EDAP+ TN on Quality Assessment of BRO

Author(s): Raúl Díez-García — Digitally signed by Raúl Díez-García Date: 2023.11.14 15:33:28 +01'00'

Raúl Díez-García
Task 5 Team

Approval: DocuSigned by: Kevin Halsall 95EFDDD4879A4CF...

Kevin Halsall
EDAP+ Service Manager

Accepted:

Clément Albinet
EDAP+ Technical Officer

EDAP+.REP.023 *Issue: 1.1* *14 November 2023*

TELESPAZIO
a LEONARDO and THALES company

AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
1.0	03 November 2023	First issue of the document
1.1	14 November 2023	Second issue, with comments from Unseenlabs implemented

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

This Technical Note (**TN**) details the results regarding the assessment of the Breizh Reconnaissance Orbiter (**BRO**) constellation products delivered by Unseenlabs.

The BRO constellation, which currently consists of 9 orbiting satellites (2 more will be launched in autumn 2023), is a Radio Frequency (**RF**) spectrum monitoring and Signals Intelligence (**SIGINT**) service for maritime surveillance.

As of 2022, the French Unseenlabs-built spectrum-monitoring payloads fly on board 9 satellites whose constellation is expecting to reach 20 satellites by 2025. Each one of the sensors have on-demand global RF geolocation capabilities, providing geolocation of potentially non-collaborative emitters along with a RF signature.

BRO products contain a list of RF detections along their associated geolocation, accuracy, and ancillary data. This allows to identify the position of sea-going emitters. This capability can be used in a wide number of applications: monitoring of protected or restricted areas (e.g., Economic Exclusive Zones), control of fishing practices, security applications, etc.

Specifically, data acquired are RF emissions from maritime radars.. The International Convention for the Safety of Life at Sea (**SOLAS**) Regulation 19 establishes the need, for all the ships over a gross tonnage of 3000, to carry an S-band radar as a minimum, with the possible addition of an X-band radar to complement it. These are used to determine and display the range and bearing of other surface craft, obstructions, buoys, shorelines and navigational marks to assist in navigation and in collision avoidance. These devices are independent to other common aids to navigation such as Automatic Identification System (**AIS**), also required by the SOLAS Regulation 19. This allows the detection of uncooperative vessels that have AIS switched off, but still operate their navigation radars. In Figure 1-1, an example product has been plotted using QGIS.

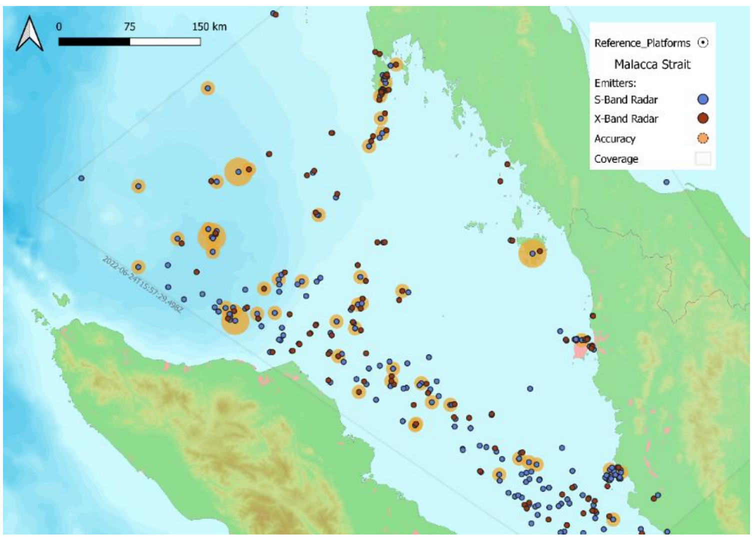


Figure 1-1: Example BRO product showing multi-band geolocation capabilities over the Malacca Strait.

The quality assessment presented in this document provides a series of checks on the product format, product metadata, geometric calibration and radiometric calibration on a small sample of products. The quality assessment performed here is in accordance with the Earthnet Data Assessment Project (**EDAP+**) Best Practice Guidelines [RD-1].

The summary tables of the results obtained have been plotted in Table 1-1:. It has been identified that the documentation of some aspects (especially regarding traceability and uncertainty determination) can be improved. In addition, the summary results for the detailed validation have been summarised in Table 1-2. Data usability and geolocation accuracy analysis have been carried out, the details of which are in Sections 3 and 4, respectively.

1.1 References

The following is a list of reference documents with a direct bearing on the content of this proposal. Where referenced in the text, these are identified as [RD-n], where 'n' is the number in the list below:

RD-1. EDAP Best Practice Guidelines, EDAP.REP.001, v2.2, February 2022.

RD-2. Unseenlabs Maritime Surveilance Service Product Data Description Document (USL.SURMAR.DATA.DESC) v2.3

RD-3. Product-sheet-UNSEENLABS – 2023 release

RD-4. FAIR guiding principles, https://www.go-fair.org/fair-principles/

RD-5. CF Standard Name Table, https://cfconventions.org/Data/cf-standard-names/current/build/cf-standard-name-table.html

RD-6. European Commission Inspire Knowledge Base, INSPIRE Directive, https://inspire.ec.europa.eu/inspire-directive/2

RD-7. QA4EV PUM guidance: https://archief34.sitearchief.nl/archives/sitearchief/20221110010000/http://qa4ecv.eu/sites/default/files/QA4ECV%20PUM%20Guidance.pdf

RD-8. QA4EV ATBD guidance: https://archief34.sitearchief.nl/archives/sitearchief/20221110010000/http://qa4ecv.eu/sites/default/files/QA4ECV%20ATBD%20Guidance.pdf

1.2 Glossary

The following acronyms and abbreviations have been used in this Report.

AIS	Automatic Identification System
ATBD	Algorithm Theoretical Basis Document
BRO	Breizh Reconnaissance Orbiter
EDAP+	Earthnet Data Assessment Project
FAIR	Findable, Accessible, Interoperable, Reusable
GUM	Guide to the Expression of Uncertainty in Measurement

NPL	National Physical Laboratory
PUG	Product User Guide
PUM	Product User Manual
RF	Radio Frequency
ROI	regions of interest
SIGINT	Signals Intelligence
SOLAS	International Convention for the Safety of Life at Sea
TN	Technical Note
VIM	International Vocabulary of Metrology

1.3 Cal/Val Maturity Matrices

This preliminary assessment was performed following the EDAP quality assessment guidelines written by the National Physical Laboratory (**NPL**) [RD-1], and the results summarised in Table 1-1 and detailed in this TN. It is considered as a preliminary assessment as it was prepared using a small sample of products over specific sites. It should be noted that this maturity matrix has been adapted to the constraints of RF Missions. In particular, the “Radiometric Calibration & Characterisation” field has been omitted due to the lack of radiometric contents (all information is geometric), the “Anciliary data” has been considered not applicable (due to the lack of auxiliary data for deriving the geolocation), Product generation section was greatly simplified too, as RF Missions only perform geometric processing.

1.3.1 Summary Cal/Val Maturity Matrix

Data Provider Documentation Review		
Product Information	**Metrology**	**Product Generation**
Product Details	Geometric Calibration & Characterisation	Calibration and Geometric Processing
Availability & Accessibility	Metrological Traceability Documentation	
Product Format, Flags & Metadata	Uncertainty Characterisation	
User Documentation		

Validation Summary
Fitness for Purpose Validation Method
Fitness for Purpose Compliance
Geometric Validation Method
Geometric Validation Results Compliance

Key
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal
Not Public

Table 1-1: Summary Cal/Val Maturity Matrix

1.3.2 Validation Cal/Val Maturity Matrix

At the time of writing this report, a mission quality assessment framework for AIS and RF missions is yet to be defined within the scope of EDAP+, and so for the purpose of this report, the general guidelines have been tailored accordingly.

BRO Detailed Validation			
Fitness for Purpose		Geometric	
Refresh rate Assessment Method	Refresh rate Results compliance	Completeness method	Completeness Results compliance
Timeliness Assessment Method	Timeliness Results compliance	Geolocation accuracy method	Geolocation Results compliance

Key
Not Assessed
Not Assessable
Basic
Good
Excellent
Ideal
Not Public

Table 1-2: Validation Cal/Val Maturity Matrix

2. DATA PROVIDER DOCUMENTATION REVIEW

In this section, the documentation review is conducted. This assessment aims to review mission quality as evidenced by its documentation. General product information (including product format) is analysed to determine if all the required information regarding the products is available to the user. In addition, metrology and product generation is assessed to determine the suitability of calibration methods and algorithms.

It should be noted that, during the framework of this evaluation, the product format was revised to account for some of the EDAP+ findings, and additional documentation was provided. The analysis below reflects the latest product format at the time of writing of this document.

2.1 Product Information

BRO data is provided in a zipped package containing a Product Data Description Document [RD-2] and the requested products:

Table	Microsoft Excel Worksheet
UNSEENLABS - Maritime Surveillance Service - Product data description - V2.3	Adobe Acrobat Document
UNSEENLABS_SURMAR_20210812T051332Z	Compressed (zipped) Folder
UNSEENLABS_SURMAR_20220227T202014Z	Compressed (zipped) Folder
UNSEENLABS_SURMAR_20220624T155730Z	Compressed (zipped) Folder

Figure 2-1: Example of contents of a SURMAR data package

Each product, identified by the string “UNSEENLABS_SURMAR” and its acquisition date, contains an “emitters” main file and a “coverage” metadata file detailing the geographical extent included in the product. In addition, a “metadata” file is provided, adding details on processing level, product ID, etc. All files are included in a number of common standard formats, including CSV and GEOJSON.

