Joint Monitoring Programme for Ambient Noise North Sea

2021 extension timeline

Validation report: 2020 data

WP 6

Deliverable/Task: 6

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Date: September 2022

INTERREG North Sea Region
Jomopans

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

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Version	Date	Review	Initial	Approval	Initial
1.0	24/06/2022				
1.1	15/09/2022				

This report should be cited:
Putland, R.L., Farcas, A., Merchant, N. D. (2022) *Uncertainty assessment between measurements and model predictions for 2020 data. Final report*. Report of the EU INTERREG Joint Monitoring Programme for Ambient Noise North Sea (Jomopans)

Contents

1. Introduction

Underwater noise mapping is needed to underpin policy and regulatory decisions which aim to reduce the impacts of underwater noise pollution on marine life. Such maps can help to evaluate the consequences of different management scenarios and highlight where greater effort to reduce impacts may be required. To ensure confidence in these maps, however, it is critical that they are thoroughly ground-truthed with in situ field measurements and that the resulting uncertainties in the maps are quantified (Farcas et al., 2020; Putland et al., 2022).

Within the scope of the JOMOPANS project, the aim of this work package was to provide an independent validation of the finalised noise maps produced for the calendar year 2020 by the modelling work package (WP4), using the field data gathered within the measurement work package (WP5). Validation was conducted on 2020 data for 14 JOMOPANS stations. This validation was also compared to the 2019 validation (Putland et al., 2021), in which model and measurement data was compared for 15 JOMOPANS monitoring stations.

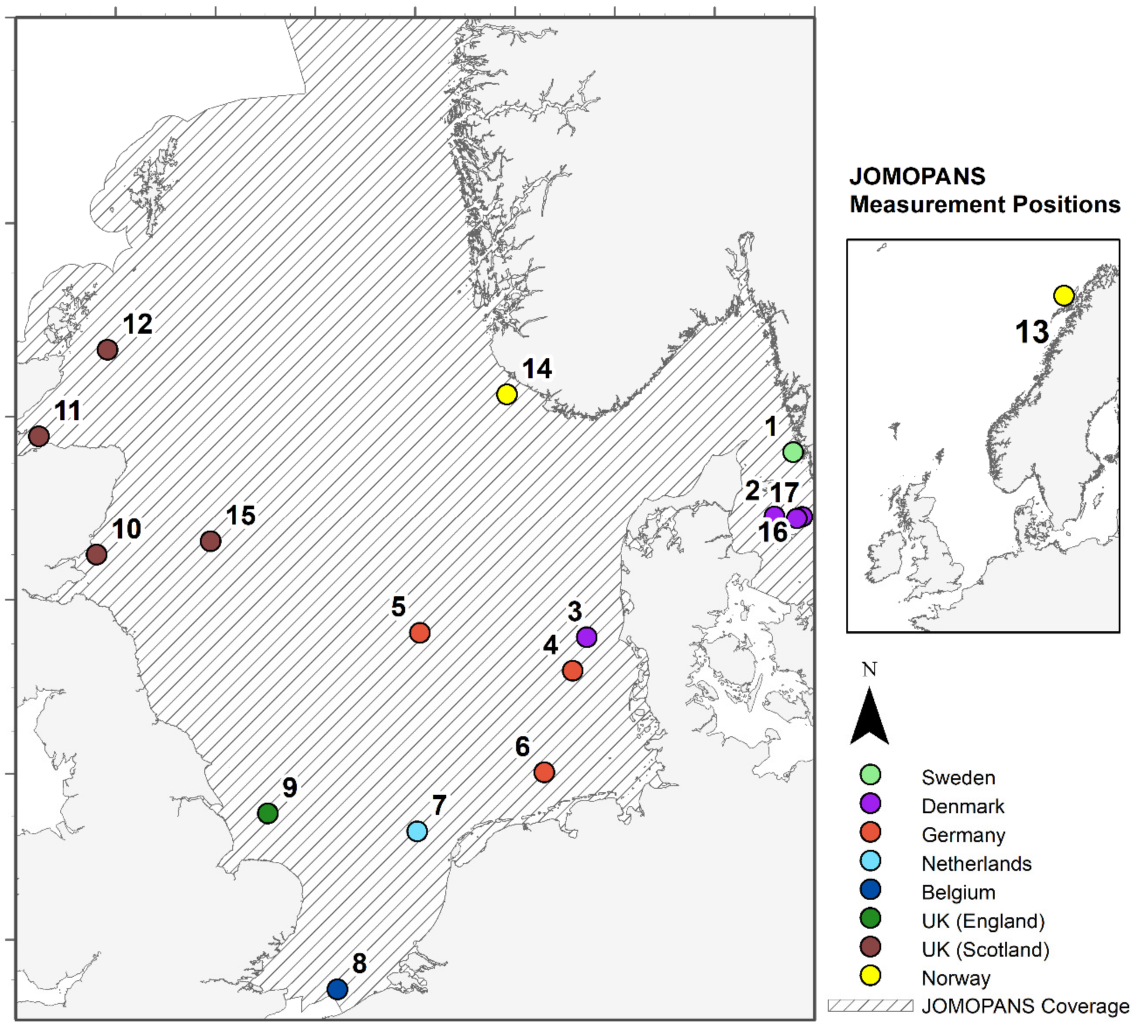


Figure 1: Underwater sound monitoring locations of the JOMOPANS project. Monitoring locations are depicted with consecutively numbered circular markers (colours represent the different partners/countries). Please note that the station provided by Sweden in 2020 was at a different location to 2019.

2. JOMOPANS 2020 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 (de Jong et al., 2022; Putland et al., 2022). 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.

Fourteen JOMOPANS sites had field measurements available from deployments during 2020 (Figure 2). Four sites (Figure 1) 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 '08-BE-WST' and '14-NO-LOV' locations were also not included in the validation exercise since no measurement data were available for 2020 when the analysis was undertaken (Table 2). Furthermore, a new Swedish site was used in 2020 (named Hönö), 6.4 km to the north of the site used in 2019 (Vinga). As such, a direct comparison between 2019 and 2020 measurements was not possible.

Months with fewer than 20 days of measurement data were excluded from the analysis to ensure monthly values were representative (Table 1). Monthly percentiles (P01, P05, P10, P25, P50, P75, P90, P95, P99, Pmin and Pmax) of the sound pressure level (computed over 1-s time intervals) for each one-third octave band frequency between 10 and 20,000 Hz were extracted from the measurement dataset. Measured SPLs 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.

