that have been extrapolated are marked with a **red** nametag. The nametag can either display the date and time of the detected or simulated vessel position or the actual name of the vessel. When positions are referred to as 'detected positions' this means that they have been retrieved from the SatAIS database and have been detected by Orbcomm satellites. On the other hand if a position is referred to as being a 'simulated position' the position has been calculated using the VPST. It must be stated that extrapolated vessel positions are in general less accurate than interpolate positions. To what extent they are more accurate still has to be determined.

10.2 DEMONSTRATION CASES

The test cases that have been used to test the VPST reflect the relevant scenarios as described in paragraph 6.1.
Test cases explained, not harbour test case, which leaves general cases: open seas and near coast line. The following table summarizes the test parameters and nature of the test

10.3 DEMONSTRATION RESULTS

10.3.1 DEMO 1 – CMA CGM MEDEA

Demonstration 1 concerns the interpolation/extrapolation of the position of one vessel travelling along a curved line between 2009-01-15 09:10:53 and 2009-01-15 22:40:08. Figure 10-1 and 10-2 display the CMA CGM MEDEA with MMSI 635010200 travelling from the Street of Gibraltar to the north of France. In figure 10-1 the interpolated position at 2009-01-15 12:00:00 is displayed. Figure 10-2 depicts the interpolated vessel position at 2009-01-15 16:00:00. The time interval between the simulation input positions ($(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$) is 13.5 hours. In this case the following time intervals for the possibility of interpolation apply for the current simulation algorithm (taking into account the maximum time interval of 12 hours between the simulation time and a detected position for the detected position to be relevant)

- from 2009-01-15 21:10:53 to 2009-01-15 22:40:08 positions are extrapolated using only $(\phi_a \lambda_a)$ as input to the simulation
- from 2009-01-15 10:40:08 to 2009-01-15 21:10:53 positions are interpolated using $(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$ as input to the simulation
- from 2009-01-15 09:10:53 to 2009-01-15 10:40:08 positions are extrapolated using only $(\phi_b \lambda_b)$ as input to the simulation

From both figures it is evident that the simulated vessel positions follow the ideal line at the correct distance from the coast.

