GEOREFERENCED SPECTRAL MAPS.
AN IMPROVED INSTRUMENT FOR ACTION PLANNING ON ENVIRONMENTAL NOISE MITIGATION

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ABSTRACT

Exposure-response relationships have been widely studied using A weighted equivalent sound pressure level (*L*eq,A) measured outside building environments in contrast with field surveys. On one hand low frequencies are minimized by A-weighted filter network. On the other hand low frequencies are predominant even inside buildings for some of the most salient sources in many cities (i.e. road traffic). These relationships do not consider that people spend a large part of their time inside building environments.

The spread of the exposure-response relationships can, presumably, be reduced by relating people response to the noise spectrum levels inside building environments instead of the outdoors *L*eq,A. Outdoors spectral maps can be georeferenced using geographical information systems. Then the indoors spectrum for each building can be estimated if the georeferenced data of façades and interiors properties were available. Furthermore city planners can use the outdoors spectral maps to estimate the adequate sound insulation of façades for new projects.

In this article a georeferenced spectral map of a part of the city of Rosario, Argentina is developed using inexpensive resources and some interesting tools for this purpose are presented using technical computing software. Different forms of presenting the data are analyzed in relation to the requirements of different agents, public, city planners, Geographical Information Systems users, etc.

Keywords: Noise Map, Environmental Noise, Soundscape approach, Spectral Noise Map, Effects of Noise.

1 INTRODUCTION

Exposure-response relationships have been widely studied using A weighted equivalent sound pressure level ($L_{eq,A}$) measured outside building environments in contrast with field surveys (Schultz, 1978; Miedema, 2007). Even more, nowadays the $L_{eq,A}$ descriptor, estimated for a whole year in Europe and a not specified long-term time interval in Buenos Airess, using simple adjustments for night and evening is used as a diagnosis tool for the development of action plans to reduce noise when necessary (EU Directive 2002/49/EC, 2002; Ley 1540 Bs As, 2005). The corrected $L_{eq,A}$ is called day-evening-night sound level (L_{den}) or day night sound level (L_{dn}) when account adjustments for evening and night or just night, respectively (ISO 1996-1, 2003). The correction for day period (7-19 h) is 0 dB, for evening (19-23 h) is 5 dB and for night (23-7 h) is 10 dB. The L_{den} is the (period-weighted) energy average of all these corrected periods.

Currently available and being developed methods for the calculation of Noise Maps use spectral information to describe the noise sources and also the propagation paths (FHWA TNM, 2008; ISO 9613-2, 1996; JRC Reference Report CNOSSOS, 2010). Particularly the CNOSSOS calculation method is being developed in response to the European Directive 2002/49/EC, and the directive states that the maps should be presented in terms of $L_{eq,A}$ descriptors but the spectral information used to compose such a map, following the CNOSSOS model, cannot be recovered from $L_{eq,A}$ map itself. Using these calculation methods it would not be technically difficult to report the spectral data as a relevant output. Furthermore, the $L_{eq,A}$ map can be composed in Geografical Information Systems (GIS) servers using georeferenced spectral data as input in order to present it to community as recommended in WG-AEN, 2008.

Low frequency sound energy is predominant in the most salient sources (i.e. traffic noise) in many cities and are less abated, in comparison with mid or high frequencies, by physical effects such as air attenuation, acoustic divergence, the attenuation of frequently used façades, barriers, walls, and other objects in the sound propagation path. So outdoor noise sources in many cities carry important energy at low frequencies that is received outdoors and especially indoors where many people spend long periods of the days. Even though the auditory system responds with less amplitude for low frequencies in the case of low levels, it is not the case for high levels. The well known problem of the A-weighting network is that it underestimates low frequencies giving an advantage to the spectral sound level without weightings.

