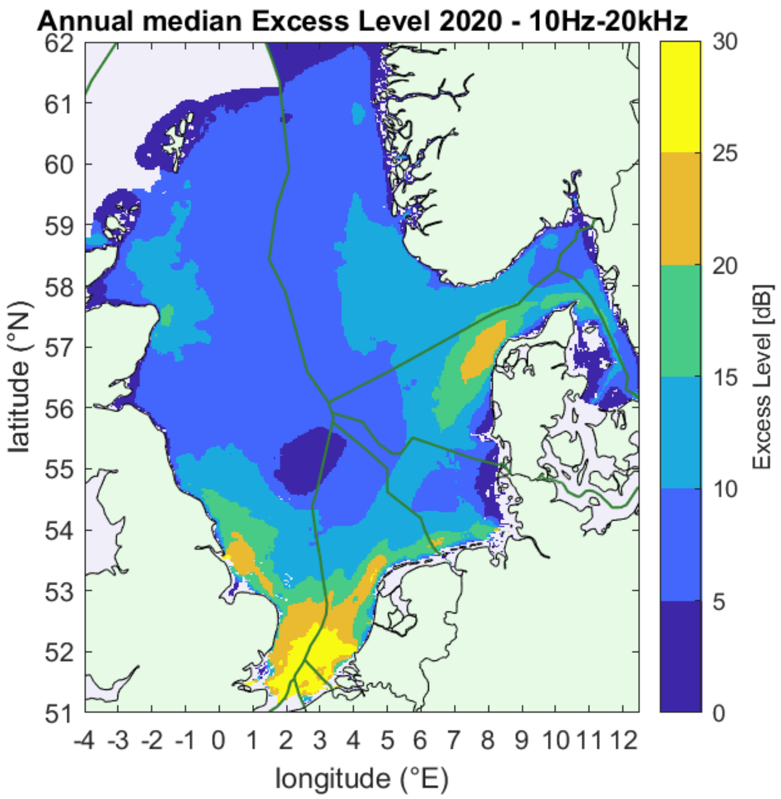
Joint Monitoring Programme for Ambient Noise North Sea

2018 – 2022

North Sea Sound Maps 2019-2020

Deliverable/Task: WP 4



Authors: Christ de Jong, Bas Binnerts, Paul de Krom, Timo Gaida

Affiliations: TNO (NL)

Date: June 2022

Project Full Title	Joint Monitoring Programme for Ambient Noise North Sea
Project Acronym	Jomopans
Programme	Interreg North Region Programme
Programme Priority	Priority 3 Sustainable North Sea Region

Colophon	
Author	Christ de Jong (WP4)
Organization Name	TNO
Email	christ.dejong@tno.nl

This report should be cited:

de Jong, CAF, Binnerts, B, de Krom, P, Gaida, TC (2022) *North Sea Sound Maps 2019-2020*. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans)

Cover picture: Annual average map of median excess level (ship noise over wind noise)

Table of contents

Summary

The Joint Monitoring Programme for Ambient Noise in the North Sea project (Jomopans) has developed a framework for an operational joint monitoring programme for ambient noise in the North Sea. Statistical sound maps can be used by managers, planners and other stakeholders to incorporate the effects of ambient noise in their assessment of the environmental status of the North Sea, and to evaluate measures to improve the environment.

The proposed framework applies numerical modelling for creating sound maps of the North Sea area, supported by local measurements for evaluation of the uncertainties in the numerical modelling.

In 2021, Jomopans produced statistical sound maps for the sound of shipping and wind in the North Sea in the twelve months of the year 2019. One of the sources of uncertainty in these sound maps is the quality and completeness of the model input data that describes the ship traffic. Raw data from the Automatic Identification System (AIS) for ship traffic has to be postprocessed to obtain snapshots of the locations of all vessels at a regular time grid, together with information about the ship type, length and speed of each vessel. This postprocessing has been further studied in the Jomopans extension (July 2021 – June 2022). AIS data from two different providers have been compared for May 2019, to quantify the uncertainty in the sound maps due to uncertainty in the AIS data. Additional sound maps were then produced for the twelve months of 2020.

In 2020 the Covid-19 pandemic affected ship traffic on the North Sea, but the change in the monthly (merchant) ship density appears to be small and variations in shipping noise smaller than the uncertainty in the sound maps.

The Jomopans monitoring approach, based on large scale sound map modelling validated with local measurements, provides a relatively stable assessment of the pressure of shipping sound on the environment at the North Sea scale. Maps of monthly median sound pressure level and excess level of shipping noise over wind noise do not show significant variation over the months of 2019 and 2020.

For local assessments at a smaller spatial or temporal scale, the uncertainty in the maps increases. Application of the monitoring approach at smaller scale would require high quality local input data (particularly of ship traffic and of local sediment properties) and local measurements to assess the contribution of other sources than shipping and wind to the soundscape.

1 Introduction

The Jomopans project has developed a framework for a joint monitoring programme for ambient noise in the North Sea. The proposed framework applies numerical modelling for creating soundscape maps of the North Sea area, supported by local measurements for evaluation of the uncertainties in the numerical modelling. Statistical sound maps can be used by managers, planners and other stakeholders to incorporate the effects of ambient noise in their assessment of the environmental status of the North Sea, and to evaluate measures to improve the environment.
The current report forms an addition to the Jomopans *Guidelines for modelling ocean ambient noise* report [de Jong et al, 2021]. For readability, the first two sections of the introduction of that report are cited here as sections 1.1 and 1.2.

1.1 Underwater ambient noise modelling

Numerical modelling of ocean ambient sound has the advantage that it can enable a much wider spatial and temporal coverage than achievable with measurements from offshore monitoring stations, with much technical difficulties (reliability and robustness of the stations and self-noise at the sensors) and at much lower cost. Moreover, numerical models provide insight in the contributions of individual source types to the ambient sound and enable studies of various past or future offshore scenarios and for noise mitigation strategies.

On the other hand, numerical modelling is limited to the sources and propagation effects for which models and the required input data for these models are available. The reliability of the model output can be limited by model simplifications, that can be necessary to keep computations manageable. The reliability also depends on the completeness and quality of the input data.

1.2 Jomopans North Sea soundscape map modelling

The Jomopans modelling framework is currently limited to the sound from shipping and from wind - generated surface wave breaking. These two were expected to be the dominant sources of the 'continuous low frequency sound (ambient noise)' that is addressed by Indicator 11.1.1 of the European Marine Strategy Framework Directive.

Summarized, the Jomopans sound map modelling focussed on the following aspects:

- Sources:
  - Ship traffic monitored by AIS/VMS,
    - characterized by 'type', length and speed
    - interpolated to 10-minute intervals
  - Wind generated surface waves
    - characterized by 10 min-average wind speed amplitude at 10 m above the water surface, from satellite observations
    - available at 1-hour intervals, linearly interpolated to 10-minute intervals
- Environment
  - Bathymetry
    - Characterized by local water depth at lowest astronomical tide
  - Sea water
    - Characterized by sound speed, density and absorption: assumed to be uniform in space and constant in time
  - Sea floor
    - Characterized by the local median grain size of the upper sediment layer at the source locations, converted to sound speed, density and absorption

The Jomopans measurements (WP5) are applied for model uncertainty assessment (WP6).

The modelled soundscape maps are applied to quantify to what extent the shipping noise exceeds the 'natural' ambient sound, represented by the modelled wind noise. The effect of this exceedance (quantified as 'excess level') on marine life remains to be quantified, but Jomopans proposes to apply statistical soundscape modelling to quantify the proportion of the time (per calendar month) and the proportion of the area (per assessment region) over which this excess level is higher than a specified cut-off value.

The Jomopans North Sea sound maps for 2019 and 2020 can be downloaded from and displayed in the Jomopans GES Tool[1] (WP7).

[1] Hosted by Arhus University, Denmark: https://jomopansgestool.au.dk/en/

1.3 Jomopans modelling guidelines

An important goal of the Jomopans modelling work package (WP4) was to be as clear as possible about the selection of metrics, models, model setting and input parameters, so that the reported approach can be used as guideline for future ambient noise modelling projects. This has resulted in the modelling guidelines reported in the Jomopans *Guidelines for modelling ocean ambient noise* report [de Jong et al, 2021] and summarized in Annex A to the present report.

1.4 Model validation and uncertainty

Monthly and annual shipping noise maps for 2019 were modelled and then independently validated against field measurements at various sites in the North Sea region (Figure 1.1), as described in [Putland et al, 2021] and [Putland et al, 2022].

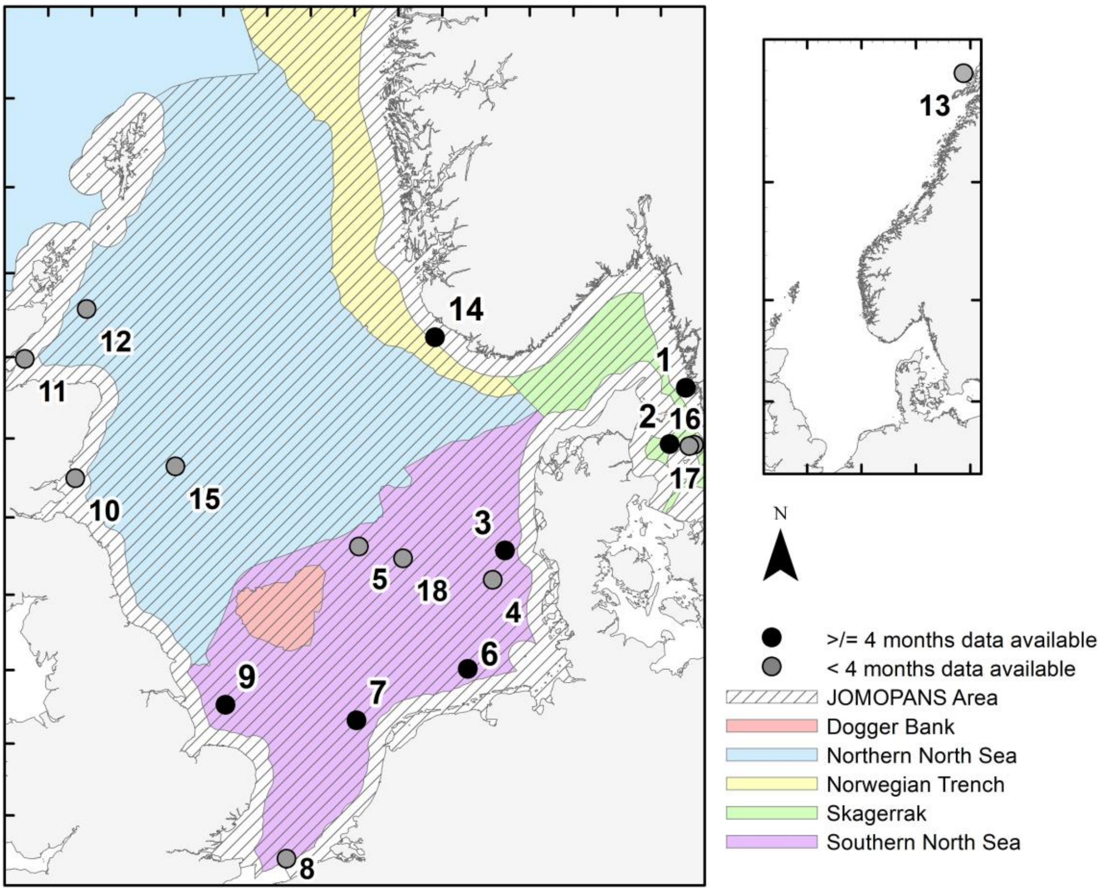


Figure 1.1 Map of the North Sea. The coloured circles indicate the locations of the Jomopans underwater sound monitoring locations. The Norwegian 'Love' monitoring station (13) served as a reference station (very low shipping) and is located in the northern area of Norway and outside of the specific project region. Figure from [Putland et al, 2022]

Uncertainties in measurements include the quality of data and whether flow noise needs to be removed by standardised pre-processing. Uncertainties in modelling of shipping noise include AIS (Automatic Identification System) coverage (the percentage of vessels that carry AIS transceivers as well as the quality of reception of AIS signals by vessel-, land- and satellite-based receivers) and the accuracy of low-frequency propagation loss estimation in shallow water, which is strongly influenced by the quality of sediment data. The comparison between model predictions and measurements also suggests that it is worthwhile considering extending the model capability to other sound sources, in addition to ships and wind, such as seismic surveys and operational source from offshore platforms and structures.

1.5 Jomopans extension

In 2021, the Jomopans project was extended with one year (July 2021 – June 2022). This allowed for further investigation of one of the main uncertainties in the sound map modelling, the quality of the AIS data, as well as the production of modelled sound maps for a second year (2020).

In 2020 the Covid-19 pandemic had a huge impact all over the world. At the initiative of the International Quiet Oceans Experiment (IQOE) a worldwide effort has started to evaluate the effects of the reduced shipping activity due to the pandemic on underwater noise.

The acquisition of additional AIS data for 2020 and the calculation of sound maps for this additional year, influenced by Covid-19, combined with extended measurement periods of several noise monitoring stations provided an opportunity to gain valuable insights in the applicability of the Jomopans framework for a joint monitoring programme for ambient noise in the North Sea.

1.6 Outline

- Chapter 2 summarizes the specific implementation for modelling of the ambient noise in the North Sea that was developed in Jomopans.
- Chapter 3 describes the analysis of the AIS data for 2019 and 2020.
- Chapter 4 provides examples of the Jomopans North Sea sound maps for 2020.
- Chapter 5 describes an analysis of the trends observed in the modelled North Sea sound maps for 2019 and 2020, including the effects of COVID-19.
- Chapter 6 provides a summary and conclusions.

2 Jomopans sound map modelling

2.1 Introduction

Jomopans has produced maps of ambient noise in the North Sea, as input for assessment of the environmental status. The EU MSFD indicator 11.2.1 quantifies ambient noise in terms of a sound pressure level, which is a quantity with five dimensions: latitude, longitude, depth, frequency and time. An ambient noise map is a two-dimensional (latitude, longitude) projection of this quantity.

Jomopans decided to focus on **shipping and wind sound sources only**. These dominate the North Sea soundscape over most of the evaluation area and time. In the future, the modelling could be extended to include contributions of other sound sources, such as offshore platforms and structures (for example offshore wind farms), or impulsive sounds (such as explosions, seismic surveys, marine piling and sonar).

Jomopans has proposed quantifying the pressure on the marine environment in terms of the excess of the sound from anthropogenic activities (shipping) over the natural background (wind) sound. This excess can directly affect the communication space for marine animals due to masking.

This chapter provides an overview of the various choices made for the modelling of maps of the ambient noise in the North Sea area and the selection of model input data and mapping procedures.

2.2 Jomopans sound map modelling

The Jomopans sound maps for shipping and wind were calculated according to the following approach (see [de Jong et al 2021]):

1. Obtain ship traffic information (location, speed, ship type and length) from AIS/VMS data, interpolate to a regular time grid (10-min), and to a regular two-dimensional source grid (0.025° resolution).
2. Calculate propagation loss (time-invariant) between source grid locations and locations on a receiver grid (0.05° longitude and 0.025° latitude resolution, averages over 10 equally spaced points over the local water depth), at centre frequencies of one-third octave bands ranging from 10 Hz to 20 kHz, using the Aquarius 3 propagation loss model. Store the calculated propagation loss in a look-up table.
3. For each ship at each time step, estimate the source level spectrum, at centre frequencies of one-third octave bands ranging from 10 Hz to 20 kHz, using the Jomopans -ECHO source level model [MacGillivray & de Jong, 2021].
4. For each time step, calculate the depth-averaged sound pressure level spectrum at each receiver grid location, by summing the contributions from all source grid cells (source level minus propagation loss).
5. Obtain wind information (speed at 10 m above the water surface), interpolate to a regular time grid (10-min), and to the receiver grid (0.05° longitude and 0.025° latitude resolution).
6. For each time step, calculate the depth-averaged sound pressure level spectrum due to the wind at each receiver grid location, using a semi-empirical wind source and propagation.
7. For each receiver grid location, determine monthly percentiles of the calculated sound pressure level spectra from ships and wind.

