Examining the value of the Acoustic Variability Index in the characterisation of Australian marine soundscapes

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ABSTRACT

The soundscape in Australian waters demonstrates a high level of variability, and is dependent upon the relative contributions from geophonic, biophonic and anthrophonic contributors. There is increasing interest in understanding soundscapes due to the implications for assessment of anthropogenic activities. Significant information exists in acoustic recordings, with a number of methods used to characterise contributors. This paper describes a new technique, the Acoustic Variability Index, that appears to be useful in distinguishing periods of transient sounds from continuous sound sources. Acoustic recordings from 30 long-term monitoring recordings from 10 geographic regions around Australia have been analysed using typical characterisation techniques and the Acoustic Variability Index. The Acoustic Variability Index results are compared with those from typical automated characterisation techniques applied to large datasets, and its value to determine changes in the soundscape is discussed. Increased understanding of the marine soundscape and its contributors is important to assist informed spatial planning of reserves and both spatial and temporal planning for anthropogenic activities.

1. INTRODUCTION

Passive acoustic monitoring in underwater environments has long occurred in Australia (e.g. Cato, 1978, Kelly et al., 1985, Cato, 1992), and globally is a rapidly expanding field, with recent programs ranging from recordings in highly specific locations (Martin et al., 2014, Parsons et al., 2016), wide scale regional monitoring (Hannay et al., 2013), regional cabled observatories (Barnes et al., 2015, Moloney et al., 2016, Mouy et al., 2015, Dewey et al., 2015) to national observing systems (Erbe et al., 2015, Lynch et al., 2014). Large scale programs examining species ranging from blue whales to beaked whales and porpoises and the soundscape they vocalise in are now possible (Martin et al., 2015).

Characterisation of underwater soundscapes to understand the three components: geophony (natural sounds such as wind, seismic, and waves), biophony (animal sounds including communication and feeding) and anthrophony (manmade sounds, including vessels and seismic survey operations (Krause, 2008)) is often an important part of passive acoustic monitoring studies. This interest is applicable for studies ranging from baseline or operational characterisation projects associated with commercial operations to research projects.

While sound has long been considered a component and indicator of ecological processes, this concept has been recently been labelled as ecoacoustics (Sueur and Farina, 2015). This field includes statistical analysis of soundscape data to assess biodiversity or ecosystem health. This can be referred to as soundscape ecology, which is the study of the 'temporal and spatial distribution of sound through a landscape, reflecting important ecosystem processes and human activities' Towsey et al. (2014), referencing Kasten et al. (2012), Pijanowski et al. (2011a), Pijanowski et al. (2011b).

Much current research into soundscape characterisation is directed at developing analysis metrics or indices that separate the contribution or effects of man-made and natural sound sources within large datasets. In theory such an index will allow for data reduction and improved ease of interpretation (Kaplan et al., 2015). An acoustic index is a statistic that summarises some aspect of the distribution of acoustic energy and information in a recording (Towsey et al., 2014). Numerous metrics have been proposed and are currently under investigation to measure acoustic community diversity or soundscape composition (Sueur et al., 2014), including acoustic diversity index, acoustic richness, temporal and frequency entropies, and the acoustic complexity index (ACI).

While the majority of research has focused on terrestrial environments (e.g. Pieretti et al., 2011, Sueur et al., 2014, Towsey et al., 2014), some of these have been examined in aquatic (Desjonqueres et al., 2015) and marine environments (Parks et al., 2014, Kaplan et al., 2015, Merchant et al., 2015).

The aforementioned attempts to apply these methods to marine soundscapes have had mixed successes (Kaplan et al., 2015). One index, the ACI, was examined in detail by Kaplan et al. (2015). It is a measure of the average absolute fractional change in signal amplitude from one frame to the next through a recording (Pieretti et al., 2011). Existing results from ACI investigations (e.g. Pieretti et al., 2011, Kaplan et al., 2015) suggest that it can provide an indication of time and frequency bands that contain continuous man-made sounds. While Kaplan et al. (2015) found some correlation between the ACI in lower frequency bands, but that at higher frequencies the ACI did not yield results that were consistent with the other marine analyses, which led the authors to summarise that additional work is needed to develop acoustic diversity indices that are suitable for the marine environment.

The definition of the index used to describe the soundscape, in particular the ACI, does not fully define how to normalise the results, which leads to a wide range of possible values depending on implementation.

Since the publication of these studies, Farina et al. (2016) proposed the ACI_{ft} as a further important companion to describe the acoustic complexity. It measures the information that differs between two successive frequency bins inside the same temporal step *t*. Coincidentally, one of the authors on our paper (BM) developed a similar index independently, calling it the Acoustic Variability Index. This Acoustic Variability Index extends the ACI_{ft} by comparing the distribution of measured index with expected distribution for very large random data sets (either normally distributed or coloured).

Farina et al. (2016) described the issue of data influences from high noise floors present in some field digital recorders, caused by sources such the analogue/digital conversion, and the electronic or electrical noise of circuits. They found that for the soundscape metrics to work appropriately, these recorder self-noises needed to be removed, which they achieved through the application of a filter to exclude data below an empirically-fixed amplitude threshold that depends on the data collection hardware. This study has applied a similar concept to standardise across the different recorders used for data collection.

This paper summarises the method of computing the Acoustic Variability Index, and presents the results in relation to 30 selected long-term monitoring recordings from 10 geographic regions around Australia, outlining the index's potential to assist with large-scale soundscape comprehension. In this paper the metric is analysed for effectiveness through a qualitative assessment in comparison to known sound sources at each measurement location. To increase the rigour of assessment, a quantitative analysis is currently underway comparing the results to existing metrics and known datasets, which will be presented in future work.