Another advantage of spectral levels is that used as input data, knowing the characteristics of the façade and the interior ambient, allows for a good calculation of indoor levels, but this estimation is not possible using $L_{eq,A}$, instead of the spectral levels. Furthermore city planners can use georeferenced outdoor spectral maps to estimate the adequate sound insulation of façades for new projects in order to obtain a previously fixed indoors sound level. The estimation of the sound insulation cannot be done using $L_{eq,A}$ based maps without spectral information.

The classical paradigm, focused in noise reduction when certain limits are exceeded, is turning into a more holistic approach called Soundscape which aims to account for cultural and heritage background associated with sound sources, space and landscapes treating sound more as a ‘resource’ than ‘waste’ (Brown, 2011). A standard method for Soundscape approach is being developed (ISO 12913-1). Some descriptors of interest for the Soundscape approach such as Loudness (ISO 532, 1975; ANSI S3.4, 2007) and Sharpness (Zwicker and Fastl, 2007) can be estimated using spectral information as input data and cannot be estimated from $L_{eq,A}$.

In summary the band spectra can be easy computed using current available methods and presented without losing the necessary data for estimating $L_{eq,A}$, can account for low frequency energy (the predominant energy in many cases), permits the estimation of physically abated level or sound insulation characteristics for materials to obtain a fixed sound level in a fixed receiver and allows the estimation of descriptors used for on-going approaches such as Loudness and Sharpness in the case of Soundscape approach.

In this article a case study is presented using inexpensive resources to estimate the spectral levels and some techniques to incorporate them in Geographic Information Systems. Some alternatives to present this kind of data are shown.

