Intercomparison of ambient acoustic spectra in inland and coastal waters

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Abstract

This paper compares the observed ambient sound levels at two very different sites, relating both to independent estimates of wind speed and rain rate. The spectra for wind-only conditions at the two sites show great differences, especially at low wind speed. The spectra associated with rain were sufficiently different from the wind-only spectra (either in terms of spectral slope or the intensity at 14.5 kHz) to support the development of a generic rather than site-specific rain detection algorithm.

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1. Introduction

Rain at sea is important for the effect it has on the damping of waves and the enhancement of air-sea gas exchange. However, it is the great concern about its effect on ocean circulation, through changes in the salinity of surface waters, that has led to the widespread interest in the global monitoring of rainfall. Tests in controlled environments have shown rain to generate a distinctive spectrum, readily distinguishable from that due to wind, and consequently there have been plans to use acoustic rain gauges (ARGs) to provide regular rainfall monitoring in selected areas. Jeff Nystuen has performed deep ocean tests of such equipment using both drifters[1] and the TOGA-TAO moorings in the Pacific[2].

Here we revert to tests close to land, where the availability of a panoply of other sensors allows a more detailed validation. The equipment used in based on sensors and circuitry developed by *Metocean Ltd of Nova Scotia*, which, every 1.5 minutes, records the acoustic intensities in 16 channels spanning 500 Hz to 50 kHz. We deployed the equipment in two very different locations: Loch Etive, a sheltered saltwater loch in southwest Scotland, and secondly off the west Wales coast near Aberporth, where the buoys were exposed to swell from the Atlantic. In both locations neighbouring meteorological buoys provided regular wind speed measurements. A number of rain sensors were available; we use here data on a 5 km x 5 km grid derived from the Met Office radars, as their availability was common to both sites. In section 2 we compare the wind-only spectra observed at the two sites, and in section 3 we examine how well the spectra of rain can be distinguished from those of wind.

2. Comparison of wind-only spectra

We discuss first the acoustic intensities generated by wind, as its contribution is nearly always present. The meteorological records from the buoy site at Aberporth were only available at hourly resolution, so, for both trials, we consider acoustic spectra in hourly ensembles. Both sets of data have been screened for rain (using the rain radar data), and for Loch Etive we used only night-time data to minimise possible anthropogenic noise.

Figure 1 shows the mean acoustic intensities at channels 4, 8 and 12 (2 kHz, 6 kHz and 20 kHz) plotted against wind speed. Loch Etive had been chosen for early trials as it was known to be an exceptionally quiet environment, with little wave activity or noise from shipping. The observations in Fig. 1a show that at low wind speeds the observed intensities were typically 17 dB less than at Aberporth for the same conditions. The discrepancy is less for higher wind speeds and frequencies. Loch Etive was a sheltered location, such that wind speeds above 8 ms^{-1} were rare. On the other hand, such winds were more common at Aberporth, enabling the mean intensity curve to be determined for higher wind speeds than in Loch Etive.

Above approximately 6 kHz, there is no wind speed dependence below 2 ms^{-1}, but such a dependence exists at the lower frequencies. However the most striking observation from the intercomparison of the two datasets is the degree of scatter in the Loch Etive data. All the plots show greater variability at low wind speeds (not surprising given the use of logarithmic units), but the variability at Loch Etive remains high over a larger range of wind speeds. Of particular note is the large apparent variability at low wind speeds for the 20 kHz data in Loch Etive (Fig. 1c). It is probable that some other noise source is intermittently contributing to the high frequency signal, but we lack the ancillary observations to