UNSEENLABS_SURMAR_20220624T155730Z_coverage	GEOJSON File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.dbf	DBF File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.kml	KML File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.prj	PRJ File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.qml	QML File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.shp	SHP File
UNSEENLABS_SURMAR_20220624T155730Z_coverage.shx	SHX File
UNSEENLABS_SURMAR_20220624T155730Z_emitters	CSV File
UNSEENLABS_SURMAR_20220624T155730Z_emitters	GEOJSON File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.dbf	DBF File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.kml	KML File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.prj	PRJ File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.qml	QML File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.shp	SHP File
UNSEENLABS_SURMAR_20220624T155730Z_emitters.shx	SHX File

Figure 2-2: Example of the contents of a single SURMAR product

Data can easily be interpreted using standard GIS software. For example, a product over the North Sea has been represented using QGIS in Figure 2-3, along with the product coverage and ancillary data (central frequency band and associated accuracy):

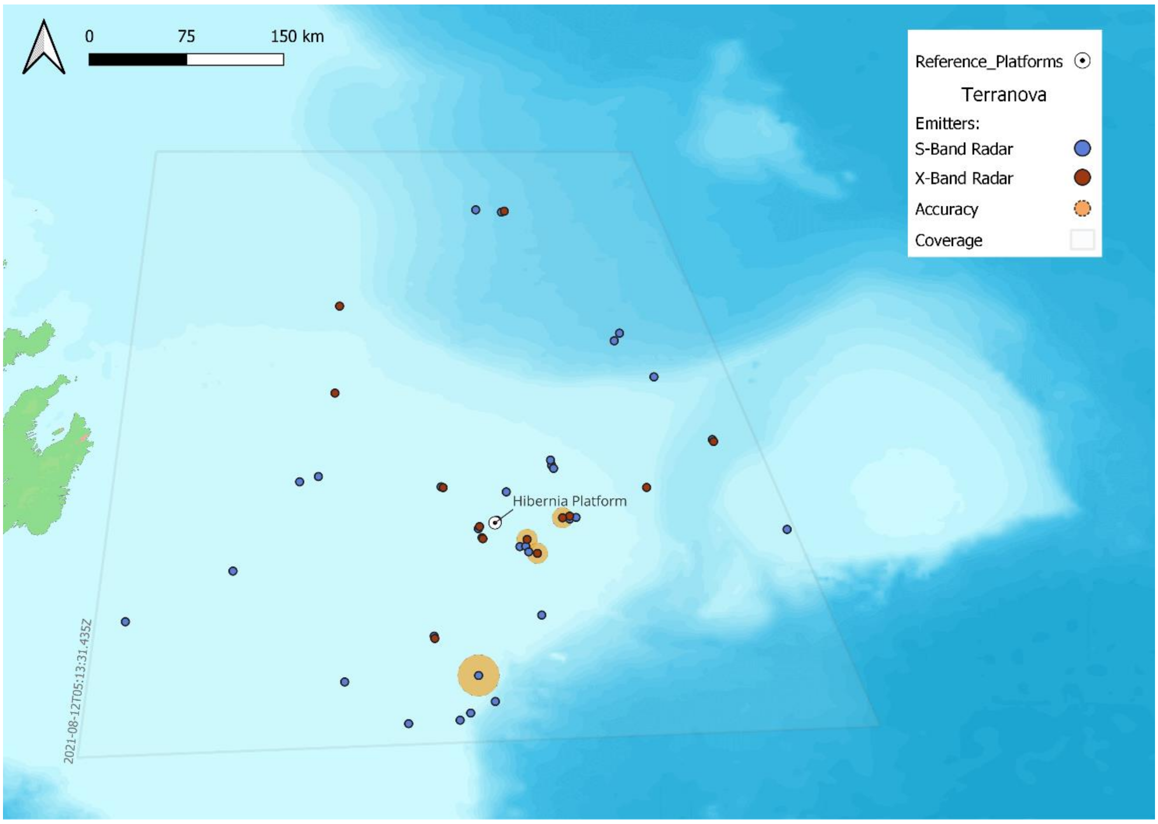


Figure 2-3: Graphical representation of BRO emitters product over Terranova platform, including central frequency and associated accuracy level.

2.1.1 Product details

The product information set as "required" by the EDAP+ guidelines [RD-1] has been detailed below for the BRO products. This information has been retrieved either from the product itself or from the documentation provided [RD-2]:

Product Details	
Grade: Excellent	
Justification	*The grade for Product Information is set to Excellent. There is some minor information that is not reported: the accuracy levels for some retrieved parameters are not defined yet in the documentation (pulse duration, carrier frequency and PRN specifically). Moreover, no DOI or URL is available to locate the products yet, but this will be provided in the future.*
Product Name	*UNSEENLABS Maritime Surveillance Service (SURMAR)*
Sensor Name	*BRO-[1-7], payload name not specified*
Sensor Type	*Single-satellite RF Direction of Arrival detector*

Mission Type	*Constellation*
Mission Orbit	*Sun Synchronous*
Product Version Number	*Processor version provided as metadata, with the following description:* *-Level 1 : emitters localisation and characterisation* *o Level 1A : localization of emitters* *o Level 1B : technical parameters of the emitters* *o Level 1C : technical parameters of the emitters including waveform* *-Level 2 : emitters (RF) and AIS fusion* *o Level 2A: AIS interpolated at data collection time* *o Level 2B: emitters (RF) and AIS correlation*
Product ID	*Products are identified using an acquisition time tag, of the format:* ***UNSEENLABS_SURMAR**_yyyymmdd**T**hhmmss**Z_emitters.*** *Product coverage is provided in a separate metadata file:* ***UNSEENLABS_SURMAR**_yyyymmdd**T**hhmmss**Z_coverage.*** ***In addition,** a unique ID is provided in the associated metadata file (ProductReference).*
Processing level of product	*Provided as medatada*
Measured Quantity Name	*RF Detection, carrier frequency, geolocation, pulse duration and pulse repetition frequency*
Measured Quantity Units	*N/A, MHz, Degrees (lat/long), ns, Hz*
Stated Measurement Quality	***Confidential information, available to the users***
Spatial Resolution	*Confidential information, available to the users*
Spatial Coverage	*Stated coverage is global. The dimension of the coverage of a given product is provided as metadata (width, height)*
Temporal Resolution	*Between 8 and 12 collections a day, depending on latitude. Information available to the customer in training material and will be added in the product sheet in the future.*
Temporal Coverage	*Products acquired and available on-demand (i.e. data is not being acquired continuously). All-time temporal coverage.*
Point of Contact	*Website contact: https://unseenlabs.space/contact-us/. In addition, point of contact given in the product metadata.*
Product locator (DOI/URL)	***Not available***
Conditions for access and use	*Not for redistribution without Unseenlabs consent*
Limitations on public access	*Strictly confidential*
Product Abstract	*Confidential, restricted diffusion and usage. Available at USL.SURMAR.DATA.DESC_v2.3 [RD-2]*

2.1.2 Availability & Accessibility

The Availability & Accessibility table describes how readily the data are available to those who wish to use them. It does not necessarily require cost-free access but is more about following the Findable, Accessible, Interoperable, Reusable (**FAIR**) Data Principles for scientific data management [RD-4].

Availability & Accessibility	
Grade: Good	
Justification	*BRO/SURMAR products are retrieved using an FTP as per specific request. There is no mechanism in place to search data in a catalogue. There is partial evidence that FAIR Data is followed because data is not "Findable" (i.e. there is no catalogue that is searchable for unique IDs). Therefore, data is considered not fully "Findable". However, it can be considered Accessible, Interoperable and Reusable. For this reason, the EDAP+ grade of Product Availability & Accessibility is "Good"*
Compliant with FAIR principles	*Not fully. Data is not (yet) Findable: it has a unique identifier associated but is not registered in a searchable resource. This will be improved in the future by implementing a searchable product catalogue. However, data is Accessible: data can be accessed using FTP, a standardized and open communications protocol. In addition, data is Interoperable, as the product formats are standard (e.g. GEOJSON is provided). Data is also Reusable: the provenance, understood as the chain of actions that led to the final processing level of the data, is tracked within the products.*
Data Management Plan	*Not available*
Availability Status	*Available for download via commercial license and filling the CERFA form.*

During the conduction of this evaluation, Unseelabs shared that there are ongoing plans for the implementation of a product catalogue with an associated search interface for historical data. The deployment of this interface, along with the individual identification of the products, would make BRO products compliant with the "Findable" guidelines, making this dataset more aligned with FAIR principles.

2.1.3 Product Format, Flags and Metadata

The Product Format assessment evaluates the accessibility of data checking their file format. An important aspect of EO data products that ensures ease of access to the widest variety of users is their format. Product metadata and flags offer users important extra layers of useful descriptive information, in addition to the measurements themselves, that can be crucial to their analysis.

Product format is graded based on the following:

- The extent to which it is documented.
- Whether a standard file format is used (e.g., netcdf).
- Whether it complies with standard variable, flag and metadata naming conventions, such as the climate and forecast (CF) metadata conventions [RD-5], or, for data from the European Union, the infrastructure for spatial information in the European Community (INSPIRE) Directive [RD-6].
- Whether flags and metadata provide an appropriate breadth of information.
- If product is derived from a constellation of satellites, the specific satellite used should be included in the product metadata.

Product Format, Flags and Metadata

Grade: Good	
Justification	*The grade for Product Format is set to Good. Products are provided in a good variety of standard data formats that make them accessible for a wide variety of use cases. In some cases, there is some evidence that CF conventions are used (see below). In addition, metadata does not identify the individual satellite that acquired the data.*
Product File Format	*Products and metadata provided in several standard file formats: CSV, DBF, GEOJSON, KLM, PRJ, QML, SHP, SHX.*

Metadata Conventions (GEOJSON)	*Example of one feature included in the main product (emitters):*
	
	{
	"geometry": {
	"coordinates": [
	-48.93379,
	45.28214
	],
	"type": "Point"
	},
	"id": 1,
	"properties": {
	"ID": 1,
	"RF_Frequency_MHz": "3042.2",
	"accuracy_level": "HIGH",
	"latitude ": 45.282141715713,
	"longitude": -48.933786300238,
	(…)
	"timestamp_utc": "2021-08-12T05:13:31.435Z"
	},
	"type": "Feature"
	},
	
	It does follow CF conventions (.e.g., latitude)

Analysis Ready Data?	*CARD4L does not provide, for the moment, a definition for what is considered ARD for RF/AIS data. Therefore, this is not applicable.*

2.1.4 User Documentation

Ideally, data products should be accompanied with the following minimum set of documentation for users, and be regularly updated as required:

- Product User Guide (**PUG**) / Product User Manual (**PUM**)
- Algorithm Theoretical Basis Document (**ATBD**)

It may be for a given mission that in place of these documents some combination of articles, publications, webpages and presentations provide a similar set of information. For the highest grades however, they should be presented as a formal document, since users should not be expected to search for the information themselves. The QA4ECV project provides guidance for the expected contents of these documents [RD-7], [RD-8], which they can be evaluated against.

User Documentation		
Grade: Good		
Justification	*The grade for Product Documentation is set to Good. The documentation available is the Product Data Description, consisting of a short description of the format of the products in table format, and several training resources available to the user (presentations and white paper). This documentation gives an overview of the mission properties, such as user cases, observation geometry, etc. Nevertheless, this information is not collated in a single document, so it cannot be considered a Product User Guide that follows the QA4ECV Documentation guidelines.* *In addition, no ATBD is delivered. Therefore, information regarding how the processing is performed or how the parameters included in the product are derived, is unavailable.*	
Document	*Reference*	*QA4ECV Compliant*
Product User Guide	*UNSEENLABS - Maritime Surveillance Service - Product data description - V2.3.pdf USL.SURMAR.DATA.DESC and training material provided to the user.*	No
ATBD	Not available	No

2.2 Metrology

The sensor's calibration and characterisation for measurement, pre-launch and on-orbit, should encompass a given sensor's behaviour to an extent and quality that is "fit for purpose" within the context of the mission's stated performance, based on its measurement function.

