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Removal of Continuous Extraneous Noise from Exceedance Levels

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ABSTRACT

Strategies for the removal of extraneous noise from L_{eq} and L_P cannot necessarily be applied to exceedance levels (L_N) without the introduction of significant error. An analysis using mine and road noise was performed to quantify the error associated with the filtering and logarithmic combination of spectral L_N to estimate overall L_N without extraneous noise. The problem is primarily viewed within the context of L_{90} mine noise measurements corrupted by insect noise. It is demonstrated that estimating overall L_{90} using the logarithmic summation of spectral L_N is associated with a maximum absolute error 4.9 dB, to 95% confidence. A second method of summing spectral L_N of many short subintervals, and arithmetically averaging the resultant sum was also analysed. This method introduced additional error, despite requiring more data and post-processing. A third, alternative method, using spectral L_P data sampled every five seconds, limited error to below 0.57 dB (95% confidence). This third method is recommended, and the convergence of this estimate method towards the exact overall L_N is quantified.

1 INTRODUCTION

Acoustic professionals are typically able to remove extraneous tonal noise from measurements using spectral analyses (Garbett 2016). If the spectrum of the tonal noise is known, an appropriate filter can be applied to measured spectral sound pressure levels. The filtered spectral data can be logarithmically summed to give an overall sound pressure level without the extraneous tonal noise. When using energy-based levels such as L_P and L_{eq}, this method is theoretically justifiable. However, the same is not generally true of statistical exceedance levels (L_N).

Of particular interest is the case of measuring distant mine noise in the presence of extraneous insect noise. Background noise measurements in the form of L_{90} levels are often desired to evaluate the acoustic impact of mining in surrounding areas. From large distances, mine noise is typically limited to frequencies at and below 630 Hz (Parnell 2015), while insect, frog and bat noise is typically found above 1 kHz (Terlich 2011, Parnell 2015).

A method of approximating the overall L_{90} without extraneous noise from unfiltered spectral L_{90} measurements is required. Anecdotally, it is understood that filtering and logarithmically combining spectral L_N as if they were L_{eq} is accepted and practiced. However, the amount of error introduced by doing so is not widely known.

Potential improvements to such a method of estimation were sought in existing and accepted practices. Approximating L_N over an 18 hour period with the arithmetic average of 18 hour-long L_N, is accepted and used in the calculation of road traffic noise (Department of Transport Welsh Office 1988, 29). It was hypothesized that over shorter time intervals, the time variance of mine noise decreases, and thus L_N and L_{eq} become quantitatively similar. It follows that logarithmically summing spectral L_N in short time intervals would incur less error, and averaging the resultant overall L_N from all short intervals would produce a reasonable estimate of the overall L_N over a longer time interval.

2 AIMS

This paper aims to quantify the error associated with removing extraneous noise from L_N measurements. The problem is approached within the context of removing extraneous insect noise from mine noise L_{90} measurements. While L_{90} is the primary focus, L_1, L_{10}, L_{50}, and L_{99} were also investigated.

Three methods of estimating overall L_N without extraneous noise were analysed with respect to their accuracy and precision. It was also intended that the process of analyzing these methods would also give rise to ways in which the methods may be improved, or alternative methods suggested. Results should be used to optimize existing and new methods.

Mine noise measurements are often gathered by sound loggers positioned at sites in proximity to mines for extended periods, and transmitted over 3G mobile networks. An additional aim is to minimise the number of measurements being recorded and transmitted.

3 METHOD

3.1 Data acquisition

Raw audio WAVE files containing sound measurements in linear pulse-code modulation (LPCM) format were desired, so that all time history and spectral information is available. Raw audio in this format gathered 2 km from a coal mine in Queensland was primarily used. These WAVE files are all 60 seconds long, and were gathered every 30 minutes over the period from 1/12/2014 to 31/1/2015. Additional 300-second raw audio samples of distant road noise was recorded in Toohey Forest, Brisbane, as an analogue for mine noise. All measurements were taken using a 01dB DUO sound level meter.

Figure 1 - Mine Noise

Insect noise in this format was acquired from Soundsnap (2016). Insect noise raw audio measurements varied in length and amount of time variance.

