in cooperation with

Institute of Space Systems

Flight Operations

Technical Note 4.1 Vessel Density Mapping

Issue 4

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

Doc.Type: Technical Note Vessel Density Mapping			*DRD N°:* TN 4.1
Doc. N°:	*Issue:* **3**	*Date:* **01/10/2010**	*Page* **1** *Of* **32**
Title : **Vessel Density Mapping**			

	Name & Function	*Signature*	*Date*
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Customer / Higher Level Contractor			
Accepted by:			
Approved by:			

DISTRIBUTION LIST	N	A	I
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Data Management: *Signature* *Date*	File: 6039_PASTA MARE_GH_TN-004-1_Density_Plot_I4

DOCUMENT CHANGE RECORD			
ISSUE	*DATE*	*CHANGE AUTHORITY*	*REASON FOR CHANGE AND AFFECTED SECTIONS*
1	15/06/09	Gatehouse	Initial version
2	14/12/09	Gatehouse	Updated with density plots of real data, and 2 algorithms depending on terrestrial data or satellite data.
3	25/06/2010	LuxSpace	Complete redrafting
4	14/10/2010	LuxSpace	Additional chapter about validation included

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Scope of the Document

This document describes the approach used to generate global vessel density maps and provides the corresponding map results.

Applicable and Reference Documents

RD1	Preparatory Action for Assessment of the Capacity of Spaceborne Automatic Identification System Receivers to Support EU Maritime Policy – Pasta Mare Technical Proposal Call for Tenders No MARE/2008/06

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1. INTRODUCTION

1.1 DEFINITION OF "VESSEL DENSITY"

The term "vessel density" has several co-notations. Therefore it is necessary at first to clarify the meaning of the term.

"Vessel density" used in the context of this document refers to "the average abundance of vessels within a defined geographical area / spatial grid".

Other definitions of "vessel density", "vessel density plot" or "vessel density statistics" seem to be quite common in the AIS sector. These refer to the number of ships travelling along a defined shipping route or crossing a specific section. For this type of statistics, the term "vessel traffic density" would be more appropriate.

1.2 THE ADDED VALUE OF VESSEL DENSITY MAPS

Vessel density maps serve two main purposes:

- improved understanding of global vessel traffic and
- as input dataset for satellite AIS mission planning and simulation.

Vessel density maps provide an overview of the global maritime traffic, allowing the identification of areas with a low ship density (e.g. the Antarctic Sea or Coast of Somalia, almost deserted because of the piracy attacs), regions with high density areas like the English Channel or international shipping lanes as part of the worldwide maritime network.

Recalling that ocean shipping stands out as the most energy efficient mode of long-distance transport, that as much as 90% of world trade is hauled by ships (equivalent to 7.4 billion tons of goods) and that the trade volume currently exceeds 30 trillion ton-miles, it becomes obvious that monitoring the ship transport network is essential for economic reasons but also for security and safety issues.

Ship density maps contribute to a better understanding of the global maritime traffic and contribute to answering important questions, for example where are the main shipping lanes, how frequent they are used, which ship types are following which route, what is transport where etc.

Of particular relevance is also to investigate how the traffic pattern changes over time. Transport pattern are never static neither ship density maps. Vessel distribution traffic pattern change over time, for example due to

- the long term increase of the global vessel fleet,
- economic up- and down cycles impacting the amount of commodities shipped,
- annual climatic situation (e.g. ice drift) or
- even climate change (opening of the North-East and North-West Passage).

Therefore density maps represent only a snapshot of the current situation and need frequent updates.

For any satellite based AIS mission design vessel density maps are an indispensable precondition. Only the detailed knowledge about the distribution of class A vessels carrying AIS transponder allows the estimation of the number of vessels in the Field of View (FoV) of the satellite. Based on this key figure the corresponding number of messages arriving at the satellite can be assessed, which is necessary for estimating potential receiver saturation, number of message collisions and other important parameters needed for a sound payload and satellite mission design.

2. METHODOLOGICAL APPROACH

The main challenge of creating a vessel density map is the fact that there are no means to obtain the position reports from all existing class A vessels at a given – and rather short – instant point in time (so called "snapshot"). Such a global snapshot would be the ideal source for producing a coherent global vessel density map.

Terrestrial AIS data seem to best suited since they can deliver such a snapshot picture, but unfortunately just for some coastal regions. For the vast open sea regions space based AIS data is the only available information source.

However, the current operating S-AIS systems cannot deliver such a "snapshot". Instead, data need to be collected over a longer time period to obtain a global picture of vessel distribution and density.

2.1 DATA SOURCES USED

As mentioned before, one single unique data source to compute a vessel density map at global level does not exist. Instead, to cope with the global scope of the vessel density map two different types of data are used:

- S-AIS from Orbcomm and Pathfinder 2 cover vast open sea areas, outside the reach of terrestrial AIS station network or regions where t-AIS stations do not exist or data are not accessible. Used data cover the period from 1st January 2010 – 31st March 2010.
- t- AIS data put at disposal by IALA.net covering high density areas of the North Sea and the Baltic Sea. t-AIS provides an almost complete vessel traffic picture over these coastal areas. In these regions space based AIS data detection capabilities are limited. The plots are based on data provided by the Danish Maritime Safety Administration (DAMSA) for the period 10 Feb 2010 - 16 Feb 2010. The used data comprises all data from DAMSA's 18 own base stations as well as from two receivers located in the North Sea operated by Maersk Oil & Gas, all data from the Finnish AIS network and data from the Swedish AIS network, for the area covering 56°N - 64°N, 15°E - 21°E.

2.2 ASSUMPTIONS

The generation of vessel density maps is based on different assumptions:

1. It is assumed that the total number of class A-vessels is currently about 62.000 (Source: Lloyds MIU Handbook of Maritime Security), i.e. the spatial pattern of these 62.000 vessels needs to be mapped at a global scale.
2. Representativity of the S-AIS sample: S-AIS does not capture at once the location of all 60.000 vessels. Instead, it requires several orbits throughout a longer time window to identify a maximum number of ships. Various tests indicate that within a time window of 8 days around 22.000 individual ships (unique MMSI's) can be identified. Any extent of the time window does not yield in a substantial increase of the number of ships. It is assumed that the ships captured by S-AIS during the 8 days periods are a valid sample of the total class A ship population, representing the true density global vessel pattern. In order to account for the total number of ships, each 8 day subset is multiplied by a weighting factor for reaching 60.000 vessels
3. Spatially representativity: It is assumed that in every part of the world vessels are identified. In high density areas (EU waters) S-AIS capture a smaller fraction of vessels. Thus those areas are not underrepresented (undersampled) in the S-AIS but compensated through the integration of the above mentioned terrestrial AIS data.
4. It is assumed that there is no seasonality in the global vessel pattern, meaning that there is no daily/weekly/monthly change in the distribution of the global vessel traffic. This assumption is only partly true as the results indicate.

2.3 APPROACH APPLIED IN COMPILING VESSEL DENSITY MAPS

The creation of a global vessel density maps is done in three steps as a consequence of the different data sources used:

1. Generation of a density map based on S-AIS data (Orbcomm and Pathfinder 2)
2. Generation of density maps based on terrestrial AIS data for the Baltic Sea, North Sea and US coastal areas
3. Merge of both maps into one common map representation

2.3.1 VESSEL DENSITY MAPS BASED ON S-AIS DATA

The approach to compile vessel density maps follows the steps described hereafter:

1. Generation of vessel position "snapshots" or subsets: Considering a time window of 8 days, all vessel positions in the S-AIS database are retrieved from the database and only the first position report from each vessel is retained.

   The 8 day time window is a trade off between number of unique ships identified and time period considered. A steady increase of unique ships can be observed until day 8 (see Figure 1). Extending the time window would not yield in a significant increase of vessel population. Narrowing down the time frame would shorten the "snapshot" period, but also reduce the number of unique ships detected by AIS satellites.

   In order to avoid duplicates, each vessel is considered once, i.e. only the first position is kept. Table 1 shows the number of vessels in each subset. The number varies between 19.000 and 23.000 individual MMSIs and represents a valid sample of around a third of the global class A vessel fleet.