It should be noted that, for RF and AIS sensors, Sensor calibration & characterization refers to the geometrical dimension of the data. Therefore, the recommended Sensor and Geometric sections of the EDAP+ assessment have been merged in this TN.

The primary criterion that must be included in a metrological description is the geolocation of the identified emitter. It should be noted that metrology also applies to other retrieved parameters. In the case of BRO constellation, this applies also to the retrieved signal parameters, such as carrier frequency, pulse duration and pulse repetition frequency.

Geometric Calibration & Characterisation	
Grade: Not Assessable	
Justification	No information on the geometric calibration is provided.
References	• *Not available*

Traceability is defined in the International Vocabulary of Metrology (**VIM**) as a

"*property of a measurement result whereby the result can be related to a reference through a documented and unbroken chain of calibration, each contributing to the measurement uncertainty*[1]."

and is reinforced in the QA4EO procedures. Traceability is therefore a key aspect of achieving reliable, defensible measurements. In this definition an important part of measurement traceability is highlighted – that it is well documented. This of course must be the case for EO data products too.

Metrological Traceability Documentation	
Grade: Not Assessable	
Justification	No information on metrological traceability is provided. No traceability chain is documented
References	• *Not available*

[1] *https://jcgm.bipm.org/vim/en/2.41.html*

To ensure measurements are both meaningful and defensible, it is crucial that they include rigorously evaluated uncertainty estimates. A comprehensive description of how to evaluate sources of uncertainty in a measurement and propagate them to a total uncertainty of the final measurand, is provided by the metrological community in the Guide to the Expression of Uncertainty in Measurement (**GUM**).

Uncertainty Characterisation	
Grade: Not Assessable	
Justification	No information on how uncertainty is characterized is provided.
References	• *Not available*

2.3 Product Generation

The applied L1 calibration algorithm, or measurement function, should be of a sufficient quality that is "fit for purpose" within the context of the mission's stated performance across all stated use cases and scene types (e.g., land, ocean, etc.). What this requires is specific to the sensor-domain and will require a degree of expert judgement. This should be based on the same reasoning applied to the pre-launch and in-flight calibration assessment and reviewed based on the ATBD.

It should be noted that, for RF and AIS sensors, Sensor calibration & characterization refers to the geometrical dimension of the data. Therefore, the recommended Calibration Algorithm and Geometric Processing sections of the EDAP+ assessment have been merged in this TN.

Calibration Algorithm & Geometric Processing	
Grade: Not Assessable	
Justification	No information regarding the calibration algorithms or how the geometric processing is performed is available. Therefore, the grade is "Not Assessable"
References	• *Not available*

3. DETAILED VALIDATION – DATA USABILITY

3.1 Introduction

This section provides a detailed independent verification of some parameters that have been considered essential for data usability. AIS and RF data usability is directly related to critical mission parameters, such as data availability, update frequency (refresh rate) and measurement latency. They are determined by mission characteristics (number of satellites in the constellation, number and visibility of ground receiving stations, capabilities of ground processing servers, etc.), and are critical parameters with a key impact in the fitness for purpose of the data.

These indicators provide an accurate and traceable view of the 'fitness for purpose' of the data, which will be verified with reference to the mission specifications provided by the constellation operator. In addition, these indicators will provide a way to intercompare similar sensors in a homogeneous way.

3.2 Refresh Rate Assessment

In this context, Refresh Rate can be defined as the average rate for which a user can expect to obtain updated data for a given region. In other words, it specifies the sampling rate at which measurements are acquired. This has important consequences for the fitness of purpose of the data, as this sampling rate should be sufficient for the use case under consideration.

This is expected to be dependent on latitude, with higher refresh rate near the poles, resulting of the higher swath overlap at higher latitudes with polar orbits.

In the product brochure, no specific figure for the revisit time is reported (RD-2 and RD-3). However, from private communication with Unseenlabs, they report that that current refresh rate is between 2 and 3 hours, depending on the latitude, with an expected final performance at full deployment of the constellation of 30 minutes, however this is not reported officially in the documentation provided.

3.2.1 Method

To independently evaluate the refresh rate claim, the delivered test datasets (covering 3-weeks of acquisitions over the East China Sea and Greenland, see Appendix A for the full list of products) have been inspected. This 3-week dataset contains solely of the coverage footprints of the products. This simulates a typical user case for the routine monitoring of territorial waters, security, etc. These areas were chosen based on criteria of availability and representativeness. The initial area is anticipated to be densely populated, whereas the second region is expected to have a lower emitter density.

Two different regions of interest (**ROI**) for which the refresh rate has been evaluated, have been defined and plotted in Figure 3-1. They cover a 1 degree x 1 degree region in the Greenland and East China Sea regions, respectively.

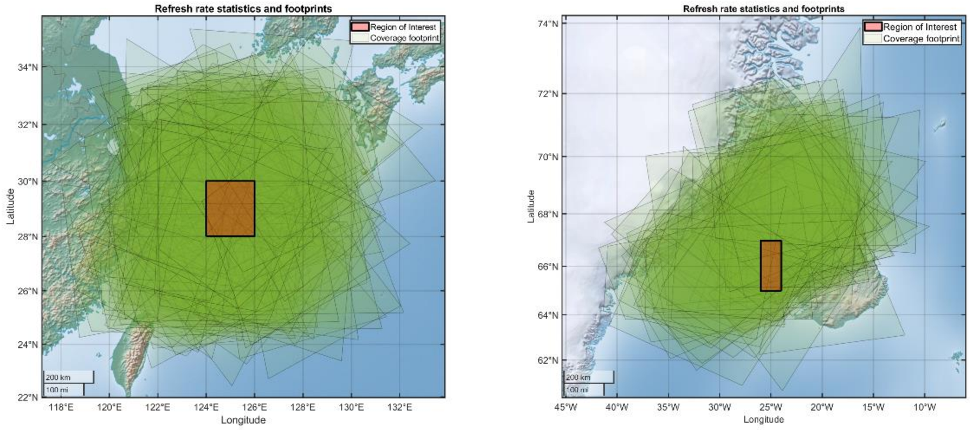


Figure 3-1: Regions of Interest defined to conduct the refresh rate analysis

The coverage track products have been ingested, filtering out any track that does not intersect the ROI. The average time between acquisitions has been computed. In addition, the statistics of the time difference are assessed (standard deviation). The existence of gaps or other unavailabilities has also been assessed.

The grade "Excellent" is achieved if the refresh rate reference is met in all cases, and no gaps or unavailabilities exist. The grade "Good" is achieved if the reference is met, but some unavailabilities are observed, or if the reference is not fully met but the refresh rate is consistent. Lastly, the grade "Basic" is achieved if the reference is not met and there are significant unavailabilities.

3.2.2 Results Compliance

The delta time (Δt) is defined as the time between a certain product acquisition timetag, and the previous available, provided that both of them intersect the ROIs defined in the previous section. In Figure 3-3 and Figure 3-2, this metric along with its statistics, have been represented.

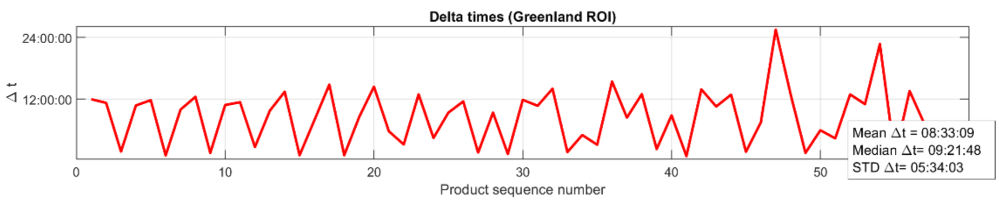


Figure 3-2: Δt for the Greenland ROI

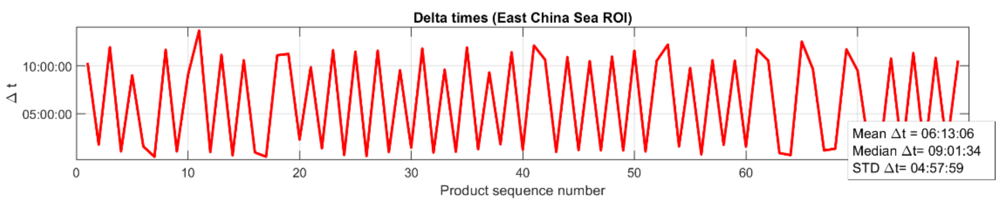


Figure 3-3: Δt for the East China Sea ROI

The summary statistics for the refresh rate are summarized in the table below too.

Table 3-1: Refresh rate statistics

Dataset	Mean Δt	Median Δt	STD Δt
Greenland (Lat 66N)	08h 33m 09s	09h 21m 48s	05h 34m 03s
East China Sea (Lat 29N)	06h 13m 06s	09h 01m 34s	04h 57m 59s

The East China Sea statistics confirm that the average refresh rates claimed by Unseenlabs can be achieved (roughly between 4-6h depending on the latitude). The Greenland ROI, however, is far from the reference. It should be noted, however, that the median delta time (a figure arguably more useful for a potential user) is higher and around 9h for both datasets.

It is surprising that the Greenland ROI, situated at high latitudes, has a lower refresh rate than the East China Sea ROI (as high latitudes are revisited more frequently than lower latitudes by a polar satellite). There is no delivered documentation that justifies these differences, but Unseenlabs clarified that this is due solely to the prioritisation attributed to data acquisitions on each specific zone.

Regarding the unavailabilities, they can be defined as periods where a non-typical delay between products is appreciated. The East China Sea dataset is very consistent, without any evident gap. Two unavailabilities are present in the Greenland dataset, as evidenced by the 2 peaks in Figure 3-2. This may also be related to the constellation not working at full performance over this ROI, something that can also explain the comparatibely higher STD of the Greenland dataset with respect the East China Sea dataset.

Given the open questions identified with the Greenland dataset, it has been decided not to consider it for the grading, as it cannot be ensured if these figures reflect the constellations capabilities at (current) full performance. Given that the East China dataset matches the claim for the average refresh rate, the result compliance grade has been selected as "Good". In addition, It is worth pointing out to future users that the constellation is still growing which will increase the revisit rate possible today.

