EUROPEAN AVIATION SAFETY AGENCY
AGENCE EUROPÉENNE DE LA SÉCURITÉ AÉRIENNE
EUROPÄISCHE AGENTUR FÜR FLUGSICHERHEIT

Research project EASA.2008/OP14

BAckground Noise level and noise levels from En Route AirCraft (BANOERAC)

14 October 2009

easa.europa.eu

ANOTEC Consulting, S.L.
aircraft noise technology

labein tecnalia

Security class	Document ID	Issue no.	Short Title	Issue date	Page
Restricted	PAN074-5-0	3	Final Report - Part 0 Executive summary	06/11/2009	1 of 12

Project		Document Title
AN074	BANOERAC	D1. Final report Part 0: Executive Summary

Summary

This document gives an overview of the main objectives and achievements of the BANOERAC project.

Document revision

Issue	Date	Affected pages	Modifications
1	14/10/2009	All	First issue
2	-	-	-
3	06/11/2009	All	Incorporation of EASA comments 06/11/2009

Controlled copies

Anotec	Customer	Other
Lib	EASA (Mr. Franken)	Labein

Approval status

Prepared by Project team	Approved by Head Engineering & Design	Verified by Responsible Airworthiness
Itziar Aspuru (Labein-Tecnalia) Nico van Oosten (Anotec)	Nico van Oosten	N/A

Introduction

Two developments in aviation industry will shortly have reached a phase where actual rulemaking work will have to commence. These developments are the preliminary studies on supersonic business jets and the revived interest in so called 'open rotor' engines. They have a common factor in that they will potentially create non negligible noise levels on the ground, not only when flying in the terminal area around airports but also while the aircraft are climbing, cruising and descending at distance from airports (hereafter referred to as "en-route noise"). If aircraft with such technology would be numerous, this would essentially mean that aircraft noise would be audible literally everywhere. The political discussion and the impact assessment will therefore require factual data on existing so called background noise levels and on actual noise levels of 'classical' aircraft in cruise in Europe and elsewhere. Such data will make it possible to put the noise levels of these new technologies in perspective with the existing situation.

EASA issued an Invitation to Tender (ItT) for a study on “Background noise level and noise levels from en-route aircraft”, with acronym BANOERAC. The contract was awarded to the proposal from the consortium, formed by Anotec and Labein-Tecnalia, both from Spain.

Before the present study EASA contracted two pilot studies with direct relation to BANOERAC.

One study, performed by SINTEF, concluded that no data is readily available on existing background noise. It was reported however that a first approximation of the background noise levels can be derived from population density. The present project intends to use this concept to establish a detailed database of estimated background noise levels in Europe.

The other study, performed by Anotec, concluded that very little and mainly outdated information on en-route noise from aircraft was available, but that it would be possible to collect meaningful information with a measurement campaign. BANOERAC aimed at carrying out such measurements.

The aim of this study is to improve insight in background noise levels in Europe and the en-route noise from aircraft. It is realised though that the scope of the study does not allow to claim that the results would be representative for all of Europe.

According to the proposal the work performed was divided in 3 parts:

Part 1. Calculation of approximation of background noise levels
Calculation of background noise levels based on population density for each EU country, building on the SINTEF report and proposing some correction for extreme situations.

Part 2. Actual measurements of background noise and aircraft en-route noise
Measuring of actual noise levels in a number of locations representative for a quiet rural area, with very low levels of background noise from man-made sources.
Noise measurements from actual passages of aircraft that are en-route (i.e. climb, cruise and descent phases).

Part 3. Final analysis and results
Analysis of the measured data and presentation and discussion of the results for both background noise and aircraft en-route noise.

1. Calculation of approximation of background noise levels

The aim of Part 1 was to generate a Background Noise Level Map for the EU27, referred to a spatial grid of 10 x 10 km resolution. In this report Background Noise (BGN) is understood as the sound at a location from a number of more or less identifiable sound sources when the direct sound from prominent sources is excluded.

In a previous study, developed by Sintef, a first approximation of the background noise levels derived from population density was defined. In an analogous way, this part of the BANOERAC project is based on this concept to establish a detailed database of estimated background noise levels in Europe and the intention was to complement this approach proposing some corrections for extreme situations; this is, incorporating the effects of transport and urban noise, including a minimum threshold for quiet rural areas, and analyzing data from Strategic Noise Maps developed by Member States as an answer to the European Noise Directive.

In the BANOERAC project Background Noise Levels are expressed by the percentile level L95 in different periods of the day (day, evening and night). L95 is the sound level exceeded for 95% of the time, so only in 5% of the time the sound level is less than L95. The unit of L95 is dB(A). This is illustrated in Figure 1.

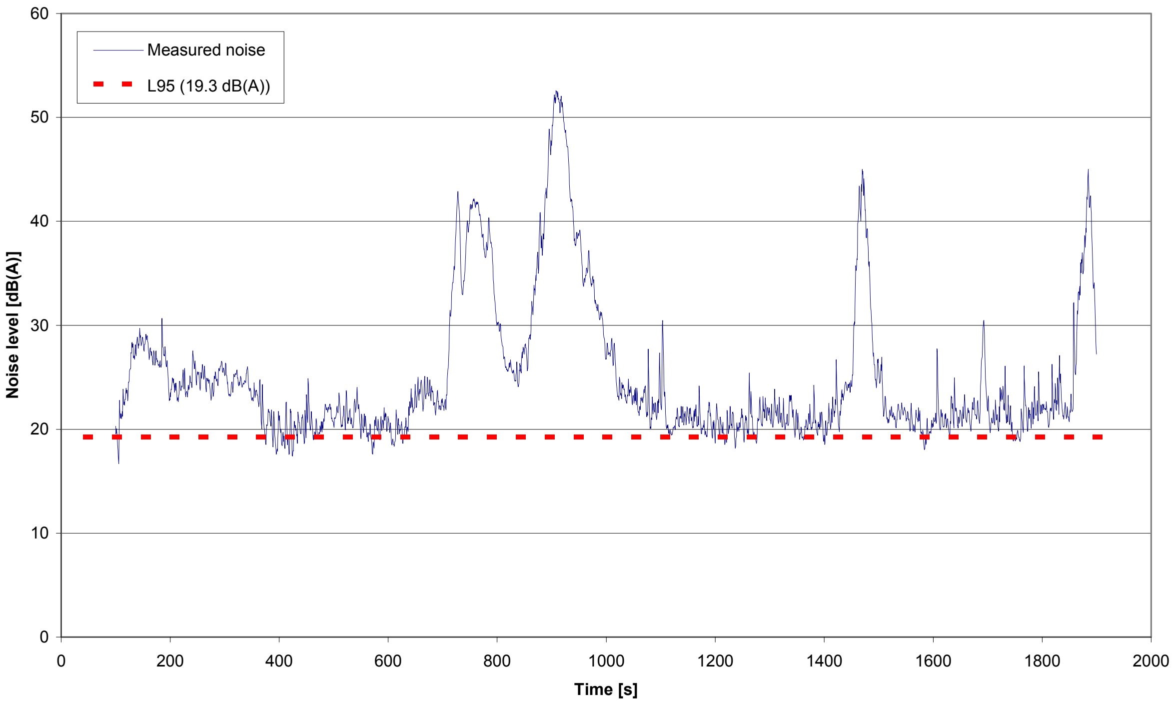


Figure 1. Example of Percentile level L95

Whereas not much information is available on L_{95}, large datasets for L_{den} are readily available for large areas as a result of the ongoing Strategic Noise Mapping exercise. This metric was therefore used as an intermediate value to calculate the L_{95} values. Thus, appropriate percentile levels are predicted on the basis of L_{den} values. In this project the assumption is that representative noise levels in each cell are understood as the acoustic energy in the cell, extended to its whole surface. This premise is applied to all acoustic parameters used in this project: $\mathbf{L_{den}}$, $\mathbf{L_{day}}$, $\mathbf{L_{evening}}$, $\mathbf{L_{night}}$, $\mathbf{L_{95,day}}$, $\mathbf{L_{95,evening}}$, and $\mathbf{L_{95night}}$.

The grid used as spatial reference to build the BGN Maps is the ETRS89 Lambert Azimuthal Equal Area 52N 10E grid, recommended by EEA.

Input data needed for development in Part 1 refer to population density data, Strategic Noise Maps, transport Infrastructure information and noise monitoring data.

The application of the methodology allows building four BGN datasets:

- Basic BGN dataset. It estimates BGN levels considering only population density data.
- Agglomeration BGN dataset. It estimates BGN levels in urban agglomerations.
- Transport BGN dataset. It estimates BGN levels in areas acoustically affected by major roads.
- Rural Quiet BGN dataset. It estimates BGN levels in areas with very low population density values. It represents the minimum threshold noise level caused by natural sounds.

These BGN datasets should not be considered independently. The BANOERAC BGN Map is built by combining values from the four datasets. As a general rule, the final value of every cell is the maximum value of all existing values coming from any dataset. Results obtained in the project have been checked by different validation procedures.

The final results achieved in this part of the BANOERAC project are the following:

- A database with all values linked to a 10 km reference grid for the EU27 countries, which contains both fundamental information for each 10 km cell and the resulting noise data. An updating tool to recalculate automatically all information is also provided.
- Printed maps with the background noise levels plotted in A4 format and also delivered as digital files in PDF format.
  Figure 2 shows an example of a final BANOERAC European BGN Map.
- Easy-to-use desktop mapping tools to visualize and consult the maps, as well as other relevant reference information.

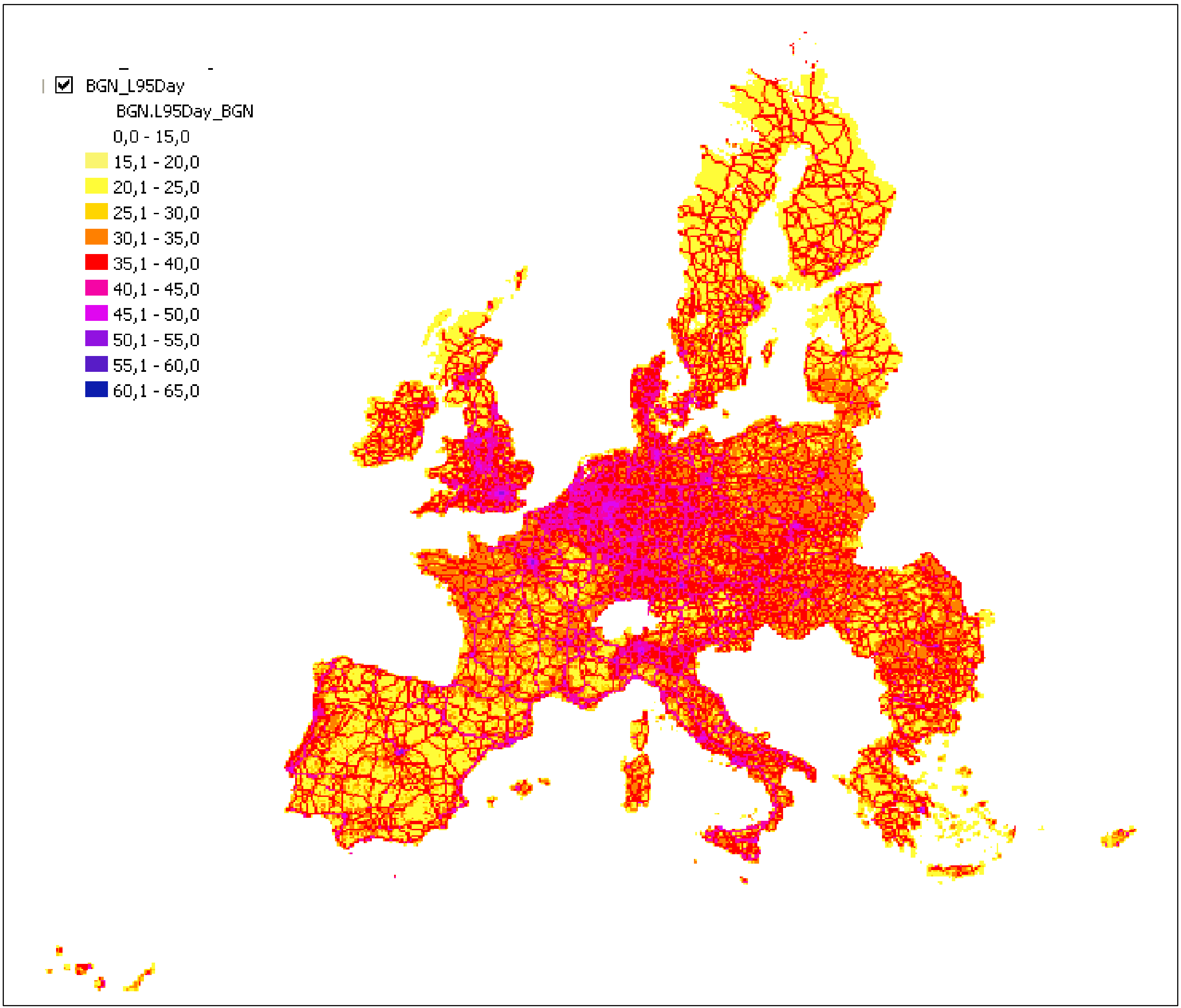


Figure 2. Background noise map (L95day)

2. Measurements of background noise and aircraft en-route noise

The main objective of Part 2 of the BANOERAC study was the performance of measurements in order to establish actual background noise levels in various environments and also to determine the noise levels of current aircraft types when en-route.

Test site selection
Due to the expected low noise levels to be measured, the test sites had to be selected carefully. Especially the aircraft en-route noise measurements required specific additional attention with respect to the proper selection of the test sites (underneath major airways).

Two test sites were defined for the dedicated background noise measurements (Diego Alvaro in Avila and Los Tablones in Granada), which were representative for Natural park and agricultural/hilly. For the aircraft en-route measurements 2 sites were selected relatively close to Madrid (Cebreros and Colmenar). It is noted that during the background noise sessions also some aircraft noise events were recorded and that during the aircraft noise sessions also some background noise could be measured.

Measurements performed

		Background noise	Aircraft en-route noise
Test site	**Period**	**Nº hours**	**Nº valid events**
Diego Alvaro	July	31.5	41
Los Tablones	July	48	21
Cebreros	Feb-May	35	780
Colmenar de Oreja	June-July	20	276
Total	**6 months**	**134.5**	**1118**

Table 2 Total nº hours/nº events obtained during the measurements

For background noise a total of 90h was planned, whereas for aircraft en-route noise a minimum of 1000 valid events was targeted. Both objectives have fully been met.

3. Final analysis and results

The main objective of Part 3 of the BANOERAC study was the analysis of the data obtained during the measurements of Part 2, in order to establish actual background noise levels in various environments and also to determine the noise levels of current aircraft types when en-route.

Determination of background noise level

The objective of the background noise measurements was to obtain the noise levels representative for very quiet areas, in order to correct the SINTEF curve (see Part 1) at the lower end (i.e. at very low population density). The Diego Alvaro site appeared the quietest site and the measurements made here were used to feed Part 1.

All noise events generated by non-natural sources (e.g. cars, aircraft) were excluded from the measurements in order to derive the background noise levels, generated by natural sources only. These noise levels of only natural origin were used in the further analysis of background noise in this part.

The following table contains the average values for the 3 periods Day (7-19h), Evening (19-23h) and Night (23-7h). These values were used in Part 1.

Period	LAeq [dB(A)]	L95 [dB(A)]
Day	29	23
Evening	27	22
Night	23	19

Table 3 Average values of background noise from natural sources only, for the 3 periods of day (Diego Alvaro site)

Figure 3 shows all the background noise measurements performed at the four test sites which cover a period of 6 months. It can thus be considered a representative dataset.

At the Los Tablones test site the background noise levels appeared to be significantly higher than elsewhere. This site was dominated by noise generated by insects such as cicadas. It is recognized that this noise is not representative for the whole of Europe, but it certainly is for the whole Mediterranean region. A correction factor might be added to the model developed in Part 1 in order to account for these local/regional effects.

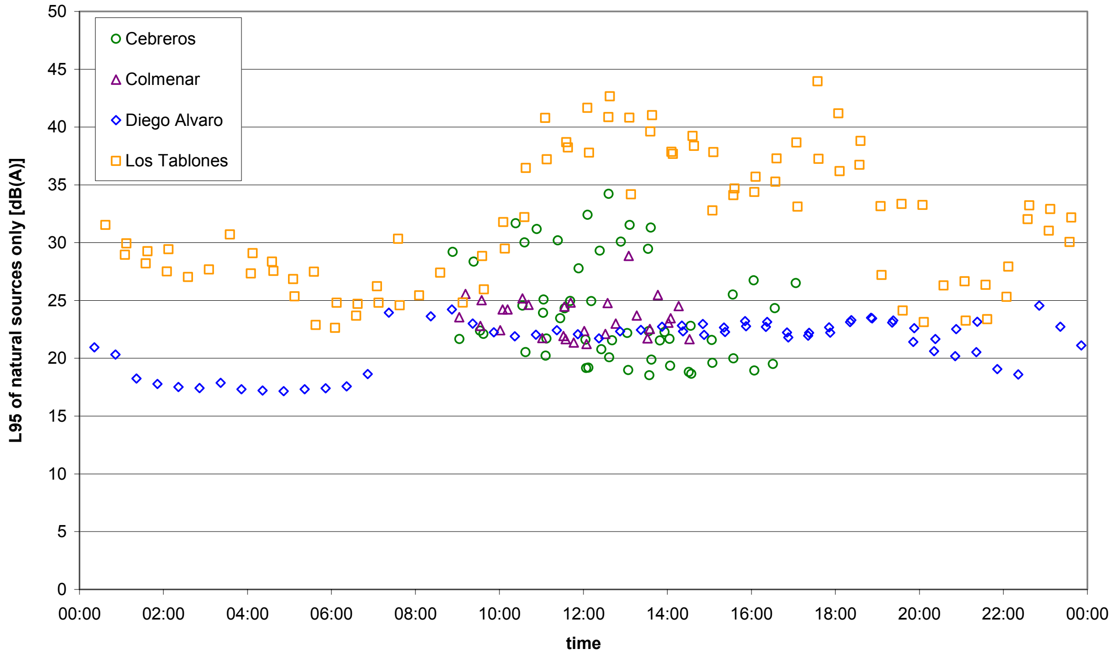


Figure 3. Recorded Background noise levels

Determination of aircraft en-route noise levels

Early in the analysis stage it became apparent that the noise from birds completely masked the aircraft noise levels. A new metric was defined by which this noise could be filtered from the results by using a cut-off for all noise above 1 kHz. It was demonstrated that for aircraft noise events this metric was fully equivalent with the standard metrics normally used. All further analysis was therefore done with this new metric.

The following classification of aircraft types was used in the final analysis.

Code	Class	Typical Models
RJ1	Regional Jet (Gen1)	F70/F100
RJ2	Regional Jet (Gen2)	CRJ, ERJ
MR1	Medium Range (Gen1)	MD80/90
MR2	Medium Range (Gen2)	A318-A321 B737-300…800
LR2	Long Range Twin	A-310, A330, B767, B777
LR4	Long Range Quad	A340, B747
Prop	Heavy Prop	ATR, ATP, DH8, F50
BJ	Business Jet	Gulfstream
GA	Small propeller	Cessna, Beechcraft
Heli	Rotorcraft	EC135, A-109
MIL	Military jet aircraft	Eurofighter

Table 4 Classification of aircraft models

Most valid events were found in the MR2, LR4 and GA classes.

The aircraft events were distributed over the 3 flight phases of interest (climb, cruise and descent) in a ratio of approximately 20%/60%/20% respectively.

The following conclusions were drawn:

- An extensive dataset on aircraft en-route noise has been obtained through high quality measurements. These measurements were performed at four different test sites over a six month period, covering winter to summer. Some measurements have been made at night. This dataset thus covers a variety of environmental conditions which makes it representative for the noise levels of current aircraft when en-route, which was the main objective of BANOERAC.

- For different aircraft classes the noise levels in climb, cruise and descent phase were obtained. A wide range of distances is covered by the dataset.

- Against initial expectations, noise in the descent phase is clearly audible.

- Comparison of the results with similar studies performed in the past, confirmed that current aircraft types are quieter in all phases of flight. Based on these studies it was also noted that at present cruise altitudes appear to be higher than in the past, thus also contributing to a reduced noise level on the ground.

- The scatter in the data was in the same order of magnitude as found in earlier studies. Although probably the influence of atmospheric conditions is very important for the noise propagation and thus the received noise levels, this was certainly not the only contributor to the observed scatter.

- Although wind speeds were always well within the established limits, it was found that the combination of even relatively low wind speeds with low elevation angles appears to give rise to an increased scatter in the data.

Figures 4 to 6 provide the final datasets for the 3 flight phases, combining all jet aircraft types in a single dataset. The datapoints contaminated by noise of wind and/or insects have been excluded from these graphs. These graphs provide the maximum noise level of the aircraft events as a function of the distance from microphone to aircraft. The distance is used here rather than the height, in order to allow its use also for operations with a certain lateral position with respect to the microphone..

