Joint Monitoring Programme for Ambient Noise North Sea

2018 – 2020

Validation report: 2019 data

WP 6

Deliverable/Task: 6.3

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Contents

1. Introduction

Maps of shipping noise levels are needed to guide policy and decision making on the management of underwater noise pollution. Such maps are envisaged as part of the monitoring and assessment of continuous underwater noise levels and their threat to marine ecosystems under the EU Marine Strategy Framework Directive [1] and the UK Marine Strategy. While large-scale noise maps have been produced for several areas, including in Canadian [2,3] and Dutch [4,5] waters, validation of such maps using field measurements has been limited. Such validation is needed to give decision-makers confidence that marine policy can be guided by reliable predictions [6], and in order to quantify the amount of uncertainty in those predictions.

Thus far, several studies have presented validations of shipping noise maps based on measurements from a single hydrophone location [7–9]. However, in several cases the models were themselves parameterised using the same measurements [10,11], rendering the applicability of such models and the validation results uncertain. In one study, the Erbe et al. [2] predictions of noise levels in the Northeast Pacific were compared to field measurements at multiple sites, however the absolute agreement of the measurements with model was not given: the comparison was based on whether the model correctly predicted the sequence of noisiest to quietest sites [12]. Such comparisons are insufficient to establish the absolute uncertainty in model predictions, which instead require a quantitative assessment of model agreement.

We are aware of only one study which has quantitatively validated shipping noise maps at multiple sites [13]. In this study, while the model agreement was found to be good (93 % of model predictions in the range 125 Hz to 5 kHz were within ± 3 dB), only a relatively small area of the domain was validated, the model relied on an empirical correction based on the measurements, and only one type of acoustic recording instrument was used in the field measurements. The JOMOPANS project presents new challenges since the geographic coverage of the measurements is larger, there are multiple recorder types for the field and the modelling is based solely on theoretical parameters [14], rather than semi-empirical corrections.

1.1 Aims and approach

The aim of this work package was to provide an independent validation of the finalised noise maps produced for 2019 by the modelling work package (WP4), using the field data gathered within the measurement work package (WP5).

Three rounds of uncertainty evaluation were undertaken:

1) The first iteration predictions produced by WP4 for 2018 were performed without access to measurement data and with a 'minimum detail' modelling configuration optimised for efficiency [15]. Subsequent comparison of the model predictions to field measurements (at 8 JOMOPANS sites) allowed for the identification of frequencies at which the discrepancy was greatest, and possible sources of this error.
2) Validation was repeated using second iteration predictions at the same 8 JOMOPANS sites for 2018. The second model iteration considered the outputs of the first validation and was refined to include frequency-dependent sediment properties in the propagation model and surface loss in the wind noise model. Additionally, WP4 updated the ship source level model based on further analysis of the ECHO data set [14].
3) Validation was subsequently conducted on 2019 model predictions (second iteration model) and measurement data for 15 JOMOPANS stations to provide a larger temporal and spatial coverage.

This report considers the third and final round of validation, quantifying the uncertainty in the final JOMOPANS noise maps which are used in the GES tool. Note that a separate uncertainty assessment was previously undertaken for the first and second iteration predictions, and provided in a separate WP6 report[16].

2. JOMOPANS 2019 Measurement Summary

Field measurements offer the most reliable way of monitoring underwater noise levels as they provide a direct measure of ambient noise in situ. However, they also have limitations which preclude their use as the primary means of monitoring underwater noise. Not least of these is the cost of procuring, calibrating, deploying, and maintaining field equipment, but even the most ambitious field measurement campaign can only hope to measure a relatively small number of point locations and often does not have full temporal coverage, which is insufficient to produce the maps of noise levels required for marine management. To produce full spatial and temporal coverage of the study area, modelling is required[14,15]. Modelling also offers the possibility to investigate hypothetical scenarios such as different past, present and future shipping levels (hindcast, 'nowcast', and forecast, respectively) by adjusting input data. Nevertheless, it remains essential to make measurements, so that the accuracy of these models can be ground-truthed against empirical data.

Fifteen JOMOPANS sites had field measurements available from deployments during 2019 (Figure 2.1.1). Three sites further sites were not included. The '13-NO-LOV Love' location, which had previously served as a reference station (very low shipping) in the 2018 validation due to its water depth and low shipping activity (from AIS records), is outside the JOMOPANS project area to the north. The '12-SC-MOR Moray Firth' and '15-SC-CNS Central North Sea' locations were also not included in the validation exercise since no measurement data were available for 2019 when this report was produced.

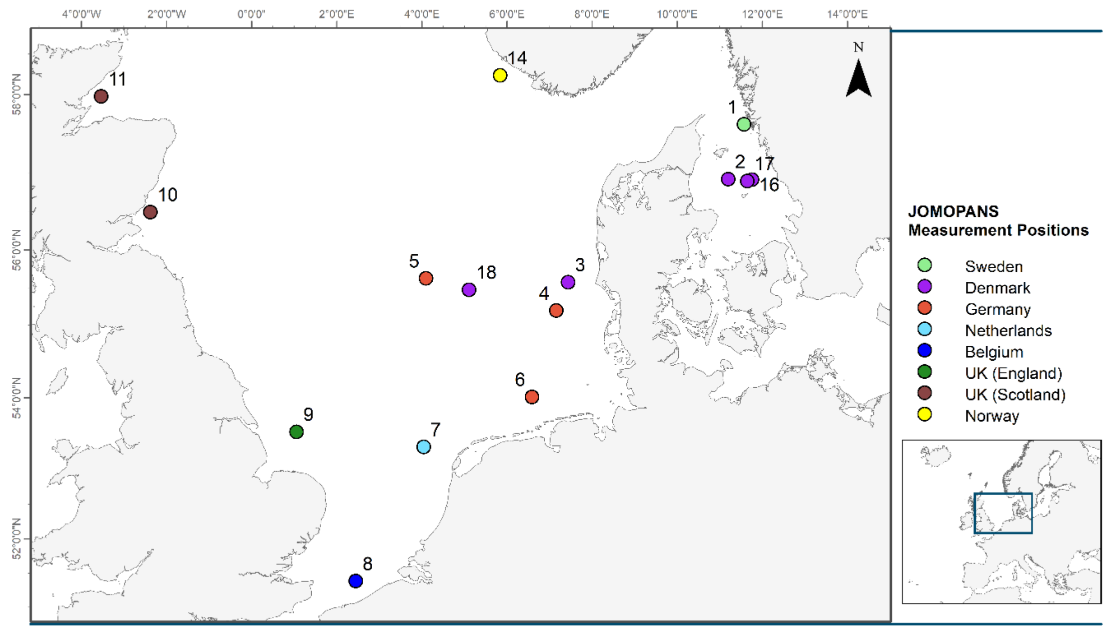


Figure 2.1: Underwater sound monitoring locations of the JOMOPANS project. Monitoring locations are depicted with consecutively numbered circular markers (colours represent the different partners/countries).

Months with fewer than 20 days of measurement data were excluded from the analysis to ensure monthly values were representative (Table 2.1). Monthly percentiles (P01, P05, P10, P25, P50, P75, P90, P95, P99, Pmin and Pmax) for each one-third octave band frequency between 10 and 20,000 Hz were extracted from the measurement dataset. Measurement dB levels were also calculated for decadal bands (D1: 20 – 160 Hz; D2: 200 – 1600 Hz; D3: 2000 – 16000 Hz) and broadband (BB: 20 – 20000 Hz). Median (P50) values were the focus of later analysis to investigate the general trends in ambient sound data.

Table 2.1: Information about the location of JOMOPANS stations used in 2019 validation and number of months of data available with more than 20 days and environmental variables provided by WP4 and WP5.

Station	Name	Latitude	Longitude	Number of months available with > 20 days data	Month											
					J	F	M	A	M	J	J	A	S	O	N	D
01-SE-VIN	Sweden_Vinga	57.62315	11.57185	11	X	X	X		X	X	X	X	X	X	X	X
02-DK-ANH	Denmark_Anholt	56.92667	11.2	5			X	X	X	X						X
03-DK-HRF	Denmark_Horns Reef	55.575	7.43833	5				X	X	X					X	X
04-DE-FN3	Germany_FINO3	55.195	7.15833	4							X	X	X	X		
05-DE-ES1	Germany_ES01	55.62571	4.09852	3										X	X	X
06-DE-FN1	Germany_FINO1	54.01486	6.58764	8			X	X	X	X	X	X			X	X
07-NL-TEX	Netherlands_Texel	53.3157	4.0429	5					X	X	X		X	X		
08-BE-WST	Belgium_Westhinder	51.383	2.44533	4						X	X	X	X			
09-UK-DOW	England_Dowsing	53.5286	1.05309	9	X	X	X	X				X	X	X	X	X
10-SC-ARB	Scotland_Arbroath10	56.4998	-2.3799	1	X											
11-SC-HEL	Scotland_Helmsdale5	57.9759	-3.536	3	X	X	X									
14-NO-NTR	Norway_Norwegian Trench	58.23675	5.83942	10		X	X	X	X	X	X	X	X	X	X	
16-DK-TN1	Denmark_TangoN1	56.91898	11.7582	3										X	X	X
17-DK-TN4	Denmark_TangoN4	56.90165	11.64818	3										X	X	X
18-DK-EDA	Denmark_ENDA	55.47385	5.110474	1											X	

2.1 Overview of measurement noise levels

Yearly median SPL (20- 20000 Hz) indicated the southern North Sea had higher noise levels recorded compared to in the Kattegat and northern North Sea (Figure 2.2). For example, Belgium Westhinder (8) had the highest broadband SPL recorded 125.2 dB re 1µPa whereas, Denmark Anholt (2) had the lowest broadband SPL recorded at 98.5 dB re 1µPa. Decade bands indicated that low frequencies (20 – 160 Hz) had a dominant influence on noise levels, with SPL ranging between 87.5 – 123.2 dB re 1µPa, while higher frequencies (2000 – 16000 Hz) had a smaller range across the stations between 93.1 – 107.7 dB re 1µPa (Figure 2.3). Little temporal variation was observed at any of the 15 stations (Figure 2.4). However, it must be noted that some stations had limited measurement data available for 2019 (Table 2.1.).

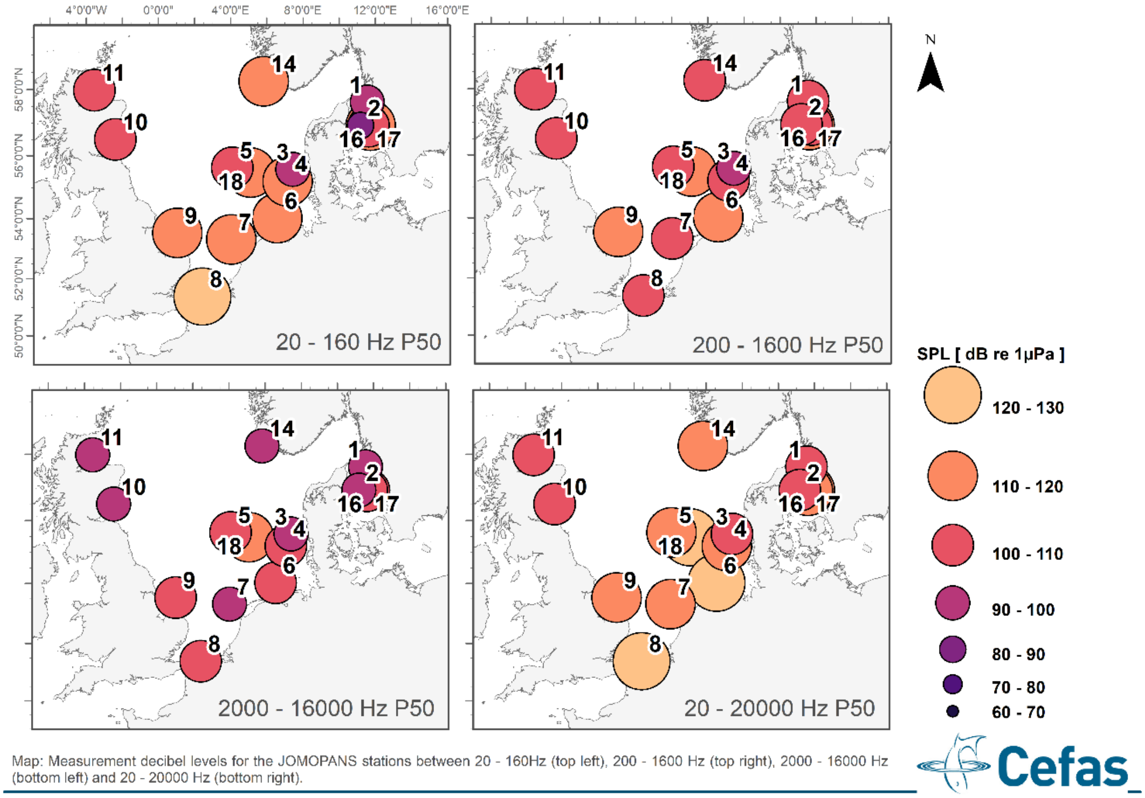


Figure 2.2: Passive acoustic monitoring sound pressure level [SPL (dB re 1µPa)] for the 15 JOMOPANS stations. Each plot shows the yearly P50 (median) value for frequencies between 20 – 160 Hz (top left), 200 – 1600 Hz (top right), 2000 – 16000 Hz (bottom left) and 20 – 20000 Hz (bottom right). Sites are numbered according to the names provided in Table 2.1.

