

Underwater Acoustics: Picking out the sound of rain

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Abstract

Wind and rain are known to be significant sources of underwater noise. Previous researchers have developed algorithms to analyse the spectral content of underwater sound, classify according to source, and provide quantitative values. In this paper we describe the evaluation of such algorithms using acoustic data gathered in Loch Etive on the west coast of Scotland. The validation datasets are provided by a buoy-mounted anemometer and a tipping-bucket gauge. In summary, the detection of rain is found to be reliable, but the quantitative comparisons show significant scatter.

1. Introduction

Rain is one of those environmental variables that is notoriously hard to measure. It varies on such short spatial and temporal scales that it is hard to get a meaningful average for a region. This problem extends to the oceans, where the area-averaged rain rate is an important part of the freshwater budget affecting the salinity and thus the density of surface waters. One of the developing technologies for this aspect of hydrology is the use of acoustic sensors to detect the sound associated with rain. By using hydrophones well below the surface it should be possible to get an areal average rather than just a point measurement. However the apparently simple task of taking laboratory results and using them to develop an environmental device for monitoring rain is complicated by all the factors of the real world.

There are many mechanisms by which rain can generate underwater sound – the percussion of raindrops on the surface (*Nystuen*, 1986), the ringing of single bubbles produced by "small-size" raindrops (*Pumphrey et al.*, 1989) and the panoply of splash products and attendant bubbles caused by "large" raindrops (*Nystuen et al.*, 1993). Thus identical rain rates may generate different acoustical spectra according to their different drop-size distributions. This situation is made much more complex by the addition of wind, which not only generates its own sound (*Vagle et al.*, 1990), but also affects that generated by rain (*Medwin et al.*, 1990).

Various organizations have developed sensors that respond to the acoustic frequencies of interest and generate estimates of rain rate. In this short paper we present some of our experiences in attempting to validate the output of one such instrument. Although we have tested the instrument in a number of different locations (*Quartly et al.*, 1998), we concentrate here on the results obtained in Loch Etive, a deep saline loch on the west coast of Scotland. The advantage of this location over a deep sea deployment is the ability to surround the area with other rainfall instrumentation.

2. Experimental setup

The Acoustic Rain Gauge (ARG) that we used was built by *Metocean Ltd* of Nova Scotia; it records the acoustic intensity in 16 channels spanning 500 Hz to 50 kHz. After some adjustments to the equipment to fit a logger and enhance the battery capacity, we were able to record spectra every 90s for a month. From August to December 1999 the instrument was operated nearly continuously in Loch Etive. The mooring arrangement was as shown in Fig. 1, with all the instruments in a deep bay on the north side of the loch. [The tipping bucket gauge had to be placed on a large raft, since we were not granted access to the nearby land; however the raft does provide a very stable platform.] Independent wind information is provided by the anemometer on the meteorological buoy (the data from the 2 WOTAN buoys are not discussed here). We also had measures of sea and air temperature, pressure and wind direction. Further validation data are provided by rain radar coverage of the regions and a *Present Weather Sensor* and *Climate Data Logger* from the UK Met. Office, which were located 8 km to the southwest of the mooring site.

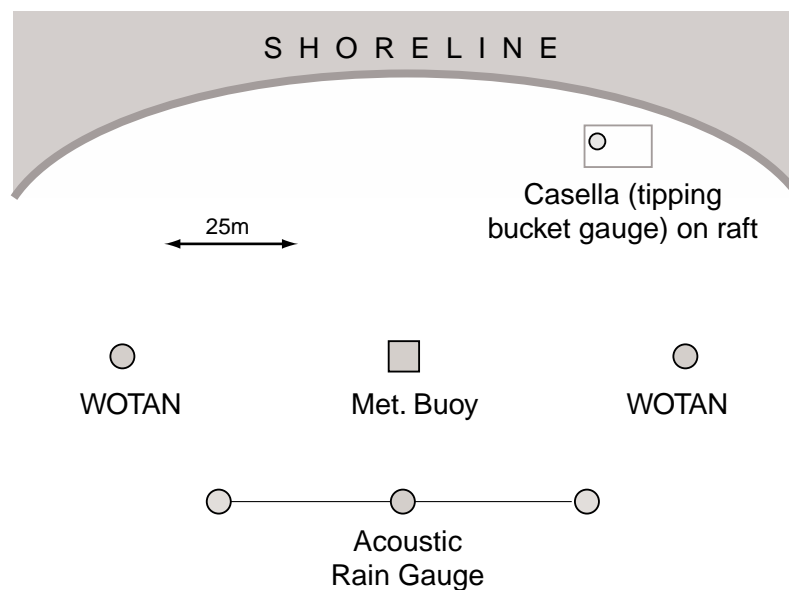


Fig. 1: Mooring arrangement in Loch Etive.

