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Deployment of a short-term geophysical field survey to monitor acoustic signals associated with the Windsor Hum

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Abstract: The Hum is a widespread phenomenon, reported in many parts of the world. It manifests itself in the form of a hum, rumble and pulsing, often felt as a sensation more than an audible sound. Starting in 2011, residents of Windsor, Ontario, Canada started reporting intermittent low frequency sound, widely referred to as the Hum (and dubbed the Windsor Hum). This report outlines the deployment of a short term geophysical field survey, performed during 2013 in Windsor, Ontario, Canada, aimed at monitoring the airwave signals associated with the Windsor Hum. The summary of the low frequency sound array deployment is presented and discussed.

Keywords: infrasound; noise; low frequency; the Hum; atmosphere

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1. Background

The phenomenon of the Hum, an elusive low frequency sound heard only by select individuals, has been generating complaints from the public worldwide for a number of years (Leventhall, 2005). The characteristic sounds associated with the Hum were described by Leventhall et al. (2003) as: "… *a steady hum, a throb, a low speed diesel engine, rumble and pulsing. A higher pitch is sometimes attributed*…". Despite its widespread occurrence, the Hum has not been sufficiently represented in scientific literature (Deming, 2004). Furthermore, in the majority of cases, its origin remains untraceable.

The Windsor Hum has been affecting the residents of the City of Windsor, Ontario, Canada and the surrounding area, as well as the neighbouring city of Detroit, Michigan, USA since circa 2011 (Silber and Brown, 2013; Novak et al., 2014). This report outlines a geophysical field survey which was performed for the purpose of monitoring and identifying the possible low frequency acoustic signals associated with the Windsor Hum. Although this geophysical study did not positively identify the source of the Hum, it is the first of the kind documented in the literature to employ the approach described here. In particular, this report offers valuable information about the methodology employed in instrumentation setup, as well as preliminary data processing and results, all of which might provide the basis for future similar studies and considerations pertaining to instrumentation choice, spatial setup and general surveying approach.

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2. Infrasound and Low Frequency Sound

As per IEC (60050-801:1994), infrasound is defined as "*acoustic oscillations whose frequency is below the low frequency limit of audible sound* (*about* 16 Hz)". However, this definition is not entirely correct since at sufficiently high levels, sound can remain audible at much lower frequencies (down to a few Hz), as has been discussed in detail by Leventhall (2009). For practical reasons, in this paper we refer to the frequencies below 20 Hz as infrasound and the frequencies from 20–125 Hz as low frequency sound. Noise is defined as any undesired and unwarranted disturbance within a useful frequency band (ANSI, 1994; Berglund et al., 1999); hereafter, we will refer to the Hum in terms of both sound and noise. The attenuation of sound increases with the square of the frequency; thus, low frequency sound can efficiently propagate over long distances (Beer, 1974). It should be noted that for low frequency sound, typical audible sound propagation ranges are of the order of several kilometers to tens of kilometers for industrial sources (ANSI, S1.26-1995). The actual range, however, is strongly dependent on the source pressure level, atmospheric winds, humidity and local topography. There are many natural and anthropogenic sources of infrasound and low frequency sound. Some of the natural sources are ocean waves, thunder, air turbulence, volcanoes, lightning, aurora, and meteors (e.g., ReVelle, 1976; Von Gierke and Parker, 1976; Backteman et al., 1983; Silber and Brown, 2014). The sources of anthropogenic origin are airplanes, trucks, machinery, mining activity, and air-conditioning/heating/ventilation systems (Blazier, 1981; Job, 1988; Berglund et al., 1996).