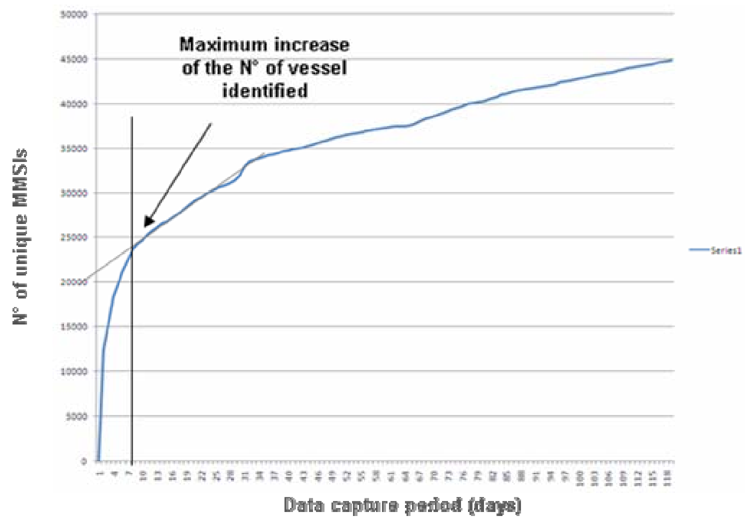

Figure 1: Relationship between N° of MMSI's observed by S-AIS and time period considered (cumulative values)

2. In total eleven "8-day subsets" are created based on Orbcomm FM 37, Orbcomm FM39 and Pathfinder 2 data, covering a 3 month period from 1st January till 31st March. Subset 7 was not further considered due to the low number of vessels. Through the generation of 11 subsets, the spatial representativity of the vessel positions is enhanced, since the effect of "white spots" (areas without any vessels) is compensated. Table 1 shows the number of vessels in each subset. The number varies between 19.000 and 23.000 individual MMSIs and represents a valid sample of around 1/3 of the global class A vessel fleet. In order to account for the totality of 60.000 class A-vessels, each subset sample is multiplied with a corresponding weighting factor.

Subset	Start date	End date	N° of unique vessels	Share of total class A vessel population (%)
1	1st Jan 2010	8th Jan 2010	19493	32.5
2	9th Jan 2010	16th Jan. 2010	19586	32.6
3	17th Jan 2010	24th Jan 2010	19947	33.2
4	25th Jan 2010	1st Feb 2010	17163	28.6
5	2nd Feb 2010	9th Feb 2010	22160	36.9
6	10th Feb 2010	17th Feb 2010	23613	39.4
7	*18th Feb 2010*	*25th Feb 2010*	*12531*	*Not considered*
8	26th Feb 2010	5th Mar 2010	21733	36.2

9	6th Mar 2010	13th Mar 2010	23171	38.6
10	14th Mar 2010	21st Mar 2010	23171	38.6
11	22nd Mar 2010	29th Mar 2010	23691	39.5

Table 1: Share of class A-vessels considered in the 11 different subsets

3. Count to grid: At first a global 1°x1° spatial grid is defined covering the entire globe. For each of the 10 subsets considered, the number of ships in each grid cell is computed. The result is a first global vessel density map, just based on one single subset.
4. Averaging: Using the 10 vessel density maps (based on the 10 subsets), for each grid cell, the average number of vessels is computed from the 10 subsets resulting in one average vessel density map.
5. Map production: the result of the averaging is finally mapped.

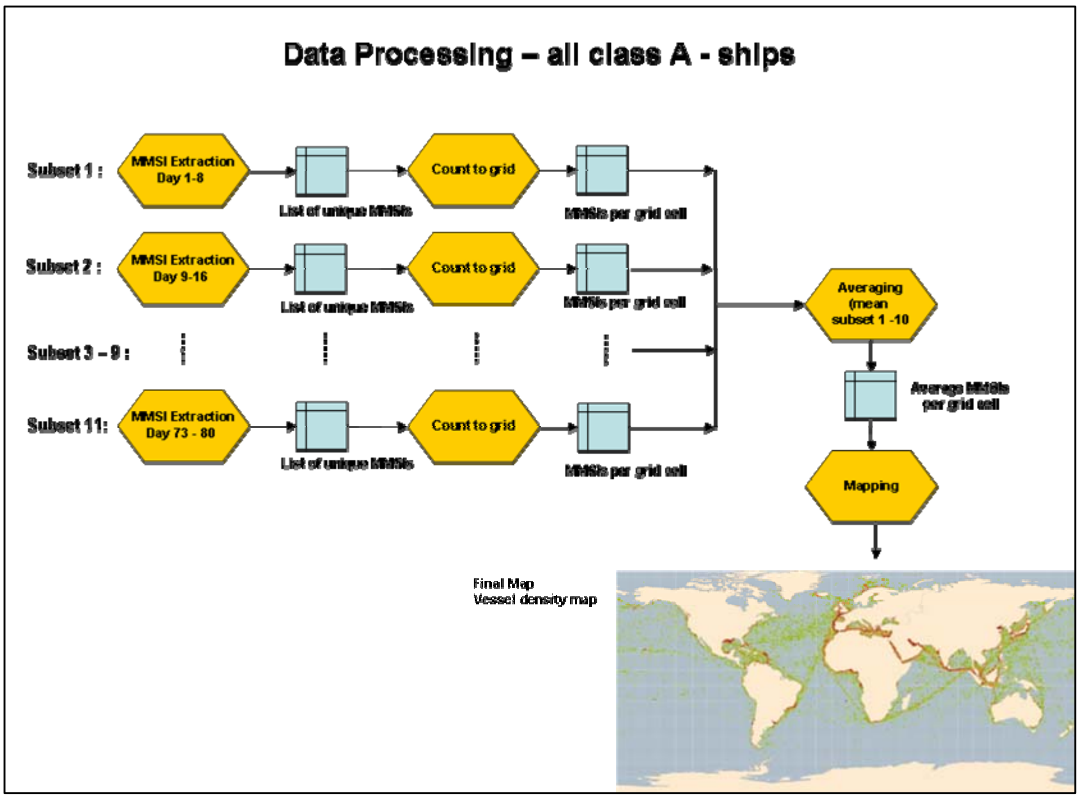

Figure 2: Data processing chain used for generating vessel density maps

2.3.2 VESSEL DENSITY BASED ON TERRESTRIAL AIS DATA

The calculation of the density maps using terrestrial AIS data follow the same approach. The only differences are:

- “snapshot” period considered is just 20 minutes, considereing the “timeliness” or latency of terrestrial AIS data.
- Grid size for which the vessel density maps are produced is set to 0.25° in order to better cope with the high density area.
- In total 7 snapshot are considered to calculate the average vessel density. Different trials showed that with seven “20 minute” subsets a stable number of ships is gained.

Subset	date	N° class A ships in the Baltic Sea ships
1	10th February	1496
2	11th February	1543
3	12h February	1535
4	13th February	1509
5	14th February	1597
6	15th February	1761
7	16th February	1784
	Average	**1604**

Table 2: N° of class A vessels in the Baltic Sea and parts of the North Sea

Figure 3 shows the vessel density map created for the Baltic Sea, based on the available AIS data, provided by DAMSA. Unfortunaltelly a complete coverage of the Baltic Sea could not be obtained. Some Gaps are visible along the Norvegian coast and the costal areas of the Baltic States.

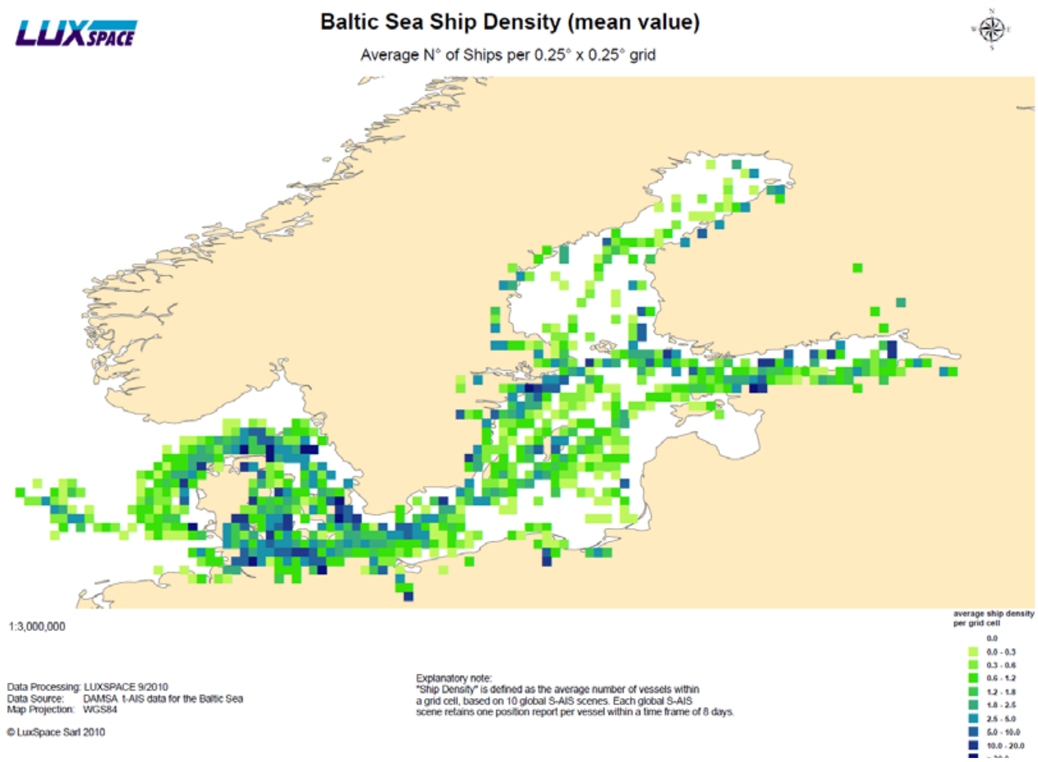

Figure 3: Vessel density map (all class A vessels) of the Baltic Sea and part of the North Sea derived from terrestrial AIS data