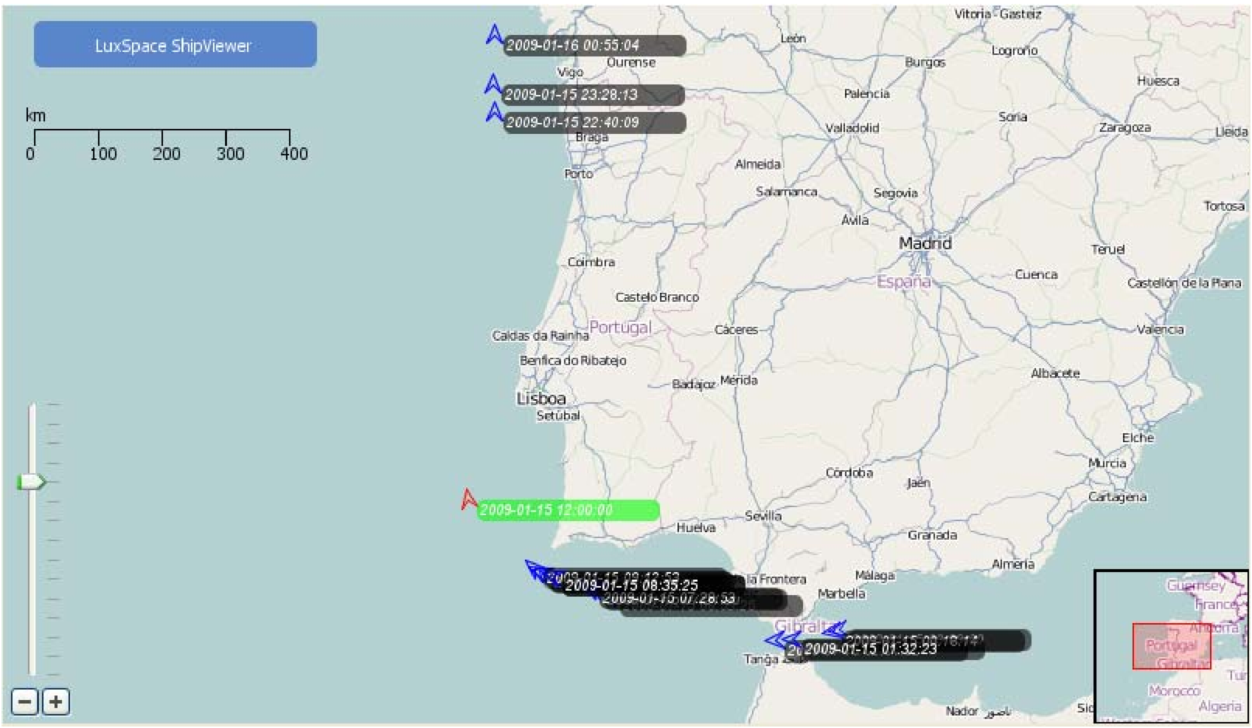


Figure 10-1: Simulated position of CMA CGM MEDEA for 2009-01-15 12:00:00

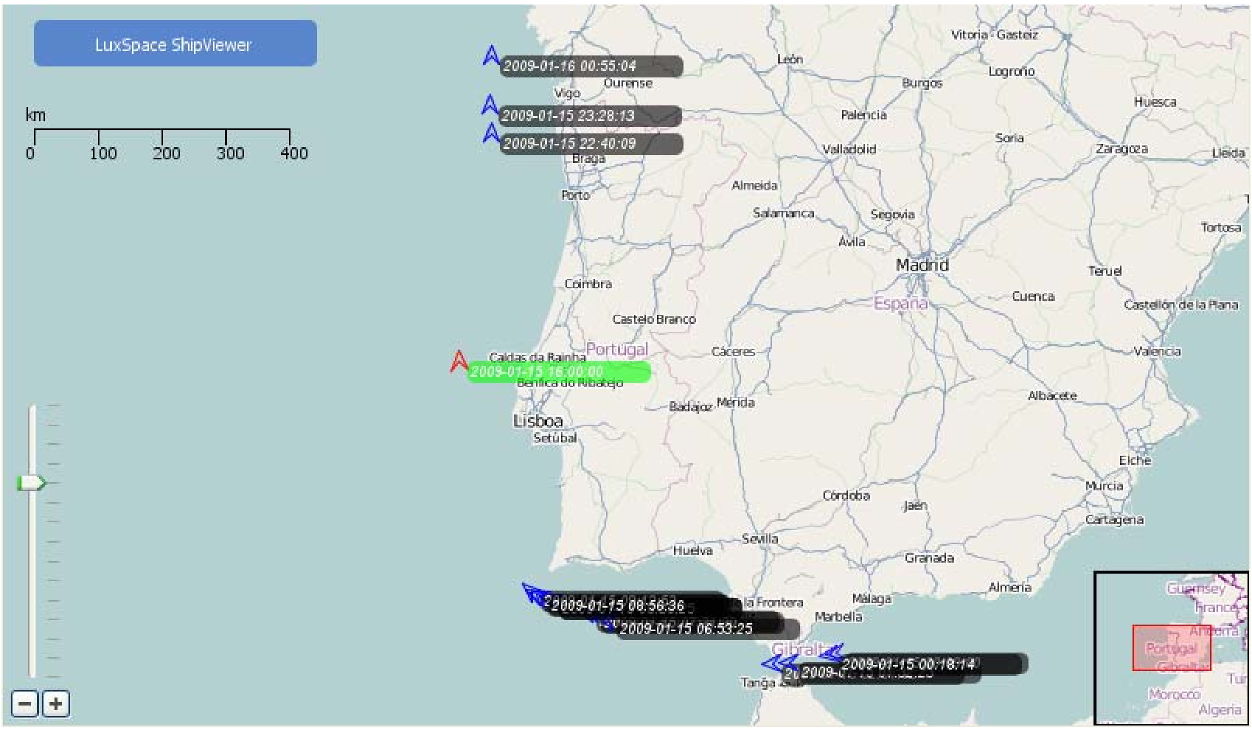


Figure 10-2: Simulated position of CMA CGM MEDEA for 2009-01-15 16:00:00

10.3.2 DEMO 2 – TENERIFE SPIRIT

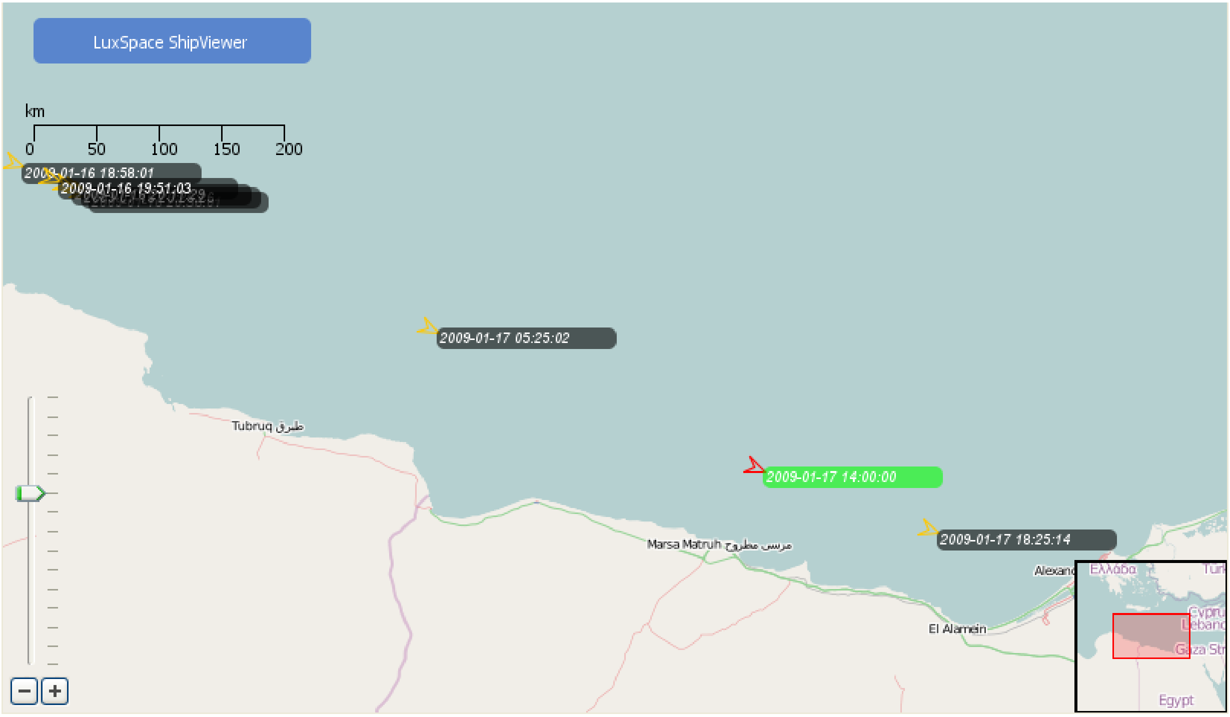


Figure 10-3: Simulated position of TENERIFE SPIRIT for 2009-01-17 14:00:00

Demonstration 2 concerns the interpolation/extrapolation of the position of one vessel between 2009-01-17 05:25:02 and 2009-01-17 18:25:14. Figure 10-3 displays the TENERIFE SPIRIT with MMSI 224442000 while travelling along the northern coast of Africa. In figure 10-3 the interpolated position at 2009-01-17 14:00:00 is displayed. The time interval between the simulation input positions ($(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$) is 13 hours. In this case the following time intervals for the possibility of interpolation apply for the current simulation algorithm (taking into account the maximum time interval of 12 hours between the simulation time and a detected position for the detected position to be relevant)

- from 2009-01-17 17:25:02 to 2009-01-17 18:25:14 positions are extrapolated using only $(\phi_a \lambda_a)$ as input to the simulation
- from 2009-01-17 06:25:14 to 2009-01-17 17:25:02 positions are interpolated using $(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$ as input to the simulation
- from 2009-01-17 05:25:02 to 2009-01-17 06:25:14 positions are extrapolated using only $(\phi_b \lambda_b)$ as input to the simulation

From both figures it is evident that the simulated vessel position follows the ideal line at the correct distance from the coast.

10.3.3 DEMO 3 – GENTLE LEADER

Demonstration 3 provides a visual elaboration of the intervals where interpolation or extrapolation is possible. It concerns the vessel position simulation of the GENTLE LEADER with MMSI number 311003300 between 2009-01-15 21:02:50 and 2009-01-16 19:51:43. It is evident that, taking into account the maximum time interval of 12 hours between the simulation time and a detected position for the detected position to be relevant, not all positions within this time interval can be interpolated.

The time interval between the simulation input positions ($(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$) is ~23 hours. In this case the following time intervals for the possibility of interpolation apply for the current simulation algorithm.

- from 2009-01-15 09:02:50 to 2009-01-16 19:51:43 positions are extrapolated using only $(\phi_a \lambda_a)$ as input to the simulation. This is shown in figure 10-5 with red tag (2009-01-16 16:00:00)
- from 2009-01-16 07:51:43 to 2009-01-15 09:02:50 positions are interpolated using $(\phi_b \lambda_b)$ and $(\phi_a \lambda_a)$ as input to the simulation. This is shown in figure 10-4 with green tag (2009-01-16 08:00:00)
- from 2009-01-15 21:02:50 to 2009-01-16 07:51:43 positions are extrapolated using only $(\phi_b \lambda_b)$ as input to the simulation