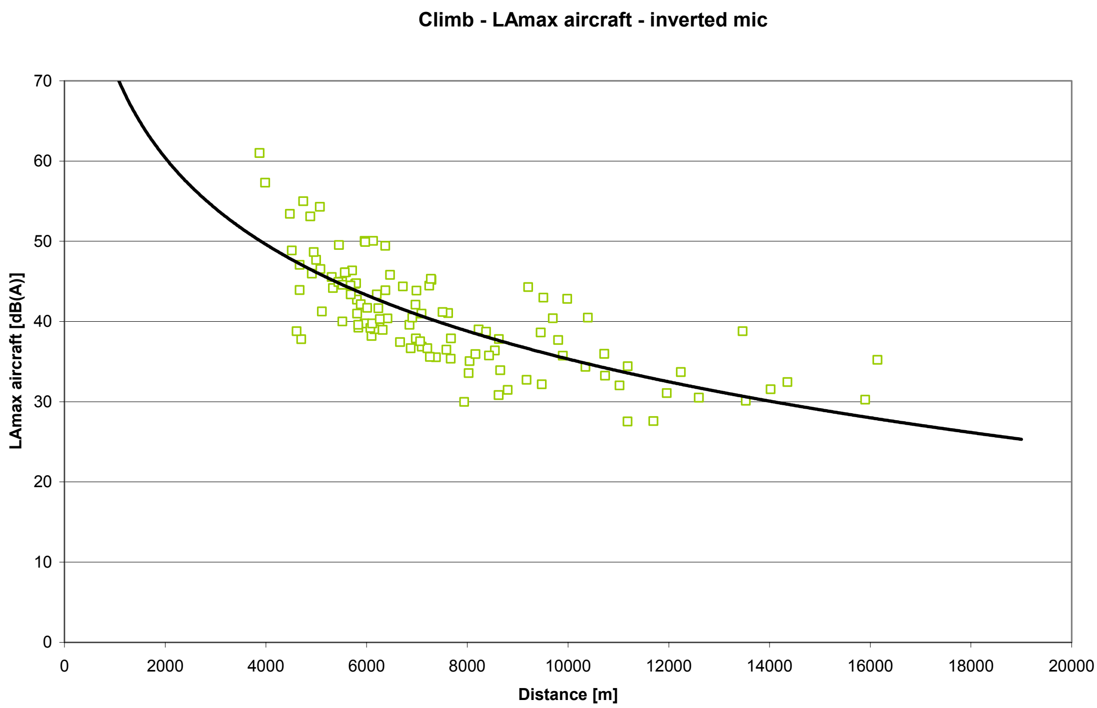


Figure 4 LAmax for all valid jet aircraft events (CLIMB phase)

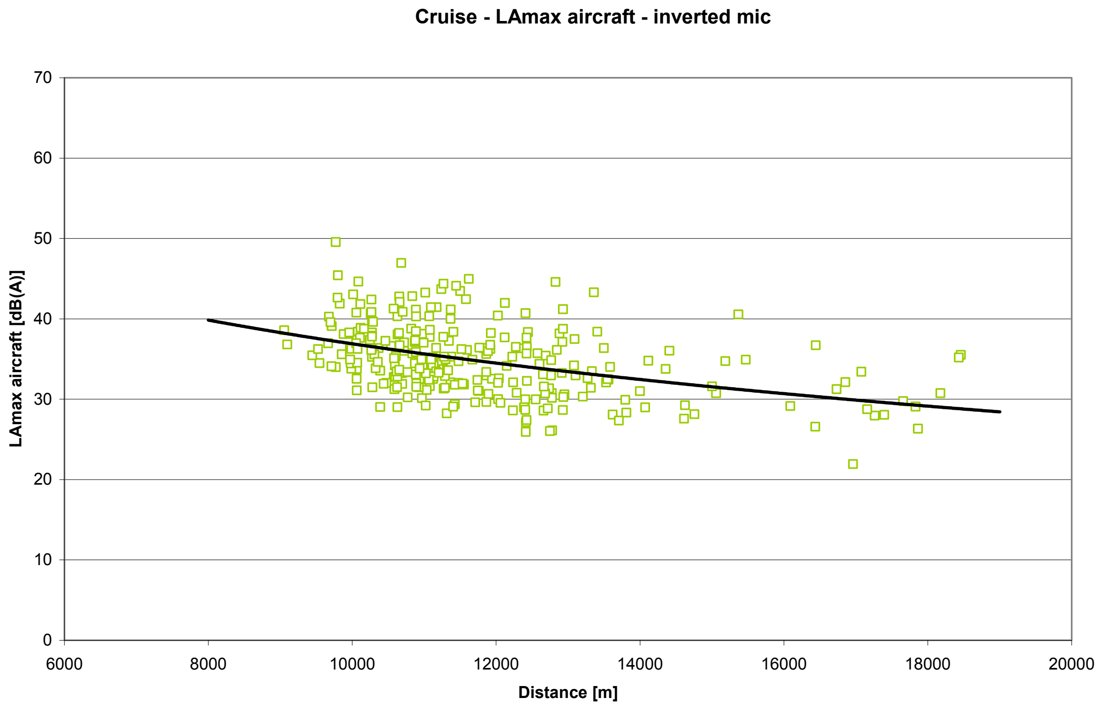


Figure 5 LAmax for all valid jet aircraft events (CRUISE phase)

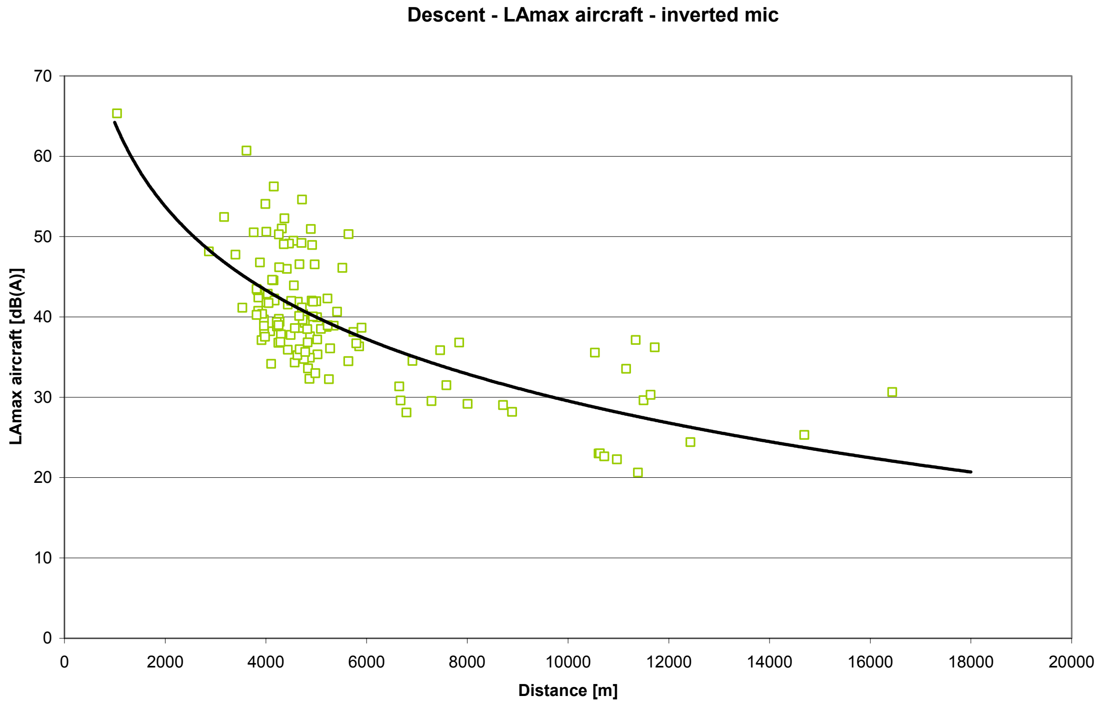


Figure 6 LAmax for all valid jet aircraft events (DESCENT phase)

The following table presents the resulting noise level at an arbitrary reference distance (5 km for climb and descent, 10 km for cruise), following the regression curves derived above.

Flight phase	Ref. dist [m]	$LAmax_{ref}$ [dB(A)]	Standard deviation* [dB(A)]
Climb	5000	46.1	4.3
Cruise	10000	36.9	4.0
Descent	5000	40.0	5.4

* when all datapoints collapsed to the reference distance by using the regressions curves

Table 5 Average noise level at reference distance (inverted mic)

It should be noted that these levels are an average level for all jet aircraft types at the indicated distance. Deviations of up to ±10 dB(A) from this average have been observed.

Security class	Document ID	Issue no.	Short Title	Issue date	Page
Restricted	PAN074-5-1	3	Final Report - Part 1	06/11/2009	1 of 97

Project		Document Title
AN074	BANOERAC	D1. Final report Part 1: Approximation of background noise levels in Europe

Summary

This report describes the work performed within the BANOERAC project.

In this Part 1, elaborated by Labein-Tecnalia, the “Approximation of background noise levels in Europe” is described.

Document revision

Issue	Date	Affected pages	Modifications
1	15/08/2009	All	First issue
2	14/10/2009	All	Incorporation of EASA comments
3	06/11/2009	All	Incorporation of EASA comments 06/11/2009

Controlled copies

Anotec	Customer	Other
Lib	EASA (Mr. Franken)	Labein

Approval status

Prepared by Project team	Approved by Head Engineering & Design	Verified by Responsible Airworthiness
Itziar Aspuru (Labein-Tecnalia) Oihana Arribillaga (Labein-Tecnalia)	Nico van Oosten	N/A

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

Introduction

Two developments in aviation industry will shortly have reached a phase where actual rulemaking work will have to commence. These developments are the preliminary studies on supersonic business jets and the revived interest in so called 'open rotor' engines. They have a common factor in that they will potentially create non negligible noise levels on the ground, not only when flying in the terminal area around airports but also while the aircraft are climbing, cruising and descending at distance from airports (hereafter referred to as "en-route noise"). If aircraft with such technology would be numerous, this would essentially mean that aircraft noise would be audible literally everywhere. The political discussion and the impact assessment will therefore require factual data on existing so called background noise levels and on actual noise levels of 'classical' aircraft in cruise in Europe and elsewhere. Such data will make it possible to put the noise levels of these new technologies in perspective with the existing situation.

EASA issued an Invitation to Tender (ItT) for a study on “Background noise level and noise levels from en-route aircraft”, with acronym BANOERAC [1]. The contract was awarded to the proposal from the consortium, formed by Anotec and Labein-Tecnalia, both from Spain [2]

Before the present study EASA contracted two pilot studies with direct relation to BANOERAC.

One study, performed by SINTEF [3], concluded that no data is readily available on existing background noise. It was reported however that a first approximation of the background noise levels can be derived from population density. The present project intends to use this concept to establish a detailed database of estimated background noise levels in Europe.

The other study, performed by Anotec [4], concluded that very little and mainly outdated information on en-route noise from aircraft was available, but that it would be possible to collect meaningful information with a measurement campaign. BANOERAC aimed at carrying out such measurements.

The aim of this study is to improve insight in background noise levels in Europe and the en-route noise from aircraft. It is realised though that the scope of the study does not allow to claim that the results would be representative for all of Europe.

According to the proposal the work performed was divided in 3 parts:

Part 1. Calculation of approximation of background noise levels
Calculation of background noise levels based on population density for each EU country, building on the SINTEF report and proposing some correction for extreme situations [3].

Part 2. Actual measurements of background noise and aircraft en-route noise
Measuring of actual noise levels in a number of locations representative for a quiet rural area, with very low levels of background noise from man-made sources.
Noise measurements from actual passages of aircraft that are en-route (i.e. climb, cruise and descent phases).

Part 3. Final analysis and results
Analysis of the measured data and presentation and discussion of the results for both background noise and aircraft en-route noise.

The project has been performed based on the following work breakdown structure:

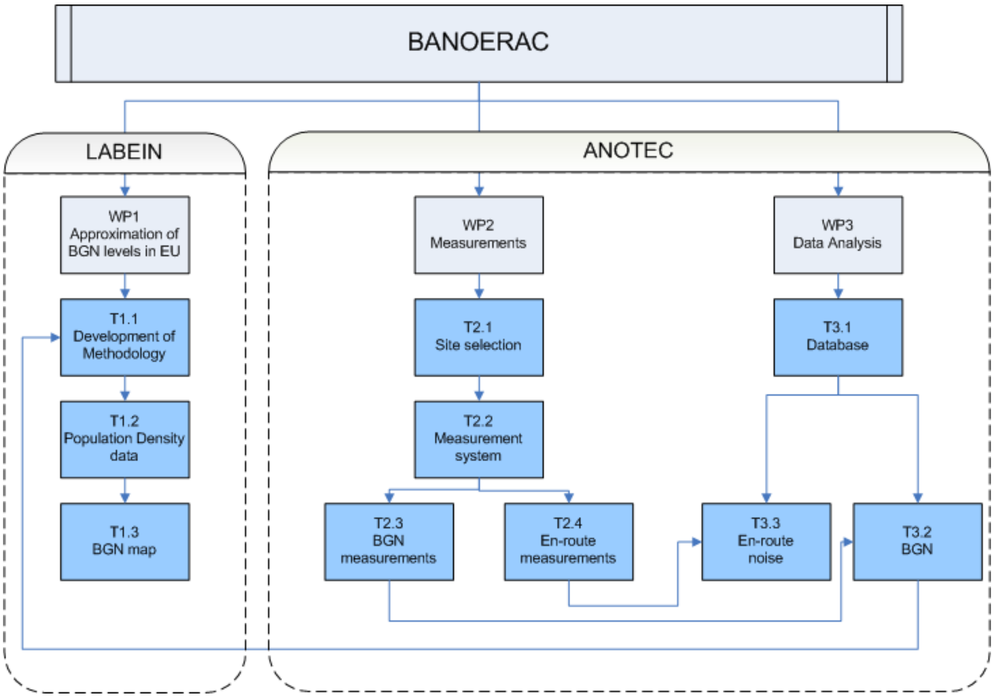


Figure 1-1 Work breakdown structure

The present document describes the work performed in WP1.

1 DEFINITIONS

According to Appendix 3 of the ICAO Environmental Technical Manual [6] the following definitions related to background noise apply:

AMBIENT NOISE The acoustical noise from sources other than the test aircraft present at the microphone site during aircraft noise measurements. Ambient noise is one component of background noise.

BACKGROUND NOISE The combined noise present in a measurement system from sources other than the test aircraft, which can influence or obscure the aircraft noise levels being measured. Typical elements of background noise include (but are not limited to): ambient noise from sources around the microphone site; thermal electrical noise generated by components in the measurement system; magnetic flux noise ("tape hiss") from analog tape recorders; and digitization noise caused by quantization error in digital converters. Some elements of background noise, such as ambient noise, can contribute energy to the measured aircraft noise signal while others, such as digitization noise, can obscure the aircraft noise signal.

POST-DETECTION NOISE: The minimum levels below which measured noise levels are not considered valid. Usually determined by the baseline of an analysis "window", or by amplitude non-linearity characteristics of components in the measurement and analysis system. Post-detection noise levels are non-additive, i.e., they do not contribute energy to measured aircraft noise levels.

PRE-DETECTION NOISE Any noise which can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, recording / playback, and analysis systems.

In the context of the present project these definitions have been maintained. However, it is necessary to take the following into account when reading the report.

As mentioned in the Introduction, the main objective of Part 1 is to determine the **background noise** levels based on population density for each EU country. For higher population densities (and thus higher noise levels) this will be equivalent to the **ambient noise**, since noise levels will generally be significantly higher than the noise floor of the measurement system. Here it is noted that noise mapping software is predicting **ambient noise**. The measurements performed in quiet areas as part of the present study obviously provide **background noise** levels, since at these low levels instrumentation noise is relevant.

The lower limit of the curve is defined by the noise present in areas with no population at all. Although measurements were made in quiet areas, some population related noise was still present. In order to extract this noise, two additional terms had to be defined:

NATURAL NOISE	The acoustical noise from all non man-made sources, mainly wind and animals. Noise of e.g. barking dogs has been included in this group, recognising that in some cases a direct relationship might exist with human presence.
NON-NATURAL NOISE	The acoustical noise from all man-made sources. This includes noise from any transport system, human beings, spurious noise (e.g. that generated due to a cable problem), etc.

Following these definitions, the background noise defining the lower limit of the curve will thus correspond to the **natural noise**.

The objective of the background noise measurements performed in Part 2 of the study is thus the determination of the **natural noise** at the various test sites. This is done by excluding any **non-natural noise** from the measurements

The metric used to express background noise is L95, whereas L95c[1] is used for describing natural noise only.

[1] L95c is determined in the same manner as L95, except that only the 'natural noise' part of the measurement is used as the basis.

2 APPROXIMATION OF BACKGROUND NOISE LEVELS IN EUROPE

The aim of this WP1 is to generate EU27 Background Noise Level Map. In this report Background (BGN) is understood as ambient noise or residual noise. This is the sound at a location from a number of more or less identifiable sound sources when the direct sound from prominent sources is excluded.

In previous study, develop by Sintef [3], it was defined a first approximation of the background noise levels derived from population density. BANOERAC project is based in this concept to establish a detailed database of estimated background noise levels in Europe. The intention is to complement this approach proposing some correction for extreme situations; this is, incorporating the effects of transport and urban noise, including a minimum threshold for quiet rural areas, and analysing data from Strategic Noise Maps developed by Member States to answer to the European Directive 2002/49/CE [14].

In the already mentioned report, Sintef proposes the following formula to estimate the background noise level based on population density (ρ):

$$L_{den} = 18 + 10 \log (\rho)$$

This formula is mentioned in this report as Basic Algorithm.

As Sintef says, an accurate description of Background Noise is important for discussing the audibility of other sources, e.g. en route aircraft noise. A certain percentile level seems to be the best descriptor (L_{95}). The noise metrics, L_{den} and L_{night}, defined by the EU Environmental Noise Directive, are not ideal for describing the Background Noise situation. However, BANOERAC project gets a general description of Background Noise levels in Europe, based on these metrics (as an intermediate values to calculate the L_{95} values) since they will become readily available for large areas as result of the ongoing Strategic Noise Mapping exercise. Thus, appropriate percentile levels are predicted on the basis of L_{den} values.

This project estimates Background Noise levels given by the percentile level L_{95} in different periods of the day (day, 07-19; evening, 19-23; and night, 23-07). The proposed methodology to estimate BGN is described on next section. Firstly, values for L_{den} parameter are estimated and, secondly, L_{95} noise levels in different periods of the day are calculated by their relationship with L_{den} values, found on the analysis of noise monitoring data. The average noise levels for each period of the day ($L_{d,}$ L_e, and L_n) are also obtained by applying correction features to L_{den} values.

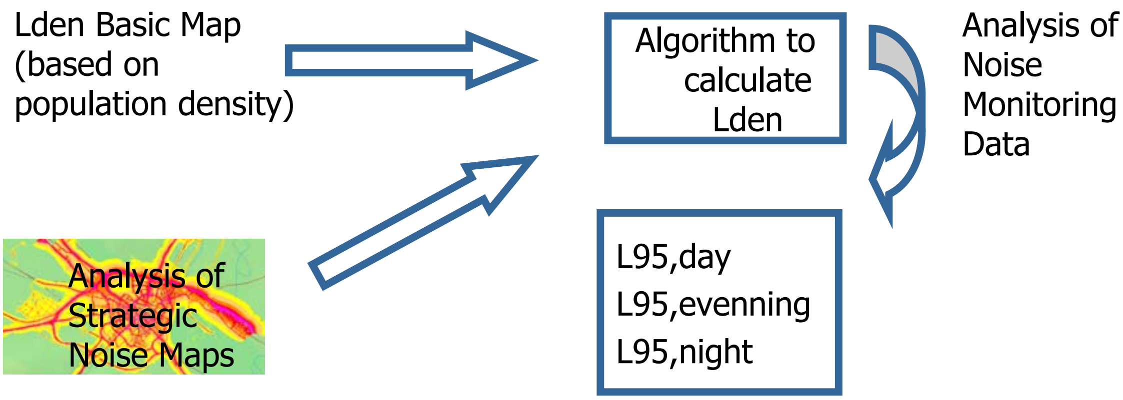


Figure 2- 1. BANOERAC Methodology to build BGN Noise Map of EU27

It is important to notice that Sintef algorithm estimates the noise metric L_{den}, so the relationship to get the percentile L_{95} is specific of this report (see table 2.1 presenting a Summary of the proposed methodology).

For this project we have collaborated with the following institutions:

- European Topic Centre Land Use and Spatial Information linked to EEA, and located at the Universidad Autónoma de Barcelona (ETC-LUSI-UAB).
- Institute for Environment and Sustainability Joint Research Centre.
- Cities of Zaragoza, London, Madrid, Florence, Paris and Lyon.
- Road Administration of Bizkaia Province (Diputación Foral de Bizkaia), Spain.

The following section (2.1) describes the methodology to estimate Background Noise. In Section 2.2 the resulting BGN maps are presented. Section 2.3 provides additional information on these maps and the corresponding database.

More detailed information may be found in the two appendices enclosed to this report:

- Appendix 1-1 describes Background Noise Levels Databases and Spatial Information, stressing the BGN database structure and the numerical processes to calculate noise levels.
- Appendix 1-2 summarizes the Delivered Digital Information in three DVD.

2.1 Methodology

EASA established in the Tender call that population density should be the basic approach to develop the methodology to estimate BGN. As it was said above, Sintef proposes a formula to estimate background noise levels only based on population density ρ. This formula is considered in this project as the Basic Algorithm:

$$L_{den} = 18 + 10 \log(\rho)$$

Nevertheless, more decisions were needed to answer to the purpose of this project, which is to estimate the European Background Noise levels, described by values related to a Spatial Grid of 10x10Km resolution. In that sense, this project solves the problem of applying Basic Algorithm in a Spatial Grid and, besides, some corrections to this algorithm are proposed to improve the representation of extreme situations in the relation between population density and Background Noise.

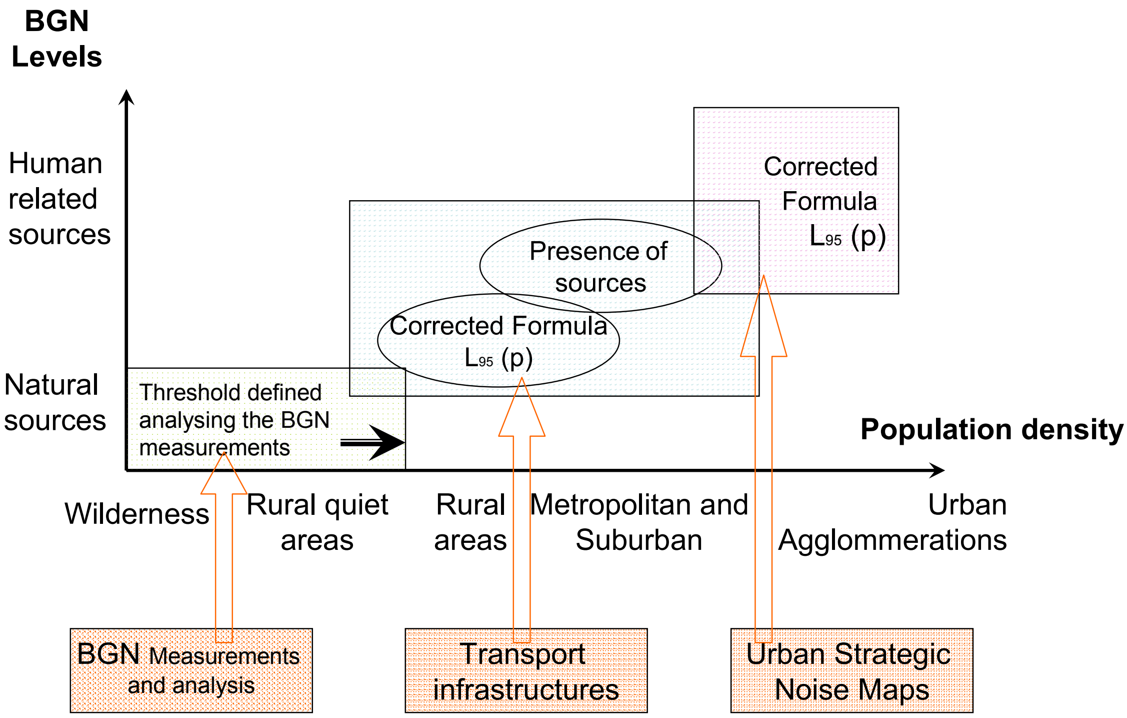


Figure 2- 2. General description of the methodological approach

These defined extreme situations are the following:

1.- Background Noise in Urban Areas,

Sintef report indicates the need to study the applicability of the Basic Algorithm in presence of agglomerations.