2.2.1 Jomopans resolution settings

Table 2.1 describes the model resolution settings that were selected for the Jomopans shipping and wind noise maps for the North Sea in 2020.

Table 2.1 Model resolution for the 2020 Jomopans North Sea sound maps

Parameter	Setting
Time steps	Every 10 minutes (e.g. 4464 snapshots for May 2020)
Frequencies	One-third octave (base-10) band centre frequencies, from 10 Hz to 20 kHz
Receiver grid	0.05 degrees longitude and 0.025 degrees latitude (about 3 km × 3 km) Depth average over 10 equally spaced grid points
Ship source grid	centered between the receiver grid points, both in longitude and latitude, see [de Jong et al, 2021; Figure D-7]
Number of radials	16
Length of radials	400 km
Resolution along radials	100 m
Interpolation from radials to receiver grid	2D linear interpolation

2.3 Calculation time for Jomopans sound maps

Producing large-scale sound maps at multiple time steps and frequencies requires extensive calculations. To illustrate this, we provide an impression of the calculation times used for the production of the 2020 maps.

In the basis, two dedicated PCs running 64-bit windows 10 were used to do the calculations with an Intel Xeon 4114 CPU @ 2.2 GHZ (10 cores) and 128 GiB of RAM memory installed. In addition, A large part of the time we also had access to other heavier PCs that were even more efficient to calculate the month statistics.

Most calculations were set up in a way that if anything goes wrong, they are automatically restarted and continue from where they were. On rare occasions the process halted and a manual restart was required. The time waiting for the user to restart is not included in this overview.

Calculating the loss lookup table for propagation between the source and receiver grids (about 208,000 files, 770 GB) for the JOMOPANS area on the dedicated machines took about 1,5 days on a high-performance PC. The same propagation loss lookup table was used for the 2019 and 2020 sound maps.

Calculating SPL levels at all receiver grid locations for one snapshot in time takes about 10 minutes, using the propagation loss look-up table. With a 10-minute resolution and 1 month of shipping data this results in about 4320 snapshots. Using 14 parallel Matlab sessions it took about 5 days to compute the sound maps for one month. We used a dedicated fast SSD for the lookup table, because reading from the lookup table took a lot of time. Some of the faster PCs (Intel 6254 CPU with 36 cores, fast raid SSDs and 1TB memory) are able to do these calculations in 2 days.

Reshuffling the data and calculating the SPL statistics and other metrics (such as excess level) took about 2 days using 6 parallel Matlab sessions. Most of that time was spent on reading and writing the data.

Table 2.2 Calculation time and data volume for Jomopans North Sea sound maps for the 12 months of 2020 using the optimal number of sessions for the available computers.

	Computation time	Data size
Calculate propagation loss	1.5 days	Prop loss database 768 GB
Calculate snapshots of SPL levels for 12 months	12 * 5 days	wind 2250 GB ships 4800 GB
Reshuffle snapshots into areas	12 * 2 days	4800 GB
Calculate month statistics	12 days	40 GB
Calculate year statistics	7 days	8 GB
Total	**105 days**	**12 TB**

3 Ship traffic data (AIS/VMS)

Ship traffic at sea is monitored by AIS (Automatic Identification System) and VMS (Vessel Monitoring System) services. The International Maritime Organization's International Convention for the Safety of Life at Sea requires AIS to be fitted aboard international voyaging ships with 300 or more gross tonnage (GT), and all passenger ships regardless of size. AIS is intended, primarily, to allow ships to view marine traffic in their area and to be seen by that traffic. Under the European Union legislation, VMS is a legal requirement for commercial fishing vessels in excess of 15 metres, to allow environmental and fisheries regulatory organizations to track and monitor the fishing activities.

Because the information from AIS and VMS is not created for the purpose of sound mapping, there are several uncertainties in this input to the modelling:

1. The information does not include all ships. Many small ships do not carry AIS transponders and ships can turn off their AIS transponders, for a variety of reasons. Moreover, land-based AIS receivers have a limited reception range (a few tens of kilometres, depending on location and weather conditions) and satellite-based receivers offer larger spatial coverage but poor temporal coverage.
2. Information from AIS provides an imperfect means of identifying vessel class and estimating source levels. For example, container ships and vehicle carriers cannot be distinguished from other types of cargo vessels through their AIS ship type identification. AIS broadcasts are not free from errors in vessel length, ship type ID, and speed, and vessel design details that truly relate to noise emissions, such as the speed at which the propellers start to develop cavitation and the type and power of the propulsion engines, are entirely absent from AIS data.

This chapter describes the analysis of the AIS (Automatic Identification System) data carried out in the Jomopans extension (July 2021 – Jun 2022).

3.1 Ship traffic data sets

For the 2019 North Sea sound mapping, Jomopans has acquired processed AIS/VMS data of the North Sea shipping from Quiet Oceans[2], further referred to in this report as provider P1. These are based on land- and satellite-based AIS data, supplemented with VMS data, though the VMS data could not be obtained from all North Sea countries, due to national restrictions. The processing included check of validity and consistency and interpolation of the individual ship trajectories to a regular temporal resolution of 10 minutes. To further enhance the data, TNO applied an additional, apparently less restrictive, trajectory interpolation and speed check, see [de Jong et al, 2021].

For the 2020 North Sea sound mapping, a tender was issued for the acquisition of AIS data for 2020. The new contract was granted to Marine Traffic[3], further referred to in this report as provider P2. To allow for a comparison of the data from different providers, the acquisition included new AIS data for one month (May) of 2019.

The data is stored in an *.csv* file for each month separately. The AIS entries from provider P2 were reported on an irregular time interval. The majority of data can be grouped into time intervals between 2 to 5 min and 20 to 25 min (Figure 3.1). However, some adjacent AIS recordings are separated by more than 25 min up to a couple of hours, as illustrated by the histogram in Figure 3.1.

[2] https://www.quiet-oceans.com/
[3] https://www.marinetraffic.com/

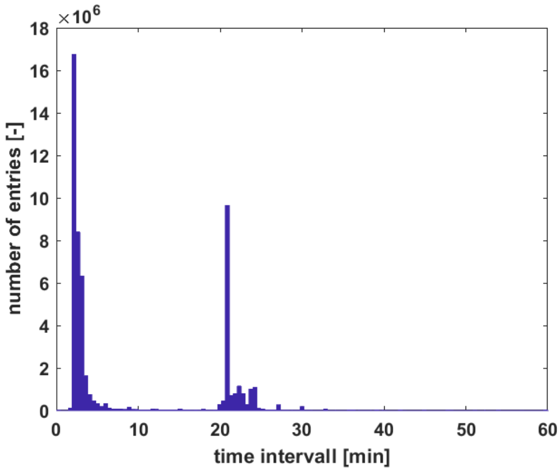


Figure 3.1 Time difference between adjacent AIS recording for May 2020 (P2).

TNO interpolated the data to a regular 10-min time grid and applied filtering, as described in the following sections. Table 3.1 provides an overview of the various steps.

Table 3.1 Overview of the various steps in which AIS datasets were delivered and processed for this project.

nr	Period	Provider	Interpolation	Comment	Ship class information
1	2019	P1	10-min (P1)	incomplete	AIS ID
2	2019	P1	10-min (P1)	update	AIS ID
3	2019	P1	10-min (P1)	+ VMS	AIS ID
4	2019	P1	10-min (P1+TNO)	update	AIS ID
5	May 2019	P2	10-min (TNO)	no VMS	AIS-ID + extra ship class indicators
6	2020	P2	10-min (TNO)	no VMS	AIS ID + extra ship class indicators

Steps 1 to 4 were described in the Annex to the Jomopans WP4 report [de Jong et al, 2021].

3.2 Ship type classification

There are various definitions of ‘ship type’ without clear standardisation. Jomopans has adopted the ship classes as defined by the ECHO programme [MacGillivray et al, 2019], for which the Jomopans-ECHO ship source level model was developed [MacGillivray & de Jong, 2021]. Table 3.2 provides the applied conversion between the ship type identification (ID) in the AIS data set and vessel class.

Quoting [MacGillivray & de Jong, 2021]: “The AIS types ‘Passenger’ (ID = 60–69) and ‘Cargo’ (I = 70–79) do not provide a clear identification of larger and faster vessels such as containerships, vehicle carriers and cruise vessels. Without access to additional ship information, these vessel classes are tentatively identified by ship length, observed mean speed and AIS hazard class.”

The AIS data provided by Provider P2 include for each ship three indicators of ship class:

1. SHIPTYPE - A numerical representation of the vessel type, which is transmitted as part of the AIS signal, i.e. the AIS SHIPTYPE ID in Table 3.2.
2. TYPE_SUMMARY - The basic vessel type (e.g. Cargo, Tanker, etc.)
3. TYPE_NAME – A more detailed vessel type (e.g. Crude Oil Tanker, Ore carrier etc.), that is collected from multiple sources and is only available if the vessel has registered a more detailed vessel type.

The TYPE_SUMMARY consists of unique 12 vessel types (Cargo; Fishing; High Speed Craft; Other; Passenger; Pleasure Craft; Sailing Vessel; Search and Rescue; Special Craft; Tanker; Tug; Wing in Ground), directly related to the SHIPTYPE. These do not make the distinction between larger and faster container vessels and other cargo vessels, and cruise vessels and other passenger vessels. The more detailed TYPE_NAME consists of 152 unique vessel subtypes, including ‘vehicles carrier’ and four types of container vessel (Container Ship; Cargo/Containership; Ro-Ro/Container Carrier; Reefer/Containership), enabling a better identification of these classes that the identification based on SHIPTYPE and speed proposed in Table 3.2. The list does not include a separate type for ‘cruise vessel'.

Table 3.2 ECHO vessel classes, with the fitted reference speed per vessel class for the Jomopans-ECHO ship source level model [MacGillivray & de Jong, 2021]

Vessel Class (C)	Old classification, based on AIS SHIPTYPE ID	New classification, based on AIS SHIPTYPE ID and TYPE_NAME	Reference speed (V_C) in knots
Fishing vessel	30	30	6.4
Tug	31,32,52	31,32,52	3.7
Naval vessel	35	35	11.1
Recreational vessel	36,37	37	10.6
Government/Research	51,53,55	51,53,55	8.0
Cruise vessel	60-69 (length $l > 100$ m)	60-69 (length $l > 100$ m)	17.1
Passenger vessel	60-69 (length $l \leq 100$ m)	60-69 (length $l \leq 100$ m)	9.7
Bulker	70, 75-79 (speed $V \leq 16$ kn)	70-79 and not Container ship or Vehicle carrier	13.9
Container Ship	71-74 (all speeds) 70, 75-79 (speed $V > 16$ kn)	TYPE_NAME contains 'Container'	18.0
Vehicle Carrier	n/a	TYPE_NAME = 'Vehicles Carrier'	15.8
Tanker	80-89	80-89	12.4
Other	All other type IDs	All other with SHIPTYPE≥30 and <100	7.4
Dredger	33	33	9.5

With the availability of the additional TYPE_NAME field in the AIS data provided by Provider P2, the ship class identification can be improved. The following updates are implemented (see Table 3.2):

1 Identification of container ships based on TYPE_NAME ('Container Ship', 'Cargo/Containership', 'Ro-Ro/Container Carrier', or 'Reefer/Containership') instead of speed.
2 Identification of vehicle carriers based on TYPE_NAME ('Vehicles Carrier')
3 Ignore sailing vessels (SHIPTYPE = 36), instead of classifying these as Recreational vessels
4 Ignore AIS entries with TYPE_NAME 'SAR Aircraft', 'Platform', 'Pontoon', 'Maintenance Platform', 'OffShore Structure' and 'Wing In Grnd'.

3.3 Interpolation and filtering

Although the quality of the AIS data is controlled by the providers, there are still significant uncertainties. It is still likely that a substantial fraction of the vessels is missing in these data, but it is currently impossible to know how many, because ships without AIS are not monitored. Several vessel trajectories are discontinuous, particularly along the shipping lanes that cross the central North Sea. This may be due to bad coverage of this area by land and satellite AIS receivers.

TNO has reviewed all AIS data and applied filtering and track interpolation in subsequent steps:

1. Ships are classified based on AIS SHIPTYPE ID and TYPE_NAME , including removal of AIS entries of sailing vessels and other irrelevant categories, see section 3.2
2. To clean the data and to improve the interpolation, speed and depth filters are applied, as described in Table 3.3.
3. The latitude, longitude and speed over ground of every individual ship track are linearly interpolated to a regular time interval of 10 min. The interpolated speed over ground is accepted if the time interval between adjacent data points of the original (irregular) AIS recordings is <=10 min. In case the time interval is >10 min (see Figure 3.1) the interpolation becomes more speculative. In that case, the ship speed is computed from the distance between the interpolated ship locations divided by the 10-min time interval.
4. Next, the interpolated data are filtered to eliminate obvious errors, using the filters described in Table 3.4.

Table 3.3 Filters applied to AIS recordings prior to interpolation. The percentages displayed give an example of the amount of removed entries in the May 2020 data from provider P2.

Filter	Goal	Removed entries (May 2020; P2)
(1) Ship class filter	Remove sailing vessels and other irrelevant categories (see Section 3.2). Is only applied to P2 based on new classification	30.1% (12,407 of 40,156 original ships)
(2) Depth filter (< 5 m)	Remove all entries located inland or in areas with a water depth below 5 m.	43.5% ($20.2 \cdot 10^6$ of $48.4 \cdot 10^6$ original entries)
(3) High speed filter (> 50 kn)	Remove all entries with an unrealistically high reported speed of more than 50 knots.	0.002% (101 entries)

Table 3.4 Overview of filters applied after interpolation. Percentages displayed valid for May 2020 data. The filters are subsequently applied according to the numbering in the first column.