2.3.3 MERGE OF T- AND S-AIS DENSITY MAPS

In order to have a coherent representation of the terrestrial and space borne derived vessel density maps, both maps are merged into one single map representation.

2.3.4 DIFFERENCIATION BETWEEN TYPE AND NAVIGATION STATUS OF SHIPS

To further explore the value of density maps, a distinction is made between different types of ships. 5 different ship types are defined and corresponding density maps are produced:

- Cargo ships
- Tankers
- Passenger ships
- Fishing vessels

- Other ships

From each 8 day subset produced, only those ships have been considered belonging to the specific ship type. Table 5 in the Annex shows statistical details about their distribution. The approach is then identical with the one explained in previous section.

Moreover, to provide a more meaningful data product for the design of future space based AIS missions, a distinction between:

- moored vessels and
- ships "en route" is made.

The navigation status (moored vs. moving) determines the AIS message submitting interval (3 minutes vs. 2-10 seconds), which is essential for the estimation of number of messages received at satellite.

Table 6 in the Annex displays details about the share of vessels and the corresponding navigation status.

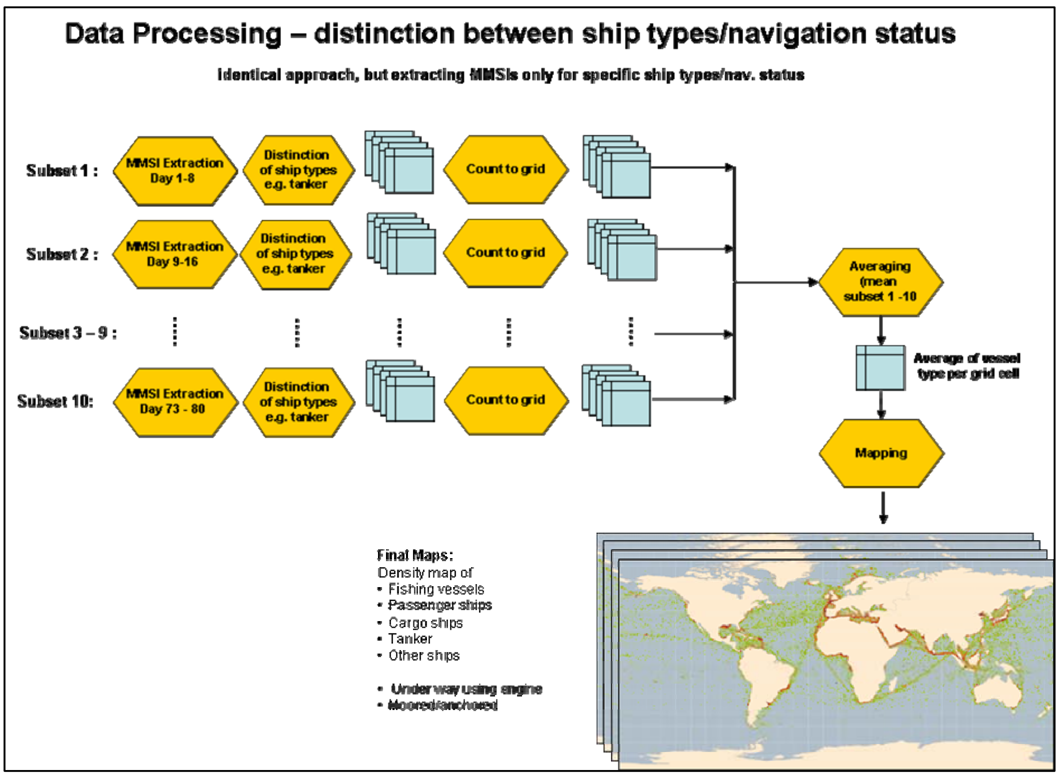

Figure 4: Data processing for compiling ship density maps for specific ship types

3. RESULTS

The results of the computation are displayed in Figures 5 to 12. The denity map of all Class A vessel clearly depicts the high vessel density areas:

- Baltic Sea,
- North Sea,
- the Mediterranean Sea,
- Red Sea,
- Persian Golf,
- Strait of Malacca,
- Japanese East Coast,
- China,
- Golf of Mexico.

Moreover, the global maritime traffic network becomes visible i.e. the main traffic lanes connecting the economic poles in Asia, Africa, Europe and the Americas crossing Atlantic, Pacific and Indian Ocean are identified.

On the other hand also the low density areas are highlighted, for example the South Pacific and notably the area off the Somali Coast, a region where vessels are rarely encountered nowadays due to the piracy attacks.

The maps on tankers and cargo vessels (Figure 6 and 7) follow in general the overall pattern, whereby the global tanker fleet trajectories, connecting main oil and gas terminals around the world, are more pronounced. In contrast to the tanker or cargo density maps, the distribution of the global fishing vessel fleet shows particular regional concentrations (Figure 9)). These concentration areas are obviously linked to the main catch areas around the world: central Pacific, North Atlantic (Iceland, Norway) Celtic Sea, along the East and West coast of South America (Peru, Chile, Argentina).

Passenger vessels (Figure 8), mostly ferries and cruise ships, are found along the coastlines but also some regional clusters can be identified, such as the Caribbean Sea, Mediterranean Sea and most notably at the Southern edge of South America and the Antarctic Peninsular. The latter cluster is not surprising, since AIS data are captured during the South summer (December – February), the main touristic season for visiting the Antarctica.

The brief interpretation of the density maps exemplifies the added value of historical AIS data and further indicates the unexploited potential of the data. The historical AIS data, available at global level presents a unique data source, which can be used to derive specific density maps (focusing on particular ship types or regions, or considering seasonal effects, changes over time etc…) or other more specific statistical products. By means of expert knowledge from the various maritime domains such as business intelligence or fishery the real value can be further and fully exploited.