Besides, since 2007 Strategic Noise Maps (SNM) in European agglomerations were made as first phase of the 2002/49 /EC Directive. So, it was done a comparative analysis between the results offered by the application of the Basic Algorithm and the information about Strategic Noise Maps from several European Cities.

A new algorithm is defined to estimate L_{den} values in Urban Agglomerations, and correction factors are proposed to calculate L_{95} values in each period of the day.

A Background Noise Map for Agglomeration is built by applying those formulas.

2.- Presence of main Transport Infrastructures.

Background Noise is clearly affected by transport noise. Although population density is a variable that could also represent the presence of transport infrastructures, there are areas in Europe with very little population but crossed by noisy main infrastructures.

Therefore, a complementary approach is defined to represent these situations. The method is only related to road infrastructures, as other modes of transport were considered not relevant, according to the scope of this project. The method is based on estimating the area influenced by the acoustic emission of roads.

An algorithm is defined to estimate L_{den} values in presence of Transport Infrastructures, and correction factors are proposed to calculate L_{95} values in each period of the day.

A Background Noise Map for Transport is built by applying those formulas.

3.- Rural Quiet Areas.

In rural quiet areas population density could not be the main factor due to the presence of natural sounds. Natural sounds imply a minimum noise level threshold to that estimated when taking only into account the human presence.

To represent these situations, a threshold noise level to BGN is described, as a correction factor to the application of the Basic Algorithm. Results achieved by Anotec in WP 2 were used.

A Background Noise Map for Quiet Rural Areas is built by applying those thresholds.

As it is said previously, the purpose of this project is to estimate the European Background Noise levels, described by values related to a Spatial Grid of 10x10Km resolution. On this sense, this project defines an acoustical concept that allows representing with a single value the existing environmental noise in a big land extension (10x10 Km cell). In this project, the assumption is that noise levels representative of a cell are understood as the acoustic energy in the cell, extended to the whole surface of each cell. This assumption is applied to all acoustic parameters used in this project: $\mathbf{L_{den}}$, $\mathbf{L_{day}}$, $\mathbf{L_{evening}}$, $\mathbf{L_{night}}$, $\mathbf{L_{95,day}}$, $\mathbf{L_{95,evening}}$, and $\mathbf{L_{95night}}$.

The grid used as spatial reference to build the BGN Maps is the ETRS89 Lambert Azimuthal Equal Area 52N 10E grid, recommend by the EEA [2] (for more details about this grid see section 2.2). WP2 gives the location of the measurement sites according to the WGS84 spatial reference, while the BGN Maps are provided in ETRS89. To improve the consistency of the project, every 10 x 10 km cell generated in WP1 has information about its centre point in WGS84 coordinates.

This spatial Grid of 10x10Km resolution is used to identify in which cells the relationship between noise and population is not the basic one, because any of the extreme situations should be considered. Therefore, Spatial Grid is used to identify cells where there are, either presence of urban agglomerations, transport infrastructures or rural quiet areas. The variables to describe the acoustical influence of each type of situation are different and they are defined in detail on sections 2.1.1 and 2.1.2 and 2.1.3.

In general, identification of situations and correction factors to apply in each of them, are based on the following data and analysis:

- Population density grid, 10x10 Km resolution, is used to build the Basic L_{den} Map, described in section 2.1.0.
- Population density grid, 1ha resolutions, is used to identify Urban Agglomerations (Population Core). This process is described in section 2.1.1.
- Results from BGN measurements carried out in WP2 and their analysis. This data allows getting the threshold noise level for Rural Quiet Areas.
- European Road Network, from Eurostat, is used to identify the presence of major roads. This process is described in section 2.1.2.

As it was already mentioned this information is complemented with:

- Strategic Noise Maps results, and
- Noise Monitoring Data.

Based on the idea described on Figure 2- 2, next figure shows the general methodology defined to get the BGN European Map. The final Map is built based on the Basic L_{den} Map, combined with the three BGN Maps representing extreme situations. These Maps are only applied in those cells where such situations are identified.

[2] The grid used as spatial reference in this project is the ETRS89 Lambert Azimuthal Equal Area 52N 10E grid, recommended by the EEA (see http://www.eionet.europa.eu/gis/geographicinformationstandards.html). This can be freely downloaded from the site http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=760.

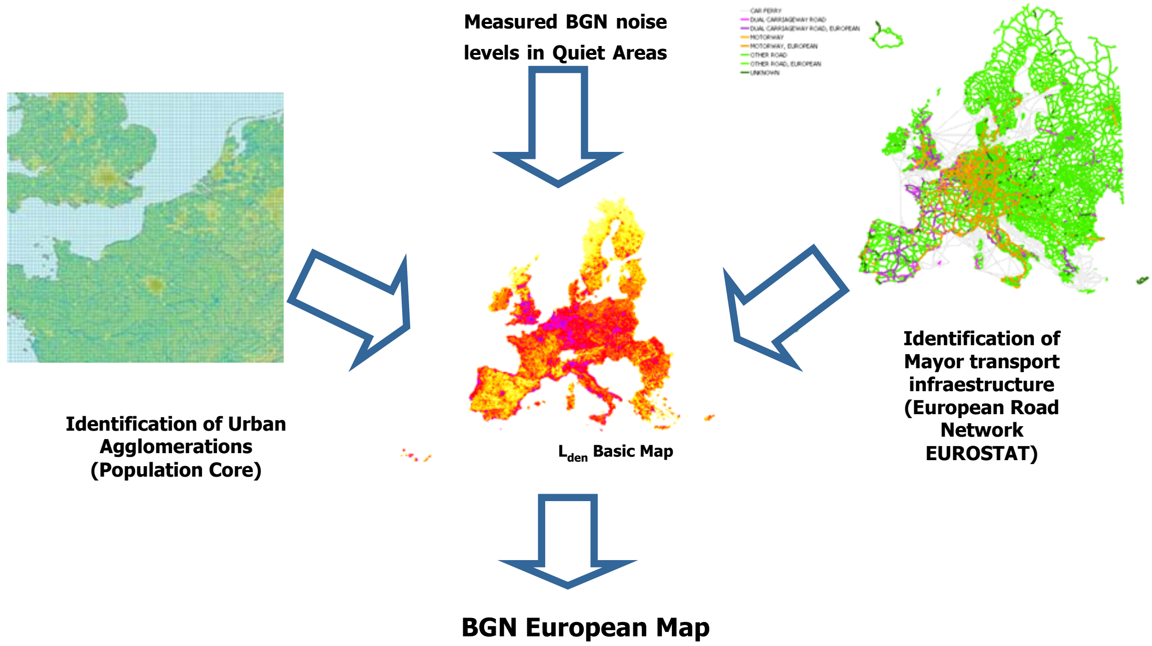


Figure 2- 3. Diagram of building process of BGN European Map

The population density approach is the main base to develop the methodology to estimate BGN. On this sense, the L_{den} Basic Map is only based on population density and it is estimated by applying the Basic Algorithm, proposed by Sintef (section 2.1.0).

This report explains the correction formula defined for extreme situations and the general methodology applied to get the Background European Map (BGN). Each of the three situations mentioned before are considered in a specific section of this report where the methodology applied is described.

The next table shows a summary of the conclusions achieved in the project in terms of methodology.

Situation represented	Conditions	Lden indicator	L95 indicator
Cells with presence of **Aglomerations (ρ (population density grid 100*100m)>500 inh/Km2)**	%IA (inhabitant area percentage) >0	LdenAg = 29,219 + 7,78 l log (r) + 0.48 %IA	Conversion from measurements of monitoring systems and continuous noise registers: L95day = LdenAg-9 L95evening = LdenAg-10 L95night = LdenAg-15
Cells with presence of **roads**	S occupied (area occupied by road buffers type 1 or 2) > 0	$L_{denTR} = 10*\log\left(\frac{\sum_{i=1}^{n} S_{occupied,type1} *10^{(63/10)} + \sum_{j=1}^{n} S_{occupied,type2} *10^{(58/10)}}{S_t}\right)$	Conversion from measurements of continuous traffic noise registers: L95day = LdenTR-10 L95evening = LdenTR-12 L95night = LdenTR-21
Cells with popultation density not representative of an Aglomeration structure, and without roads	r (population density)>23 inh/km2 %IA = 0 S occupied = 0	Basic Algorithnm LdenB = 18 + 10*log(r)	Conversion from measurements in natural parks: L95day = LdenB-8 L95evening = LdenB-9 L95night = LdenB-12
Cells with a population density low or null (**quiet rural areas**)	r (population density)<23 inh/km2	Measurements in natural parks: 31,2 dBA	Measurements in natural parks: L95day = 23 L95evening = 22 L95night = 19
BGN			**Max L95 (day)** **Max L95 (evening)** **Max L95 (night)**

Table 2- 1. Summary of the whole methodology

The table shows the criteria to identify each extreme situation and the formulas to be applied to get the Background Noise levels in each case. In that sense,

- Background Noise Map for Agglomeration comprises cells overlapping agglomerations.
- Background Noise Map for Transport comprises cells overlapping areas affected by the acoustical effect of main roads.
- Background Noise Map for Rural Quiet Areas comprises cells with very little population (lower than 23 inh/km^2).

When building the final BGN Map, criteria to combine the four Maps are crucial. As general rule, the process to combine the Maps is the following: when a cell contains values from more than one Map, the maximum value is considered.

L_{95} indicator is calculated by applying a conversion factor to L_{den} values. These factors were obtained from the analysis of measurement monitoring systems in urban agglomerations and close to transport infrastructures. In case of Rural Quiet Areas the values were taken directly from measurements in Natural Parks developed in WP2. Finally, the Basic Algorithm proposed by Sintef estimates L_{den} values and gives a possible relationship to L_{95} values with a high level of uncertainty. In this project, it is proposed a method to create a Basic Noise Map in L_{95} values. Considering the whole methodology, this Map is only considered when no road and agglomeration is present, so it is proposed to use the same conversion factor from L_{den} values to L_{95} as it is defined in rural quiet areas.

Next sections (2.1.1 and 2.1.2) describe the methodology defined for each situation. The general structure followed in these sections is:

- General Concept: the aim is to describe the general concept of the correction needed.

- Description of the baseline data: it describes the start up data
- Description of the tasks:
  - Definition of the methodology to obtain the correction factor L_{den}.
  - Validation of the methodology, using available information.
  - Definition of the conversion factor to calculate L_{95} values (day, evening and night) from L_{den} estimations.
  - Conclusions.

Section 2.1.0 describes the methodology to build the Basic L_{den} Map, based only on the population density, and section 2.1.4 gives the general methodology main conclusions.

2.1.0 Basic BGN Map

The Basic Background Noise Map is built by applying the Basic Algorithm to the European Spatial Grid of 10x10Km resolution.

The Basic Algorithm, proposed by Sintef, is a formula to estimate the background noise level based on population density (ρ):

$$L_{den} = 18 + 10 \log(\rho)$$

Population density data is based on the Population density grid of EU-27+, developed by the Join Research Center. This information is available from the European Environmental Agency's web (EEA). The resolution of this data is 1 ha and the value of each cell indicates the estimated density in inhab/km^2.

The origin data included EU 27 plus Croatia, so the first process with this data was to reduce the information to only Europe 27. The geographical coverage of the data is represented in the next picture, where the Countries drawn in blue (dark) are those which have been taken into account.

■ Austria, Belgium, Bulgaria, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom

Figure 2- 4. EU 27 countries

It was created a Spatial Grid representing EU27, composed by unit cells of 10 x 10 km. This Grid was obtained by summing up the unit cells given by EAA [3] for each EU 27 Country.

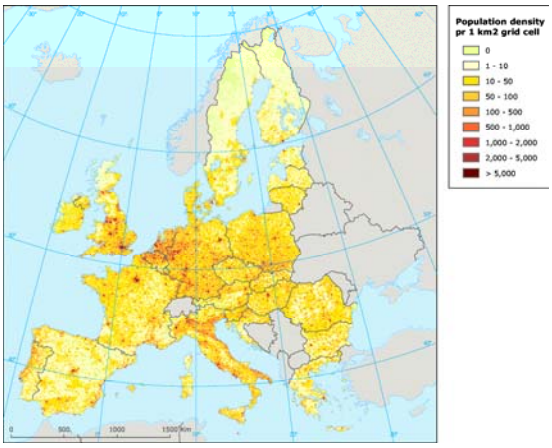


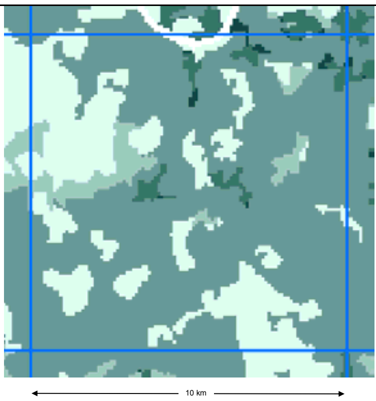
Figure 2- 5. Example of representation for population density data

The Population Grid has a 1 ha resolution. It has been used to create a Grid with less resolution (10 X 10 Km), in accordance with the aim of the project. The original data could not be used, since it would make it very difficult to apply the defined methodology for all Europe, and the BGN Map and its database would be nearly impossible to handle due to its enormous size. Besides this, the process of creating the 1ha resolution Population grid is still under revision and it presents some anomalies in specific situations. An intermediate process was therefore developed to get the density population in 100 km^2 (unit cell of analysis). The steps are the following:

1. Sum up the whole population of all 1 ha. unit cells which belong to the same 100 km^2 cell.
2. Division of this value per cell area (100 km^2) to get the aggregated density population (inhabitants/ km^2).

Next figure shows the superposition of the two population density data.

[3] http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=760.



Original Population density data developed by Join Research Centre. Resolution 1ha, and value in inh/km^2:

- 0 - 1.208
- 1.208 - 4.036
- 4.036 - 12.468
- 12.468 - 31.075
- 31.075 - 205.612

Blue colour: Cell of the grid (size 10*10km). The population density assigned to this cell is 6.134 inh/m^2.

Figure 2- 6. Population density adapted to the analysis unit cell

Considering the assumption adopted in this project about the representation of a land extension of 10x10 Km by a single acoustical value, the Basic Algorithm was applied in every cell to its Population Density value. L_{den} Basic Map is obtained.

The following figure shows the BGN Basic Map in L_{den} resulting by the application of described methodology.

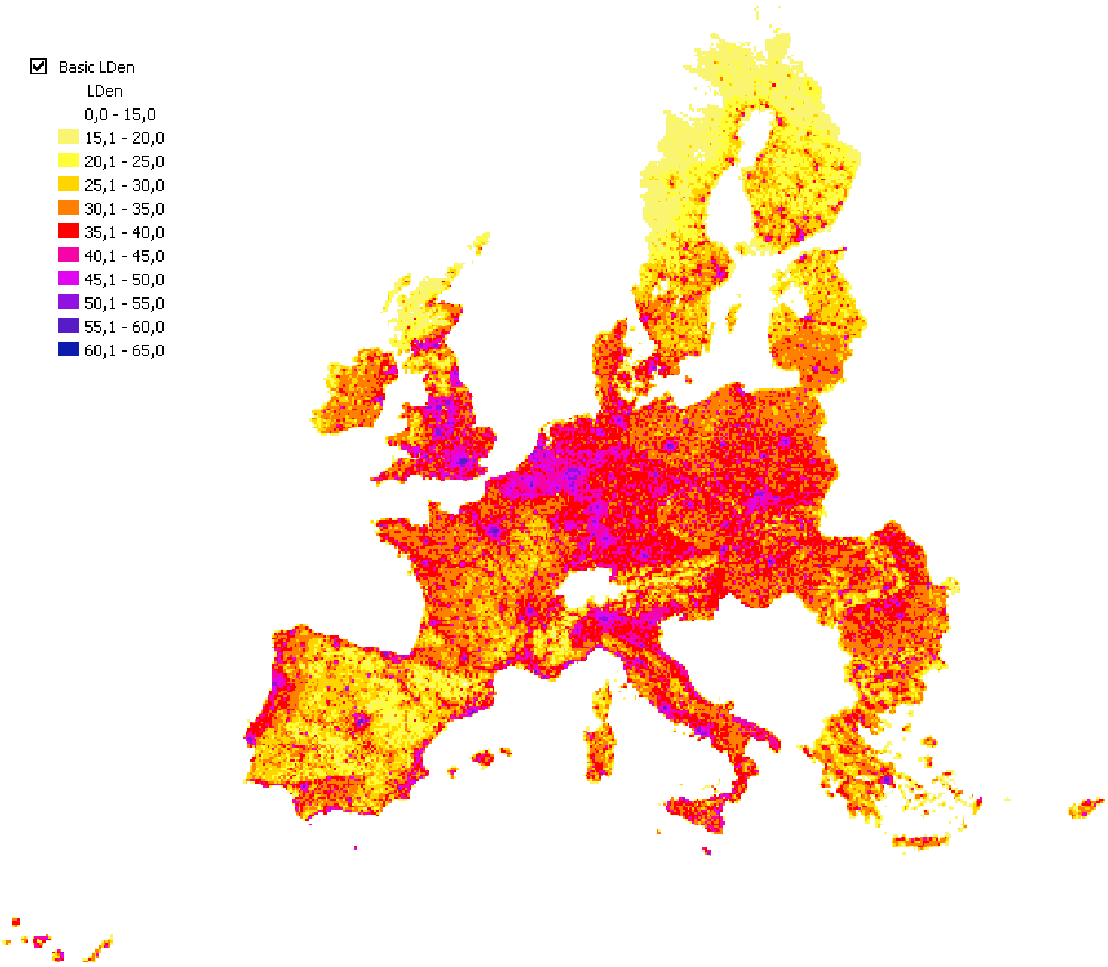


Figure 2- 7. L_{den} Basic Map based on population density

Determination of Basic L_{95} Background Noise level

The purpose of this project is to estimate L_{95} noise values to represent Background Noise levels in different periods of the day (day, 07-19; evening, 19-23; and night, 23-07). Therefore, the Basic Algorithm to estimate L_{den} values should be complemented by a relationship between L_{den} noise values and L_{95} noise values for each period of the day.

The Basic Algorithm proposed by Sintef estimates L_{den} values and gives a possible relationship to L_{95} values with a high level of uncertainty. In this project, it is proposed a method to create a Basic Noise Map in L_{95} values. Considering the whole methodology, this Map is only considered when no road and agglomeration is present, so it is proposed to use the same conversion factor from L_{den} values to L_{95} as it is defined in rural quiet areas.

Therefore, the proposed correction factors to estimate other acoustic parameters from L_{den} values are the following. Firstly, the corrections to obtain the equivalent levels for day, evening and night periods of the day:

$$L_{day} = L_{den} - 2$$
$$L_{evening} = L_{den} - 4$$
$$L_{nigth} = L_{den} - 8$$

Secondly, corrections to obtain the $\mathbf{L_{95}}$ levels for day, evening and night periods of the day:

$$L_{95,day} = L_{den} - 9$$
$$L_{95,evening} = L_{den} - 9$$
$$L_{95nigth} = L_{den} - 13$$

It is considered that the analysis done is consistent and valid to answer to the scope of this project. However it must be emphasized that if more accuracy was required a specific project would be needed to adjust a more accurate relation between the studying parameters.

2.1.1 Urban agglomerations

2.1.1.1 General concept

The work developed in this project pursues to obtain background noise levels applicable to the Countries which integrate the European Union.

The initial work foundations have been extracted from a previous report developed by Sintef [3]. In this report it is establish that *"…everyday human activity will generate sound, and where there are more people, more activity will generate more sound"*. The SINTEF report indicates that this idea was developed initially for the US EPA in 1974 [7], and the results were validated and confirmed by Cathrine Stewart et al in 1999 [8]. This work presents an algorithm which establishes the noise value index, L_{dn}, taken from population density (inhabitants/km^2).

For the aim of this study, it is correct to regard that the L_{dn} index presents "equal" values to the L_{den} index. The SINTEF report includes this consideration with the following paragraph: *"Road traffic is the dominating source for background noise. Miedema et al [9] have found that for road traffic noise the difference L_{den} - L_{dn} varies between 0.1 dB and 0.3 dB. Their conclusion is based on studies in Europe, Japan and the United States. For practical purposes L_{den} and L_{dn} can therefore be interchanged when describing the background noise using the results from existing studies." [3].*

It is relevant to indicate that the same report includes the following sentence: *"The relationship is valid for areas not directly exposed to a major sound source (away from major roads, rail roads, airports, industrial plants, etc.)".*

In this sense, the same SINTEF report indicates the need to study the applicability of the above mentioned equation in presence of agglomerations. Also it is identified as an opportunity the current situation in which is available much information from the first phase of the 2002/49 /EC Directive. This first phase supposed the development of Strategic Noise Maps (SNM) in European agglomerations with more than 250000 inhabitants.

Therefore, to propose an adequate methodology to obtain the background noise levels applicable to the European territory, it has been considered necessary to make a comparative analysis between the results offered by the algorithm expressed in the already mentioned reports and the information about Strategic Noise Maps received from several European Cities.

From this comparison we propose an appropriated complementary term to be incorporated to the base algorithm as a consequence of the presence of an agglomeration.

This analysis was structured in 4 tasks that have been described in following paragraphs on 2.1.1.3.

- **Task 1.- Basic methodology to compare the base algorithm results and Strategic Noise Maps in agglomerations**
- **Task 2.- Application of the methodology to compare SNM and basic algorithm to European cities**
- **Task 3.- Determination of L_{den} index adapted formula**
- **Task 4.- Determination of L_{95} Background Noise level**

Before describing this analysis the starting data is mentioned in next section.

2.1.1.2 Description of the baseline data

In this section a summary is given to facilitate the understanding of the data analysis carried out to define the methodology.