Figure 2 - Cicada and Frog Noise

3.2 Data processing

The mine noise WAVE files were processed to find L_P, L_{eq} and L_N in ⅓ octave bands and the overall levels, simulating the processing performed by a typical class 1 SLM, in accordance with AS IEC 61672.1-2004 (Standards Australia 2004). Processing was undertaken by a Python 3.6.2 algorithm designed, coded and validated by the author for this application. Using dedicated code such as this allows extensive control over experimental variables, such as the audio sampling rate, and the L_N measurement interval.

The primary (mine/road) noise overall L_N serve as control data, containing no extraneous noise. Preliminary analysis was performed on 60-second mine noise raw audio measurements. Further analysis used 300 second road noise raw audio, and 900-second mine noise measurements formed by splicing fifteen 60 second measurements together.

Primary noise raw audio was also linearly combined with extraneous noise, giving a “corrupted” pressure measurement. This corrupted audio was similarly processed to find L_P, L_{eq}, and L_N in ⅓ octave bands. The corrupted noise L_N were used to estimate the exact (primary noise only) overall L_N. Three methods for the estimation of overall L_N without extraneous noise were analysed:

1. Logarithmically summing spectral L_N (details given in section 4)
2. Averaging L_N over short subintervals (details given in section 5)
3. Post-processing downsampled L_P (details given in section 6)

4 ESTIMATION METHOD 1: SUMMATION OF SPECTRAL L_N

The primary method under analysis logarithmically sums spectral L_N in ⅓ octave bands known to exclusively contain mine noise. Based on the works of Garbett (2016) and Parnell (2015), ⅓ octave bands including and below 630 Hz were used in this sum. This cutoff frequency was selected to capture all mine noise in the sum, without the inclusion of higher frequency extraneous noise such as insect noise.

4.1 Results

Significant error was associated with this method in all L_N. Table 1 is a summary of the resultant error of this method being applied to fifteen-minute samples of 6 hours of mine noise audio. L_{90} and L_{99}, were consistently underestimated, while L_1 and L_{10} were typically overestimated.

Table 1 - Error Summary of Estimation Method 1: Summation of Spectral L_N

L_N		L_1	L_{10}	L_{50}	L_{90}	L_{99}
Mean Error (dB)		-0.62	-0.16	1.79	3.55	4.87
Standard Deviation of Error (dB)		1.31	0.55	0.58	0.67	0.99
95% Prediction Interval of Error (dB)	Low	-3.24	-1.25	0.64	2.22	2.88
	High	2.00	0.94	2.94	4.88	6.86
Maximum Absolute Error (dB)		3.35	1.12	2.83	4.68	6.00
Proportion Exceeding 1 dB Error (%)		29%	4%	92%	100%	100%

The addition of high frequency extraneous noise had an insignificant impact on the error. Table 2 shows the resultant error from a single 60 second mine noise measurement, with and without extraneous cicada noise. This example is typical of all mine and insect noises analysed in this way.

Table 2 - Effect of High Frequency Extraneous Noise

L_N	L_1	L_{10}	L_{50}	L_{90}	L_{99}
Mine Only Error (dB)	-2.80	-1.27	1.50	2.73	4.63
Mine + Insect Noise Error (dB)	-2.80	-1.28	1.49	2.72	4.61

The error introduced by this method is correlated with incoherence in the time variance of spectral L_P of the mine noise. Typical time variance in mine noise spectral L_P is shown in Figure 3. Peaks and troughs of different frequency bands rarely coincide.