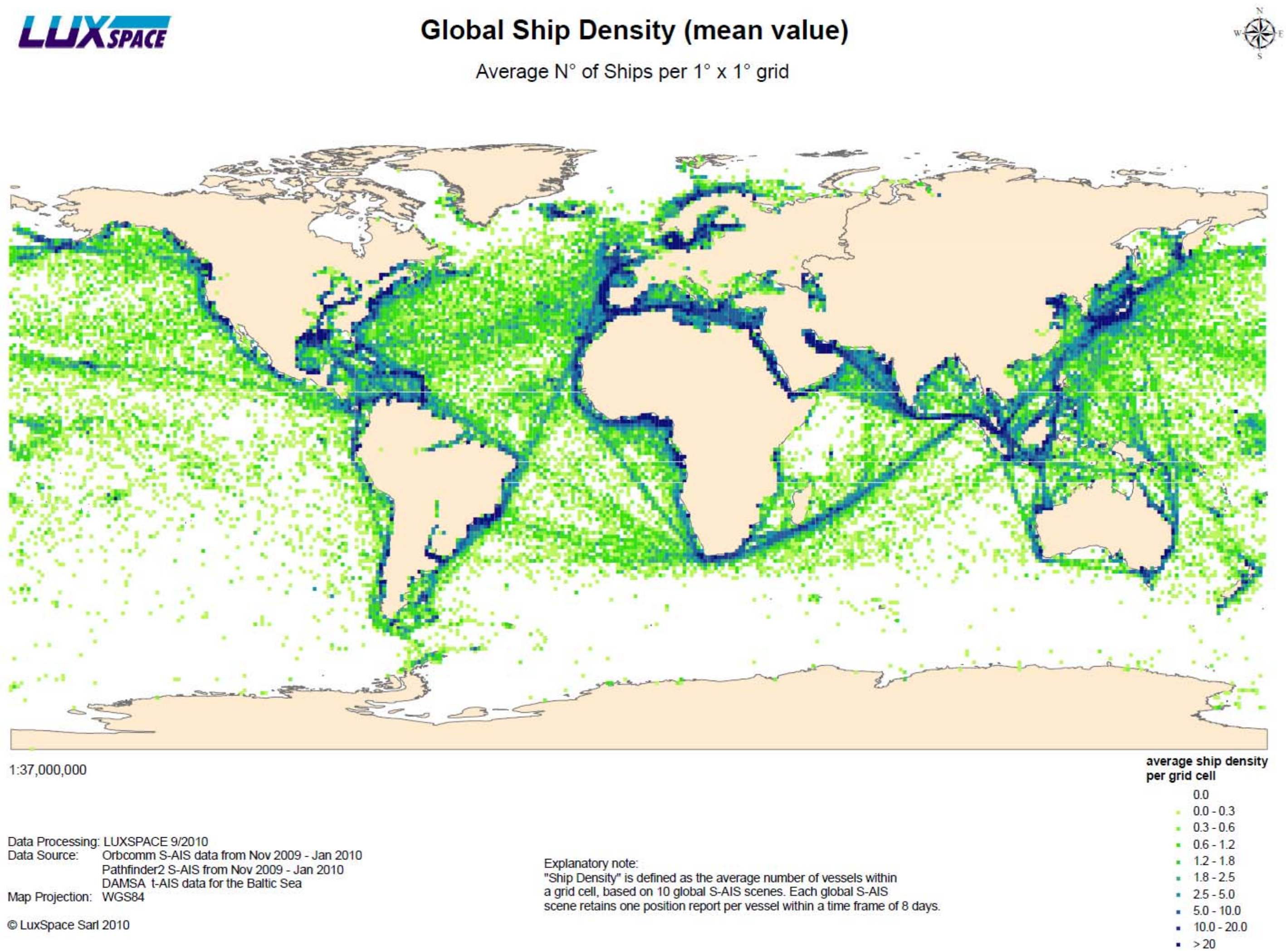

Figure 5: Global Ship Density Map - all class A vessels)

