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Aria of the Dutch North Sea

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3.1. EFFECT ON SOUND SPEED PROFILE ON SHIPPING SOUND MAPS

This section is submitted as [H.Ö Sertlek , B. Binnerts and M.A. Ainslie, The effect of sound speed profile on shallow water shipping sound maps, under review by JASA Express Letters]

Abstract: Sound mapping over large areas can be computationally expensive because of the large number of sources and large source-receiver separations involved. In order to facilitate computation, a simplifying assumption sometimes made is to neglect the sound speed gradient in shallow water. The accuracy of this assumption is investigated for ship generated sound in the Dutch North Sea, for realistic ship and wind distributions. Sound maps are generated for zero, negative and positive gradients for selected frequency bands (56 Hz to 3.6 kHz). The effect of sound speed profile for the decidecade centred at 125 Hz is less than 1.7 dB.

3.1.1. INTRODUCTION

Regulations in the USA [Marine Mammal Protection Act,1972; Endangered Species Act of 1973] the European Union (EU)[Directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008; Commission Decision of 1 September 2010], and worldwide [Lucke et al,2013] aim to protect and preserve the marine environment. The EU's Marine Strategy Framework Directive (MSFD) requires member states to achieve or maintain Good Environmental Status (GES) by the year 2020. Specifically, the wording of Descriptor 11 of GES requires underwater noise to be at levels that do not adversely affect the marine environment. The MSFD further requires monitoring of trends in the ambient noise within the 1/3 octave bands 63 and 125 Hz (centre frequency) [Commission Decision of 1 September 2010; Dekeling et al,2014]. These regulations increase the interest in understanding both local and global soundscapes [Anon et al, 2014]. The EU's expert group (TSG Noise) recommends the use of sound maps as a tool to monitor GES [Dekeling et al,2014]. While there is no standard procedure for sound mapping, the isovelocity assumption is sometimes used in shallow water simulations for simplicity. The errors resulting from neglecting the sound speed gradient are not self-evident. This paper focuses on assessing the validity of the isovelocity assumption for a realistic distribution of ships in shallow water. The aim of the present paper is to quantify the maximum relative error caused by the use of isovelocity assumption instead of realistic sound speed profile (SSP) for different frequencies for different locations with representative shipping density. In order to simulate a realistic distribution of ships in the North Sea, an Automatic Identification System (AIS) snapshot from January 2014 is used. The Wales and Heitmeyer formula is used for the monopole source level of the ships [Wales and Heitmeyer,2002]. The sound pressure level (SPL) is calculated for isovelocity, negative and positive sound speed profile gradients. SPL maps are shown for decidecade frequency bands (a decidecade is a logarithmic frequency interval equal to one tenth of a decade [ISO/DIS 18405]. This frequency interval is sometimes referred to as a "one-third octave" because it is approximately equal to one third of an octave) and compared with the isovelocity case results. The effect of the SSP for dense and sparse shipping is analysed.

3.1.2. METHOD

The effect of the SSP is quantified by comparing SPL relative to that for an isovelocity profile. The sound map for the isovelocity case is referred to henceforth as the "baseline map". Next, the

relative difference between the baseline maps and the selected SSP cases are compared by calculating the relative SPL as $\mathrm{SPL}_{\mathrm{Relative}}(x,y) \equiv \mathrm{SPL}_{\mathrm{SSP}}(x,y) - \mathrm{SPL}_{\mathrm{ISO}}(x,y)$, where $\mathrm{SPL}_{\mathrm{ISO}}$(the isovelocity baseline) and $\mathrm{SPL}_{\mathrm{SSP}}$ (SPL for a specified SSP) both include contributions from wind and shipping, and no other sources. At each location, the mean-square sound pressure is computed at 15 receiver depths and averaged over these receiver depths

For shipping, SPL is calculated as SPL=SL-PL, where SL is calculated from Wales and Heitmeyer, extrapolated to higher frequencies by following the trend measured by [Arveson & Vendittis,2000], as illustrated by Figure 8.16 from [Ainslie,2010]. The PL is calculated using adiabatic normal mode theory[Jensen et al,1994]. The eigenvalues are pre-calculated using KrakenC[Porter,1990] for each sound speed profile. The assumed source depth is 5 m for all ships. The sea surface is assumed flat, neglecting the effect of surface losses and scattering. The resolution of the receiver grid is 0.02 degrees. The propagation loss (PL) is calculated between each source and receiver separately. The contributions from each ship are then summed incoherently.