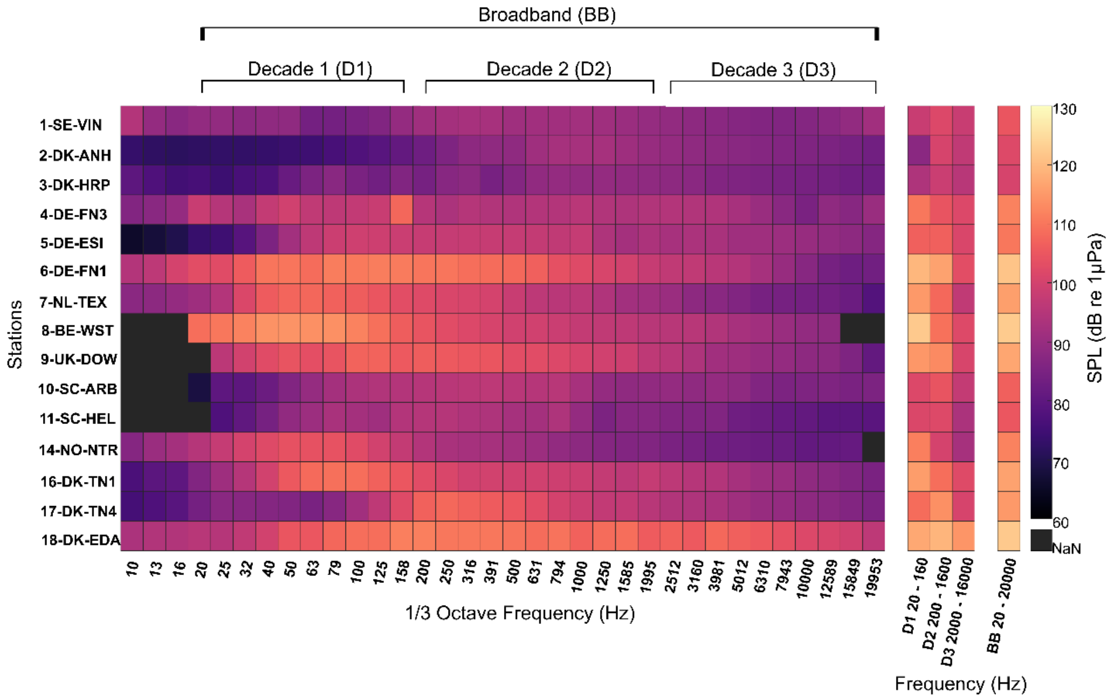


Figure 2.3: P50 (median) measurement noise levels [dB] in 2019 shown for all JOMOPANS stations and various frequencies (1/3 octave frequency bands, 20-160 Hz, 200 – 1600 Hz, 2000 – 160000 Hz and 20-20000 Hz).

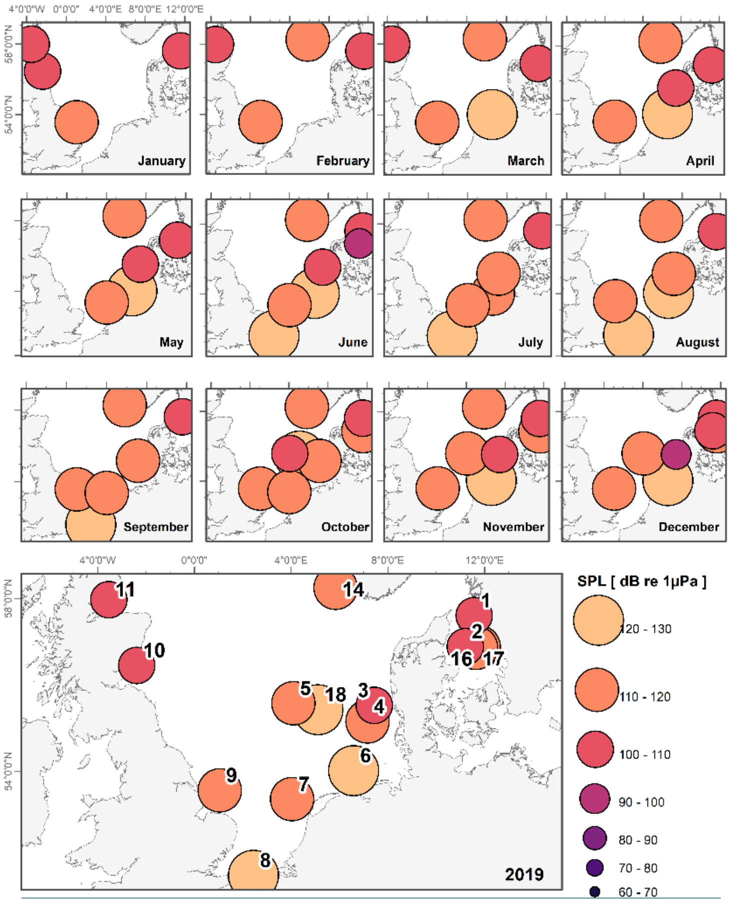


Figure 2.4: Passive acoustic monitoring sound pressure level [SPL (dB re 1µPa)] for the 15 JOMOPANS stations between 20 – 20000 Hz. Top 12 plots show the monthly P50 (median) value for each station and bottom plot shows yearly P50 value for each station. Sites are numbered according to the names provided in Table 2.1.

2.2 Station characteristics and possible sources of uncertainty

While field monitoring is the most reliable way of measuring noise levels, it is not without potential pitfalls. Measurements can be contaminated by turbulence from tidal flow around the hydrophone (flow noise) and recording instruments may have insufficient sensitivity to register the full bandwidth of noise levels in the environment. If the mooring system is poorly designed, then self-noise from the equipment itself can also skew the measurements[17].

The WP4 model was based around predictions for ship traffic (with type, length and speed taken from AIS and VMS records) and wind noise (generated from surface waves). However, other sound sources not included in the modelling parameters were expected to contribute to the noise levels recorded at individual stations (WP5 measurements). Extraneous noise sources (i.e., not including routine shipping traffic and wind) in the 2019 measurements were identified through local information provided by the respective project partner responsible for each location, and seasonal environmental patterns were investigated.

The following information is provided to identify expected sources of uncertainty prior to comparing measurement data to model predictions.

2.2.1 Evidence of seasonal thermoclines

Sound speed, density, and absorption of the water column in the WP4 model was assumed to be constant over the 2019 time period. However, the combined effect of salinity and temperature will determine the stratification and the effect on sound propagation. At 01-SE-VIN there was a strong thermocline in the summer of 2019 (Figure 2.5) which would have led to a corresponding change in the sound speed profile which may have reduced reflection losses at the seabed and reduced scattering at the surface.

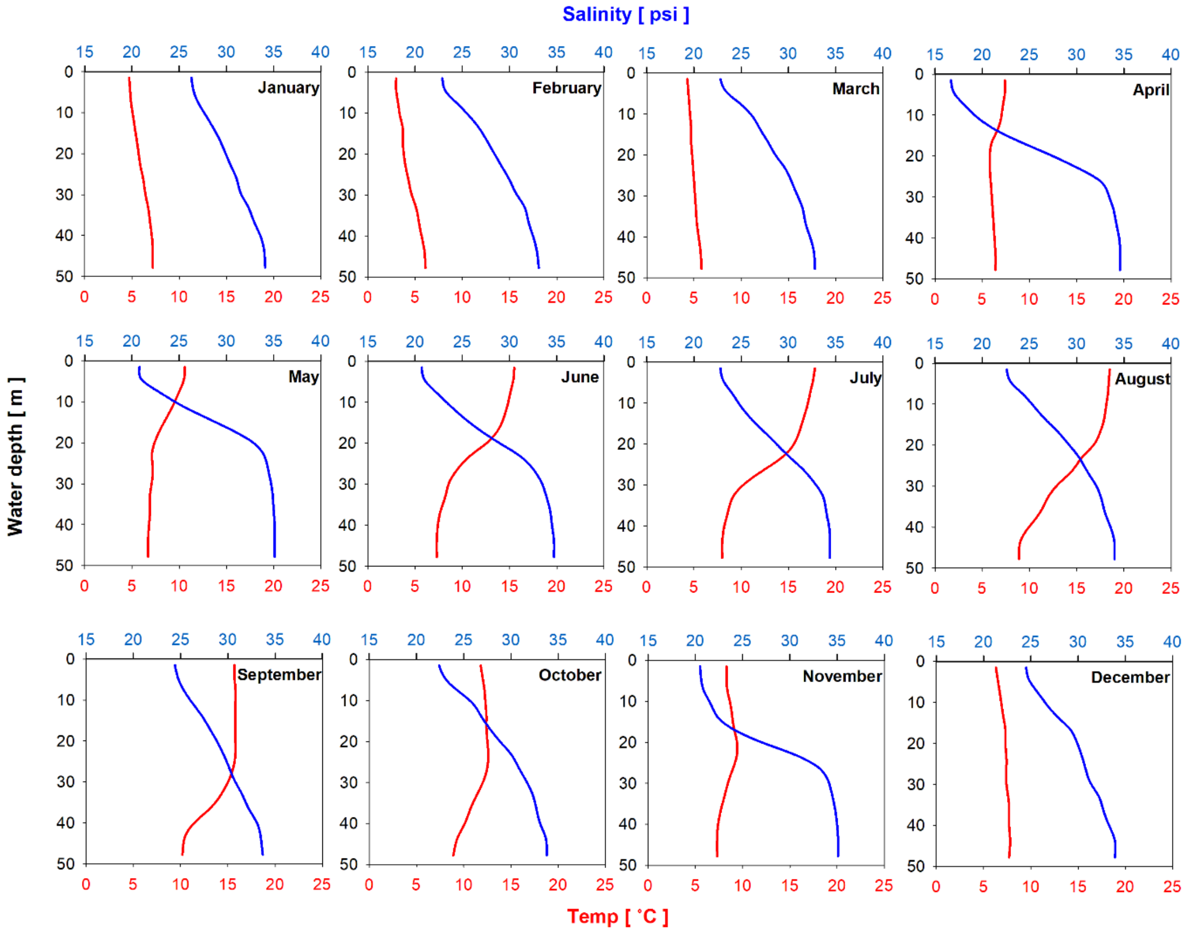


Figure 2.5: 2019 Environmental data collected on salinity and temperature at the 01-SE-VIN JOMOPANS station (data provided by FOI).