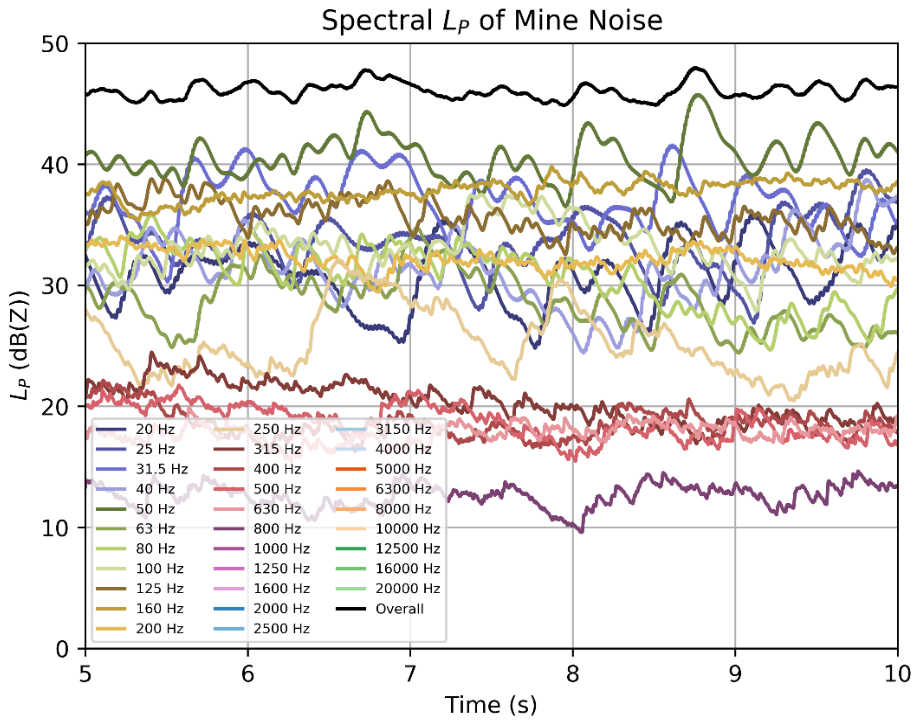

Figure 3 - Time Variance in Spectral L_P of Mine Noise

A contrived example was derived, in which the time variance of mine noise L_P in a single frequency band was used in all frequency bands. The L_P time history produced is depicted in Figure 4.

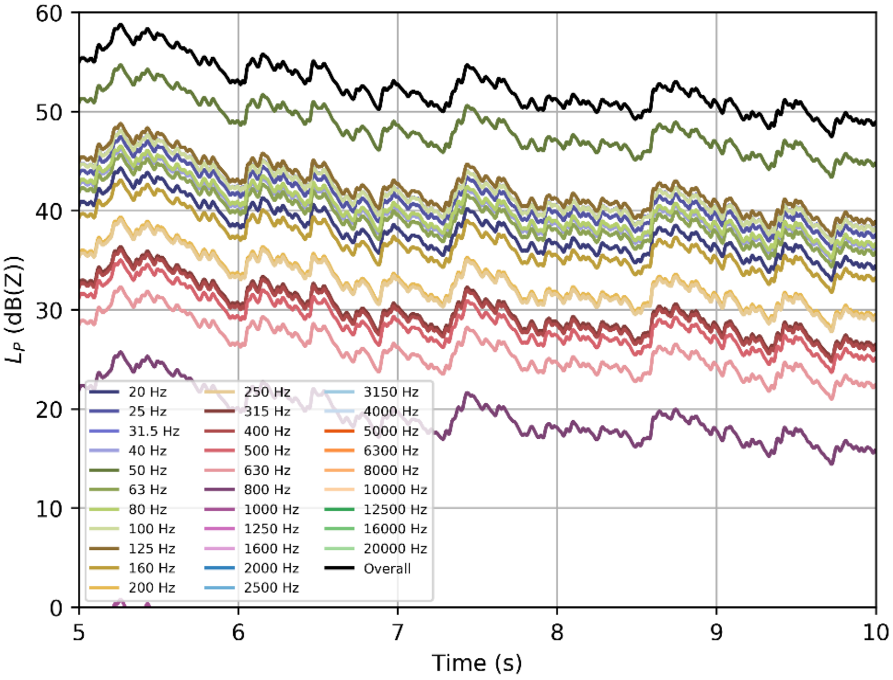

Figure 4 - Time Variance Coherence Experiment L_P

Method 1 was applied to this to this contrived example, and versions of it which offset each consecutive frequency band by a time offset. The coherence decreased as the offset was increased. The results of these experiments are summarised by Table 3.

Table 3 - Time Variance Coherence Experiment Results

Time Offset (s)	Error (dB)				
	L_{1}	L_{10}	L_{50}	L_{90}	L_{99}
0	0.00	0.00	0.00	0.00	0.00
0.01	0.00	-0.05	0.01	0.19	0.20
0.05	-0.57	-0.17	0.00	0.56	0.58
0.1	-0.87	-0.15	-0.06	0.88	0.78
0.5	-1.47	-0.60	0.24	1.19	1.96
1	-1.95	-0.95	0.37	1.58	2.34

4.2 Discussion

The amount of error introduced by this estimation method is significant; error in L_{90} is expected to be as high as 4.88 dB (95% confidence). By logarithmically summing spectral L_N as if they are L_P or L_{eq}, the method makes the unjustifiable assumption that those L_N are exceeded simultaneously in all spectra. That is, that peaks and troughs of the spectral time variance in L_P are coherent and simultaneous. The typical mine noise spectral time variance was shown to be incoherent, and error was demonstrated to be a function of the spectral L_P coherence. The variation in error for sound samples of the same type (mine) was attributed to differences in the specific time variance of each sample.