The wind generated sound is computed using the method of [Ainslie et al,2011], which assumes an isovelocity water column and locally uniform water depth.The chosen wind speed corresponds to the lowest mean monthly value (around 5 m/s at 10 m height) in the Dutch North Sea [ERA40 database from www.knmi.nl].

3.1.3. SOURCE DISTRIBUTION AND ENVIRONMENT

To investigate the effect of the SSP, a realistic ship distribution is used based on AIS data (available online at http://www.marinetraffic.com). The original AIS data had some gaps because of not receiving AIS signals for the northern part of the Dutch North Sea. The Maritime Mobile Service Identity (MMSI) number of each ship was tracked and the ship locations were interpolated over time for each ship separately. Next, a single time snapshot of AIS data is used in the simulation. In Figure 1 (right plot), a snapshot in time showing the shipping distribution as obtained from AIS data is shown. In the background of AIS distribution, the shipping density of the same day is plotted. The shipping density is plotted in gray tones, with the brightest tones (white) corresponding to the highest density. This shipping density graph suggests that the used points represent a representative ship distribution. The corresponding bathymetry (available online at http://www.emodnet-hydrography.eu) is plotted on the left. The two black markers in the bathymetry figure illustrate two locations, one southern and one northern, with dense and sparse

shipping activity, respectively. These locations are used later in the simulations to study the effect of the SSP in detail. The sediment type is assumed to be medium sand for the region considered.

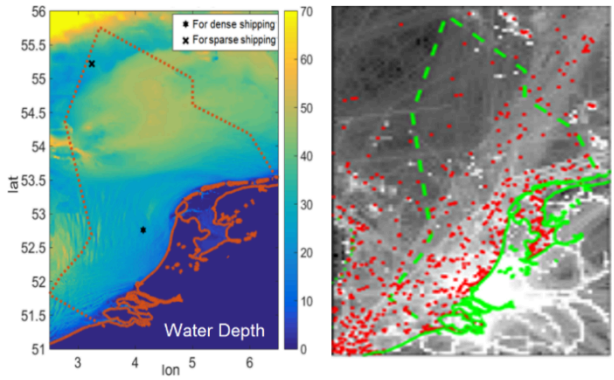

Figure 1. The bathymetry (left) and ship distribution (right) of an AIS snapshot from January 2014 (red circles) over the Dutch North Sea (bounded by the green line). The background (in grey tones) shows the shipping density of the same day (the white tones correspond to the highest shipping density). The distant (sparse shipping) and nearby (dense shipping) receiver points are shown on the bathymetry map.

The sound speed for the isovelocity case is 1500 m/s. Average winter and summer speed profiles are used from World Ocean Atlas (http://www.nodc.noaa.gov/OC5/woa13) between 2000 and 2010. These profiles are shown in Fig. 2.