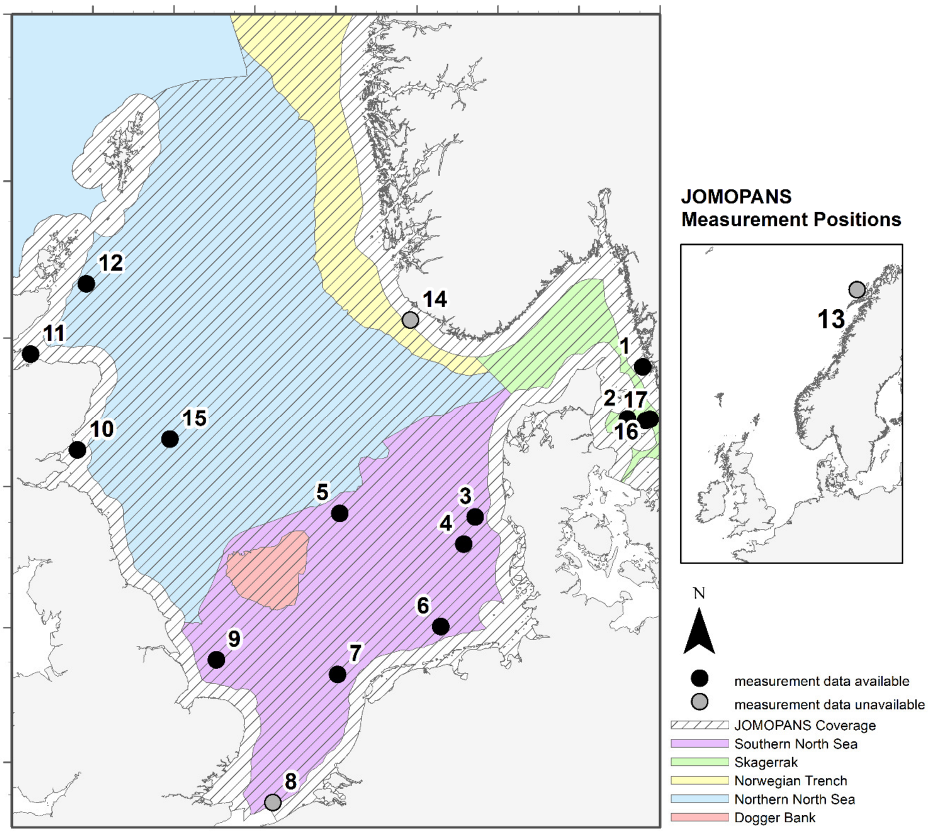


Figure 2: Underwater sound monitoring locations indicating whether measurement data was available for the 2020 data period and the area of the North Sea positioned in.

Table 1: JOMOPANS stations used in 2020 validation including number of months of data available with > 20 days monitored (regardless of measurement duty cycle) and environmental variables provided by WP4 and WP5.

Station	Name	Latitude	Longitude	Number of months available with > 20 days available	Months with > 20 days available											
					J	F	M	A	M	J	J	A	S	O	N	D
01-SE-HON	Sweden_Hon	57.6798	11.5916	5						x	x	x		x	x	
02-DK-ANH	Denmark_Anholt	56.9234	11.1999	4	x									x	x	x
03-DK-HRF	Denmark_Horns Reef	55.6908	7.5853	4					x	x		x		x		
04-DE-FN3	Germany_FIN03	55.195	7.1583	2											x	x
05-DE-ES1	Germany_ES01	55.6257	4.0985	8			x	x	x	x			x	x	x	x
06-DE-FN1	Germany_FINO1	54.0149	6.5876	3									x	x	x	
07-NL-TEX	Netherlands_Texel	53.3157	4.0429	4	x	x	x		x							
09-UK-DOW	England_Dowsing	53.5289	1.0532	11	x	x	x	x	x		x	x	x	x	x	x
10-SC-ARB	Scotland_Arbroath10	56.4998	-2.37989	8	x	x	x					x	x	x	x	x
11-SC-HEL	Scotland_Helmsdale5	57.7926	-3.5357	5	x							x	x	x		x
12-SC-MOR	Scotland_MorayFirth	58.7055	-2.1611	1	x											
15-SC-CNS	Scotland_CentralNorthSea	56.64707	-0.09393	1	x											
16-DK-TN1	Denmark_TangoN1	56.9191	11.7575	4	x									x	x	x
17-DK-TN4	Denmark_TangoN4	56.902	11.6491	5	x	x								x	x	x
				Total number of sites	9	4	4	2	4	4	2	5	5	8	10	9

Table 2: Comparison of field data availability in 2020 vs. 2019.

Station	Name	Latitude	Longitude	Year	Months with > 20 days available											
					J	F	M	A	M	J	J	A	S	O	N	D
01-SE-HON	Sweden_Hon	57.6798	11.5916	2020						x	x	x		x	x	
01-SE-VIN	*Sweden_Vinga*	*57.62315*	*11.57185*	*2019*	*x*	*x*	*x*		*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*
02-DK-ANH	Denmark_Anholt	56.9234	11.1999	2020	x									x	x	x
				2019			*x*	*x*	*x*	*x*						*x*
03-DK-HRF	Denmark_Horns Reef	55.6908	7.5853	2020					x	x		x		x		
				2019				*x*	*x*	*x*					*x*	*x*
04-DE-FN3	Germany_FIN03	55.195	7.1583	2020											x	x
				2019							*x*	*x*	*x*	*x*		
05-DE-ES1	Germany_ES01	55.6257	4.0985	2020			x	x	x	x			x	x	x	x
				2019										*x*	*x*	*x*
06-DE-FN1	Germany_FINO1	54.0149	6.5876	2020									x	x	x	
				2019			*x*	*x*	*x*	*x*	*x*	*x*			*x*	*x*
07-NL-TEX	Netherlands_Texel	53.3157	4.0429	2020	x	x	x		x							
				2019					*x*	*x*	*x*		*x*	*x*		
08-BE-WST	*Belgium_Westhinder*	*51.3830*	*2.4453*	*2019*						*x*	*x*	*x*	*x*			
09-UK-DOW	England_Dowsing	53.5289	1.0532	2020	x	x	x	x	x		x	x	x	x	x	x
				2019	*x*	*x*	*x*	*x*				*x*	*x*	*x*	*x*	*x*
10-SC-ARB	Scotland_Arbroath10	56.4998	-2.37989	2020	x	x	x					x	x	x	x	x
				2019	*x*											
11-SC-HEL	Scotland_Helmsdale5	57.7926	-3.5357	2020	x							x	x	x		x
				2019	*x*	*x*	*x*									
12-SC-MOR	Scotland_MorayFirth	58.7055	-2.1611	2020	x											
				2019												
14-NO-NTR	*Norway_Trench*	*58.2367*	*5.8394*	*2019*		*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	*x*	
15-SC-CNS	Scotland_CentralNorthSea	56.64707	-0.09393	2020	x											
				2019												
16-DK-TN1	Denmark_TangoN1	56.9191	11.7575	2020	x									x	x	x
				2019										*x*	*x*	*x*
17-DK-TN4	Denmark_TangoN4	56.902	11.6491	2020	x	x								x	x	x
				2019										*x*	*x*	*x*
18-DK-EDA	*Denmark_ENDA*	*55.4738*	*5.1105*	*2019*											*x*	

2.1 Overview of measurement noise levels

Most sites which had field measurements for both 2019 and 2020 recorded a decrease in median sound pressure levels of at least 3 dB (6 out of 11 sites; Table 3), while three sites remained within ±3 dB of 2019 levels, and two increased by >3 dB, based on the broadband noise level (20-20,000 Hz). These annual values do not reflect direct comparisons since different months may have been monitored in each year (see Table 2). Nevertheless, a general decrease in noise levels may be expected due to the effects of government restrictions arising from the COVID-19 pandemic which typically began around March 2020 (Sertlek, 2021; Thomson and Barclay, 2020).

The highest broadband sound pressure levels in both years were recorded at Germany's FIN01 station, while the lowest levels were recorded in Denmark, at Horns Reef in 2019 and at Anholt in 2020 (Table 3).

Table 3: Annual median sound pressure levels recorded in 2019 and 2020 at several frequency bandwidths.