2.2.2 Uncertainty in sediment type

For the Kattegat stations (01-SE-VIN, 02-DK-ANH, 16-DK-TN1, 17-DK-TN4) there was a lack of high-quality sediment property data with the local median grain size extrapolated from areas outside the Kattegat. Furthermore, the sediment is comprised of mud atop a limestone layer which is particularly challenging to model accurately.

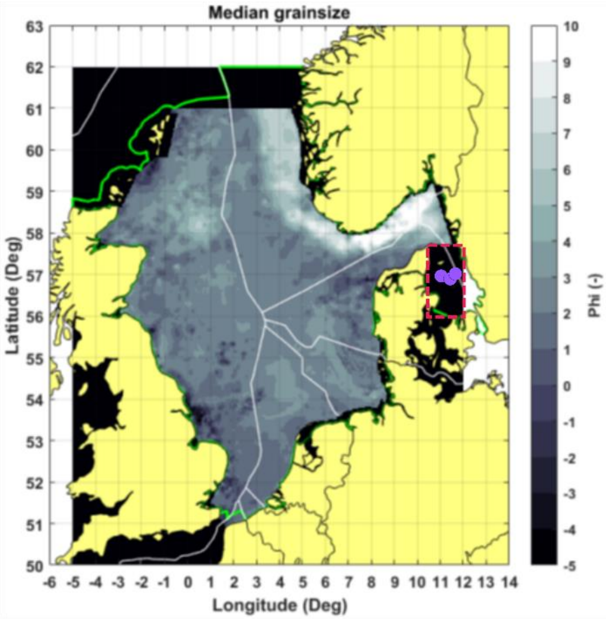


Figure 2.6: Map of median grain size [15] *with JOMOPANS locations from the Kattegat superimposed in purple circles and the red box showing the area where there is sediment uncertainty.*

2.2.3 Water depth

Some JOMOPANS stations were in shallow water (17-DK-TN4 in ~16 m) which makes low frequency propagation more challenging to predict. Additionally, while the model averages sound levels throughout water depth, the recorders were typically mounted on the seafloor, and in some cases the difference may be highly significant. For example, the 14-NO-NTR recorder was positioned close to the seafloor in ~340 m water. This is likely to result in an underestimate of distant shipping noise levels.

2.2.4 Presence of recreational fishing vessels not accounted for in AIS or VMS data

Small inshore fishing vessels may not be included in the AIS/VMS data used to assess ship traffic levels, since AIS transponders are only compulsory for vessels exceeding 300 gross tons. To account for some of this missing information, historical datasets of fishing records can be used to show general spatial patterns of shipping activity. For example, at 10-SC-ARB and 11-SC-HEL lobster creel trawlers are known to operate (Figure 2.7).

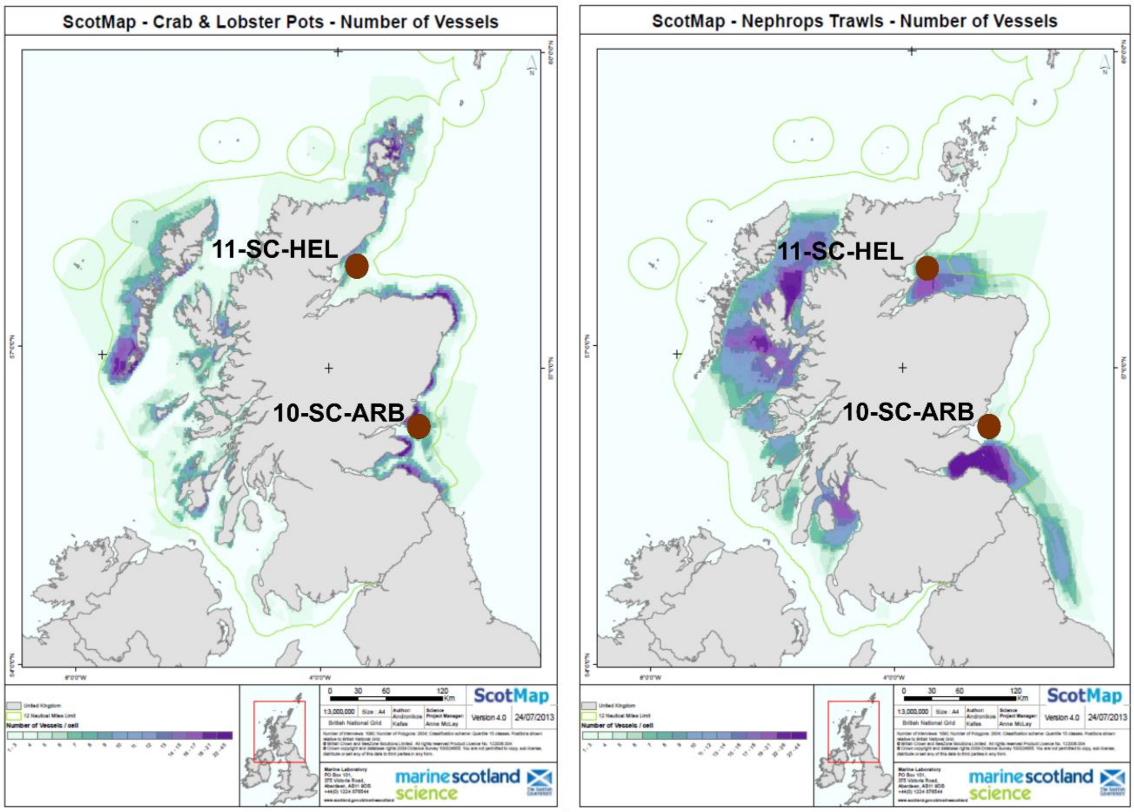


Figure 2.7: Number of vessels (purple indicates more vessels) around the Scottish coastline during a 2013 survey of crab and lobster potting (left) and nephrops trawls (right)[18]. Location of 10-SC-ARB and 11-SC-HEL superimposed onto imagery by the brown circles.

2.2.5 Offshore wind farms

Some of the JOMOPANS stations [03-DK-HRF, 04-DE-FN3 and 06-DE-FN1 (Figure 2.8)] were positioned close to offshore wind farms with widely dispersed turbines. Service vessels for the wind farm are likely to be a primary source of noise at these sites, they moor against wind turbine foundations by steaming against the base, such that they are stationary while generating considerable noise. Since the noise model assumes that stationary vessels are silent, these noise sources may be left out of the model. Together with the operational noise from the turbines, this could lead to the model underestimating sound levels at these stations.

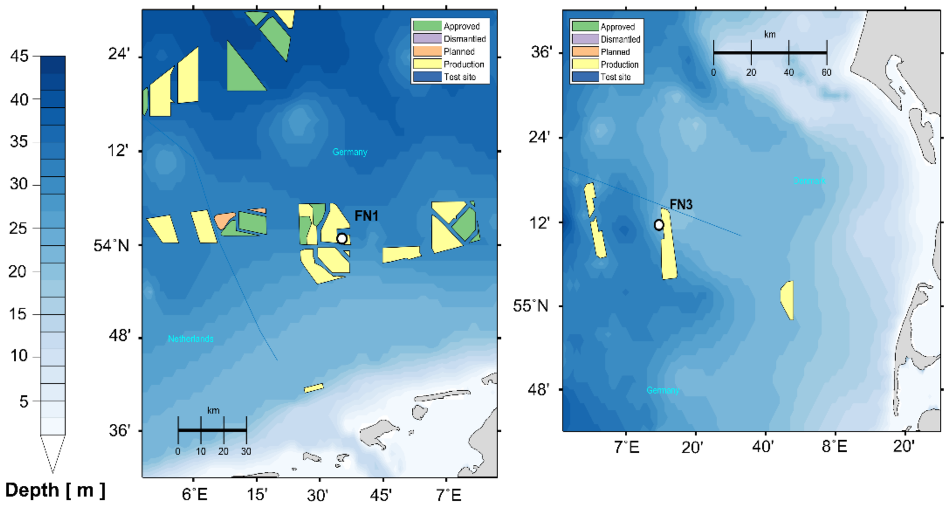


Figure 2.8: Map showing proximity of offshore wind farms [dismantled (purple); planned (orange); in production (yellow) and test sites (dark blue)] in relation to JOMOPANS stations 04-DE-FN3 and 06-DE-FN1.

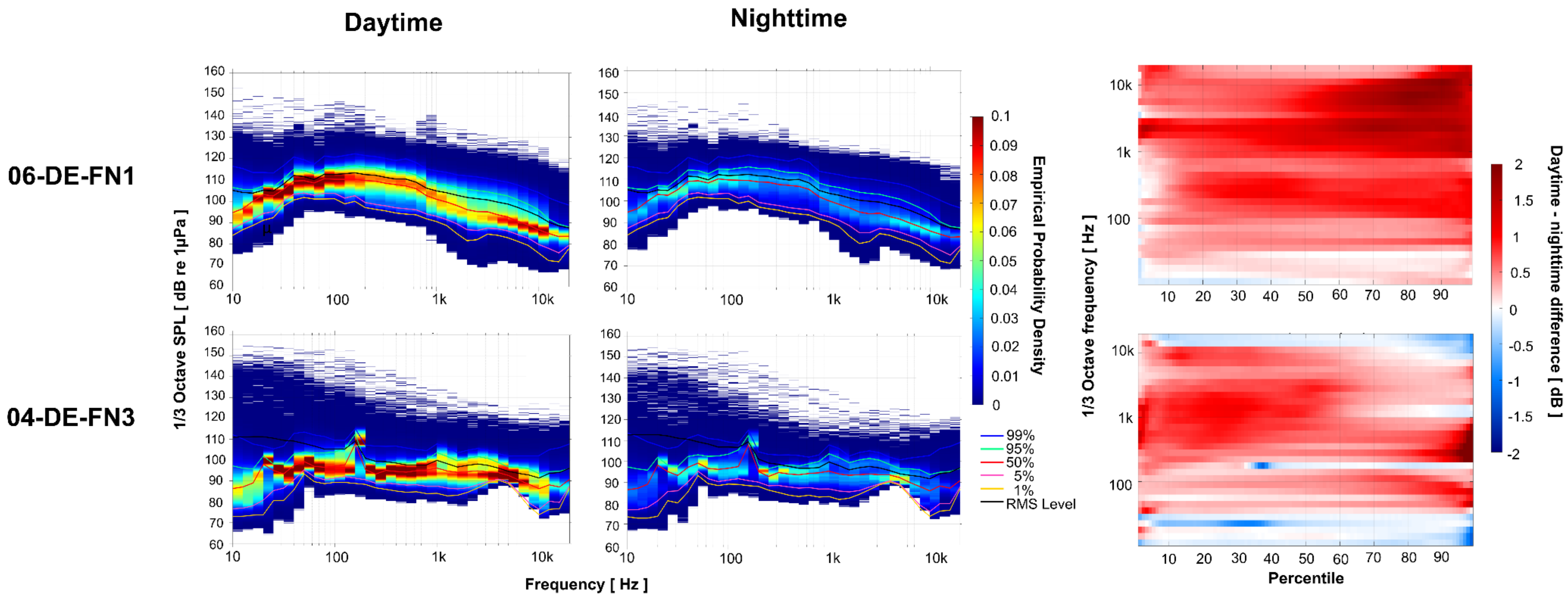


Figure 2.9: 1/3 Octave sound pressure levels for 06-DE-FN1 over the whole time period (left), night-time only (middle) and (right) a comparison of daytime-night-time [positive values (red) indicate daytime SPLs larger].

Third octave SPLs were compared between night-time (20:00 – 06:00 local time) and daytime (06:00 – 20:00 local time) recordings at 04-DE-FN3 and 06-DE-FN1. Daytime recordings were up to 2 dB louder (Figure 2.9) suggesting that service vessels may be a contributing factor to sound recordings at this location although further detailed analysis is warranted.