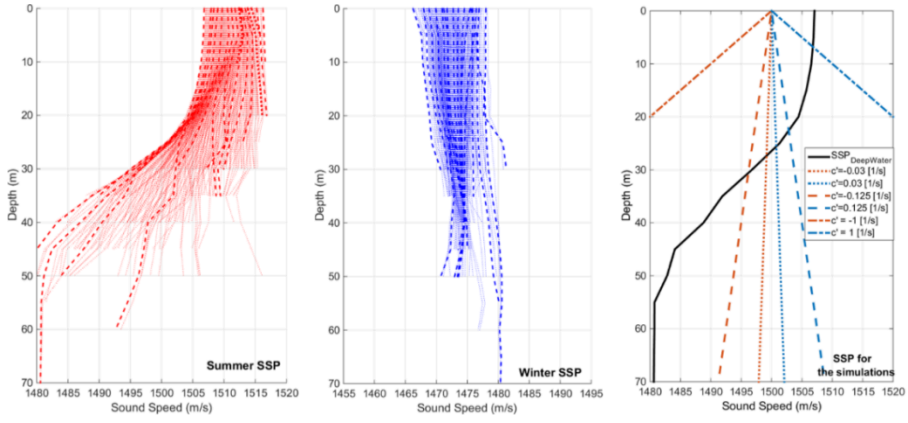

Figure 2. Summer (left), winter (middle) and the selected (right) SSPs for the Dutch North Sea

Fig. 2 gives an insight into choice of the sound speed profile for the comparisons. In this section, sound speed gradients of ± 0.03, ± 0.125, $\pm 1\ s^{-1}$ are used. The simulation is also repeated for a summer sound speed profile, representative for the deepest part of the Dutch North Sea to study the effect of this specific profile on propagation.

3.1.4. COMPARISONS

The baseline (isovelocity) maps are shown in Figure 3. Next, the sound maps for the relative SPL are generated for the different sound speed gradients. In Fig.4, the relative SPL maps for the negative and positive gradients are shown for two decidecade bands and a broadband map from 56 Hz to 3.6 kHz.

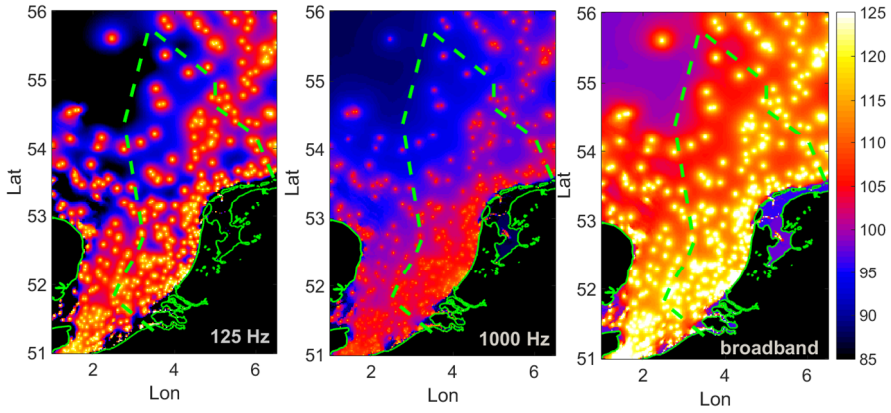

Figure 3. The sound maps for the isovelocity case (SPL_{ISO} dB re $1\mu\mathrm{Pa}^2$). *The squared sound pressure is depth-averaged over 15 receiver depths. Ship source depth is 5 m. The sound maps are generated for 125 Hz, 1 kHz decidecade bands and broadband (56 Hz to 3.6 kHz). The wind generated sound is added to all maps (wind speed is 5 m/s at 10 m above sea surface).*

Fig. 4 shows that the effect of the sound speed profile is decreasing for nearby ranges (corresponding to dense shipping) and increasing when there is a larger relative contribution from distant sources (sparse shipping). Where the shipping density increases, the effect of SSP decreases, because the distance to the nearest ship decreases. In order to illustrate this effect, two locations are chosen on sound maps in regions of high and low shipping density. The receiver points' latitude and longitude coordinates are (52.76° N, 4.14 °E) for dense shipping and (55.22° N, 3.24° E) for sparse shipping. Then, relative SPL is plotted versus frequency for each sound speed gradient. The variation of relative SPL versus frequency is shown by Fig. 5.