While this report focuses on the geophysical field survey deployment to potentially identify the Hum, it is important to first briefly review the effects of low frequency noise on human perception. Hearing sensitivity and the perception of low frequency sound varies among individuals (Leventhall, 2009), with the hearing threshold being as low as 15 Hz for earphone listening (Yeowart et al., 1967) and 4 Hz in an acoustic chamber (Watanabe and Møller, 1990) at the 107 dB level. Low frequency sound can invoke subjective reactions, as determined by various laboratory, field, and in the community studies. In general, humans tend to react more adversely to artificial noise (Von Gierke and Parker, 1976; Job, 1988). Impulsive noise sources, such as quarry blasting, are known to cause higher levels of subjective reactions compared to non-impulsive noise of the same level (Job, 1988; Bullen et al., 1991). Another issue is that masking of low frequency sound by the surrounding higher frequencies tends to cease during night time when the majority of the population are asleep. At that time, low frequencies tend to dominate, thus contributing to increased levels of annoyance and disturbance (Berglund et al., 1984; Persson and Björkman, 1988; Persson and Rylander, 1988; Berglund et al., 1996). A paired comparison test carried out by Kraemer (1973) has revealed that the perceived level of annoyance peaks at certain frequency combinations (30–50 Hz), especially if it is at a constant loudness level. Another study (Vasudevan and Gordon, 1977) determined that the throbbing levels mostly occur in the 30–40 Hz frequency range.

Exposure to low-frequency noise is common in modern urban environments, especially in heavily industrialized regions. Compared to high frequency, low frequency sound is also less attenuated by various structures, and it can cause rattling of walls and other objects (Hood and Leventhall, 1971; Berglund et al., 1996). Although low frequency sound has been studied for several decades, only in recent years has it received much attention in terms of its effects on humans, especially pertaining to physiological and psychological effects, annoyance levels and subjective perceptions in urban and industrialized areas (e.g., Bryan, 1976; Cohen and Weinstein, 1981; Berglund et al., 1999; Fields and Shepherd, 2001).

The reports of persistent annoyance from sound, especially those associated with the Hum, are not new. While the first references to "unidentified humming sounds" date back to the 18th century (Deming, 2004), the first documented reports of the phenomenon emerged around 1970 (Deming, 2004; Leventhall, 2005). A comprehensive review of historical hum reports can be found in Deming (2004). The Hum is generally registered by 2–10 percent of the population (Mullins and Kelly, 1995; Deming, 2004) in particular locations around the world, such as the United Kingdom, New Zealand, Australia, the United States, Germany and Japan (Deming, 2004; and references therein). By convention, the Hum associated with a specific geographic location is thus named after that location. Some of the most prominent locations of the Hum are Copenhagen (Denmark) (Leventhall et al., 2003), Bristol (England), Largs (Scotland), Hueytown (Alabama, USA) (Deming, 2004; and references therein), Kokomo (Indiana, USA) (Cowan, 2003, 2008), and Taos (New Mexico, USA) (Mullins and Kelly, 1995; Deming, 2004; Cowan, 2008; and references therein). Although the first known scientific study was performed nearly four decades ago by Vasudevan and Gordon (1977), due to its ambiguous and problematic nature, the Hum largely remains within the realm of anecdotal reports (e.g., Deming, 2004).

In each of these cases, there are reports of residents being kept awake at all hours of the night, subject to the intermittent hum noise in their own homes and disrupting their lives (e.g., Mcquillan and Martin, 2001; Deming, 2004; Leventhall, 2005; Cowan, 2008). Some describe the noise as similar to an idling diesel engine or industrial machines in the distance (e.g., Cowan, 2003; Leventhall et al., 2003; Leventhall, 2005). While not everyone in the affected communities has heard the Hum, for those who have, the Hum sensation is a constant annoyance. Furthermore, those who do report hearing the Hum also describe side effects including loss of sleep and insomnia, nausea, muscle spasms, chronic stress, difficulty concentrating, fatigue, heart palpitations, headaches, increased tension, eye strain, pins and needles, irritable ear pressure, and personality changes (Leventhall et al., 2003; Deming, 2004; Cowan, 2008). Not all of the self-proclaimed 'hummers' suffer from side effects, but for many of the documented cases, it is reported that the quality of life for these individuals may be lessened by negative impacts on relationships and careers. Vasudevan and Gordon (1977) recognized that low frequency throbbing noise is '*very probably a real phenomenon and not imagined or self-generated*', which is also supported by some recent studies, such as the Kokomo Hum (Cowan, 2008). With each report also comes a wide range of potential sources. Predictions vary from mechanical sources (generators, worn industrial machines, ventilation systems (e.g., Berglund et al., 1996; Pedersen et al., 2008), gas pipelines (Krylov, 1995), ground borne vibrations (e.g., Manley and Styles, 2002; Rushforth et al., 2002), radio towers (Cowan, 2008), and, to human physiological traits such as psychological problems and tinnitus (Rice, 1994; Leventhall et al., 2003).