2.2.6 Machinery/ generator sound

04-DE-FN3 was positioned nearby an offshore platform with a generator attached. In the measurement data there was a ~200 Hz tone present (Figure 2.10) and there was evidence of continuous noise throughout the lower frequencies (< 250 Hz) which could have been from the platform and/or generator.

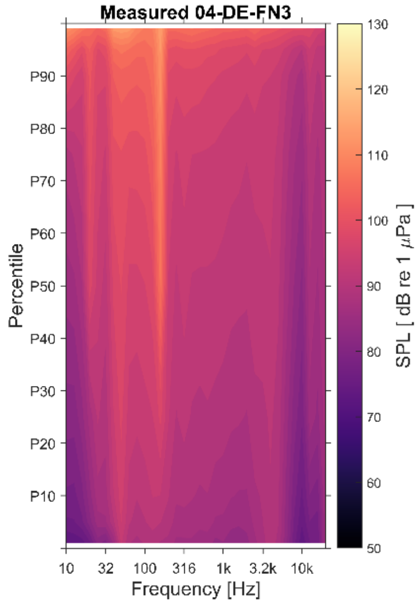


Figure 2.10 Percentile heatmap for SPL recorded at 04-DE-FN3 over the 2019 recording period.

2.2.7 Seismic surveys

Station 18-DK-EDA was positioned close to an oil rig and between 31st September 2019 and 9th October 2019 a seismic survey occurred in the North Sea Marine Biogeographic region (*per comms.* Aarhus University) therefore there is the possibility for airgun noise of high magnitude to have been recorded. Sound levels recorded at this station were therefore expected to be higher than model predictions during this time. Additionally, partners noted that seismic shots at a number of JOMOPANS stations, for example at 05-DE-ES1 on 17th September 2019 until mid-October (*per.comms* BSH).

2.2.8 Sound sources identified by JOMOPANS partners

During the 2018 validation exercise, the signatures of ship passages were visible in the low frequencies (between 50 – 1000 Hz) and noise levels were significantly correlated to wind speed at higher frequencies (> 1 kHz)[16]. The WP4 model is based around predictions for ship traffic and wind noise. However, other sound sources may contribute to measurements, and result in an underestimation by the model, including those identified by JOMOPANS partners for their respective stations in Table 2.2.

Table 2.2: Summarised overview of sound sources at the different JOMOPANS stations [19]*. Shipping lane: located near a shipping route; no AIS ships: recreational and fishing vessels with no AIS or VMS are present; CTVs: maintenance vessels (Crew Transfer Vessels) for offshore wind farms are present; operation noise: from offshore wind-farms or oil-rigs are present; seismic surveys: explorations (e.g. air guns) are conducted; construction work: piling and other construction activities at sea; sonar: echolocation from ships are present; explosions: detonations of explosive ordinance; other sources: noise from deployment on site and any biological sound*

	Continuous sound sources				Impulsive sound sources				Other sources			
Station	Shipping lane	No AIS ships	CTVs	Operational noise	Seismic surveys	Construction work	Sonar	Explosions	Flow noise	Mooring noise	Platform noise	Biological sound
01-SE-VIN	X	X							X			
02-DK-ANH		X	X	X	X		X		X	X		X
03-DK-HRF	X	X	X	X	X	X	X	X	X	X	X	X
04-DE-FN3			X								X	
05-DE-ES1					X					X		
06-DE-FN1	X		X	X		X	X		X		X	
07-NL-TEX	X								X	X		
08-BE-WST	X	X	X			X		X	X			X
09-UK-DOW	X								X			
10-SC-ARB		X			X				X	X		X
11-SC-HEL		X			X	X		X		X		X
14-NO-NTR												
16-DK-TN1	X	X	X	X	X		X		X	X		X
17-DK-TN4	X	X	X	X	X		X		X	X		X
18-DK-EDA		x	x	x	x	x	x	X	x	x	x	X

3. JOMOPANS 2019 Validation

3.1 Methodology

Measurement data for 15 JOMOPANS stations was provided by WP5 on behalf of the JOMOPANS partner organisations. Monthly percentiles (P01, P05, P10, P25, P50, P75, P90, P95, P99, Pmin and Pmax) for each third octave frequency between 10 and 20000 Hz were extracted from the measurement dataset. Sound pressure levels were also calculated in decadal bands (D1: 20 – 160 Hz; D2: 200 – 1600 Hz; D3: 2000 – 16000 Hz) and broadband (BB: 20 – 20000 Hz). Yearly information was calculated by taking the P50 of monthly values.

Model prediction data between 10 – 20000 Hz (percentiles for each third octave frequency to correspond with the measurement data) was provided by WP4 for every month in 2019 at the nearest grid point location to each of the 15 JOMOPANS stations. Note that the nearest grid position may have been up to 1 km away from the sensor location, whereas for the earlier report [16] model 1 and 2 iterations were performed for the station location.

The difference between datasets was compared by subtracting measurement data from model predictions for each third octave frequency between 10 – 20000 Hz (spectral; Section 3.2) and each month (temporal; Section 3.3). Measurement and model data was also compared for decadal bands (D1: 20 – 160 Hz; D2: 200 – 1600 Hz; D3: 2000 – 16000 Hz) and broadband (BB: 20 – 20000 Hz). A positive value indicated modelled sound levels were higher than measured. A negative value indicated modelled sound levels were lower than measured (possibly indicating that there were additional noise sources in the measurement data which were not included in the model). Comparing between monthly differences gave an indication of temporal patterns in model-measurement agreement. The median yearly value was subsequently calculated from the available months of measurement and model data. Some stations had better temporal coverage than others.

The degree of model-measurement agreement was also compared to three independent variables: water depth (m), sediment type (Φ) and an estimated for shipping density (Table 3.2). This analysis is presented in section 3.4.

3.2 Spectral differences between model and measurement data

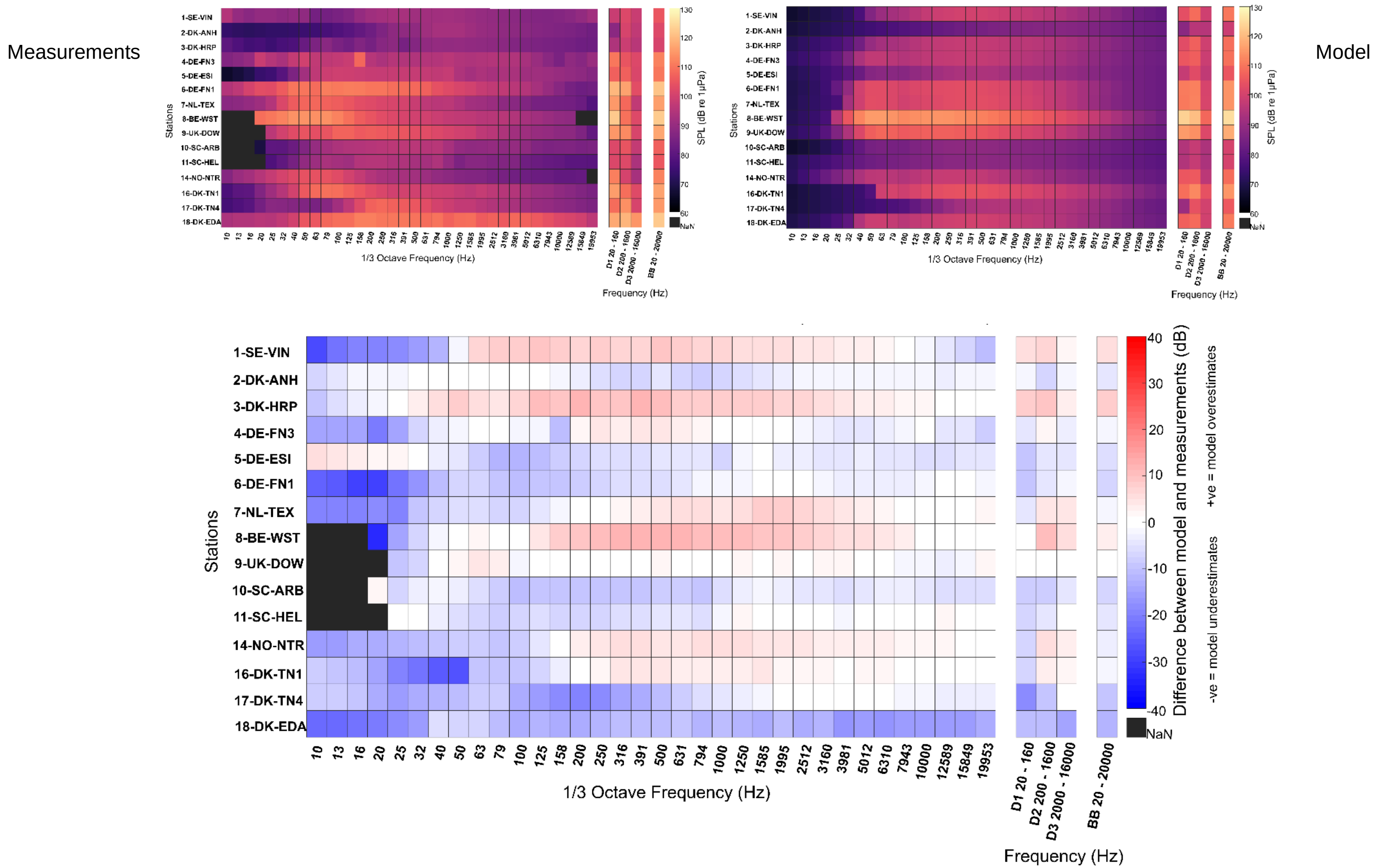


Figure 3.1: P50 (median) difference between model and measurement noise levels [dB] in 2019 for all JOMOPANS stations and frequencies (1/3 octave frequency bands, 20-160 Hz, 200 – 1600 Hz, 2000 – 16000 Hz and 20-20000 Hz). Negative values (blue) indicate that the model underestimated the measured values, and positive (red) vice versa.

Table 3.1: Difference in the median between model and measurement noise levels at all sites across 2019 for decadal bands (20 – 160 Hz; 200 – 1600 Hz; 2000 – 16000 Hz) and broadband (20 – 20000 Hz). Negative values indicate that the model predicts lower levels than the measured data, and vice versa. Cells exceeding ± 6 dB are highlighted.

JOMOPANS Station	P50 (median) Model – P50 Measurement difference [dB]			
	20 – 160 Hz	200 – 1600 Hz	2000 – 16000 Hz	20 – 20000 Hz
01-SE-VIN	5.2	7.0	1.4	5.4
02-DK-ANH	-1.6	-6.4	-2.1	-4.6
03-DK-HRF	8.1	9.1	3.7	7.7
04-DE-FN3	-4.4	2.4	-4.3	-2.1
05-DE-ES1	-9.2	-4.6	-4.0	-6.0
06-DE-FN1	-9.1	-4.9	-2.1	-7.3
07-NL-TEX	-5.0	3.8	4.0	-1.7
08-BE-WST	1.2	11.2	5.8	2.8
09-UK-DOW	0.5	0.7	1.0	0.6
10-SC-ARB	-8.4	-7.6	-4.5	-7.3
11-SC-HEL	-6.5	-4.1	-0.1	-4.5
14-NO-NTR	-6.4	5.0	3.1	-3.4
16-DK-TN1	-7.0	3.5	1.5	-2.3
17-DK-TN4	-18.1	-9.8	-0.8	-9.6
18-DK-EDA	-11.1	-11.1	-14.8	-11.6

Across all sites, the general pattern of difference between model and measurement data was the model underestimated noise levels (relative to the field measurements) at low frequencies (< 50 Hz), either under or overestimated noise levels at mid frequencies (100 – 1000 Hz) depending on station and had comparatively low uncertainty (< 6dB) at high frequencies (> 1 kHz) (Figure 3.2.1).