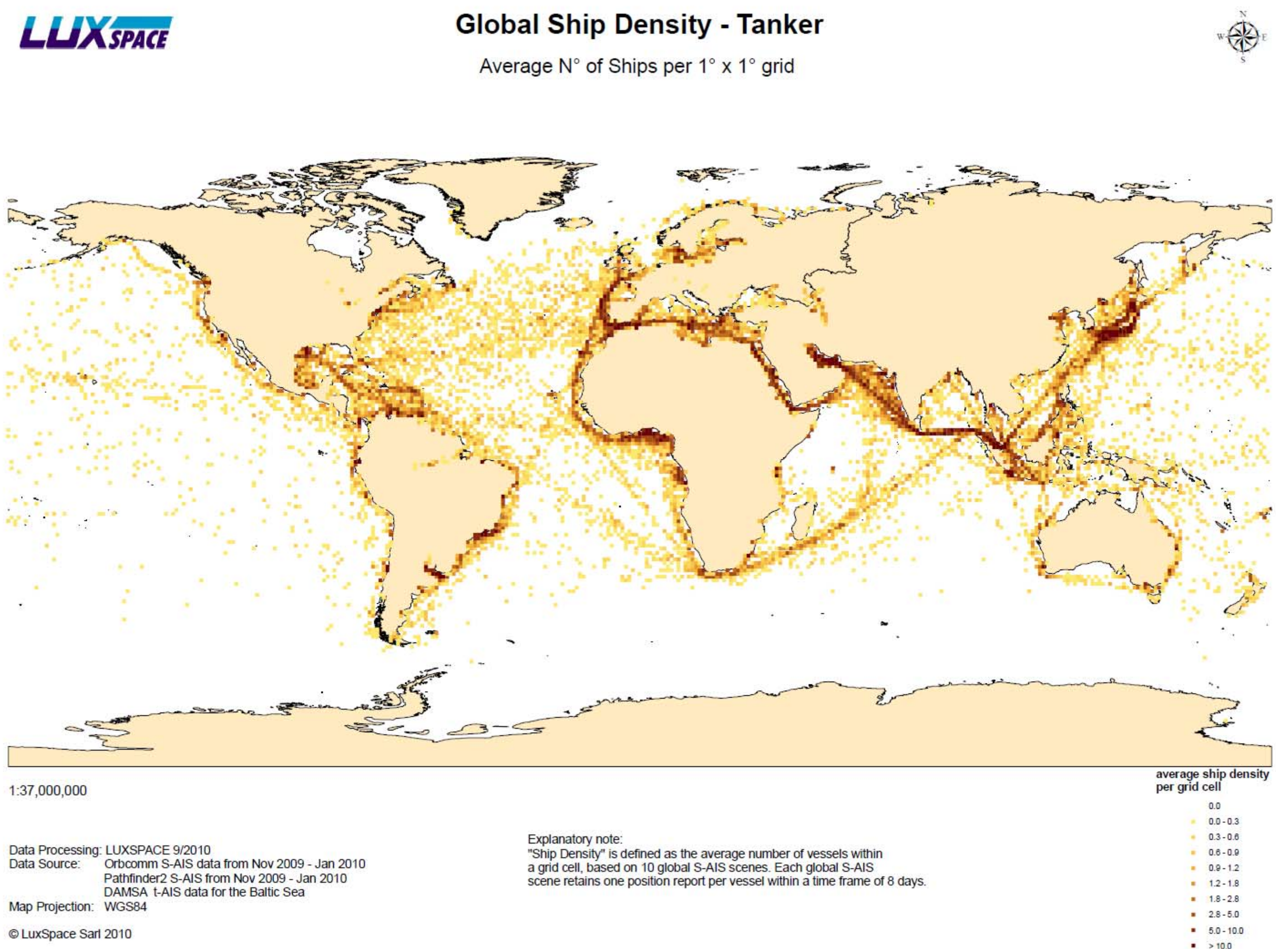

Figure 6: Global Ship Density Map – Tanker

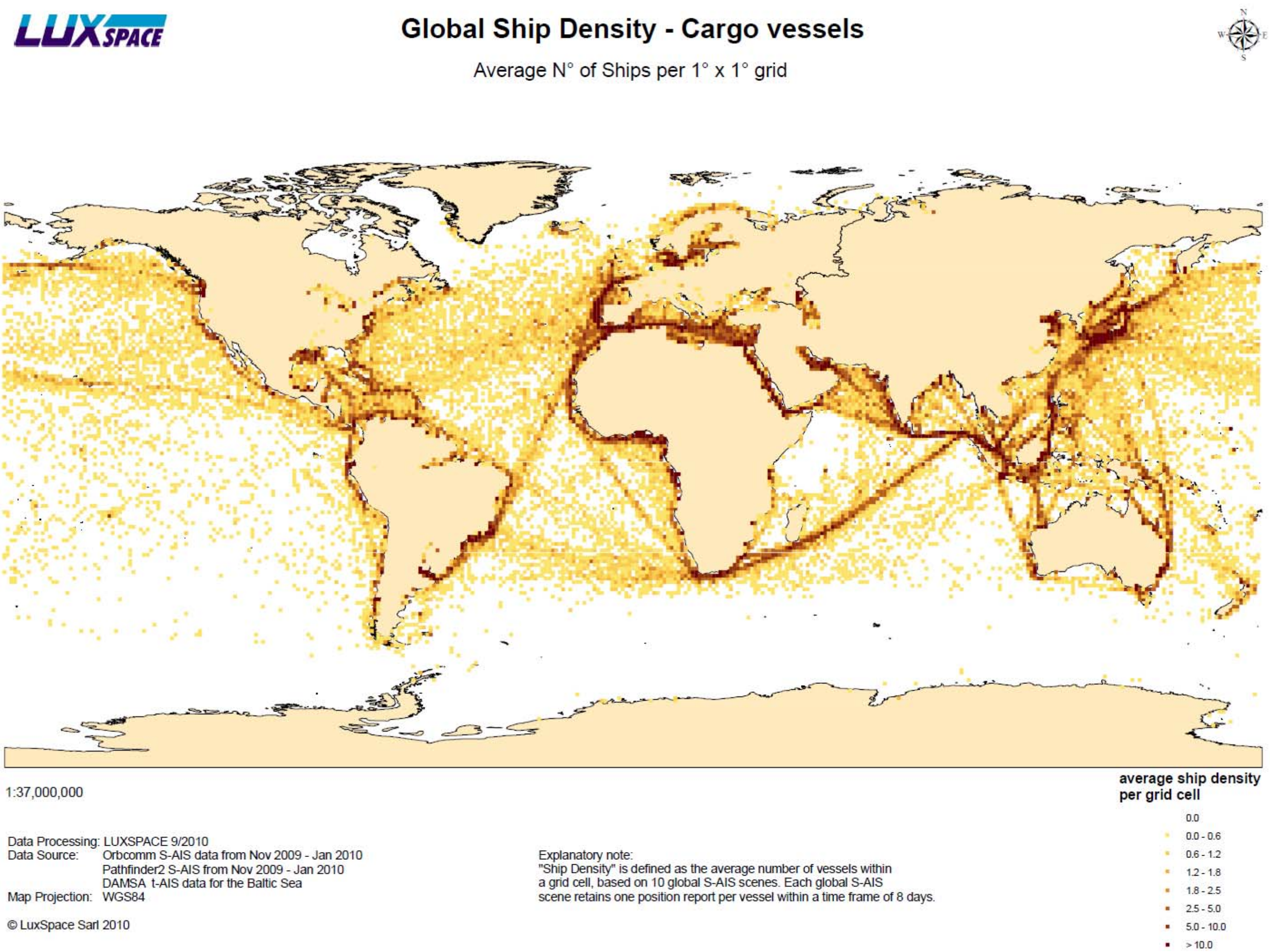

Figure 7: Global Ship Density Map – Cargo ships

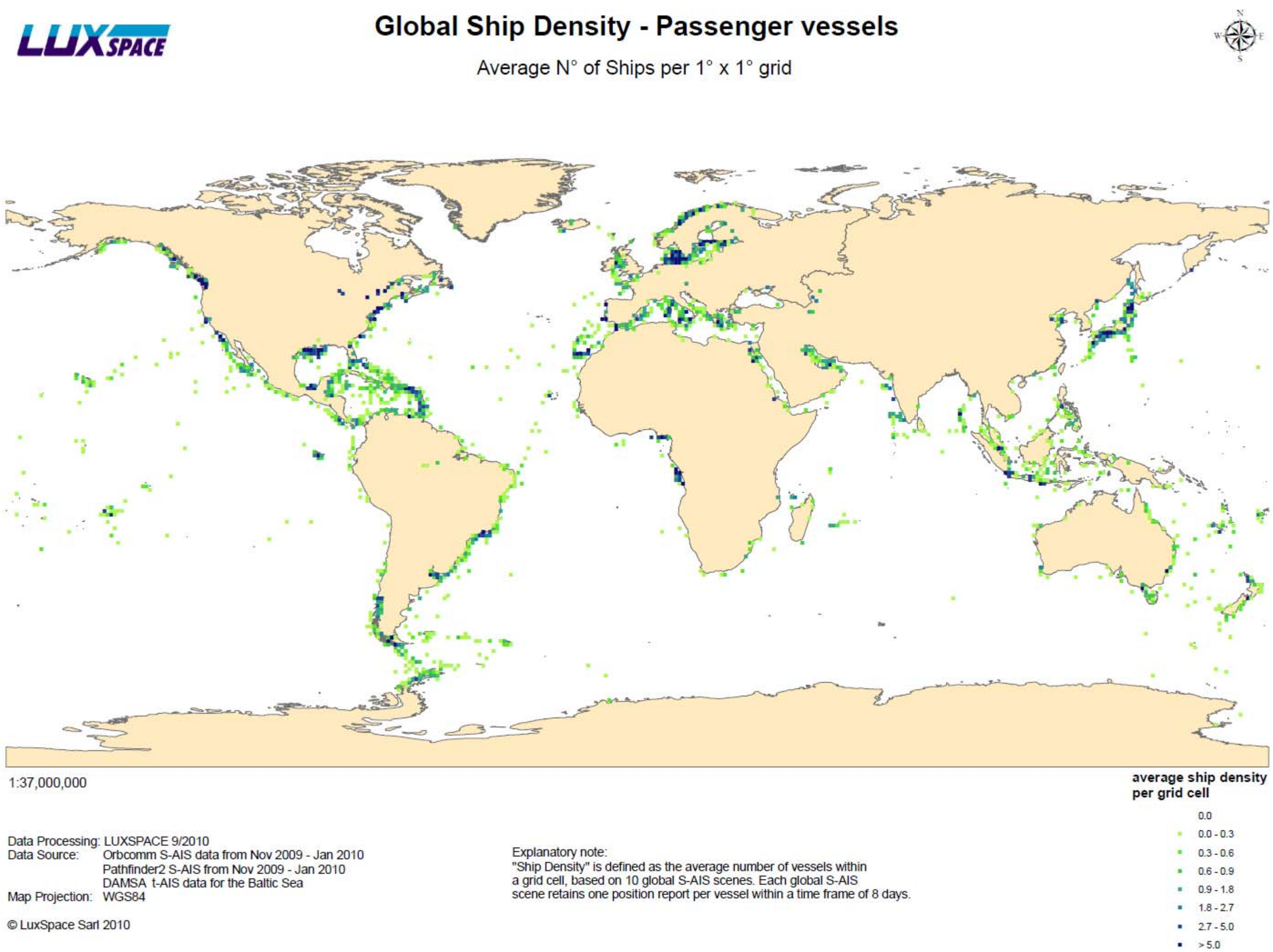

Figure 8: Global Ship Density Map – Passenger Ships