2 STUDY AREA

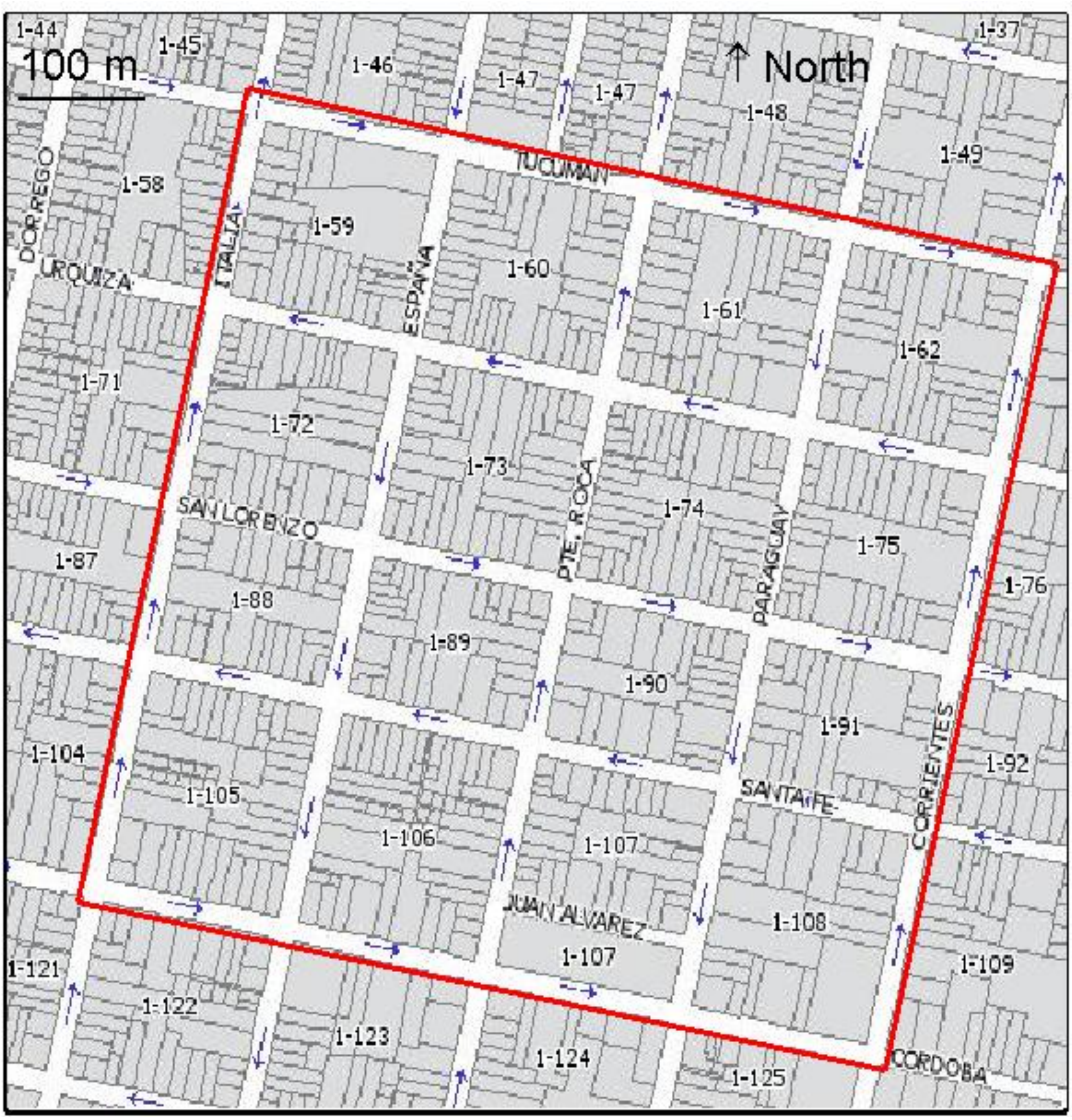

Figure 1: Study area. Using WMS GIS service by IDE Rosario (www.rosario.gov.ar/sitio/alias/ide/index.html).

Rosario city follows a Hippodamus urban layout characterized by a grid of streets. The study area was chosen in a part of the city with homogeneous characteristics depicting a square (see red square in Figure 1) of five crossing streets between Italia and Corrientes streets in the east-west direction and also five between Córdoba and Tucumán streets in the south-north direction. The study area is centered at south latitude near 32º56’22.2’ and west longitude of about 60º38’54.6’’.

The land use for the study area is residential with some small commerce. The streets are asphalted and the traffic is controlled by traffic lights in some of the streets intersections. The traffic is composed in first term by light vehicles and motorcycles, in second term by bus and finally by vans and heavy vehicles.

3 NOISE ASSESMENT METHODS

Noise maps can be developed using many methods that can be grouped into two big branches. In the first group direct noise measurement e required and in the second one are estimated using valid calculation methods. In this case study the available calculation methods were discarded because they were not previously validated for any part of Rosario city.

3.1 Direct measurement

A direct measurement method was developed using inexpensive resources. These resources are presented in other articles but herein a brief introduction is made in order to depict the whole method together.

The third octave bands level for road traffic was analyzed to state a stabilization time (Miyara et al., 2008) to define a minimum measuring period. As result from this study a measurement period of fifteen minutes was fixed for the field measurements and, after post-processing the data, it was checked that each measured band was stabilized.

Audio signals were recorded using the analog audio microphone output of two class 1 sound meters connected to both portable sound recorders. The sound meters were set to not use any weighting network. The microphones were placed at 1.5 meters height and 1 meter from the street in every measurement point. A 1 kHz pure tone of 94 dB was also recorded in order to have a reference of the acoustic signal and was used to calibrate the recorded signals. The recorders were previously tested to ensure suitability for use in acoustical measurements (Miyara et al., 2010). Only one measurement point was fixed for each street because the relevant parameters (i.e. traffic flow and profile form) were assumed constants trough the studied longitude of the streets. The position of each point responds to a random number sequence with uniform probability density function between 0% and 100 % of the studied length. The assumed characteristics of the traffic flow and street profile are suitable for the purpose of this study but should be analyzed for other activities such as action planning.

Then, the third octave bands levels were computed for each recorded point. The method for each band consists in computing the total energy of the spectral points, resulting from a Fast Fourier Transform algorithm, which falls in the frequency band of interest. A self developed algorithm previously validated by comparison with a standard class 1 instrument was used (Miyara et al., 2009; Accolti and Miyara, 2009 and 2010).