At low frequencies, possible reasons for uncertainty include the addition of flow noise, a lack of quality data on sediment type in the Kattegat (17-DK-TN1), and water depth. Some stations were positioned in shallow waters (03-DK-HRF; 17-DK-TN1) while others were in deep water (14-NO-NTR) with the recorder close to sea floor. In the latter case, an underestimate of distant shipping noise was expected owing to the model being depth averaged.

At mid frequencies, additional sound sources were not accounted for in the model. For example, a seismic survey that occurred in October 2019 in the central North Sea (18-DK-EDA), generator noise from a nearby platform (05-DE-ES1), offshore wind farm developments generating noise from crew transfer vessels (CTVs) (06-DE-FN1) and fishing vessels potentially absent from AIS/VMS records (10-SC-ARB).

3.3 Temporal differences

To determine the temporal frequency of uncertainty between model and measurements was also analysed monthly. Overall, uncertainty between the modelled and measured data followed the same trend across the months (Figure 3.3.2, Table 3.3.2), except at 03-DK-HRP which had a difference of 0.8 dB in April and 11.3 dB in June.

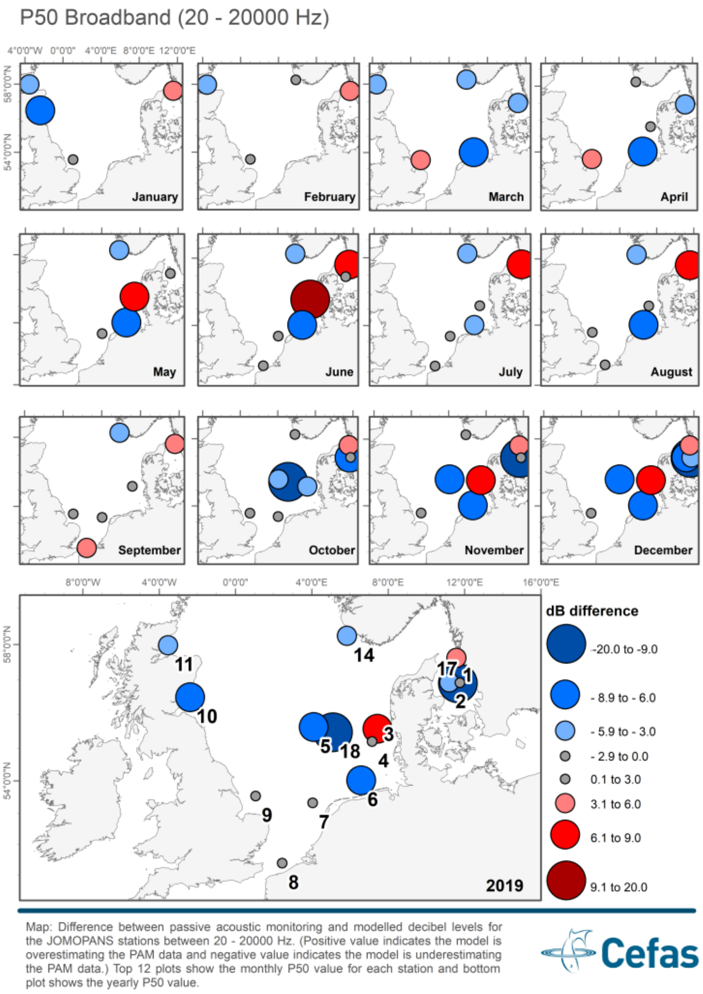


Figure 3.2: Difference in P50 (median) between passive acoustic monitoring and modelled decibel levels for the JOMOPANS stations between 20 – 20000 Hz. Positive (red) value indicates model predictions are larger than the PAM data and a negative (blue) value indicates the model predictions are lower than the PAM data. Top 12 plots show the monthly P50 value for each station and bottom plot the yearly P50 value.

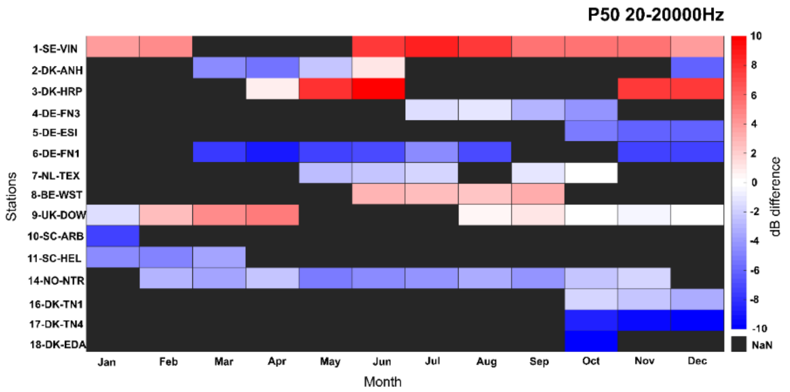


Figure 3.3: Heatplot of dB difference (modelled – measured) values for P50 20-20000 Hz.

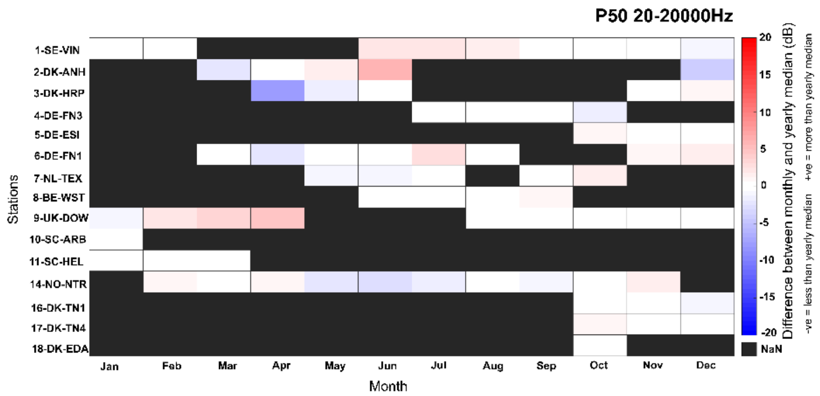


Figure 3.4: Heatplot of the difference between monthly median measurement values and yearly median measurement variables for P50 (median) 20-20000Hz. Negative values (blue) represent the monthly median is less than the yearly value. Positive values (red) indicate the monthly median is more than the yearly value.

There was also limited variability in the monthly measurement data compared to yearly median values across the JOMOPANS stations (Figure 3.4). At 01-SE-VIN the broadband SPL increased during the summer months compared to the yearly median. Additionally, at 02-DK-ANH and 09-UK-DOW broadband SPL increased during June and April respectively compared to the yearly median. Whereas, at 03-DK-HRP, broadband SPL decreased during March.

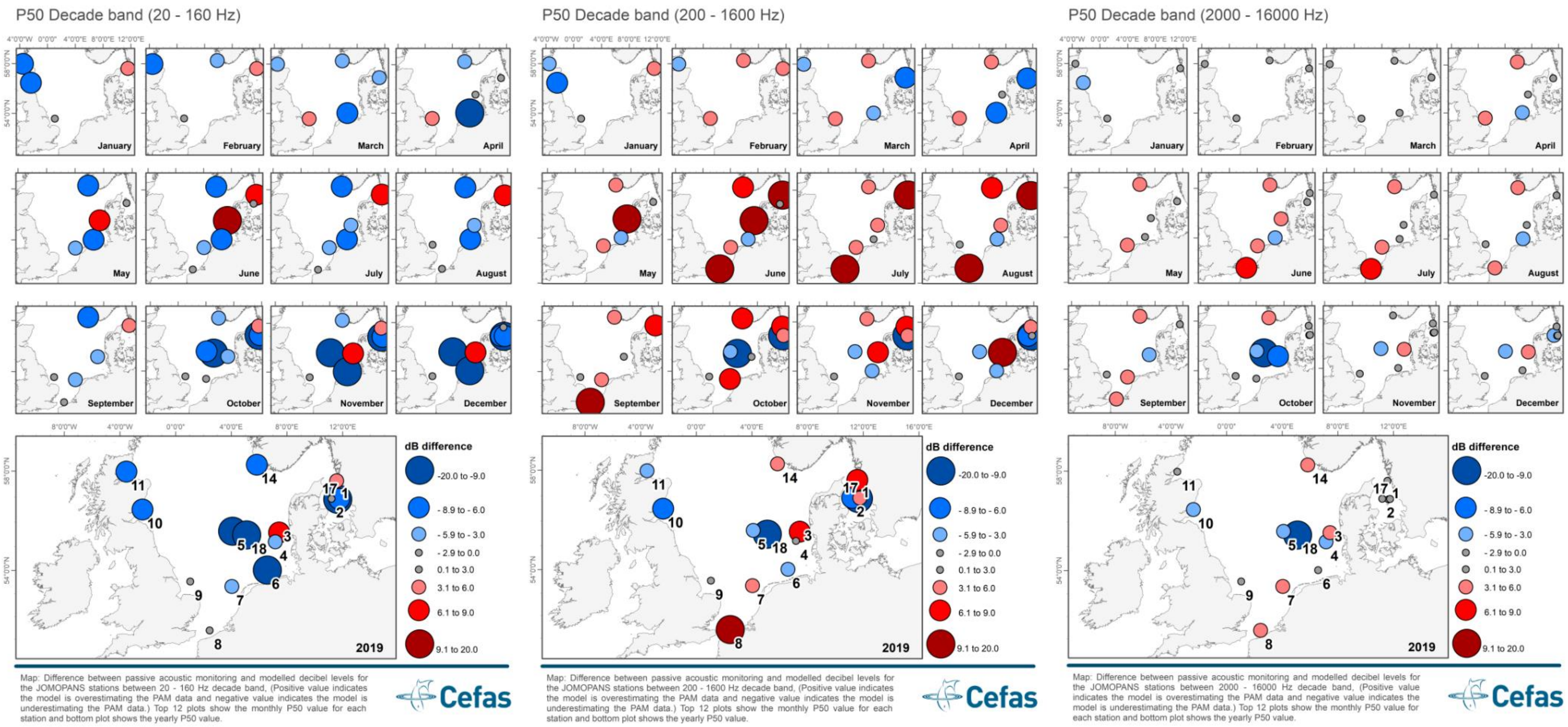


Figure 3.4: Difference in P50 (median) between passive acoustic monitoring and modelled decibel levels for the JOMOPANS stations for 20 – 160 Hz (left), 200 – 1600 Hz (middle) and 2000 – 16000Hz (right). Positive (red) value indicates the model predictions are larger than the PAM data and a negative (blue) value indicates the model predictions are smaller the PAM data. The top 12 plots show the monthly P50 value for each station (crosses represent when data was unavailable for that station) and bottom plot shows the yearly P50 value.

3.4 Comparing differences to sediment type, shipping density and water depth

Water depth, sediment size and shipping density was provided for the 15 stations by WP4 and WP5 (Table 1, Figure 3.4.1).

Sediment grain size (Φ) is a convenient means of visualizing and statistically analysing grain size distributions over a wide range of particle sizes, from -5 Φ (for a diameter of 32 mm, or very coarse pebbles) to +10 Φ (for a diameter of 1/1024mm, or clay)[20]. The sediment grain size, at the JOMOPANS stations, ranged from 0.6 Φ (coarse sand) at 09-UK-DOW, to 7.0 Φ (fine silt) at 14-NO-NTR.

