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The spatial structure of underwater noise due to shipping activities in the Celtic Sea

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Underwater noise is now classed as pollution alongside chemical pollution and marine litter (MSFD, 2012). Underwater noise from man-made sources arises from a number of sources including shipping activities. There are numerous examples of sound-induced effects recorded for various marine mammals, either in controlled situations, or opportunistically (MSFD-GES, 2012). Broad or narrow band continuous sounds, as well as pulses, have been documented to cause effects ranging from slight behaviour change, to activity disruption, avoidance or abandonment of preferred habitat (see Clark et al., 2009). Underwater ambient noise generated by shipping activities has increased significantly over the past decades (e.g. Mcdonald et al., 2006). Noise from shipping is a major contributor to the ambient noise levels in ocean, particularly at low (<300 Hz) frequencies (see McKenna et al., 2012).

In this paper we study the patterns and seasonal variations of underwater noise in the Celtic Sea due to shipping by using a coupled ocean model (POLCOMS) and a robust acoustic model (HARCAM). The ocean model is a 3D primitive equation finite difference model which was set up with 2 km horizontal resolution and 30 sigma levels in the vertical, see (Shapiro 2011, Chen et al, 2013). For this study, the model domain covers the Celtic Sea between 50.08°N to 51.83°N and 7.90°W to 4.00°W, with the tidal forcing applied at the open boundaries (11 constituents). The ocean model was run for the year 2010 using meteo forcing from NCEP-II data set (NCEP-DOE Reanalysis-II, 2013) to provide high-resolution hourly temperature and salinity fields for the acoustic model. The acoustic model was used to assess the underwater sound transmission loss (TL, or the decrease in acoustic intensity as underwater sound propagates away from a source), the absolute received level (RL, or the difference between the level at source and the TL), and the sound exposure level (SEL, or a cumulative measure of received sound energy over time at a specific location) under varying environmental parameters.

The transmission loss was calculated along 2D vertical transects (range and depth) assuming that the horizontal curvature of sound rays is small and the source is treated as an omnidirectional monochromatic point (Katsnelson, et al., 2012). Despite being generated by an omnidirectional source, the shipping noise pattern away from the ship is highly directional in both the horizontal and vertical planes (Hamson, 1997) due to azimuthal dependence of environmental conditions (depth of sea, temperature, salinity, seabed parameters). In order to evaluate the directional variability of noise we calculated the TL along multiple 2D transects from a single source with an azimuthal resolution of 2.5°. The sound levels were calculated within the area of up to 120 km from the ship. The source of sound was taken as a typical large cargo ship (length 155 m, average speed 15.5 knots).

Results of the ocean modelling show that the 3D pattern of the sound speed (SS) is closely linked to the temperature distribution. It reveals a strong vertical gradient in the summer and nearly uniform distribution in the winter. In the summer the sound speed patterns show strong horizontal gradients associated with the subsurface (i.e. not having a signature at the sea surface) coastal thermal fronts.

In summer, when the ship sails on the onshore side of the front, the sound energy is mostly concentrated in the near-bottom layer (between seabed and 20m level). In winter, the sound from the same source is distributed more evenly in the vertical. The difference between the sound level in summer and winter at 10 m depth is as high as 15 dB at a distance of 40 km from the ship in the offshore direction. When the ship is on the seaward side of the front, the sound level is nearly uniform in the vertical, and the transmission loss is significantly greater (25dB at 40 km distance) in the summer than in the winter.

The directional structure of the received sound level (RL) from the same ship is different at different depth levels and in different seasons and is highly dependent on the location of the ship in relation to the thermal front. When the ship is in shallow waters (i.e. onshore of the thermal front in summer), the received sound energy at 15 m depth is mostly concentrated in an narrow band (about 20 km) along the coast. At deeper depth levels the pattern is more omnidirectional. In the winter the pattern is omnidirectional both at shallow and deep levels. When the ship is in

deeper waters (i.e. offshore of the thermal front in summer) the pattern of the RL is nearly omnidirectional both in summer and winter for all studied depth levels.

The sound exposure levels were calculated for the passage of the ship along the common shipping line from the western end of Cornwall to South Wales. The SEL values differ dramatically between summer and winter, with difference of the order of 10-15 dB over majority of the study area.

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