2. METHODS

2.1 Acoustic Variability Index

The method developed for the Acoustic Variability Index builds upon the concept of the ACI_{ft} proposed by Farina et al. (2016). Our changes include recasting the ACI_{ft} as a divided difference so that is converges to 1, subtracting the measured index from the expected distributions to get the variability indication; and using an automated approach to eliminating recorder self-noise from recorders with noise floors that interfere with index calculation. We have also proposed source-specific frequency bands for analysis of underwater data (Table 1) that are slightly arbitrary, and can be refined to focus on sources of specific interest.

The Acoustic Variability Index starts with a slightly modified calculation of the ACI_{ft}, which we've called the ACI_{ft2} (1). It is computed by subtracting the magnitude of adjacent zero-overlapped Fast Fourier Transform (FFT) spectra over a frequency band of interest (Table 1), normalising by the energy in *both* spectra, then averaging over each minute.

$$ACI_{ft2} = \frac{1}{N_t N_f} \sum_{f=f_{bottom}}^{f=f_{top}} \sum_{t=FFT\ 1}^{t=1\ minute} \frac{(FFT(f,t+1) - FFT(f,t))}{(FFT(f,t+1) + FFT(f,t))} \tag{1}$$

Where FFT(f, t) is the magnitude of the f'th frequency bin at time 't', the top and bottom frequencies are given in Table 1, N_f is the number of frequency bins, and N_t is the number of FFTs per minute of data. The values below '1' occur when the spectrum does not change from one FFT to the next, i.e. continuous sources. The values above '1' are caused by variable or transient sources that do change between FFT bins. By limiting the analysis to restricted frequency bands we found that it is easier to identify the effects of low frequency sources that would otherwise be lost through the large number of high frequency bins that change in response to different sources.

This process can be replicated using a simulated time series to obtain the expected distribution, based on random noise, which has the central value of 1 and a confidence interval that is dependent on the number of successive adjacent FFT spectra averaged. For instance, the 10-40 Hz band only has 60 FFT bins and 120 FFT spectra per minute for a total of 7200 bins per minute whereas the 2000-16000 Hz band has 840,000 bins per minute, which results in a much tighter expected distribution both for normally distributed noise and coloured noise (Figure 1).

Our objective is determining if the measured sound has transient or continuous characteristics by comparing the measured distribution of ACI_{ft2} compared to the expected distribution. Coloured ocean noise converges to 1.0165 rather than 1 (Figure 1). To adapt the algorithm to the actual distribution we align the peak of the modelled distribution with the measured peak as long as the measured peak feel in the range {1.0, 1.05}. The modelled and measured distributions are then subtracted and the differences are summed for the values above '1' and below '1', and expressed as a percentage of the total number of samples examined. Both a maximum and minimum are returned. A value of '-50%' means that 50% of the data is below the expected distribution, which means that a noise source is present that reduces the energy variability – i.e. a continuous noise source. Values around 0% mean no deviation from random distributions, positive values indicate that there are sources present that create short-term fluctuations in the sound – i.e. transients.

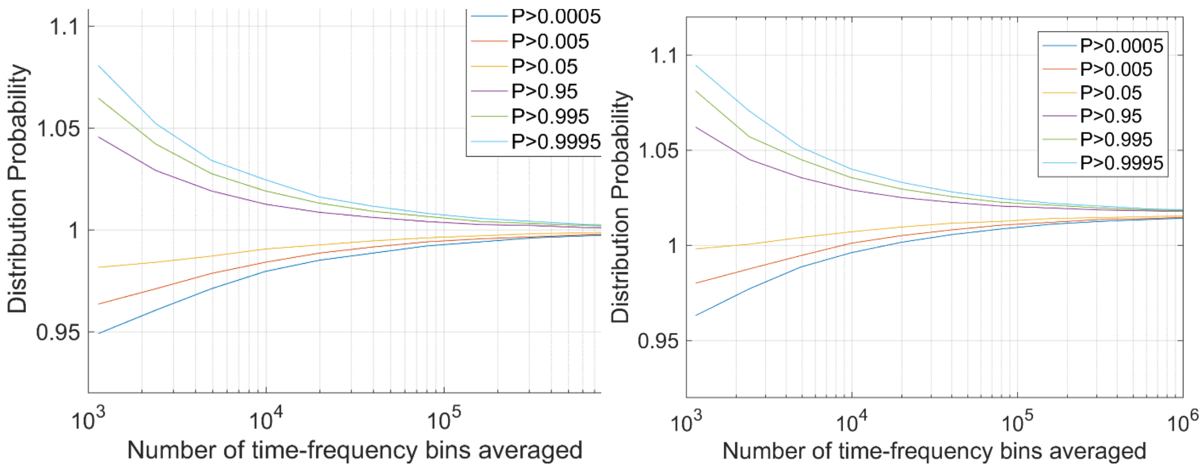


Figure 1. Asymptotic behaviour of the ACI_{ft2} distribution as the number of time-frequency bins increases. (Left) normally distributed noise converging to 1.0. (right) Coloured ocean noise converging to 1.0165. The coloured noise was implemented by attenuating the white noise spectrum by 10 dB/decade starting at 600 Hz. All slopes tested from 10 – 19 dB/decade produced the same result.