3. Effect of wind

One of the greatest noise contaminants is the wind, which generates sound across a broad range of frequencies. Thus we need to understand its effect in order to be able to allow for it. Figure 2a shows how the mean acoustic spectra vary with wind for rain-free conditions. The mean background level shows little variation with wind speed for winds less than 2 ms^{-1} , so the algorithm of *Vagle et al.* (1990) is only valid for winds higher than that. However in the range $3\text{-}7 \text{ ms}^{-1}$ their relationship lies above the mean levels that we observe, but their algorithm is for inferring wind speeds from acoustic intensity rather than *vice versa*. For a given wind speed, the broad spread of acoustic intensity about the mean (typical s.d. of $\sim 5 \text{ dB}$) was not significantly reduced by forming 20-minute (13-14 observations) averages. Thus for these rain-free observations, some other (slowly varying) factor is modulating the acoustic levels generated by wind. This could be wind direction (through its effect on the fetch), atmospheric stability or tidal currents (affecting the wind speed relative to the water surface). We have yet to investigate this in detail.

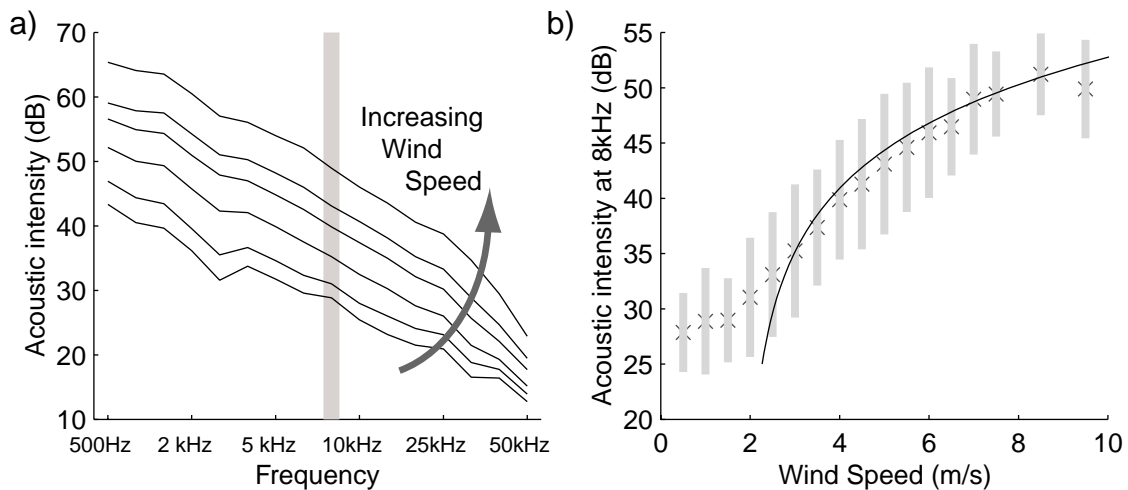


Fig. 2: a) Mean acoustic intensity as a function of frequency (8 kHz channel highlighted in grey). b) Acoustic intensity at 8 kHz as a function of wind speed. (Grey bars show variation in level (mean ± 1 s.d.); black curve gives the inversion of Vagle et al. (1990).)

It should be noted that, even for our data, the 8 kHz channel shows a lower s.d. about a mean wind speed curve (Fig. 2b) than do most of the other channels. Coupled with its low response to light rain, this confirms that 8 kHz is the best single channel to use for wind estimation.