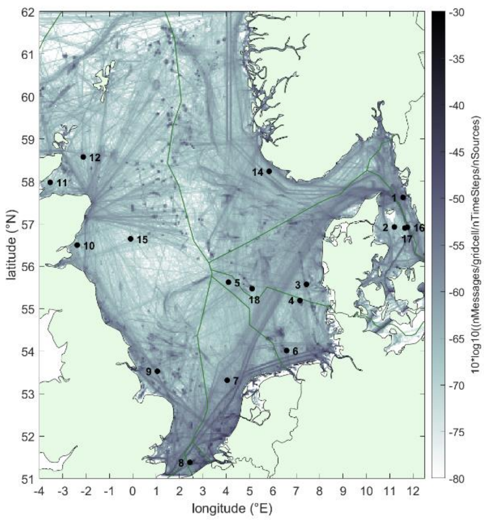
Shipping density was estimated around the station locations using the May 2019 AIS data (one month was chosen as an approximation for AIS nominally throughout the year). It is presented as $10\log_{10}\left(\Sigma_{t,R}\left(\frac{N}{R^2}\right)\right)$, with N the number of ships per map grid cell per time step t and R the distance between the centre of the grid cells and the station location. This estimation provides a qualitative indication of the closeness of ship traffic to the stations. However, the 1/R^2 scaling of the density estimate does not account for the ship source levels (dependent on ship type, size, and speed) nor the local propagation. The shipping density, at the JOMOPANS stations, ranged from 23.5 at 11-SC-HEL, to 41.4 at 18-DK-EDA [which is near oil rigs so standby vessels would be regularly transiting the area].

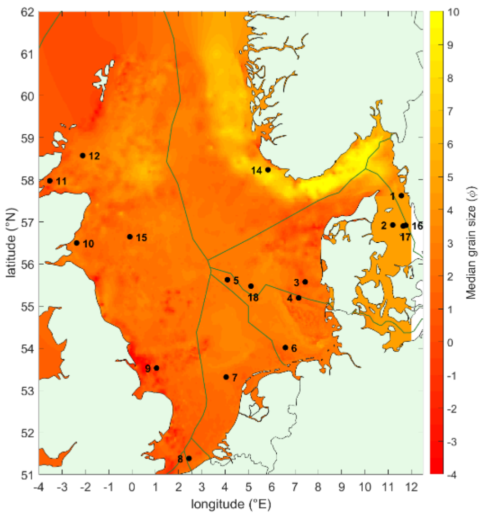
The shallowest JOMOPANS station was 02-DK-ANH at 10.8 m and the deepest was 14-NO-NTR at 340.9 m. However, most stations were positioned in water depths between 20 – 40 m.

A Spearman's rank product correlation was used to determine the degree of association between each variable (sediment grain size, shipping density and water depth) and the yearly median difference (modelled measured) at each site. The resulting correlation coefficient is a number between -1 and +1 that indicates the extent to which two variables are correlated. A positive correlation indicated that both variables increased or decreased together, whereas a negative correlation indicated that as one variable increased, the other decreased, and vice versa.

Table 3.2: Information about the location of JOMOPANS stations used in 2019 validation and environmental variables provided by WP4 and WP5.

Station	Name	Water depth [m]	Sediment grain size [Φ]		Shipping density for May 2019 (used as an approximation for the yearly value)
01-SE-VIN	Sweden_Vinga	43.3	4.3	Coarse silt	32.9
02-DK-ANH	Denmark_Anholt	10.8	4.5	Coarse silt	31.9
03-DK-HRF	Denmark_Horns Reef	14.9	1.3	Medium sand	28.6
04-DE-FN3	Germany_FINO3	21.7	0.8	Coarse sand	29.0
05-DE-ES1	Germany_ES01	35.1	2.4	Fine sand	33.4
06-DE-FN1	Germany_FINO1	28.8	2.4	Fine sand	33.3
07-NL-TEX	Netherlands_Texel	26.5	2.2	Fine sand	28.5
08-BE-WST	Belgium_Westhinder	21.0	1.4	Medium sand	35.3
09-UK-DOW	England_Dowsing	19.1	0.6	Coarse sand	29.8
10-SC-ARB	Scotland_Arbroath10	48.2	3.0	Very fine sand	23.7
11-SC-HEL	Scotland_Helmsdale5	48.9	1.1	Medium sand	23.5
14-NO-NTR	Norway_Norwegian Trench	340.9	7.0	Fine silt	26.1
16-DK-TN1	Denmark_TangoN1	38.1	4.5	Coarse silt	34.7
17-DK-TN4	Denmark_TangoN4	16.4	4.5	Coarse silt	31.1
18-DK-EDA	Denmark_ENDA	45.3	2.5	Fine sand	41.4





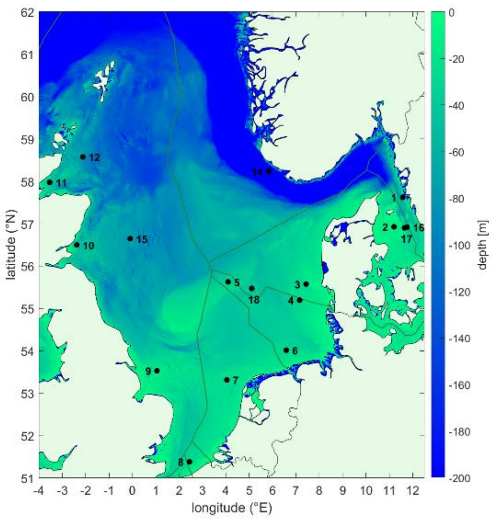


Figure 3.5: Maps of shipping density (top left), median grain size (top right) and water depth (bottom left) with JOMOPANS locations indicated by the black circles.

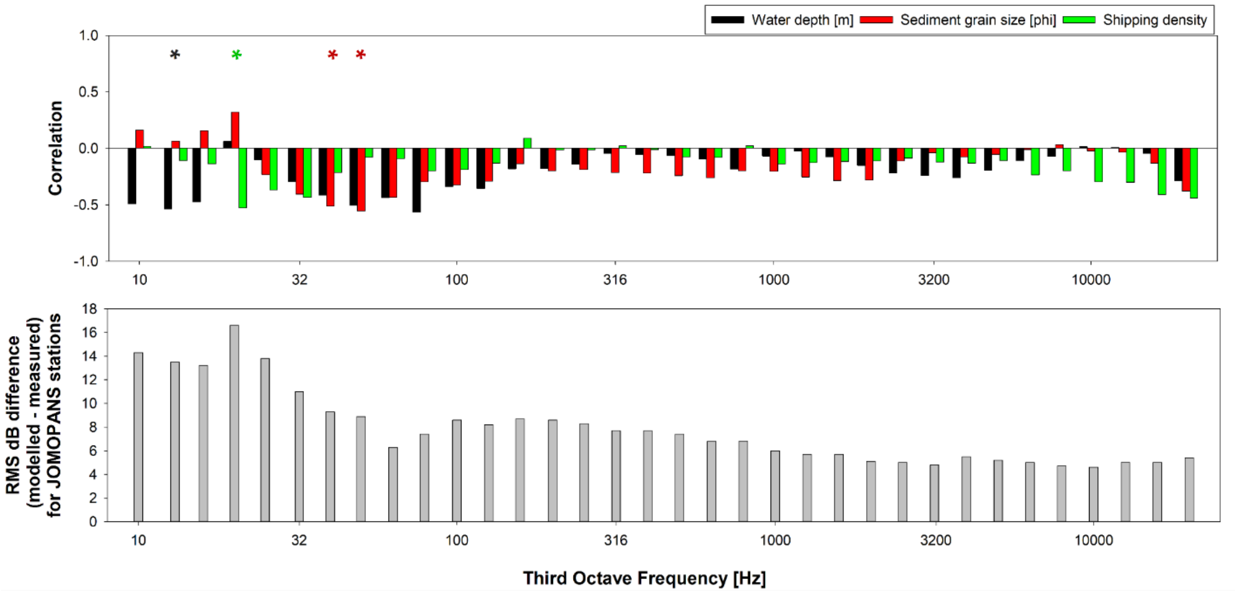


Figure 3.6: (Upper) Pearson's correlation of water depth [m] (black), sediment grain size [Φ] (red) and AIS density (green) compared to median yearly modelled minus measured difference over each 1/3 octave frequency band. Statistical significance is indicated by the corresponding-coloured asterisk. (Lower) RMS dB difference (modelled – measured) for P50 (median) yearly data from the 15 JOMOPANS stations, indicating the overall magnitude for model vs. measurement error.

There was significant negative correlation for sediment grain size at 40 Hz and 50 Hz (Figure 3.6). A possible explanation is that the difference between model and measured data in the lower frequencies is largest at stations that have a smaller sediment grain size (silt and mud) such as in the Kattegat and Norwegian sites.

There was a significant negative correlation (indicating measurement data becomes larger than model data) between shipping density and dB difference at 20 Hz (as indicated by the asterisks on Figure 3.6). The difference between measurement and model data was in the low frequencies at 18-DK-EDA (Table 3.2), which also had the largest shipping density. There was a significant negative correlation for the association between dB difference at 13 Hz and water depth (Figure 3.6, Table 3.2). The model is depth averaged so an underestimate of noise from distant shipping was expected, particularly for deep water sites. At low frequencies it also should be noted that flow noise at individual stations may affect comparisons between model and measurement data.

This analysis considered these three factors (water depth, gain size, shipping density) separately, but a significant effect of these parameters in combination cannot be ruled out based on these results.

Table 3.3: Output of Pearson's correlation statistical test for association between the dB difference (modelled – measured) for each 1/3 octave frequency band P50 (median) yearly value for each JOMOPANS station) and water depth, sediment grain size and shipping density. Highlighted cells indicate statistical significance as p value < 0.05.

1/3 Octave Frequency Band [Hz]	Water depth [m]		Sediment grain size [Φ]		Shipping density	
	Correlation coefficient	P value	Correlation coefficient	P value	Correlation coefficient	P value
10	-0.491	0.116	0.161	0.614	0.0182	0.946
13	-0.536	0.042	0.064	0.839	-0.109	0.734
16	-0.473	0.132	0.156	0.633	-0.136	0.673
20	0.061	0.835	0.321	0.278	-0.528	0.0405
25	-0.100	0.714	-0.233	0.396	-0.368	0.171
32	-0.298	0.269	-0.406	0.127	-0.434	0.101
40	-0.417	0.117	-0.511	0.050	-0.216	0.426
50	-0.504	0.054	-0.556	0.030	-0.0786	0.773
63	-0.436	0.101	-0.432	0.104	-0.0893	0.743
79	-0.564	0.028	-0.298	0.275	-0.2	0.465
100	-0.339	0.209	-0.325	0.230	-0.189	0.489
126	-0.357	0.185	-0.291	0.287	-0.132	0.629
158	-0.181	0.506	-0.136	0.620	0.089	0.743
200	-0.179	0.514	-0.201	0.465	-0.014	0.954
251	-0.143	0.602	-0.189	0.489	-0.013	0.954
316	-0.043	0.873	-0.215	0.433	0.021	0.934
398	-0.054	0.842	-0.219	0.426	-0.011	0.964
501	-0.064	0.812	-0.242	0.374	-0.077	0.773
631	-0.096	0.724	-0.260	0.339	-0.082	0.763
794	-0.184	0.498	-0.199	0.465	0.023	0.923
1000	-0.068	0.802	-0.203	0.457	-0.139	0.611
1259	-0.025	0.923	-0.253	0.353	-0.125	0.648
1585	-0.075	0.783	-0.284	0.300	-0.118	0.667
1995	-0.150	0.584	-0.282	0.300	-0.111	0.686
2512	-0.220	0.418	-0.110	0.686	-0.088	0.743
3162	-0.239	0.381	-0.038	0.883	-0.121	0.657
3981	-0.261	0.339	-0.075	0.783	-0.132	0.629
5012	-0.195	0.473	-0.052	0.842	-0.109	0.686
6310	-0.109	0.686	-0.011	0.964	-0.236	0.388
7943	-0.070	0.793	0.033	0.903	-0.198	0.465
10000	0.016	0.944	-0.022	0.934	-0.297	0.275
12589	0.007	0.974	-0.034	0.893	-0.300	0.269
15849	-0.044	0.868	-0.131	0.648	-0.411	0.138
19953	-0.286	0.332	-0.379	0.192	-0.440	0.126
20 – 160	-0.357	0.185	-0.357	0.185	-0.168	0.540
200 - 1600	-0.064	0.812	-0.228	0.403	-0.082	0.763
2000 - 16000	-0.191	0.481	-0.071	0.793	-0.122	0.657
20 - 20000	-0.270	0.319	-0.407	0.127	-0.130	0.629