The instantaneous traffic flow was measured at each point using a self developed hand counter that allows counting in four different categories (i.e. 1. light vehicles, 2. motorcycles, 3. heavy vehicles and 4. buses). This kind of counters can be easily programmed for any portable computing device such as net-book, tablet-pc or even mobile phones or, as it was carried out in this study, by recording tone bursts with different frequencies for each category using a hand recorder. A vector with instants and associated category of event can be obtained by post-process of the tones or the output of the computing devices and associated with the audio recordings. Also a data logger for discrete events geographically and temporally referenced could be (and is being) developed for this purpose.

4 INTEGRATION TO GEOGRAPHICAL INFORMATION SYSTEMS

Georeferenced data used in Geographical Information Systems (GIS) can be generally of two kinds; raster or vector data. The raster data is well assimilated as an image file in which each pixel represents a little area of earth space. The vector data can be points, lines or surfaces referenced to points described in geographical reference systems.

Spatial data infrastructure (SDI in English or IDE in Spanish) are several institutional GIS aligned to support multiple GIS applications and promote their use (e.g. IDE Rosario, IDE Santa Fe or IDE Republica Argentina). They generally provide a server and online tools that returns useful data in response to client queries using these IDEs tools or other client tools such as the Matlab Mapping toolbox (The MathWorks, 2011).

4.1 Raster data and Web Mapping Service

The Web Mapping Service (WMS) is a standard protocol defined by the Open Geospatial Consortium (OGC) (http://www.opengeospatial.org/standards/wms) for GIS communication. This protocol allows the map data management by layers (e.g. map 1 streets layer, map 2, buildings layer) using raster type data. The storage of vector data can be done in different image formats such as TIFF, GIF, PCX, etc or more specific protocols such as GeoTIFF, ADRG, ESRI grid, etc.

WMS protocol was used through Matlab Mapping Toolbox to access the data of the layers parcels, street names, block numbers and street direction in the study area as shown in Figure 1 and just layer parcels shown in Figure 2. The IDE Rosario server provided the raster used data (www.rosario.gov.ar/sitio/alias/ide/index.html).

The process to obtain the images was carried with two queries. The first query was sent to the server which returned the available layers. In the second query some layers were chosen and a spatial region for the study area was defined. The representation system is also returned in the associated metadata and used to report the other layers in the same representation system (EPSG 22185).

4.2 Vector data and Shapefile protocol

The Shapefile is a well documented protocol composed by a set of at least three files. The proprietary is the ESRI company (ESRI 1998) but allows data translators from other companies and actually is a facto standard among GIS software and agents. This protocol allows the storage of vector type data. In this case study the features were points and the attributes are the thirty-one third octave band levels.

This protocol was used, through Matlab Mapping Toolbox, to compose the results assigning a geographical reference to the estimated levels. A geographic layer associated to the spectral levels was composed using a previous layer containing the center points and with of each street.

4.3 Resolution for results presentation

The values for two types of variables are reported in georeferenced spectral maps. The space or georeferenced related variables and the frequency band level variables. Of course a discretization must be carried and the step length of each variable fixes the resolution of each scale.

In the case of space the data discretized in distance units (i.e. in meters) can afterwards be interpreted in angular units (e.g. in radians) to describe the geographic coordinates units.

The Working Group on the Assessment of Exposure to Noise of the European Environment Agency recommends a common 10 m grid that can be modified as spaced as 100 m in some aircraft noise cases and as finer as 2 meters in cases where buildings face each other across narrow roads (WG-AEN, 2006).

The 1987 version of the ISO 1996-2 presented a color definition (see Table 1) associated with a band of 5 dB of L_{eq} from below 35 dB to 85 dB (WG-AEN, 2008). Although the color definition has been suppressed from the 2007 version of ISO 1996-2 its use is currently popularized and recommended.