A simple comparison of wind speed from the meteorological buoy with that from the acoustic sensor gives a scatter of $\sim 1.5 \text{ms}^{-1}$ (Fig. 3a). However that figure hides the good correlation that can sometimes be found between the two sources of data. Figure 3b shows a 2-day record from Loch Etive during which time the r.m.s. difference of the two measures was only 1.1ms^{-1} , and would be appreciably less without the anomalously high acoustic signal at the start of day 328. In our earlier work in Loch Long (Quarty et al., 1998) we found a worse overall agreement between anemometer and acoustic gauge, but again with periods when the output of the two instruments was well correlated.

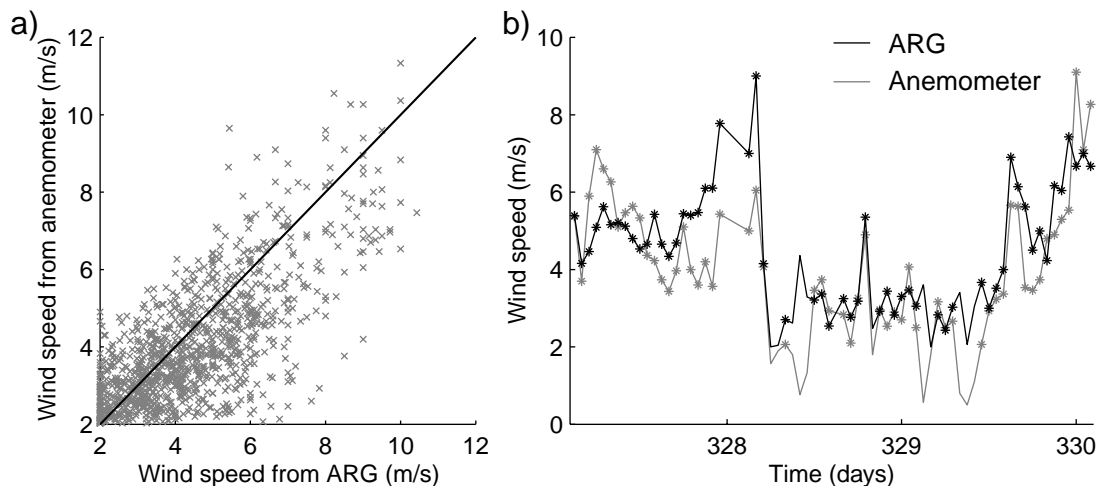


Fig. 3: Comparison of hourly-averaged wind speeds. a) Scatter plot shows only moderate agreement; b) Time-section indicates that both instruments record same changes.

4. Detecting and measuring rain

The signature of light rain or drizzle is predominantly due to raindrops of diameter 0.8-1.1mm (Medwin *et al.*, 1990), which generate a peak around 14.5 kHz (Fig. 4a). However in this regime increased wind can suppress the rain signal through reducing the number of raindrops impacting the surface at normal incidence (Medwin *et al.*, 1990). Thus the recommendation of Nystuen and Selsor (1997) is just to note the presence of a 14.5 kHz peak, and assign a rain rate of 1 mm hr⁻¹.