In estimating L_{90}, this method consistently underestimated the exact values, and as such is not a conservative estimate method.

5 ESTIMATION METHOD 2: AVERAGING OF SHORT L_N

The second estimation method involves dividing a L_N measurement interval into short subintervals. In each subinterval, spectral L_N are calculated, and those at or below 630 Hz logarithmically combined. The mean of the resultant sums is taken, giving an estimate of the overall L_N for the entire interval.

5.1 Results

This method is highly dependent on the length of the subintervals, as is shown in Figure 5. Using long subintervals, the error is unsurprisingly similar to that produced by method 1;. L_1 and L_{10} are overestimated, while L_{90} and L_{99} are underestimated. Using shorter subintervals, these trends are reversed.

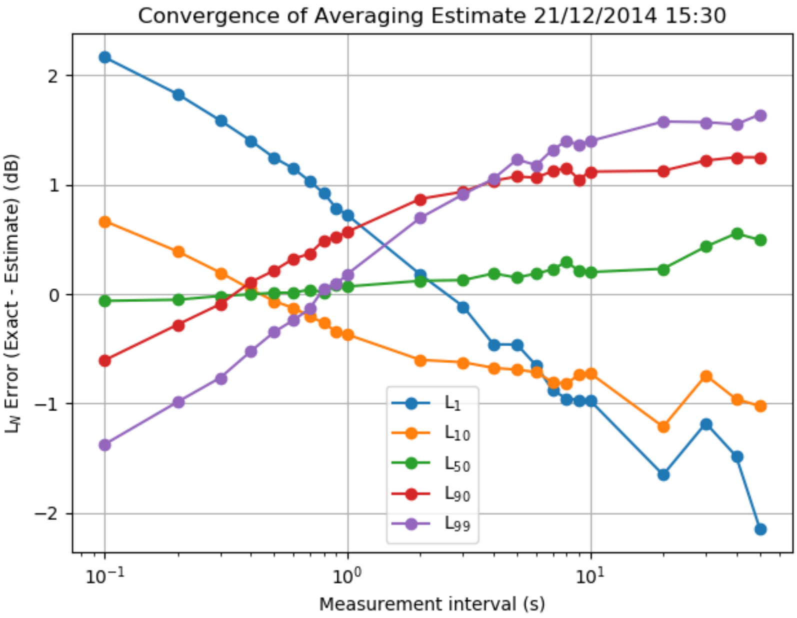

Figure 5 - Convergence of Averaging Estimate 21/12/2014 15:30

The subinterval duration which minimises error varies greatly between measurements. This is corroborated by Figure 6, which shows the standard deviation of error of 96 mine noise measurements. The error associated with this method increases substantially as the subinterval duration decreases.