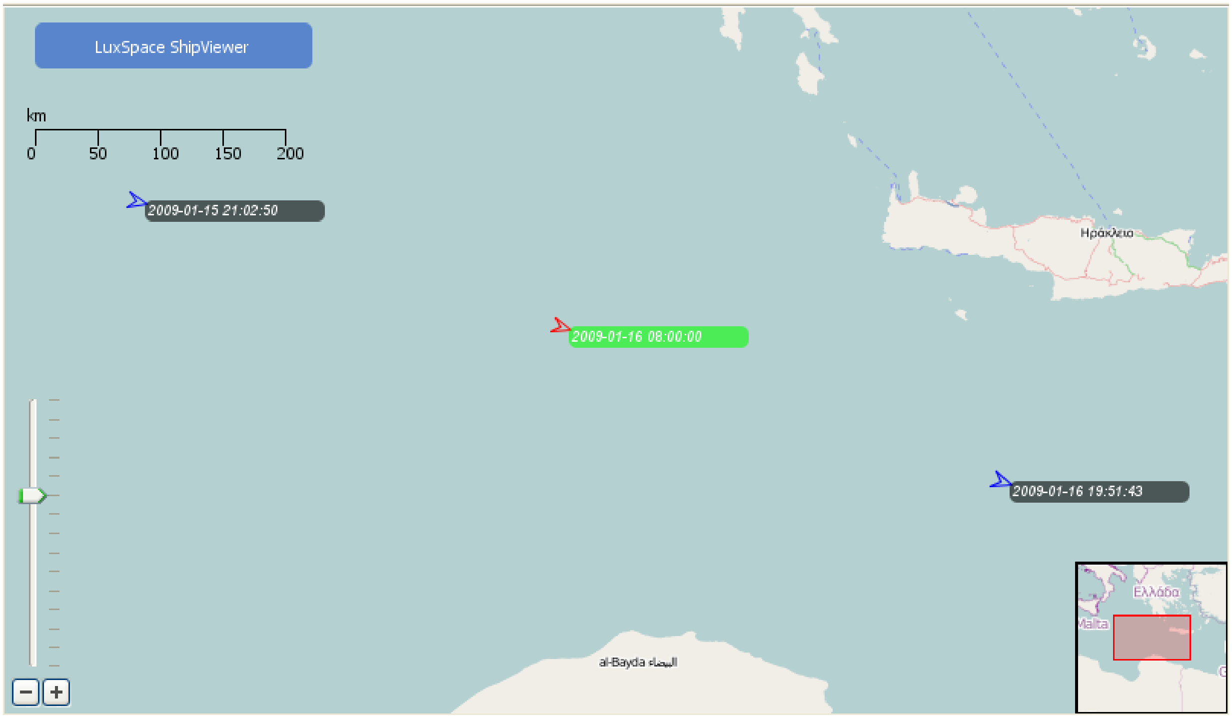


Figure 10-4: Interpolated position of GENTLE LEADER

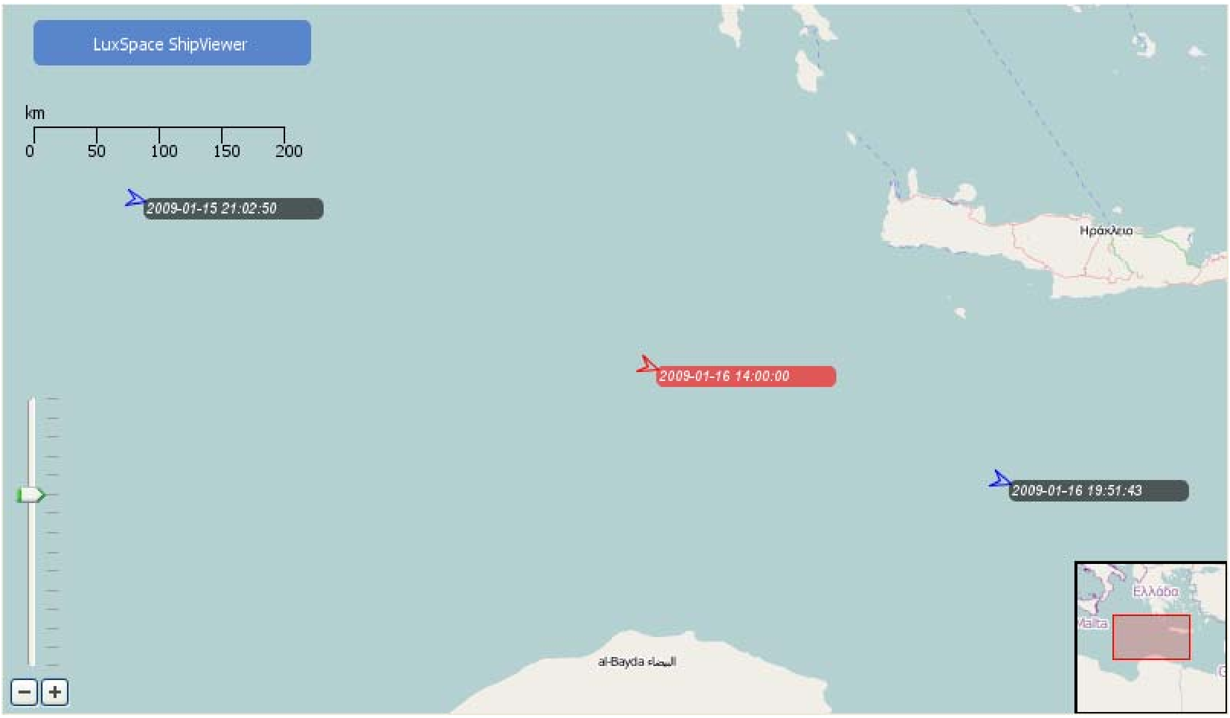


Figure 10-5: Extrapolated position of GENTLE LEADER

10.3.4 DEMO 4 – NORTHERN ATLANTIC

The following figure depicts a demonstration scene in the Northern Atlantic interpolating the positions of all vessels travelling through this area for 2009-01-17 14:00:00. The course of the vessels has been connected in order to clearly visualize the logic of the interpolated positions. Besides the simulated positions the plot only displays the positions before the simulated positions. Evidently, since the simulated positions are interpolated, also positions after the simulated positions have been taken into account.

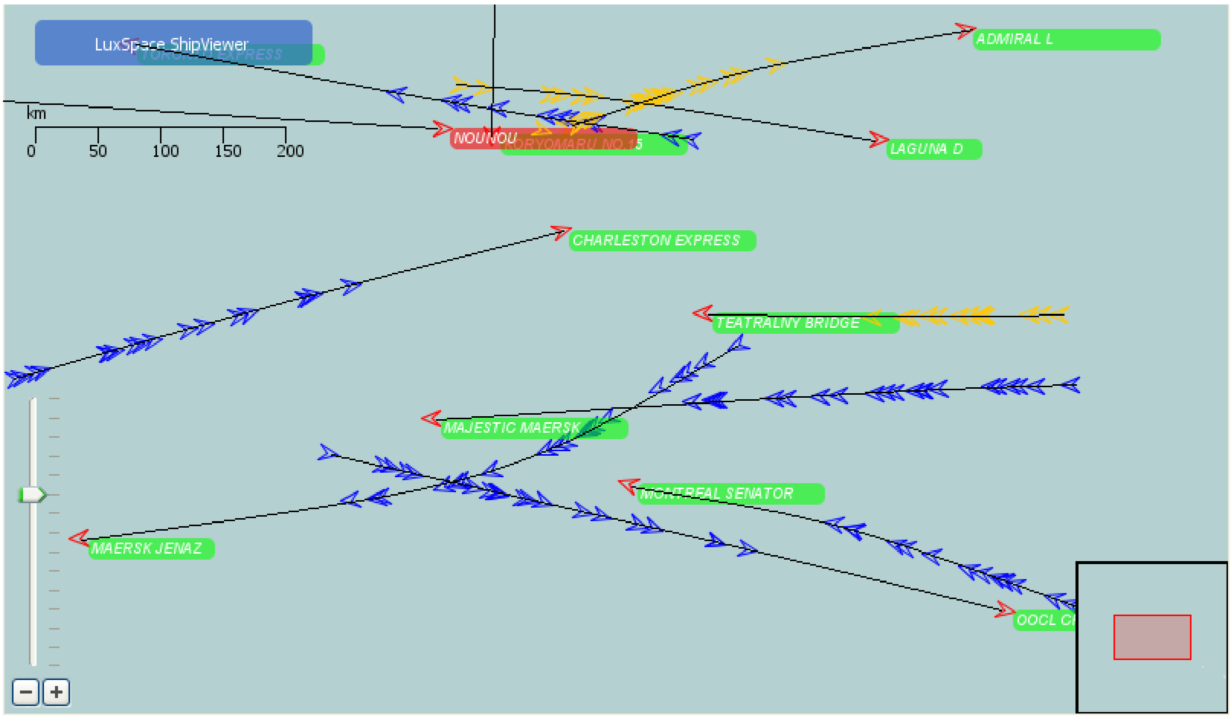


Figure 10-6: Simulated vessel positions in Northern Atlantic for 2009-01-17 14:00:00

10.3.5 DEMO 5 – BERMUDA 1

Demonstration 5 endeavours to demonstrate the main purpose of the VPST, enabling a more convenient and more thorough analysis of the performance of SatAIS data. The simulation area has been defined in Bermuda to be the red square with coordinates (upper latitude: 35.6, lower latitude: 29.84, upper longitude: -59.33, lower longitude: -65.43) for simulation time 2009-01-16 12:20:34. The applicable time interval (see chapter 7 for an explanation) is taken as 2009-01-15 00:00:00 to 2009-01-18 00:00:00.

Figure 10-7 depicts a complete overview of the resulting simulated vessel positions with in addition the vessel positions as retrieved from the database for this simulation area and applicable time interval. Figure 10-8 provides a close-up. The interesting results however can be seen when the positions as retrieved from the database are erased as displayed in figure 10-10. When the performance of SatAIS would be analyzed inside the simulation area the result of figure 10-10 can be used from which it can easily be deduced which vessels are located inside the simulation are at 2009-01-16 12:20:34. These vessels are listed in table 10-1 which is a print-out of the VPST output file.

Figure 10-9 displays the track with simulated position of one vessel inside the simulation area, the OVERSEAS RIMAR with MMSI 538002289