This method appears to be able to identify when there are continuous and transient noise sources that are affecting the character of the soundscape. One example of this is that seismic surveys create regular pulse trains of transients, which generate large positive acoustic variability values, while snapping shrimp and their impulsive clicks can also generate large positive acoustic variability values in frequency bands over 2 kHz. However, in order to be a useful indicator of trends, the metric requires long term data sets. In this case the results were summed and presented for each month of recordings. A summary of the possible contributors to the soundscape in each of the frequency bands of interest is provided in Table 1. Not all contributors are included in each band, and as such the categories should not be considered exclusive, with the energy from many of the sources bleeding into the other frequency bands selected.

Table 1: Frequency bands used for summary analysis.

Reference Number	Frequency Band (Hz)	Typical Biophony sources	Anthrophony sources	Geophony sources	Pseudo-noise
1	10 – 40; FFT duration 0.5 sec	**Transient**: Pygmy blue, Omura's, sei and fin whales. **Continuous**: NA	**Transient:** Seismic surveys **Continuous:** Large vessels / offshore drilling rigs	**Transient:** Seismic **Continuous:** NA	**Transient:** Strum **Continuous:** Flow noise

Reference Number	Frequency Band (Hz)	Typical Biophony sources	Anthrophony sources	Geophony sources	Pseudo-noise
2	40 – 200; FFT duration 0.25 sec	**Transient**: Pygmy blue, Omura's, humpback, Bryde's, minke, southern right, sei, fin and sperm whales. **Continuous**: Fish chorusing	**Transient:** Seismic surveys, piling **Continuous:** Large vessels, drilling operations, sand pumps	**Transient:** thunder **Continuous:** Sediment movement	**Transient:** Strum **Continuous:** Flow noise
3	200 – 2000; FFT duration 0.125 sec	**Transient**: Humpback, minke, southern right and sperm whales. Low frequency components of odontocete whistles. Individual fish. Benthic crustaceans (such as snapping shrimp). **Continuous**: Fish/biological chorusing	**Transient:** Seismic surveys, piling **Continuous:** Vessels, drilling operations, sand pumps	**Transient:** thunder **Continuous:** Wind & wave action	**Transient:** Strum **Continuous:** Flow noise
4	2000 – 16000; FFT duration 0.0625 sec	**Transient**: Odontocete whistles. Individual fish. Benthic crustaceans (such as snapping shrimp). **Continuous**: Fish/biological chorusing	**Transient:** Pleasure craft **Continuous:** Close large vessels	**Transient:** NA **Continuous:** Wind, wave action and rain	—

2.2 Typical characterisation methods

Underwater ambient acoustic data is normally presented in terms of one or more of the following:

- Statistical distribution of sound pressure levels in each 1/3 octave band.
- Spectral level percentiles: Histograms of each frequency bin per 1 minute of data. Typically, the 5th, 25th, 50th, 75th, and 95th percentiles are plotted, where the 95th percentile curve is the frequency-dependent level exceeded by 5% of the 1 minute averages.
- Broadband and in-band rms sound pressure levels (SPLs) over time (entire deployment, period of interest).
- Rhythm plots for hourly, daily, tidal cycle or daylight levels over entire deployments or periods of interest.
- Spectrograms (entire deployment or period of interest).
- Daily sound exposure levels (SEL_{24h}): computed for the total received sound energy, along with other relevant sources such the detected seismic survey energy, and the detected shipping energy. The SEL_{24h} is the linear sum of the 1-minute sound exposure levels. For shipping, the 1-minute SEL are the linear 1-minute squared SPL levels multiplied by the duration, 60 s. For seismic survey pulses, the 1-minute SEL are the linear sum of the per-pulse SEL.

In order to assist with the analysis and view the data on a large scale, the ambient noise for each deployment and at each station was analysed by Hamming-windowed fast Fourier transforms (FFTs), with 1 Hz resolution and 50% window overlap. The 120 FFTs performed with these settings are averaged to yield 1-minute average spectra. These 1-minute averaged, 1 Hz spectral density levels were energetically summed over the frequency bands under analysis (Table 1) across entire months to obtain monthly average broadband levels (dB re 1 µPa) (L_{eq}'s). The acoustic data were also analysed with JASCO's seismic and shipping detectors (Martin, 2013). For vessel detection, the number of discrete tones were detected in each audio file. In the 'shipping band' defined as 40–315 Hz (the frequency band typical for large shipping vessel sounds), the SPL is calculated for each minute. Shipping is detected when the SPL in the shipping band is at least 3 dB above the 12-hour median, at least five shipping tonals are present, and the SPL in the shipping band is within 8 dB of the total SPL.

2.3 Acoustic datasets

2.3.1 Overview

JASCO Applied Sciences has been conducting long term monitoring programs in Australian waters since 2010, and has collected a substantial amount of data. The majority of the programs have been performed for confidential clients, however after relevant approvals processes are complete, some of these datasets are able to be used for scientific research. Two such project related datasets are presented here from projects performed for Woodside Energy Limited and PTT Exploration and Production Public Company Limited Australasia (PTTEPAA). JASCO has also conducted research under contract to the Australian Marine Mammal Centre (AMMC), and contributed equipment, including Autonomous Multichannel Acoustic Recorders (AMARs) and analysis capabilities to joint research projects, such as those in Table 2 with James Cook University (JCU) (MacGillivray et al., 2014) and the Wildlife Management Branch of the Tasmanian Department of Primary Industries, Parks, Water and Environment (DPIPWE). Future analysis will include data from a 12-month, three monitoring station program in the Timor Sea, split into two 6-month deployments, with AMARs sampling at 48 and 250 ksps and collecting 10.8 Tb of data (McPherson et al., 2016).