Filter	Goal	Removed entries (May 2020; P2)
(1) Area filter	The noise modelling only considers the area where AIS data is available. If the vessel crosses the border of that area during a part of the time, no interpolations is carried out. Two filters to cover false interpolation from entries very close and further away from the boarder are implemented: **Filter 1**: Lat(i) > lat_min-0.01° | Lat(i) < lat_max-0.01° | lon(i) > lon_min-0.01° | Lon(i) < max_lon-0.01° & $t_i - t_{i-1}$ > 40 min **Filter 2**: Lat(i) > lat_min-0.2° | Lat(i) < lat_max -0.2° | Lon(i) > lon_min - 0.2° | Lon(i) < lon_max-0.2° & $t_i - t_{i-1}$ > 120 min	9.6% ($4.2 \cdot 10^6$ of $44.0 \cdot 10^6$ interpolated entries)
(2) Vessel track filter	To remove all tracks where the vessel has travelled either a longer path than the interpolated straight line, or it has stopped in between. Based on the time interval and the comparison between the original reported and lat/lon speed these false tracks are identified and the interpolated values between the adjacent original data points are removed. Only entries with a sufficient high reported speed (>2 kn) are considered for this false track identification. **Filter**: $t_i - t_{i-1}$>10 min and $v_{\mathrm{AIS}}/3 > v_{\mathrm{lat/lon}}$ and $v_{\mathrm{lat/lon}} > 2\ \mathrm{kn}$	58.7% ($25.8 \cdot 10^6$ entries)
(3) Low speed filter (< 0.2 kn)	To replace all entries with a low speed. These entries are negligible in the noise modelling and are also more prone to false interpolation.	11.8% ($5.2 \cdot 10^6$ entries)
(4) Depth filter (< 5 m)	To remove all interpolated entries, which are interpolated on a location inland or in a very shallow water depth.	1,0% ($0.44 \cdot 10^6$ entries)
(5) High speed filter (> 50 kn)	To replace all entries with an unrealistically high calculated speed. This filter is applied in case the interpolation has introduced speeds >50 kn. The entries are removed and the interpolation is carried out again based on the remaining “realistic” speeds.	No entries removal

3.4 Ship density plots

Ship density plots are used to show the distribution of ships per area. The AIS entries per unit area n_i (grid cell i) are counted and normalised over the maximum number of ship entries $N_{\max}$ for the considered time period (with $x = n_i/N_{\max}$, see colour label of density plots). For this report a grid cell of 0.05° in longitude and 0.025° in latitude direction (~3 km × 3 km) and a time period of a full month are chosen. The ships tracks are interpolated on a 10-min time grid, that means for a month with 31 days 4464 entries per ship are possible (i.e., $N_{\max}$ = 4464). Here is an example how to read the density plots: If a ship is sailing for a full month in a single grid cell, it would result in a density value of 1 and if in addition a second ship sails for half of the month in the same grid cell, a density value of 1.5 is reached. To improve the readability of the density plots, the density values are expressed in the $10\log_{10}(x)$ scale, so that a density value x=1.5 is represented as $10\log_{10}(1.5)$ ≈1.8.
As an example, Figure 3.2 illustrates the total effect of the track interpolation on the density plot for the month May 2020 (from provider P2).

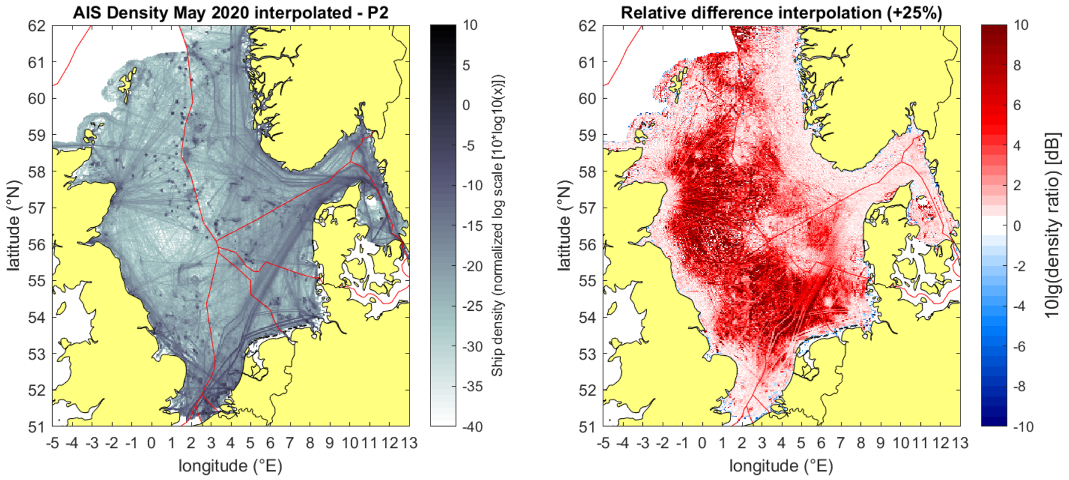


Figure 3.2 AIS density plots (Provider P2) for May 2020: (left) interpolated AIS recordings and (right) relative difference between interpolated and reduced original AIS recordings. Here, the logarithmic values from the reduced original entries were subtracted from the interpolated entries. The percentage value indicates the percental increase in the total number of ship entries due to the interpolation.

Figure 3.3 shows examples of density plots for different ship types. Merchant ship traffic (bulkers, tankers and container ships) is concentrated along main shipping lanes, while fishing boats sail in different areas. The patterns are very similar for 2019 and 2020.

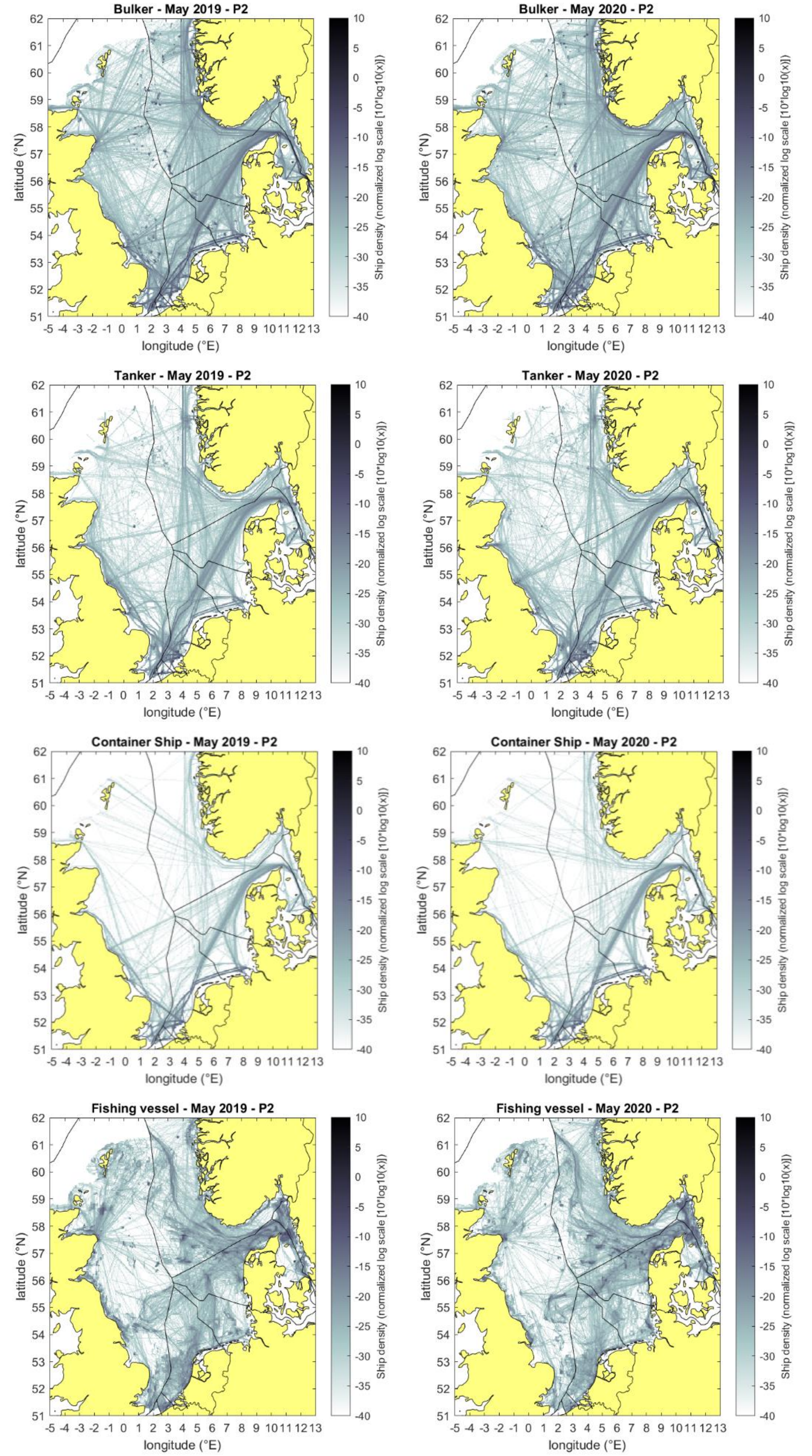


Figure 3.3 Examples of density plots of interpolated vessel tracks (Provider P2) for selected ship types (see headers) in (left) May 2019 and (right) May 2020.

4 Jomopans sound maps and indicators

Sound maps and indicators for the years 2019 and 2020 illustrated the application of The Jomopans monitoring framework for ambient noise.

4.1 Jomopans sound map types

The maps represent monthly or annual percentiles of sound pressure level (SPL) and excess level (EL) and Dominance, which are defined as follows.

Excess Level (EL) is calculated for each time step as the difference between the total SPL from all ships and wind and the SPL from wind alone. Two different versions of EL are provided, (i) representing the instantaneous “ambient noise” SPL from all ships and wind over the instantaneous “natural” wind noise SPL and (ii) representing the excess of the instantaneous “ambient noise” SPL from all ships and wind over the median SPL of “natural” wind noise over the month (or year).

Dominance based on EL represents the percentage of evaluation time over which the excess level exceeds a specified cut-off value. Two different cut-off values have been selected: 6 dB and 20 dB.

16 different types of maps are produced for 2019:

1. 50th percentile (median) SPL from wind
2. 50th percentile (median) SPL from all ships
3. 50th percentile (median) SPL from all ships and wind
4. 90th percentile (median) SPL from all ships and wind
5. 50th percentile (median) SPL from fishing ships
6. 50th percentile (median) SPL from cruise/ferry ships
7. 50th percentile (median) SPL from bulkers
8. 50th percentile (median) SPL from container ships
9. 50th percentile (median) SPL from tankers
10. 50th percentile (median) SPL from dredgers
11. 50th percentile (median) EL from ships and wind over instantaneous wind noise
12. 50th percentile (median) EL from ships and wind over monthly median wind noise
13. Dominance based on EL over instantaneous wind noise with a 6 dB cut-off value
14. Dominance based on EL over instantaneous wind noise with a 20 dB cut-off value
15. Dominance based on EL over monthly median wind noise with a 6 dB cut-off value
16. Dominance based on EL over monthly median wind noise with a 20 dB cut-off value

For 2020, additional map types were added. Firstly, there was a request to add maps for all defined ship classes:

17. 50th percentile (median) SPL from tugs
18. 50th percentile (median) SPL from naval ships
19. 50th percentile (median) SPL from recreational ships
20. 50th percentile (median) SPL from government/research ships
21. 50th percentile (median) SPL from passenger ships
22. 50th percentile (median) SPL from vehicle carriers
23. 50th percentile (median) SPL from ‘other’ ships

Next, based on discussions in the EU task group TG Noise, there was a request to quantify percentage of time over which the instantaneous SPL from ships and wind exceeds a given threshold value. This is included here as an alternative type of dominance, which we have tentatively named ‘dominance based on SPL’:

Dominance based on SPL represents the percentage of evaluation time over which the SPL exceeds a specified threshold value. Four different threshold values have been selected: 90, 100,110 and 120 dB re 1 µPa.

24. Dominance based on SPL with a 90 dB re 1 µPa threshold value
25. Dominance based on SPL with a 100 dB re 1 µPa threshold value
26. Dominance based on SPL with a 110 dB re 1 µPa threshold value
27. Dominance based on SPL with a 120 dB re 1 µPa threshold value

Each of these maps is calculated for 6 different frequency bandwidths:

i. 'Broadband', covering the 10 Hz to 20 kHz one-third octave bands
ii. 'Decade 1', covering the 20 Hz to 160 Hz one-third octave bands
iii. 'Decade 2', covering the 200 Hz to 1.6 kHz one-third octave bands
iv. 'Decade 3', covering the 2 kHz to 16 kHz one-third octave bands
v. 63 Hz one-third octave band
vi. 125 Hz one-third octave band

The three decades are broadly aimed at the hearing sensitivity of different animal groups. For example, fish are generally sensitive to sound in the lowest band (20 Hz to 160 Hz), while harbour porpoises are mainly sensitive to shipping sound in the highest band (2 kHz to 16 kHz). 63 Hz and 125 Hz are the bands selected for EU descriptor D11C2, initially proposed to monitor shipping noise.

Maps have been produced for the 12 months and for the full year, for 2019 and for 2020.

In total this has resulted in 16 (map types) × 6 (frequency bands) × 13 (evaluation periods) = 1248 maps for 2019, that can be downloaded from and displayed in the Jomopans GES Tool. These maps are shown in [de Jong and all, 2021].

Including the additional map types, we produced 27 (map types) × 6 (frequency bands) × 13 (evaluation periods) = 2106 maps for 2020.

4.2 SPL percentile maps

Map types 1 to 10 and 17 to 23 (section 4.1) present the spatial distribution of a temporal percentile of the calculated SPL, for various specific combinations of sound sources.

4.2.1 Wind

Figure 4.1 shows maps of the annual median broadband wind noise in 2019 and 2020.

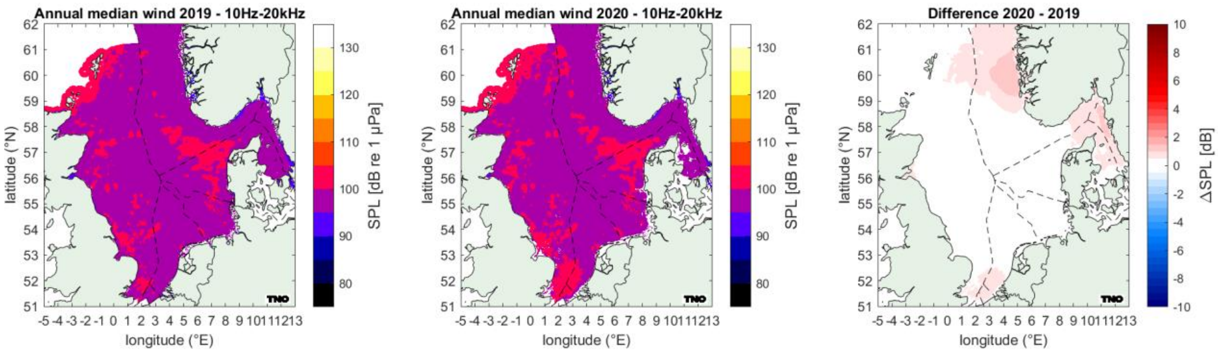


Figure 4.1 Map of the annual median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband wind-generated noise in the North Sea region in 2019 (left panel) and 2020 (middle panel) and the dB-difference between the two maps (right panel).

The annual median of the broadband wind-generated noise is very similar over the 2 years, with maximum local differences of the order of 1 dB.

Figure 4.2 shows maps of the monthly median broadband wind noise for 2020. As in 2019 [de Jong et al, 2021], the wind noise is generally higher in the winter months than in the summer months.