3. The Windsor Hum

Windsor, Ontario, Canada is situated along the Detroit River and across Detroit, Michigan, USA (Figure 1). Riddled with heavy industry, high traffic volumes, and rail and shipping channel operations, this border city is no stranger to noise. The situation is further exuberated by its proximity to a heavily industrialized region on the USA side of the border. Starting circa 2011, the citizens of Windsor began noticing and reporting a bothersome and persistent hum type disturbance, most noticeable in the south and west sides of Windsor and the neighbouring Town of LaSalle (Figure 1). The reports described the rumblings as intermittent in nature, but often persisting for several hours. The annoyance, now termed the 'Windsor Hum', is commonly described as either a deep, low-frequency hum, like a furnace or an idling diesel truck or as a deep, pulsating and vibrating noise, which is perceived more as a sensation rather than an audible sound. It is thus consistent with other reports of the Hum around the world.

An investigation undertaken by the Ministry of the Environment of Ontario (MOE) was unsuccessful in localizing the point of origin, given the presence of too many potential sources in the region. From June 2011 to August 2011, Natural Resources Canada (NRCan) performed a seismic study in an attempt to identify the nature (underground or airborne) of the source for the Hum and the probable location (Bent and Withgold, 2011). Considering that initial reports were indicative of the ground-based source, a seismic survey seemed an appropriate course of action. Several seismometers were installed around the city in an attempt to localize

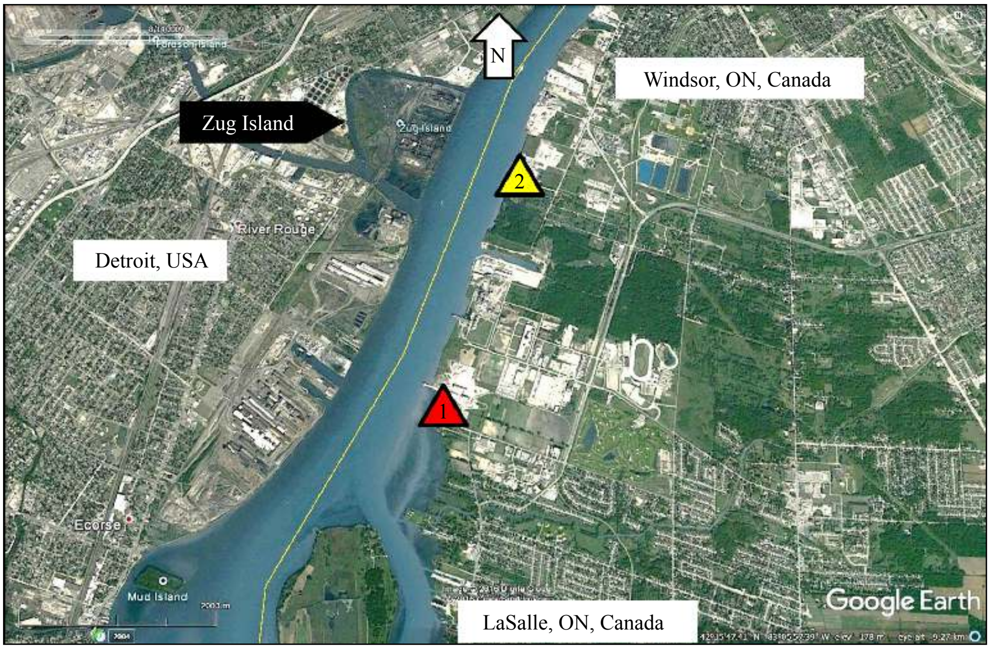

Figure 1. A regional map of the Windsor-LaSalle-Detroit area showing the general region where public Hum reports were received during the study period. Triangles show the locations of the two infrasound/low frequency sound arrays. Note that almost all reports were to the South or South-East of both arrays.

the source of the Hum. The NRCan study led to the following conclusions: (i) the long duration of the excitations were not consistent with earthquake or other seismic activities, (ii) the prominent frequency of the excitation was approximately 35 Hz, and (iii) due to the speed of the propagating energy, the excitation was an airborne noise source and not a ground vibration (Bent and Withgold, 2011). These findings eliminated the ground based (seismic) sources, as well as very low frequency electromagnetic waves. While the latter are also thought to adversely affect humans under certain conditions (Tenforde, 1992; Jauchem, 1997), it remains unclear whether they are associated with any auditory effects (Leventhall et al., 2003). While this seismic study did not ascertain the exact source of the Hum, triangulation of the data suggested Zug Island (Figure 1) as the most probable general location of a monotone signal correlated with Hum reports by the public. Based on these initial results, an acoustic study, which would further characterize the nature and location of the Hum seemed warranted (Bent and Withgold, 2011).