Noise level (dB)	Color	Sample
Below 35	Light green	
35 to 40	Green	
40 to 45	Dark green	
45 to 50	Yellow	
50 to 55	Ochre	
55 to 60	Orange	
60 to 65	Cinnabar	
65 to 70	Carmine	
70 to 75	Lilac red	
75 to 80	Blue	
80 to 85	Dark blue	

Table 1: ISO 1996-2:1987 color definitions.

The 5 dB steps scale in Table 1 is in line with recommendations of the EU Directive 2002/49/EC, 2002.

5 PRESENTING RESULTS

Even though the word ‘map’ is mentally associated with an image, the output of the proposed Georeferenced Spectral Maps is just the structured previously processed data. In this section some graphical outputs are presented but the actual output is the structured data, in this case, following the Shapefile protocol.

5.1 Spectral map vector layer

The final output of this process is a vector layer with the third octave bands levels as attributes for features corresponding to points located in a 10 m grid of points in the street area (i.e. outdoor spectral levels).

This protocol, as a structure for the data, also allows incorporating other important attributes to each point. For example one attribute called *MeasOrEst* for each point shows if it was actually a measuring point or an estimated one. A list of attributes is presented from the fifth row to the last ones in Table 2.

Attribute	Description
Geometry	Shapefile kind of geometry (point)
BoundingBox	Shapefile geographic referenced area in degrees [lon1 lat1 lon2 lat2] ([-60.6485 -32.946 -60.641 -32.9395])
X	Longitude data of each feature. (longitude of each point)
Y	Latitude data of each feature. (latitude of each point)
MeasOrEst	Measured or estimated point (1 for measured other case 0)
Light	Number of light vehicles
Motorcycles	Number of motorcycles
Heavy	Number of heavy vehicles
Buses	Number of buses
ter20	20 Hz centered third octave band level (dB)
ter25	25 Hz centered third octave band level (dB)
…	…
Ter16 000	16 000 Hz centered third octave band level (dB)

Table 2: Attributes

5.2 Graphical presentation

Many forms of presenting the data were evaluated searching for one providing a quickly and easy to visually understand fashion but without important loss of detail. The following list shows the evaluated methods for graphical presentation of data

I. a whole map for each third band data
II. a whole map for each octave band data
III. a whole map for each three octave band data (i.e. low, mid and high bands)
IV. octave band data on request for each point
V. third octave band data on request for each point

The octave band or the three octaves band levels are easy computed by energy summing the content of the third octave band.

Methods I to III use precision as defined in Table 1 for the amplitude of each band and the 10 m grid for the spatial grid. Methods IV to V use precision of 0.1 dB for the amplitude of each band and the same 10 m grid for the space.

The method I has the advantage of showing all the output data but, for the whole audible range, more than 30 maps are needed. It was discarded because does not provide a quickly and easy to understand visual data.

The Figure 2 shows the results following method II. It gives a quick show of the low, mid and high energy in the left, mid and right columns respectively without loss of the details inside the three octaves bands. Octave bands spectra usually gives a good approximation for sound insulation specification of façades, barriers and other objects causing or used for insulation. Of course a third octaves band gives a better approach for sound insulation specifications but in case of need for such details method V can be used. The data as provided by this method is useful for city planners to estimate the minimum requirements for sound insulation characteristics of façades.

The method III gives an actually quick view of the whole scene but is not enough for specification of sound insulation properties of materials. However it can be used for communicative purposes or as a first attempt for incorporating the spectral factor in the information to the public tasks associated with noise maps action planning.

Note that results presented using methods I to III can be the returned data in many layers for a WMS query if the spectral map vector layer is available at the server.