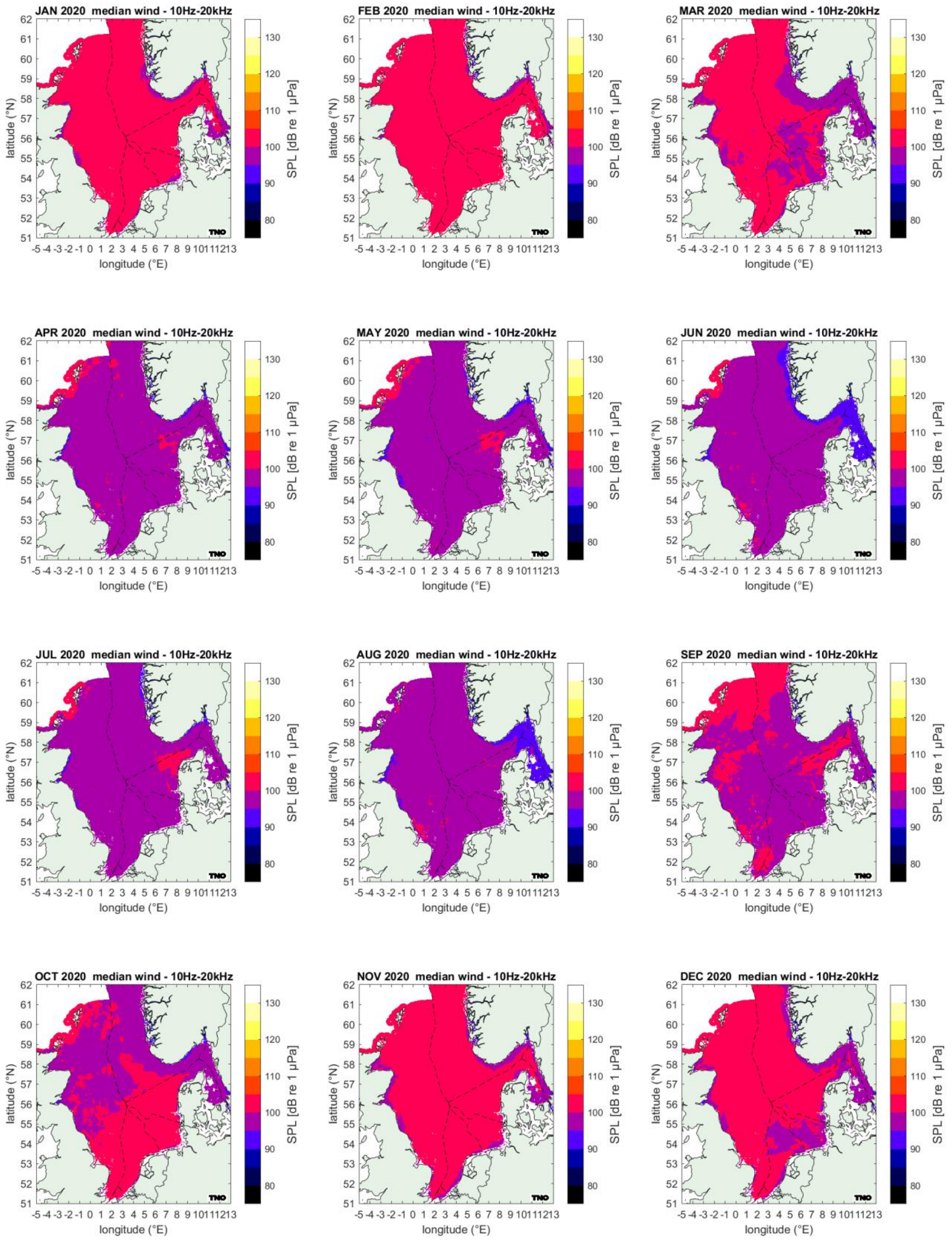


Figure 4.2 Maps of the monthly median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband wind-generated noise in the North Sea region for the 12 months of 2020.

Figure 4.3 shows maps of the annual median wind noise in 2020 in the three decade frequency bands. This illustrates that the wind generated-noise is higher in the two upper decades than in the lowest decade.

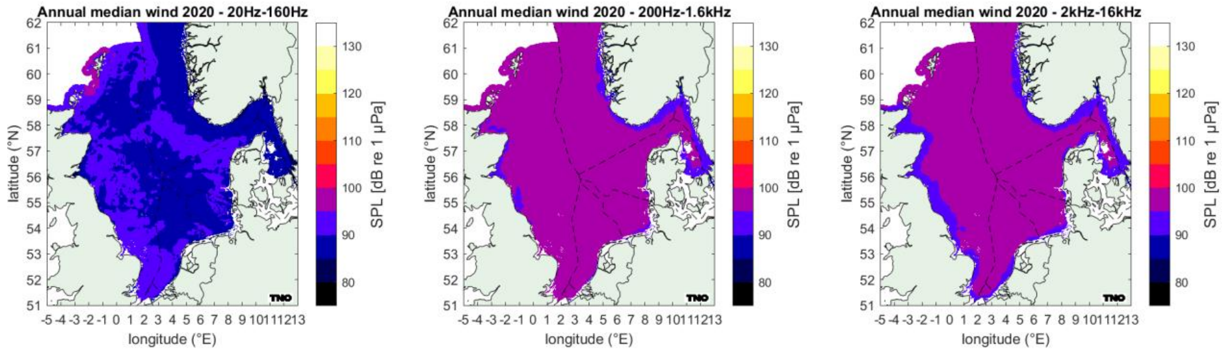


Figure 4.3 Maps of the annual median (50th percentile) of depth-averaged SPL in dB re 1 μPa² of wind-generated noise in the North Sea region in 2020 in the three decade bands.

4.2.2 Shipping + Wind

Figure 4.4 shows maps of the total annual median broadband ambient noise generated by shipping and wind in 2019 (AIS data from provider P1, see Chapter 3) and 2020 (AIS provider P2). The difference in the annual median SPL due to shipping is somewhat larger than the difference in wind noise (Figure 4.1).The largest local differences (up to 3 dB) are seen in UK waters. The differences are further discussed in Chapter 5.

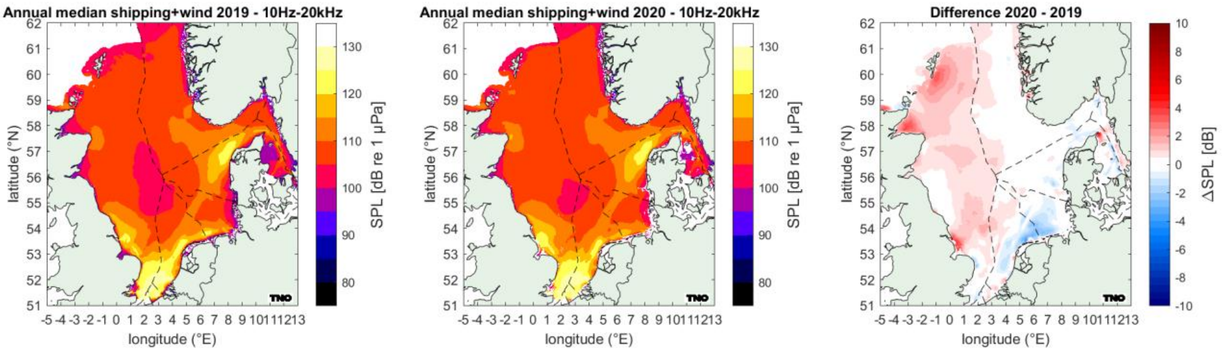


Figure 4.4 Map of the annual median (50th percentile) of depth-averaged SPL in dB re 1 μPa² of broadband noise generated by shipping and wind in the North Sea region in 2019 (left panel, AIS data from provider P1) and 2020 (middle panel, AIS data from provider P2) and the difference between the two years (right panel).

Figure 4.5 shows maps of the annual median noise from shipping and wind in 2020 in the three decade frequency bands. This illustrates that shipping noise dominates in the two lower decades. In the upper decade ship noise only dominates around the main shipping lanes.

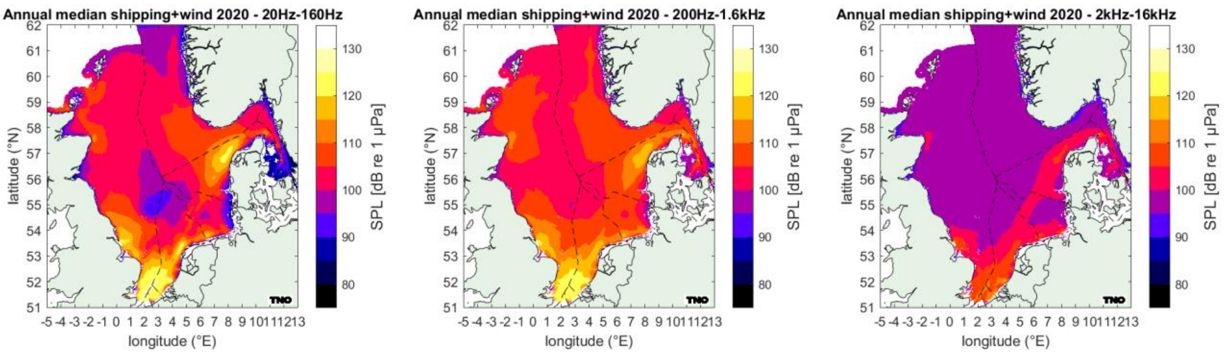


Figure 4.5 Maps of the annual median (50th percentile) of depth-averaged SPL in dB re 1 μPa² of noise generated by shipping and wind in the North Sea region in 2020 in the three decade bands.

Figure 4.6 shows maps of the monthly median broadband noise generated by shipping and wind. Broadband noise from shipping dominates over wind noise and the median shipping noise varies little over the months.

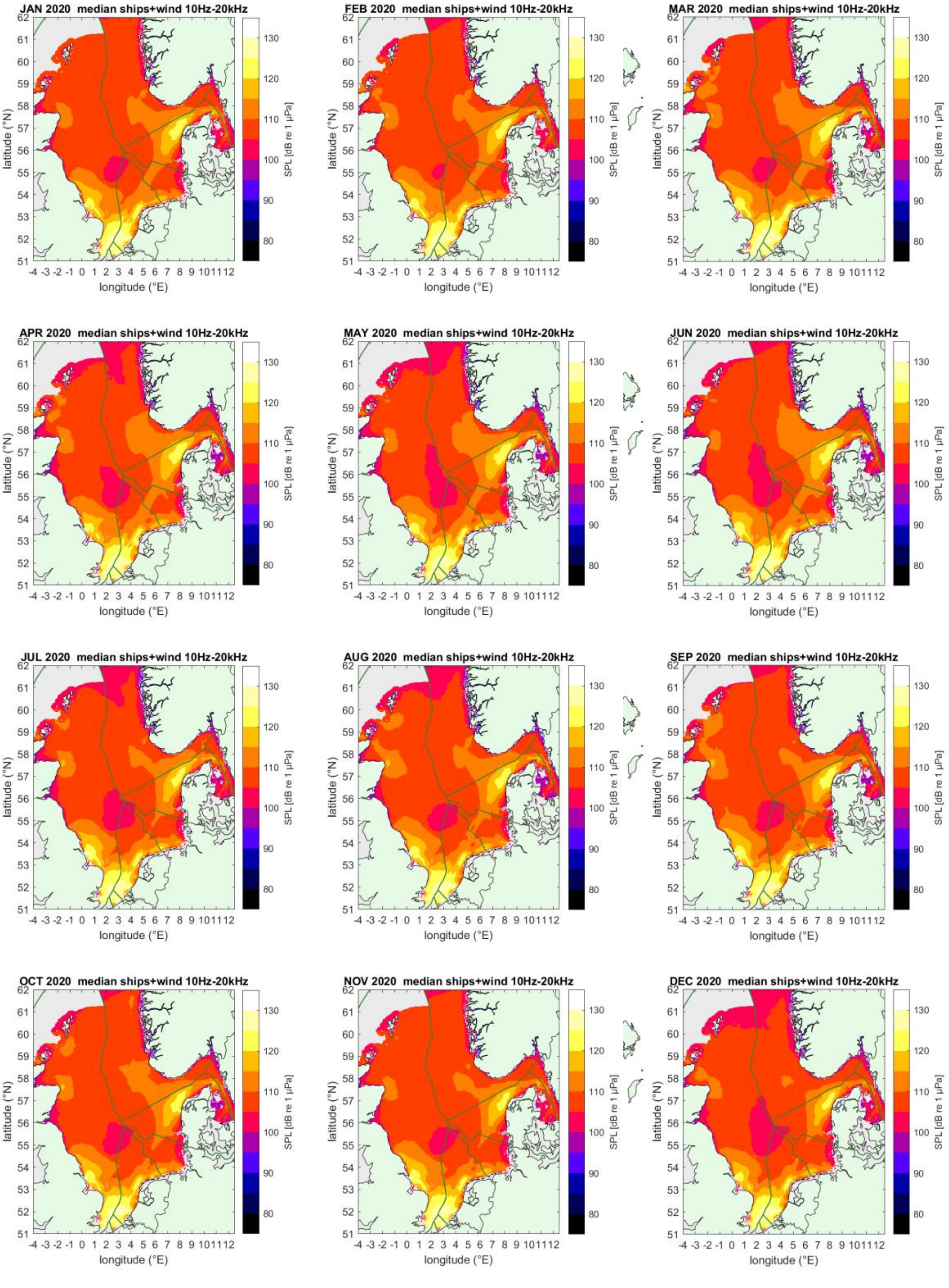


Figure 4.6 Maps of the monthly median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband wind-generated noise in the North Sea region for the 12 months of 2020. The median shipping noise varies little over the months.

4.3 Individual ship type contributions

Figure 4.7 shows maps of the annual median broadband noise generated by four individual ship types that have the largest presence in the AIS data in 2019 (AIS provider P1) and 2020 (AIS provider P2).

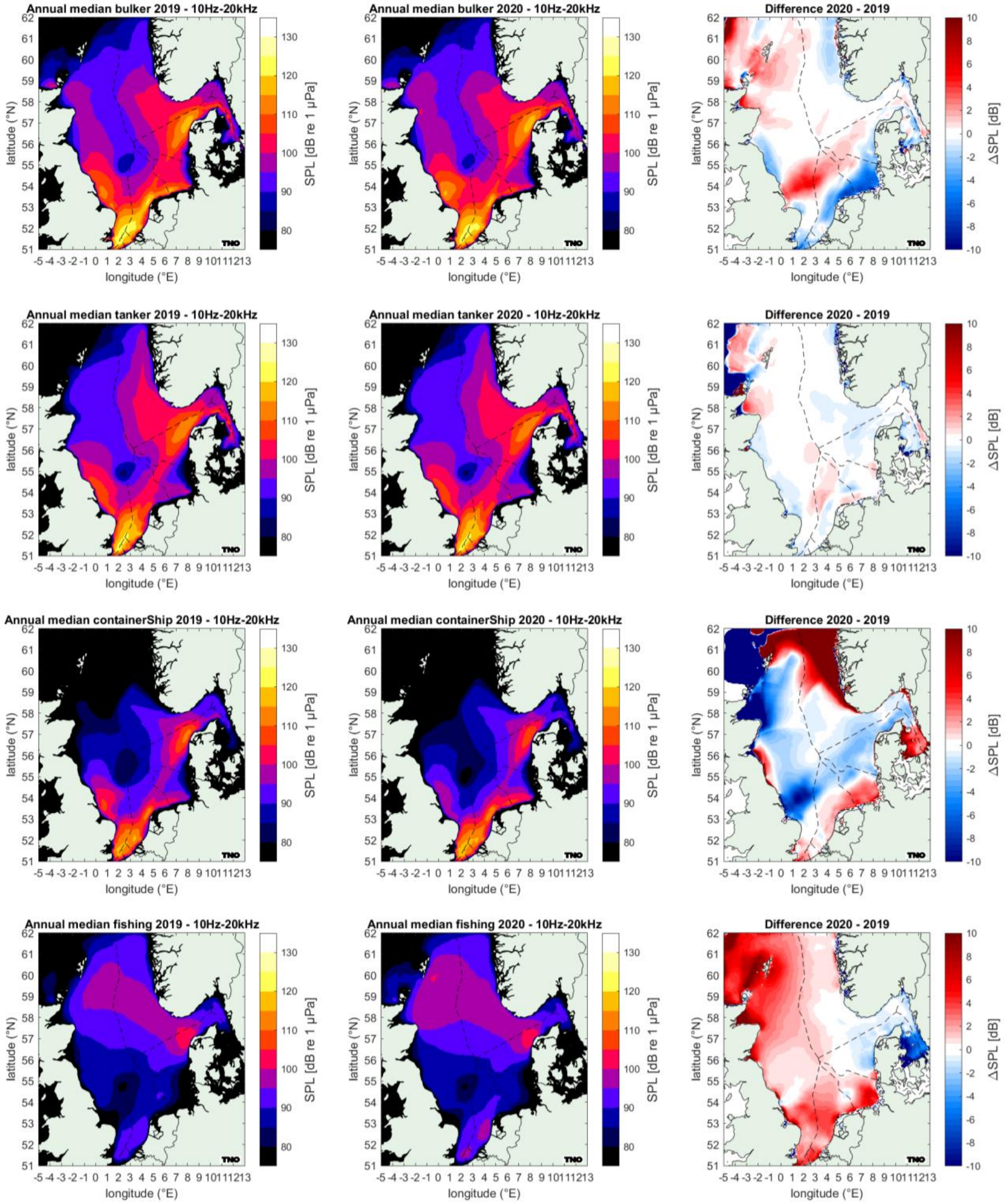


Figure 4.7 Map of the annual median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband noise generated by four different ship types (bulkers, tankers, container ships and fishing[4] boats), see the header of the subplots) in the North Sea region in 2019 and 2020.