3.3 Timeliness/Latency Assessment

The timeliness of the data is a fundamental factor to consider for the fitness of purpose of the data, especially in time-sensitive applications, particularly common in the case of RF-data. For example, in the case of maritime security, such as piracy or illegal fishing, fast and accurate detection and response can be critical to prevent or mitigate damage. Similarly, in the context of search and rescue operations, the timely receipt of up-to-date information is a fundamental asset for an effective response.

In this context, timeliness or latency can be defined as the delay between the time when data is acquired by the RF platform and the time when it is available for use by the end user. This latency is caused by a number of factors, including the time it takes for the data to be transmitted from the sensor to a ground station, the time required for the data to be processed, and the time necessary for the data to be available to the user.

In the product brochure, no specific figure for the maximum latency time is reported (RD-2 and RD-3). In addition, no information is available on the location or number of ground receiving stations used for retrieving the data.

From private communication with Unseenlabs, it was reported that the expected (maximum) latency between acquisition and delivery is between 6 and 24 hours.

3.3.1 Method

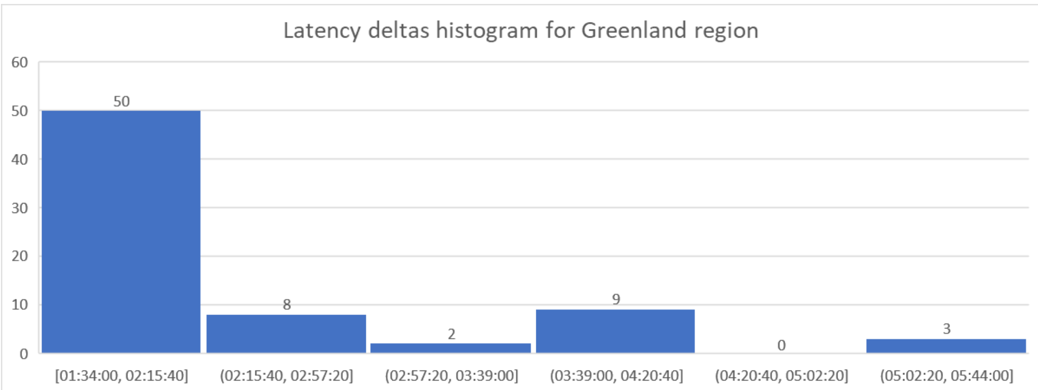
In order to evaluate the timeliness of BRO datasets, a live-data interface was requested. This simulates a typical user case for the live monitoring of territorial waters or ship tracking. However, at the time of writing this report, this interface is not available, although there are plans of creating one.

Unseenlabs provided the timestamps for a limited set of products over Greenland and the East China Sea. Unseenlabs remarked this is for a prioritized production. The availability times were compared with the acquisition times of the products. The statistics of this difference were computed and assessed. The maximum, median, average and standard deviation values are taken as the main metrics for this analysis. Given that the analysis relies on the provision of the timestamps by Unseenlabs, and is not a fully independent validation, the methodology grading is set to Basic.

The grade "Excellent" is achieved if the timeliness reference is met in all cases. The grade "Good" is achieved if the reference is met in most cases. Lastly, the grade "Basic" is achieved if the reference is not met.

3.3.2 Results Compliance

The reception timestamps for the products and the deltas with respect to acquisition were provided and are presented below.



Maximum	05:44:00
Median	01:56:00
Mean	02:20:15
STD	01:01:52

The statistics fully meet the reference maximum latency. Therefore, the grade for this analysis is "Excellent".

4. DETAILED VALIDATION – GEOLOCATION ACCURACY

4.1 Introduction

In this section, an independent assessment on the geolocation accuracy is carried out. In section 4.2, a pairing between the RF retrievals and AIS reference dataset is conducted, and the completeness of the dataset is checked and evaluated. In section 4.3, the obtained pairings are used to analyse the geolocation accuracy of the RF data.

4.2 Completeness Analysis

The completeness of the dataset is a critical aspect, as it directly impacts the accuracy and reliability of the information derived from it. Incomplete datasets may contain gaps or missing retrievals, which can lead to inaccurate or biased analyses and conclusions. This could have significant implications for decision-making processes such as security assessment or protected areas monitoring.

4.2.1 Method

With the objective to evaluate the completeness of the dataset, AIS data has been used as a reference to compare with. AIS data has been considered the best reference data available for vessel detection. Although it is known that AIS may be affected by some unavailability problems due to message collisions (specially in highly congested areas) and coverage, it is a stablished and proven method for vessel identification. In addition, many ancillary information regarding the type of vessel is provided along with the position (for example, velocity, tonnage, typology, etc) which may help the subsequent analysis. Other vessel identification strategies have been explored (notably, SAR-based vessel detection), and have been found less reliable.

AIS data has been provided to EDAP+ by Unseenlabs to aid the verification, and has been acquired using an undisclosed combination of satellite, terrestrial and ship-borne sources. The position of the vessels has been interpolated to time-collocate them with the RF products, using to that effect the velocity information provided by the AIS message. It should be noted that this reference has been provided already interpolated by Unseenlabs to EDAP+. Therefore, this interpolation and the underlying uncertainties related to the AIS data have not been independently verified.

To compare both datasets, a match-up between the radar detections and AIS points must be performed. This is required to determine whether a certain radar detection appears or not in the other dataset.

For each radar retrieval, a suitable AIS matching point is to be found. If the vessels are relatively distant between them, and therefore AIS and radar points are naturally grouped, a Nearest Neighbour approach suffices to pair the datasets. This however is not enough when several ships are clustered together, as the Nearest Neighbour method tends to assign many radar retrievals to a single AIS point. To overcome this, a more sophisticated approach has been followed. The intended pairing is a variant of the Linear Assignment Problem. In order to solve this in an efficient way, the Hungarian algorithm (also known as the Kuhn-Munkres algorithm) has been used[2]. This algorithm can find a pairing that minimizes the total distance between points, with the additional requirement that each AIS retrieval can only have one matching radar point.

---

[2] *A fast implementation in Matlab has been used: Yi Cao (2023). Hungarian Algorithm for Linear Assignment Problems (V2.3) (https://www.mathworks.com/matlabcentral/fileexchange/20652-hungarian-algorithm-for-linear-assignment-problems-v2-3), MATLAB Central File Exchange. Retrieved April 17, 2023.*

Once this paring has been performed, the percentage of detected & undetected vessels is recorded, and used as a tentative figure of merit regarding the completeness. Detected vessels are defined as such vessels for which a pairing has been found, i.e., they can be found in both radar and AIS datasets. Undetected vessels (misses), are defined as vessels found in the AIS dataset but not on the radar detections. In addition, ships detected in radar but not in AIS (overdetections) are reported as well and are to be considered either missed AIS detections or potential dark ships. All this processing was carried out using in-house developed scripts in Matlab.

It has been noted that acquisitions often appear in pairs: one carrier frequency corresponding to X-band, and other in S-band. This is attributable to the fact that is common for sea-going vessels to carry a multi-band radar to take advantage of the different propagation properties of the different bands (X-band providing better resolution, but being more prone to attenuation and cluttering), as recommended by the SOLAS regulations. This appears as independent observations in the Unseenlabs SURMAR products. As they are obviously originated by the same vessel, using the Hungarian algorithm would overestimate the number of detections, as both observations would be assigned to different vessels. To account for this, the Hungarian pairing has been performed separately for each band, and then both pairings have been added. In the resulting pairing, it is possible that each AIS have assigned an S-band and an X-band retrieval, but not more.

It should be noted that assessing the completeness of the RF dataset this way is complex and presents some caveats. First of all, Satellite AIS data retrievals cannot be considered totally reliable, as it is prone to message collisions, and depends heavily on the coverage of the region under consideration and the number of vessels present. In addition, as it depends on the radiating power of the source, some vessels may be missed. Furthermore, some ‘’uncooperative’’ vessels may be present in the dataset, navigating with spoofed position or deactivated AIS.

In second place, even if AIS is considered reliable enough as a reference, there are some instances where the Unseenlabs radar-based retrieval will not provide equivalent results. For example, small vessels or systems may use AIS systems, but not radar, as SOLAS regulations instruct (AIS is compulsory for vessels for >300 tonnage, while navigation radars are compulsory for >5000). In addition, moored vessels may report their AIS information but have their Radar navigation aids deactivated. Therefore, the representativeness of AIS data as a fiducial measurement used for RF retrievals has to be carefully assessed.

To increase the representativeness of AIS and minimize potential errors, a pre-filtering process was performed on the AIS retrievals. Vessels reporting mooring conditions with a speed of less than 0.1 knots were not included in the completeness analysis. Additionally, small ships such as buoys were removed by only considering vessels with an approximate tonnage of 500 or greater. To avoid obviously incorrect assignments, pairings with a distance of more than 30 km were discarded. This distance corresponds to the maximum expected error in BRO products, as stated in the documentation. Despite these precautions, there is still a possibility of some vessels being incorrectly paired. Therefore, the completeness analysis was conducted on all available products, and the conclusions are discussed qualitatively and quantitatively in the following sections.

4.2.2 Results Compliance

The products assessed in this section are detailed in Figure 4-1. Products acquired over two distinct areas were considered. On one hand, two products covering the 5th of March (one in early morning and one in the afternoon) over the occidental coasts of Iceland were evaluated. This is a low-density area where the pairing is trivial. On the other hand, a set of 12 products over the East China Sea were processed, covering 2 days (7 and 8th of March). These are highly populated products with many different retrievals, covering several different environments (coastal, riverine, open sea traffic, etc).

Table 4-1: Products used in the completeness analysis.