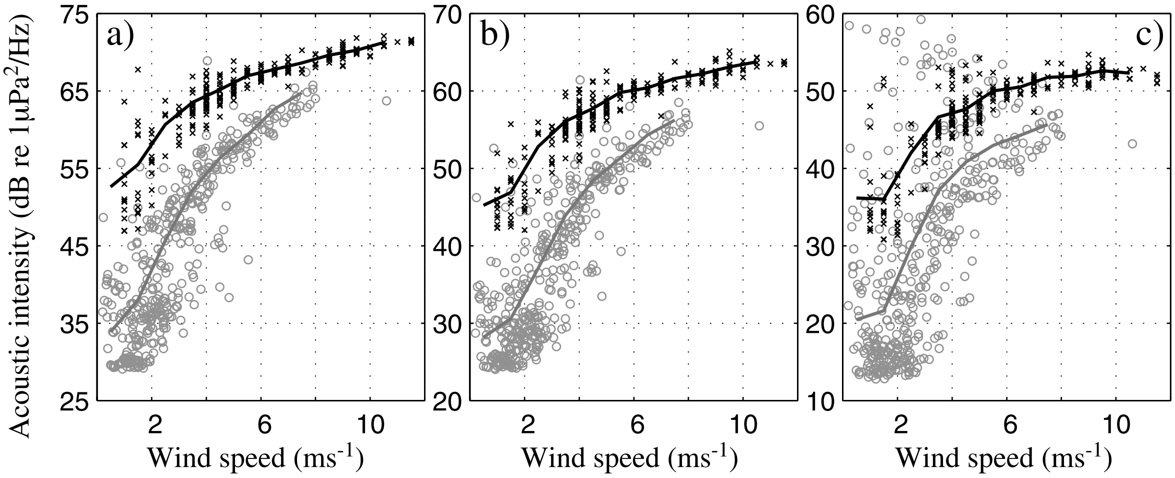

Figure 1. Observed acoustic intensities as a function of wind speed at a) 2 kHz, b) 6 kHz and c) 20 kHz. (Note the scaling on the y-axes are different.) The light circles (dark crosses) show individual hourly averages for Loch Etive (Aberporth), and the light (dark) line shows the average intensity for each 1ms^{-1} bin. [Note the wind speed data from Aberporth are quantized at 0.5 ms^{-1}.]

confirm this. In nearly all cases, the hourly averages for a given set of conditions (wind speed and location) show a greater degree of scatter than the individual 1.5-minute records do within an hour. This indicates that in 'rain-free' conditions knowledge of the wind speed alone is not sufficient to explain the observed acoustic levels. The acoustic intensities due to wind may be varying due to wave development (fetch), atmospheric stability or the spasmodic existence of non-meteorological sources.

3. The detection of rain

The underwater acoustic spectra associated with wind-only conditions are close to linear in log-log space i.e. dB vs. $\log_{10}$(frequency). We determined the spectral slopes by fitting a line over the span 0.5-10 kHz (Fig. 2a) and then examined the variation of this parameter with wind speed and the absence/presence of rain. Fig. 2b shows that at high wind speeds the spectral slope observed at both sites is around -15 dB/decade, whereas at low wind speeds the magnitude of the slope can be much greater. The results for Aberporth are consistent with the wind contribution always having a slope of ~-14 dB/decade, but that at low wind speeds some other 'background' source is more prominent.

The underwater acoustic spectrum in medium to heavy rain (more than, say, 3 mm h^{-1}) is expected to have a much flatter slope. The circles on Fig. 2b show the spectral slopes when the radar data indicate rain within the pixel over Loch Etive. These points, including both light and heavy rain confirm that rain is associated with less steep spectral slopes, albeit that some values lie within the variability associated with 'wind only'. However, as there is a great disparity between the cell size of the rain radar product and the effective listening area of the ARG, it is probable that several of the spectra are incorrectly classified. There were few observations of rain at Aberporth, and all those corresponded to drizzle, which does not affect the spectral slope.

The second distinctive feature of rain-affected spectra is the 13-20 kHz 'drizzle peak', associated with the small bubbles produced by light rain[3]. By extrapolating the line fitted for the range 0.5-10 kHz, we can determine how much the observed intensity at 14.5 kHz exceeds that expected (see Fig. 2a). Figure 2c shows the size of the drizzle peak, for the observations both with and without rain. At low wind speeds the enhancement by rain of the intensity at 14.5 kHz can be more than 10 dB, but the effect is muted for wind speeds above 6 ms^{-1}. This is because wind reduces the efficacy of bubble formation by small raindrops[4].

4. Discussion

There are considerable differences in the acoustic intensities recorded at the two sites. The sheltered location in Loch Etive led to typically lower wind speeds than Aberporth, but the sound levels were lower at Loch Etive for nominally the same wind speeds, with this effect being particularly pronounced at low wind speeds (Fig. 1a). Although the buoys had undergone major modification between the two deployments, this is not believed to be the cause. The difference in absolute sound levels at the two sites are probably due to i) the absence of wave activity in Loch Etive, ii) a much shallower bottom at

Aberporth, affording the possibility of additionally detecting sound reflected from the bottom, and iii) strong stratification in Loch Etive due to fresh water riverine input.