Australia's Integrated Marine Observing System (IMOS) (Erbe et al., 2015, Lynch et al., 2014) has been operational since 2008, with the Centre for Marine Science and Technology (CMST) at Curtin University leading the Passive Acoustic Observatories facility. The facility plays an important role in understanding the unique Australian marine environment. While data collection began in 2008, the majority of available data is from after early 2010. The locations of the IMOS acoustic stations are shown in Table 2, with the majority of data collected at a sampling frequency of 6 ksps. The data analysed for this research was provided by the eMarine Information Infrastructure (eMII) unit of IMOS in late 2015, and at that point in time represented all of the publically accessible IMOS acoustic recordings through eMII, and also represented that viewable through the AODN (Australian Ocean Data Network, 2016) as of July 2016. All data provided that it was possible to analyse is presented.

Details of all the acoustic data presented in this paper are provided in Table 2, and an overview map of the locations is provided in Figure 2.

Table 2: Acoustic dataset details

Reference Number	Location Name	Data Source	Sampling Rates (ksps)	On† (minutes)	Off† (minutes)	Data Start Date	Data End Date	Depth (m)
1	Wheeler Reef, Great Barrier Reef, QLD	JASCO / JCU	64 and 375	7.1	7.9	27-Apr-13	29-Jul-13	18
2	Mermaid Beach, Gold Coast, QLD	JASCO / AMMC	32	16	1	09-Sep-10	01-Oct-10	10.00
						04-Jan-11	28-Jan-11	
						04-Mar-11	03-Apr-11	
						14-May-11	08-Jun-11	
3	Tuncurry, NSW	IMOS / CMST	6	4.33	10.67	10-Feb-10	04-Oct-10	190
				8.33	6.67	06-Apr-11	26-Apr-12	188
4	Derwent River, TAS	JASCO / Tasmanian DPIPWE	8 and 375	11.3	3.7	19-May-15	12-Oct-15	18
5	Portland, VIC	IMOS / CMST	6	8.33	6.67	06-May-09	22-Dec-09	168
				8.33	6.67	07-Feb-10	25-Sep-10	
				5	10	10-Dec-10	03-Dec-11	
				6.67	8.33	07-Nov-12	17-May-13	
6	Perth Canyon, WA	IMOS / CMST	6	3	12	26-Feb-08	29-Aug-08	430-490
				7.5	7.5	13-Nov-09	22-Jul-10	

Reference Number	Location Name	Data Source	Sampling Rates (ksps)	On† (minutes)	Off† (minutes)	Data Start Date	Data End Date	Depth (m)
				6.67	8.33	06-Aug-10	08-May-11	
				5	10	14-Jul-11	19-Jun-12	
7	Pilbara, WA	IMOS / CMST	6	5	10	20-Nov-12	16-Oct-13	216
8	James Price Point, Kimberly Region, WA	Woodside / JASCO	16	16	1	22-Mar-10	11-May-10	10
			32			10-May-10	07-Jul-10	
			32			09-Jul-10	06-Sep-10	
			32			08-Sep-10	06-Nov-10	
			32			06-Nov-10	05-Jan-11	
9	Offshore Kimberly Region, WA	IMOS / CMST	6	5	10	20-Nov-12	17-Oct-13	216
10	North west Timor Sea, WA	PTTEPAA / JASCO	32	60	1440	02-Dec-10	16-Mar-11	236
				60	1440	01-Dec-10	08-Jun-11	75
				28	32	09-Jun-11	19-Oct-11	77
				28	32	09-Jun-11	12-Oct-11	125
				28	32	09-Jun-11	02-Oct-11	129

†On and Off time for low frequency sampling channel only

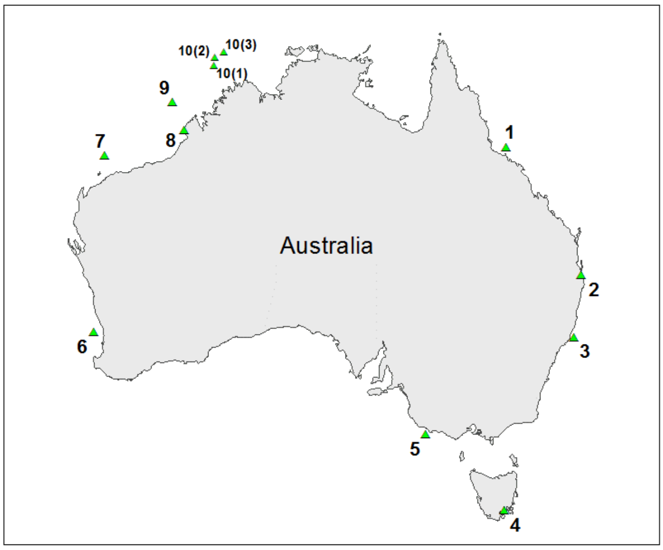


Figure 2: Map of monitoring locations, with reference locations labelled as per Table 2.

2.3.2 Dataset context

The context of the data contained within each dataset is important for understanding the Acoustic Variability Index value in relation to the soundscape contributors. The general contributors to Australian marine soundscapes within the categories of biophony, anthrophony and geophony are presented in Table 1. The presence and level of contribution is different between each monitoring location and varies over time. Ideally the content of each dataset would be provided to allow comprehension of the Acoustic Variability Index and analysis band average in the context of the contributors. This would typically be comprised of spectrograms, in-band SPL and hourly/daily/tidal cycle/daylight level rhythm plots, percentile and daily SEL with contributor assignment plots. However due to the limited space available, only two particular examples have been selected for detailed analysis based upon the Acoustic Variability Index results.