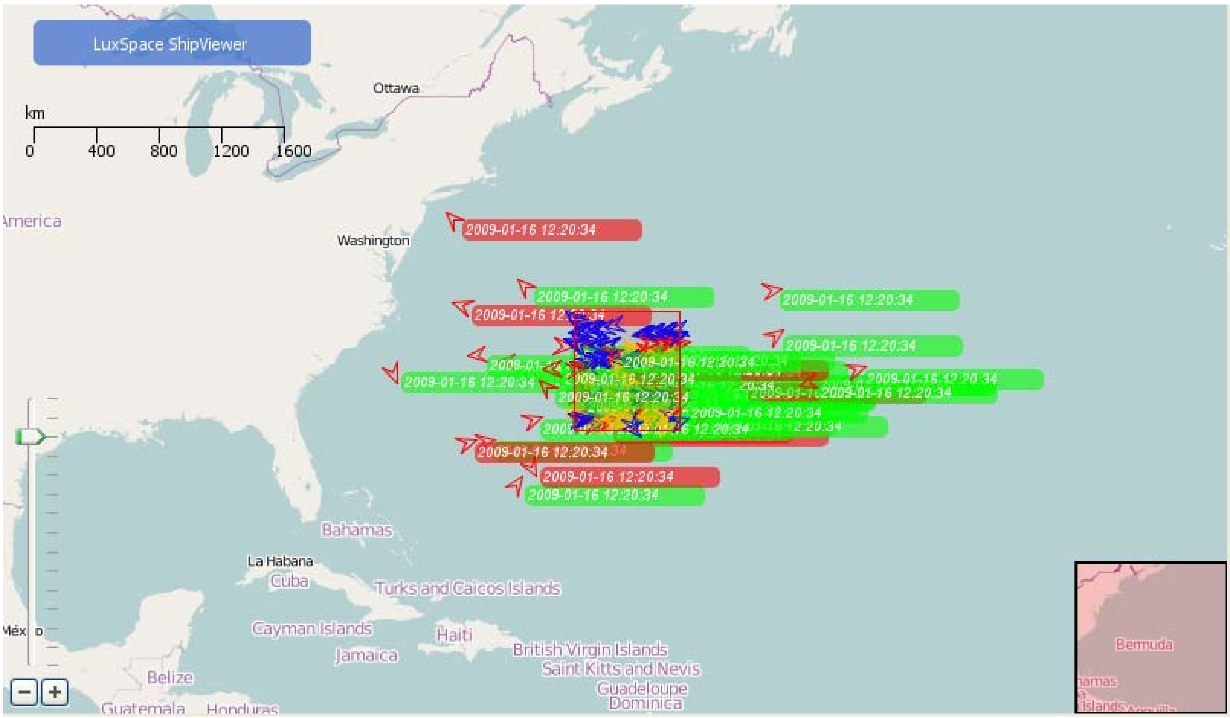


Figure 10-7: Simulated vessel positions in Bermuda for 2009-01-16 12:20:34

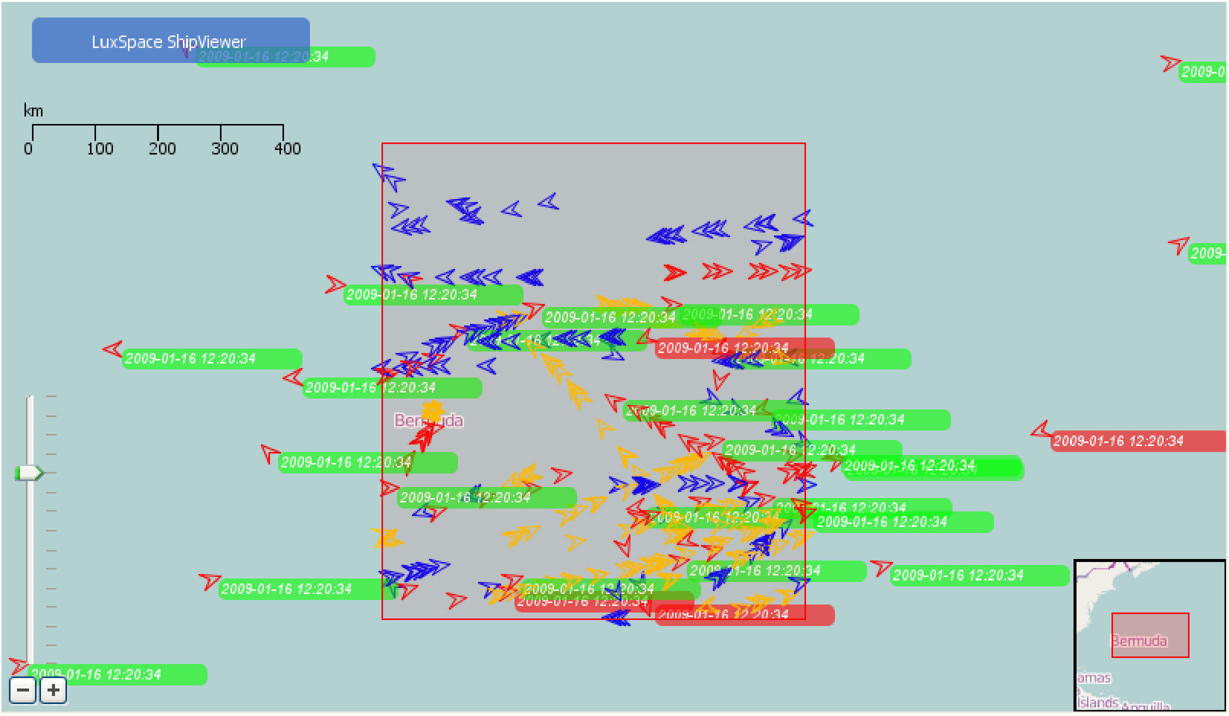


Figure 10-8: Simulated vessel positions in Bermuda for 2009-01-16 12:20:34

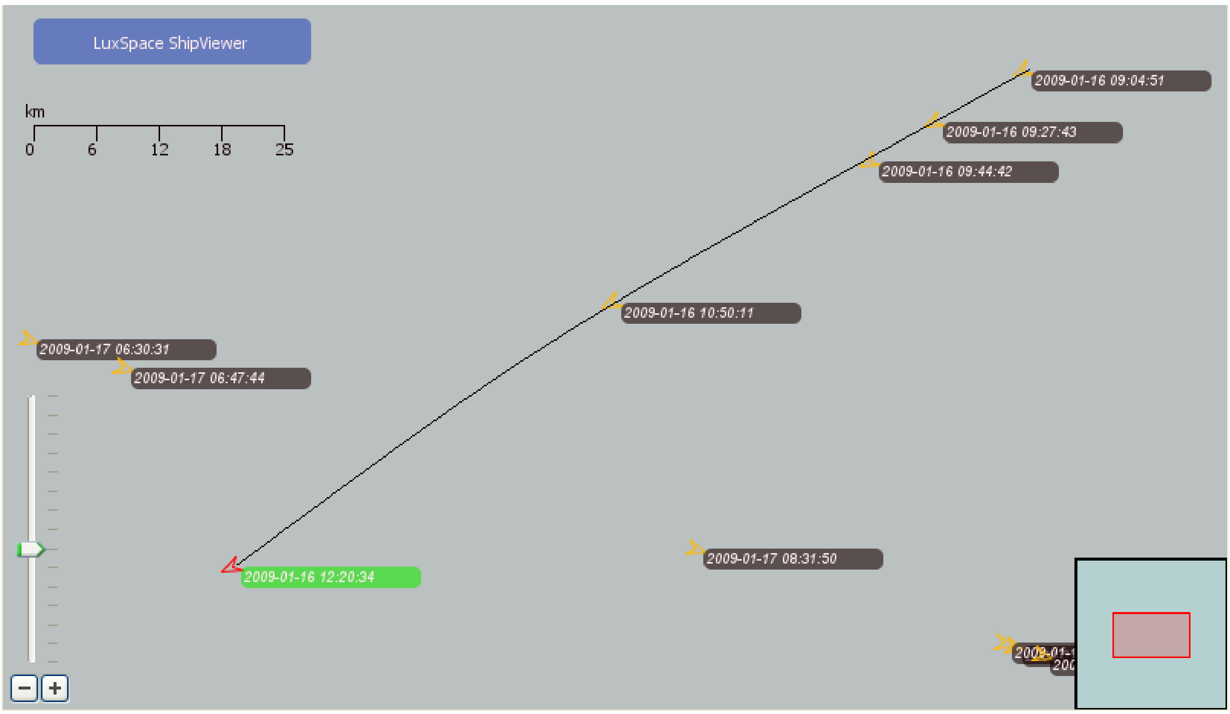


Figure 10-9: Simulated position of OVERSEAS RIMAR for 2009-01-16 12:20:34

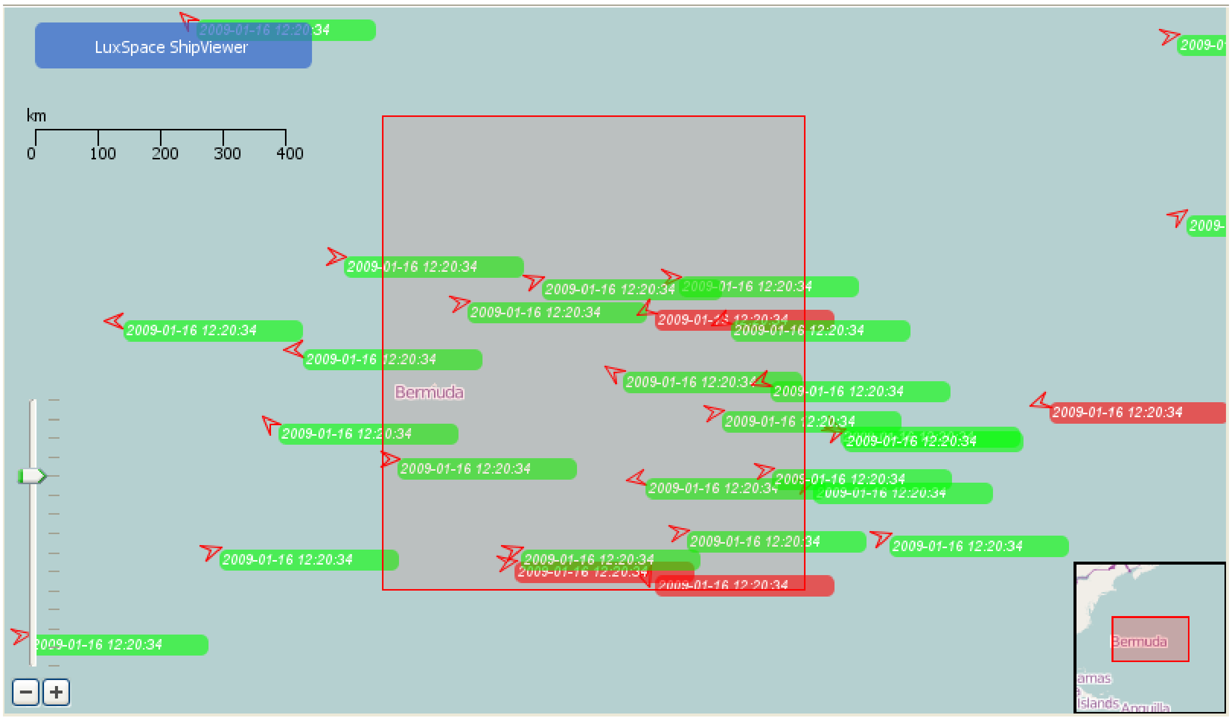


Figure 10-10: Simulated vessel positions in Bermuda for 2009-01-16 12:20:34

MMSI	Name	Latitude	Longitude
311181000	not available	30.00205	-61.6216
305066000	BBC ALABAMA	31.45397	-65.3253
235054775	BRO ARTHUR	31.14955	-59.3461
538003079	COMMENCEMENT	33.27655	-61.6287
538002289	OVERSEAS RIMAR	33.14533	-60.5156
235011090	not available	31.21945	-61.7613
212380000	BALTIC MARINER	31.32111	-59.9214
312571000	not available	30.17738	-63.6432
372700000	OCEANIC CORAL	33.67297	-61.2672
563461000	STAR OKIANA	30.32424	-63.5606
636011339	CMA CGM SAPPHIRE	33.64114	-63.2498
636010808	OKHOTSK SEA	30.55989	-61.1559
308808000	LAPIS ARROW	32.40078	-59.9519
538090328	not available	33.36409	-64.3241
538090253	KING DORIAN	32.04359	-60.6555
240498000	not available	32.51621	-62.0933

Table 10-1 Simulated vessel positions in Bermuda (output file)

10.3.6 DEMO 6 – BERMUDA 2

In demonstration 6 all vessel positions area simulated for simulation time 2009-01-16 16:20:34 in the same region as demonstration 5. Figure 10-12 displays the simulated vessel positions inside the simulation area while table 10-2 lists these vessels with their respective simulated position information.