The difference between the two years is probably smaller than the difference between the AIS

[4] Note that not all fishing boats are represented in AIS and that VMS data were supplied by Norway, Sweden, Denmark and Germany for 2019 only.

providers. The difference in ship type classification (see section 3.2) explains the increased density of bulkers in front of the English coast and the reduced density of container ships in the same area.

4.4 Excess Level

Figure 4.8 (broadband) and Figure 4.9 (three decade bands) show maps of the annual median excess level of noise generated by shipping and wind over wind noise. This illustrates that low-frequency shipping noise dominates over wind noise over most of the North Sea area during 50% of the time. At higher frequencies (the 2 kHz to 16 kHz decade), positive excess is limited to the areas around the main shipping lanes in the Southern North Sea, Skagerrak and Kattegat.

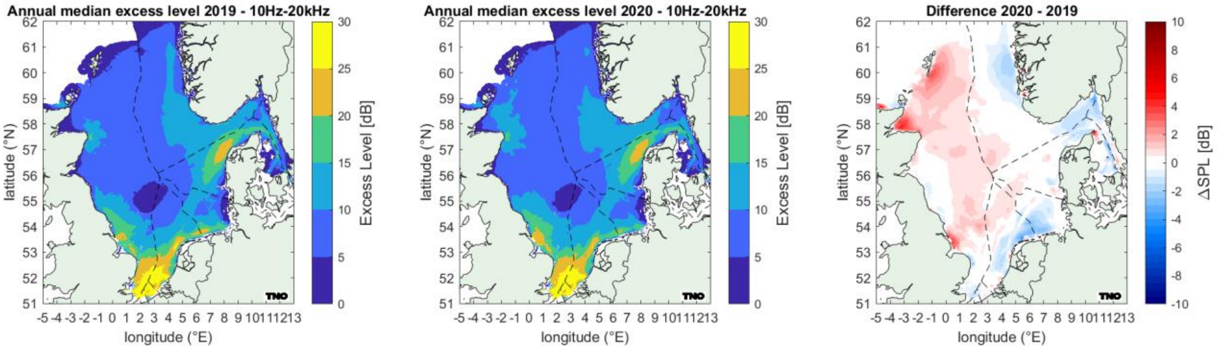


Figure 4.8 Map of the annual median (50th percentile) broadband excess level (in dB) in the North Sea region in 2019 (left panel) and 2020 (middle panel) and the difference between the two years (right panel).

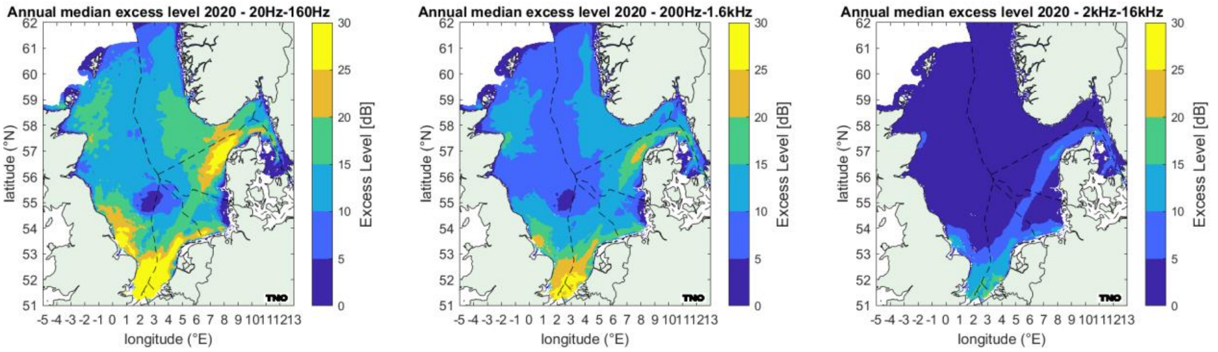


Figure 4.9 Maps of the annual median (50th percentile) excess level (in dB) in the North Sea region in 2020 in the three decade bands.

4.5 Dominance

Figure 4.10 shows maps of the annual dominance, quantifying the percentage of the time over which the broadband excess level of noise generated by shipping and wind over wind noise is above a cut-off value of 20 dB. Under the simplifying assumption of spherical spreading loss of the communication signals and insignificant absorption, a 20 dB excess translates into a decrease in maximum communication distance by 90% (see WP7 report). The 20 dB cut-off value is mainly exceeded in the areas around the main shipping lanes in the Southern North Sea, Skagerrak and Kattegat.

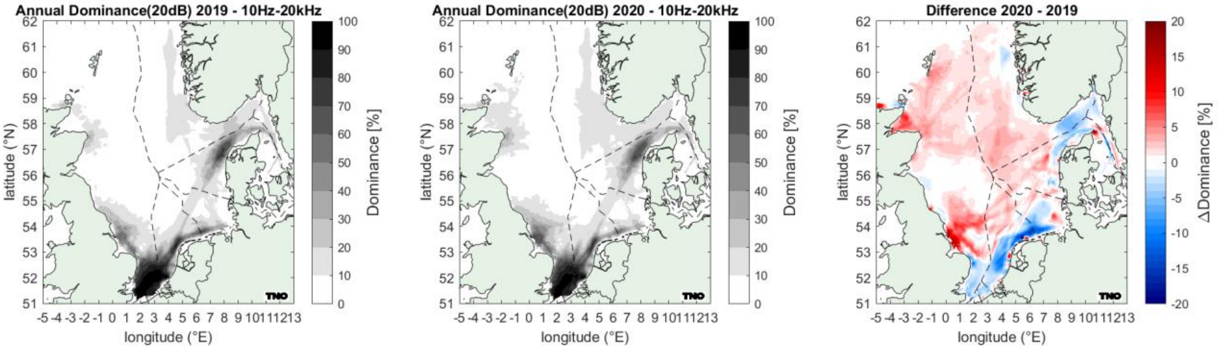


Figure 4.10 Map of the annual broadband dominance for an excess level cut-off of 20 dB, in the North Sea region in 2019 (left panel) and 2020 (middle panel) and the difference between the two years (right panel).

Figure 4.11 shows that the dominance of shipping noise occurs mainly at lower frequencies. It is very limited in the highest decade band (the 2 kHz to 16 kHz decade).

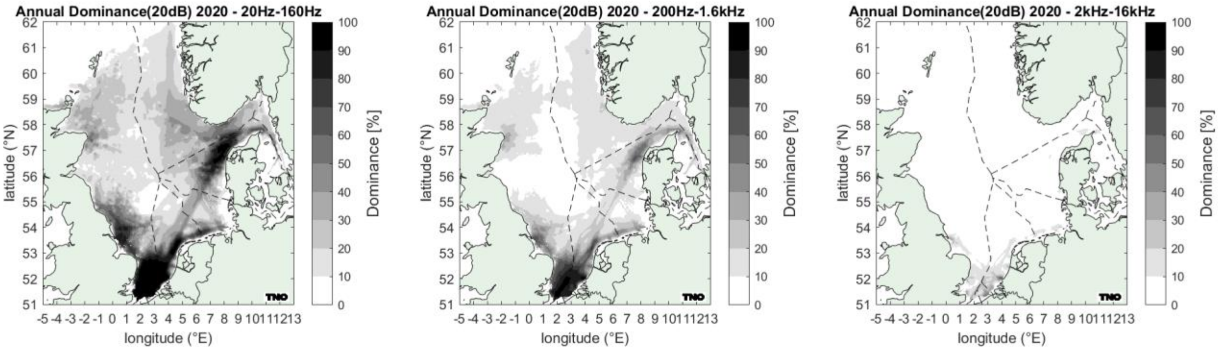


Figure 4.11 Maps of the annual dominance for an excess level cut-off of 20 dB, in the North Sea region in 2020, in the three decade bands.

Figure 4.12 shows maps of the monthly dominance, quantifying the percentage of the time over which the broadband excess level of noise generated by shipping and wind over wind noise is above a cut-off value 20 dB. The dominance percentages are higher in the summer months, mainly because of the lower wind noise levels in that period (Figure 4.2), while the ship noise levels vary little over the months (Figure 4.6).

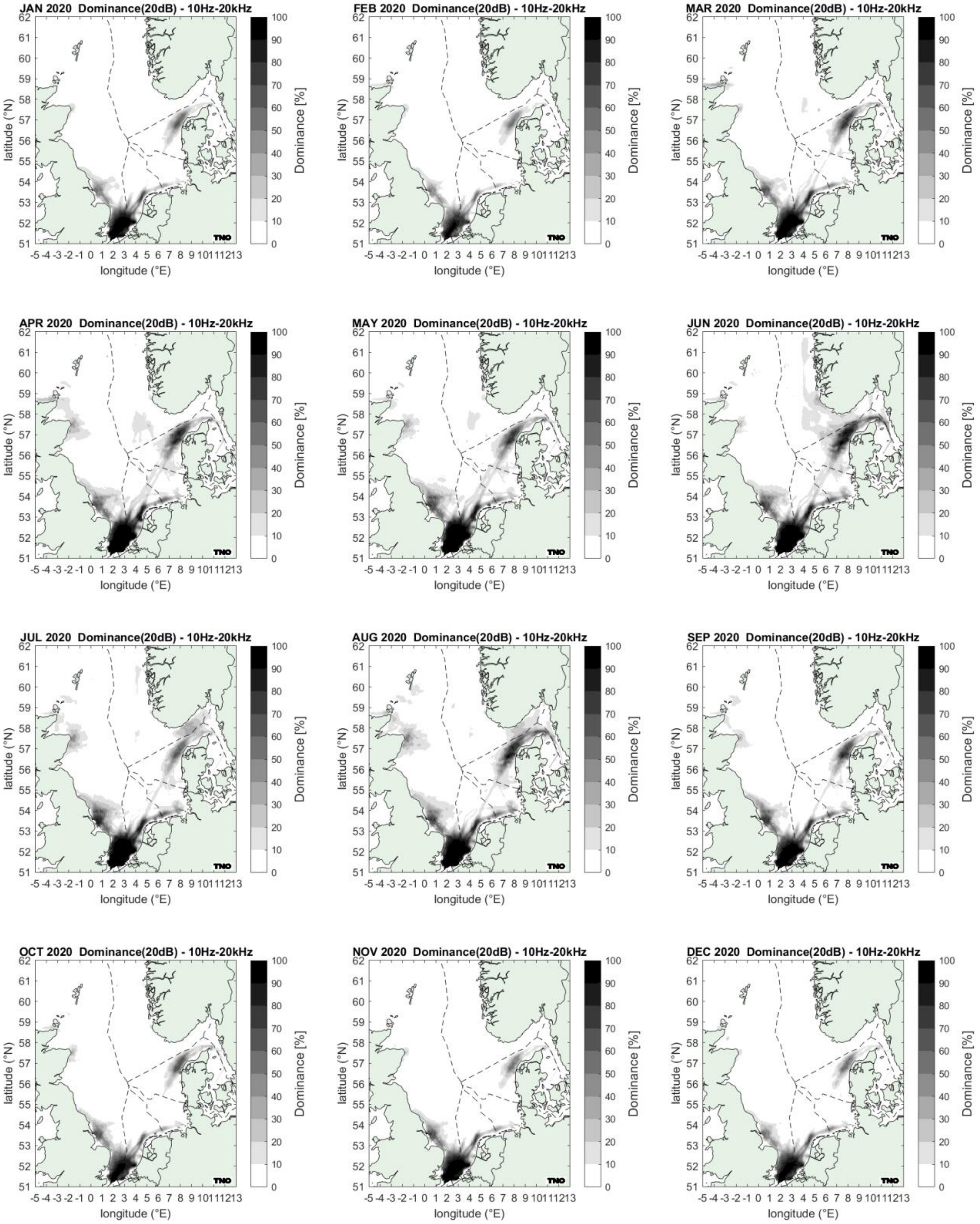


Figure 4.12 Map of the monthly broadband dominance for an excess level cut-off of 20 dB, in the North Sea region for the 12 months of 2020.

4.6 Pressure curve and pressure index

The dominance maps (section 4.5) can be evaluated in terms of the cumulative distribution of the percentage of the evaluation area as a function of the dominance values. The resulting ***'pressure curve'*** (also referred to as ***'pressure function'***) illustrates the percentages of the time and of the area over which the excess level of noise generated by shipping and wind over wind noise is above a specified cut-off value. Figure 4.13 shows the pressure curves for a cut-off value of 6 dB (blue area) and 20 dB (red area), for the six frequency bands.

The (shaded) area under the pressure curve quantifies the percentage of the evaluation area as well as the percentage of the evaluation time interval, in the evaluation frequency band, where the excess level exceeds the specified cut-off value. Jomopans has defined ***'pressure index'*** as the ratio (here expressed as a percentage) of this area to the total area (100%×100%) of the pressure curve graph. The legends to the graphs in Figure 4.13 give the corresponding values of the pressure index.