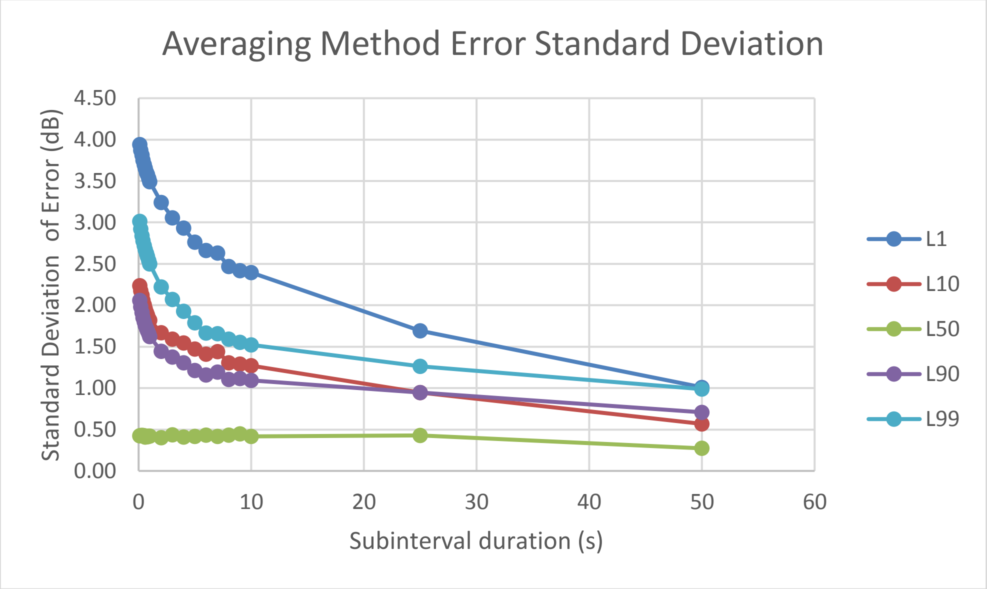

Figure 6 - Method 2 Standard Deviation of Error

5.2 Discussion

The error associated with this estimation method is highly dependent on the subinterval duration used. Using longer subintervals, the method behaves in a very similar way to method 1, for the same reason of spectral L_P incoherence. Using short subintervals causes the mean calculation to be dominated by mediocre subintervals, which contain neither peaks nor troughs. Consequently, L_1 and L_{10} are typically underestimated, while L_{90} and L_{99} are overestimated.

Overall the variability in error increases as the subinterval duration decreases, making this estimation method more inaccurate than method 1.

6 ESTIMATION METHOD 3: POST-PROCESSING OF DOWNSAMPLED L_P

This method makes use of downsampled spectral instantaneous sound pressure levels (L_P). For example, ⅓ octave band L_P logged once per second. These downsampled L_P can be accurately filtered and logarithmically summed with mathematical justification (Bies, Hansen and Howard 2017, 47). The filtered overall L_P were sorted and indexed to estimate the overall L_N for the entire interval. Such an operation can be redily performed in common spreadsheet software such as Microsoft Excel. Convergence of the estimate towards the exact L_N as a function of the L_P logging interval was analysed.

6.1 Results

As expected, very accurate L_N were calculated from L_P sampled at very short sampling intervals. Figure 7 quantifies the increase in the error as the sampling interval increases. The error given is the maximum absolute expected error, to 95% confidence. These data are based on 24 mine noise raw audio measurements, each 900 seconds in length, spliced together from 60-second mine noise measurements.

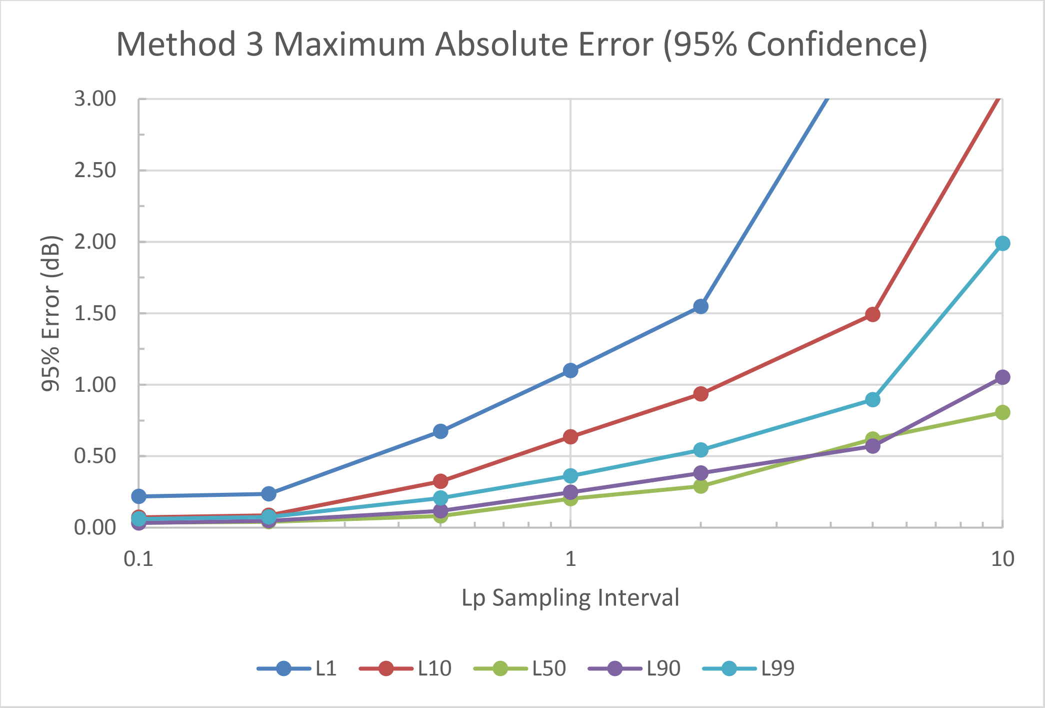

Figure 7 - Method 3 Maximum Absolute Error

The accuracy of this method increases with the duration of the interval over which L_N is estimated. Table 4 summarises the error decrement in L_{90} for a constant L_P sampling interval of 1 second.