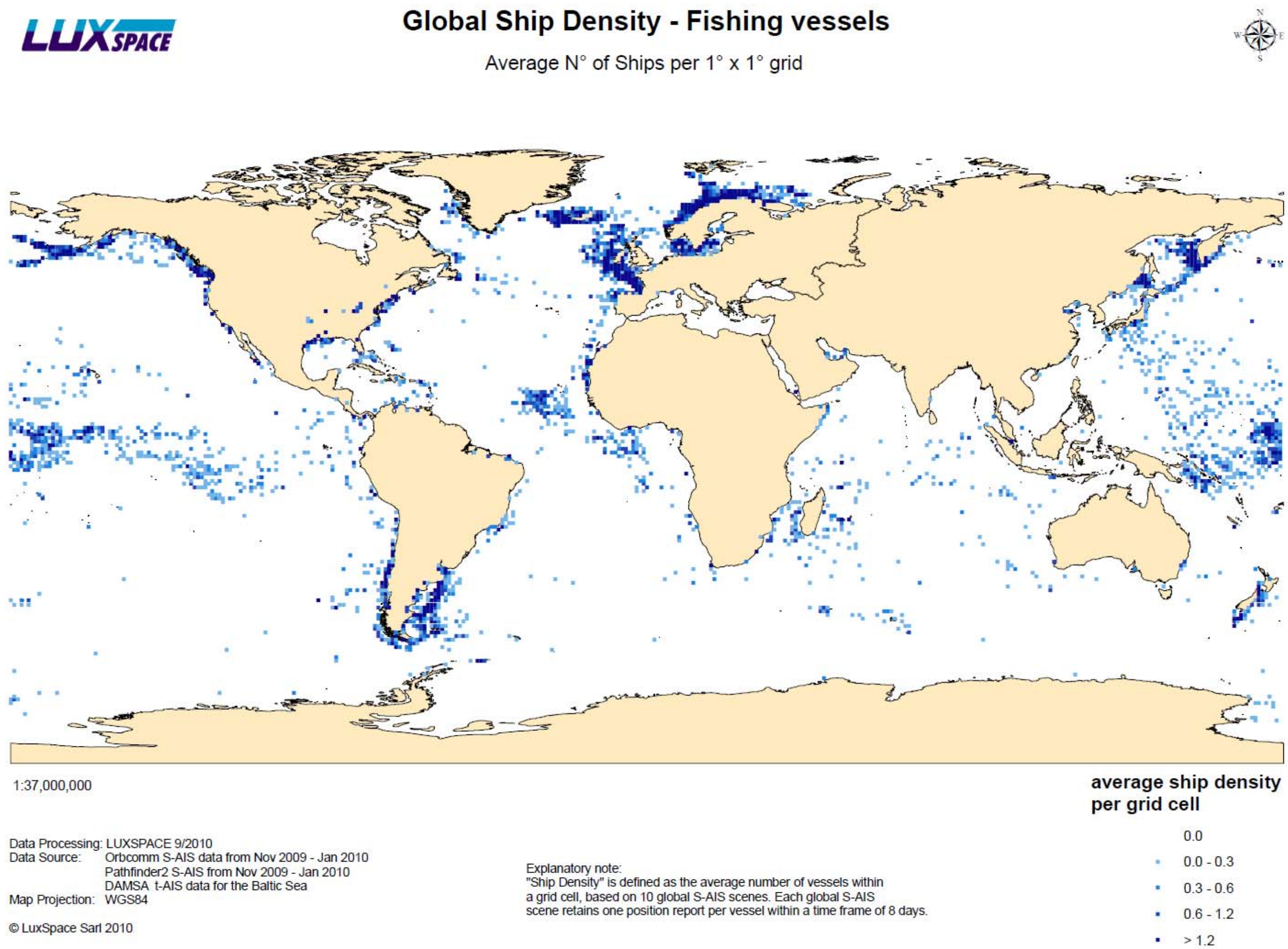

Figure 9: Global Ship Density Map – Fishing Vessels

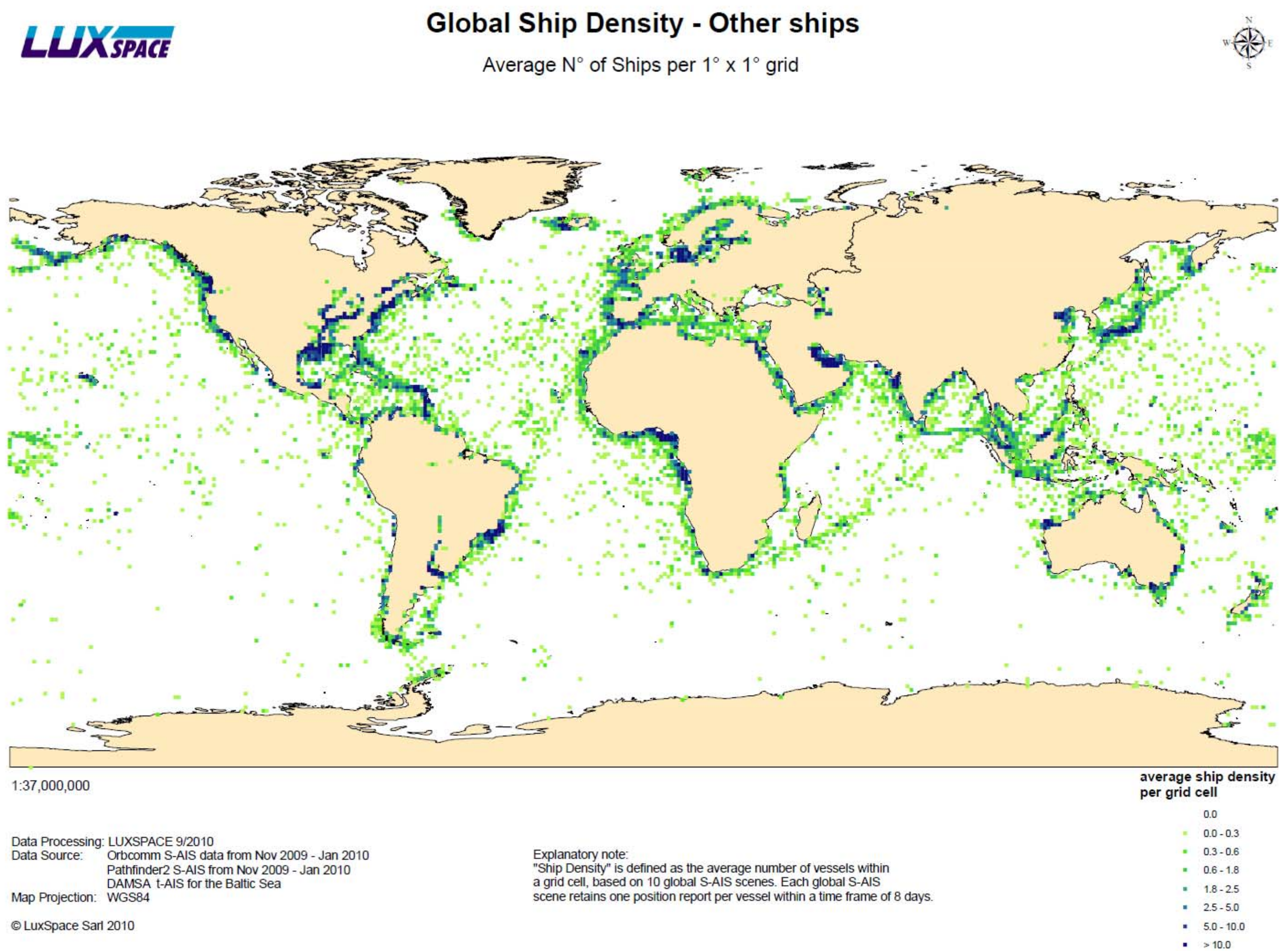

Figure 10: Global Ship Density Map – Other ships

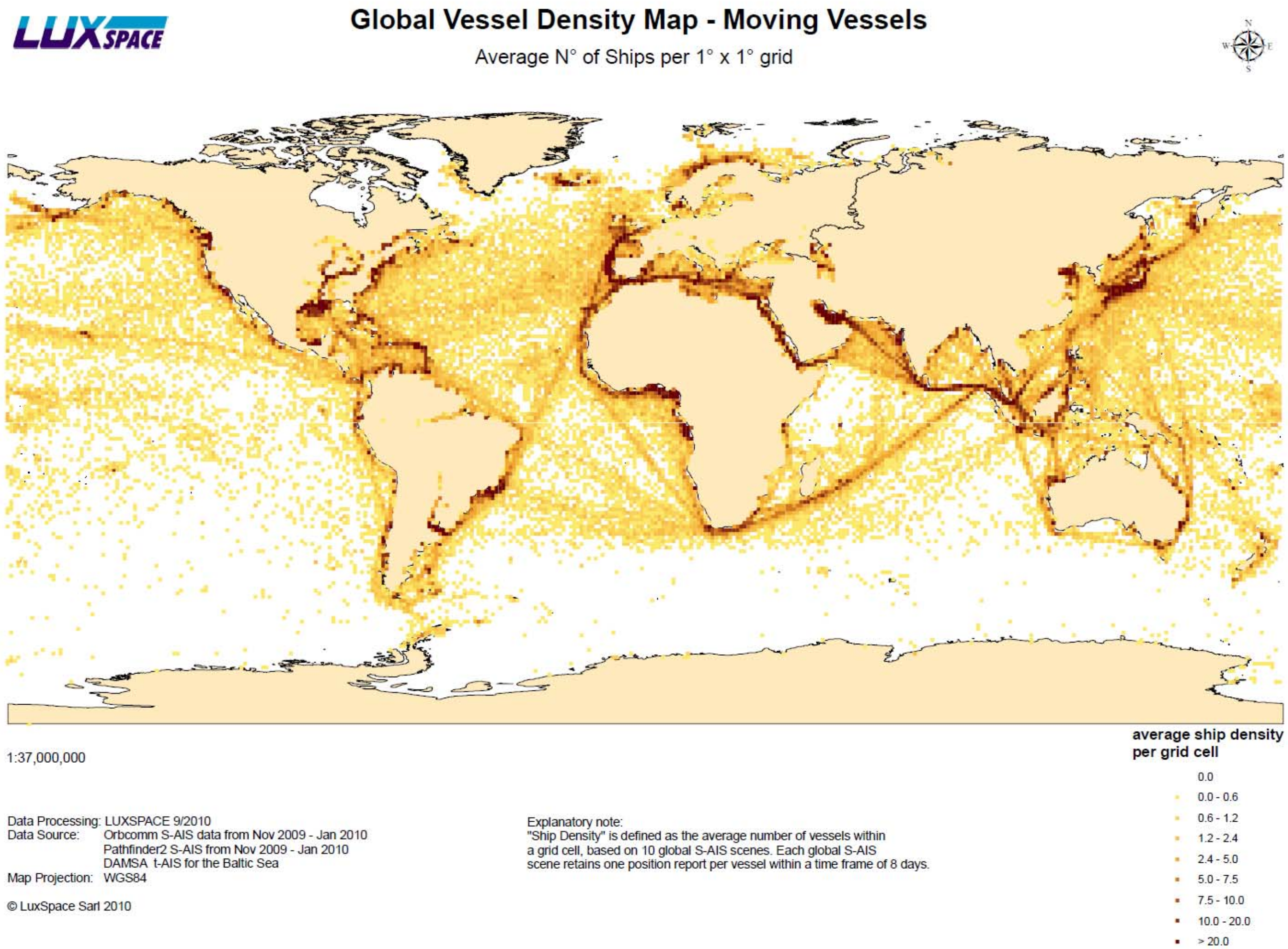

Figure 11: Global ship Density Map – Navigation Status "under way"