Type	Acquisition time	File Name
SURMAR	20230305T003351Z	UNSEENLABS_SURMAR_20230305T003351Z_emitters.geojson
SURMAR	20230305T214209Z	UNSEENLABS_SURMAR_20230305T214209Z_emitters.geojson
SURMAR	20230307T020518Z	UNSEENLABS_SURMAR_20230307T020518Z_emitters.geojson
SURMAR	20230307T021848Z	UNSEENLABS_SURMAR_20230307T021848Z_emitters.geojson
SURMAR	20230307T034030Z	UNSEENLABS_SURMAR_20230307T034030Z_emitters.geojson
SURMAR	20230307T123831Z	UNSEENLABS_SURMAR_20230307T123831Z_emitters.geojson
SURMAR	20230307T141301Z	UNSEENLABS_SURMAR_20230307T141301Z_emitters.geojson
SURMAR	20230307T142522Z	UNSEENLABS_SURMAR_20230307T142522Z_emitters.geojson
SURMAR	20230308T022139Z	UNSEENLABS_SURMAR_20230308T022139Z_emitters.geojson
SURMAR	20230308T032600Z	UNSEENLABS_SURMAR_20230308T032600Z_emitters.geojson
SURMAR	20230308T033049Z	UNSEENLABS_SURMAR_20230308T033049Z_emitters.geojson
SURMAR	20230308T122649Z	UNSEENLABS_SURMAR_20230308T122649Z_emitters.geojson
SURMAR	20230308T140152Z	UNSEENLABS_SURMAR_20230308T140152Z_emitters.geojson
SURMAR	20230308T143219Z	UNSEENLABS_SURMAR_20230308T143219Z_emitters.geojson

For each of these data products, an associated AIS dataset was provided by Unseenlabs. These datasets were obtained from an undisclosed AIS provider, and interpolated to the acquisition time of the RF dataset. In Figure 4-1, the AIS self-reported location and bearing have been represented for the Icelandic products. Note the relative low number of vessels in this area and the large number of moored ships on the coast of Iceland. Most of them are local fishing vessels, as indicated by the ancillary AIS information.

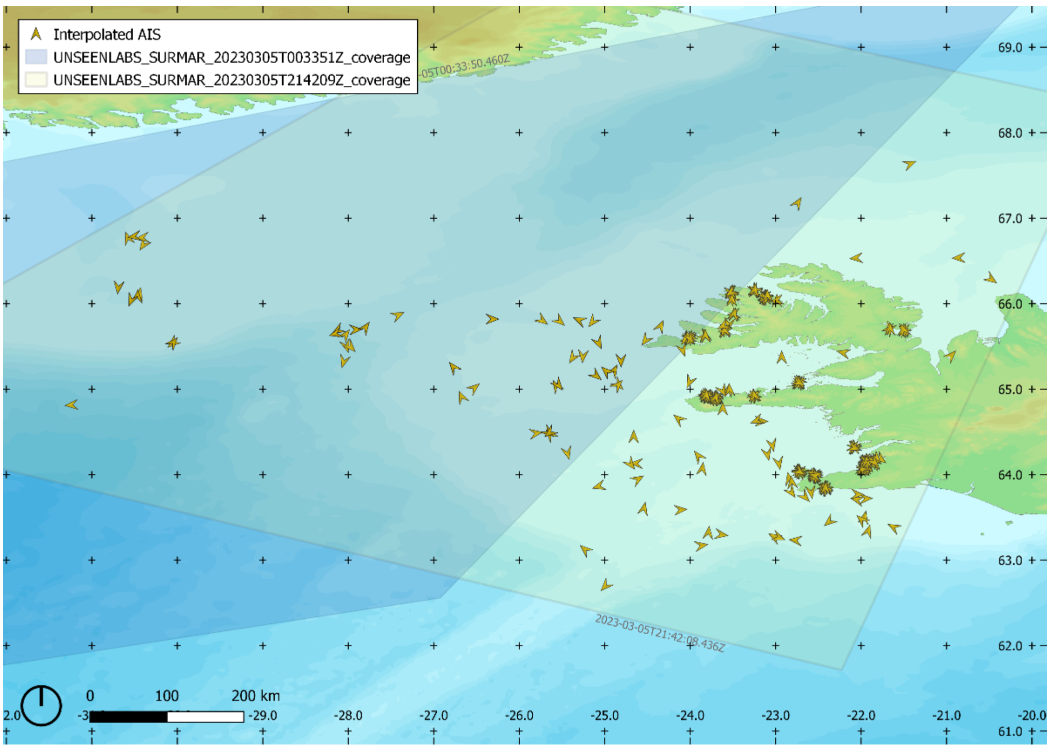


Figure 4-1: Interpolated reference AIS geolocations used to evaluate the completeness of the dataset.

In Figure 4-2, the pairing resulting from the Hungarian algorithm has been represented for the product acquired at 20230305T214209Z, over the coast of Iceland. It can be appreciated how the majority of RF retrievals have an AIS detection in the close vicinity. Both AIS and Radar detections have been plotted. If a suitable pairing is found, this is indicated with a black line. Any AIS retrieval for which no matching has been found is annotated with a red cross. Moreover, any radar retrieval for which no AIS is reported are indicated with a green circle. In the detail of Figure 4-3, it can be appreciated how radar acquisitions often appear in pairs of S/X-band detections, and are to be attributed to a single emitter.

In this case, it can be appreciated how the RF retrieval is able to detect 48 (77.41%) of the AIS receivers. In addition, 12 RF observations without a matching AIS acquisition under 30 km have been detected. They have been highlighted with a green circle in the figures. They should not be considered false positives, but rather true detections not provided by AIS. As they are mostly located in open sea, without other vessels close, the risk of lost AIS data due to collisions is considered low. Without ruling out a possible problem with the AIS coverage over this area, these kinds of retrievals highlight one of the major advantages of RF data over AIS: the capability of monitoring uncooperative ('dark') vessels.

Additionally, 14 AIS emitters are not reported in the BRO dataset. As explained, these missing detections may be originated by several factors, not always attributable to a faulty acquisition. Interestingly, several of the misses appear clustered in a small fleet (see lower-right area in Figure 4-2). This indicates that it may be attributed to a common feature of these ships rather than an issue with the RF retrievals.

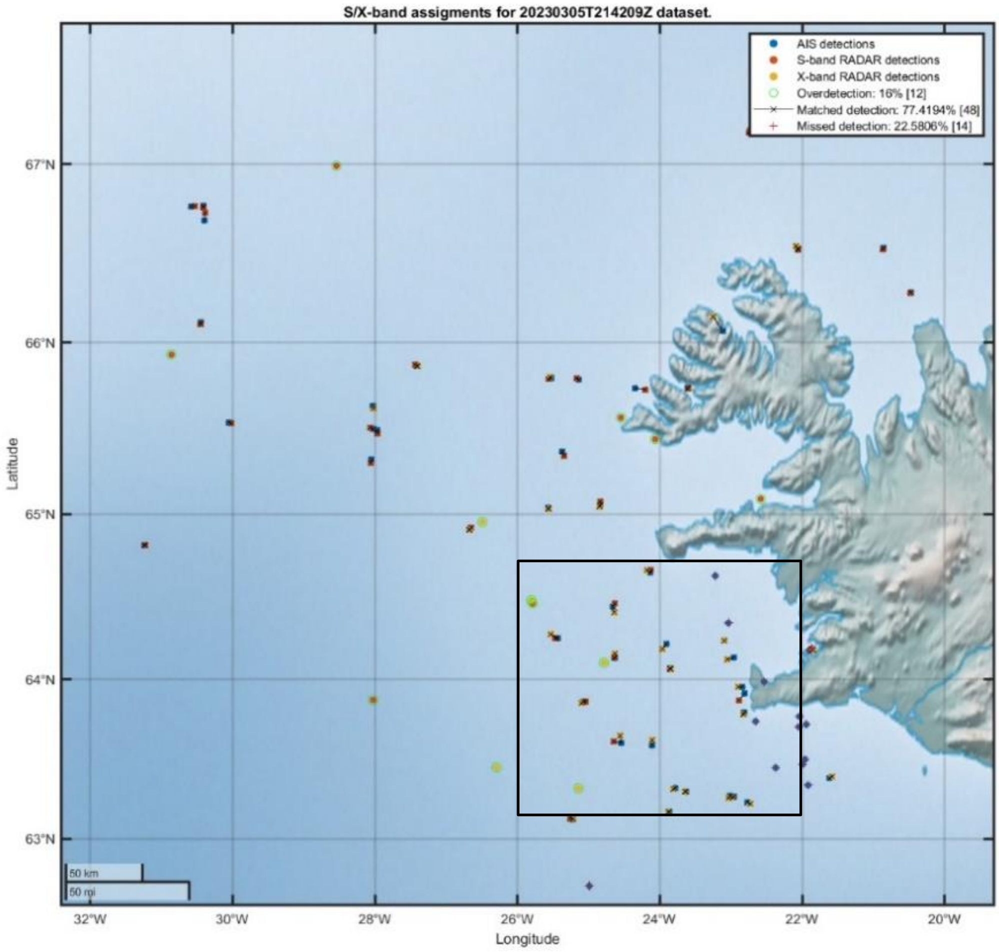


Figure 4-2: Completeness analysis over the Iceland dataset. RF data has been paired with the nearest AIS following the Hungarian algorithm. AIS points without any associated RF emitter have been highlighted (misses), along with RF retrievals without an associated AIS point (dark vessels). Detailed area in following plot is also indicated.

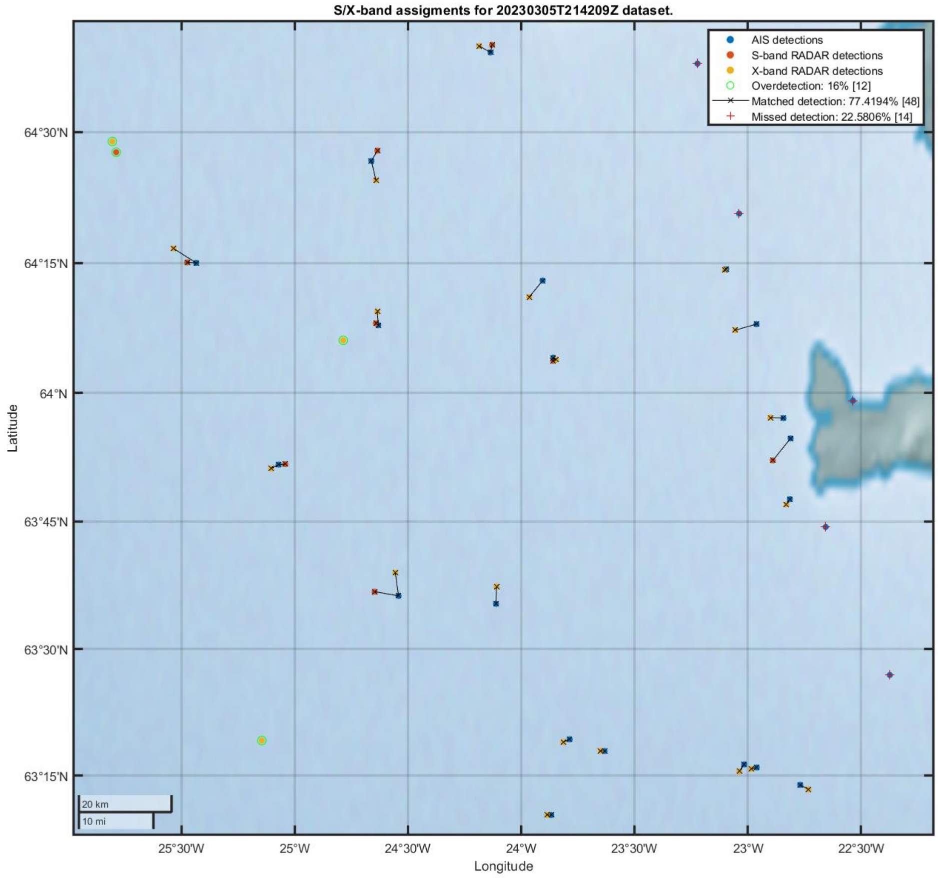


Figure 4-3: Detail on some RF/AIS detection, and how the Hungarian pairing has been done. It can be appreciated how some RF retrievals appear in pairs but are associated to a single AIS point / vessel.