As can be seen in figure 10-11 at 2009-01-16 16:20:34 the simulation area encircled in red was outside the field of view of each of the Orbcomm AIS satellites. This simulation time was therefore part of a time interval for which no information was available of the vessel positions in this area of interest. Using the VPST these vessel positions can be simulated thereby enhancing the time resolution of SatAIS. When vessel position information comes available from other data sources for the time interval for which the Orbcomm AIS satellites were not able to deliver data from the region of interest, the PVST enables the possibility of analyzing SatAIS for this time instance nonetheless. Interesting is to see that most of the simulated vessel positions have been interpolated (green name tag). This indicates that the update performance of SatAIS data in this region is quite high since the simulation algorithm was able to use vessel positions with regular update intervals.

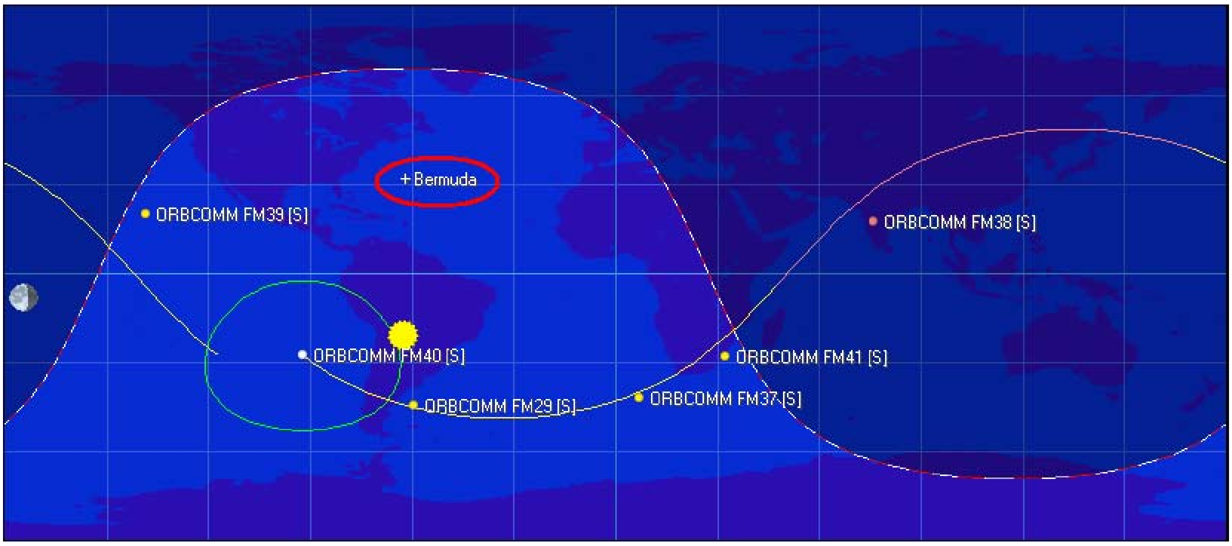


Figure 10-11: Orbcomm ground track over Bermuda for 2009-01-16 16:20:34

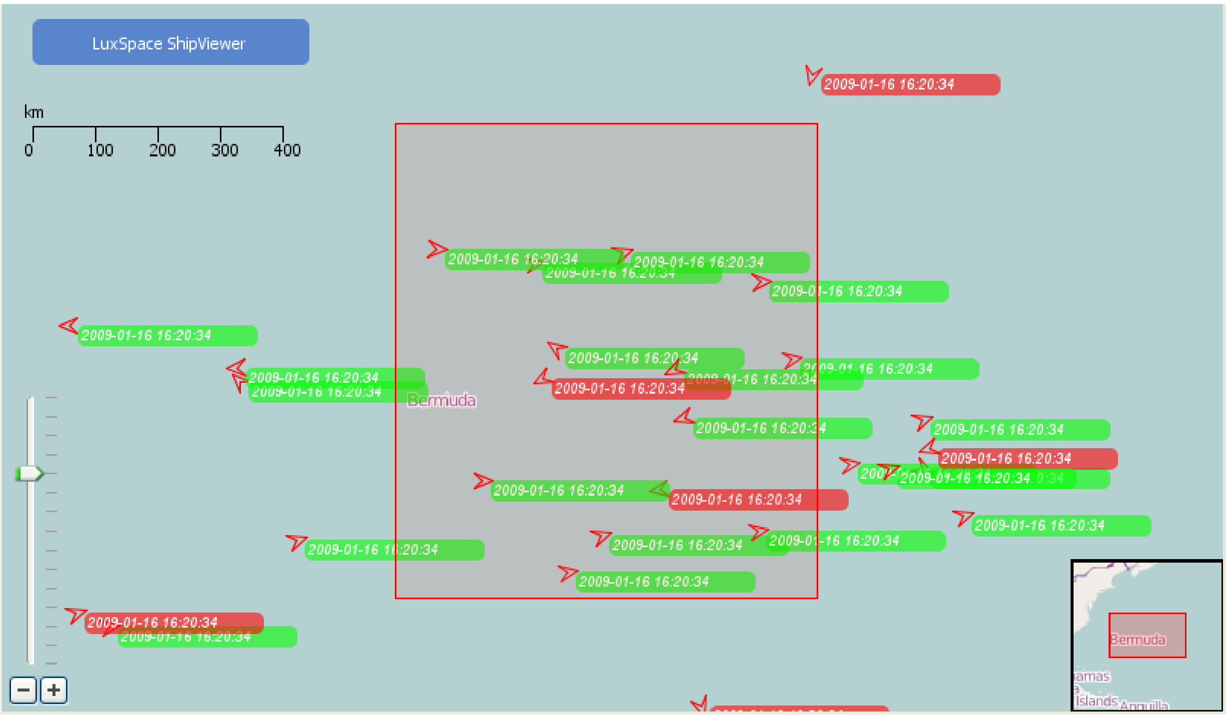


Figure 10-12: Simulated vessel positions in Bermuda for 2009-01-16 16:20:34

MMSi	Name	Latitude	Longitude
305066000	BBC ALABAMA	31.28073	-64.1789

538003079	COMMENCEMENT	32.53643	-63.301
538002289	OVERSEAS RIMAR	32.64283	-61.3882
235011090	not available	31.18289	-61.6058
215339000	ZARIFA ALIYEVA	34.10562	-64.8348
312571000	not available	30.15678	-62.9361
372700000	OCEANIC CORAL	33.71512	-60.1431
563461000	STAR OKIANA	30.61667	-62.4652
636011339	CMA CGM SAPPHIRE	34.06794	-62.1461
636010808	OKHOTSK SEA	30.66955	-60.1957
308808000	LAPIS ARROW	32.0508	-61.2587
538090328	not available	33.93242	-63.4166
538090253	KING DORIAN	32.77641	-59.7064
240498000	NAUTILUS	32.90894	-63.101