Station	20 – 160 Hz		200 – 1600 Hz		2000 – 1600 Hz		20 – 20000 Hz		ΔSPL	Change in annual broadband SPL
	2019	2020	2019	2020	2019	2020	2019	2020		
01-SE-HON		88.7		99.8		96.1		101.6		N/A
01-SE-VIN	98.1		101.7		98.2		104.8			N/A
02-DK-ANH	87.8	72.6	100.6	89.5	96.8	88.7	102	92.2	-9.8	Decrease
03-DK-HRF	93.8	101.6	98.3	101.3	95.3	98.4	100.5	105.5	+5.0	Increase
04-DE-FN3	110.1	116.5	104.4	117.5	101.6	110.2	111.8	120.5	+8.7	Increase
05-DE-ES1	106.5	106.8	106.6	106.6	101.1	101.1	110.2	110.3	+0.1	Same
06-DE-FN1	119.5	118.7	116.5	119.5	103	104.9	121.5	122.2	+0.7	Same
07-NL-TEX	115	116.2	107.9	109.9	96.7	99.8	115.9	117.2	+1.3	Same
08-BE-WST	122.1		109.4		101.9		122.5			N/A
09-UK-DOW	114.8	111.4	112.8	110	100.9	101.6	117.1	114	-3.1	Decrease
10-SC-ARB	101.6	90.6	104.3	94.1	97.2	86.4	106.7	96.2	-10.5	Decrease
11-SC-HEL	101.4	87.6	102	90.4	93.3	85	105	93	-12.0	Decrease
12-SC-MOR		90.7		96.3		85.2		97.6		N/A
14-NO-NTR	111.3		100.4		92.4		111.8			N/A
15-SC-CNS		103.1		104.4		99.9		107.6		N/A
16-DK-TN1	115.6	94.6	108.9	90.9	102.2	85	116.6	96.5	-20.1	Decrease
17-DK-TN4	108.6	98.7	113.6	94.5	100.7	83.2	115	100.2	-14.8	Decrease
18-DK-EDA	117.4		119.1		114.6		122.2			N/A

Compared to noise levels recorded in the Skagerrak and Northern North Sea during 2020 (Figure 3), the Southern North Sea tended to have greater noise levels, likely linked to the higher density of shipping traffic and the development of offshore renewable energy. These general patterns are reflected in the distribution of noise levels in individual third-octave bands, as shown in Figure 4.

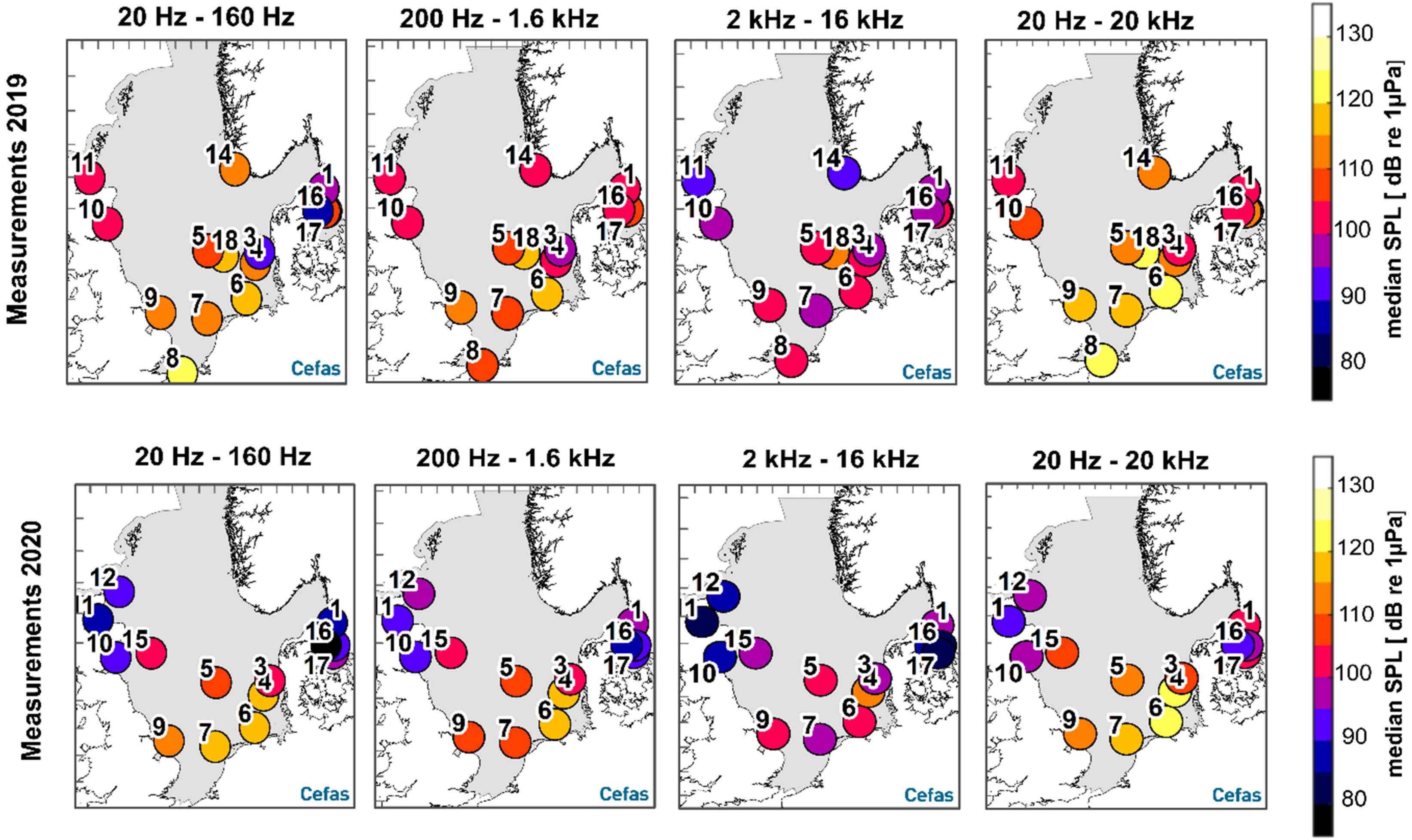
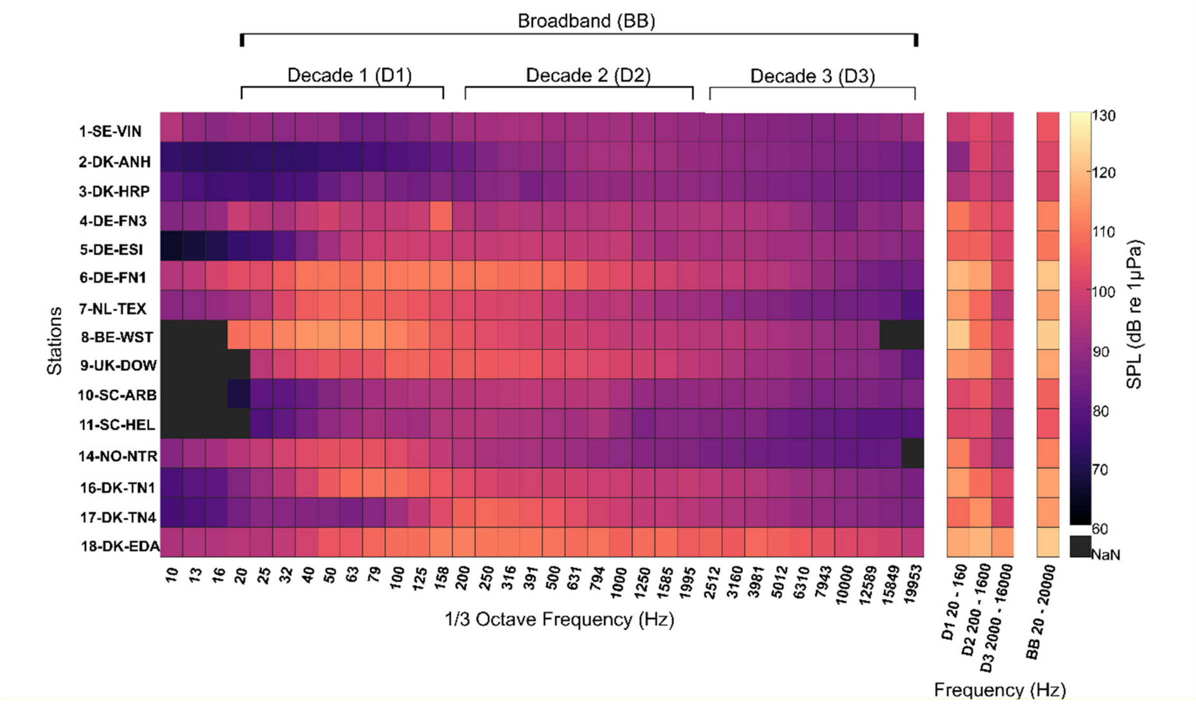