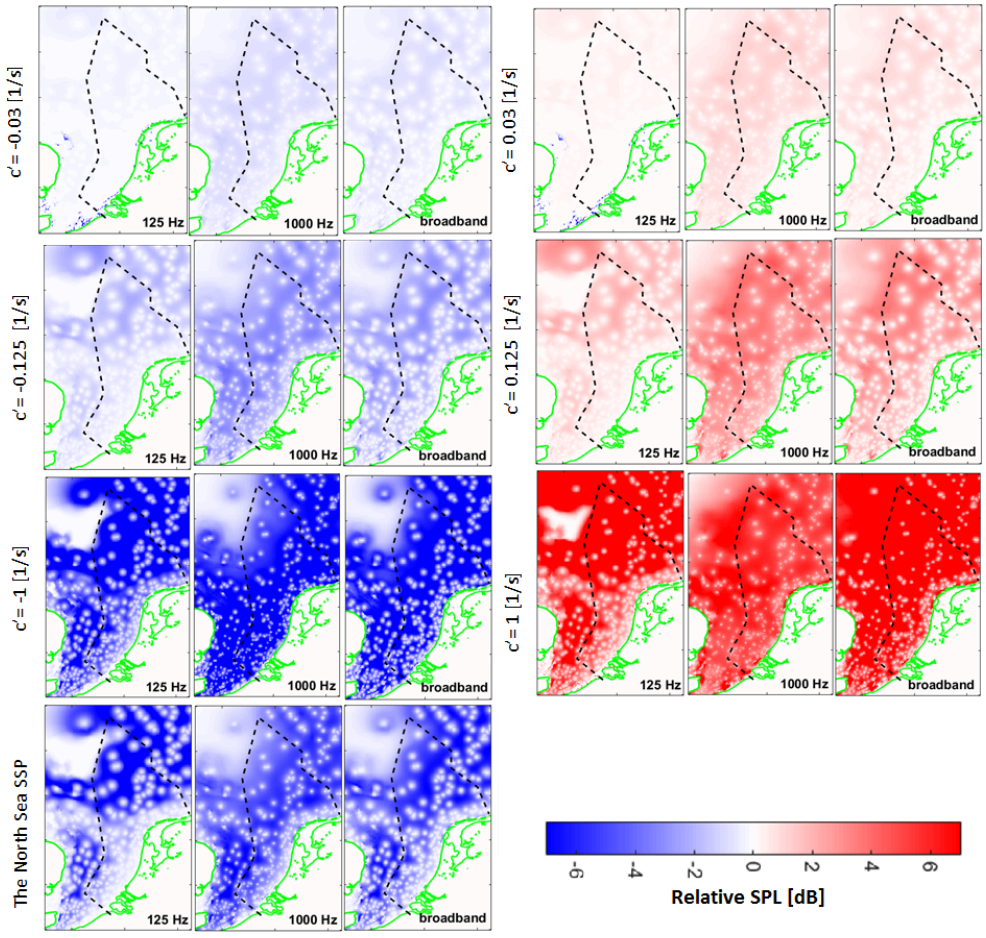

Figure 4. Relative SPL ($SPL_{\mathrm{Relative}} = SPL_{\mathrm{SSP}} - SPL_{\mathrm{ISO}}$) for negative(left) and positive (right) gradients (0.03 s^{-1}, 0.125 s^{-1}, 1 s^{-1} and the North Sea SSP). The sound maps are generated for 125 Hz and 1 kHz decidecade bands and a broadband map for the frequency range 56 Hz to 3.6 kHz (all decidecade bands from 63 Hz to 3.2 kHz).