Table 10-2 Simulated vessel positions in Bermuda (output file)

10.3.7 DEMO 7 - CAPE VERDE

Demonstration 7 demonstrates the applicability of the VPST to analyze the performance of SatAIS at any given moment in time. Figure 10-13 displays the simulated vessel positions with in addition the vessel positions as retrieved from the database. Figure 10-15 depicts only the simulated vessel positions from which the number of vessels inside the simulation area (red square) can clearly be seen. These vessels are listed in table 10-3 which is a print-out of the VPST output file. Figure 10-12 displays the track of a single vessel with simulated position inside the simulation area.

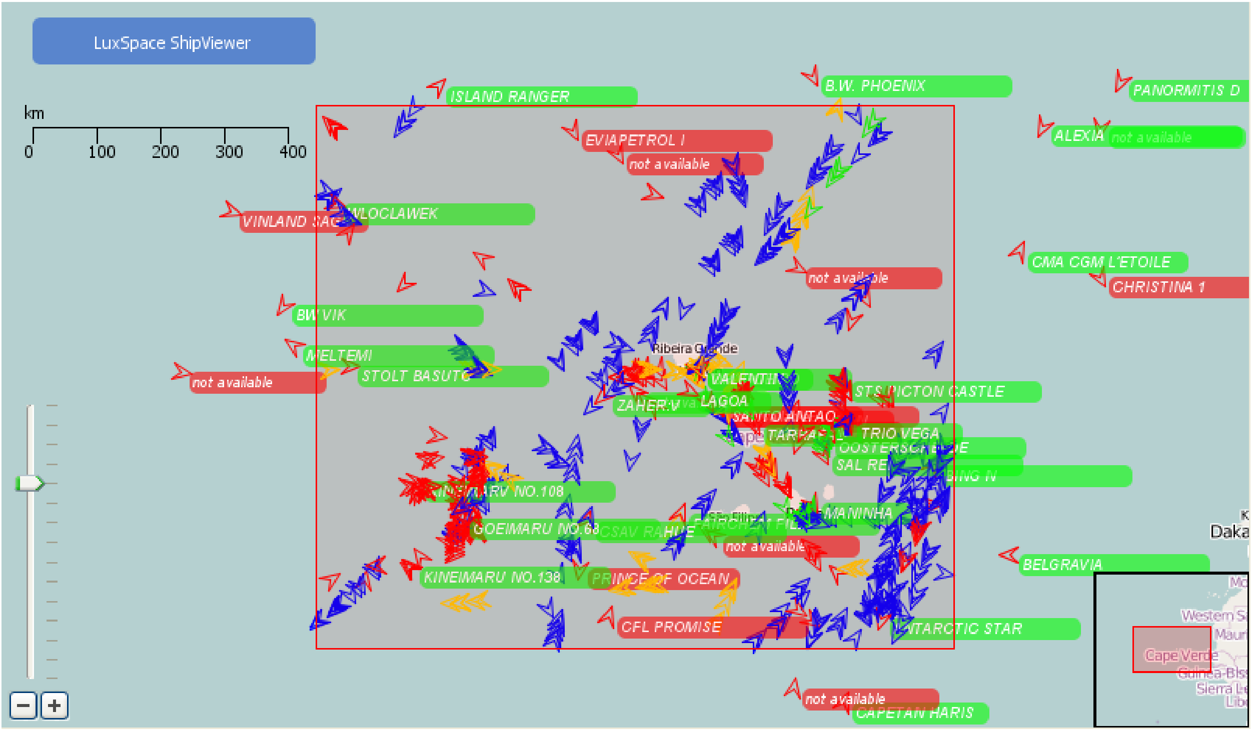


Figure 10-13: Simulated vessel positions in Cape Verde

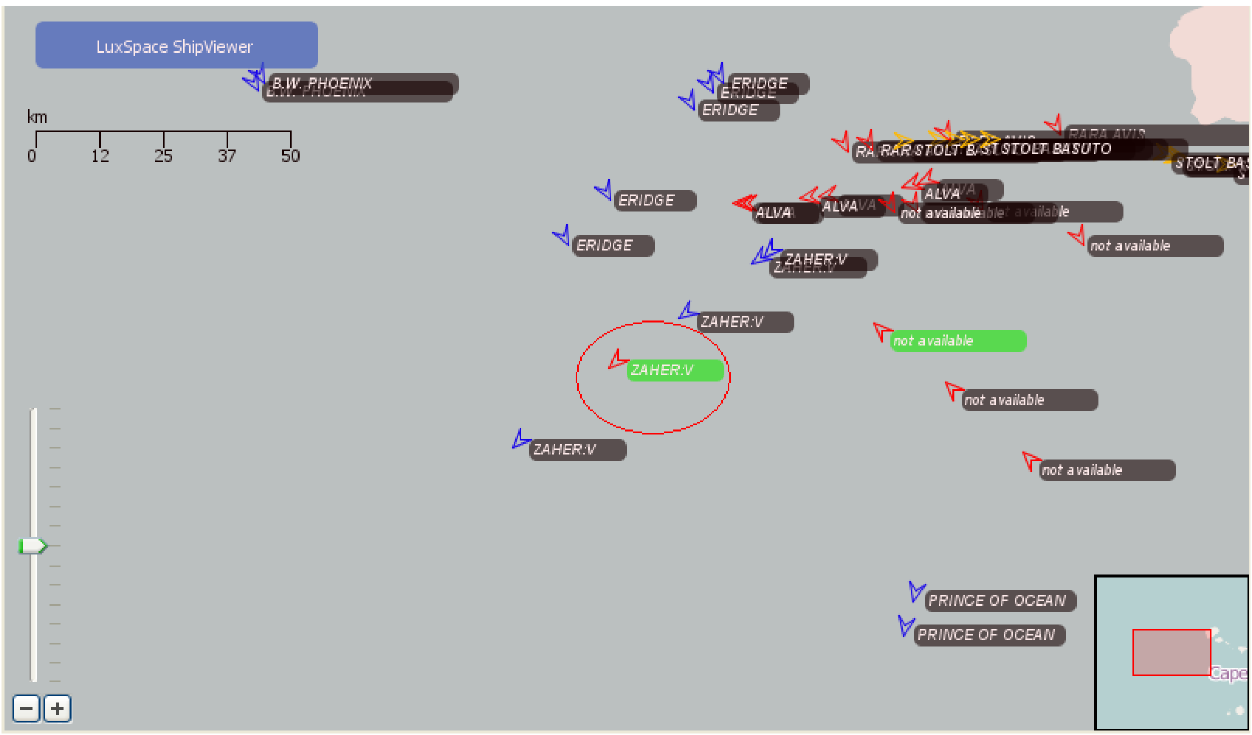


Figure 10-14: Simulated position of ZAHER V

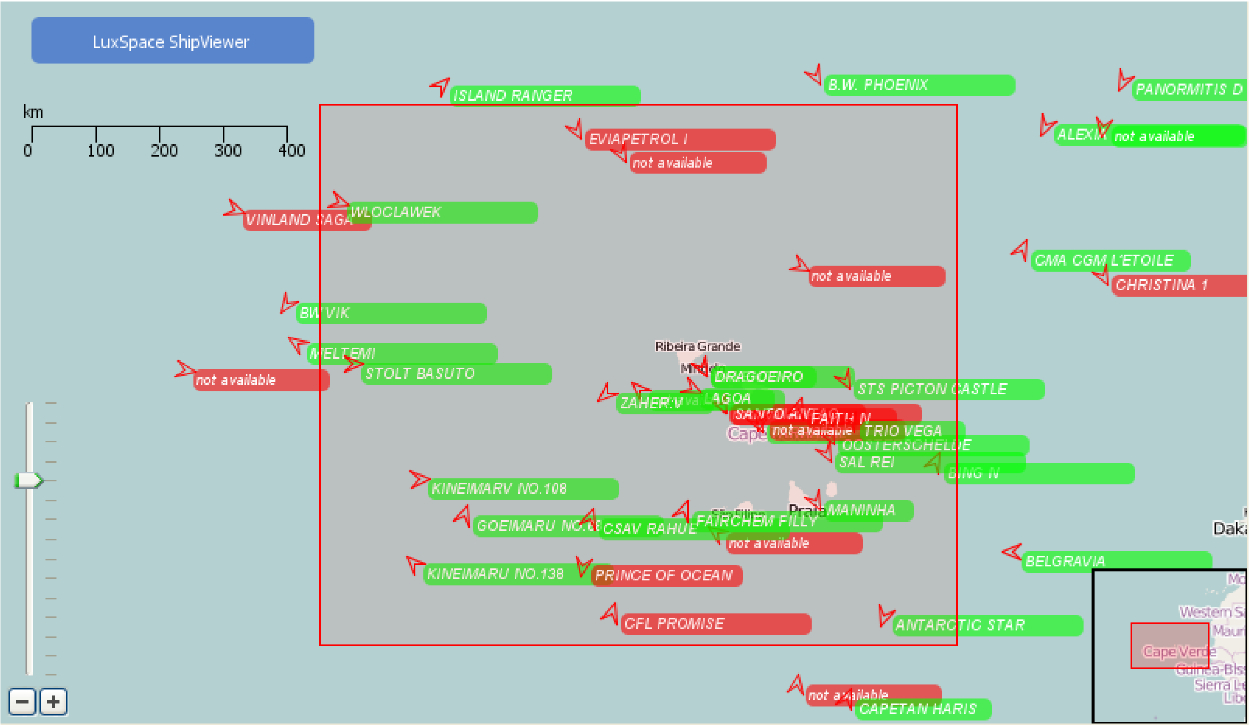


Figure 10-15: Simulated vessel positions in Cape Verde

MMSI	Name	Latitude	Longitude
245959000	CFL PROMISE	13.51568	-26.2646
617020000	not available	19.76263	-26.1382
377471000	not available	16.38014	-24.7198
636091346	CSAV RAHUE	14.8053	-26.5836
240285000	EVIAPETROL I	20.062	-26.773
356861000	TRIO VEGA	16.14739	-22.8904
565144000	STOLT BASUTO	16.92678	-29.9465
432346000	KINEIMARU NO.138	14.19279	-29.0626
617028000	MANINHA	15.07191	-23.3821
431723000	KINEIMARV NO.108	15.36322	-28.9831
249836000	WLOCLAWEK	19.10057	-30.1268
450501000	ZAHER:V	16.52494	-26.3434
240168000	not available	14.61742	-24.7768
372566000	FAIRCHEM FILLY	14.92051	-25.2486
740349000	not available	16.1644	-24.1671
636013945	BING N	15.57292	-21.6969
617052000	DRAGOEIRO	16.8829	-24.9898
355693000	PRINCE OF OCEAN	14.16104	-26.6789
617053000	SAL REI	15.71407	-23.2469
354167000	ANTARCTIC STAR	13.47969	-22.4294
518000019	STS PICTON CASTLE	16.71281	-22.981
351628000	FAITH N	16.30052	-23.6296
617058000	SANTO ANTAO	16.36411	-24.7123
240510000	not available	16.56176	-25.8693
431154000	GOEIMARU NO.68	14.84771	-28.3533
617045000	TARRAFAL	16.11842	-24.1919
353863000	not available	18.24978	-23.6153

Table 10-3 Simulated vessel positions in Cape Verde (output file)

11. FUNCTIONAL APPLICABILITY

The actual applicability of the algorithm in practical situations, as indicated by the test results, has been demonstrated. Due to the absence of reference data from other vessel information data sources the accuracy of the VPST has only been evaluated to a limited extend. However, visual inspection of the results shows that in nearly all cases the positions that are simulated follow the line that most likely represents the actual vessel track. The functional applicability with respect to the performance of SatAIS data analysis is significant. Due to the fact that the vessel positions in a certain area can be simulated for every moment in time, the VPST will clearly solve the synchronization problem when SatAIS data will be compared to other data sources in further phases of the PASAT MARE project.

12. FUTURE IMPROVEMENTS

The following paragraphs describe a number of improvements of which LuxSpace is currently analysing the applicability and way of implementation.

12.1 VESSEL TRAFFIC LANES

An improvement with respect to position extrapolation and to a smaller extend to position interpolation, would be taking into account vessel traffic lanes. Most vessels, especially on international routes when crossing the Atlantic, follow vessel traffic lanes. In other words, they follow a corridor which takes them in the most efficient way from one point to the other. In these corridors, vessels most often travel at constant speed and heading. Therefore, when all significant traffic corridors, as displayed in figure 12-1 are taken into account, vessel position prediction would be possible over a larger timespan.