2.4 Analysis and comparison methods

The purpose of the analysis is to determine if the newly proposed metric has merit, and if there are any aspects of the soundscape that it provides a more useful rapid characterisation tool for. The analysis of the data in band limited sets is intentional due to the different contributors in each band, as outlined in Table 1.

The data analysed for this paper came from three difference recorder types, CMST's noise loggers (CMST 2016), Aural-M2's (Multi-Électronique, 2016) and JASCO AMARs (JASCO Applied Sciences, 2016). The noise floor varies between acoustic recorder types, and depends upon the gain settings or sensitivity configuration. An automated approach to eliminating low SPL data per band using a threshold of 10 dB above the 99.5th percentile, which is assumed to represent the noise floor of the recorder, with the caveat that no more than 1/2 of the data set should be removed This builds upon the blanket SPL threshold method proposed by Farina et al. (2016), and was implemented in an attempt to remove any bias from different recorders, despite the index no longer being able to consider information captured by more sensitive recorders.

3. RESULTS

3.1 Acoustic Variability Index

Acoustic Variability Index plots for all the analysed data over all time, arranged by geographic location, are shown in Figure 3. The points on the plot indicate the positive and negative bounds on the ACI_{ft2} for each frequency band per month. The data from all times are included, however they have been plotted on a single year timescale. The monitoring locations with more than one year of data are shown in Figure 4. Two selected aspects examining transient biological drivers (Section 3.2), and an extended contribution from a continuous (anthropogenic) driver (Section 3.3) have been selected to examine particular features.

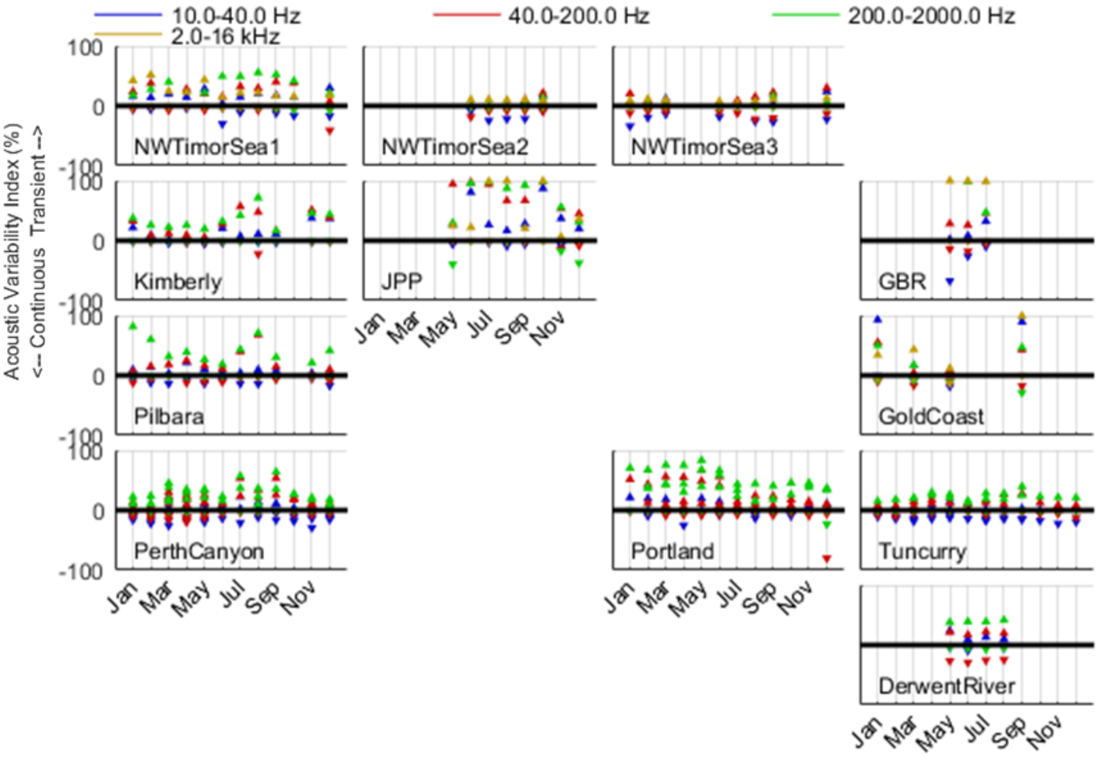


Figure 3: Acoustic Variability Index plots displayed over a single year timeframe. Frequency bands used for analysis (Table 1) are shown, the 2–16kHz data is only present for datasets with the information (Table 2).

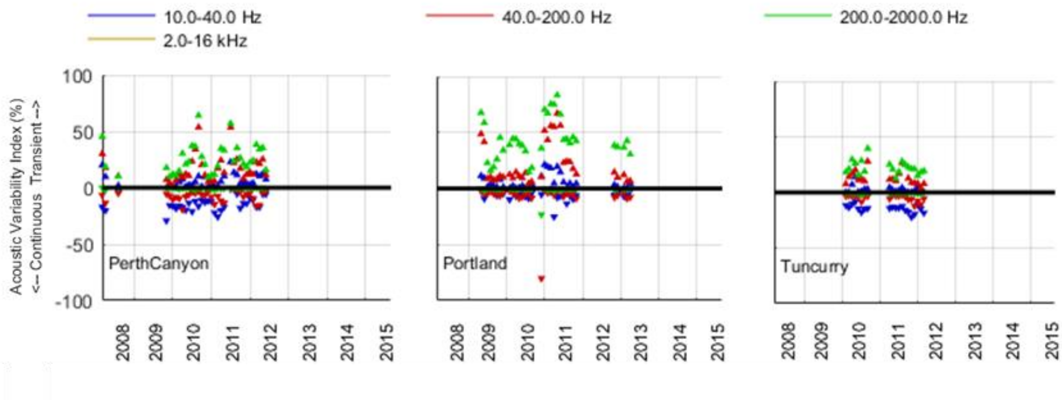


Figure 4: Acoustic Variability Index plots displayed over cumulative deployments for locations with over a year of data as part of concept demonstration.