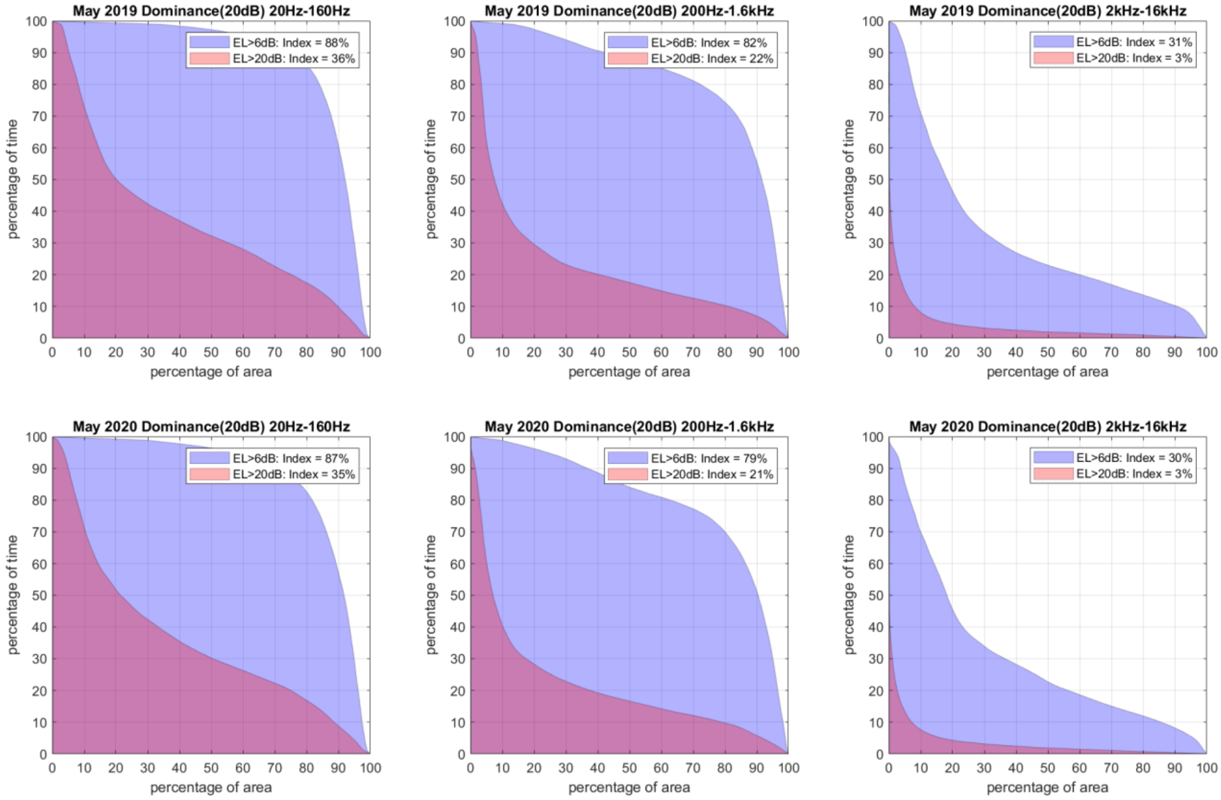


Figure 4.13 Pressure curves, illustrating the percentages of the time and of the area over which the excess level of noise generated by shipping and wind over wind noise is above a cut-off value of 6 dB (blue area) and 20 dB (red area), for the three decade frequency bands. The assessment area for these pressure curves is the full North Sea area and the assessment period is the month of May 2019 (upper panels) and May 2020 (lower panels).

4.7 Dominance over an SPL threshold

In addition to the shipping noise metrics proposed in the Jomopans modelling guidelines (de Jong et al, 2022), we have added maps of the percentage of evaluation time over which the SPL from shipping and wind exceeds a specified SPL threshold value. Figure 4.14 shows these maps for the broadband noise from shipping and wind, with threshold values 100, 110 and 120 dB re 1 µPa respectively. Comparison with Figure 4.10 shows that the maps for dominance over a broadband SPL of 120 dB re 1 µPa is very similar to the map of dominance over instantaneous wind noise plus 20 dB. This roughly corresponds with the observation that the annual median wind noise SPL is about 100 dB re 1 µPa.

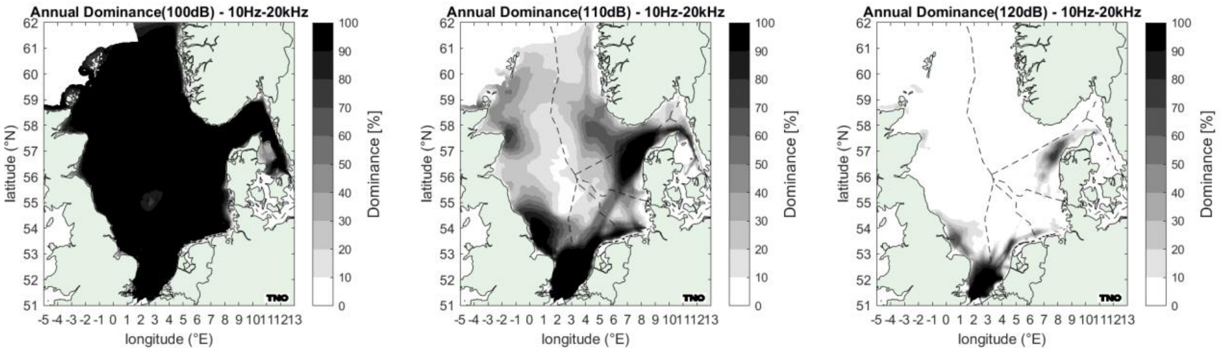


Figure 4.14 Map of the annual (2020) broadband dominance in the North Sea region over SPL threshold values of 100 dB re 1 µPa (left panel), 110 dB re 1 µPa (middle panel) and 120 dB re 1 µPa (right panel).

5 Uncertainty and trend analysis

The calculation of sound maps for a second year provides a first opportunity to analyse variations over a longer period (trends). In addition, the change in provider and the additional data delivered by the second provider made it possible to analyse the uncertainties in the sound map calculations associated with these differences. The AIS input (different providers, presence/absence of VMS data, application of area and vessel track filters, see Chapter 3) and ship classification are the only aspects that are different in the calculation of the sound maps for 2019 and 2020. The same matrix of calculated propagation loss between source and receiver grids has been used for both years.

5.1 Comparison between May 2019 AIS data from providers P1 and P2

Providers P1 and P2 provided AIS recordings for the same month May 2019 allowing a comparison between the interpolated and filtered densities calculated from both sets, illustrated in Figure 5.1 and Figure 5.2.

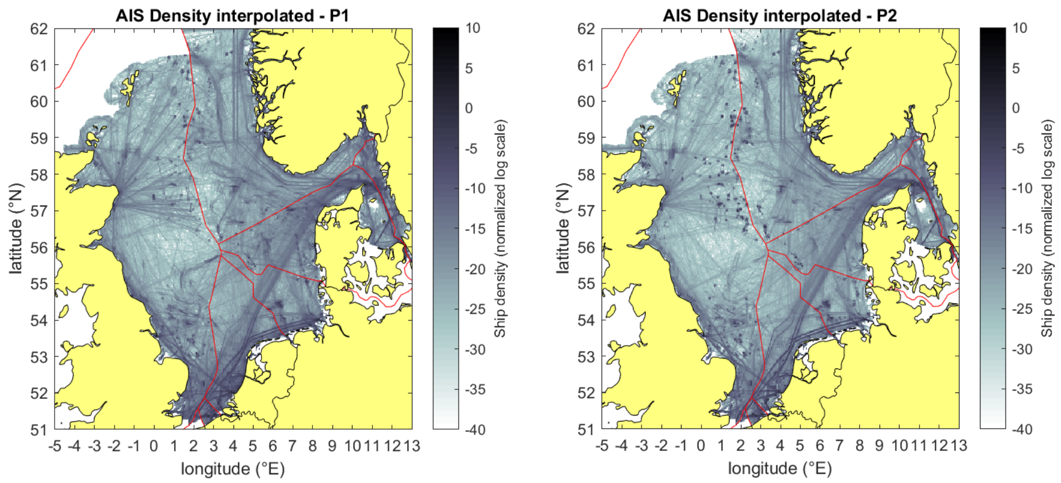


Figure 5.1 Density plots of interpolated vessel tracks for May 2019 retrieved from (left) Provider P1 and (right) Provider P2

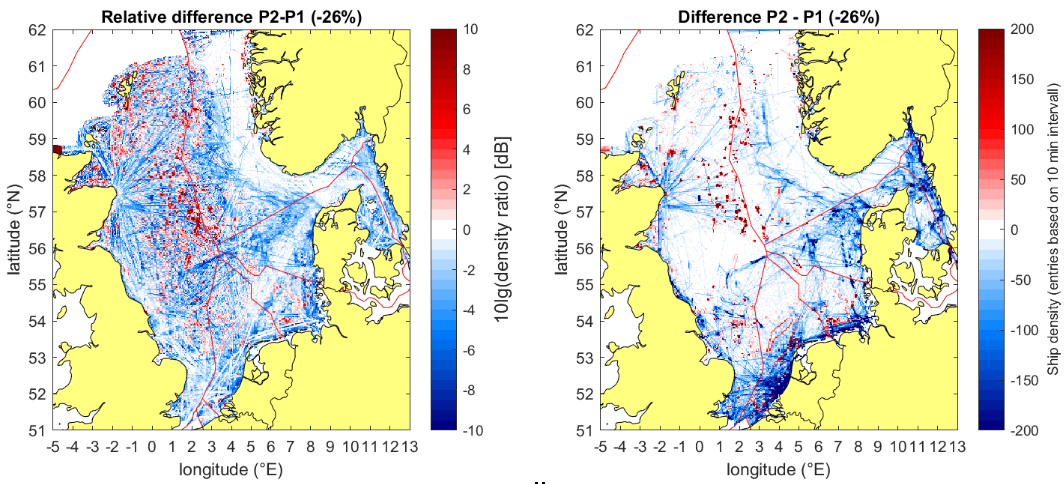


Figure 5.2 Difference in vessel density between Provider P1 and Provider P2 interpolated AIS datasets for May 2019. (left) Difference based on subtraction of log scale and (right) difference based on absolute number of entries per 10 min time interval and grid cell. Blue indicates more ship entries in Provider P1 dataset and red indicates more ship entries in Provider P2 dataset. The percentage of -26% means more total interpolated ship entries in the Provider P1 data.

Figure 5.3 gives an overview of the total numbers of AIS entries per vessel class in the interpolated and filtered data sets from providers P1 and P2 for the month of May in 2019 and 2020. The P1 dataset for May 2019 includes 26% more entries than the P2 dataset for the same month. The P1 dataset includes more entries from fishing vessels, thanks to the addition of VMS (Vessel Monitoring System) data. The P2 dataset is based on the new ship classification, including the associated removal of AIS entries described in section 3.2, which particularly reduces the number of entries from recreational vessels (sailing boats removed). The difference between the data from P2 for 2019 and 2020 is discussed in section 5.3.

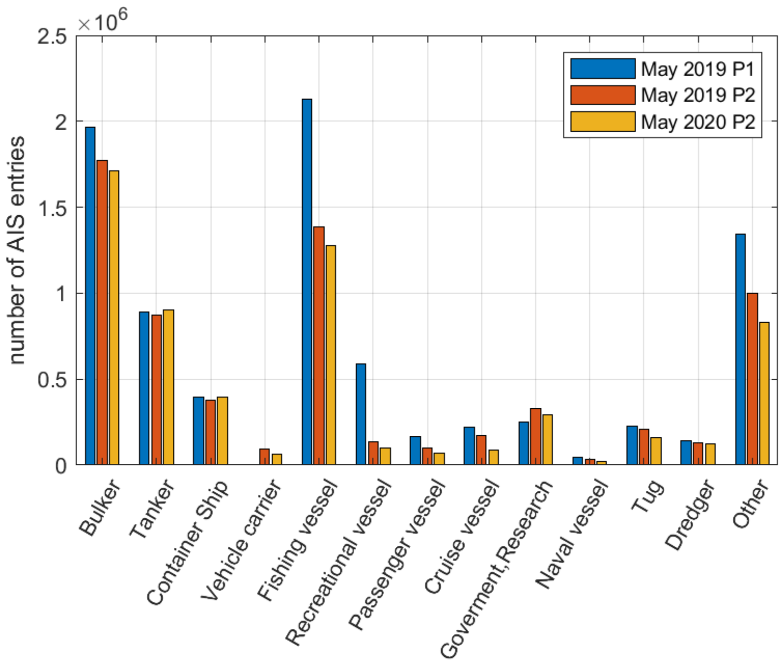


Figure 5.3 Comparison of the number of AIS entries (at 10 minute intervals) per vessel class in the AIS data sets from providers P1 and P2 for the month of May in 2019 and 2020.

Figure 5.4 shows the calculated median sound maps from shipping and wind for May 2019, based on the interpolated AIS data from the two providers.

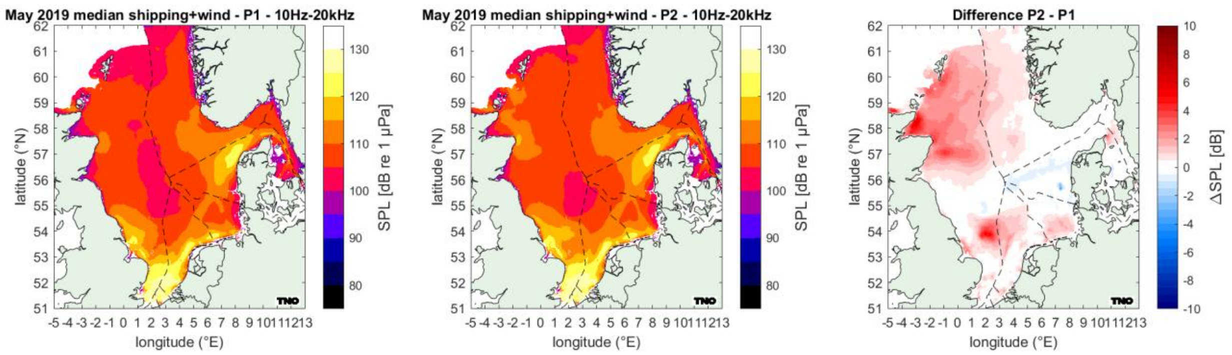


Figure 5.4 Map of the monthly median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband noise generated by shipping and wind in the North Sea region in May 2019, based on the interpolated AIS data from provider P1 (left panel) and provider P2 (middle panel) and the dB-difference between the two maps (right panel).

Local differences are observed of up to 5 dB, particularly in UK waters, where the median SPL for 2020 is higher than that for 2019. Although shipping noise dominates the broadband SPL, there is no clear direct correspondence of the difference in SPL with the difference in shipping density (Figure 5.2), because the acoustic source level of the various ships depends strongly on ship type, size and speed.

Table 5.1 shows that the calculated North Sea underwater noise pressure indices for the same month (May 2019) based on the two sound maps differ up to 3 %. Hence, analysis of trends in the pressure index is limited by an uncertainty of a few percent.

Table 5.1 Pressure index, calculated for the various dominance metrics, for May 2019, for the full North Sea area and for the three decade frequency bands, based on the AIS data from the two providers.

	Decade 1 20 Hz – 160 Hz bands	Decade 2 200 Hz – 1.6 kHz bands	Decade 3 2 kHz – 16 kHz bands
P1	38 %	24 %	4 %
P2	36 %	22 %	3 %

5.2 Effect of the new ship classification on the May 2019 sound map

Soundscape maps based on the AIS data from provider P2 were calculated using the 'old' and 'new' ship classification schemes described in §3.2. Figure 5.5 show maps of the monthly median SPL from these two calculations. Differences are small, with a maximum local difference of 2 dB.