Figure 3: Annual median sound pressure level [SPL (dB re 1µPa)] recorded at JOMOPANS stations in 2019 (top) and 2020 (bottom), for frequencies between 20 – 160 Hz (left column), 200 – 1600 Hz (left middle), 2000 – 16000 Hz (right middle) and 20 – 20000 Hz (right). Sites are numbered according to the convention provided in Table 1.

2019



2020

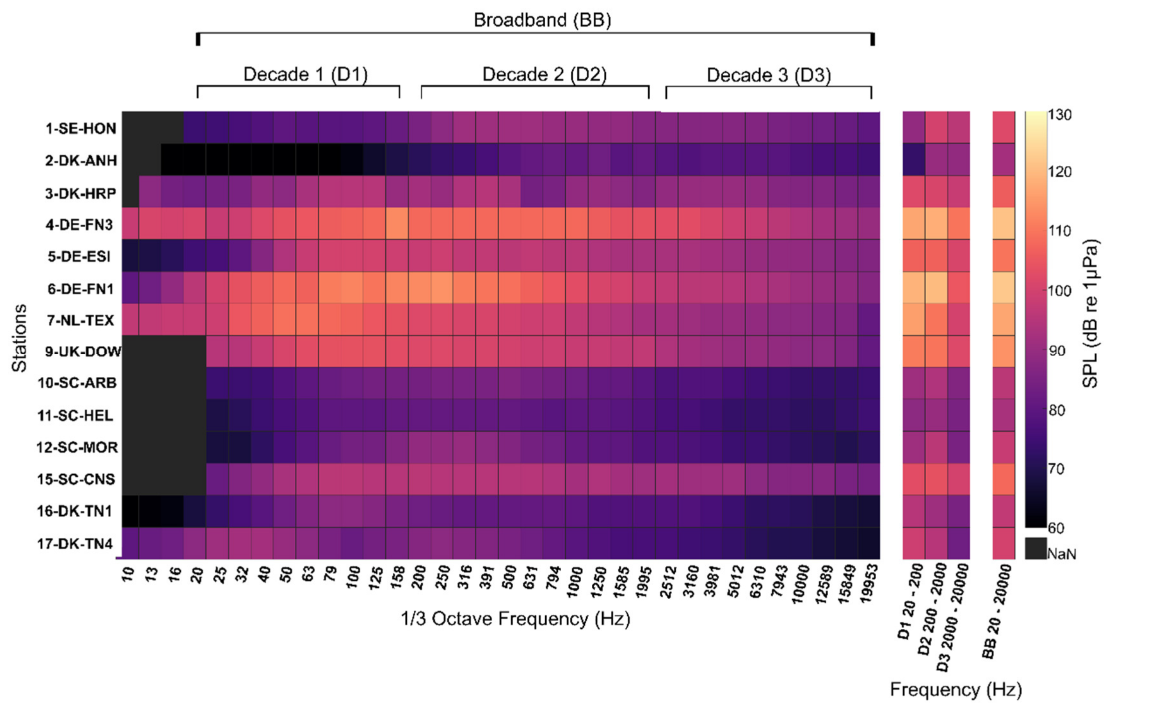


Figure 4: P50 (median) measurement noise levels [dB] shown for all JOMOPANS stations in 2019 (top) and 2020 (bottom) and various frequencies (1/3 octave frequency bands, 20-160 Hz, 200 – 1600 Hz, 2000 – 160000 Hz and 20-20000 Hz).

While site-specific identification of sources in the field measurements was not possible for the 2020 data given the time constraints, the main sources of noise are likely to remain similar to those reported for 2019. Accordingly, we have included a summary of the sound sources identified in the 2019 dataset (Table 4). The most prevalent sources are understood to be vessels not accounted for in AIS or VMS data (e.g. recreational fishing vessels), offshore wind farm construction, seismic surveys, and machinery noise.

Table 4: Summarised overview of sound sources at the different JOMOPANS stations in 2019 (Fischer et al., 2021). 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 2020 Validation

3.1 Methodology

Measurement data for 14 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) of sound pressure level for each one-third octave frequency band 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 as a broadband level (BB: 20 – 20000 Hz). Annual levels were calculated by taking the P50 of monthly values.

Model predictions at one-third octave centre frequencies between 10 – 20000 Hz were provided as percentile levels of depth-averaged SPL by WP4 for every month in 2020 at the nearest grid point location to each of the 14 JOMOPANS stations. Note that the nearest grid position may have been up to 1 km away from the sensor location.

The difference between datasets was computed by subtracting measurement data from model predictions for each one-third octave band between 10 – 20000 Hz (spectral) for each month (temporal). Measurement and model data were 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). Temporal patterns in model-measurement agreement were also investigated. The annual median level was subsequently calculated from the available months of measurement and model data. Some stations had better temporal coverage than others.

3.2 Spectral differences between model and measurement data 2020

Across all sites, the general pattern of difference between model and measurement data was that the model overpredicted relative to the field measurements in the northern North Sea (stations 10-15; Figure 2; Figure 5) and underpredicted relative to the measurements in the southern North Sea (stations 3-7; Figure 2; Figure 5). The Skagerrak area (sites 1,2, 16, 17) was more mixed, with both over and underprediction observed (Figure 5). Further detail is provided on the model/measurement agreement at different percentiles for each site in Figure 6 and Figure 7.

Similarly to the 2019 validation, in the southern North Sea, the greatest underestimation was at low frequencies (<50 Hz), with agreement generally improving with increasing frequency (Figure 5). At low frequencies, possible reasons for uncertainty include the addition of flow noise (confirmed to be present by WP5), a lack of quality data on sediment type and presence of seasonal thermocline in the Kattegat, and water depth. At mid frequencies, additional sound sources were not accounted for in the model. For example, offshore wind farm developments generating noise from crew transfer vessels (CTVs) while stationary (06-DE-FN1) and fishing vessels potentially absent from AIS/VMS records (10-SC-ARB).