In Figure 4-4, the pairing for a more complex scenario over the East China Sea has been represented (product 20230307T020518Z). In this scenario, 693 RF detections and 1070 AIS emitters are reported. As it can be appreciated in the Figure, the number of matching points in this case is considerably lower, with only a 57% of matching retrievals (605 vessels). The number of AIS retrievals not-present in RF data is considerable, with 43% missed ships. The large number of misses are as well clustered, being especially concentrated in the coastal areas of China. This is compatible with small fishing fleets operating without navigation radars.

In addition, 88 vessels not detected by AIS are reported in the RF dataset. Since these retrievals are located in open seas, this may be related to problems with AIS coverage in these areas (where only satellite-based AIS is available).

Similar scenarios have been observed for other coastal datasets. Besides coastal areas, riverine areas (such as the Yangtze estuary covered by 20230307T034030Z, in Figure 4-5) also exhibit large number of misses with respect AIS.

It can be concluded that, for coastal and riverine areas, AIS is not representative enough to be used as a fiducial reference for RF data validation. In contrast, open sea conditions are more suitable, but the coverage of AIS of these areas has to be carefully considered. For example, in Figure 4-6 a product covering the East China Sea in the proximity of Japan and Okinawa demonstrates this (product 20230307T141301Z). In this case, the number of matching vessels is high (74%), demonstrating that most of the AIS features are detected in the RF dataset. However, there is also a large number of overdetections of RF with respect AIS (118 cases), potentially highlighting AIS coverage issues. Furthermore, it should be noted that most misses appear clustered as well.

All completeness assessments performed have been included in Figure 4-6 and Figure 4-7. In Table 4-2, the summary metrics for all products analysed have been represented.

Table 4-2: Summary completeness results

Product acquisition	Area	Successful pairings	RF Misses	RF Overdetection	Notes
20230305T003351Z	Iceland	88.23% [15]	11.76 % [2]	3.70 % [1]	Open Sea
20230305T214209Z	Iceland	77.41% [48]	22.58 % [14]	16 % [12]	Open Sea
20230307T020518Z	East China Sea	56.54% [605]	43.45 % [465]	10.09% [88]	Coastal
20230307T021848Z	East China Sea	59.31% [258]	40.68% [177]	20.5% [82]	Open Sea
20230307T034030Z	East China Sea	47.18% [1452]	52.81% [1625]	2.75% [54]	Riverine
20230307T123831Z	East China Sea	56.37% [650]	43.62% [503]	4.42% [35]	Coastal
20230307T141301Z	East China Sea	73.40% [265]	26.59% [96]	27.09% [123]	Open Sea
20230307T142522Z	East China Sea	36.08% [1197]	63.91% [2120]	0.73% [11]	Riverine
20230308T022139Z	East China Sea	63.33% [171]	36.66% [99]	14.28% [38]	Okinawa
20230308T032600Z	East China Sea	28.02 [1097]	71.97% [2817]	0.35% [5]	Riverine
20230308T033049Z	East China Sea	37.04% [396]	62.95% [673]	6.03% [35]	Coastal
20230308T122649Z	East China Sea	84.10% [418]	15.89% [79]	16.28% [92]	Open Sea
20230308T140152Z	East China Sea	43.64% [828]	56.35% [1069]	6.04% [62]	Coastal
20230308T143219Z	East China Sea	68.65% [1253]	31.34% [572]	10.50% [200]	Coastal

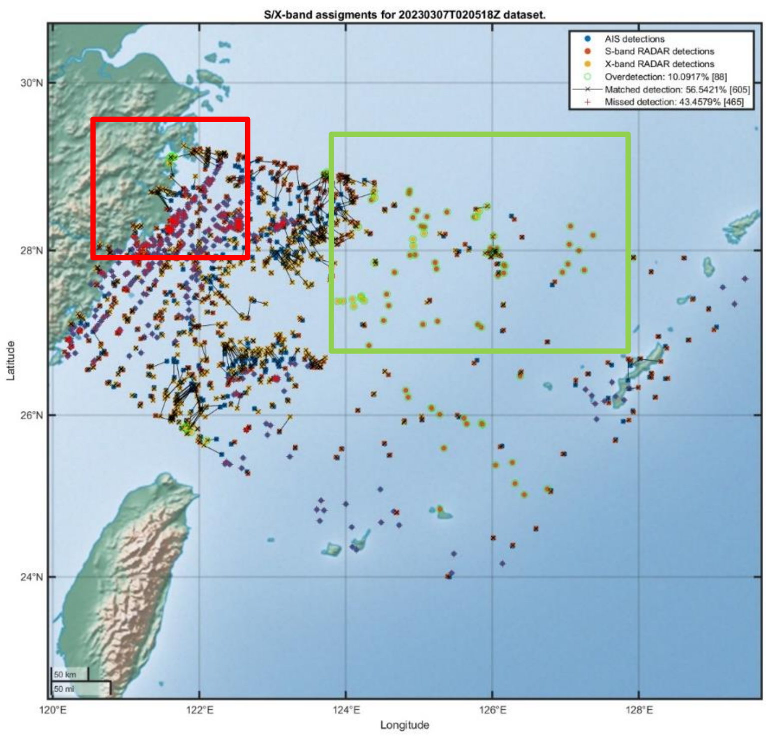


Figure 4-4: Completeness analysis over the East China Sea. RF data has been paired with the nearest AIS following the Hungarian algorithm. AIS points without any associated RF emitter have been highlighted (misses), along with RF retrievals without an associated AIS point (dark vessels). Note the large number of misses near the coast (red box), and the large number of RF overdetections in open sea (green box).

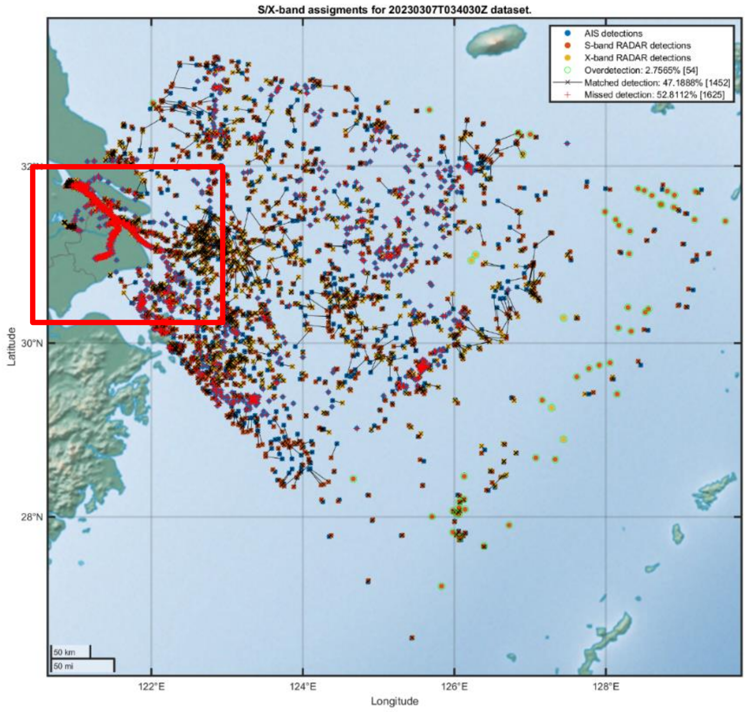


Figure 4-5: Completeness analysis over the Yangtze estuary and approaches. Note the large number of missed detections in the estuary (indicated in a red box).

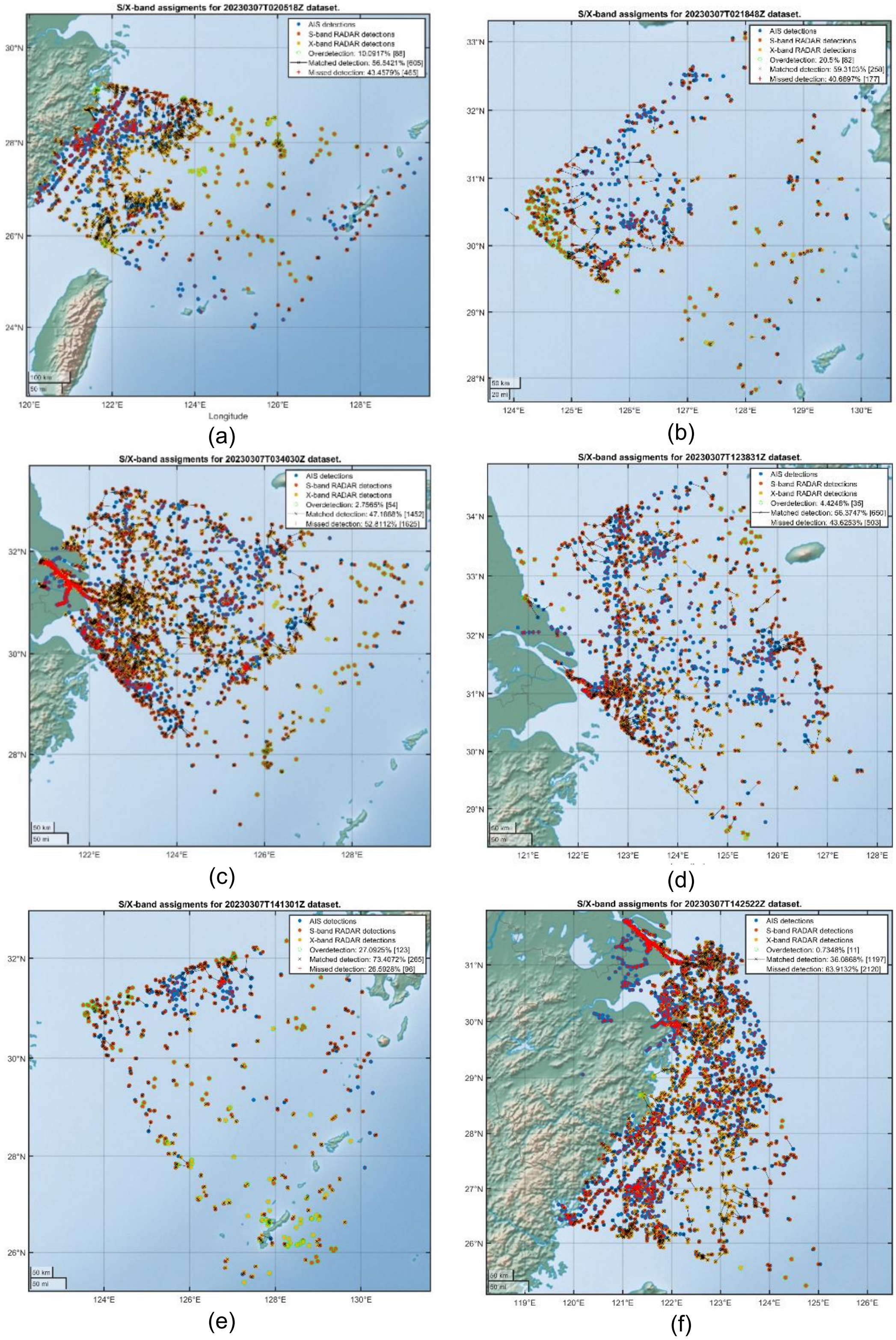


Figure 4-6: Completeness analysis over the East China Sea. 6 assessed products covering the 07/04/2023.