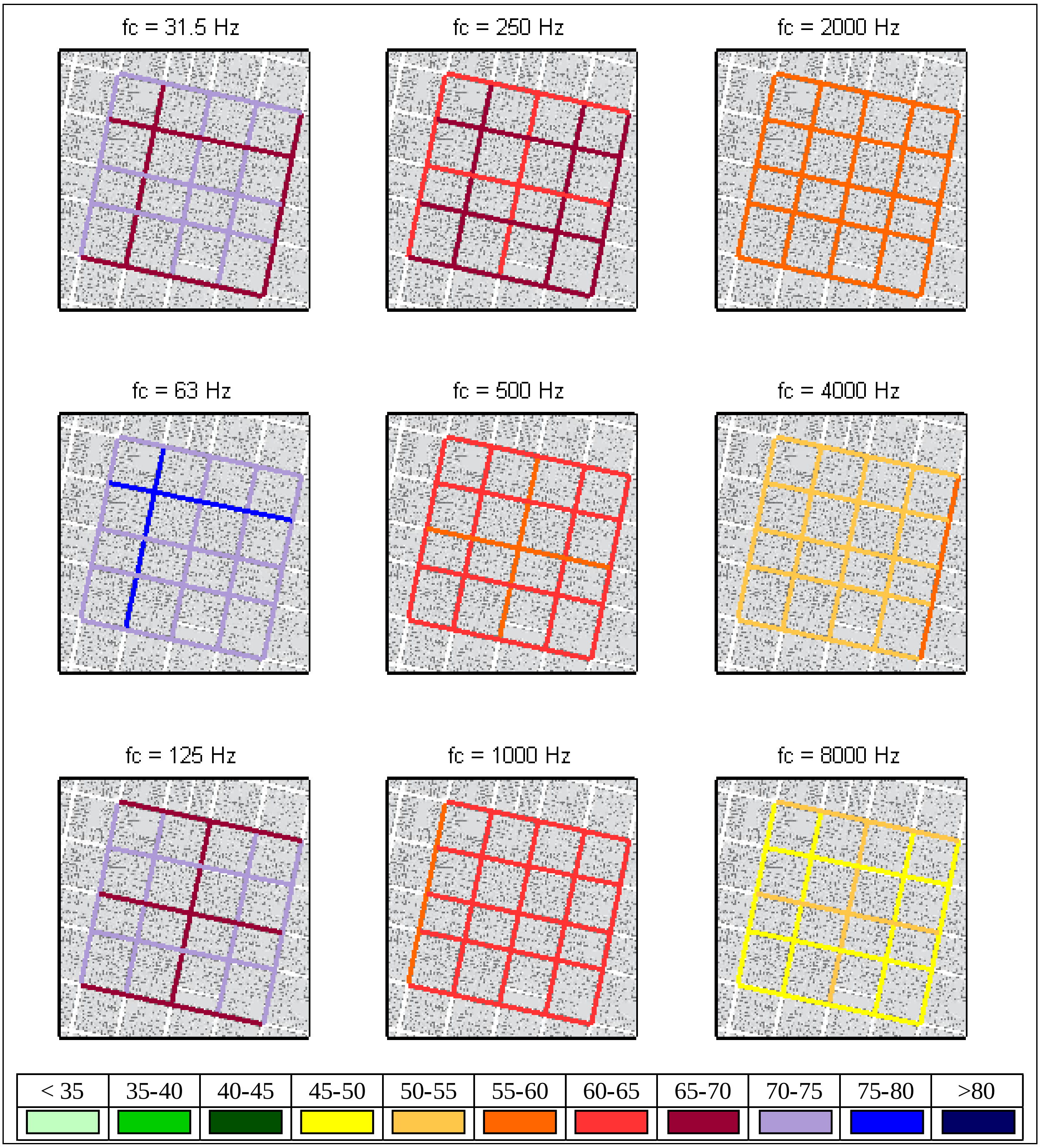

Figure 2: 1/1 Octave bands noise map

Results presented using methods IV and V are shown in Figure 3. The red line with diamond markers show the octave band levels (i.e. method IV) and the blue line with circles show the third band levels (i.e. method V) for a previously queried point located in Presidente Roca Street. These two methods have the advantage of a better resolution in amplitude related to the previous three ones but have the disadvantage of not showing the results for all the studied area at the same time. Of course the method V gives more detail but the simplicity of method IV can be of interest for quick calculations in typical noise control problems.