Following a press conference held in January 2013 at the University of Windsor to announce a federal government funded research project to locate the source of the Windsor Hum as a process to protect the quality of life for citizens of Windsor, the Department of Foreign Affairs and International Trade (DFAIT) contracted Western University (London, Ontario) and University of Windsor (Windsor, Ontario), Canada to conduct a joint acoustic study to investigate the source of the Windsor Hum. The survey conducted by the University of Windsor had the purpose to validate the existence and characterize the noise for the Hum phenomenon, and, if successful, confirm the source characteristic, using noise source identification (NSI) technology to pinpoint the source emitter (Novak et al., 2014). The particulars about the Windsor University field study are not discussed here. The role of Western University was to deploy two portable infrasound arrays in the Windsor area over the period of approximately one month to monitor the Hum and determine its dominant frequency, direction and possibly geolocation (Silber and Brown, 2013), if any signals are found.

4. Instrumentation

The portable infrasound arrays, herein referred to as Array 1 and Array 2 (Figure 1), were deployed with the four elements (sensors) set up in an off center triangular formation, such that the three outer elements were approximately 20 m away from the centre element (Figure 2a, b). The positions of individual sensors were measured with a high accuracy differential GPS (dGPS) unit (absolute accuracy of 10 cm). The small separation between the elements was designed to optimize the arrays for detection and processing of frequencies well above 20 Hz. One disadvantage of such small apertures however, is the possibility of spatial aliasing (Christie and Campus, 2010; Garces, 2013). More about a triangular type of infrasound array setup can be found in Silber and Brown (2014). The microbarograph sensors used in the study were four inlet Chaparral 25 microphones manufactured by Chaparral Physics at the University of Alaska. The digitizers were Taurus models manufactured by Nanometrics, which sample at 250 Hz. The sampling rate of 250 Hz limits the highest resolvable frequency (the Nyquist frequency) to 125 Hz, well into the audible range. To reduce local wind noise and turbulence, porous garden hoses were attached to each one of the sensors. The power was supplied by solar panels and car batteries (Figure 2c). The data was continuously streamed to NRCan, and then sent to a Western University one to two days later for analysis.