Density population data

As it is said before, population density data is based on a work developed by the Join Research Center, which output is the Population density grid of EU-27+.

The resolution of this data is 1 ha and the value of each cell indicates the estimated density in inhab/km^2. This Population density grid has been used as the base to create the Population Core, which allows the identification of agglomerations among Europe and the application of the methodology to obtain the Agglomeration BGN Map.

Strategic Noise Maps information

The methodology proposed to represent BGN in Urban Agglomerations is defined taken into account, as much as possible, actual information about Noise Maps. The European Noise Directive [14] has required for 2007 the generation of Strategic Noise Maps to Agglomeration bigger than 250.000 inhabitants.

In that sense, this project thanks the collaboration of the European Topic Centre for Land Use and Spatial Information (ETC-LUSI-UAB) consortium in Spain, which manages European Spatial data for the European Environment Agency, and also is commissioned to assess the Strategic Noise Maps reported by the Member States, answering to the European Noise Directive.

ETC-LUSI-UAB is responsible of the process of compiling all the information about Strategic Noise Maps sent by Member States to the EU Commission. However, not all European Countries have nowadays sent spatial information of the Strategic Noise Maps. Besides, specific formats are required to carry out the process of analysis defined in this project.

The methodological process developed in the study and the conclusions obtained on it are based on the noise levels information related to the agglomerations of Zaragoza (Spain), Berlin and Hamburg (Germany) and Prague (Czech Republic). The justification of the selection of the above mentioned agglomerations has been included in following sections.

The information mentioned above, has been adapted in the following tasks, as needed for the study. As a general comment, is important to keep in mind that an analysis on continental scale implies to use multiple sources of information. This situation implies a considerable risk as it depends on data received from quite different production origins. The above mentioned disparity introduces in the process of analysis a series of uncertainties that can produce certain deviations in the obtained results. Due to the project working scale, potential consequences associated to the nature of the starting data are assumed.

2.1.1.3 Description of the process tasks

The process to establish an appropriated complementary term to be incorporated to the base algorithm as a consequence of the presence of an agglomeration is structured in the next main points:

1. Definition of the methodology to identify the presence of agglomerations. It is based on the Population density grid of EU-27+ (developed by the Join Research Center), available in 1 ha resolution. The result of this methodology is the Population Core.
2. Definition of the methodology to compare noise levels (L_{den}) given by the Strategic Noise Maps (SNM) and the Base Algorithm, both applied to the 10x10 km Spatial Grid.
3. Validation of the methodology defined in the second point for the comparison between SNM and Base Algorithm noise levels.
4. Application of the methodology defined in some European cities.
5. Statistical process to establish L_{den} index adapted formula to represent the effect of the presence of agglomerations.

First two steps are included in Task 1. The other points correspond to Tasks 2 to 4. Task 1 and Task 2 has used the pilot agglomeration of Zaragoza as an actual example that offers enough information to define the method of the analysis and its validation.

Task 1.- Basic methodology to compare the base algorithm results and Strategic Noise Maps in agglomerations

Previous to the methodological analysis the **pilot agglomeration** is selected. The quality and quantity of information available from the selected agglomeration is critical for the methodological analysis. So these were the main criteria to choose it.

The pilot agglomeration selected is Zaragoza agglomeration, in Spain. Zaragoza is the capital city of the province with the same name and also the capital of the regional administration of Aragón. It is placed in the North-East of Spain. With an approximate area occupied of 10 km^2, it has a population about 640.000 inhabitants.

The decision is supported on the following points:

- Firstly, Labein-Tecnalia has a wide knowledge of the city characteristics since Labein-Tecnalia was the Zaragoza Strategic Noise Map redactor. Therefore it is assured to have a complete view of the urban distribution of the city and the particularity of noise sources.
- Secondly, has been determinant the immediate availability of acoustic, population, geographic and administrative data.
- Complementary, it is also available a more detailed information about its population and occupied residential areas. This information is associated to an administrative Land Use, named “Junta Vecinal”. Each “Junta Vecinal” is related to one of the 16 rural districts that compose the agglomeration of Zaragoza. This data has been applied in Task 2 for validating the methodology of comparison between SNM and Base Algorithm noise levels.

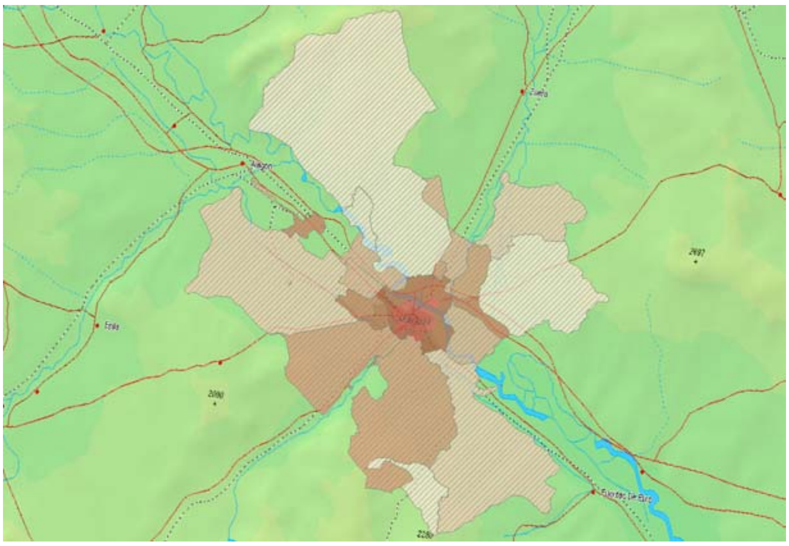


Figure 2- 8. Graphics representation of the “Juntas Vecinales” defined for the Agglomeration of Zaragoza

Once the pilot agglomeration is selected, the first step in this task, is the definition of the **methodology to identify the presence of agglomerations**.

With this purpose, a new entity **Population Core** is defined and created. This is a spatial figure that represents an area that establishes the physical limits for an agglomeration.

The area of the Population Core is used in this project for the following purposes:

- To identify the presence of an agglomeration in every 10x10 Km cell. This is done by calculating the percentage surface of each cell occupied by any agglomeration. This percentage surface is named as **Percentage Inhabited Area** (**%IA)**. This data is applied for calculations in Task 2 to 3.
- To define the area of the Strategic Noise Map that is properly associated to the agglomeration avoiding the areas associated to its transport infrastructures.

Figure 2.9 shows the process to identify the presence of an agglomeration in a 10x10 Km cell. It is an example where the cell is coloured in grey and the dark polygon represents an agglomeration. The overlapping area constitutes the **Percentage Inhabited Area** (**%IA).**

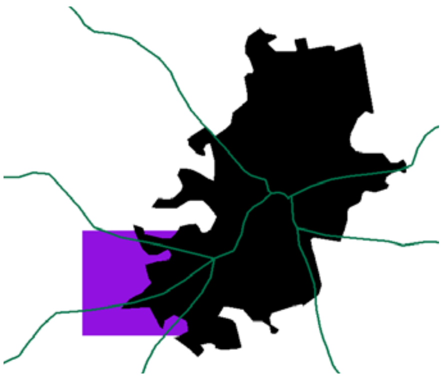


Figure 2- 9. Example of the identification of an agglomeration in a cell and the process to calculate %IA. (Lithuania, Cell Code 10kmE528N360)

This Population Core entity is based on the Population density grid of EU, of 1 ha resolution. So, it uses the most accurate available information. It is created by joining homogenous areas with values of density population greater than 500 inh/km^2. Consequently several polygons are defined as physical entities that contain information about population densities.

Figure 2- 10. Representation of the Population Core defined for Zaragoza Agglomeration.

The second step in this Task is to define the **<u>methodology to compare noise levels (Lden) given by the Strategic Noise Maps (SNM) and the Base Algorithm, both applied to the 10x10 km Spatial Grid.</u>**

As it has been indicated as methodological General Concept for urban agglomerations (section 2.1.1.1), the adapted formula to represent the effect of the presence of agglomerations is defined after making a comparative analysis between the results offered by the base algorithm (see section 2.1.0) and the information associated to European Cities Strategic Noise Maps.

- **Strategic Noise Map** of Zaragoza is available in the adequate format for its post processing. The map used for this analysis is the representative of L_{den} index and traffic noise source as main noise source in urban areas.

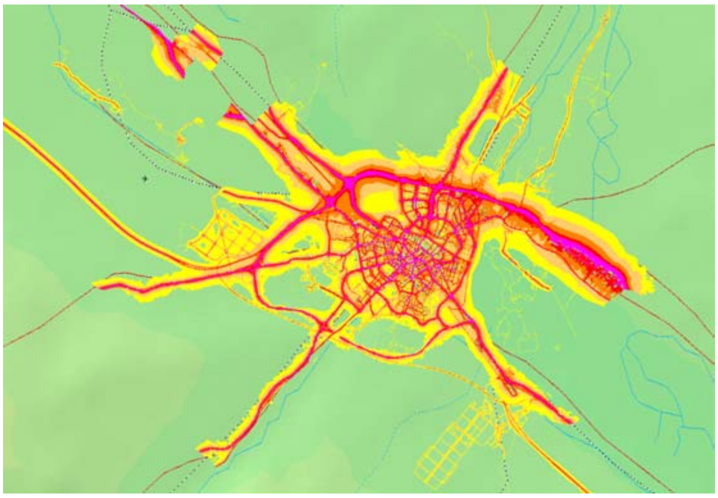


Figure 2- 11. Strategic Noise Map of Zaragoza. Trafic noise source and L_{den} noise index

Strategic Noise Maps represent estimated noise levels in 5 dB ranges. In the scope of this project a cell of 10 X 10 Km is represented by a unique noise level value. Therefore, a simplification method is defined and applied to get the representative value of a Noise Mapped area.

This process to simplify the SNM is defined after considering the following matters:

- **Noise Map data format**. In this task different tests were made: eliminating buildings surface from the noise map surface, eliminating residential land use surface from the noise map surface, or applying the whole noise map surface. When comparing obtained results, the best option in terms of less difference to L_{den} base algorithm results is the application of the whole noise map surface. Besides, two other approaches require a complex spatial analysis that seems too difficult when thinking on every agglomeration among Europe.
- **Methodology to obtain the value for the L_{den} index for SNM**. Three different approximations have been tested. SNM starting information are areas representing noise levels in 5 dB ranges. The three options are the following: to apply the upper value of the range; to apply arithmetic average value in dB; or to apply the energetic average noise levels. The test compares results obtained when applying each of the three options to the L_{den} values and those calculated with the Base algorithm.
  Finally the acoustic energetic average approach is considered more representative of the calculated superficial L_{den}.

To allow the comparison between actual Strategic Noise Maps and calculated base algorithm L_{den} noise levels, both should be referred to the same geographical area. This area is the Population Core assigned to the agglomeration. Therefore, SNM is overlapped with Population Core by using GIS tools and it is only considered the common area.

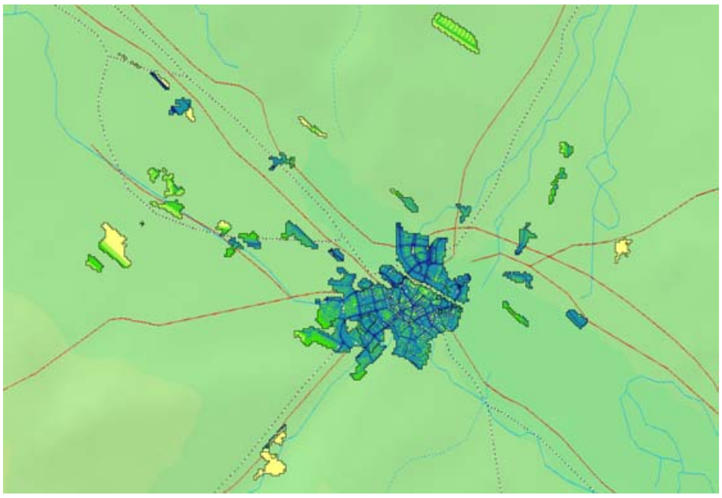


Figure 2- 12. Strategic Noise Map cut by the Population Core polygon in Zaragoza

Finally, the achieved results from actual SNM and calculated base algorithm are compared. To do this, the Reference Spatial Grid (10x10 km resolution) is considered. Therefore, noise levels data (L_{den}) related to Strategic Noise Map are extrapolated to 10x10 km cells by means of an "energetically spatial average level", weighting noise values by the surface occupied by them.

$$L_{den10x10} = L_{denP.Core} + 10Log(S_{P.Core.}/S_{10x10})$$

where:

- $L_{den10x10}$ is the noise level associated to the 10x10 km cells, in dB(A).
- $L_{denP.Core}$ is the noise level obtained from the Strategic Noise Map cut by the Population Core, in dB(A)
- $S_{P.Core.}$ is the area occupied by the Population Core, in km^2
- S_{10x10} is the area occupied by the 10x10 cell, in km^2 . It is 100km^2.

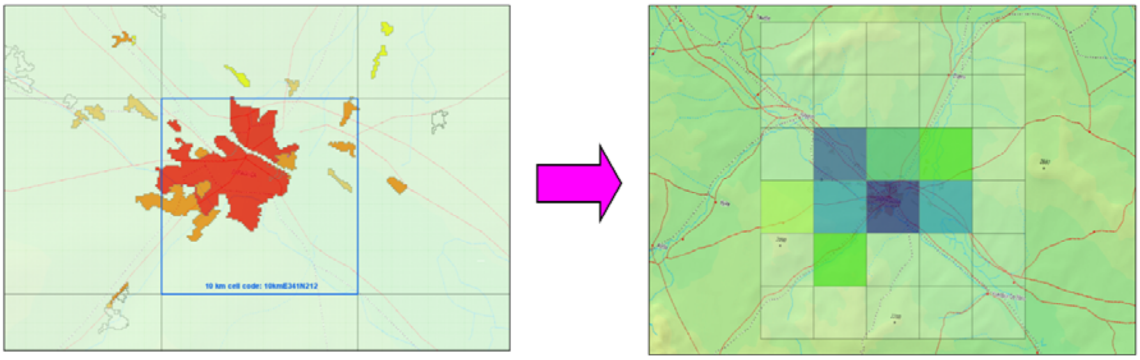


Figure 2- 13. Extension of Noise Levels in the Population Core to Grid 10x10 km resolution

- On the other hand the calculation of L_{den} values associated to 10x10 km grid **applying the base algorithm** is immediate by means of substituting the population density data in the formula (see section 2.1.0),.

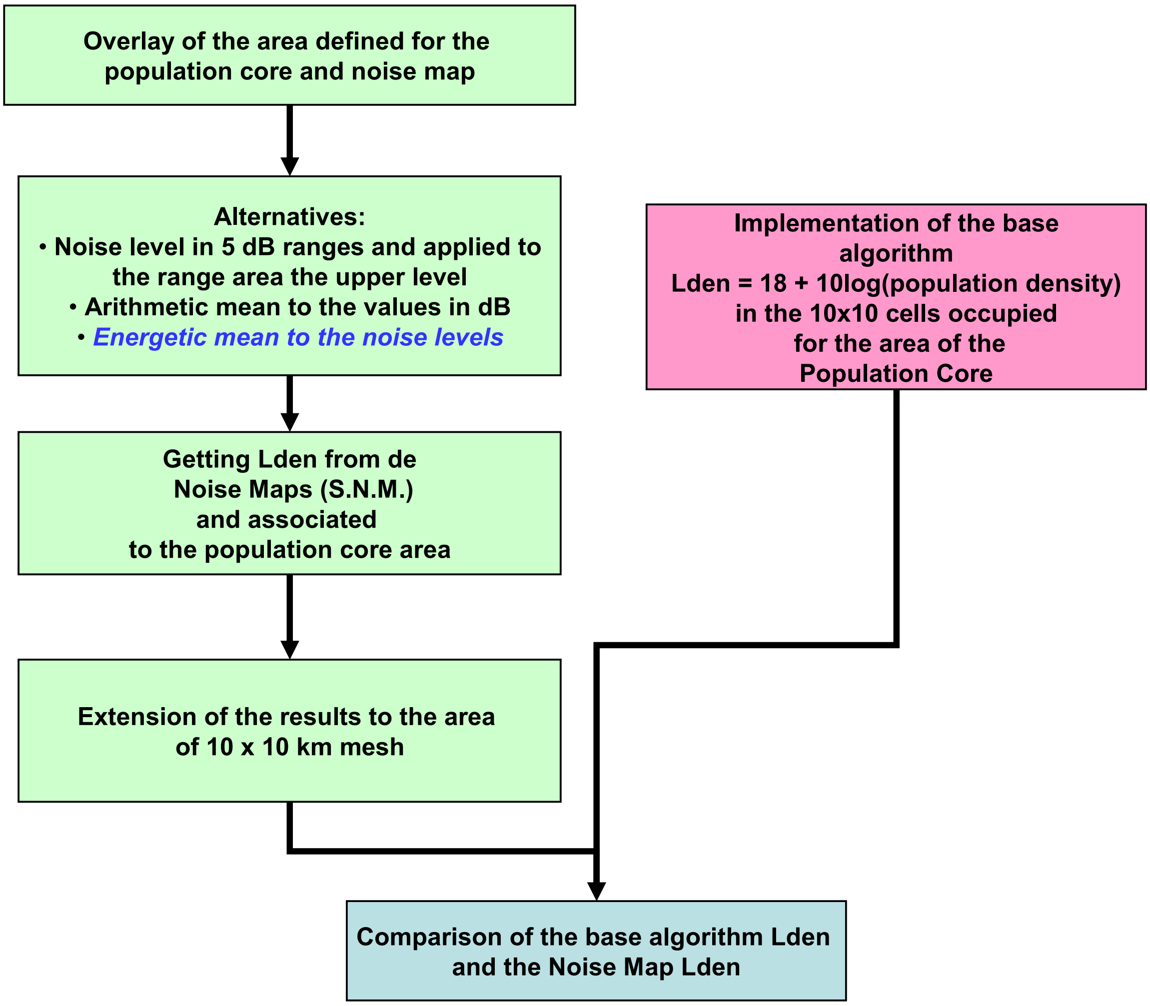


Figure 2- 14. Scheme of the process to obtain and to compare the representative L_{den} noise levels of actual Strategic Noise Maps and calculated with the base algorithm.

Last step in this Task is the **validation of the whole process** defined to compare actual values to calculated ones. As it is mentioned above in the pilot city of Zaragoza it is available more detailed data about population density, this is the population information associated to each "Junta Vecinal", a local administrative unit. The validation process is to analyse the differences between actual Strategic Noise Map L_{den} values and the calculated ones, either using data from the Population Core or from the "Junta Vecinal".

Therefore, the method proposed in step two of this task has been applied to both type of information: Population Core and "Juntas Vecinal". The comparison of both approaches leads to the following conclusions:

- When using data coming from "Junta Vecinal", extended to 10x10 km grid, the differences in L_{den} between actual Strategic Noise Maps values and calculated noise levels by applying the basic algorithm have been about 10 dB.
- On the other hand, when using data coming from Population Core, extended to 10x10 km grid, the differences in L_{den} between actual Strategic Noise Maps values and calculated noise levels by applying the basic algorithm have been between 4 and 5 dB.
- These results indicate that the process based on Population Core data is closer to actual SNM values than when using more precise population data
- Anyhow, there are still differences and the analysis of possible causes concludes the following:
    - The process of overlapping Population Core entity with the Strategic Noise Map is difficult due to the different data origins. This fact could contribute to get differences.
    - In Zaragoza, and in most of European cities, main transport infrastructures contribute to the L_{den} Noise values. In the Sintef report it is establish that the proposed basic algorithm is only valid when there is no direct incidence of noise sources.
    - Nevertheless, according to the relationship between noise and population established in the Basic Algorithm, the Strategic Noise Map actual L_{den} values would mean a very high density of population.

As a conclusion of this task, it is said that the method based on the Population Core entity is valid, as it is close to actual SNM values. However there are still differences and in next tasks a better approach is proposed, after analysing a sample of European agglomerations.

Task 2.- Application of the methodology to compare SNM and basic algorithm to European cities

The European Topic Centre for Land Use and Spatial Information (ETC-LUSI-UAB) has collaborated in this task, giving access to the agglomeration Strategic Noise Maps sent by Member State as a response to the European Noise Directive.

The criteria to select European agglomerations to be used in this analysis are the following:

- Europe Representation. As the conclusions are applied to the whole Europe, the intention is to find agglomeration with different characteristics (total population, density, geographical distribution, etc.) to create a valid sample. The selection finally made comprises small and a big size agglomeration and North, Sourth East and West cities are represented.
- Formats. The method needs having information in a specific formats as it requires values associated to a spatial grid (raster format) to calculate the actual SNM L_{den} value. Standard image representation formats as pdf or jpg are not useful for the study. This requirement has become a critical point in the selection, due to the lack of SNM information.

Finally, the selection of the agglomerations is:

- Berlin: 3 million inhabitants,
- Hamburg: 2 million inhabitants, and
- Prague: 1 million inhabitants.
- Zaragoza agglomeration is also considered in the sample, as it is already analysed. Zaragoza: 640.000 inhabitants.

The four cities constitute a representative sample of European agglomerations.