3.4.1 Comparison to sediment type detailed

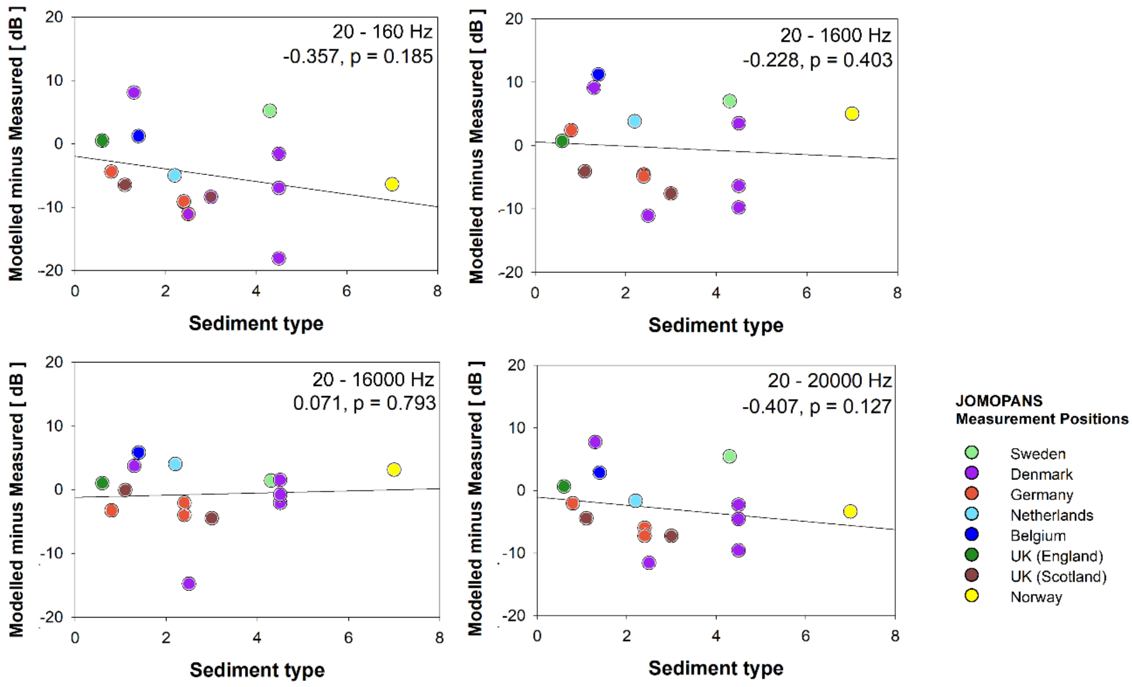


Figure 3.7: Comparison between sediment grain size and modelled minus measured difference [dB] for all JOMOPANS stations. Top left 20 – 160 Hz, top right 200 – 1600 Hz, bottom left 2000 – 16000 Hz and bottom right 20 – 20000 Hz. Spearman's correlation coefficient and p value shown on each individual graph.

As sediment grain size [Φ] increases (moving from sand to silt), the difference between model and measurement becomes more negative indicating the measurement data is larger than the model predictions, especially at low frequencies (Figure 3.7). For example, sandy stations (such as 09-UK-DOWS and 04-DE-FN3) had smaller uncertainty between measurement and model data than silty stations (such as 16-DK-TN1 and 17-DK-TN4). However, this observation is not statistically significant as some other silty stations (01-SE-VIN, 02-DK-ANH AND 14-NO-NTR) had low uncertainty (Table 3.4).

Table 3.4: dB difference between P50 (median) modelled minus measurement 2019 data for different frequency bands sorted from largest to smallest sediment grain size. Highlighted cells indicate difference between model and measurements exceeds ± 6 dB.

Station	Sediment grain size [Φ]		20-160 Hz	200-1600 Hz	2000-16000 Hz	20-20000 Hz
14-NO-NTR	7.0	Fine silt	-6.4	5.0	3.1	-3.4
02-DK-ANH	4.5	Coarse silt	-1.6	-6.4	-2.1	-4.6
16-DK-TN1	4.5	Coarse silt	-7.0	3.5	1.5	-2.3
17-DK-TN4	4.5	Coarse silt	-18.1	-9.8	-0.8	-9.6
01-SE-VIN	4.3	Coarse silt	5.2	7.0	1.4	5.4
10-SC-ARB	3.0	Very fine sand	-8.4	-7.6	-4.5	-7.3
18-DK-EDA	2.5	Fine sand	-11.1	-11.1	-14.8	-11.6
05-DE-ES1	2.4	Fine sand	-9.2	-4.6	-4.0	-6.0
06-DE-FN1	2.4	Fine sand	-9.1	-4.9	-2.1	-7.3
07-NL-TEX	2.2	Fine sand	-5.0	3.8	4.0	-1.7
08-BE-WST	1.4	Medium sand	1.2	11.2	5.8	2.8
03-DK-HRF	1.3	Medium sand	8.1	9.1	3.7	7.7
11-SC-HEL	1.1	Medium sand	-6.5	-4.1	-0.1	-4.5
04-DE-FN3	0.8	Coarse sand	-4.4	2.4	-3.3	-2.1
09-UK-DOW	0.6	Coarse sand	0.5	0.7	1.0	0.6

3.4.2 Comparison to shipping density detailed

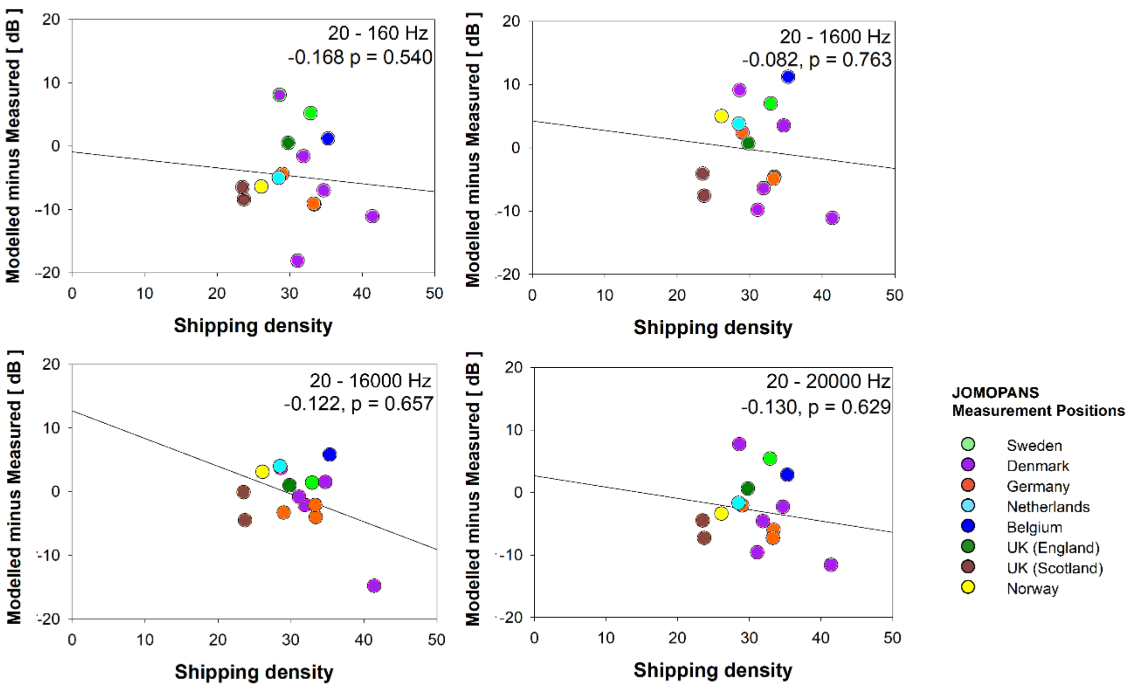


Figure 3.8 Comparison between shipping density and modelled minus measured difference [dB] for all JOMOPANS stations. Top left 20 – 160 Hz, top right 200 – 1600 Hz, bottom left 2000 – 16000 Hz and bottom right 20 – 20000 Hz. Pearson correlation coefficient and p value shown on each individual graph.

As shipping density increased measurement data became larger than model data (modelled – measurement becomes negative). The largest uncertainties are at 18-DK-EDA and 08-BE-WST in the 200 – 2000 Hz band and these two stations had the largest shipping density (Table 3.5). However, the overall pattern was not statistically significant (Figure 3.8).

Table 3.5: dB difference between P50 (median) modelled minus measurement 2019 data for different frequency bands sorted from largest to smallest shipping density. Highlighted cells indicate difference between model and measurements exceeds ± 6 dB.

Station	Shipping density	20-160 Hz	200-1600 Hz	2000-16000 Hz	20-20000 Hz
18-DK-EDA	41.4	-11.1	-11.1	-14.8	-11.6
08-BE-WST	35.3	1.2	11.2	5.8	2.8
16-DK-TN1	34.7	-7.0	3.5	1.5	-2.3
05-DE-ES1	33.4	-9.2	-4.6	-4.0	-6.0
06-DE-FN1	33.3	-9.1	-4.9	-2.1	-7.3
01-SE-VIN	32.9	5.2	7.0	1.4	5.4
02-DK-ANH	31.9	-1.6	-6.4	-2.1	-4.6
17-DK-TN4	31.1	-18.1	-9.8	-0.8	-9.6
09-UK-DOW	29.8	0.5	0.7	1.0	0.6
04-DE-FN3	29.0	-4.4	2.4	-3.3	-2.1
03-DK-HRF	28.6	8.1	9.1	3.7	7.7
07-NL-TEX	28.5	-5.0	3.8	4.0	-1.7
14-NO-NTR	26.1	-6.4	5.0	3.1	-3.4
10-SC-ARB	23.7	-8.4	-7.6	-4.5	-7.3
11-SC-HEL	23.5	-6.5	-4.1	-0.1	-4.5