In some cases, specific information was available which may account for some observed phenomena. For example, the decrease in sound levels observed at sites 2, 16 and 17 may be linked to a change in shipping routes in the Kattegat, although this should also be captured in the AIS data and hence the modelling. The two sites which were significantly underestimated by the model, stations 4 and 6 (Table 5), are known to be close to or within offshore windfarms, and generator and platform noise has been reported in the 2019 measurements. This would explain the discrepancy, since these sound sources are not captured by the AIS data on which the noise maps are based.

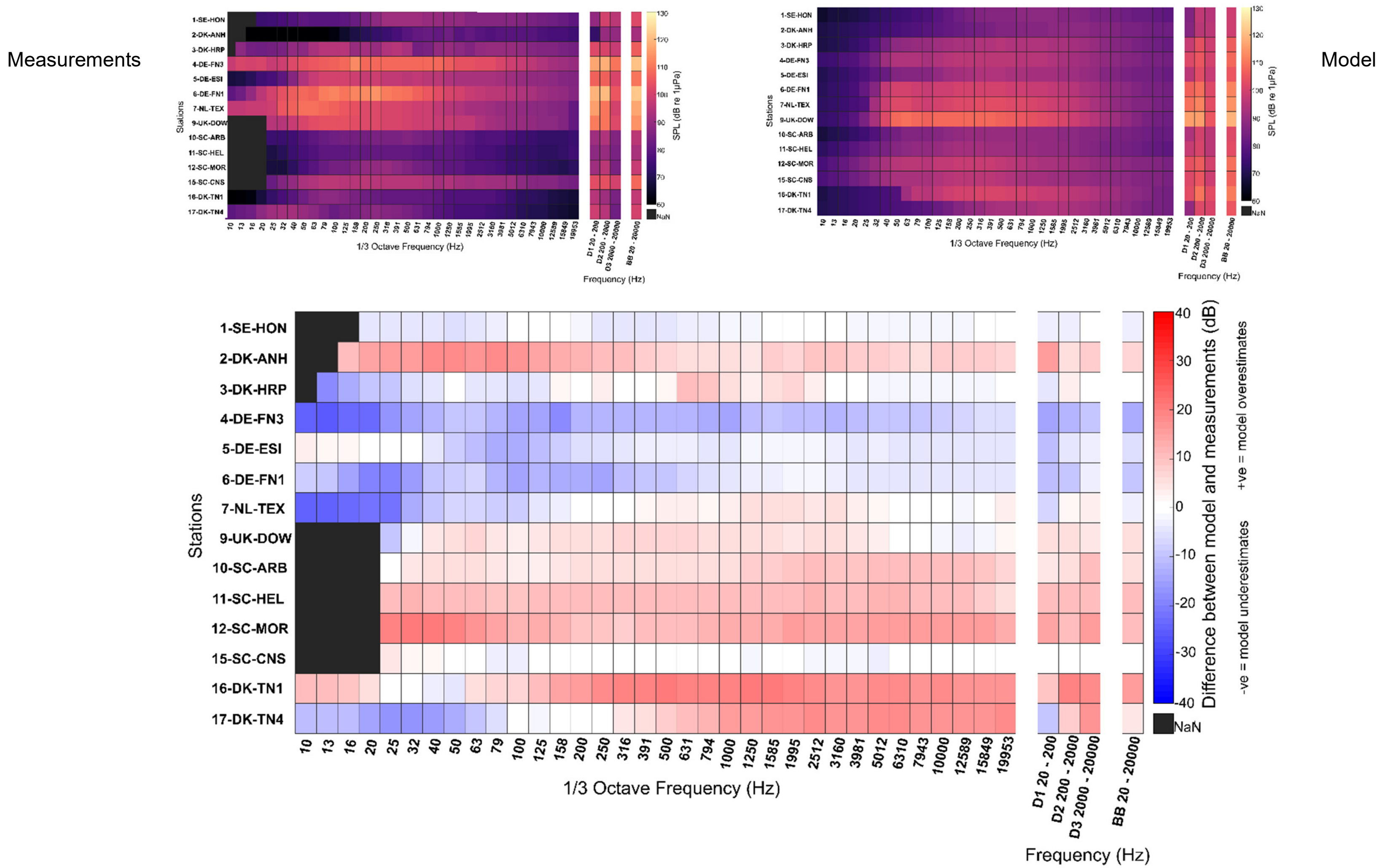


Figure 5: difference between P50 (median) values of model and measurement sound pressure levels [dB] in 2020 for all JOMOPANS stations and frequencies (1/3 octave frequency bands, 20-160 Hz, 200 – 1600 Hz, 2000 – 16000 Hz and 20-20000 Hz). Negative values (blue) indicate that the model underestimated the measured values, and positive (red) vice versa.