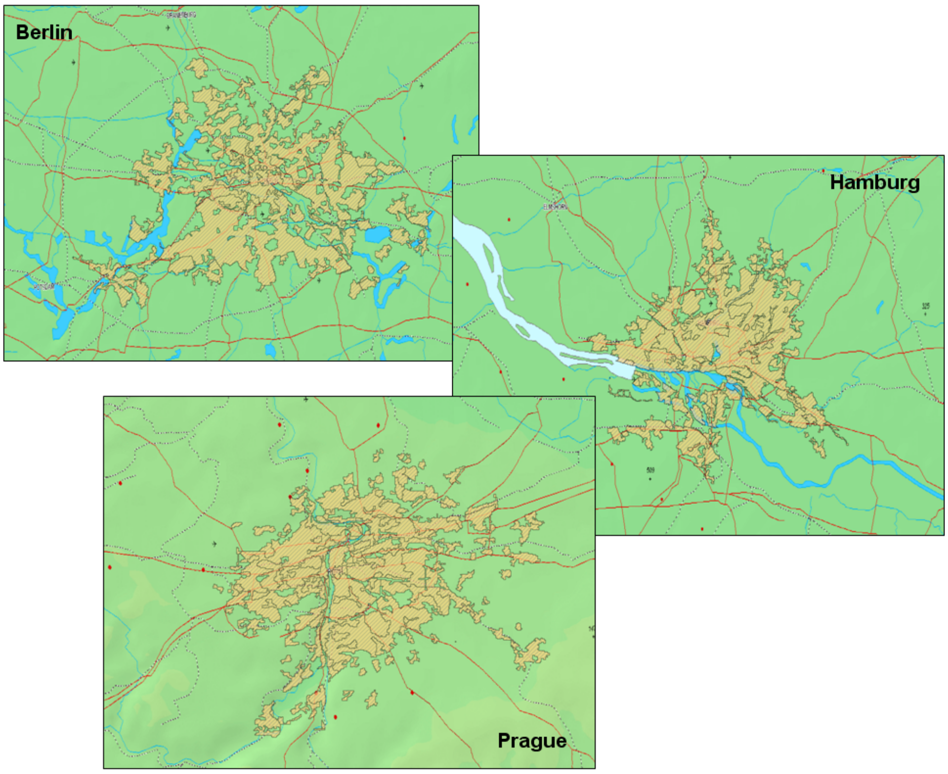


Figure 2- 15. Population Core entities that define Berlin, Hamburg and Prague agglomerations

The process defined in Task 1 is applied to the three selected agglomerations. Figure 2-16 shows a description of the process. As a resume, it implies the following steps:

- To calculate L_{den} representative of the Strategic Noise Map referred to the area delimited by the Population Core. This value is extended to the 10x10 km cell.
- To apply the Basic Algorithm (L_{den} = 18 + 10log (population density)) to the population density grid 10x10 Km resolution.
- To compare L_{den} results and analysing the differences between both values.

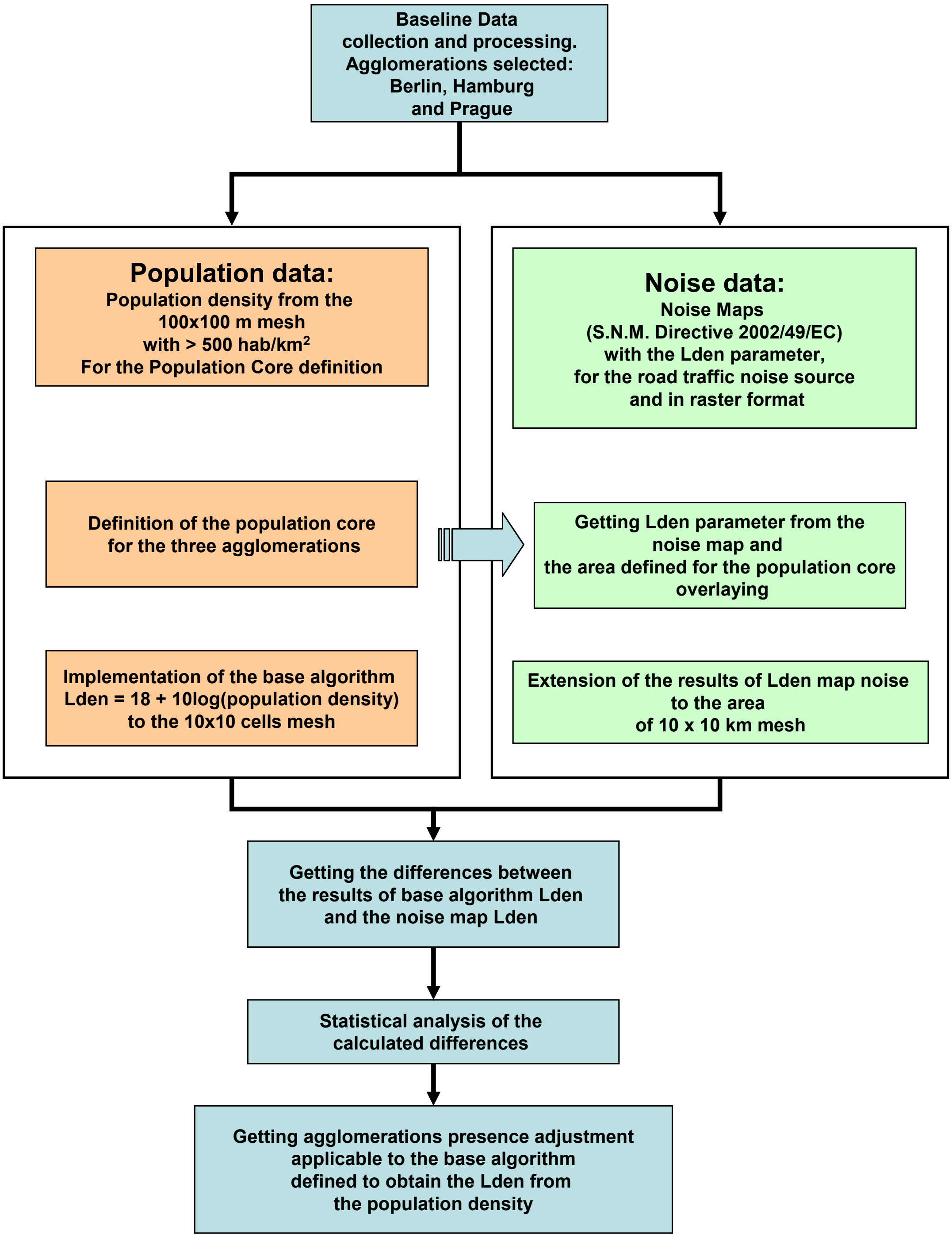


Figure 2- 16. Scheme of the methodology to compare SNM and basic algorithm and Determination of Lden index adapted formula

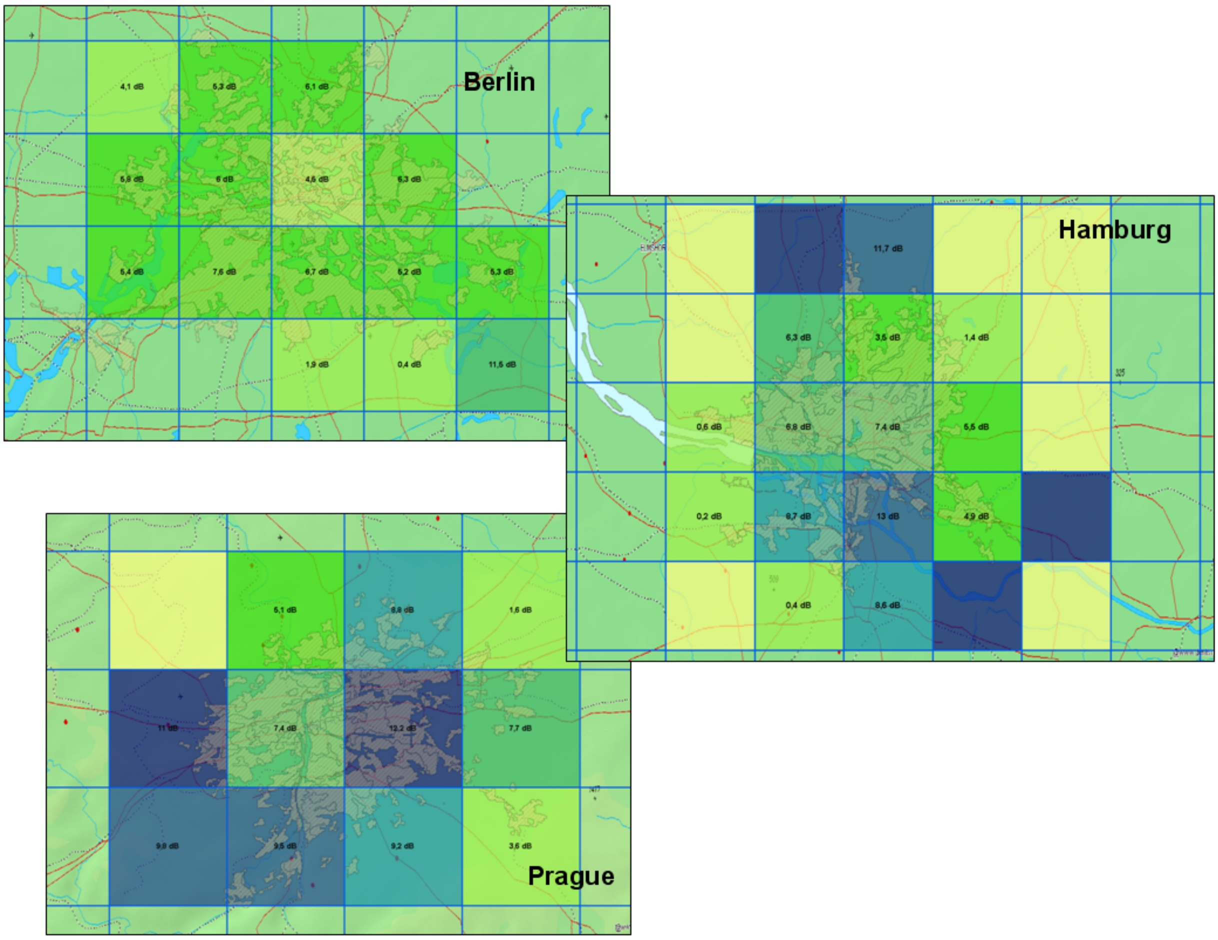


Figure 2- 17. Comparison between SNM values and Basic Algorithm results in Berlin, Hamburg and Prague. The agglomerations are represented by the cells of 10x10 Km and the values in each cells shows the noise levels differences.

Applying the defined methodology the following results have been obtained:

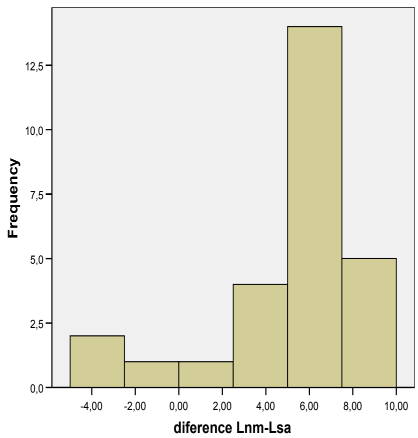
- Berlin:
  The agglomeration is defined by 11 cells.
  Calculated differences of L_{den} go from 4 up to 7dB.
- Hamburg:
  The agglomeration is defined by 8 cells.
  Calculated differences of L_{den} go from 1 up to 8dB.
- Prague:
  The agglomeration is defined by 7 cells.
  The calculated differences of L_{den} go from 1 up to 9dB.
- Zaragoza (calculated in previous task):
  The agglomeration is defined by 1 cell.
  The calculated difference of L_{den} is 5 dB.

Task 3.- Determination of L_{den} index adapted formula

The L_{den} index adapted formula is defined as a conclusion of the analysis of differences found in the 27 cells that represent European selected cities. These data are studied statistically and a new algorithm is proposed.

The **analysis of the L_{den} differences** between actual Strategic Noise Map L_{den} values (L_{nm}) and values calculated applying Basic Algorithm (Sintef Algorithm, L_{sa}), gives the following preliminary conclusions:

- Most differences between L_{nm} and L_{sa} were positives and within the range from +4 up to +7 (mean=5,09; standard deviation=3,38). This means that the Basic Algorithm underestimates L_{den} value, at least in urban agglomerations.



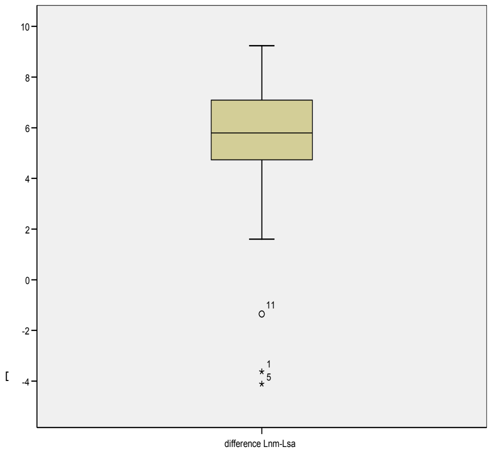


Figure 2- 18. Analysis of differences between Strategic Noise Map (L_{nm}) and Basic Algorithm (L_{sa}) (N=27 inhabited areas)

- The exploratory analysis of data shows a high standard deviation. One option is to consider the three negative values like outliers in the sample: one of Berlin (-4.11), other of Prague (-3.63) and the other of Hamburg (-1.35). The cells that contain these negative values correspond to low urban density areas. After removing data form the sample, the standard deviation (data dispersion) was smaller (mean´=6,10; standard deviation´=1,75).

A regression analysis of the sample was conducted to optimize the calculation of L_{den} and to propose a new adapted formula to be applied in agglomerations. Two regression analyses were carried out. The first one was a preliminary approximation, considering only L_{sa} as independent variable and using the entire sample in the analysis. In the second phase, the percentage of inhabited area (%IA) is included as independent variable, and the outlier values have been removed from the sample.

- **First Regression Analysis**:
  - The entire sample is used. N=27: N-Prague=7, N-Hamburg=8, N-Berlin=11 and N-Zaragoza=1.
  - Regression analysis considers Strategic Noise Map L_{den} values (L_{nm}) as dependent variable and results obtained by Basic Algorithm (L_{sa}) as independent variable.
  - The analysis concludes the following algorithm as a first adjustment of the Basic Algorithm:

$$L_{r1} \rightarrow L_{nm} = 6{,}478 + 0{,}993\, L_{sa}$$

This model explains 83,6%[4] of the variance of L_{den} of Noise Maps[5] ($F(22{:}1)=118{,}119$; $P<0{,}001$).

The differences found between L_{nm} and L_{r1} are in the ranges from -1 up to +1. Nevertheless, there are values out of the previous range, mainly values smaller than -1, and they correspond to areas with a low percentage of inhabitants.

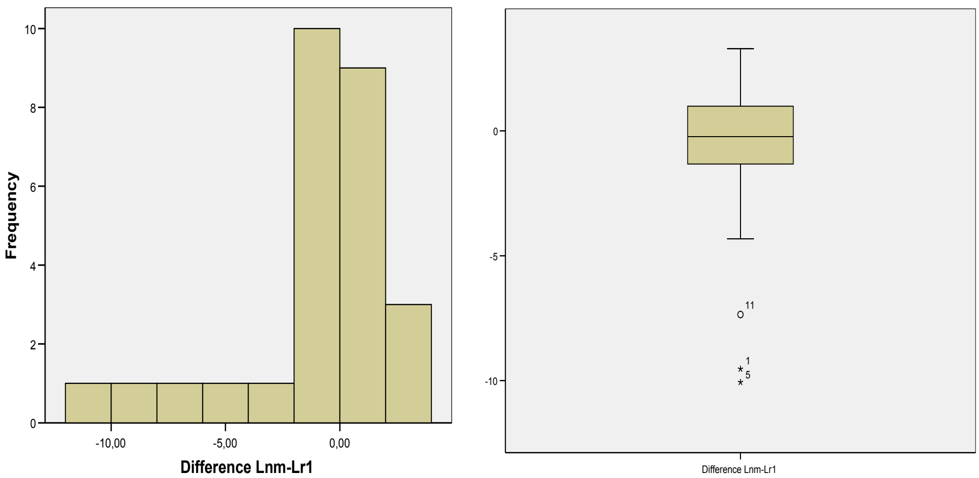


Figure 2- 19. Analysis of the differences between Strategic Noise Map (L_{nm}) and the first adjustment of Basic Algorithm (L_{r1}) (N=24 inhabited areas)

Figure 2- 19 shows the adjustment between L_{nm} and L_{r1}. In general, the data is well adjusted. One emphasized aspect is the differential localization of Prague data (lower and left part of the picture) with regard to data of the other European cities (higher and right part). A possible cause is that the urban density of Prague is lower than the one of other analyzed European cities.

---

[4] The correlation between Lnm and Lsa is 0,918 (R). For the explained varianza there are two indices: square correlations (R^2), which value is 0,843 or 84,3%, and adjusted square correlation (R^2_c), which value is 0,836 or 83,6%. The most restrictive or conservative index has been used in our analysis.

[5] The F (F), statistic test of this regression analysis, had a valor of 118,119, that with freedom levels of 22 and 1 (22:1) was significative statistically with probability (P) lower than 0,1% → ($F(22{:}1)= 118{,}119$; $P<0{,}001$).

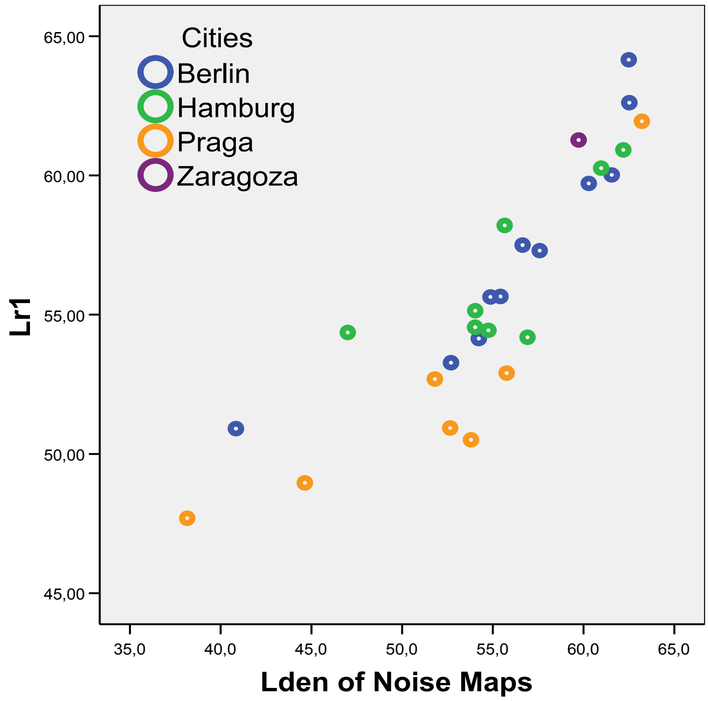


Figure 2- 20. First regression Analysis. Adjustment between L_{nm} and L_{sa} adjusted (L_{r1}) (N=24 inhabited areas)

- **Second Regression Analysis**:

Once the first results were analyzed, changes in the sample and in considered variables were proposed to optimizate the process.

Regarding the variables to be considered, it was analyzed the dependence of the differences found between SNM values and the adjusted Basic Algorithm referred to a new variable, as it is the Percentage Inhabited Area (%IA) in each cell.

As it can be seen in the following figure, most dispersed values correspond to cells with less than 40% surface occupied by the agglomeration (%IA). The highest values of the difference L_{nm}-L_{r1} correspond to outlier data, whose percentages of inhabited areas are lower than 30%.

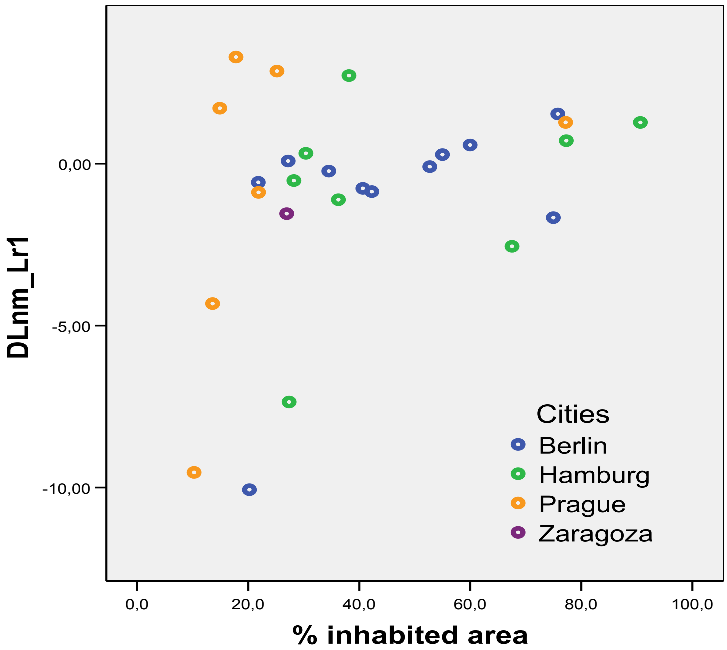


Figure 2- 21. Relationship between the difference between L_{nm} y L_{sa} adjusted (L_{r1}), and percentage of inhabited areas (%IA) (N=24 inhabited areas)

Regarding the sample, as it was said some cells are considered as outliers data and are taken out for the second analysis. These are the cells with data bigger than 2.5 dB in absolute value (n=8) (percentage of inhabited area is in brackets)

- Prague (4): -9.53 (10.3%), -4.32 (13.6%), 2.86 (25.2%), and 3.29 (17.8%).
- Hamburg (3): -7.36 (27.4%), -2.55 (67.5%), and 2.72 (38.2%).
- Berlin (1): -10.07 (20.2%).

After that, the sample consists in 19 urban areas.

Description of the Second Regression Analysis:

- The selected sample is used (N=19 → 3 from Prague, 5 from Hamburg, 10 from Berlin and 1 from Zaragoza).
- Regression analysis considers Strategic Noise Map L_{den} values (L_{nm}) as dependent variable and results obtained by Basic Algorithm (L_{sa}) and percentage of inhabited area (%IA) as independent variable.
- The analysis concludes the following algorithm as a optimized adjustment of the Basic Algorithm:

$$L_{r2} \rightarrow L_{nm} = 15,215 + 0,778\ L_{sa} + 0,048\ \%IA$$

This new model explains 95,60% [6] of the variance of L_{den} of Strategic Noise Maps, compared with 92,9% [7] of the variance explained with the previous model (L_{r1}). The statistical test of regression analysis shows that this model is relevant to explain the variability of L_{den} of Noise Maps [8].

These results indicate that the contribution in this model of the percentage of cell area covered by the agglomeration (inhabited areas, %IA) is relevant. When inhabited area is include in the analysis the best adjustment is achieved from Basic Algorithm to Strategic Noise Maps data (+3%) and more than 95% of the variability of Strategic Noise Maps is explained with only two variables: Basic Algorithm (93% of their L_{den} variance) and Percentage of Inhabited Area (+3%).

Following Figure shows the adjustment of the new model.