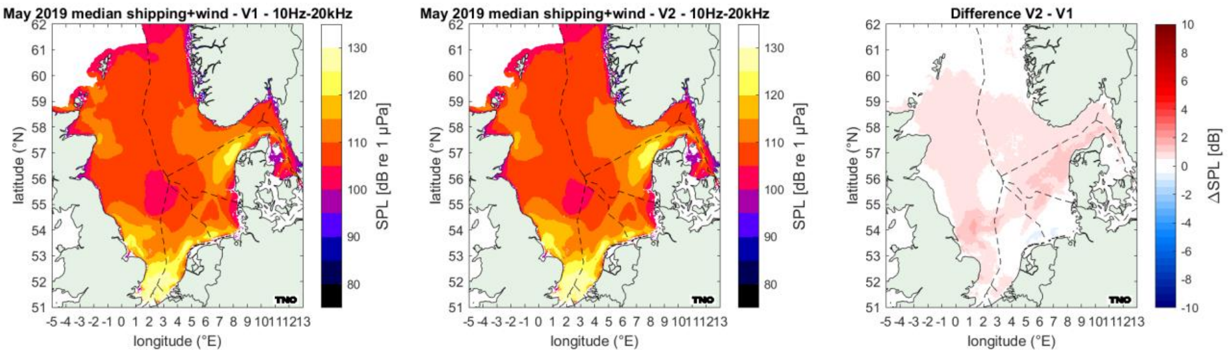


Figure 5.5 Map of the monthly median (50th percentile) of depth-averaged SPL in dB re 1 µPa² of broadband noise generated by shipping and wind in the North Sea region in May 2019, based on the interpolated AIS data from provider P2 and the old (V1; left panel) and new (V2;middle panel) ship classification schemes (Table 3.2) and the dB-difference between the two maps (right panel).

5.3 Comparison between May 2019 and May 2020

Provider P2 provided datasets for the same month (May) of 2019 (pre-COVID) and 2020 (during COVID). The same processing and interpolation steps are applied to both datasets allowing an assessment of the possible effect of COVID on the vessel activity in the area. A total decrease of 12% in the vessel entries is observed from 2019 to 2020 (see Figure 5.7).

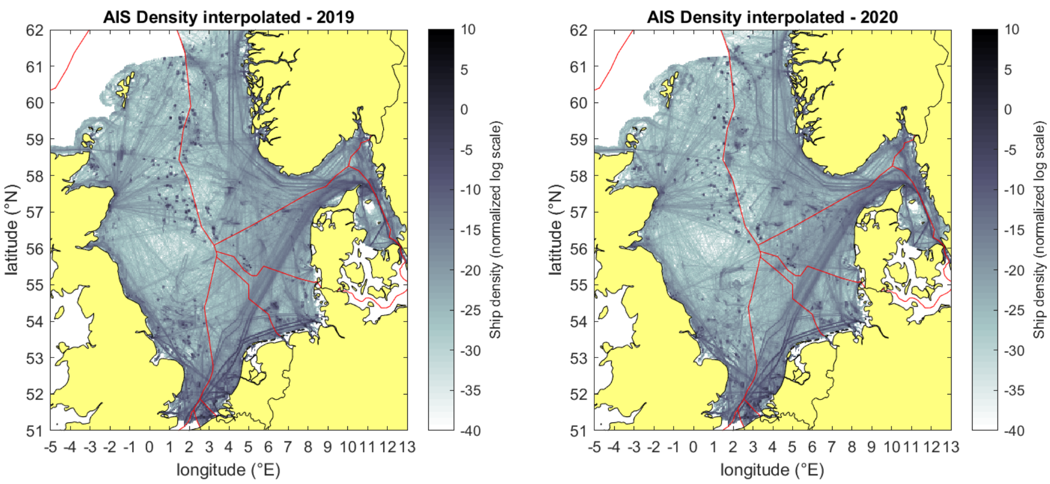


Figure 5.6 Density plots of interpolated vessel tracks (Provider P2) for (left) May 2019 and (right) May 2020.

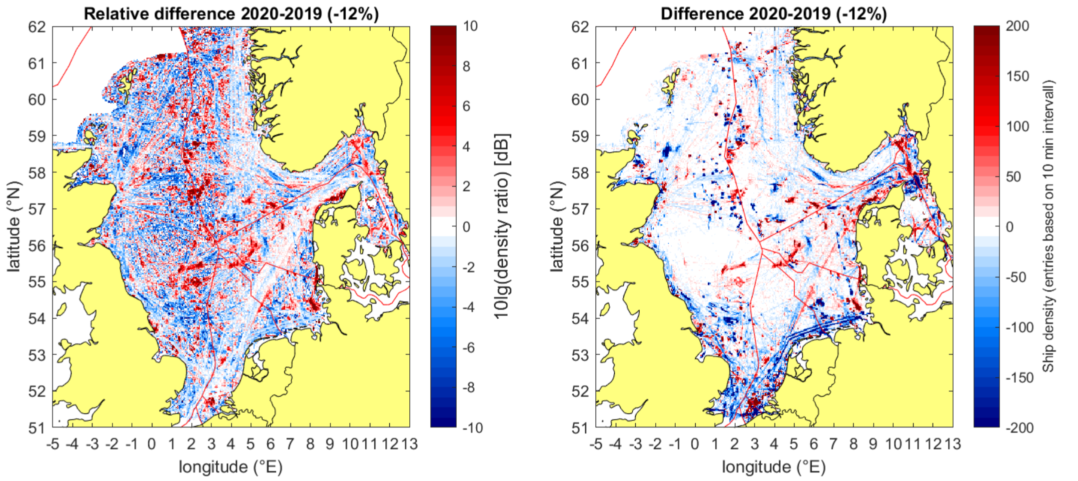


Figure 5.7 Difference in vessel density (Provider P2) between May 2020 and May 2019 based on interpolated AIS data. (left) Difference based on subtraction of log scale and (right) difference based on absolute number of entries per time 10 min time interval and grid cell. Blue indicates more ship entries in May 2019 and red indicates more ship entries in May 2020. The percentage of -12% means a decrease of total number of ship entries from May 2019 to May 2020.

The corresponding sound maps are shown in Figure 5.8 and May 2020. Note: in the hypothetical case that all ship entries would produce the same contribution to the underwater sound energy, a 12% reduction of the number of entries would result in a reduction of the SPL by $10\log_{10}(0.88)\ \mathrm{dB} \approx -0.6\ \mathrm{dB}$. The maps show that the reduction is not uniformly distributed, and that the reduction is somewhat larger (up to 3 dB) at some locations. Note that these differences are of the same order as the differences in the comparison between the AIS providers (section 5.1), so that the observed difference between May 2019 and May 2020 (during Covid) is not considered significant. Though locally the modelling result suggest a reduction of a few dB, the uncertainty of the AIS data observed from the comparison of the P1 and P2 providers limits drawing conclusions on a North Sea Scale; in particular when different AIS providers (and processing methods) are used as input.

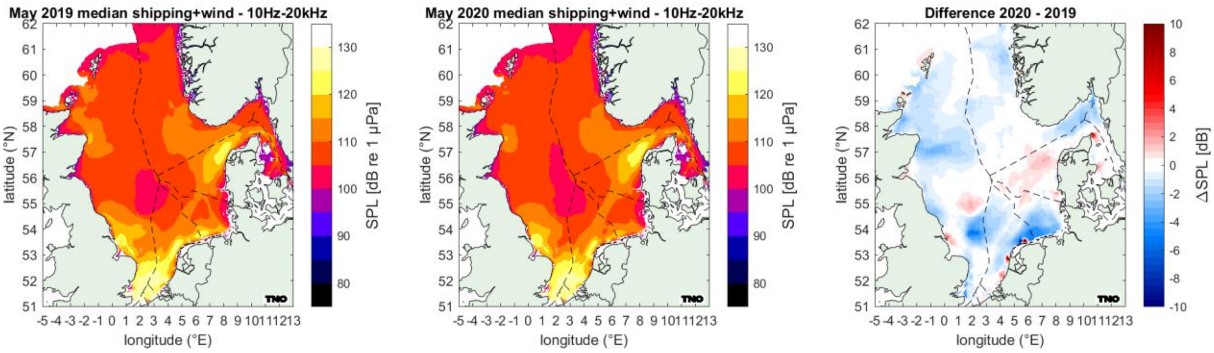


Figure 5.8 Map of the monthly median (50th percentile) of depth-averaged SPL in dB re 1 μPa^2 of broadband noise generated by shipping and wind in the North Sea region in May 2019 and May 2020, based on the interpolated AIS data from provider P2 and the dB-difference between the two years (right panel).

Table 5.2 shows that the difference between the calculated North Sea underwater noise pressure indices for May 2019 and May 2020 are insignificant, in comparison with Table 5.1.

Table 5.2 Pressure index, calculated for the various dominance metrics, for May 2019 and May 2020, for the full North Sea area and for the three decade frequency bands, based on the AIS data from provider P2.

	Decade 1 20 Hz – 160 Hz bands	Decade 2 200 Hz – 1.6 kHz bands	Decade 3 2 kHz – 16 kHz bands
May 2019	36 %	22 %	3 %
May 2020	35 %	21 %	3 %

5.4 Spatial and temporal median SPL from shipping and wind

Figure 5.9 shows the monthly spatial and temporal median of the SPL from shipping and wind in the North Sea, as calculated for 2019 and 2020. The median SPL shows moderate variations over the months, with a slight increase of the shipping noise combined with a clear decrease of the wind noise in the summer months.

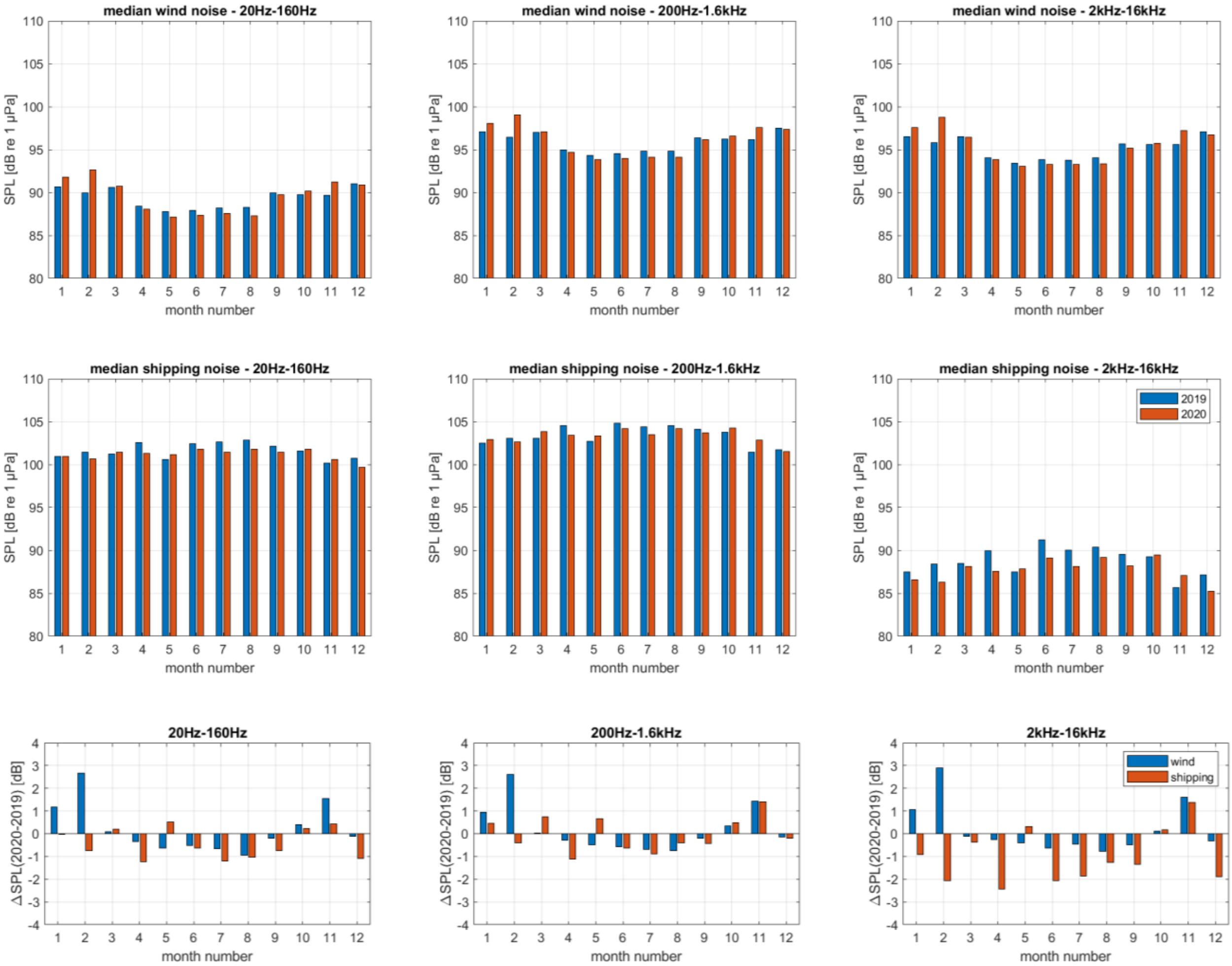


Figure 5.9 Monthly spatial and temporal median SPL of wind (upper panels) and shipping (middle panels), over the 12 months of the year (blue: 2019, red: 2020), for the full North Sea area and for the three decade frequency bands. The lower panels show the dB-difference between the years.

The pressure index is based on dominance, which quantifies the percentage of time over which the shipping noise exceeds wind noise. Because this is a relative metric, the index can increase if shipping noise increases as well as if wind noise decreases. Figure 5.10 illustrates how the calculated pressure index for the full North Sea area varied over the twelve months of 2019 and 2020.

The pressure index appears to be somewhat higher during the summer months than during winter. Analysis of the SPL percentile maps of wind noise (section 4.2.1) and shipping + wind noise (section 4.2.2) led to the conclusion that this variation of the pressure index is mainly due to the variation of the wind over the months. The shipping noise is relatively constant over the months, while the wind noise is lower in the summer months when the wind speeds are generally lower. For example, the observed lower pressure index in February 2020 compared to February 2019 appears to be caused by a higher wind noise in 2020 rather than by a decrease in shipping noise (see Figure 5.9). These comparisons include the effect of the two different AIS-providers for the two years and of the different vessel class identification scheme, see the analysis in section 5.1. Note also that the pressure index cannot be very well explained from differences in the monthly median SPL of ships and wind (Figure 5.9), because it is based on the statistics of the instantaneous excess of shipping noise over wind noise.

The comparison of the pressure indices for the full Jomopans North Sea area over the months of 2019 and 2020 does not show a significant difference between the two years. This suggest that the effect of the COVID-19 pandemic on the traffic density of some ship classes (Figure 4.7) has not significantly affected the overall pressure of shipping sound on the North Sea scale. That may be different at a local scale, as indicated by various studies around the world, such as [Dahl et al, 2021] and [Basan et al, 2012], that have shown (subtle) local reductions of the ambient noise associated with reduced shipping during the pandemic.

The available North Sea maps enable future local studies (at a resolution of 0.05 degrees longitude by 0.025 degrees latitude, i.e. about 3 km × 3 km).