Much of the choice for the sites was dictated by the logistics of se-

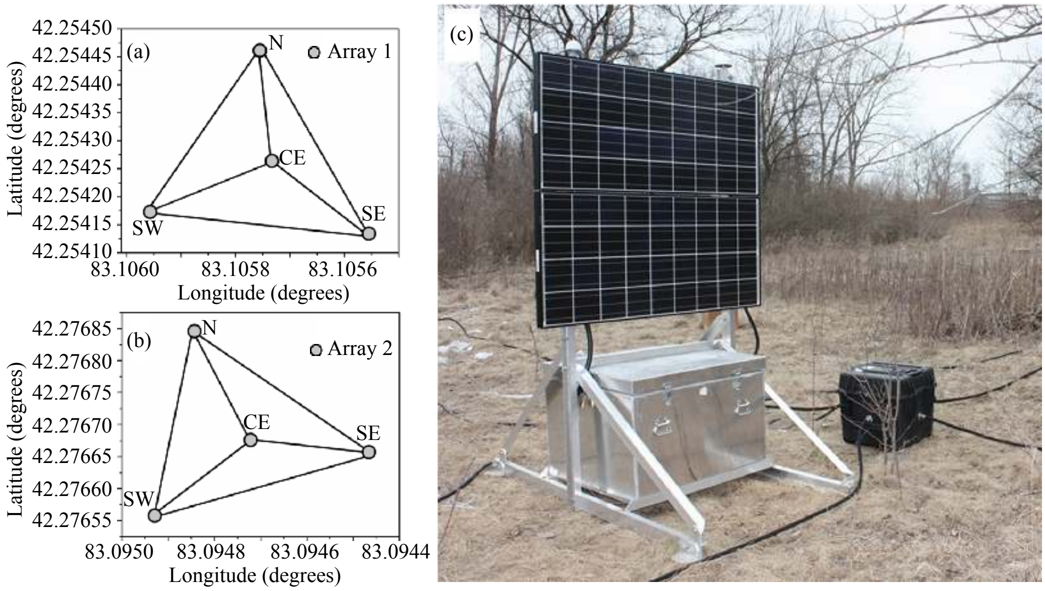

Figure 2. The setup and configuration for (a) Array 1 and (b) Array 2. The axes represent latitude and longitude. (c) Picture showing the Array 2 installation (Center Element) at the site. The sensor was housed in the black box, with porous garden hoses hooked to the four inlets. The array was powered by the solar panels and vehicle batteries.

curity and ability to obtain permission for sitting for the full month of the study, as well as the proximity to Zug Island and the general region of most citizen complaints. Array 2 was deployed on 20 February, 2013 directly across from Zug Island (~1.5 km away), while Array 1 was deployed on 4 March, 2013 south of Zug Island (~3.5 km away). Array 1 was situated approximately 3 km south of Array 2. Aside from their proximity to Zug Island, both the Array 1 and Array 2 sites had 24 hour security, which made them excellent location choices for this study. Array 2 was placed at a site with heavy vegetation cover, and was secluded, while Array 1 was in an open field and very close to the river bank. A possible issue with the Array 2 site was continuous construction activity and ongoing truck traffic proximal to the array. Additionally, sand/dirt piles being used for bridge construction blocked the direct view to the river and may possibly have interfered with horizontally travelling sound waves efficiently reaching the array from across the river. Both arrays were decommissioned on 8 April, 2013, after 36 days of operation.

5. Search for Acoustic Signals

To search for possible signals in the infrasound array data associated with the Hum, it was useful to have some indication of Hum occurrences (date, time, duration) and the type of sound (low frequency hum, vibrations, pulses) experienced by people in Windsor. This permits correlation of infrasound signals with Hum reports. In this regard, a dedicated e-mail for residents to report Hum detections in addition to a reporting form set up through the Department of Physics and Astronomy website, Western University was established, and publically announced to residents through local media. The reports through both of the aforementioned proxies were compiled and subsequently used to search for possible acoustic signals.

From residents' reports, the sounds and annoyance level associated with the Hum were generally more subtle and less prominent during the study period (20 Feb–8 Apr, 2013) than previously experienced (e.g., during 2012). It is not certain whether this was due to seasonal effects or some other reasons. Qualitatively, many reports suggested that the sounds are the most prominent during nights and/or on cloudy days. The propagation of sound in real air depends on meteorological factors such as wind, temperature and humidity (Beer, 1974). The reported sounds associated with the Hum fell into three distinct categories: (i) an idling engine-type sound (also identified as a furnace sound); (ii) pulsing or rumblings; and (iii) vibrations.

The most commonly reported general direction of the Hum was from the West-Northwest for all locations east of the Detroit River (Windsor and LaSalle) and East-Southeast from the west of the Detroit River (Michigan). Residents noted that some or all categories could be reported at any one time. Commonly, some residents explicitly reported a quiet (Hum-free) day while others experienced substantial annoyance from the Hum. The nature of these complaints was broadly consistent with witness descriptions of low frequency sound associated with the hum phenomena in other parts of the world. The Windsor area is exceedingly noisy acoustically, as is the case for most major urban areas. This complicated the airwave signal analysis and geolocation as often multiple sources from multiple directions are actively producing acoustic signals at any given time. Both infrasound arrays were equipped with extremely sensitive microphones, capable of picking up very slight changes in air pressure (one part in a millionth of the ambient atmospheric pressure under ideal conditions). To protect privacy of those reporting the Hum, the complainant identifiers, such as individual names and/or addresses, were not retained. Only place marks with approximate locations were mapped for the purpose of correlating the complaints with the reported timing, observer reported direction and nature of the Hum.