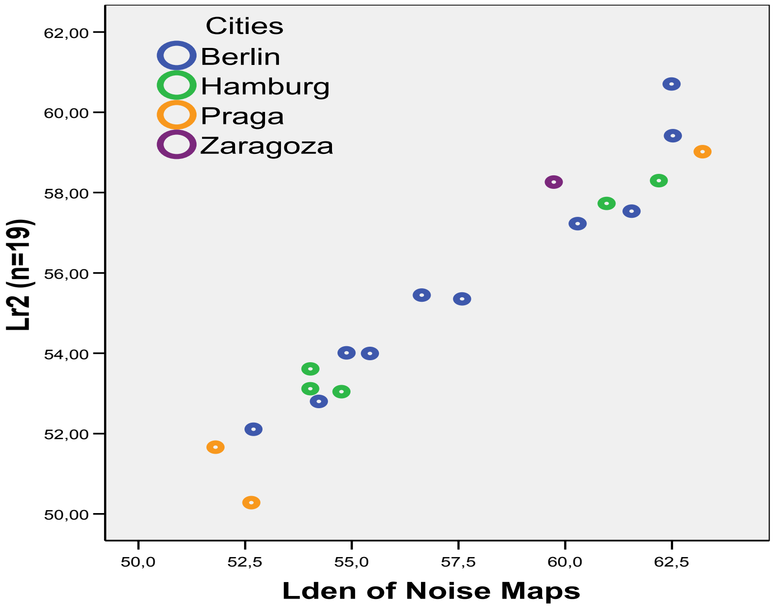


Figure 2- 22. Second regression Analysis. Adjustment between L_{nm} and L_{sa} adjusted ($_{Lr2}$)) (N=19 inhabited areas)

[6] The correlation between L_{nm} and the new model (L_{sa} + %IA) is 0,980 (R). For the explained varianza there are two indices: square correlations (R^2), which value is 0,961 or 96,1%, and adjusted square correlation (R^2_c), which value is 0,956 or 95,6%. The most restrictive or conservative index has been used in our analysis.

[7] The correlation between L_{nm} and the new model (without %IA) is 0,966 (R). For the explained varianza there are two indices: square correlations (R^2), which value is 0,933 or 93,3%, and adjusted square correlation (R^2_c), which value is 0,929 or 92,9%. The most restrictive or conservative index has been used in our analysis.

[8] The F (F), statistic test of this regression analysis, had a valor of 195,237at with freedom levels of 16 and 2 (16:2) was significative statistically with probability (P) lower than 0,1% → (F(16:2)= 195,237; P<0,001).

As a conclusion of this Task, the new algorithm to calculate L_{den} values to represent, in the framework of this project, the Background Noise Levels in Urban situations is the following:

$L_{denAg} = 29{,}219 + 7{,}78 \log(\rho) + 0{,}048\ \%IA$

where,

- ρ is the population density of the analyzed cell, and
- % IA is the percentage of the area of the cell that overlaps any polygon of the Population Core. This value was calculated by applying a spatial analysis of the information.

This new algorithm is applied in all the Spatial Grid 10x10 km resolution built in this project to create the BGN Map for Urban Agglomerations. This new algorithm is applied in those cells that contain urban area. Those are the cells which area overlaps any polygon of the Population Core. Finally, the criterion to apply this algorithm among the total grid is that the value of %IA is higher than cero.

The following figure shows the BGN Map for Urban Agglomerations in L_{den} resulting by the application of described methodology. In this map only cells that fulfil the requirement for % of IA are represented.

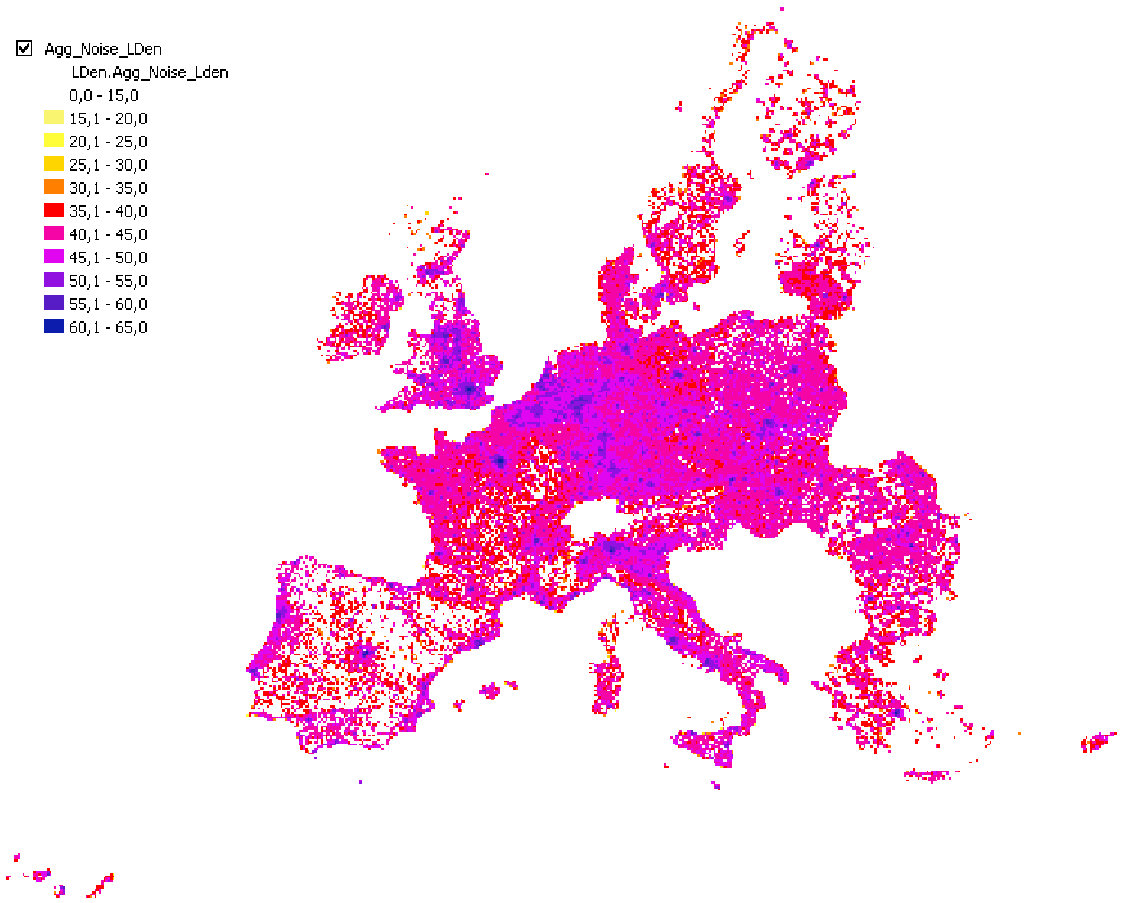


Figure 2- 23. BGN Map in L_{den} values for Urban Agglomerations

Task 4.- Determination of L_{95} Background Noise level

The purpose of this project is to estimate L_{95} noise values to represent Background Noise levels in different periods of the day (day, 07-19; evening, 19-23; and night, 23-07). Therefore, after having a new algorithm to estimate L_{den} values in urban agglomerations, it is needed to find and define a relationship between L_{den} noise values and L_{95} noise values for each period of the day.

The proposed correction factors to estimate L_{95} noise values from L_{den} values are based on the analysis of Noise Monitoring Data. In order to get as much representative data as possible, 7 Local and Infrastructure Administrations were asked for giving access to Noise Monitoring Data.

The data used to estimate the correction is as follows:

- Evolution of L_{Aeq} noise levels along 24hours at least for 3 days.
- Evolution of L_{A95} noise levels along 24hours at least for 3 days.

The project could analyze Noise Monitoring Data from London and Madrid networks. Besides this information, as Labein-Tecnalia manages lots of Noise Monitoring Data from different Spanish sites, Noise Monitoring Data from other Spanish cities were also analyzed. The city of Barakaldo was considered (it is a medium size town in the Basque Country) and the already mentioned city of Zaragoza (it has more than 100.000 inhabitants).

Noise Monitoring Data was analyzed, looking for relationship between L_{den} noise values and L_{95} noise values for each period of the day. This analysis was made in every site and every day with noise data. Considering all the noise data available in the project, 78 parameters were analyzed. The average relationships between the acoustic parameter considered are the following:

	Barakaldo	Zaragoza	London	Madrid
L_{den} - L_{day} (dB)	1.3	2.0	1.3	2.9
L_{den} - $L_{evening}$ (dB)	3.5	5.3	4.0	3.3
L_{den} - L_{night} (dB)	9.3	8.9	8.0	8.4

	Barakaldo	Zaragoza	London	Madrid
L_{den} - $L_{95,day}$ (dB)	7.4	9.6	5.7	9.2
L_{den} - $L_{95,evening}$ (dB)	10.7	11.6	7.2	9.8
L_{den} - $L_{95,night}$ (dB)	18.4	17.1	9.4	16.2

Table 2- 2. Analysis of Noise Monitoring Data. Noise level differences

The standard deviation of the data analyzed was calculated.

Standard deviation	Barakaldo	Zaragoza	London	Madrid
L_{den} - L_{day} (dB)	0.3	2.1	0.8	0.7
L_{den} - $L_{evening}$ (dB)	0.2	2.3	0.8	1.3
L_{den} - L_{night} (dB)	0.2	2.1	1.0	1.3

Standard deviation	Barakaldo	Zaragoza	London	Madrid
L_{den} - $L_{95,day}$ (dB)	0.2	3.9	1.1	1.7
L_{den} - $L_{95,evening}$ (dB)	0.9	3.9	1.3	1.1
L_{den} - $L_{95,night}$ (dB)	0.4	4.1	2.1	3.6

Table 2- 3. Analysis of Noise Monitoring Data. Standard deviation

The standard deviation of the data from Zaragoza is bigger than the other cities due to the variability of the sites, as they are shown on next pictures, of noise registering.

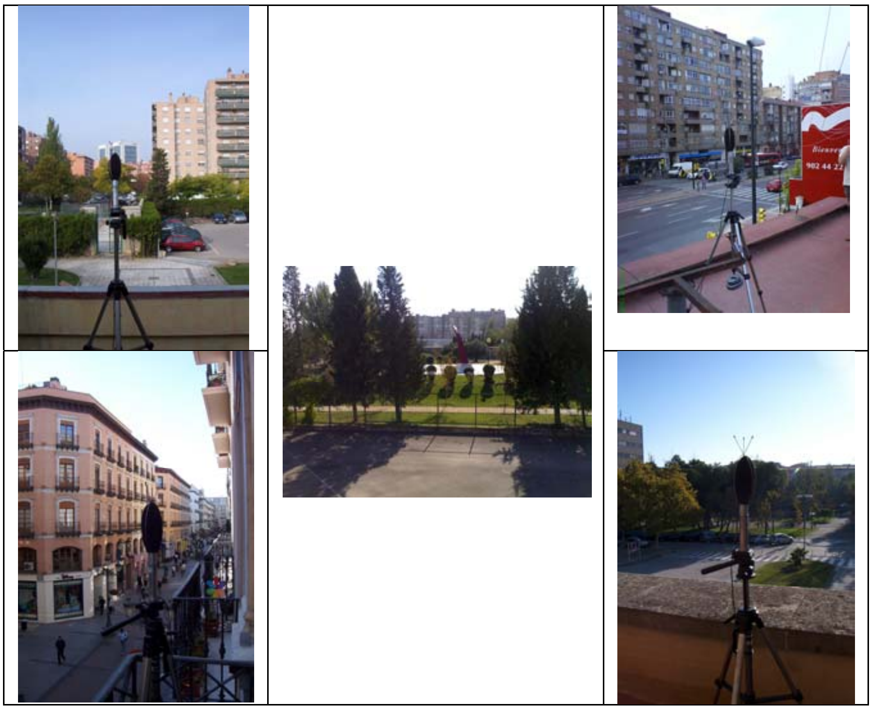


Figure 2- 24. Noise monitoring places

Analysing together data from different cities and sites, the proposed correction factors to estimate other acoustic parameters from L_{den} values were obtained. Firstly, the corrections to obtain the equivalent levels for day, evening and night periods of the day are the following:

$$\mathbf{L_{day} = L_{den} - 2}$$

$$\mathbf{L_{evening} = L_{den} - 3}$$

$$\mathbf{L_{nigth} = L_{den} - 8}$$

Secondly, corrections to obtain the $\mathbf{L_{95}}$ levels for day, evening and night periods of the day are the following:

$$\mathbf{L_{95,day} = L_{den} - 9}$$

$$\mathbf{L_{95,evening} = L_{den} - 10}$$

$$\mathbf{L_{95nigth} = L_{den} - 15}$$

It is considered that the analysis done is consistent and valid to answer to the scope of this project. However it must be emphasized that if more accuracy was required a specific project would be needed to adjust a more accurate relation between the studying parameters. This is due to high variability of urban situations.

The following figure shows the BGN Map for Urban Agglomerations in L_{95day} resulting by the application of described methodology. In this map only the cells that fulfil the requirement for % of IA are represented.

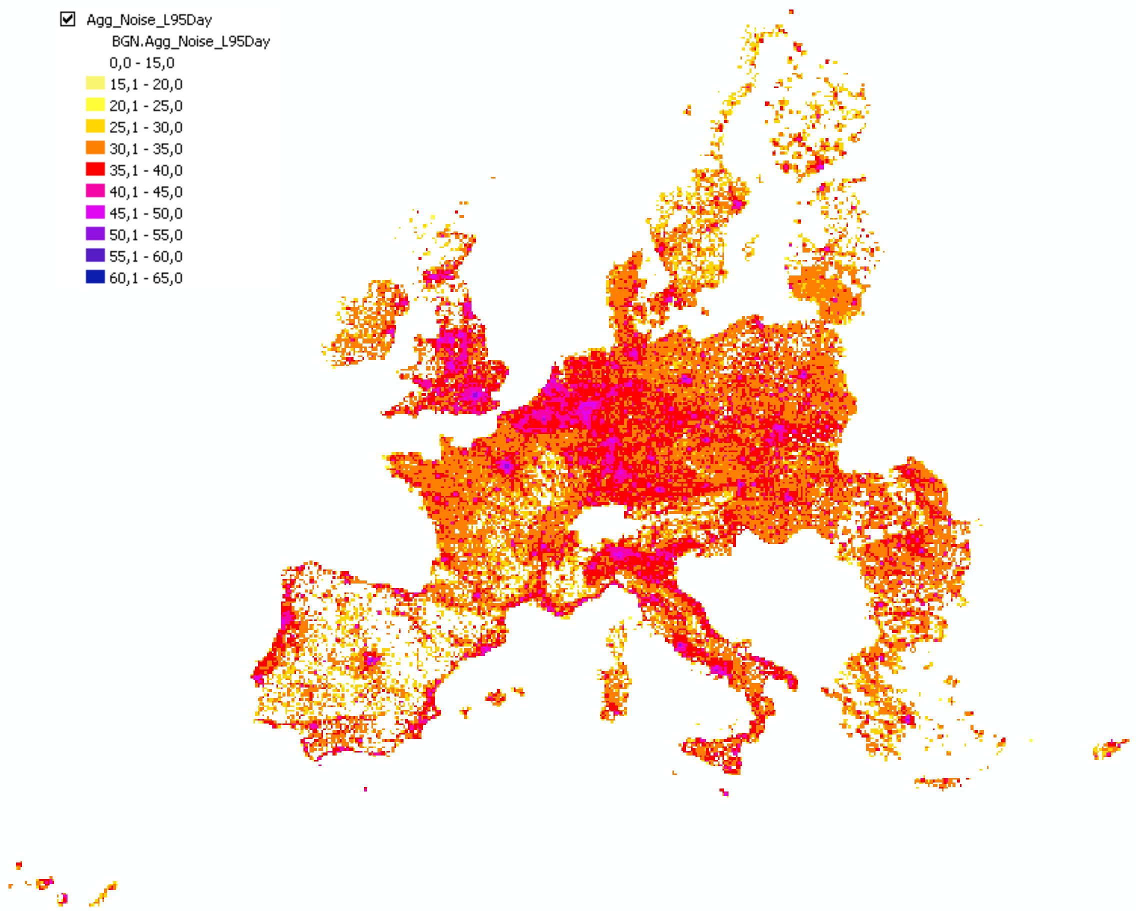


Figure 2- 25. BGN Map in $L_{95,\ day}$ values for Urban Agglomerations

Conclusion:

The Background Noise Map for Urban Agglomerations is built considering those cells of the 10 X 10 Km grid with %IA higher than zero.

The algorithm and formulas applied to build these Maps are the following:

- Urban Agglomerations L_{den} Map:
  $L_{denAg} = 29{,}219 + 7{,}78 \log(\rho) + 0{,}048\ \%IA$

  where,

  ρ is the population density of the analyzed cell, and

% IA is the percentage of the area of the cell that overlaps any polygon of the Population Core. This data was created in a Spatial analysis of the data.

- Urban Agglomerations L_{day} Map:

  $$\mathbf{L_{day} = L_{den} - 2}$$

- Urban Agglomerations $L_{evenning}$ Map:

  $$\mathbf{L_{evening} = L_{den} - 3}$$

- Urban Agglomerations L_{night} Map:

  $$\mathbf{L_{nigth} = L_{den} - 8}$$

- Urban Agglomerations $\mathbf{L_{95,day}}$ Background Noise Map:

  $$\mathbf{L_{95,day} = L_{den} - 9}$$

- Urban Agglomerations $\mathbf{L_{95,evenning}}$ Background Noise Map:

  $$\mathbf{L_{95,evening} = L_{den} - 10}$$

- Urban Agglomerations $L_{95,night}$ Background Noise Map:

  $$\mathbf{L_{95nigth} = L_{den} - 15}$$

This process is applied in those cells that contain urban area. That means those cells which area overlaps any polygon of the Population Core.

These Maps are combined with Maps generated on other situations to build the BANOERAC Noise Map for each acoustic parameter.

2.1.2 Transport Infrastructure

The presence of transport infrastructure generates noise, so these sources must be considered when estimating Background Noise levels. Besides this, as the acoustical effect of transport infrastructures is not directly related with the population density, a complementary approach is defined to represent these situations.

The correction factor due to the presence of transport infrastructures in open land has been studied considering the spatial unit of analysis defined (10 x10 km). This correction factor is applied in those cells in which any regional infrastructure is present.

To identify the presence of any transport infrastructure on a cell, information about the infrastructure network has been overlaid spatially on the grid. This process gives information about the cells that contains information about a transport line and about its type. Different types of infrastructures have been defined attending to their acoustic emission characteristics (traffic volume, mainly). The experience acquired in noise mapping has allowed estimating the area affected by higher noise levels due to the infrastructure. This effect contributes to get a new formula to estimate Transport BGN, in spite of the Basic Algorithm that obtains the BGN considering only the population density.

The influence in BGN of the presence of roads and railway lines has been studied. Due to the fact that the noise generated by these two transport modes is different (the first one generates a continuous noise, while the railway noise is intermittent), they have been studied separately. In case of railway noise, the study has concluded (see section 2.1.2.2) that there is no need to consider railway lines in this methodology due to in the scope of this project, railway noise does not contribute to L_{95} noise indicator. Meanwhile, a correction formula is defined to estimate the effect on BGN due to the presence of major roads. This algorithm considers the length of the road overlaid on each cell, its typology, and its area of acoustic influence.

Next sections describe the methodology for each transport infrastructure separately.

2.1.2.1 Road Transport

In the framework of this project the effect of road traffic on BGN is described by the size of the area acoustically affected. In general, this area depends on the acoustic emission of the road and the topography around it. The acoustic emission is determined by the characteristics of the road: total traffic flow, percentage of heavy vehicles, speed or type of road surface. Considering the geographical extension of the study, this information is reduced to the most critical parameter regarding its influence on the acoustical emission of the road, which is the total traffic flow. On the other hand, the analysis of Strategic Noise Map results allows estimating the area acoustically affected by roads.

Next figure shows a Strategic Noise Map of a Major Road (noise contours) where it is possible to understand the concept of acoustically affected area and how it is influenced by traffic flow and by topography along the road.

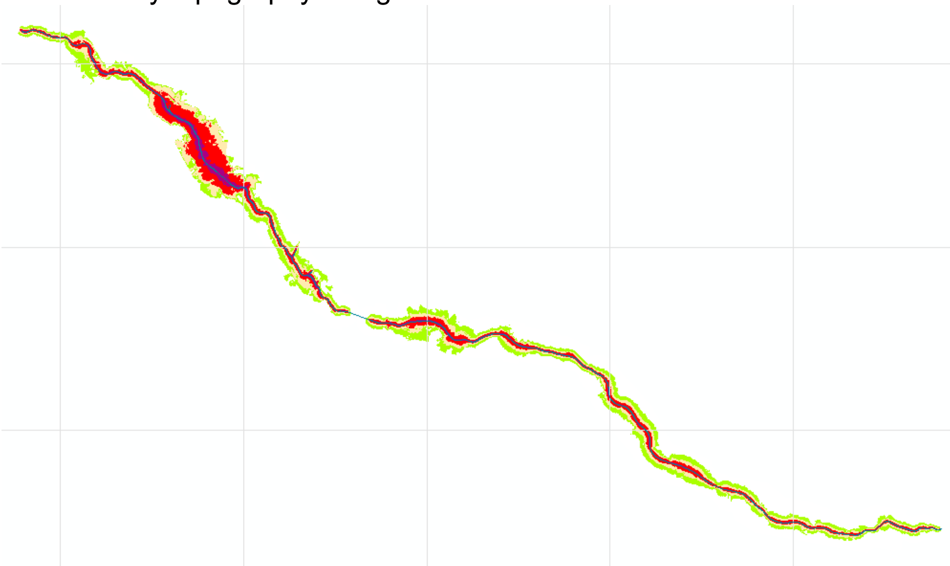


Figure 2- 26. Strategic Noise Map of a Major Road.

2.1.2.1.1. General concept

It is said previously that the effect of the roads in BGN values is based on the acoustically affected area.

The affected area is defined as a buffer around the road and it is characterized by two parameters:

- The surface of the affected area, named also as surface occupied by the road (from now on denoted by S).
- The noise level associated to this area. It is the noise level that can represent the acoustical influence of the road on this surface (from now on denoted by L).

The new algorithm to represent BGN in situation close to roads gives the L_{den} values calculated from those two parameters.

In order to propose this new algorithm, the following steps were carried out:

1. Analysis of Road Network Data to define types of roads, regarding their traffic flow.
2. Methodology to obtain values for L and S parameters from Strategic Noise Map results.
3. Definition of values for L and S parameters to be applied among Europe.
4. Definition of the new algorithm to be applied in every 10x10Km cell.
5. Justification of the new algorithm by its application to European cells.
6. Determination of L_{95} Background Noise level.