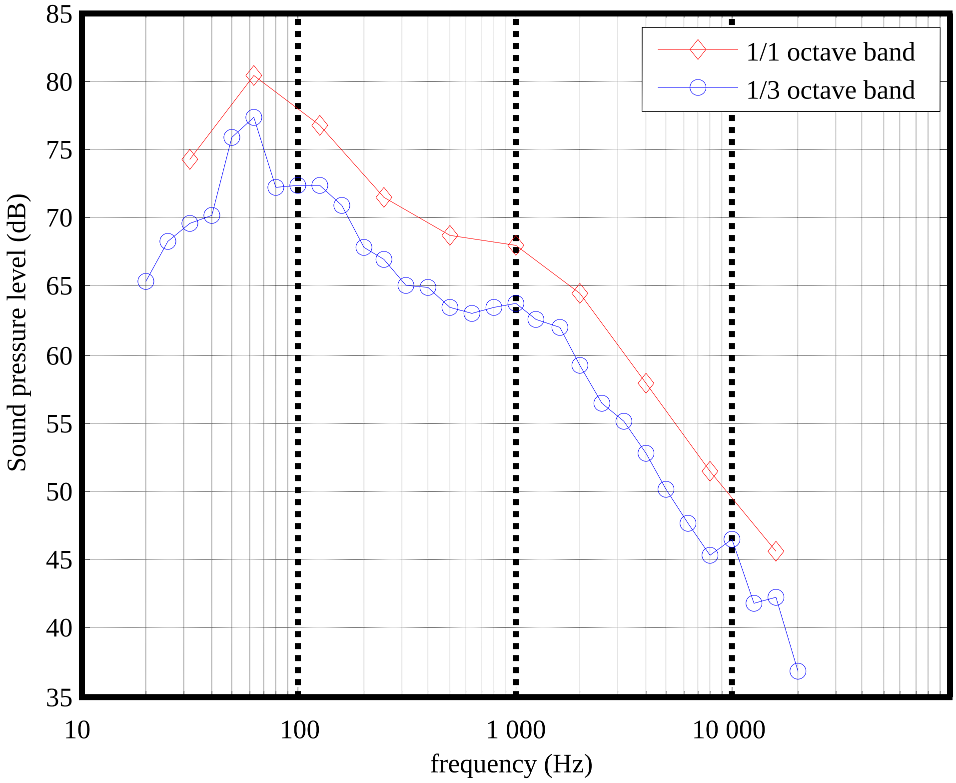

Figure 3: Band spectrum returned for a point located at Presidente Roca street.

The results from method IV and V (Figure 3) can be somehow (i.e. using protocols such as Web Features Service) returned from the server as result of a query for the spectral data of one geographic point or can be returned using a simple routine for searching the closest point in the grid in the Shapefile layer directly at the client using a computing or GIS software.

6 CONCLUSIONS

Advantages of incorporating the spectral content factor in noise mapping are the possibilities of reducing the spread of exposure-response relationships by relating them to actually heard characteristics of noise (i.e. low frequency, attenuated by typical façades, with the influence of interior characteristics of sound such as frequency-dependent reverberation). Also the spectral maps provide better possibilities in comparison with classical maps for city planners and architects involved in action planning and architectural design in relation to noise abatement or Soundscape design.

An informational structure for developing a georeferenced layer with the spectral maps compatible with Geographical Information Systems is presented adopting a well known protocol (i.e. Shapefile). The cost raise for composing spectral maps in comparison with classical $L_{\mathrm{eq,A}}$ maps is insignificant because is the same data arranged in other way preventing the loss of already calculated data (i.e. the spectrum) or, in the case of measurements, the herein presented method is actually quite inexpensive if compared with commercially available alternatives with third octave band analysis.

Some possibilities to handle this data were analyzed for diverse kind of action planning and design tasks such as presenting the maps to the public or planning the sound insulation requirements of façades.

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