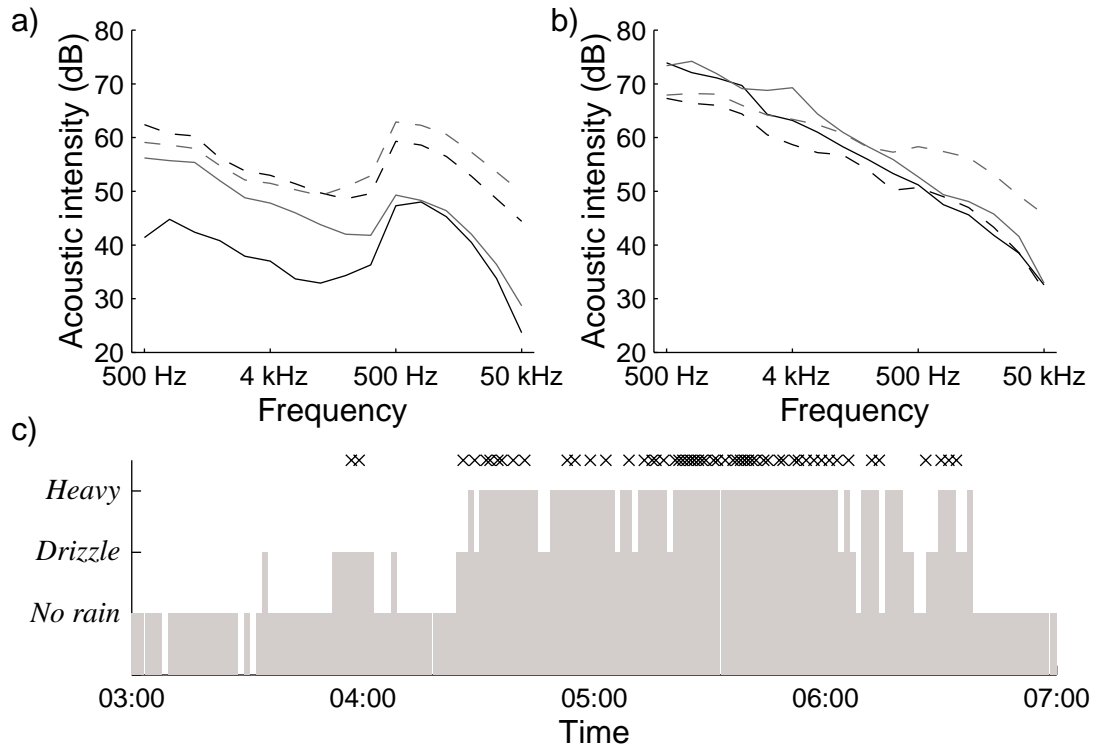


Fig. 4: a) Various spectra of light rain under different wind conditions. b) Same for heavy rain. c) Comparison of rain detection for the early morning of Day 300; crosses mark times when bucket tipped, grey bars indicate rain classification from acoustic data. (Lack of grey indicates data classified as 'contaminated'.)

Large raindrops present in heavy rain affect frequencies from about 5 kHz upward, as illustrated in Fig. 4b (cf. slope of high wind spectra in Fig. 2a). As heavy rain will significantly affect the 8 kHz channel, wind speed algorithms are no longer viable. Often, the acoustic detection and classification of rain accurately matches the rain detected by other sensors (see Fig. 4c); however there may be a problem with the presence of other acoustic sources which can affect any of the frequencies of interest. Nystuen and Selsor (1997) showed that distant shipping often manifests itself as low frequency noise, with the difference in intensities between 5 kHz and 25 kHz exceeding 20 dB (instead of normally ~12 dB). Similarly biological sources such as snapping shrimp (present in shallow tropical waters, but not Scottish lochs!) only generate significant sound between 3 and 10 kHz, and so redden the spectrum. Nystuen and Selsor's algorithms are coded into the instrument we have so that those anomalous signals are flagged as 'contaminated'.

The acoustic signal of heavy rain is not believed to be affected by the wind, so quantitative measures of heavy rain should be achieved in a wide range of wind conditions. The rain algorithm of Nystuen *et al.* (1993) simply uses the power level in the 5 kHz channel. However we still note many anomalous records that are not automatically flagged. In some cases there are many hours with very high levels at all frequencies,

which the instrument classifies as ‘heavy rain’. On other days, the fraction of acoustic data classified as ‘contaminated’ may be 25-30%, whilst on a previous day few data were so flagged. This again points to environmental changes which are not adequately represented by just the two parameters, wind and rain. These both affect the reliability of quantitative comparisons (Fig. 5).