The new algorithm proposed to estimate BGN L_{den} values in situations close to roads is the following:

$$L_{denTR} = 10 * \log\left(\frac{\sum_{i=1}^{n} S_{occupied,type1} * 10^{(L_1/10)} + \sum_{j=1}^{n} S_{occupied,type2} * 10^{(L_2/10)}}{S_t} \right)$$

where,

$S_{ocuppied,type\ i}$ is the surface of the cell occupied by any buffer representing the affected area by road type i,
S_t is the total surface of the cell, and
L_1 and L_2 are the noise level assigned to the two type of road defined

The algorithm uses the $S_{occupied}$ value to estimate the acoustic energy in the spatial unit of analysis. Therefore, this algorithm applies clearly the assumption made in this project about the extension the acoustic energy in the cell to represent the BGN values of the cell.

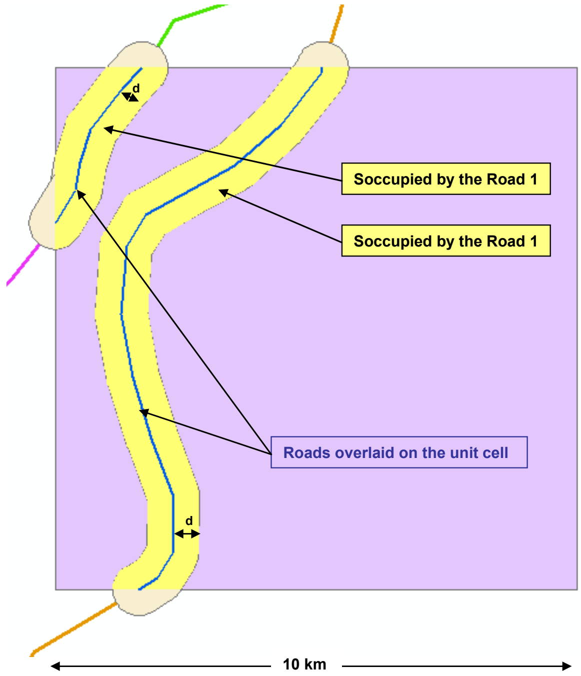


Figure 2- 27. Algorithm to calculate L_{denTR}. Acoustic energy expanded in the cell

2.1.2.1.2. Description of the baseline data

This section summarizes the data analysis carried out to define the methodology.

Strategic Noise Maps information

The methodology proposed to represent BGN in areas close to Major Roads is defined taken into account, as much as possible, actual information about Noise Maps. The European Noise Directive [14] has required for 2007 the generation of Strategic Noise Maps of Major Roads.

The European Topic Centre for Land Use and Spatial Information (ETC-LUSI-UAB) is responsible of the process of compiling all the information about Strategic Noise Maps sent by Member States to the EU Commission. ETC-LUSI-UAB has collaborated in the project. However, there is a lack of information about Major Roads Strategic Noise Maps.

To solve this situation, Strategic Noise Maps of Major Roads of Bizkaia have been analysed, thanks to the Road Infrastructures Department of the Province of Bizkaia. Their Strategic Noise Maps were made by Labein-Tecnalia.

Road infrastructure information

The methodology defined in this project to build the BGN Maps implies the calculation of an algorithm to represent the influence on the background levels due to the presence of mayor roads infrastructure. Therefore data about road infrastructures in Europe 27 is required.

Spatial information of the European Transport Networks developed by Eurostat Institution has been used [9]. The available information concerning mayor transport infrastructure is shown on the table below:

Transport Networks:

Transport networks	Scale	Coverage	Feature type	Format	Period	Coordinate Reference system	Size (MB)	Files to download
Road Network	1:1 Million	Europe	Line	Coverage	1991-1997	ETRS89	1.2	RDEU.zip

Table 2- 4. Eurostat Road Transport Network data

The quality of these data is guaranteed by Eurostat, especially concerning information among European areas homogeneity and representation accuracy. Although the road transport information from Eurostat is old, it covers all EU27 and it is also easy to use, so it has been considered suitable for the purpose of this project.

This project needs to identify the presence of major roads among Europe 27. This information is given by Eurostat Transport Network data.

It is also needed the estimation of the area acoustically affected by each identified road. Therefore, some information about the traffic conditions of each road would be also interesting (total traffic flow, percentage of heavy vehicles and speed). Considering the geographical extension of the study, this information is reduced to the most critical parameter regarding its influence on the acoustical emission of the road, which is the total traffic flow.

Eurostat covers road type information, and in some cases their European and national names. But there is no data concerning traffic flow. Therefore, it is defined a process to categorize the roads considering an estimation of their traffic flow, in such a way that a road of the same group has similar traffic flow. The criterion used to classify the roads is based on the type of road.

[9] http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/archives

Eurostat road network is divided into the following types of road:

- CAR FERRY
- DUAL CARRIAGEWAY ROAD
- DUAL CARRIAGEWAY ROAD, EUROPEAN
- MOTORWAY
- MOTORWAY, EUROPEAN
- OTHER ROAD
- OTHER ROAD, EUROPEAN

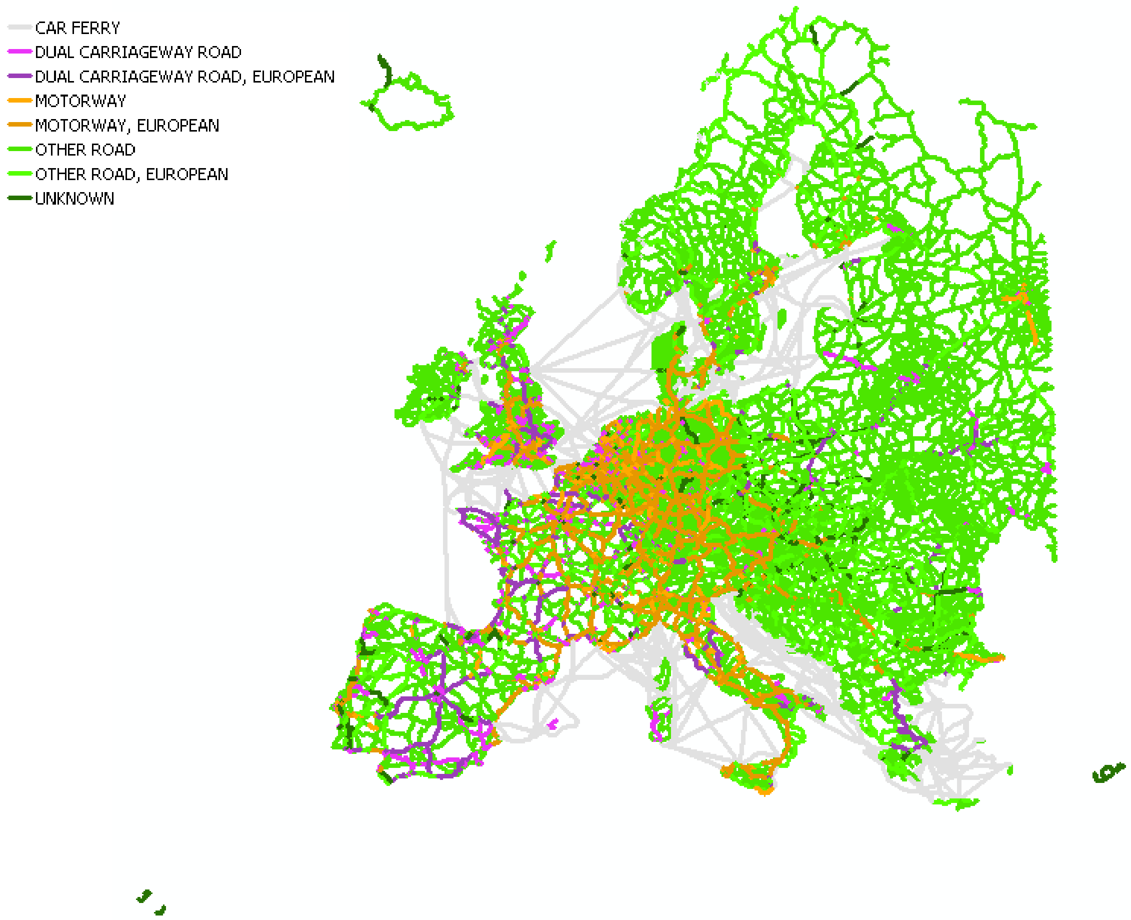


Figure 2- 28. Eurostat road network divided in seven categories

More sources of information referred to European Road Traffic flows were considered. In that sense, the information about Strategic Noise Maps sent by Member States to the EU Commission should include data about the representative traffic flow of each Major Road. However, not all Countries have sent these data. This information is available in Environment Forum of the European Communication and Information Resource Centre Administrator (CIRCA) [11], Information from Major Roads in Hungary, Belgium and Spain were analyzed. For these Countries, it has been looked if there is any correlation between Eurostat categories and the information obtained from the Strategic Noise Maps files.

Following tables show the analysis of the information found at CIRCA about Major Roads in the three countries.

HUNGARY		
Road name	**Annual traffic (*1000 vehicles)**	**Eurostat Type of Road**
M0	13.882	Motorway
M1	9.400	Motorway
M3	12.247	Motorway
M5	10.236	Motorway
M7	10.946	Motorway
N8	6.819	Other Road
N6	7.734	Other Road
N2	7.331	Other Road

Table 2- 5. Hungary Major Road annual traffic flow and their Eurostat categorization

BELGIUM		
Road name	**Annual traffic (*1000 vehicles)**	**Eurostat Type of Road**
A13	8.815	Motorway
A15	23.013	Motorway
A16	12.501	Motorway
A17	11.863	Motorway
A25	13.748	Motorway
A26	13.850	Motorway
A27	16.183	Motorway
A28	7.665	Motorway
A3	23.734	Motorway
A4	22.375	Motorway
A54	12.060	Motorway
A602	24.708	Motorway
A7	17.580	Motorway
A8	10.038	Motorway
R0	19.710	Motorway
N25	7.437	Dual Carriageway/Other road
N27	6.935	Other road
N29	6.891	Dual Carriageway/Other road
N3	7.640	Other road
N30	8.304	Other road
N4	8.724	Dual Carriageway/Other road
N5	8.560	Dual Carriageway/Other road
N50	9.855	Dual Carriageway/Other road
N51	7.300	Dual Carriageway/Other road
N55	6.571	Dual Carriageway/Other road
N56	6.388	Other road
N59	7.848	Dual Carriageway
N6	8.395	Dual Carriageway/Other road

N61	6.935	Other road
N63	9.217	Dual Carriageway/Other road
N67	8.760	Other road
N7	7.209	Dual Carriageway/Other road
N80	9.125	Dual Carriageway/Other road
N81	8.943	Dual Carriageway/Other road
N90	6.862	Dual Carriageway/Other road
N91	8.213	Dual Carriageway/Other road
N92	8.852	Dual Carriageway/Other road
N98	6.800	Dual Carriageway/Other road
A501	14.600	Not classified
A503	14.700	Not classified
A604	13.872	Not classified
B501	12.775	Not classified
N238	7.118	Not classified
N535	6.023	Not classified
N536	6.570	Not classified
N547	9.855	Not classified
N569	6.935	Not classified
N58	8.760	Not classified
N610	12.410	Not classified
N617	9.855	Not classified
N633	6.230	Not classified
N663	7.939	Not classified
N672	6.022	Not classified
N683	15.330	Not classified
N830	7.300	Not classified
N905	6.935	Not classified
N947	8.030	Not classified
N947a	6.935	Not classified
N967	8.760	Not classified
R3	12.923	Not classified
R5	7.118	Not classified
R50	6.570	Not classified
R52	8.760	Not classified
R53	6.570	Not classified
R9	16.250	Not classified
Richelle/Rolin	6.661	Not classified
Wallonie/Croyère	11.680	Not classified

Table 2- 6. Belgium major road annual traffic flow and their Eurostat categorization

In the available data from Spain, there is no logical relationship between the Eurostat categories and the traffic flow at different main roads of the Spanish network. Looking into major roads of Bizkaia province in Spain, the only road classified by Eurostat as Motorway type has more than 32 million vehicles per year.

The analysis of available traffic flows says that maximum annual traffic flow is 24 million vehicles and the minimum 6 million, as it was expected [10]. There are several Major Roads not classified by Eurostat network. Motorway type road gathers all roads that have higher traffic flow.

It is proposed to define only two types of roads, by using Eurostat Road Transport Network categories. This criteria implies a simplification, but it can be considered that the influence of traffic flow in noise levels is logarithmic (doubling traffic only increases noise levels in 3 dB). Besides this, the low quality of the information supports a very simplified approach.

So, once analyzed the data, the proposal is that all Major Roads in Europe are classified in two types, defined by their category in Eurostat Road Transport Network:

- **Road Type 1:** All Major Roads assigned as **MOTORWAY or MOTORWAY EUROPEAN** categories in Eurostat Road Transport Network.
  It is assumed an annual traffic flow **higher than 9 million vehicles**.

- **Road Type 2:** All Major Roads assigned as **DUAL CARRIAGEWAY ROAD, DUAL CARRIAGEWAY ROAD, OTHER ROAD and OTHER ROAD EUROPEAN** categories in Eurostat Road Transport Network.
  It is assumed an annual traffic flow **lower than 9 million vehicles**.

Taking out the road "Not classified", this classification explains 90% of Road Type 1 and 92% of Road Type 2 in Hungary and Belgium data.

2.1.2.1.3. Description of the process tasks

This section is structured on three tasks:

- **Task 1.- Definition of the algorithm to calculate L_{den}**
- **Task 2.- Validation of the algorithm**
- **Task 3.- Determination of L_{95} Background Noise level**

Task 1.- Definition of the algorithm to calculate L_{den}

Considering the low quality of information and the lack of Road Strategic Noise Maps data, it is assumed that resulting L_{den} data cannot be accurate. In spite of this, the methodology proposed keeps a conceptual approach because, even with this starting up information, it is considered an interesting improvement to the Basic Background Noise Map.

The two parameters that characterized the area affected by every road are the following:

[10] Remember that, according to the European Noise Directive, the first round of Strategic Noise Maps (2.007) applies to Major Roads, those that have a annual traffic flows higher than 6 million vehicles.

- The surface of the affected area, named also as surface occupied by the road (from now on denoted by S).
- The noise level associated to this area. It is the noise level that can represent the acoustical influence of the road on this surface (from now on denoted by L).

In this section, it is proposed a procedure to assign these values to each road. Strategic Noise Maps results were used to define and justify this procedure. In that sense, the first step is to estimate the L value and the affected area (S) from a Road Strategic Noise Map.

1.1.- Analysis of Noise Level (L) and affected area (S) in Strategic Noise Maps

a) Procedure to estimate L_{den} and the affected area valid to represent the whole Noise Map of a Road

To **calculate L_{den} of a noise map**, it has been used the concept of "energetically spatial average level", weighting noise values by the surface occupied by them.

$$L_{den} = 10 * \log\left(\frac{S_{level1} * 10^{L_{level1}/10} + S_{level2} * 10^{L_{leve2}/10} + \ldots S_{leveln} * 10^{L_{leveln}/10}}{S_t}\right)$$

where,

$L_{level\ i}$ mean each of the values in dBA levels represented in the isolines of the SNM;
$S_{level\ i}$ means the area in km^2 affected by i noise level and,
S_t is the total influence area of the noise map.

This method requires that the Noise Map information include noise values in a grid (raster format).

The **affected area** is described as a buffer around each road. Therefore, the affected area is defined by the width of this buffer (d).

To calculate the width (d) representative of the affected area, the L_{den} Noise Map is analysed spatially by means of GIS tools. The width (d) is understood as the distance from the road to the limit of the noise map (55dBA isoline). The resulting width (d) of the affected area (S) is the average of the distances encountered by calculating point by point along the road length. This width estimation was an arduous task. In case better information is available, it could be calculated automatically by adopting software. A specific project could solve this task easily.

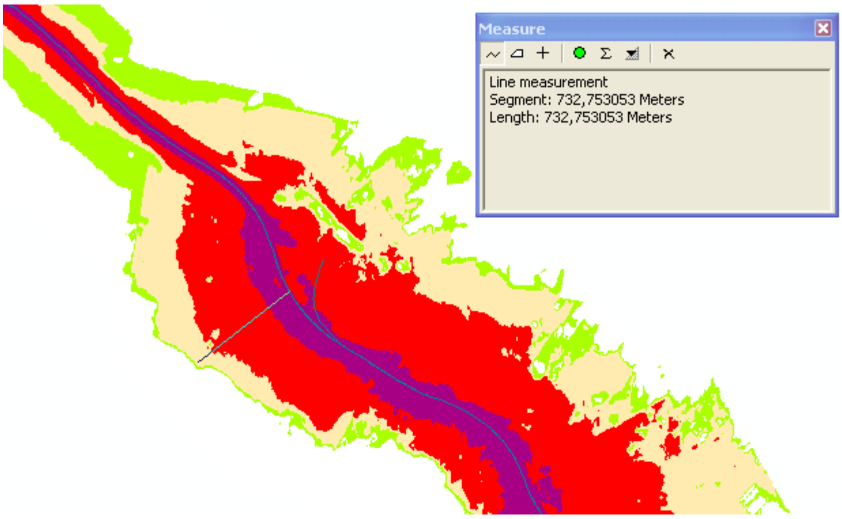


Figure 2- 29. Calculation point to point of the width average (d) to define the affected area (S)

b) Analysis of Noise Level (L) and affected area (S) in Strategic Noise Maps.

In Figure 2-30, it is clear that there are differences on the area of influence along the same road, it is due to changes in traffic flow and to the topography around the road.

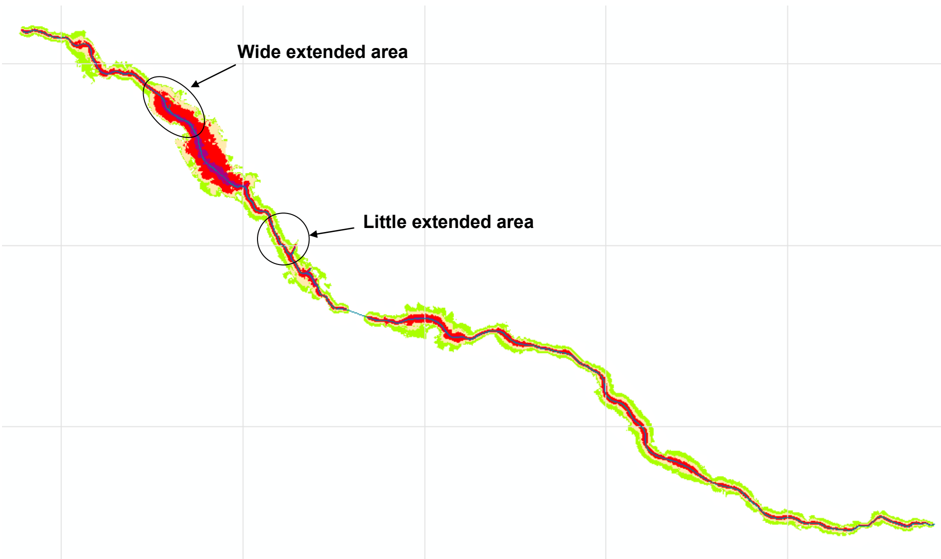


Figure 2- 30. Strategic Noise Map of Main Road

Assuming these variations of noise contours in Strategic Noise Maps, an analysis was made in two main roads to understand the behaviour of parameters L and d. The exercise is applied in two main roads of the province of Bizkaia (Spain). The exercise distinguished three different conditions:

- To consider the whole road as a single entity.

- To consider a stretch where the road affects to a reduced area.
- To consider a stretch where the road affects to an extended area.

The procedure to estimate L_{den} and the affected area (d) was applied in Noise Maps of two roads, considering in each of them the three defined conditions. The values obtained in the exercise are shown on next table:

Condition	Road 1		Road 2	
	Noise level Lden (dBA)	Average width to define the affected area d (m)	Noise level Lden (dBA)	Average width to define the affected area d (m)
Whole map	65.8	500	60.8	300
Wide affected area	69.0	700	61.9	500
Little affected area	70.7	400	64.7	200

Table 2- 7. Example to analyse the behaviour of L and d parameters in SNM

After this first analysis the conclusion is that, in spite of the obvious differences between the values reported for each case, the behaviour of the two parameters in the three situations is similar. In situations with little area affected (low d), the L values are higher; and where the affected area is bigger (d high), L values are lower. Finally, when the road is considered as a whole, the two values are less extreme.

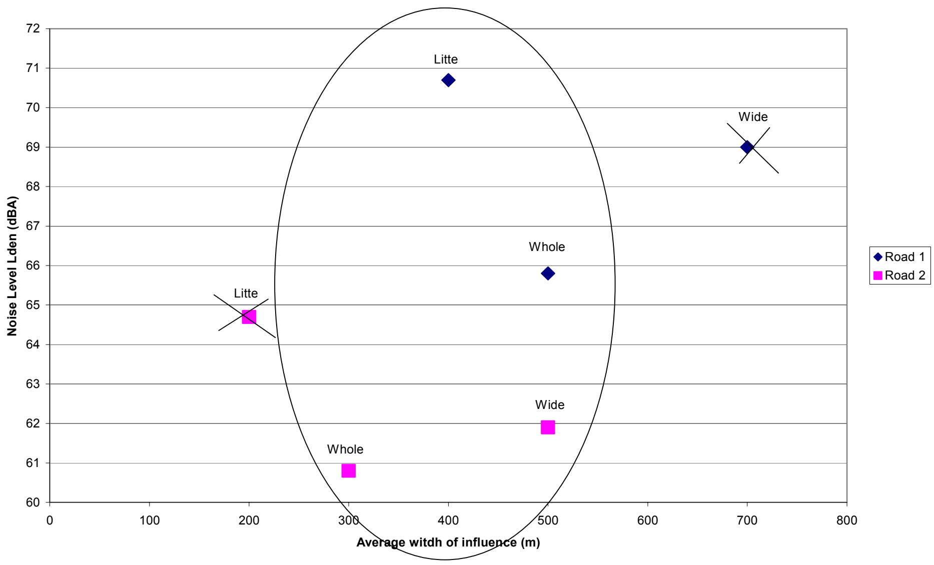


Figure 2- 31. Noise level and the width extension for three different conditions

Therefore, in this project it is concluded that it is valid to consider the entire road noise map in once, as obtained results represent the average of every specific situation along the road. The difficulty of having information to distinguish both types of situations when applying the method to the whole Europe also supports this decision.

1.2.- Assigning L and S to the type of roads

a) Defining d and S for the whole map

In the previous analysis it was observed that the distances (d) from the road to the limit of the Noise Map contours vary from 200m up to almost 700m. The cell unit is 10 x 10 km, so a range of differences of 500 m it is not a big one.