12.2 HISTORICAL TRACKS OF THE SAME VESSEL

A large number of vessels follow during their operational lifetime for a certain shipping company the same routes over and over again. Therefore, the probability that a vessel follows in a certain area a course that is close to the course followed in the same area during the last visit, is quite large. The algorithm would further evolve into a more intelligent system which learns from previously predicted vessel positions.

12.3 DESTINATION OF A VESSEL

In situations where vessel positions have to be simulated close to the coast line or even in the thus far excluded harbour situations, taking into account the destination of a vessel could improve the accuracy of simulated vessel positions. Especially in combination with taking into vessel traffic lanes as described in paragraph 12.1, this could mean a significant improvement. The algorithm would further evolve into a more intelligent system which learns from previously predicted vessel positions.

13. CONCLUSIONS

The development and implementation of a tool to simulate vessel positions by interpolation or extrapolation, has led to a system which allows a more efficient analysis of the performance of SatAIS data. In addition the track of vessels can be simulated for the near future up to 12 hours and gaps in existing tracks can be filled in order to be able to visualize the position of the vessel along its track at every moment in time. When during the next phases vessel information comes available within the PASTA MARE project from other sources besides satellite based AIS, the performance of the VPST will be analysed more in-depth. The applicability that has been shown in a number of demonstrations however, indicates that the VPST is a promising tool able to fulfil its goals. The improvements suggested in chapter 12 will be evaluated and implemented when considered to be a significant improvement.

APPENDIX A

2009-07-10 03:54:53 ORBCOMM FM39 [S] 149.1 5.0 ? 2506 57.2 5.0
2009-07-10 03:56:28 ORBCOMM FM39 [S] 133.2 5.9 ? 2424 57.5 5.2
2009-07-10 03:58:02 ORBCOMM FM39 [S] 117.5 5.0 ? 2506 57.8 5.3

2009-07-10 03:59:50 ORBCOMM FM37 [S] 157.7 5.0 ? 2504 58.2 5.6
2009-07-10 04:02:06 ORBCOMM FM37 [S] 134.7 7.0 ? 2331 58.6 5.8
2009-07-10 04:04:22 ORBCOMM FM37 [S] 111.7 5.0 ? 2507 59.1 6.1

2009-07-10 04:36:48 ORBCOMM FM41 [S] 184.6 5.0 ? 2500 65.4 10.2
2009-07-10 04:40:45 ORBCOMM FM41 [S] 142.0 12.6 ? 1915 66.2 10.7
2009-07-10 04:44:42 ORBCOMM FM41 [S] 99.4 5.0 ? 2503 67.0 11.2

2009-07-10 04:37:15 ORBCOMM FM29 [S] 183.5 5.0 ? 2505 65.5 10.2
2009-07-10 04:41:09 ORBCOMM FM29 [S] 141.6 12.3 ? 1938 66.3 10.7
2009-07-10 04:45:03 ORBCOMM FM29 [S] 99.7 5.0 ? 2506 67.0 11.2

2009-07-10 04:41:27 ORBCOMM FM38 [S] 187.2 5.0 ? 2502 66.3 10.8
2009-07-10 04:45:32 ORBCOMM FM38 [S] 142.8 13.3 ? 1872 67.1 11.3
2009-07-10 04:49:37 ORBCOMM FM38 [S] 98.6 5.0 ? 2506 67.9 11.8

2009-07-10 05:20:15 ORBCOMM FM40 [S] 203.8 5.0 ? 2509 73.8 16.0
2009-07-10 05:25:02 ORBCOMM FM40 [S] 149.3 18.9 ? 1576 74.8 16.6
2009-07-10 05:29:48 ORBCOMM FM40 [S] 95.1 5.0 ? 2507 75.7 17.3

2009-07-10 05:32:46 ORBCOMM FM39 [S] 209.0 5.0 ? 2503 76.3 17.7
2009-07-10 05:37:42 ORBCOMM FM39 [S] 151.8 21.0 ? 1483 77.2 18.4
2009-07-10 05:42:38 ORBCOMM FM39 [S] 94.7 5.0 ? 2505 78.2 19.1