3.2 Biological sources of transients

Two locations were selected for comparison to the ACI_{ft2} results to provide more detailed examples of biological sources of transient signals. The selected locations were Wheeler Reef, located within the Great Barrier Reef, and James Price Point in Western Australia (Locations 1 and 8) for the periods July and July–August respectively. Humpback whales were migrating past both locations during this time. To provide context for the Wheeler Reef soundscape, the daily rhythm plot and long-term spectrogram are shown (Figure 5). Biological noise from reef fauna such as fish and crustaceans was the dominant contributor, and the highest number of humpback whales was recorded in mid-July. Large vessels detected during the month were typically over 20 km from the AMAR (MacGillivray et al., 2014), although a number of smaller pleasure craft were detected. Similar plots for James Price Point are shown (Figure 6), where humpback whales were a dominant almost daily contributor (with particularly strong contributions on July 17th, 31st and August 9th), with daily biological activity, vessels and pseudo-noise from flow during large tidal flows also present. The mooring used at James Price Point was client defined, with the recorder incorporated into a larger frame with other instruments and moving parts. This is not typical, with acoustic instruments typically isolated from all possible noise sources and significant efforts undertaken to reduce possible pseudo-noise.

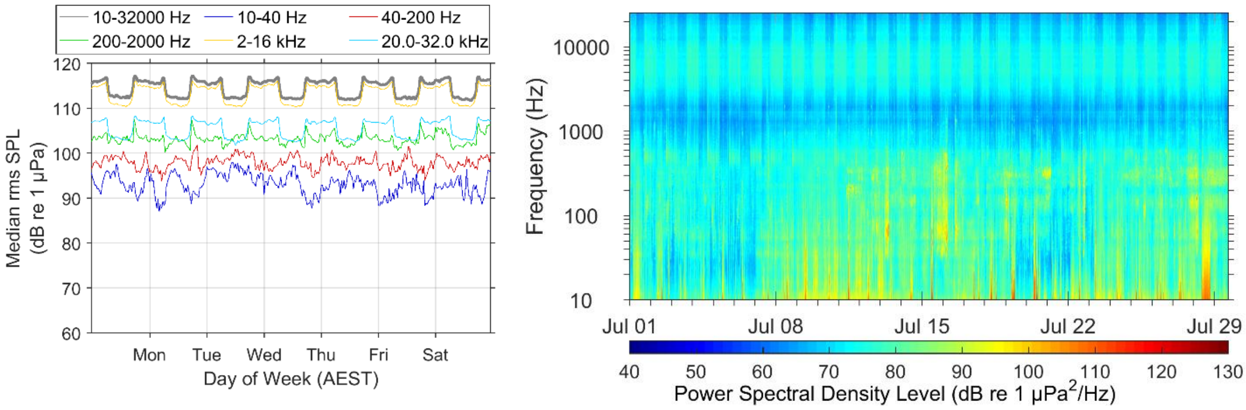


Figure 5: Wheeler Reef (Location 1), July 2013. Daily rhythm plot (left) and spectrogram of power spectral densities (right).

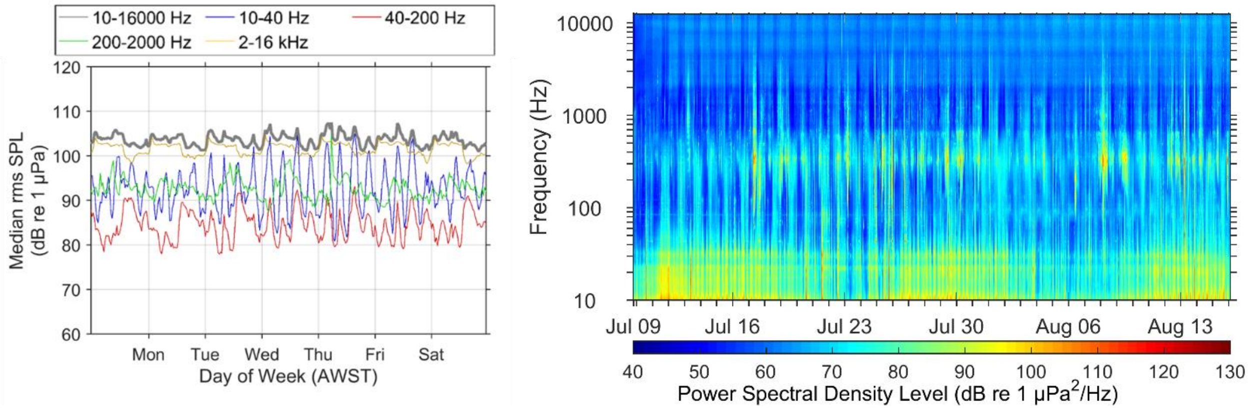


Figure 6: James Price Point (Location 8), July–August 2010. Daily rhythm plot (left) and spectrogram of power spectral densities (right).