3.4.3 Comparison to water depth [m] detailed

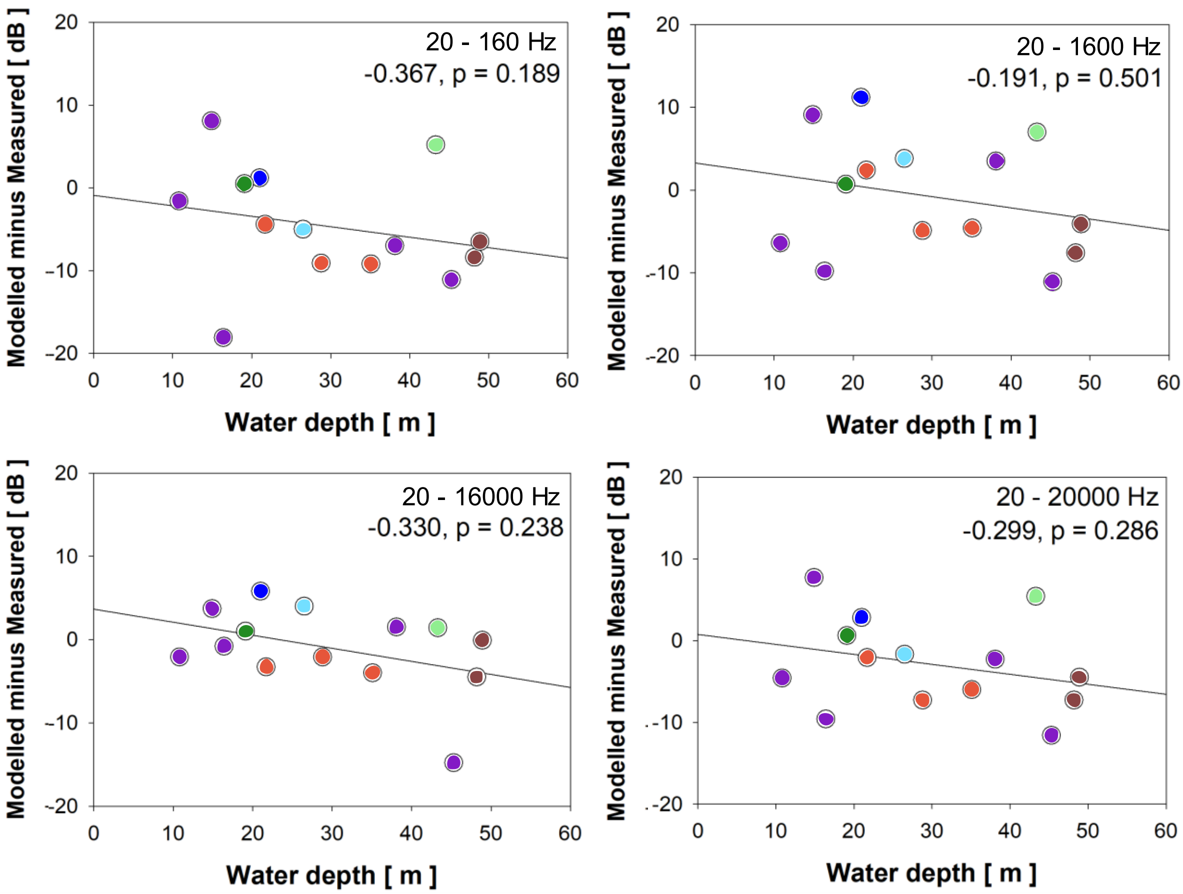


Figure 3.9: Comparison between water depth and modelled minus measured difference [dB] for all JOMOPANS stations. Top left 20 – 160 Hz, top right 200 – 1600 Hz, bottom left 2000 – 16000 Hz and bottom right 20 – 20000 Hz. Pearson correlation coefficient and p value shown on each individual graph.

There was no correlation when the decade band and broadband frequency dB difference was compared to water depth (Figure 3.9). When NO-NTR (the deepest site) was removed (Figure 3.10) there was a slight negative correlation (as water depth increases the measured data is larger than the model predications), however the correlation was not statistically significant as there was a wide variation in the difference data compared to water depth.

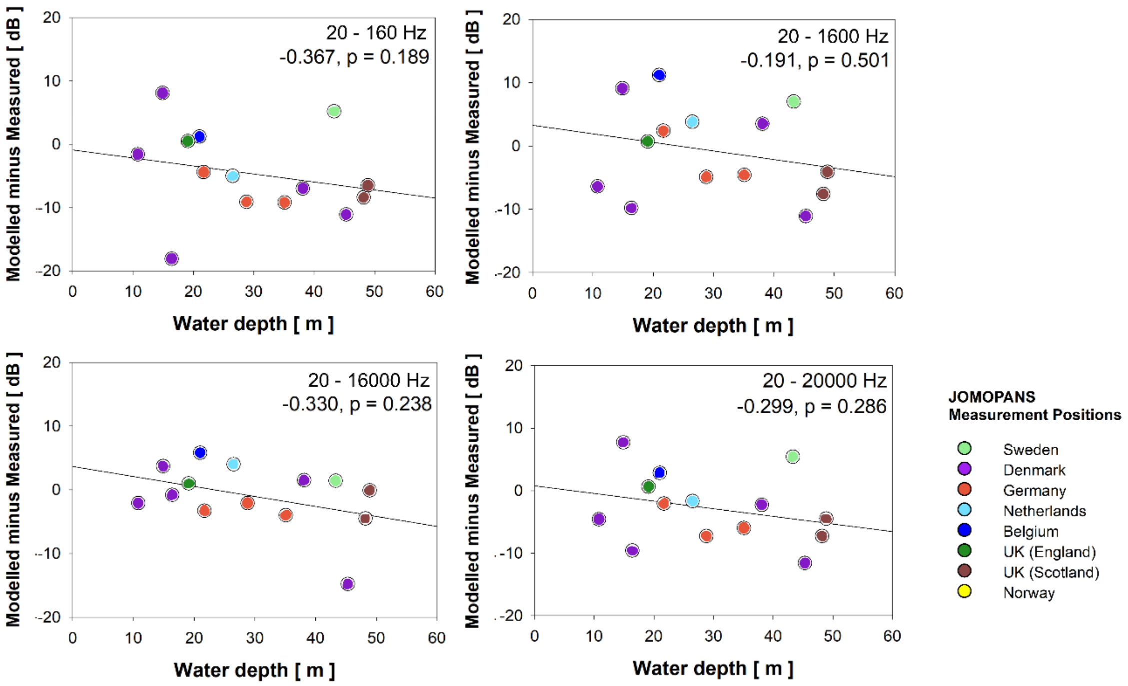


Figure 3.10: Comparison between water depth and modelled minus measured difference [dB] for 14 JOMOPANS stations (minus 14-NO-NTR). Top left 20 – 160 Hz, top right 200 – 1600 Hz, bottom left 2000 – 16000 Hz and bottom right 20 – 20000 Hz. Pearson correlation coefficient and p value shown on each individual graph.

Table 3.6: dB difference between P50 (median) modelled minus measurement 2019 data for different frequency bands sorted from largest to smallest shipping density. Highlighted cells indicate difference between model and measurements exceeds ± 6 dB.

Station	Water depth [m]	20-160 Hz	200-1600 Hz	2000-16000 Hz	20-20000 Hz
14-NO-NTR	340.9	-6.4	5.0	3.1	-3.4
11-SC-HEL	48.9	-6.5	-4.1	-0.1	-4.5
10-SC-ARB	48.2	-8.4	-7.6	-4.5	-7.3
18-DK-EDA	45.3	-11.1	-11.1	-14.8	-11.6
01-SE-VIN	43.3	5.2	7.0	1.4	5.4
16-DK-TN1	38.1	-7.0	3.5	1.5	-2.3
05-DE-ES1	35.1	-9.2	-4.6	-4.0	-6.0
06-DE-FN1	28.8	-9.1	-4.9	-2.1	-7.3
07-NL-TEX	28.7	-5.0	3.8	4.0	-1.7
04-DE-FN3	26.5	-4.4	2.4	-3.3	-2.1
08-BE-WST	21.7	1.2	11.2	5.8	2.8
09-UK-DOW	20.1	0.5	0.7	1.0	0.6
17-DK-TN4	19.1	-18.1	-9.8	-0.8	-9.6
03-DK-HRF	16.4	8.1	9.1	3.7	7.7
02-DK-ANH	10.8	-1.6	-6.4	-2.1	-4.6

4. Validation Summary and Recommendations

In general, the model predicted lower sound levels than the measured data at low frequencies (< 2 kHz), while the model more closely agreed with the measurements at higher frequencies (> 2 kHz). In the 2-16 kHz frequency band, all but one site was predicted to within ± 6 dB. At low frequencies (< 2 kHz), shipping noise typically dominates, and despite model predictions being based on a recent and sizeable dataset of ship source level measurements, the validation results demonstrate the difficulty of accurately predicting shipping noise levels, due to multiple uncertainties. These uncertainties include the quality of AIS coverage and the accuracy of low-frequency propagation loss estimation in shallow water which is strongly influenced by the quality of sediment property data. Additionally, noise sources which were not included in the model added to the uncertainty in predictions at low frequencies (< 2 kHz), such as:

- Vessels without active AIS transponders
- Seismic surveys
- Wind farm operational noise, construction noise and service vessels
- Generator/ platform noise

Overall, the analysis did not identify consistent errors which could be attributed to specific input data or methodological issues. Instead, it appears that the discrepancies between model and measurements were caused by a complex combination of factors.

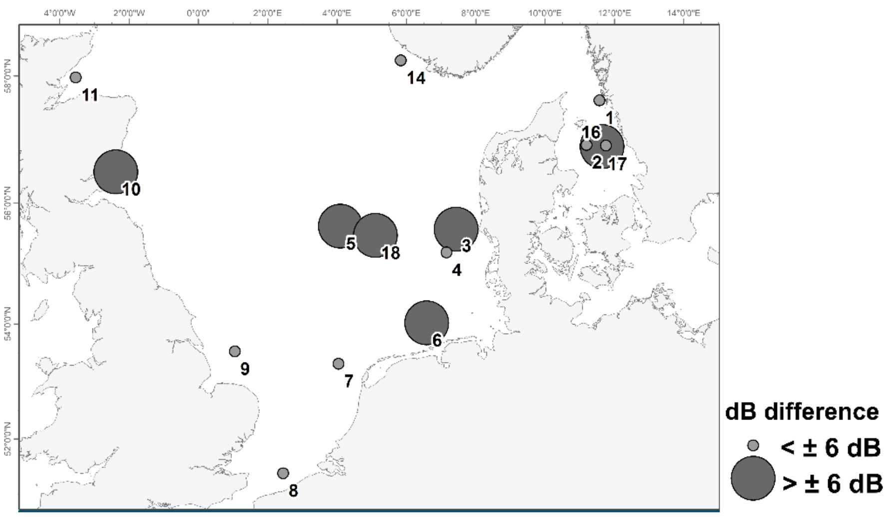


Figure 4.1: dB difference for broadband frequency (20 – 20000 Hz) comparing P50 (median) yearly measurement and model data. Possible reasons for uncertainty at individual stations: 3; proximity to an oil rig, 5; generator at platform, 6: offshore wind farm noise, 10; non AIS fishing vessels, 17; sediment uncertainty in the Kattegat, 18; seismic survey present and proximity to oil rig.

The validation process highlighted the complexity of analysis and limitations in both the field measurements and the acoustic modelling which could be improved upon.

In terms of measurement data, at some sites, tidal flow noise contaminated the recordings at low frequencies, rendering parts of the time series unusable. Further data treatment to exclude data taken during maximum tidal currents may resolve this issue. However, the method of cleaning and evaluating data quality prior to comparing it to model predictions needs to be standardised.

The number of months of measurement data available varied between stations due to loss of equipment/breakdown or weather preventing equipment changeover. It was challenging to assess temporal variation in uncertainty when some stations only provided one or two months of data for comparison. However, stations with high temporal resolution showed little seasonal variation over 2019. Rather than increasing temporal coverage, it is recommended to review the possibility of providing a more complete spatial coverage of measurements for model validation. For example, additional stations could be placed in the Skagerrak and along the northern English coastline.

During the uncertainty analysis, it was beneficial to have information from JOMOPANS stations across a variety of sediment types, water depths and noise sources because individual factors could be separated and analysed in detail. A second deeper water station along the Norwegian coastline would help to assess the validity of using a depth averaged SPL in these waters. Additional stations within the southern Kattegat would improve understanding of model performance in muddy sediment areas.

The limitations in modelling included shortcomings in the input data, particularly suspected gaps in the AIS ship tracking coverage and the availability of suitable sediment data, but also the inclusion of other sources of noise, such as small vessels without AIS transponders or seismic surveys. It may be worthwhile to open the modelling capability to include other sound sources. However, there is a trade-off between additional input sources to the model improving accuracy while increasing model complexity (such as computational cost, time, and difficulty in interpretating areas of uncertainty).

In terms of recommendations for modelling moving forward, a detailed analysis of individual ship passages, looking at the closest point of approach from both measurement and model data in the North Sea, would improve the validation of the ship noise model. This would be a large computational task that would need to be automated for comparison. Further data treatment could separate intermittent and continuous noise sources as data may have been skewed by short term events such as seismic surveys.

It may also be useful for future modelling to consider subregions (‘acoustic basins’) of the Noise Sea, such as the Kattegat, southern North Sea and northern North Sea to separate areas of environmental variability and/or different sound propagation properties. Acoustic basins (as proposed in the summary record of the meeting of OSPAR’s Intersessional Correspondence Group on Noise 2014) are defined as geographical areas which have logical boundaries, typically based on bathymetry, where is useful to combine data from sources within that area to determine the sound field, and where sound sources from outside that area are of lesser relevance [21].

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