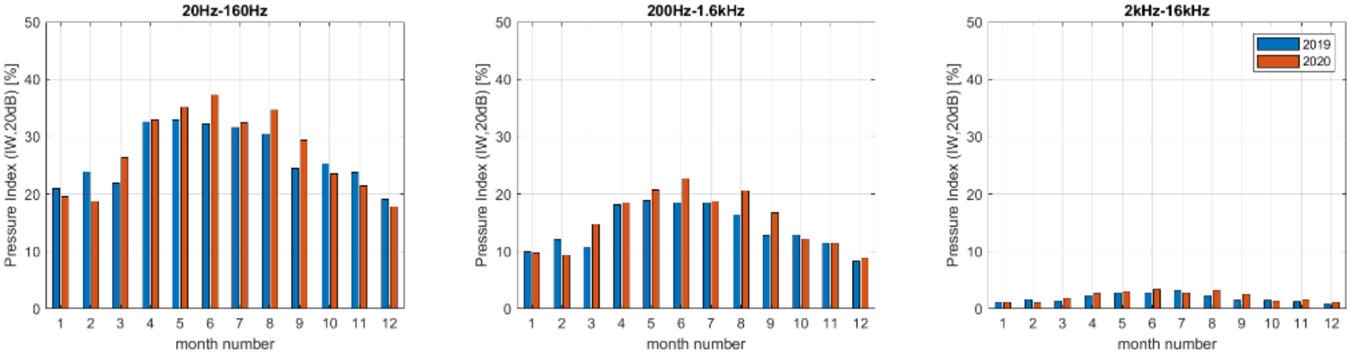


Figure 5.10 Pressure index variations over the 12 months of 2019 (upper) and 2020 (lower), for the full North Sea area and for the three decade frequency bands. The bars represent the pressure index based on an excess of 20 dB or more over instantaneous wind noise.

6 Summary and conclusion

In 2021, Jomopans produced statistical sound maps for the sound of shipping and wind in the North Sea in the twelve months of the year 2019, see [de Jong et al 2021]. One of the sources of uncertainty in these sound maps, see [Putland et al, 2021] and [Putland et al, 2022], is the quality and completeness of the model input data that describes the ship traffic.

The Jomopans project was extended with one year (July 2021 – June 2022). This allowed for further investigation of the effects of the quality of the AIS (Automatic Identification System) data on the produced sound maps, as well as the production of modelled sound maps for a second year (2020). It was shown that uncertainties associated with AIS provision can lead to local differences in the broadband SPL map of the order of 5 dB, but at the North Sea scale the acoustic pressure index is affected by not more than a few percent.

In 2020 the Covid-19 pandemic affected ship traffic on the North Sea, but the change in the monthly (merchant) ship density appears to be small and variations in shipping noise smaller than the uncertainty in the sound maps.

The Jomopans monitoring approach, based on large scale sound map modelling validated with local measurements, provides a relatively stable assessment of the pressure of shipping sound on the environment at the North Sea scale. Maps of monthly median sound pressure level and excess level of shipping noise over wind noise do not show significant variation over the months of 2019 and 2020. Local differences in the monthly median SPL of the order of a few dB are considered insignificant in view of the uncertainty of the input for the sound map modelling.

For local assessments at a smaller spatial or temporal scale, the uncertainty in the maps increases. Application of the monitoring approach at smaller scale would require high quality local input data (particularly of ship traffic and of local sediment properties) and local measurements to assess the contribution of other sources than shipping and wind to the soundscape.

7 References

Ainslie, M. A. (2010) *Principles of sonar performance modeling*. Berlin: Springer-Praxis.

Basan, F., Fischer, J.-G. and Kühnel, D. (2021) Soundscapes in the German Baltic Sea Before and During the Covid-19 Pandemic. Front. Mar. Sci. 8:689860

Binnerts, B, de Jong, CAF, Karasalo, I, Östberg, M, Folegot, T, Clorenneq, D, Ainslie, MA, Warner, G, Wang, L (2019) Model benchmarking results for ship noise in shallow water. Proceedings of the 5th Underwater Acoustics Conference and Exhibition UACE2019, Hersonissos, Crete, Greece

Binnerts, B, de Jong, CAF, von Benda-Beckmann, S, de Krom, P. Östberg, M, Folegot, D, Ainslie, MA, Welch, S (2021) Model predictions 2018 measurement sites. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS).

Dahl, P.H., Dall'Osto, D.R. and Harrington, M.J. (2021) Trends in low-frequency underwater noise off the Oregon coast and impacts of COVID-19 pandemic. J. Acoust. Soc. Am. 149(6), 4073–4077

de Jong, C., Ainslie, M., Dreschler, J., Jansen, E., Heemskerk, E. and Groen, W. (2010) Underwater noise of Trailing Suction Hopper Dredgers at Maasvlakte 2: Analysis of source levels and background noise. Report TNO-DV 2010 C335.

de Jong, C.A.F., Binnerts, B., Östberg, M., Folegot, T. and Ainslie, M.A. (2018) *Jomopans model and data inventory*. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS).

de Jong, C.A.F., Binnerts, B., Östberg, M., Karasalo, I., Folegot, T., Clorennec, D., Ainslie, M.A., MacGillivray, A., Warner and G., Wang, L. (2020) *Jomopans model benchmarking and sensitivity studies.* Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS)

de Jong, CAF, Binnerts, B, Robinson, S, Wang, L (2021) *Guidelines for modelling ocean ambient noise*. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans)

Dekeling, R.P.A., Tasker, M.L., Van der Graaf, A.J., Ainslie, M.A, Andersson, M.H., André, M., Borsani, J.F., Brensing, K., Castellote, M., Cronin, D., Dalen, J., Folegot, T., Leaper, R., Pajala, J., Redman, P., Robinson, S.P., Sigray, P., Sutton, G., Thomsen, F., Werner, S., Wittekind, D., Young, J.V. (2014) Monitoring Guidance for Underwater Noise in European Seas, Part II: Monitoring Guidance Specifications, JRC Scientific and Policy Report EUR 26555 EN, Publications Office of the European Union, Luxembourg

MacGillivray, A.O. and de Jong, C.A.F. (2021) A Reference Spectrum Model for Estimating Source Levels of Marine Shipping based on Automated Identification System data. J. Mar. Sci. Eng. 2021, 9, 369. https://doi.org/ 10.3390/jmse9040369

Putland, R, Farcas, A. Merchant, N. de Jong, CAF, Binnerts, B. (2021) Validation report: 2019 data. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (JOMOPANS).

Putland, R.L., de Jong, C.A.F., Binnerts B., Farcas, A., and Merchant, N.D. (2022) Multi-site validation of shipping noise maps using field measurements. Marine Pollution Bulletin 179, 113733

Annex A Guidelines for soundscape modelling

Monitoring the ambient sound in the sea via numerical modelling has many advantages over direct measurements. Modelling is much cheaper than measurements at sea, it offers a wider spatial and temporal coverage and it provides direct insight in the contributions of different sound sources. However, there are many uncertainties and being able to model ambient sound with confidence requires careful consideration of the various modelling choices as well as model validation by measurements.
Figure A-1 illustrates the steps to be taken for the soundscape modelling process. The list below provides guidelines for sound map modelling based on the lessons learned in the Jomopans project, see [de Jong, CAF, Binnerts, B, Robinson, S, Wang, L (2021) *Guidelines for modelling ocean ambient noise*. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea].

Project area and acoustic metric definition

- Select the project area, assessment period, the required spatial resolution of the maps and the frequency range and resolution
- Define source and receiver grids

Environmental data portals

- Obtain input data for the acoustic modelling of the environment:
    - Bathymetry
        - EMODnet provides bathymetry data for European waters
    - Seabed properties (Folk class or median grain size)
        - A map of median grain sizes of North Sea surface sediments is available from the World Data Center for Climate portal [Bockelmann, 2017].
        - Convert to (frequency-dependent) density, compressional wave speed, and absorption
    - Sea water properties (density, sound speed and absorption)
        - Standard uniform sea water properties provide an appropriate first-order approximation for many shallow water environments
        - In deeper water and in shallow water with significant stratification of temperature and/or salinity, it may be necessary to incorporate sound speed gradient effects.
    - Wind speed (speed at 10 m above the water surface
        - The Copernicus website[5] provides ERA5 hourly wind speed data
        - Interpolate to a regular time grid and to the receiver grid.
        - Note that the 10-minute averaging time of the wind data leads to uncertainty in the calculated statistics of SPL-metrics with a shorter averaging time. Higher resolution wind data would be required but is not available.

AIS data

- Obtain ship traffic information (location, speed, ship type and length) from AIS/VMS data
        - Check the quality of the input data, and, where possible, supplement missing data by means of track interpolation ([de Jong et al, 2021]
        - Interpolate to a regular time grid and (optionally) to a regular two-dimensional source grid
        - Ideally, the source data should extend well outside the received grid, to avoid underestimation of the shipping noise at the outer edges of the receiver grid.

Propagation loss model configuration and verification

- Select an appropriate propagation loss model
        - For low-frequency (< 2 kHz) shipping noise in a shallow-water environment, such as the main North Sea area, models based on normal modes, parabolic equation or wavenumber integration are appropriate.
- Select appropriate model configuration settings
- Verify the model implementation and model configuration settings (for shallow-water propagation models) by running the proposed benchmark scenarios.

[5] https://cds.climate.copernicus.eu/cdsapp#!/dataset/reanalysis-era5-single-levels?tab=form

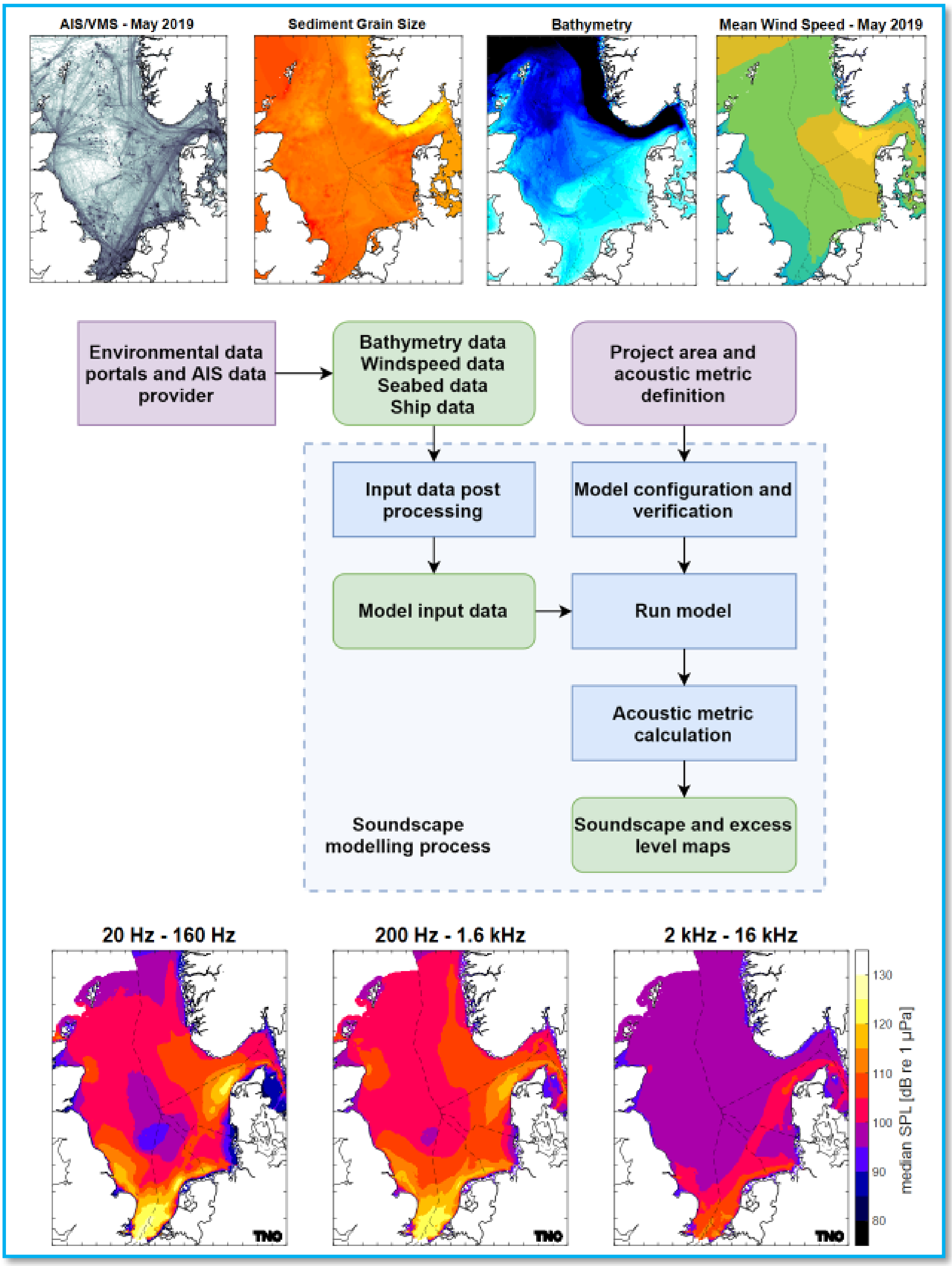


Figure A-1 Schematic illustration of the soundscape modelling process, with example maps of input data (upper graphs) and resulting soundscape maps (bottom graphs).

Run model

- Calculate the propagation loss between source grid and receiver grid locations averaged over the local water depth, at the selected frequencies.
    - If temporal variations of the environment can be ignored, these calculations can be made computationally efficient by precomputing the propagation loss between the source grid receiver grid locations and storing the calculated propagation loss in a look-up table.
    - The calculations can also be made computationally more efficient by calculating propagation loss along radials from the source location and then interpolating the results

to the receiver grid locations.

- For each ship at each time step, estimate the source level spectrum, at the selected frequencies, using the Jomopans -ECHO source level model.
- For each time step, calculate the depth-averaged sound pressure level spectrum at each receiver grid location, by summing the contributions from all source grid cells (source level minus propagation loss).
- For each time step, calculate the depth-averaged sound pressure level spectrum due to the wind at each receiver grid location, using a wind source and propagation model.

Acoustic metric calculation

- For each receiver grid location, calculate monthly percentiles of the sound pressure level spectra from ships and wind.
- For each receiver grid location, calculate monthly percentiles of the excess level spectra (the difference between the sound pressure level from the total of ships and wind and from wind noise alone) and dominance (the percentage of evaluation time over which the excess level exceeds a specified cut-off value).

Reporting

- All steps in the soundscape modelling process need to be detailed when reporting soundscape maps, where possible motivated:
    - Project description (selected area and acoustic metrics),
    - Selected spatial, temporal and frequency range and resolution,
    - Selected input data (sources and environment), with spatial and temporal resolution,
    - Any processing applied to the input data (e.g. interpolation or extrapolation)
    - Selected models (source level and propagation loss)
    - Applied model configurations (parameter settings)
    - Applied postprocessing (e.g. interpolation, statistics, etc.)

Discussion and conclusion

- The Jomopans sound maps provide an unprecedented insight in the relevance of shipping for the North Sea sound scape.
- If models and input data are available, a similar approach can be applied for other sources of ambient underwater noise than shipping and wind, such as operational wind turbines, seismic surveys, oil- and gas platforms, etc.
- The quality of the produced sound maps depends to a large extent on the quality of the available input data. None of the sources of input data used in this study has been developed for the purpose of underwater ambient noise mapping. Hence, AIS/VMS coverage is generally incomplete and the conversion of available seabed properties to acoustic model parameters is uncertain.
- There are still many remaining issues to be solved to be able to quantify and possibly reduce uncertainties in the modelled soundscape maps. The main issues are incompleteness (missing sources) and uncertainty in the input data and uncertainties associated with the model
- Recommendations for further research are summarized in [de Jong et al, 2021]
- The Jomopans soundscape modelling capability provides the possibility to carry out scenario studies: A desk study of the effects of slow steaming for reducing emissions as well as underwater radiated noise from marine traffic on the North Sea, commissioned by the Belgian Marine Environment Service, was presented at the seminar[6] “Solutions for underwater noise from shipping”.

[6] https://www.health.belgium.be/en/news/solutions-underwater-noise-shipping