Figure 7 (top) shows an example of the modelled ACI_{ft2} compared to the measured index before being converted to a percent difference. The example selected is for Wheeler Reef, July 2013. This comparison shows that the all bands except the 10-40 Hz band have measured indices greater than '1', indicating that transient signals dominate the dataset. Figure 7 (middle) displays any patterns in ACI_{ft2} throughout the day. The 10-40 Hz band exhibits mostly continuous behaviour, except the L_5 which has an increase likely due to small vessels with rapidly changing spectra on the reef during the day, which is support by an increase in SPL at the same time. In Figure 7 (bottom) the SPL are dominated by the high frequency (2-16 kHz) noise from biological sources especially during the night hours (16:00 to 08:00). The ACI_{ft2} in this band decreases very slightly during the night hours due to the level of crustacean activity becoming so high that the soundscape is slightly more continuous than during that day; however, it remains extremely transient in nature with a variability index ~ 1.06, which is much higher than could be expected from any random data (Figure 1).

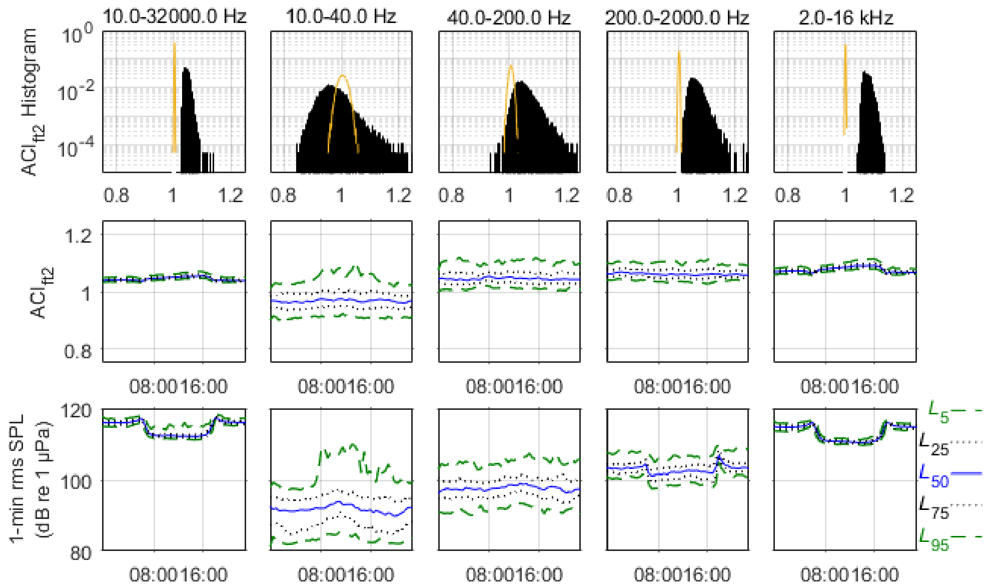


Figure 7: Wheeler Reef (Location 1), July 2013. Plot of hourly rhythm SPL percentiles (bottom), the Acoustic Variability Index distributions (middle), and ACI_{ft2} (top), theoretical (red-orange) and actual (black).

For both example locations and corresponding time periods, the statistical distribution of the 1-minute SPL in each frequency analysis band (Figure 8) are shown. The boxes of the statistical distributions indicate the first (25%) and third (75%) quartiles. The whiskers indicate the maximum and minimum range of the data, while the solid bar is the L_{eq} and the dashed the 50% quartile. This is compared to the ACI_{ft2} sum probability plots (Figure 8) for the frequency analysis bands, derived from the distributions shown in Figure 7 (top), with the maximum and minimums representing the positive and negative ACI_{ft2} values for the month. These combined plots were created for each month for all of the analysed data during the analysis, as a precursor to creating Figures 3 and 4, along with a figure showing the monthly L_{eq}'s.

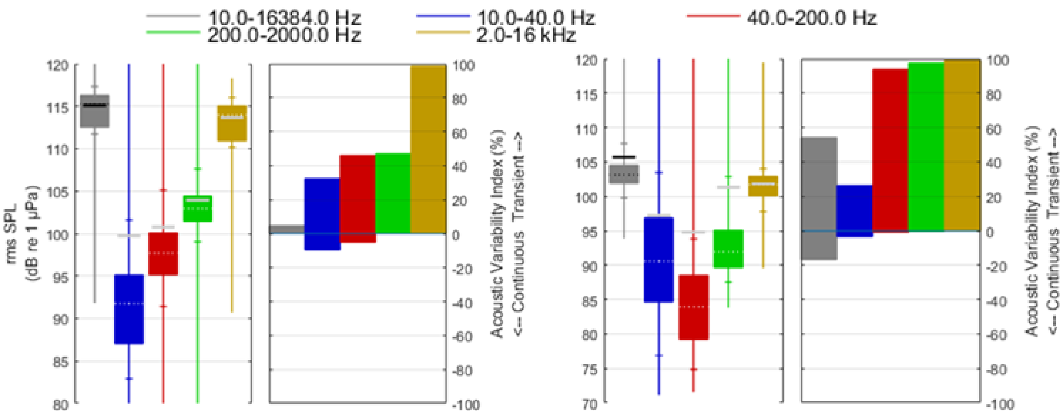
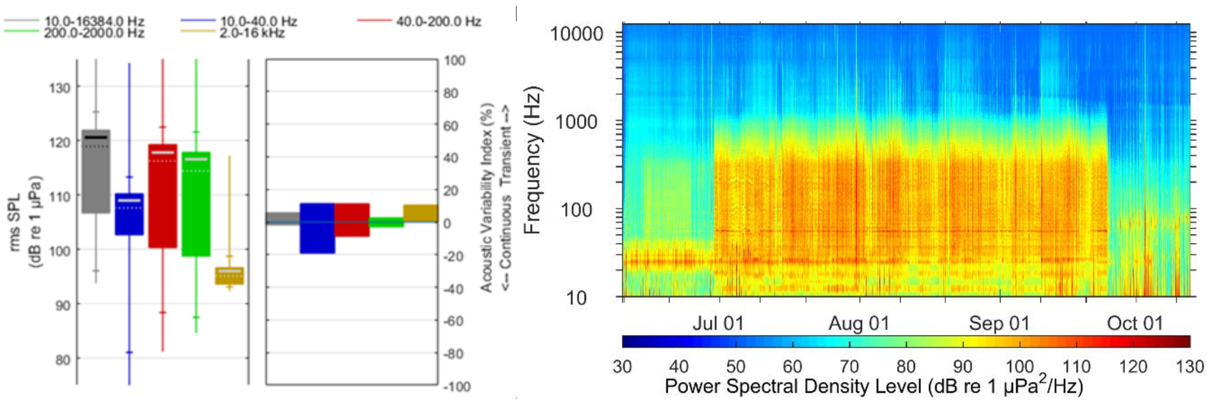