2009-07-10 05:38:21 ORBCOMM FM37 [S] 212.2 5.0 ? 2505 77.3 18.5
2009-07-10 05:43:23 ORBCOMM FM37 [S] 153.3 22.4 ? 1428 78.3 19.2
2009-07-10 05:48:25 ORBCOMM FM37 [S] 94.5 5.0 ? 2506 79.3 19.9

2009-07-10 06:16:55 ORBCOMM FM41 [S] 226.6 5.0 ? 2502 84.9 23.9
2009-07-10 06:22:16 ORBCOMM FM41 [S] 161.3 29.2 ? 1206 86.0 24.7
2009-07-10 06:27:37 ORBCOMM FM41 [S] 95.7 5.1 ? 2499 87.1 25.4

2009-07-10 06:17:21 ORBCOMM FM29 [S] 225.9 5.0 ? 2504 85.0 24.0
2009-07-10 06:22:42 ORBCOMM FM29 [S] 160.6 28.9 ? 1217 86.1 24.7
2009-07-10 06:28:02 ORBCOMM FM29 [S] 95.6 5.0 ? 2502 87.1 25.5

2009-07-10 06:21:42 ORBCOMM FM38 [S] 228.2 5.0 ? 2506 85.9 24.6
2009-07-10 06:27:06 ORBCOMM FM38 [S] 161.9 30.1 ? 1186 87.0 25.4
2009-07-10 06:32:29 ORBCOMM FM38 [S] 96.0 5.0 ? 2506 88.0 26.1

2009-07-10 07:01:16 ORBCOMM FM40 [S] 238.7 5.0 ? 2510 94.0 30.3
2009-07-10 07:06:49 ORBCOMM FM40 [S] 168.9 35.1 ? 1070 95.2 31.0
2009-07-10 07:12:20 ORBCOMM FM40 [S] 99.4 5.0 ? 2502 96.3 31.8

2009-07-10 07:13:58 ORBCOMM FM39 [S] 242.0 5.1 ? 2502 96.7 32.1
2009-07-10 07:19:31 ORBCOMM FM39 [S] 171.7 36.4 ? 1042 97.9 32.9
2009-07-10 07:25:04 ORBCOMM FM39 [S] 101.1 5.0 ? 2499 99.1 33.6

2009-07-10 07:19:39 ORBCOMM FM37 [S] 244.1 5.0 ? 2506 97.9 32.9
2009-07-10 07:25:14 ORBCOMM FM37 [S] 173.1 37.1 ? 1028 99.1 33.7
2009-07-10 07:30:48 ORBCOMM FM37 [S] 102.3 5.0 ? 2503 100.4 34.4

2009-07-10 07:58:37 ORBCOMM FM41 [S] 253.0 5.0 ? 2503 106.8 38.3
2009-07-10 08:04:13 ORBCOMM FM41 [S] 181.2 38.4 ? 1003 108.1 39.1
2009-07-10 08:09:48 ORBCOMM FM41 [S] 109.6 5.0 ? 2498 109.5 39.8

2009-07-10 07:59:04 ORBCOMM FM29 [S] 252.5 5.0 ? 2504 106.9 38.4
2009-07-10 08:04:40 ORBCOMM FM29 [S] 180.9 38.5 ? 1004 108.2 39.1
2009-07-10 08:10:15 ORBCOMM FM29 [S] 109.2 5.1 ? 2497 109.6 39.9

2009-07-10 08:03:27 ORBCOMM FM38 [S] 253.9 5.0 ? 2508 107.9 39.0
2009-07-10 08:09:03 ORBCOMM FM38 [S] 182.5 38.4 ? 1006 109.3 39.7
2009-07-10 08:14:39 ORBCOMM FM38 [S] 110.6 5.0 ? 2501 110.6 40.5

2009-07-10 08:43:17 ORBCOMM FM40 [S] 259.6 5.0 ? 2510 118.1 44.2
2009-07-10 08:48:51 ORBCOMM FM40 [S] 189.2 36.0 ? 1050 119.6 44.9
2009-07-10 08:54:23 ORBCOMM FM40 [S] 119.1 5.0 ? 2498 121.1 45.6

2009-07-10 08:56:01 ORBCOMM FM39 [S] 261.1 5.0 ? 2507 121.6 45.8
2009-07-10 09:01:32 ORBCOMM FM39 [S] 192.0 34.5 ? 1079 123.1 46.5

2009-07-10 09:07:01 ORBCOMM FM39 [S] 122.6 5.1 ? 2490 124.7 47.1

2009-07-10 09:01:45 ORBCOMM FM37 [S] 262.0 5.0 ? 2504 123.2 46.5
2009-07-10 09:07:14 ORBCOMM FM37 [S] 193.5 33.4 ? 1103 124.8 47.2
2009-07-10 09:12:42 ORBCOMM FM37 [S] 124.9 5.0 ? 2495 126.4 47.8

2009-07-10 09:40:51 ORBCOMM FM41 [S] 265.0 5.0 ? 2505 135.3 50.8
2009-07-10 09:46:07 ORBCOMM FM41 [S] 201.5 27.1 ? 1265 137.0 51.4
2009-07-10 09:51:22 ORBCOMM FM41 [S] 137.8 5.0 ? 2491 138.8 51.9

2009-07-10 09:41:20 ORBCOMM FM29 [S] 264.9 5.0 ? 2504 135.4 50.9
2009-07-10 09:46:37 ORBCOMM FM29 [S] 201.0 27.5 ? 1255 137.2 51.4
2009-07-10 09:51:53 ORBCOMM FM29 [S] 137.0 5.0 ? 2494 139.0 51.9

2009-07-10 09:45:44 ORBCOMM FM38 [S] 265.1 5.0 ? 2504 136.9 51.3
2009-07-10 09:50:58 ORBCOMM FM38 [S] 202.3 26.3 ? 1291 138.6 51.8
2009-07-10 09:56:11 ORBCOMM FM38 [S] 139.4 5.0 ? 2494 140.4 52.3

2009-07-10 10:25:47 ORBCOMM FM40 [S] 265.2 5.0 ? 2506 151.3 54.7
2009-07-10 10:30:39 ORBCOMM FM40 [S] 209.3 20.3 ? 1511 153.1 55.0
2009-07-10 10:35:31 ORBCOMM FM40 [S] 152.9 5.0 ? 2493 155.0 55.3

2009-07-10 10:38:36 ORBCOMM FM39 [S] 264.5 5.0 ? 2500 156.2 55.5
2009-07-10 10:43:16 ORBCOMM FM39 [S] 211.6 18.1 ? 1605 158.1 55.8
2009-07-10 10:47:56 ORBCOMM FM39 [S] 158.3 5.0 ? 2487 160.0 56.0

2009-07-10 10:44:23 ORBCOMM FM37 [S] 264.0 5.0 ? 2501 158.6 55.8
2009-07-10 10:48:55 ORBCOMM FM37 [S] 213.1 16.8 ? 1671 160.4 56.1
2009-07-10 10:53:27 ORBCOMM FM37 [S] 162.0 5.0 ? 2489 162.2 56.3

2009-07-10 11:24:01 ORBCOMM FM41 [S] 257.9 5.0 ? 2500 175.0 57.1
2009-07-10 11:27:33 ORBCOMM FM41 [S] 220.5 10.7 ? 2037 176.5 57.2
2009-07-10 11:31:06 ORBCOMM FM41 [S] 182.8 5.0 ? 2491 178.0 57.2

2009-07-10 11:24:29 ORBCOMM FM29 [S] 258.5 5.0 ? 2501 175.2 57.1
2009-07-10 11:28:06 ORBCOMM FM29 [S] 220.0 11.0 ? 2016 176.8 57.2
2009-07-10 11:31:42 ORBCOMM FM29 [S] 181.6 5.0 ? 2488 178.3 57.2

2009-07-10 11:29:00 ORBCOMM FM38 [S] 256.8 5.0 ? 2503 177.2 57.2
2009-07-10 11:32:23 ORBCOMM FM38 [S] 221.3 10.0 ? 2086 178.6 57.2
2009-07-10 11:35:45 ORBCOMM FM38 [S] 185.8 5.0 ? 2491 180.0 57.2

2009-07-10 12:10:57 ORBCOMM FM40 [S] 236.8 5.0 ? 2499 194.9 56.5
2009-07-10 12:11:52 ORBCOMM FM40 [S] 227.6 5.3 ? 2469 195.3 56.5
2009-07-10 12:12:47 ORBCOMM FM40 [S] 218.5 5.0 ? 2495 195.7 56.5