Table 4 - Error Decrement for Longer Measurements

Sample duration (s)		60	300	300	900
Number of samples		384	72	14	24
Primary Noise Type		Mine	Spliced Mine	Road	Spliced Mine
Mean Error (dB)		0.00	0.01	0.04	0.02
Standard Deviation of Error (dB)		0.38	0.24	0.14	0.11
95% Prediction Interval of Error (dB)	Low	-0.76	-0.47	-0.23	-0.20
	High	0.76	0.50	0.31	0.25
Maximum Absolute Error (dB)		2.46	0.89	0.39	0.28
Proportion Exceeding 1 dB Error (%)		2%	0%	0%	0%

Table 5 gives summary statistics for a sampling interval of 5 seconds, based on 24 mine noise measurements, each 900 seconds in length.

Table 5 - Method 3 Error Summary

L_N		L_1	L_{10}	L_{50}	L_{90}	L_{99}
Mean Error (dB)		0.06	-0.07	-0.05	0.05	0.12
Standard Deviation of Error (dB)		1.73	0.71	0.28	0.26	0.39
95% Prediction Interval of Error (dB)	Low	-3.40	-1.49	-0.62	-0.48	-0.66
	High	3.52	1.35	0.52	0.57	0.90
Maximum Absolute Error (dB)		4.88	2.02	0.81	0.56	0.88
Proportion Exceeding 1 dB Error (%)		46%	13%	0%	0%	0%

6.2 Discussion

The convergence of estimation method 3 towards the exact overall L_N is shown in Figure 7. As the sampling interval lengthens, the downsampled L_P captures fewer peaks and troughs in the time variance, and is less likely to capture the extent of those peaks and troughs. This loss of information accounts for the error introduced by the application of this method.

While such evidence of convergence may not be surprising given the mechanism of the estimate, it is useful in determining an optimal L_P sampling interval. Reasonable accuracy can be achieved at sampling intervals below 5 seconds. High accuracy can be achieved at the expense of the acquisition, transfer, storage and post-processing of large amounts of data. Accuracy within ± 0.57 dB can be achieved (with 95% confidence) at a L_P sampling interval of 5 seconds.

7 CONCLUSIONS AND RECOMMENDATIONS

All three methods were effective in removing high frequency extraneous noise. The type, nature, and amplitude of the extraneous noise was not found to have a significant impact on the error produced. Given that the methods only make use of frequency bands solely containing primary noise, this is in accordance with expectations.

The practical value of the methods which estimate overall L_N from spectral L_N (methods 1 and 2) is questionable. Within the context of estimating L_{90} as a descriptor of background mine noise, not only is the amount of error introduced significant, but also largely variable.

The only situations in which method 1 can be recommended are those which involve very high coherence between spectral L_P time variance. This is expected to limit this method to contrived examples, rather than practical applications.

Method 2 involves the acquisition, transfer, storage and post-processing of additional data over method 1, without any improvement in accuracy. As a result, this method cannot be recommended in any context.

Method 3 does is similarly intensive in terms of data and post-processing, but justifies this with far more accurate and reliable results with respect to methods 1 and 2. This method is recommended in situations where extraneous noise and primary noise can be distinctly separated by frequency. It is further recommended that the L_P sampling interval be selected based on how much error is considered acceptable for the specific context or purpose. The convergence data of error (Figure 5) is intended to assist in this regard.

It is recommended that future research consider the accuracy of an estimation method which makes use of an error correction . For example, spectral L_N from all frequencies could be summed and then subtracted from the overall L_N, giving an indication of the error introduced for a particular sample. This error could be added to thhe result of applying method 1 to that sample, as a correction, thereby improving the accuracy of method 1 without the need for large amounts of data.

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