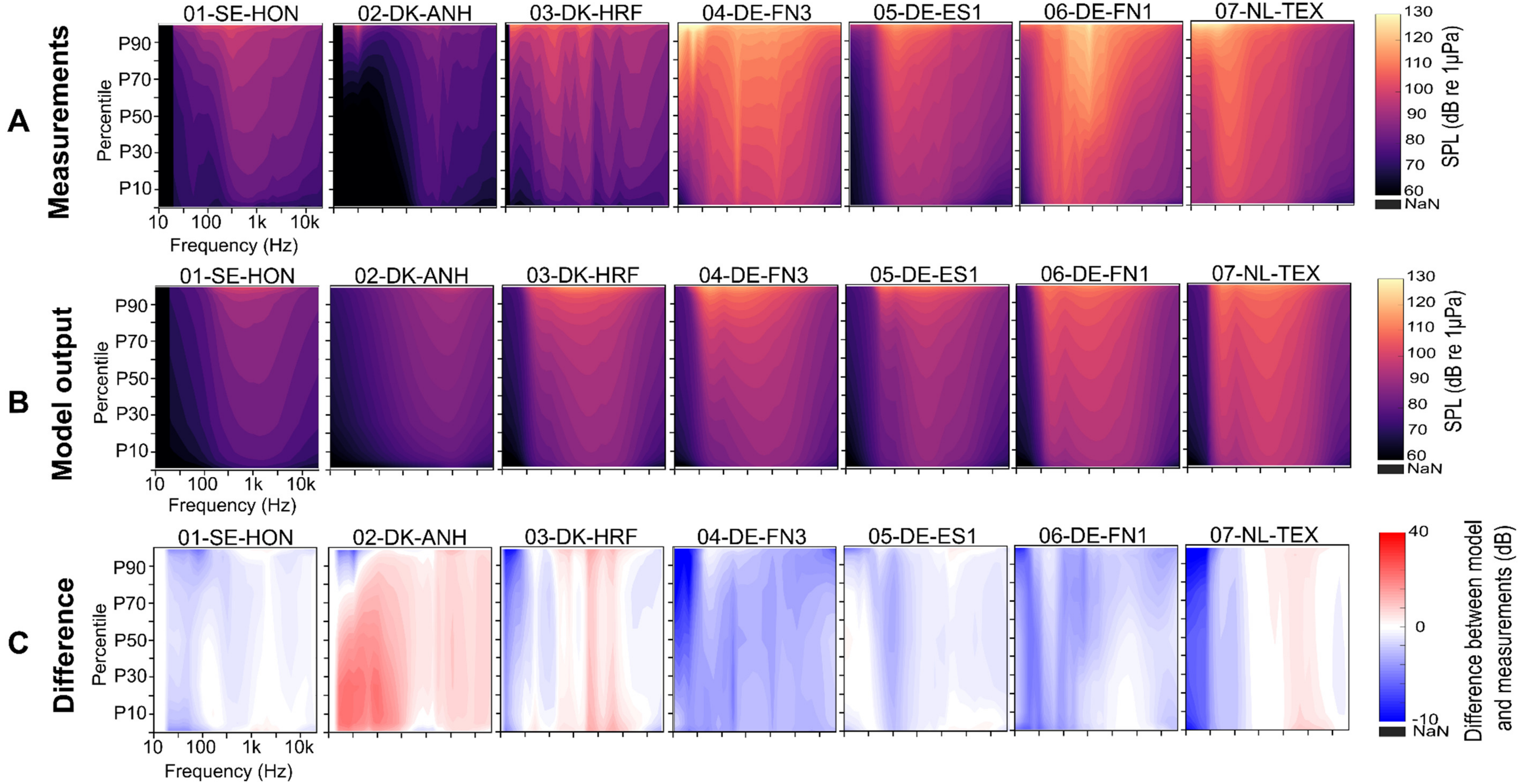


Figure 6: Annual percentile plots for seven JOMOPANS stations (01-07) showing (A) measurements; (B) model predictions; and (C) model minus measurements.

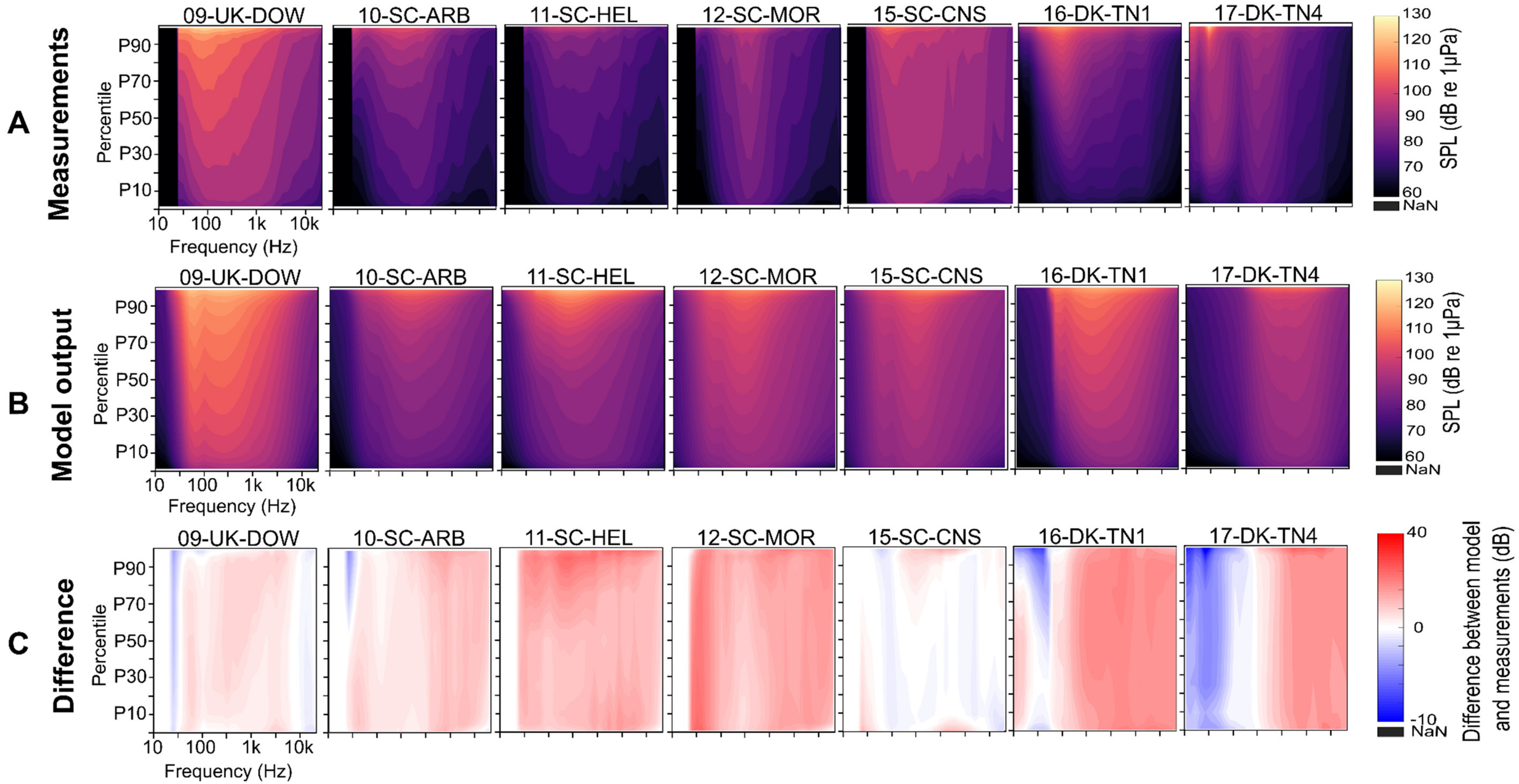


Figure 7: Annual percentile plots for seven JOMOPANS stations (09-17) showing (A) measurements; (B) model predictions; and (C) model minus measurements.

Table 5. Difference in the median between model and measurement noise levels (modelled minus measured) at all sites across 2020 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.

Station	20 – 160 Hz		200 – 1600 Hz		2000 – 1600 Hz		20 – 20000 Hz		Over/under prediction in 2020	Increase/ decrease in difference
	2019	2020	2019	2020	2019	2020	2019	2020		
01-SE-HON		-2.6		-3.1		-1.4		-2.5	N/A	N/A
01-SE-VIN	5.2		7		1.4		5.4		N/A	N/A
02-DK-ANH	-1.6	14.9	-6.4	6.3	-2.1	7.7	-4.6	7.2	Over	Increase
03-DK-HRF	8.1	-3.6	9.1	2.5	3.7	0.6	7.7	0.4	Over	Decrease
04-DE-FN3	-4.4	-14.2	2.4	-12.1	-3.3	-10.4	-2.1	-12.6	Under	Increase
05-DE-ES1	-9.2	-10.5	-4.6	-3.7	-4	-3.2	-6	-5.5	Under	Decrease
06-DE-FN1	-9.1	-11.4	-4.9	-10.2	-2.1	-3.3	-7.3	-10.4	Under	Increase
07-NL-TEX	-5	-7.4	3.8	1.9	4	3.3	-1.7	-3.3	Under	Increase
08-BE-WST	1.2		11.2		5.8		2.8		N/A	N/A
09-UK-DOW	0.5	4.6	0.7	6.4	1	3.6	0.6	5.3	Over	Increase
10-SC-ARB	-8.4	3.8	-7.6	5.5	-4.5	9	-7.3	5.7	Over	Decrease
11-SC-HEL	-6.5	10	-4.1	10.3	-0.1	10.6	-4.5	10.2	Over	Increase
12-SC-MOR		13.6		9.9		14.5		11.3	Over	N/A
14-NO-NTR	-6.4		5		3.1		-3.4		N/A	N/A
15-SC-CNS		-1		0.1		-1		-0.4	Under	N/A
16-DK-TN1	-7	8.5	3.5	18.8	1.5	17.9	-2.3	14.8	Over	Increase
17-DK-TN4	-18.1	-9.5	-9.8	7.6	-0.8	17.3	-9.6	4.3	Over	Decrease
18-DK-EDA	-11.1		-11.1		-14.8		-11.6		N/A	N/A