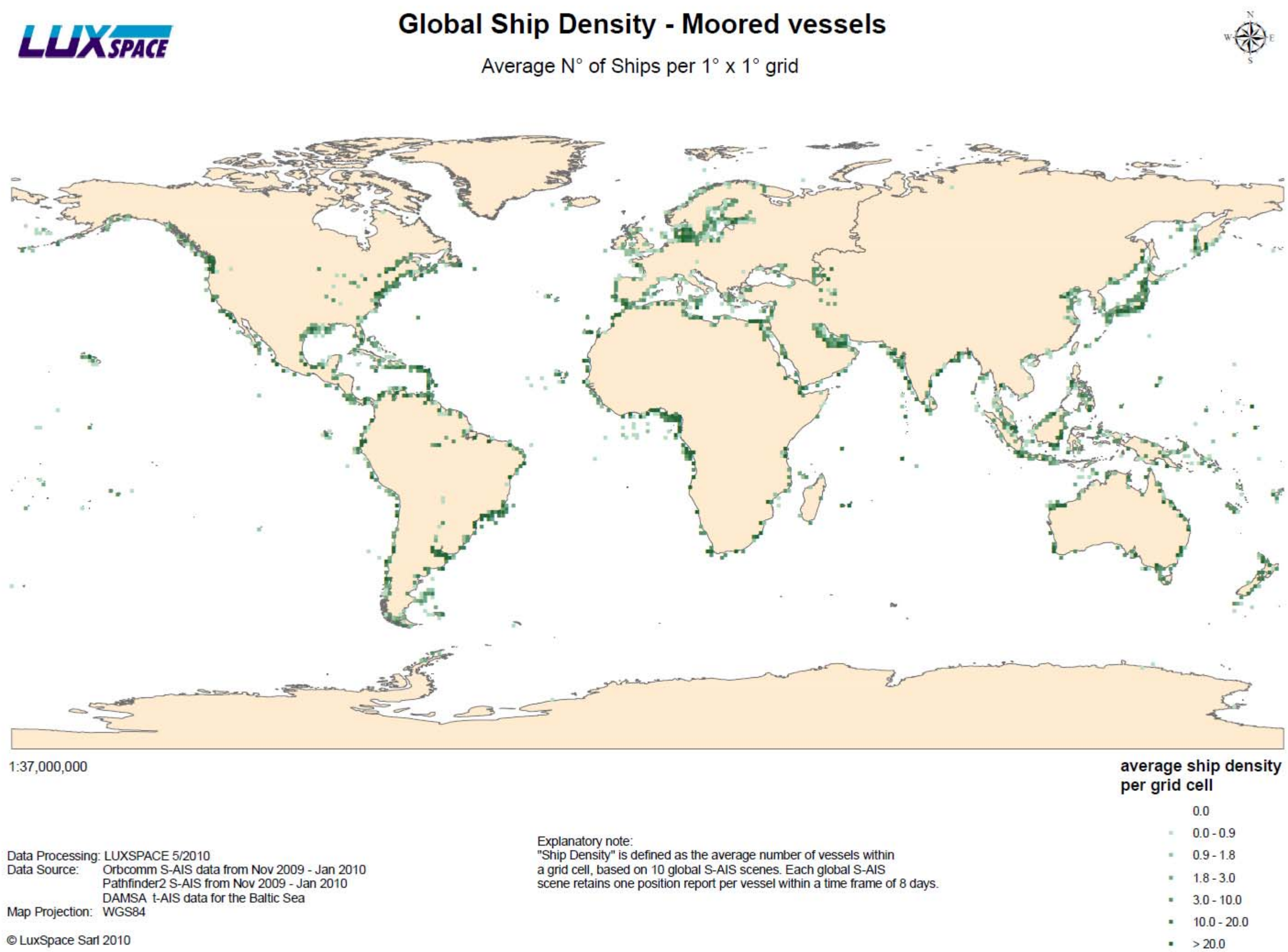

Figure 12: Global Ship Density Map – Navigation Status "moored"

4. VALIDATION OF S-AIS BASED VESSEL DENSITY MAPS

When validating the S-AIS density maps, a distinction can be made between qualitative and quantitative validation can be made. The qualitative validation refers to a visual comparison of density maps created with different and thus independent data sources. Aim is to cross correlate the density pattern displayed in the various maps. The quantitative validation tries to assess the validity of the density map in terms of concrete figures.

However, it needs to be stressed that a valid data source for both, the qualitative and quantitative validation is lacking. Thus the results can be only being considered as a proxy.

For the qualitative assessment of the validity of the S-AIS data two reference data sources are used:

- Atlantic Merchant Vessel Emergency Reporting (AMVER)[1]
- World Meteorological Organization Voluntary Observing Ships (WMO-VOS)[2]

As indicated in Table 3, there is a considerable difference in the basic data used for crating the WMO-VOS and the AMVER density maps: a smaller overall sample, only commercial vessels considered and - more importantly - the vessel density is given only in qualitative terms (from low to high).

	S-AIS	WMO-VOS	AMVER
Sample: N° ships	22000	3374	3809
Ship types	All ship types, all flags etc.	Commercial and research vessels	Commercial vessels (US Flag)
Information return	quantitative	Qualitative	qualitative
Bias		Sample Location Vessel type Not up to date	Sample Location

Table 3: Comparison of WMO-VOS, AMVER and S-AIS data sources used to generate vessel density maps

Despite these differences in the compilation of the density maps, the visual cross correlations shows the coincidence of the three density maps regarding global vessel traffic pattern, the distribution of the high and low density areas as well as the main shipping lanes.

[1] A detailed description of AMVER vessel reporting system is given at: http://www.amver.com/density.asp

[2] More infor about WM VOS can be found at: http://www.vos.noaa.gov/vos_scheme.shtml)

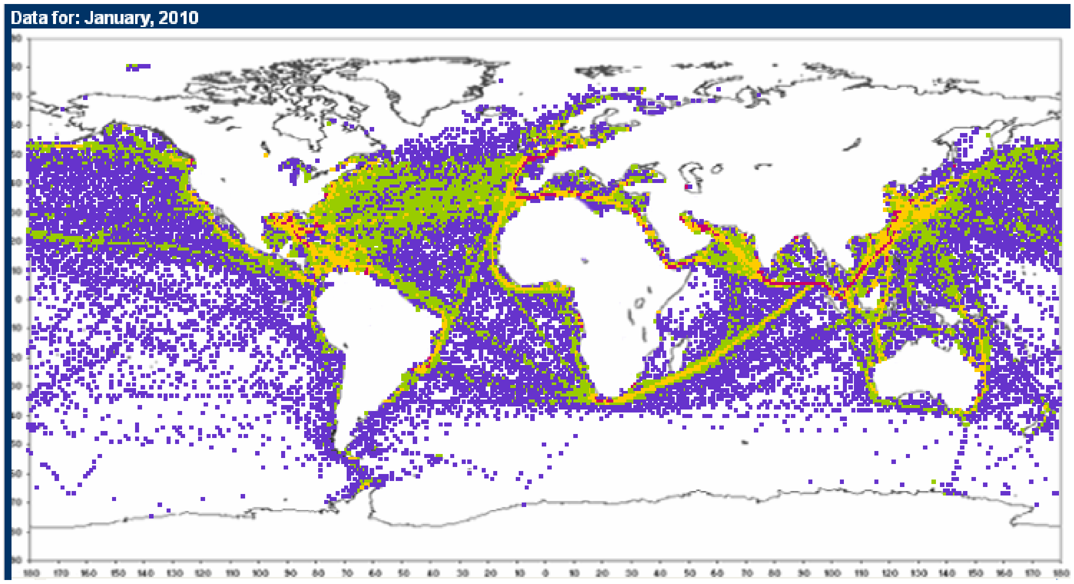

Figure 13: AMVER vessel density map (based on AMVER data from January 2010, source: http://www.amver.com/density.asp)