Figure 8: SPL statistical distribution and Acoustic Variability Index sum probability plots for James Price Point (Location 8, left) and Wheeler Reef (Location 1, right), for the periods shown in Figures 5 and 6.

3.3 Continuous (anthropogenic) drivers

The deployments at the monitoring locations of Tuncurry, Derwent River, Portland and Perth Canyon (Locations 3–6) are close to shipping lanes or ports, and thus the soundscapes are influenced by shipping to varying degrees, primarily in the frequency bands of 10-40 and 40-200 Hz (note that small vessels contain significant energy to 315 Hz and beyond during close approaches). Indications of the contribution to these soundscapes are demonstrated in Figures 3 and 4. However, one monitoring location, north-west Timor Sea (Location 10), in particular station 2, indicated an extended period of continuous noise contribution from an area normally less influenced by shipping, and it has been selected for further examination. Plots from the analysis of this deployment are shown in Figure 9. The station recorded the operations of a Mobile Offshore Drilling Unit (MODU) and associated vessel traffic from July–late September. The continuous nature of the sound source, fluctuating typically over longer time periods (and therefore less difference on a minute to minute basis), is shown in the spectrogram, and reflected in the acoustic variability distributions and sum probability plots. A large number of Omura's whales calls (Cerchio et al., 2015), with a peak energy at approximately 27 Hz, were recorded prior to the MODU operations, and likely contribute to the positive index value in 10-40 Hz band.



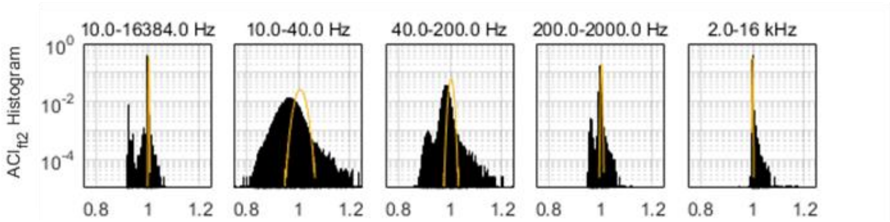


Figure 9: North-west Timor Sea, Station 2 (Location 10(3)), June–October 2011. SPL statistical distribution and Acoustic Variability Index sum probability plot (left), spectrogram (right) and Acoustic Variability Index distributions (bottom), both theoretical (orange) and actual (black).

4. DISCUSSION

4.1 General discussion

The initial investigation into the application of the Acoustic Variability Index to a large number of recordings from many geographic regions around Australia is promising. The index appears to be a reasonable indicator for the presence within the soundscape of, or relative contributions from, transient or continuous sound sources. Further investigation of the metric in relation to fish chorusing events has been identified as a requirement, however was not presented in this paper due to length limitations. The presence of seismic surveys generates large positive ACI_{ft2} values in all bands, but particularly the 10–40 Hz and 40–200 Hz bands. Comparatively, high levels of biological activity, such as reef chorusing in the higher frequency bands, can generate ACI_{ft2} values higher than could be expected for random data. The index, through negative ACI_{ft2} values, can be a good indicator of shipping or shipping type noise. In the absence of significant anthropogenic or biological activity, the values in all frequency bands remain close to zero. Large negative ACI_{ft2} values are a strong indicator of pseudo-noise from flow over hydrophones or mooring movement.

The promise shown by the index warrants a detailed analysis of the index's performance statistics, along with a comparison to the wider range of indices, including the acoustic diversity index, acoustic richness, temporal and frequency entropies (Sueur et al., 2014), and other variants of the acoustic complexity index (Farina et al., 2016). The authors have commenced work to conduct such an analysis, comparing the results to existing metrics and known datasets, which will be presented in future work.

Future use of the index could use additional or alternate frequency bands, which could assist in the analysis of factors relating to marine fauna communication and listening space (Clark et al., 2009, Barber et al., 2010). It could also be used to assist with analysis of the acoustic adaptation hypothesis (AAH) as described in (Sueur and Farina, 2015), particularly the unique acoustic signature of different environments, such as coral reefs (Piercy et al., 2014).

5. CONCLUSIONS

How to properly analyse 'big data' is a growing field of research, and highly relevant to Australia due to an increasing number of underwater acoustic datasets, including long term monitoring in specific locations through the IMOS program. As monitoring programs become more extensive they include greater numbers of recorders with higher sampling rates and lower noise floors that can store large amounts of data, therefore, the application of informative indices will become increasingly important. The Acoustic Variability Index produces very interesting and informative results when plotted over time, and further investigation is warranted.

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