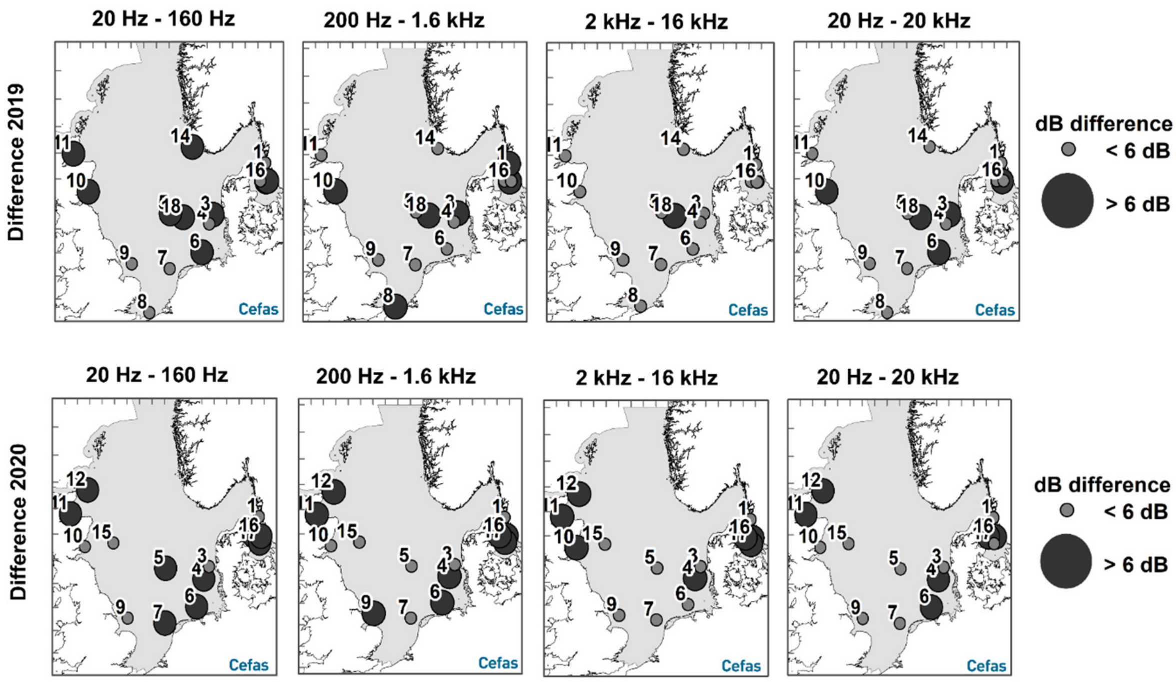


Figure 8: Difference between measurement and model outputs for the JOMOPANS stations in 2019 (top) and 2020 (bottom). Each subplot shows the yearly P50 (median) value for the difference between 20 – 160 Hz (left), 200 – 1600 Hz (left middle), 2000 – 16000 Hz (right middle) and 20 – 20000 Hz (right). Sites are numbered according to the convention in Table 1.

3.4 Temporal differences

To investigate temporal changes in model/measurement agreement, differences between the model predictions and measurements were also analysed monthly. Selected sites having the greatest temporal coverage are shown in Figure 9 - Figure 11. These sites were typical of the overall consistency in agreement across time for each site.

In general, there was limited variability in the monthly differences of across the JOMOPANS stations, with one exception being the shift from over- to underestimation at the UK Dowsing site during April and May 2020, due the construction of the Triton Knoll windfarm nearby. This temporal consistency in model/measurement agreement suggests that the underlying factors resulting in differences between measurements and model are also consistent across time, and may therefore be more straightforward to resolve.

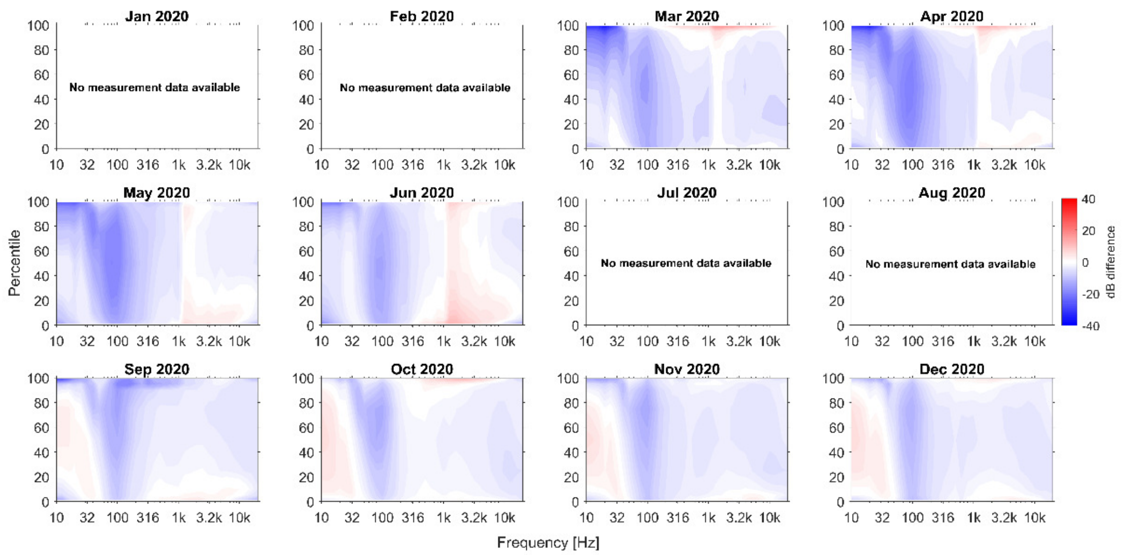


Figure 9: Monthly differences between measurements and model at the German ES01 site (site 5) in the central North Sea.

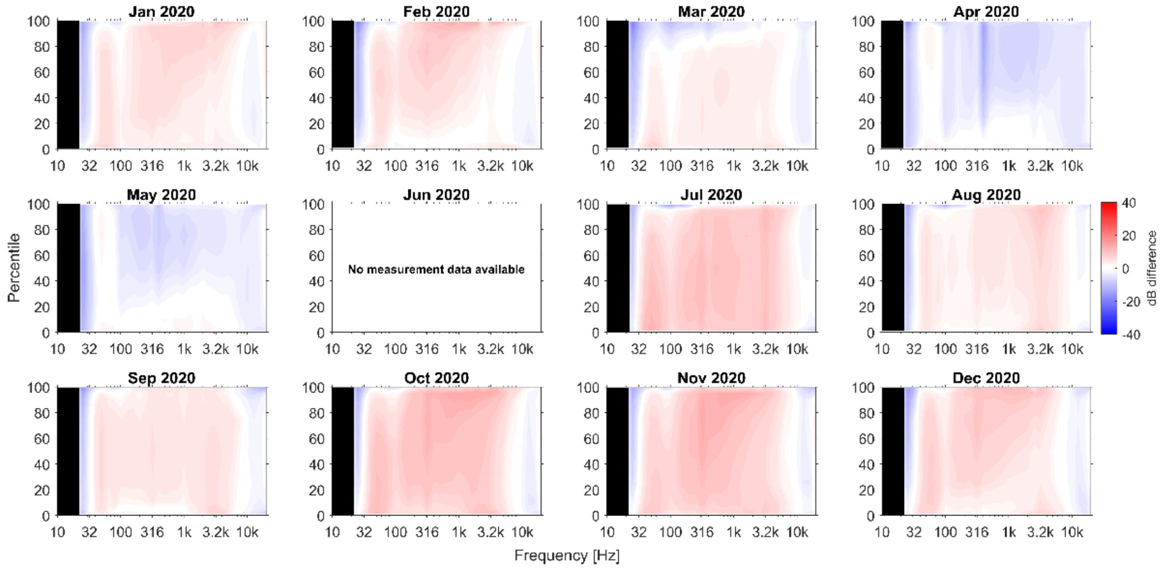


Figure 10: Monthly differences between measurements and model at the UK Dowsing site (site 9) in the southern North Sea.