6. Preliminary Analysis

The raw waveforms were initially processed and analysed in *MATLAB*® using MatSeis 1.7 (Harris and Young, 1997; Young et al., 2002), which is used for basic filtering and cross-correlating low frequency sound waveforms between array elements. Associated spectrograms (distribution of acoustic energy as a function of frequency and time) were used to investigate signals potentially linked to the Hum and to determine the dominant frequency. However, since MatSeis 1.7 is not sufficiently sensitive nor is it optimized for very noisy arrays (such as in this study), the Progressive Multi-Channel Correlation Method (PMCC) was used to search for pressure airwave signals in more detail. PMCC is very efficient for detecting low amplitude, coherent infrasound signals (Cansi, 1995; Le Pichon and Cansi, 2003), which is especially important for noisy sites. It utilizes a sequence of frequency bands together with user-specified time windows to identify 'families', or detections associated with a single coherent signal, in effect identifying the timing and frequency range for a coherent signal. This family association among PMCC 'pixels' is done by specifying allowed ranges or thresholds for inclusion in a family across a number of parameters, which may include the signal timing, back (arrival) azimuth, coherence, correlation and trace velocity. Description of the technique and application of PMCC to infrasonic array processing can be found in Brachet et al. (2010).

A signal search was performed in all frequencies between 5–125 Hz for a number of time segments including all intervals where public reports of the Hum were made as well as a number of randomly selected control intervals. Since the previous seismic study, conducted by NRCan, had identified the frequency range of interest (approximately 35 Hz), particular attention was paid to signals in this spectral region with the goal of establishing arrival directions for a possible source. It should be noted that even if a probable signal is found, unless both arrays detect the same signal, it is not possible to determine the location of the source, as there is no precise indication of the distance the signal travelled before reaching any one array. Only back azimuth cross-bearing intersections from both arrays would provide a geolocation. Several randomly selected time segments were analysed to establish a baseline of typical airwave signals received at each array and determine overall dominant frequencies and general directions of arrival. An example of the PMCC visual output is shown in Figure 3.

The aim was to search for possible signals at both arrays using PMCC within 30–60 minutes of a public Hum report. Since the high sampling rate (250 Hz vs. usual 20–50 Hz for a typical infrasound array) is taxing on the software and thus computing time, only data segments of 30–60 min could be analysed at any one time. Therefore, it was necessary to perform successive analysis on