However, despite all this, various parameters derived from the spectra correspond quite clearly with independent observations of rain. The drizzle peak is the most distinctive feature. Under low wind conditions, light rain causes an enhancement of the 14.5 kHz signal by more than 10 dB; this effect is much diminished in high winds. Medium and heavy rain rates reduce the spectral slope, but this effect appears less clear cut, on account of the great variability for wind-only conditions at Loch Etive. Thus, despite the very different wind-only 'background' spectra, similar techniques can be used for *detecting* rain at the two sites. Quantitative estimates of rain from acoustical sensors often show large errors[5], but much of the mismatch may be due to errors in the ancillary data or a marked difference in the spatial or temporal resolution of the acoustic and validation data.

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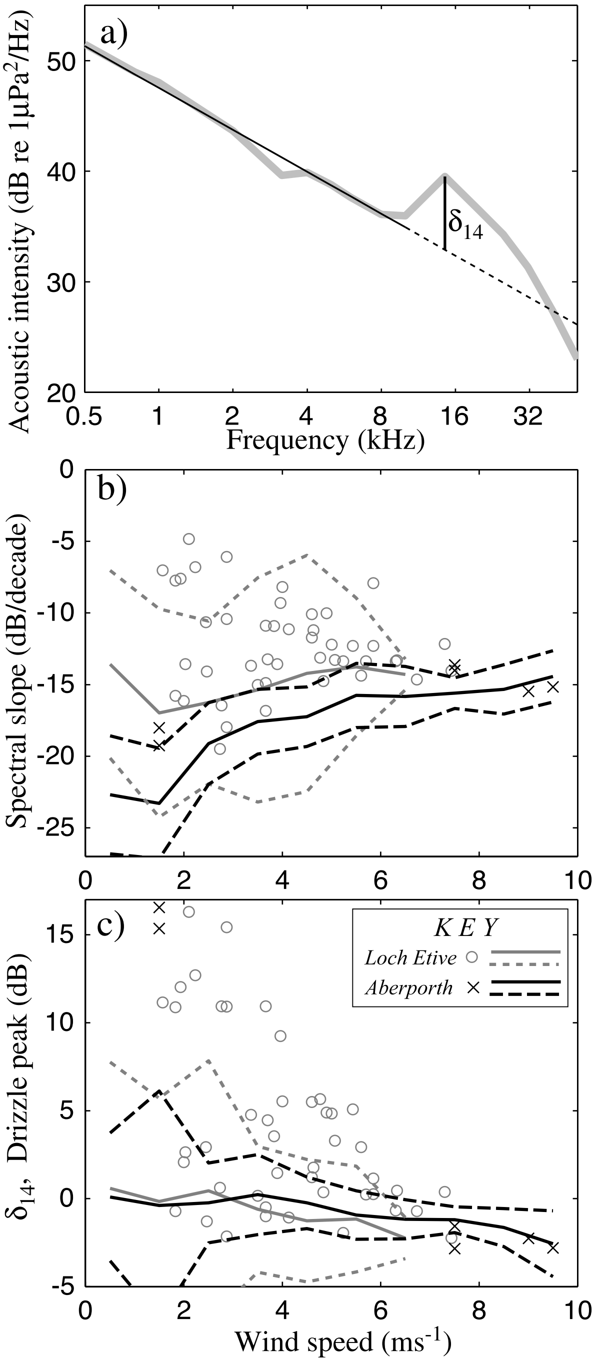

Figure 2. a) Definition of spectral slope (over 0.5-10 kHz) and drizzle peak, δ_{14}, using an example spectrum from Loch Etive. b) Spectral slope and c) drizzle peak as a function of wind speed and rain rate. [The lines indicate the approximate envelope of observations for wind-only conditions, with the solid lines delineating the mean binned in intervals of 0.5 ms^{-1}, and the dashed lines representing ±2 std. dev. either side. The crosses and circles are for individual instants classified as rain according to the radar data.]