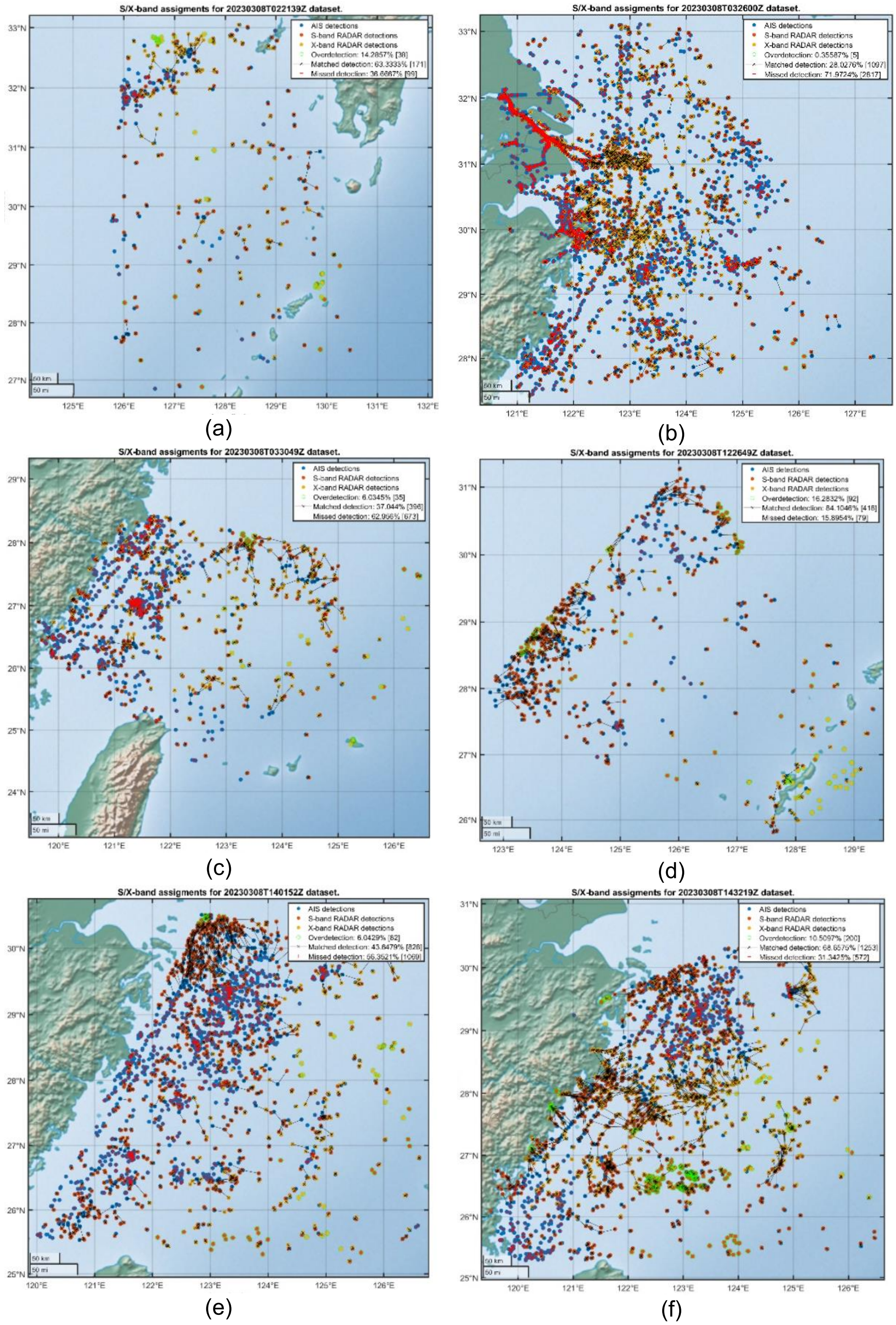


Figure 4-7: Completeness analysis over the East China Sea. 6 assessed products covering the 08/04/2023.

4.3 Geolocation Errors Assessment

Quantifying the geolocation error of the RF retrieval is an essential step that enables the use of data in an accurate and reliable way. A proper understanding of geolocation errors is critical in many applications, such as identifying individual vessels, establishing confidence intervals and decision thresholds, and more. Without a proper understanding of geolocation errors, interpreting data and making informed decisions based on the information, can be challenging.

As detailed above, Unseenlabs BRO products contain a single quality indicator that details whether the geolocation accuracy for a certain retrieval is High, Medium, or Low. The quality indicator associated with geolocation is estimated in relation to the quality of the signal received, since this has an impact on the accuracy of the calculated location."

4.3.1 Method

In order to provide an independent analysis that complements the BRO quality flagging, the geolocation accuracy has been assessed by comparison to the self-reporting position of AIS emitters.

In the previous section, pairs of matched AIS retrievals and RF detections were obtained, and the distance between the matched pairs can now be evaluated. The AIS retrievals provide self-reported locations obtained using GNSS services on the ground, which can be considered very accurate for the purposes of this validation and treated as a "ground truth" position[3]. Thus, the distance between a particular AIS retrieval and its corresponding RF detection can be understood as the geolocation error attributable to the RF geolocation method.

Geolocation errors probability density function were estimated per product as a normalized histogram of the differences. Basic statistics, such as average distance, median distance, and standard deviation, were computed and are provided as summary figures of merit. In addition, the aggregated normalized histogram of all products evaluated has been computed. In addition, to cross-verify these results with the RF data quality annotation, the histogram has been computed separately for each quality case.

It should be noted that the existence of spoofed AIS geolocations cannot be ruled out. However, it has been considered to affect only to a very minor fraction of emitters. In addition, the existence of incorrect pairings is expected to contribute to an overestimation of the geolocation errors. Therefore, these figures of merit are to be considered an upper bound of the real geolocation errors. In order to evaluate this effect, statistics from a reduced set of products for which we are confident on the pairing (i.e. open sea products in representative conditions) has been produced as well, and compared with the total statistics.

4.3.2 Results Compliance

For each product detailed in Table 4-1, the normalized histograms have been computed. As an example of the errors obtained in a single product, the histogram for 20230307T020518Z is represented in Figure 4-8.

---

[3] It should be noted that AIS data has been interpolated to the times of the RF acquisition. This may have an impact in geolocation error assessment. Without further information on how this interpolation has been done, it is not possible to ascertain anything regarding this impact.

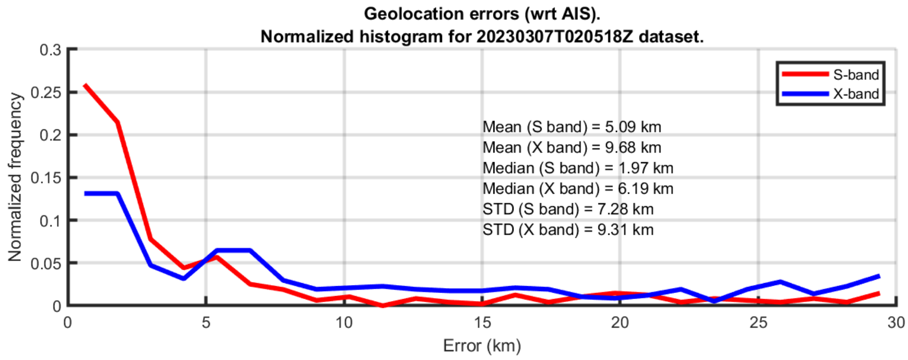


Figure 4-8: Histogram of geolocation errors for 20230307T020518Z

In Figure 4-9, the aggregated histogram, taking into account all products in Table 4-1, is plotted. The distribution has its maximum around 2.5 km, with decreasing tails for higher errors. There is a local maximum peak around 5 km. The mean value of the error is around 5.4 km, with a median value of 2.5 km. The tails of the distribution extend considerably, with a non-negligible number of emitters scoring above 10 km of error (STD ~ 6.7 km). The comparison between S-band and X-band confirms that both bands offer very similar performance in terms of geolocation accuracy.

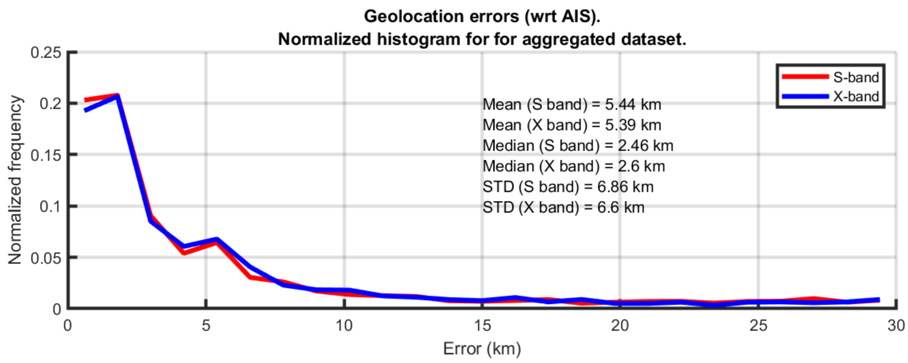


Figure 4-9: Aggregated histogram of geolocation errors

In addition, in Figure 4-10, the aggregated histogram for each quality class has been represented. It can be observed how the "High quality" class offers the lower geolocation error, as expected. The average in this case is 5.73 km, with a median of 2.15 km. These retrievals are the most frequent and dominate the aggregated histogram. "Medium" and "Low" quality classes offer very distinct statistics with respect to the first class. They however have similar performance between them, with around 7 km of average, and a median of 5.3 km. As mentioned previously, the quality indicator associated with geolocation is estimated in relation to the quality of the signal received. Unseenlabs stated that their quality indicators are conservative, which may explain the proximity of the errors for the 'Low' and 'Medium' indicators in the sample of products evaluated.