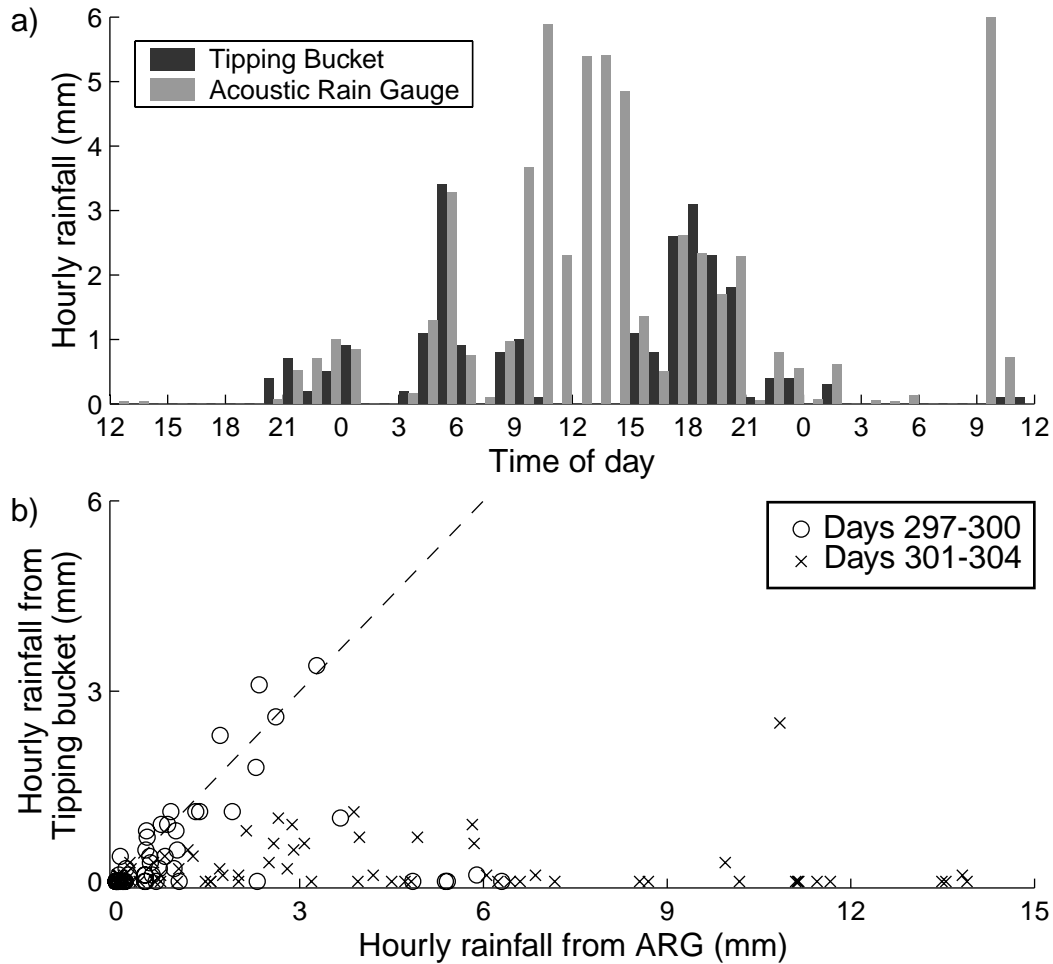


Fig. 5: a) Time series of hourly rainfall accumulations from two independent sensors (midday Day 299 to midday Day 301). b) Scatter-plot for 8-day series.

In the periods illustrated there are very few instances of rain picked up by the tipping bucket but not the ARG; and also the acoustic method rarely underestimates the tipping bucket value. These observations indicate that the ARG is sensitive enough to detect the smallest rain rates, and can give accurate values up to reasonable rain rates. However there is a problem with acoustic contamination giving false detections of rain, and also sometimes leading to very high rain rate estimates. One possible cause is anthropogenic noise from near-shore activity (the mooring site is quite close to a managed mussel farm). Thus while Figs. 3 and 5 show good quantitative agreement can be achieved over reasonable periods, it is clear that a better classification of the noise environment is required to overcome both the occasional large extents of "contaminated data" and the anomalously large rain values from nominally "heavy rain data". However we do not wish to develop particular flagging criteria for a specific loch, given that the eventual field of operation will be the deep ocean.

5. Conclusions and further work

Whilst the various mechanisms for noise generation by rain are now fairly well understood in the laboratory, the extension to a real-world application is more problematic. The sound levels associated with wind show significant variation about a wind speed-only relationship. Using wind direction information and air-sea temperature differences we plan to investigate whether the fetch or atmospheric stability have a definite effect.

This is not too important for the detection of drizzle, as its signal at 14.5 kHz is quite pronounced. However for the quantitative estimation of heavy rain, we do need to better understand all the processes affecting frequencies around 5 kHz. Part of that improvement may be in the better recognition of data contaminated by other sources of sound.

Acknowledgements

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