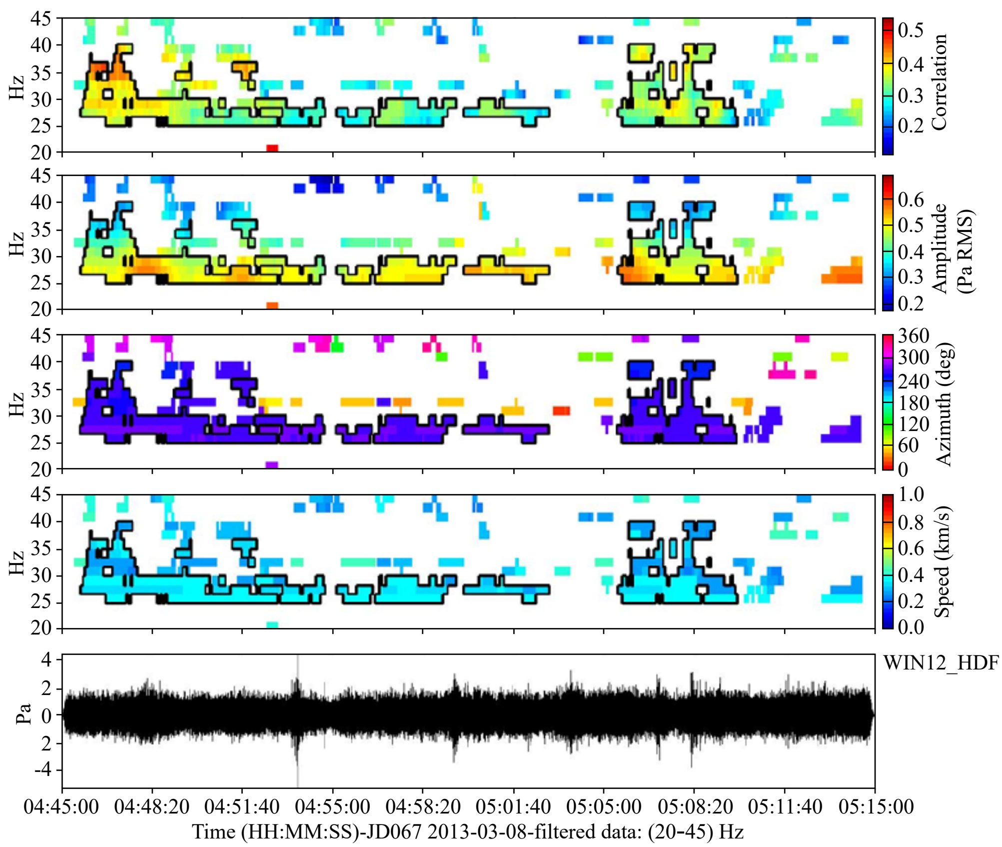

Figure 3. The PMCC results main window for 08 March 2013. The sub windows, starting from the top, are as follows: Correlation—a measure of the signal coherency across the array; Amplitude—root mean square of the signal amplitude in Pascal (Pa); Azimuth—apparent direction of the signal arrival in degrees, measured clockwise from north; Speed—apparent signal velocity in km/s as it arrives at the array. Horizontally travelling airwave is typically in the range of 0.330 km/s, higher speeds >0.40 km/s indicate steeper arrivals; the lowermost window is the signal as recorded by the Center Element. 'Boxed' regions indicate signal 'families'. The hum was reported to be active at this time.

a number of waveform sections in a long time segment (for example, a time period of 5 hours would have to be analysed in at least five separate data chunks). Additionally, instead of analysing the entire frequency range (up to 125 Hz) at once, successive examination of several narrow frequency bands was performed to detect the possible signals associated with the Hum. To initially identify the possible signals associated with the Hum, a number of PMCC settings were manually tested and then modified to attempt to optimize the search for signals of interest. Trace velocities less than 0.290 km/s do not belong to the infrasound/low frequency sound spectrum (e.g., Le Pichon and Cansi, 2003); thus, such signals were not classified as a viable detection.

7. Preliminary Results

Even though they were stationed only about 3 km apart from each other, Array 1 and Array 2 showed very different intrinsic signal characteristics, most probably due to the local site (topography), prevailing winds relative to possible sources and ambient noise conditions. The magnitude of the signal amplitude was generally in the range of several tenths of a Pascal. For comparison, the atmospheric pressure at sea level is 101,325 Pa. The difficulty in isolating any meaningful signals was exuberated by the fact that the Windsor area is extremely noisy, with omnidirectional noise present at all frequencies at all times, as shown in the radar plot for a two-hour window on 17 March 2013 (Figure 4). The Array 1 site was significantly noisier than the Array 2 site, with a number of distinct signals in discrete frequency 'bands' and 'packets' arriving from multiple directions at various speeds at the time of Hum reports. Considering the short length of the study, any statistical analyses of the various signals arriving to the arrays were not practical, as they would not provide meaningful information (especially in absence of the positively identified signals associated with the Hum).

We found and identified two frequencies of interest which were present at irregular intervals, one at approximately 28–30 Hz and another one at approximately 35 Hz. These two frequencies were particularly prominent during the Hum activity periods reported by local residents, but may or may not be associated with the Hum. The coherent and strongly correlated signal came either in distinct 'packets', each lasting for several minutes (usually around 35 Hz) or as a semi-continuous signal (mostly near 30 Hz) lasting from tens of minutes to several hours and with sporadic bursts and showing fluctuating amplitude/coherency. Even though the "packets" (~35 Hz) often coincided with reports of rumbles and pulses heard and felt by some residents, in other instances when the pulsing-type of Hum was reported, such features were not seen. Thus, we did not find a completely consistent correlation between the qualitative Hum report categories and the spectral character of the most probable signals associated with the Hum at Array 1. The direction of arrival of signals within the 30–35 Hz frequency band at Array 1, based on 54 separate occurrences within the data sample analysed was 265.2±4.2 degrees. It is not clear which one of these two frequencies (30 Hz or 35 Hz) was associated with a specific Hum category reported (if they were related to the Hum). As previously mentioned, the Hum comes in several categories, ranging from the persistent idling/droning/furnace noise to the pulsing/rumbling/vibrations. Based on the association of the reports with the specific signal signatures, the most consistent (though not universal) associations seem to suggest that the droning/idling may be associated with the 30 Hz frequency, while the pulses may come from the 35 Hz frequency. Since the data sample only covers the time period of just over a month and during the Hum 'downtime' relative to the usual activity, it was difficult to pinpoint with much certainty which type of annoyance is associated with a specific frequency band or if in fact, they are producing the Hum.