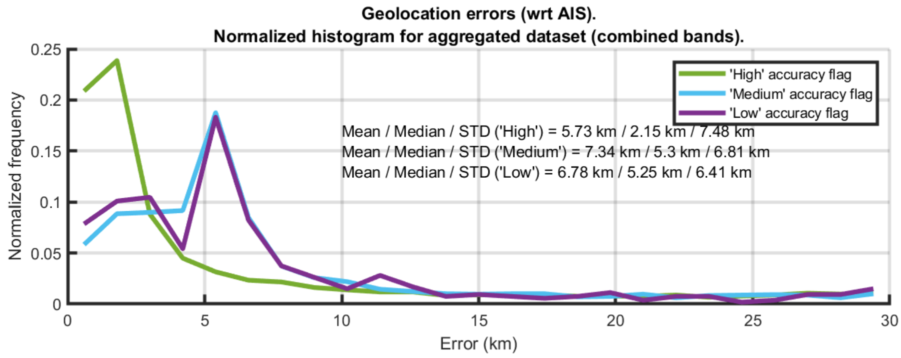


Figure 4-10: Aggregated histogram of errors per quality class

In order to reduce as much as possible the influence of bad pairings into the geolocation error assessment, statistics from a reduced set of curated products have been computed. In particular, only products in open sea conditions have been considered (see Table 4-1). The statistics obtained are very similar to Figure 4-9, demonstrating that bad pairings have a minimal influence in this metric.

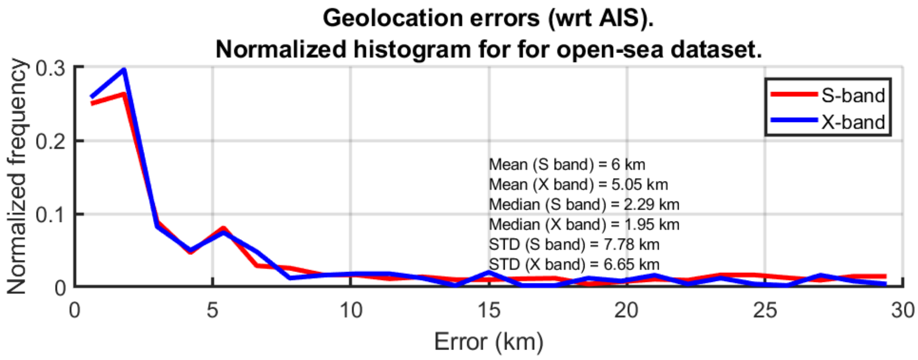


Figure 4-11: Aggregated histogram of errors for the open-sea datasets

In addition, the distribution of the azimuths of the errors has been evaluated, to understand if they are isotropic (e.g., uniformly distributed for each direction). In Figure 4-12, the azimuths of the errors have been represented, along with the 3σ statistical significance interval, computed following the binomial criteria[4]. There are few directions for which the errors are overly represented, and therefore cannot be considered isotropic. According to Unseenlabs, there is no technical explanation for this anisotropy. It seems more likely to be linked to the influence of some voluntary modifications to the AIS which would have an impact on the statistics calculated on the study sample.

[4] *Abdi, H. (2007). Binomial distribution: Binomial and sign tests.* Encyclopedia of measurement and statistics, 1.

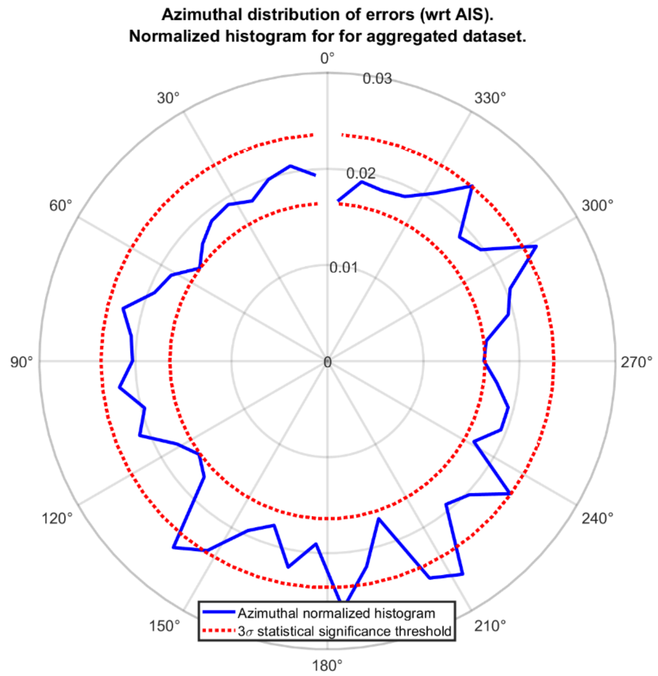


Figure 4-12: Distribution of the geolocation error azimuths

Provided that the geolocation errors obtained are roughly aligned with the geolocation accuracy claimed by the different quality classes, the grade has been set to Good. There are however some unexplained points, such as the non-isotropy of the errors or the fact that the 'low' quality class has very similar statistics to the 'medium' quality class.

4.4 Conclusions

After conducting this detailed validation of the completeness and geolocation accuracy of Unseenlab's SURMAR products, some conclusions regarding the methodology used can be laid out.

AIS data is a powerful dataset that can be used as a reference for vessel geolocation services. It is a well stablished method that is able to provide very accurate (self-reported) vessel positions. However, as it has been described, there are several considerations that have to be taken into account to guarantee the representativeness of the reference datasets with respect to the data under validation.

On one hand, AIS data reliability has to be guaranteed. Given that open seas are only covered by Satellite-AIS, and this is prone to misses, coastal areas with proper land-based AIS coverage are preferred. However, to reduce message collisions (given AIS is a time-multiplexed service), this environment should not be too congested. In the present exercise, the Iceland TDS is roughly aligned with these requirements.

On other hand, depending on the type of technology used for vessel detection (in the case of Unseenlab's SURMAR, detection of radar emissions), raw AIS retrievals may be not representative enough. In the present exercise, it has been found out that AIS is emitted by certain vessels that are not emitting radar signals. For example, in moored, riverine or near coast conditions, radar is not used. These AIS retrievals have to be filtered out to make the reference dataset more representative of the expected results. This is expected to depend heavily on the type of technology used.

Moreover, the need for an independent evaluation of the AIS accuracy is highlighted in order to assign uncertainties to the obtained geolocation accuracies. This has not been possible in the present exercise, but it is recommended to be considered in the future.

In conclusion, this exercise has allowed the EDAP+ team to start building a common validation framework for RF data. These lessons learnt will be useful in subsequent EDAP+ RF data analyses.

APPENDIX A Mission Test Dataset

Table 4-3: Products used in the Refresh Rate Analysis

Site	Product_Identifier (L1)
Iceland	UNSEENLABS_SURMAR_20230306T134615Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230307T014356Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230307T125910Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230307T144555Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230308T013039Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230308T131723Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230308T141854Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230309T001507Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230309T124100Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230309T141243Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230310T010308Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230310T122554Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230310T150545Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230311T004916Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230311T141426Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230311T151833Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230311T231308Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230312T140138Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230312T150528Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230312T233252Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230313T135654Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230313T194047Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230313T225032Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230314T114504Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230314T161052Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230315T013154Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230315T130356Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230315T143922Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230316T000110Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230316T011905Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230316T130925Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230316T235028Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230317T135042Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230317T153114Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230317T203108Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230317T233747Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230318T150237Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230318T232539Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230319T122309Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230319T143915Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230319T232834Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230320T002207Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230320T141531Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230321T004813Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230321T133906Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230321T152239Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230321T225037Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230323T002110Z_coverage.geojson

Site	Product_Identifier (L1)
Iceland	UNSEENLABS_SURMAR_20230323T131710Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230323T144826Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230323T204407Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230324T010519Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230324T135926Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230325T005122Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230325T005931Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230325T234159Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230326T003538Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230326T140924Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230326T211557Z_coverage.geojson
Iceland	UNSEENLABS_SURMAR_20230326T224806Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T020518Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T021848Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T123831Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T141301Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T142522Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T022139Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T032600Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T033049Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T122649Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T140152Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T143219Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230309T014403Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230309T021325Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230309T030837Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230309T031713Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230309T121848Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230310T015959Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230310T025938Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230310T134045Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230310T140829Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230310T144731Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T012221Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T014721Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T021951Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T025039Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T133035Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230311T135651Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T011124Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T030718Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T032937Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T132050Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T140049Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230312T144449Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230313T022207Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230313T025418Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230313T030343Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230313T143222Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230313T150714Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230314T023854Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230314T024302Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230314T034258Z_coverage.geojson

Site	Product_Identifier (L1)
East China Sea	UNSEENLABS_SURMAR_20230314T131510Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230314T141913Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230314T144244Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T021729Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T023022Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T032706Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T124628Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T130302Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230315T140524Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T015954Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T031644Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T123547Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T135049Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T135428Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230316T142419Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T014928Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T030010Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T030349Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T133602Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T150447Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230317T151100Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T013729Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T014927Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T025019Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T134457Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T144141Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230318T145652Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T012626Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T023657Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T031205Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T133453Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T141834Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230319T144505Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T022007Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T025754Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T032405Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T132221Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T133411Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230320T135451Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T020744Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T024656Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T034308Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T132117Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T132926Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230321T141427Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230322T004911Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230322T023434Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230322T130209Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230322T130643Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230322T143939Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230323T021031Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230323T022156Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230323T125046Z_coverage.geojson

Site	Product_Identifier (L1)
East China Sea	UNSEENLABS_SURMAR_20230323T125433Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230323T134809Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230323T142851Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T030022Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T123937Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T133647Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T134932Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T141425Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230324T151058Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230325T024653Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230325T025402Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230325T122436Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230325T135948Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230325T145459Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T014041Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T014100Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T023019Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T135028Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T143239Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230326T144102Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230327T013001Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230327T030055Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230327T133359Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230327T140913Z_coverage.geojson
East China Sea	UNSEENLABS_SURMAR_20230327T143123Z_coverage.geojson

Table 4-4: Products used in the Completeness Analysis

Site	Product_Identifier (L1)
Iceland	UNSEENLABS_SURMAR_20230305T003351Z_emitters.geojson
Iceland	UNSEENLABS_SURMAR_20230305T214209Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T020518Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T021848Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T034030Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T123831Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T141301Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230307T142522Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T022139Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T032600Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T033049Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T122649Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T140152Z_emitters.geojson
East China Sea	UNSEENLABS_SURMAR_20230308T143219Z_emitters.geojson

[END OF DOCUMENT]