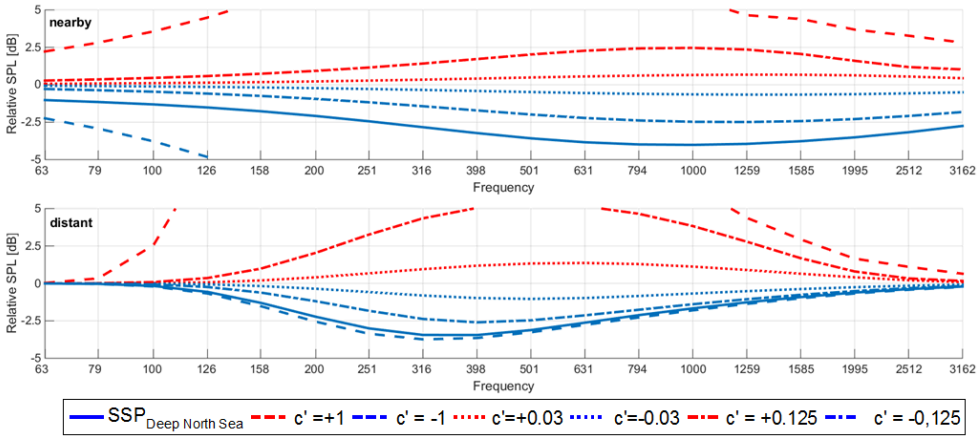

Figure 5. Relative SPL in decidecade bands from 63 Hz to 3.2 kHz *(with the wind noise contribution) is plotted versus decidecade centre frequency for each sound speed gradient at the receiver for the dense (upper figure – "nearby") and sparse (lower figure – "distant") shipping. The receiver points' latitude and longitude coordinates are) (52.76^{o}N, 4.14^{o} E) for dense shipping and (55.22^{o}N, 3.24^{o}E) for sparse shipping.*

These comparisons show that the relative SPL increases with increasing frequency at low frequencies because the effect of the SSP is enhanced if the associated surface duct (if the sound speed gradient is positive) or bottom duct (if it is negative) is cut on[Ainslie,2010a]. The effect of SSP starts to decrease at higher frequencies, as can be expected by the increasingly important influence of volume absorption and wind-related surface loss, both of which reduce the importance of long range propagation paths (See Chapter 3.2). The frequency of maximum effect is between 300 Hz and 1 kHz. The largest effect for the 125 Hz decidecade band, for the North Sea SSP, is -1.7 dB as seen from Fig.5 for the deep water SSP of the North Sea at nearby receiver (we exclude ±1 s^{-1} case as this gradient is unrealistically large).

3.1.5. SUMMARY AND CONCLUSIONS

Sound maps are generated for the decidecade frequencies between 63 Hz and 3.2 kHz. The spatially averaged SPL is used to estimate the average error due to the neglect of sound speed profile in the entire maps. Squared pressure is averaged over depth and area to calculate the spatially averaged SPL. These relative differences in the spatially averaged SPL are summarized in

Table 1 for the 125 Hz decidecade and 56 Hz-3.6 kHz bands. This table shows that the effect of the SSP on the spatially averaged SPL is less than 1.5 dB except 1 s^{-1} which is one of the extreme cases. This relative SPL is less than 1.2 dB for the 125 Hz decidecade band.

Table 1. The relative differences in the spatially averaged SPL for the broadband and 125 Hz.

SSP gradient [1/s]	**Relative Spatially averaged SPL for broadband (63 Hz to 3 kHz) [dB]**	**Relative spatially averaged SPL for 125Hz [dB]**
-1	1.5 dB	-0.3 dB
-0.125	0.3 dB	0.1 dB
-0.03	0.2 dB	-1.1 dB
0.03	-0.1 dB	-0.3 dB
0.125	-0.4 dB	-0.8 dB
1	-3.4 dB	-1.0 dB
The North Sea SSP	0.7 dB	0.7 dB

The comparisons for the dense and sparse shipping receiver locations help to understand effects of local shipping density. The effect of the sound speed profile on the shipping sound is larger for the distant receiver location than for the nearby receiver location. The relative SPL for the North Sea SSP becomes lower when the wind contribution is added to SPL. The realistic values should be similar to results obtained for 0.03 s^{-1} and 0.125 s^{-1} gradients which are much more similar to sound speed gradient of the shallow water according to Figure 2. The sound speed gradients are more similar to 0.03 s^{-1} and 0.125 s^{-1}. The maximum error is around 5 dB at 500 Hz decidecade band for the sound speed gradient of 0.125 s^{-1}. The increase in the wind speed decreases this error. For these gradients, the relative SPL is less than 2.5 dB for a winter profile and to up to 5 dB for a summer profile.