The analyses have revealed that the airwave signals at Array 2 predominantly arrived with back azimuth of ~60°, which is the gener-

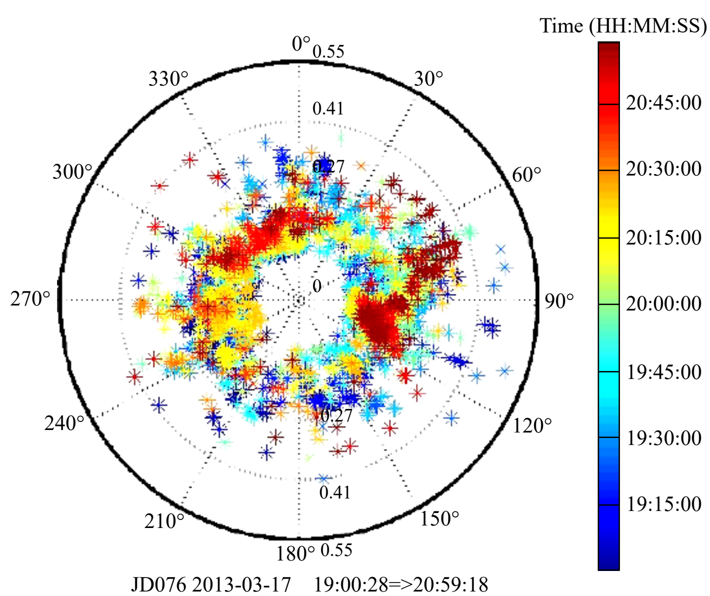

Figure 4. A radar plot covering the two-hour window from 19:00–20:59 UTC on 17 March 2013. The residents reported the Hum to be active during this time segment.

al direction of downtown Windsor. A steady signal at about 25–30 Hz, present most of the time, was detected. Another, much weaker signal, present only occasionally (mostly during the Hum activity as reported by the residents), occupied the 35 Hz frequency band. The two signals, 30 Hz and 35 Hz, seemed to be interconnected, as the 'peaks' or pockets of energy occurred at the same time in both frequency bands. The apparent direction of arrival for all these signals generally pointed in the 60° direction from the Array 2 site. This direction is not consistent with the general direction of Zug Island.

Although these signals were not always present during the Hum reporting time periods, it should be noted that the construction of a new cross-border bridge underway during the time of the array deployment at the river may have created a physical barrier possibly preventing free propagation of airwaves coming from the direction of the United States at this site. The general absence of airwave signals emanating from other directions does not imply the absence of noise. The physical conditions at the Array 2 site might have hindered the propagation of airwaves from certain directions. Typically, heavy vegetation usually serves as a buffer and helps reduce local noise at an array. However, the presence of heavy vegetation, coupled with the fact that the Array 2 site was situated on a slightly concave terrain, might have had the opposite effect.

8. Concluding Remarks

Given that the general reports were indicative of the low Hum activity, coupled with short time frame of the study and the overall high noise in the geographical area of interest, the results presented here should be considered qualitative and preliminary. A longer surveying time, with multiple arrays, accompanied by more comprehensive and numerous resident reports, would be advisable for future studies that would embark on detecting and characterizing the possible acoustic signals associated with the Hum.

The complexities of acoustic propagation in the local Windsor conditions, including geology, vegetation, ground reflections, propagation paths, interference, turbulence, etc., may all or in part play a role in sound propagation. Possible sources may include quarry activity or industrial ventilation systems. For example, quarry activity is known to produce impulsive sounds (Job, 1988) and there could be some coupling mechanism of line blasting with the ventilation/release systems. The Kokomo Hum was found to have been caused by a faulty cooling fan (Cowan, 2003). However, in the case of the Windsor Hum, given the relatively short duration of the field study, coupled with the fact that no data about any of the industrial sites were available, it is not possible to speculate on possible sources of the Hum. While this geophysical field investigation did not ascertain the exact source of the Hum, it provides framework for new pathways in considering future studies and approaches to localize the Hum phenomenon. For future considerations, a more focused geophysical study over a longer time period is recommended.

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