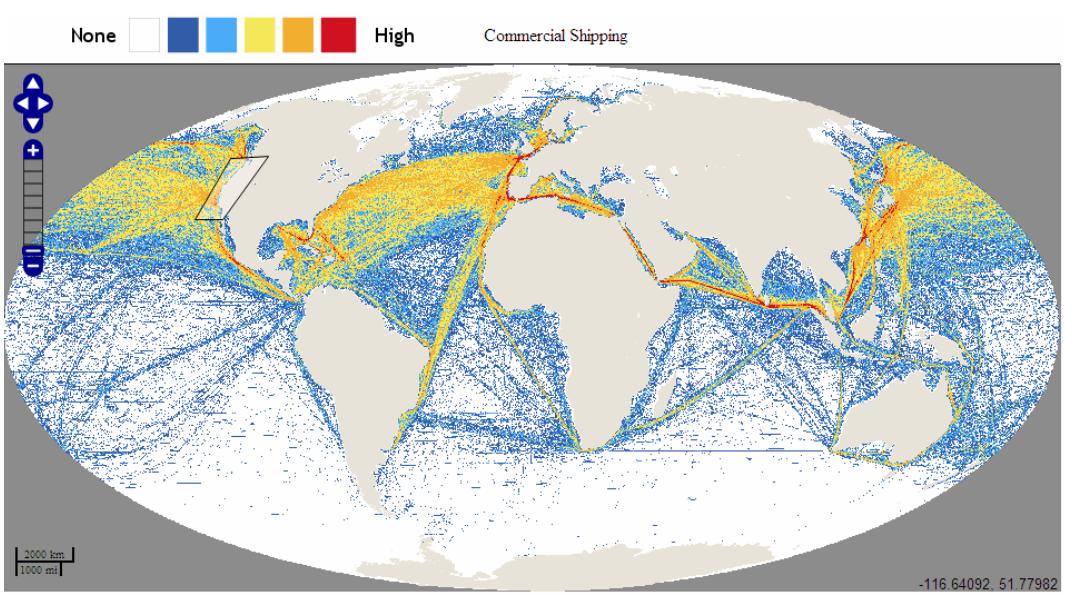

Figure 14: Vessel density map based on WMO-VOS (based on data VOS data from 2004/2005, source: http://www.nceas.ucsb.edu/globalmarine/impacts

By means of terrestrial AIS data as well as data collected form the flight campaign it is tried to validate the correctness of the figures (n° of vessels in specific areas) returned from the density maps. For specific areas, for which reference data (t-AIS, data from the flight campaign) are available, the number of vessels is extracted and cross correlated. If the numbers are matching – at least in broad terms – the validity of the density map is indicated.

It needs to be stressed that the data from terrestrial stations and the fight campaign are "snapshots" reflecting the vessel density at instant point in time and not an average vessel density. Therefore, a certain variation in the total number of vessels in the area can be accepted. Moreover, the terrestrial station network (AISlive and Vesseltracker) is not covering the entire test regions, thus their figures are lower compared to the flight campaign and the S_AIS density map. Table 4 shows the result of the comparison for 6 test regions. Despite this difference, it can be seen that – exact for the North Sea, the number of vessels extracted from the density map matches quite well with the observations from terrestrial AIS and those collected during the flight campaign. The results indicate the correctness and validity of the S-AIS density map.

Area	N° of Vessels by:		
	Terrestrial AIS (Vesseltracker/AIS-live)	Flight Campaign	S-AIS Density map
Baltic Sea	1291	1652	1507
North Sea	3582	3492	1526
Western Mediterranean Sea	1221	1819	1786
Eastern Mediterranean Sea	1265	n.a.	1418
Strait of Malacca	1522	n.a.	1844
Persian Golf	1024	n.a.	1178

Table 4: Count of vessels based on real observations and the S-AIS based density map

5. ANNEX

Subset	1	2	3	4	5	6	7	8	9	10	11
Date (ddmm-ddmm)	0101-0801	0901-1601	1701-2401	2501-0102	0202-0902	1002-1702	1802-2502	2602-0503	0603-1303	1403-2103	2203-2903
Share of total population	32.5%	32.6%	33.2%	28.6%	36.9%	39.4%	20.9%	36.2%	38.6%	38.6%	39.5%
multiplication factor	3.1	3.1	3.0	3.5	2.7	2.5	4.8	2.8	2.6	2.6	2.5

defined vessels categories/ number of vessels											
other ships (0-29; 31-59; 90-99; >100)	5513	5300	5368	4496	5997	6651	3744	5990	6398	6398	6592
Fishing Vessels (30)	1164	1153	1191	1107	1213	1206	548	1208	1210	1210	1217
Passenger Ships (60-69)	733	714	680	596	769	844	45	765	829	829	850
Cargo Ships (70-79)	8610	8872	9139	7895	10182	10635	5999	9825	10457	10457	10737
Tanker (80-89)	3473	3547	3569	3069	3999	4277	2195	3945	4277	4277	4295
total	19493	19586	19947	17163	22160	23613	12531	21733	23171	23171	23691
defined vessels categories/ Share (%)											
other ships (0-29; 31-59; 90-99; >100)	28.3%	27.1%	26.9%	26.2%	27.1%	28.2%	29.9%	27.6%	27.6%	27.6%	27.8%
Fishing Vessels (30)	6.0%	5.9%	6.0%	6.4%	5.5%	5.1%	4.4%	5.6%	5.2%	5.2%	5.1%
Passenger Ships (60-69)	3.8%	3.6%	3.4%	3.5%	3.5%	3.6%	0.4%	3.5%	3.6%	3.6%	3.6%
Cargo Ships (70-79)	44.2%	45.3%	45.8%	46.0%	45.9%	45.0%	47.9%	45.2%	45.1%	45.1%	45.3%
Tanker (80-89)	17.8%	18.1%	17.9%	17.9%	18.0%	18.1%	17.5%	18.2%	18.5%	18.5%	18.1%
total	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%

Table 5: Share of vessel types within each S-AIS subset (identification of ship types according to information from AIS message)

subset	1	2	3	4	5	6	7	8	9	10	11
Date (ddmm-ddmm)	_0101-0801	_0901-1601	_1701-2401	_2501-0102	_0202-0902	_1002-1702	_1802-2502	_2602-0503	_0603-1303	_1403-2103	_2203-2903
Navigation status/ number of vessels											
0 = under way using engine	13491	14074	14152	12338	15859	16823	9324	15723	16661	16661	16895
1 = at anchor	1522	1284	1419	1152	1552	1715	723	1419	1604	1604	1751
2 = not under command,	230	223	207	179	223	229	143	185	212	212	217
3 = restricted manoeuvrability	405	395	392	341	437	481	255	460	518	518	486
4 = constrained by her draught,	19	17	29	20	25	25	9	22	12	12	17
5 = moored	1441	1437	1472	1241	1625	1747	862	1596	1682	1682	1842
6 =aground	8	9	8	7	9	6	3	6	7	7	15
7 engaged in fishing	211	287	281	297	345	351	166	319	318	318	321
8 = under way saling	520	549	608	511	683	724	326	626	673	673	627
9 - reserved for future use	25	20	26	15	31	30	13	26	31	31	39
10- reserved for future use	12	14	15	12	16	14	9	16	19	19	17
11- reserved for future use	8	11	11	9	17	15	7	14	15	15	14
12- reserved for future use	10	10	9	7	10	11	5	9	9	9	6
13- reserved for future use	2	3	4	3	4	5	2	4	4	4	8
14- reserved for future use	5	4	4	2	4	7	2	5	8	8	9
15 default	1584	1249	1310	1026	1320	1430	682	1303	1398	1398	1427
sum	19493	19586	19947	17160	22160	23613	12531	21733	23171	23171	23691
Navigational status (grouped)/ Number of vessels											
under way (0, 7,8)	14222	14910	15041	13146	16887	17898	9816	16668	17652	17652	17843
moored (1, 2,3,4,5,6, >9)	5271	4676	4906	4014	5273	5715	2715	5065	5519	5519	5848
sum	19493	19586	19947	17160	22160	23613	12531	21733	23171	23171	23691
Navigational status (grouped)/ Share of vessels											
under way (0, 7,8)	73.0%	76.1%	75.4%	76.6%	76.2%	75.8%	78.3%	76.7%	76.2%	76.2%	75.3%
moored (1, 2,3,4,5,6, >9)	27.0%	23.9%	24.6%	23.4%	23.8%	24.2%	21.7%	23.3%	23.8%	23.8%	24.7%

Table 6: Share of different navigation status within each S-AIS subset (identification of navigation status from AIS message)