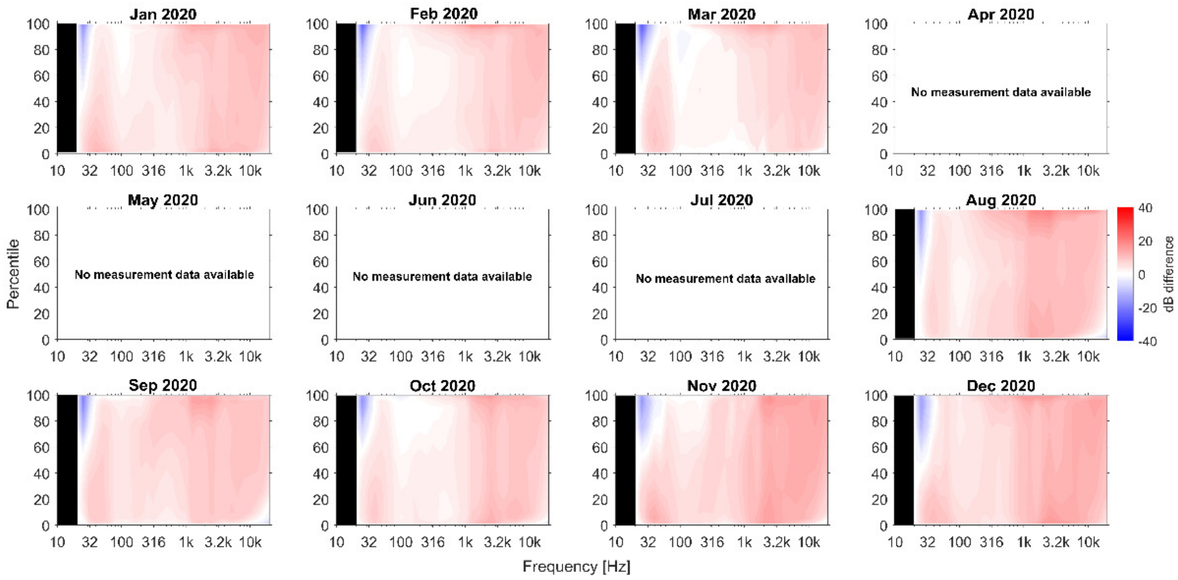


Figure 11: Monthly differences between measurements and model at the UK Arbroath site (site 10) in the northern North Sea.

4. Validation Summary and Recommendations

In general, the model predicted lower sound levels than the measured data in the southern North Sea (sites 3-7; Figure 2; Table 5), and higher sound levels than the measurements in the northern North Sea (sites 10-15; Figure 2; Table 5). The reasons for these differences are not clear in all cases and may not be attributable to model error, but in the southern North Sea, the proximity of some sites to operational wind farms and platforms is known to be a factor. In the Kattegat area (sites 1, 2,16,17), there was no general pattern (Table 5). Compared to the 2019 validation (Putland et al., 2021), a greater proportion of sites and frequency bands were overestimated by the model (Table 5). The trends in over- and under-prediction across frequency were also less consistent: for 2019, a majority of sites were underestimated at low frequencies (20–160 Hz), while the model more closely agreed with the measurements at higher frequencies (> 2 kHz), with all but one site having predictions within ±6 dB of the measurements (Table 5). However, for 2020, this pattern was absent: at low frequencies, almost as many sites were overestimated as underestimated (4 vs. 5) by >6 dB, and a majority of sites (7 out of 13) were outside the ±6 dB range in the high frequency band (2-16 kHz; Table 5).

The reasons for these discrepancies are not fully clear, but it is notable that of the 11 sites for which an annual comparison of measured noise levels was possible, 6 reported a decrease in noise levels of >3 dB, 3 sites remained within ±3 dB of 2019 levels, and only two sites (3 and 4) reported an increase >3 dB (Table 3). However, it should also be noted that relatively few sites had significant overlap in the months reported during 2019 and 2020 (Table 2). At 5 of the 6 decreasing sites, the fall in noise levels was severe, exceeding 9 dB (Table 3). It therefore appears that the overall picture of model/measurement agreement is that the general pattern of decreasing noise levels measured in 2020 (vs 2019) was not reflected by the model predictions, or at least not to the same degree, and may require further investigation of the measurements to rule out other sources of variability including measurement error. It has not been possible to evaluate the extent to which these discrepancies were driven by atypical shipping patterns arising from COVID-19 related restrictions in 2020 (including vessels not tracked by AIS), although given that the majority of these differences in shipping patterns would be captured by AIS, this factor may not account for much of the discrepancy between model and measurements.

In contrast to the 2019 validation, there was insufficient time during the 2020 validation to assess the measurement data in detail. The 2019 validation concluded that it was not possible to identify consistent errors which could be attributed to specific input data or methodological issues. Instead, it appeared that the discrepancies between model and measurements were caused by a complex combination of factors. This is likely to remain the case. As monitoring, modelling, and validation continue in future years, it may become possible to distinguish consistent factors in model/measurement discrepancy over longer time spans. For now, the confounding effects of COVID-related alterations to human activities make it especially difficult to draw general conclusions from this exceptional period of disruption.

Nevertheless, the underlying sources of model and measurement uncertainty are likely to remain the same. In the case of modelling, despite the model predictions being based on a recent and sizeable dataset of ship source level measurements, the validation results demonstrate the difficulty of accurately predicting ambient noise levels at low frequencies (<2 kHz) even when shipping noise dominates. The 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 validation at low frequencies (< 2 kHz), such as small vessels without active AIS transponders, seismic surveys, wind farm construction and operation, and generator/ platform noise. It may be worthwhile to broaden the model input data to include other sound sources. However, there is a trade-off between any improvement in model accuracy and the increased model complexity (due the increased computational cost, time, and difficulty in interpretating areas of uncertainty).

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 further developed and 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 2020. Rather than increasing temporal coverage, it is recommended to review the possibility of providing a more complete spatial coverage of measurements for model validation, including a variety of sediment types, water depths and noise sources.

Future work to improve the model could include a detailed analysis of individual ship passages, looking at the closest point of approach from both measurement and model data in the North Sea, to improve the validation of the ship noise model. This would be a large computational task that would need to be automated.

Acknowledgements

We thank all the partners within the JOMOPANS consortium for providing valuable feedback on this report, especially thanking Christ de Jong and Bas Binnerts from WP4 – modelling; and Dennis Kühnel, Jens-Georg Fischer and Fritjof Basan from WP5 – measurements for their substantial contributions.

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