It is proposed to have a unique value for the width (d) of the buffer to define the affected area due to the presence of a road. This proposal is based on giving more importance to the noise level (L) parameter of the buffer, than to its size (S and d). To understand this decision it can be remembered the assumption established in this project which stands that noise levels representative of a cell are understood as the acoustic energy in the cell extended to the whole surface of each cell. This makes the noise level (L), representative of the acoustic energy, more important than the size of the buffer. As it is mentioned above, in case this process needs to be more precise, this parameter would be better adjusted.

Therefore any road of any type has an affected area (S) defined by a buffer around it with a fixed width. Avoiding the extreme situations the fixed value proposed is 400m for all types of roads.

b) Defining L for the whole map

Once the affected area is defined, the next step is to get the L_{den} level (called "L") of each type of road.

To define this noise level that characterizes the acoustical influence of a road, Strategic Noise Map results are analysed. As it is already mentioned there is a lack of information about Major Roads Strategic Noise Maps. To solve this situation, Strategic Noise Maps of Major Roads of Bizkaia have been analysed, thanks to the Road Infrastructures Department of the Province of Bizkaia.

It was decided previously to define only two types of roads. Road Type 1 with an annual traffic flow higher than 9 million vehicles, and Road Type 2 with an annual traffic flow lower than 9 million vehicles.

Therefore, it was calculated the "L_{den}" representative value for each of the Major Roads by applying the defined procedure to the Noise Maps. Next table shows the results and the corresponding type of road classification with respect to traffic flow.

Road name	Annual traffic (*1000 vehicles)	Lden (dBA)	Type
A8	32.481	65	1
BI625	9.435	60	1
BI644	13.704	58	1
BI631	9.254	59	1
BI637	22.873	64	1
BI634	6.605	56	2
BI3791	8.987	59	2
BI3730	8.235	57	2
BI3737	8.891	58	2
BI3749	7.754	57	2
BI623	6.109	61	2
BI626	6.437	52	2
BI635	6.815	58	2

Table 2- 8. Noise level L_{den} generated by Bizkaia Major Roads and their traffic flow

The same values are shown on next figure:

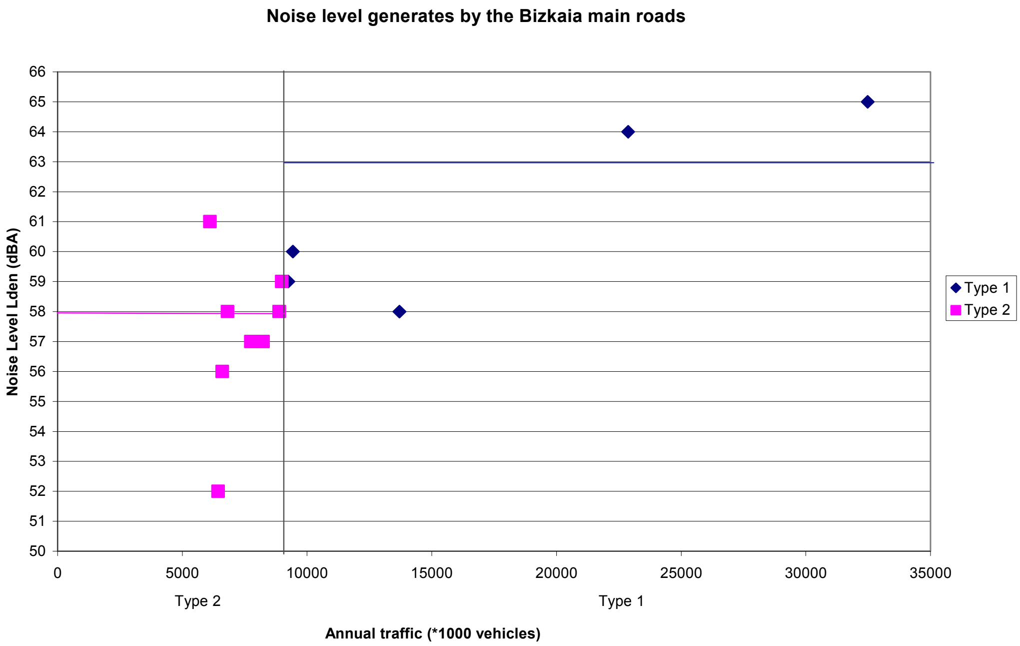


Figure 2- 32. Analysis of noise level generated by Bizkaia Major Roads and their traffic flow

Previous figure shows that L_{den} values for the two types of roads vary considerably. Nevertheless, it is proposed to assign a fixed noise level L_{den} to each type of road. On this sense,

- The average of L values of Roads Type 2 is 58 dBA.
- There is very few information about Road Type 1. Among them roads with higher traffic volume are considered more representatives for this category. It is proposed to apply 63dBA as the fixed L value for Road Type 1.

The conclusion of this step is that European Major Roads are identified by means of Eurostat Road Network, and the acoustic effect of these roads is estimated by the following values of the two variables (L and d).

Eurostat name	Type road	Lden (dBA)	Distance of influence (m)
DUAL CARRIAGEWAY ROAD	2	58	400
DUAL CARRIAGEWAY ROAD, EUROPEAN	2	58	400
MOTORWAY	1	63	400
MOTORWAY, EUROPEAN	1	63	400
OTHER ROAD	2	58	400
OTHER ROAD, EUROPEAN	2	58	400

Table 2- 9. Eurostat network classified in two type of roads

1.3.- Assigning L_{den} and S to a unit cell

The last step to estimate the influence of roads in background noise is to apply the methodology defined to the Spatial Grid of 10x10 Km resolution.

The area acoustically affected by traffic noise is represented by a buffer around the road. So, a buffer 400m width is generated around every road in the Eurostat Road Network.

As it is said before, the concept of a noise parameter representative of a geographical area is the acoustic energy extended to the whole surface. The application of this concept to the analysis of the influence of roads, establishes the following relationship between L_{den} and the parameters of the roads L ($L_{den,\ type\ i}$) and S ($S_{occupied}$):

$$L_{den} = 10 * \log(\frac{S_{ocupied}}{S_t} * 10^{(Lden,typei/10)})$$

Where,

$S_{ocupied}$ is the affected area, drawn in yellow or clear grey in the figure;
S_t is the total area of the unit cell, drawn in purple or in dark grey, and
$L_{den,type\ i}$ is the noise level L_{den} assigned to the area. It depends on the type of road, as it is established in the previous table.

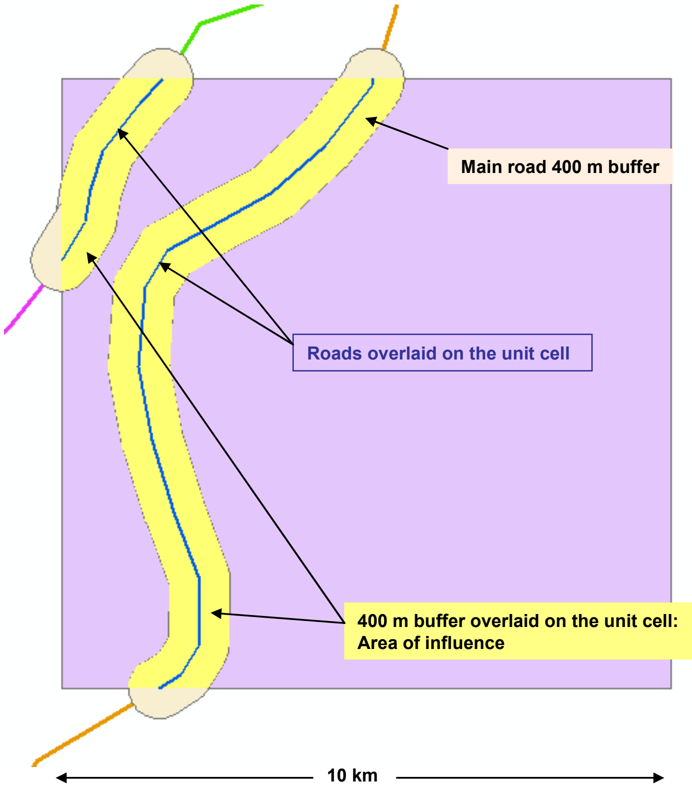


Figure 2- 33. Spatial analysis to calculate L_{den} value of every cell

As it is shown on the figure, it is usual to have more than one road over the same cell. In those cases the total correction noise level L_{den} representative of the cell is obtained by adding up energetically contributions of each road.

As a conclusion of this Task, the new algorithm to calculate L_{den} values to represent, in the framework of this project, the Background Noise Levels in areas affected by road traffic noise is the following:

$$L_{denTR} = 10 * \log\left(\frac{\sum_{i=1}^{n} S_{occupied,type1} * 10^{(L_1/10)} + \sum_{j=1}^{n} S_{occupied,type2} * 10^{(L_2/10)}}{S_t}\right)$$

where,

$S_{ocuppied,type\ i}$ is the surface of the cell occupied by any buffer representing the affected area by road type i,

S_t is the total surface of the cell, and

L_1 and L_2 are the noise level assigned to the Road Type 1 and Road Type 2.

This new algorithm is applied in all the Spatial Grid 10x10 km resolution built in this project to create the BGN Map for Transports. This new algorithm is applied in those cells close to Main Roads. Those are the cells which area overlaps a buffer that defines the acoustical affected area originated by any major road. Finally, the criterion to apply this algorithm among the total grid is that the values of $S_{ocuppied,type\ 1}$ or $S_{ocuppied,type\ 2}$ are higher than zero.

The following figure shows the BGN Map for Transport in L_{den} resulting by the application of described methodology. In this map only cells that fulfil the requirement for of $S_{ocuppied,typei}$ are represented.

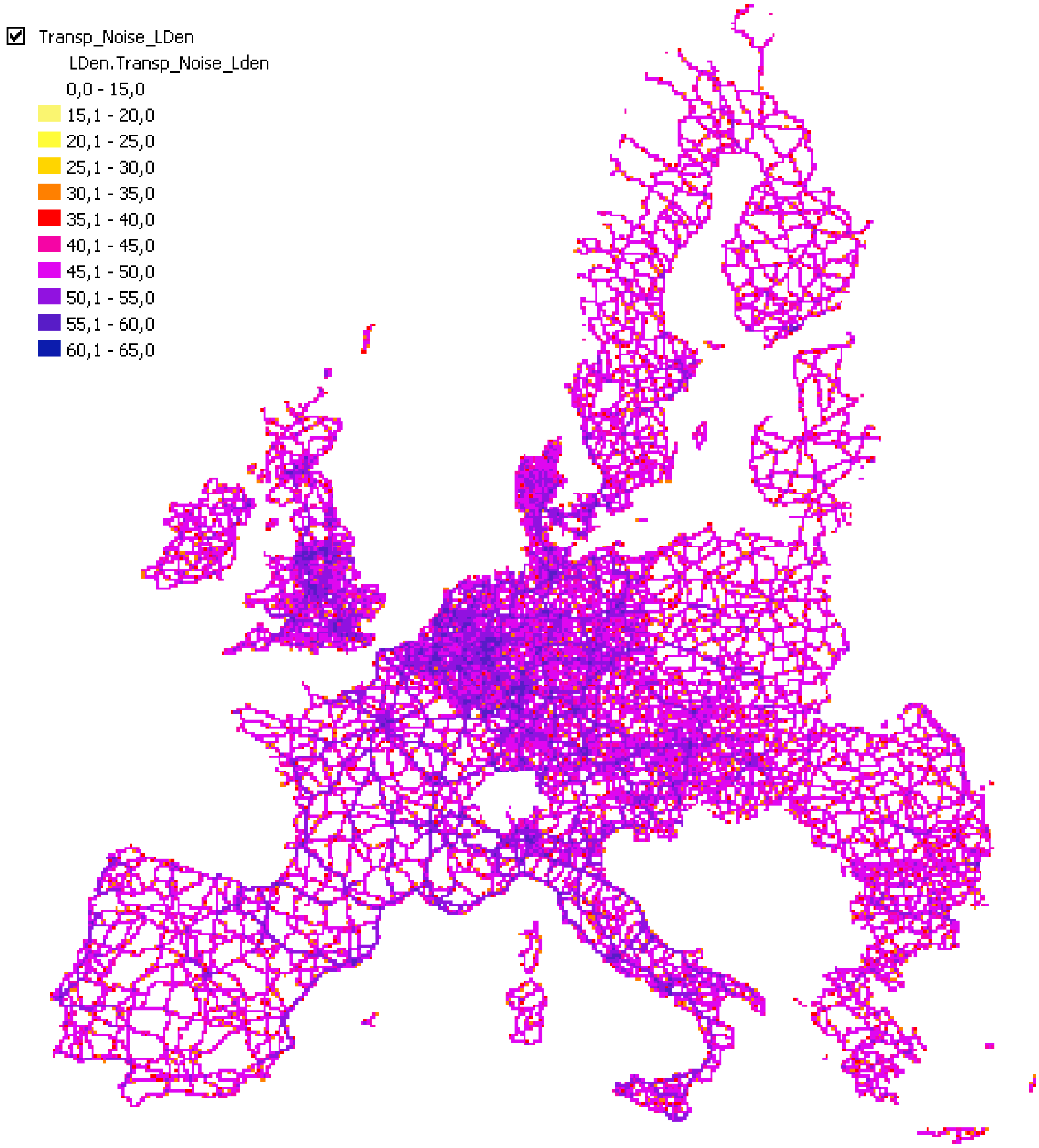


Figure 2- 34. BGN Map in L_{den} values for Road Infrastructures

Task 2.- Validation of the algorithm

As there are not European Road Strategic Noise Maps available, the validation cannot be done by comparison between the proposed algorithm and the actual SNM values. In spite of that, the validation is understood as a confirmation of the interest of this approach in relation to the Basic L_{den} Noise Map, which algorithm only considers population density.

As the scope of the project is the whole EU27, 10 cells of the Spatial Grid have been selected randomly. The cells are located in the following Countries:

- France
- Germany
- Greece
- Italy
- Lithuania
- Netherlands
- Poland
- Romania
- Sweden
- United Kingdom

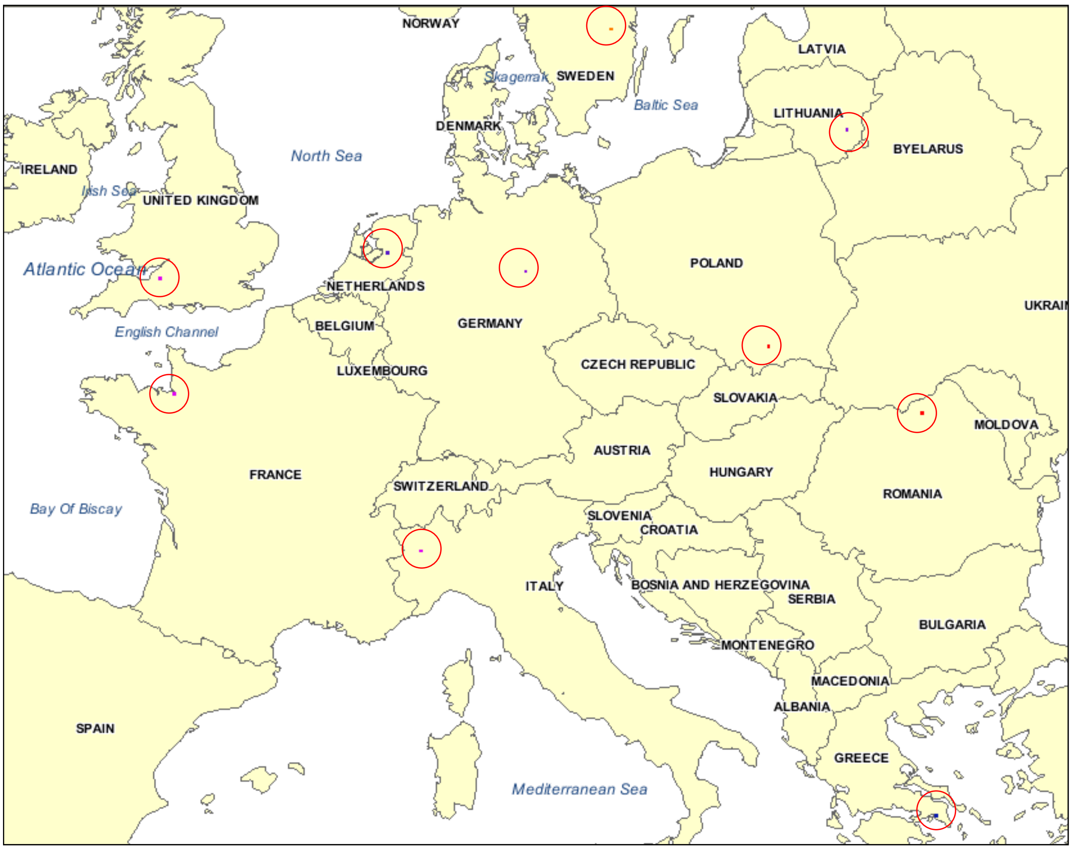


Figure 2- 35. Validation process. Location of selected cells among EU 27

In each of the selected cells the L_{den} noise level referred to the influence of Major Roads was calculated by applying the whole process described in this chapter. It was also applied the basic algorithm to calculate L_{den} values from population density values. Resulting noise levels are the following:

Country	$S_{occupied}$ Type1_Area (%)	$S_{occupied}$ Type2_Area (%)	$L_{den, TR}$ Transp_Noise_Lden	Population Density (inh/km2)	Basic L_{den} Algorithm	Difference between Transp_Noise_L_{den} and basic L_{den}
France	0,0	9,1	**47,6**	37	33,7	**13,9**
Germany	10,0	8,9	**54,1**	397	44,0	**10,1**
Greece	0,0	22,7	51,6	15.340	**59,9**	**- 8,3**
Italy	0,6	0,0	40,8	280	**42,5**	**- 1,6**
Lithuania	0,0	17,8	**50,5**	305	42,8	**7,7**
Netherlands	10,3	25,6	**55,6**	1.070	48,3	**7,4**
Poland	0,0	0,0	0,0	25	**32,0**	**- 32,0**
Romania	0,0	0,9	**37,3**	63	36,0	**1,3**
Sweden	0,0	0,2	**31,4**	4	24,4	**7,1**
United Kingdom	0,0	9,4	**47,7**	34	33,3	**14,4**

Table 2- 10. Noise level in transport infrastructure network presence

The last column contains differences between both approaches and the maximum value of each cell is in bold.

For a better understanding of the process the following figure shows the analyzed cell of United Kingdom. In this case, the Basic L_{den} noise level, estimated considering only population density, is 33 dBA. This cell is affected by two roads of type 2, which buffers occupy 9 % of the surface of the cell. Therefore, the L_{den} noise level obtained when considering the effect of these roads goes to 47dBA. The following figure shows the presence of road infrastructures in this cell.

Figure 2- 36. United Kingdom, Cell Code 10kmE344N320.

Most of the selected cells follow the same behaviour as previous example. Nevertheless, there are some cases where Basic L_{den} value is higher than L_{den} value obtained considering roads influence. This is the case of the cell selected in Greece. The following figure shows the presence of road infrastructures and agglomeration in this cell. Although there are several major roads in the cell ($S_{occupied}$ is 23 %), there is also a high population density. Consequently, in this cell Basic L_{den} value is the highest ones.

Figure 2- 37. Greece, Cell Code 10kmE552N176

The validation process concludes the following assumptions:

- The presence of road infrastructures is not totally represented by the Basic Algorithm, considering only population data. So, it is confirmed the need of applying the defined algorithm to represent the influence of roads in Background Noise.
- It is important to define adequate criteria to combine results of the algorithm proposed to represent all situations (Agglomerations, Roads and Quiet Rural Areas).

Task 3.- Determination of L_{95} Background Noise level

The purpose of this project is to estimate L_{95} noise values to represent Background Noise levels in different periods of the day (day, 07-19; evening, 19-23; and night, 23-07). Therefore, after having a new algorithm to estimate L_{den} values in areas affected by Major Roads, it is needed to find and define a relationship between L_{den} noise values and L_{95} noise values for each period of the day.

The proposed correction factors to estimate L_{95} noise values from L_{den} values are based on the analysis of Noise Monitoring Data. In order to get as much representative data as possible, 7 Local and Infrastructure Administrations were asked for giving access to Noise Monitoring Data. None of them gave data referred to traffic noise, so Noise Monitoring data generated by Labein-Tecnalia have been used. In section 2.2.2 it is mentioned more information about selected administrations.

The data used to estimate the correction is as follows:
- Evolution of L_{Aeq} noise levels along 24hours at least for 3 days.
- Evolution of L_{A95} noise levels along 24hours at least for 3 days.

The project could analyze Noise Monitoring Data from 6 continuous traffic noise registers measured in Spain, especially in Zaragoza and in the Basque Country. Measurements were carried out at a large distance of about 100m. None of the Monitoring Systems registered the L_{95} indicator, but the L_{90}, but it has been considered that these two parameters are similar.

Noise Monitoring Data was analyzed, looking for relationship between L_{den} noise values and L_{95} noise values for each period of the day. This analysis was made in every site and every day with noise data. Considering all the noise data available in the project, 102 parameters were analyzed.

Analysing together data from different sites, the proposed correction factors to estimate other acoustic parameters from L_{den} values were obtained. Firstly, the corrections to obtain the equivalent levels for day, evening and night periods of the day are the following:

$$\mathbf{L_{day} = L_{den} - 3}$$

$$\mathbf{L_{evening} = L_{den} - 4}$$

$$\mathbf{L_{nigth} = L_{den} - 8}$$

Secondly, corrections to obtain the $\mathbf{L_{95}}$ levels for day, evening and night periods of the day are the following:

$$\mathbf{L_{95,day} = L_{den} - 10}$$

$$\mathbf{L_{95,evening} = L_{den} - 12}$$

$$\mathbf{L_{95nigth} = L_{den} - 21}$$

These data have the following standard deviation:

	Standard deviation		Standard deviation
$L_{den} - L_{day}$ (dB)	1.6	**$L_{den} - L_{95,day}$ (dB)**	3.3
$L_{den} - L_{evening}$ (dB)	1.2	**$L_{den} - L_{95,evening}$ (dB)**	3.2
$L_{den} - L_{night}$ (dB)	1.3	**$L_{den} - L_{95,night}$ (dB)**	5.1

Table 2- 11. Standard deviation

It is considered that the analysis done is consistent and valid to answer to the scope of this project. However it must be emphasized that if more accuracy was required a specific project would be needed to adjust a more accurate relation between the studying parameters.

The following figure shows the BGN Map for areas affected by Transport in L_{95day} resulting by the application of described methodology. In this map only the cells that fulfil the requirement for $S_{occupied,\ typei}$ are represented.

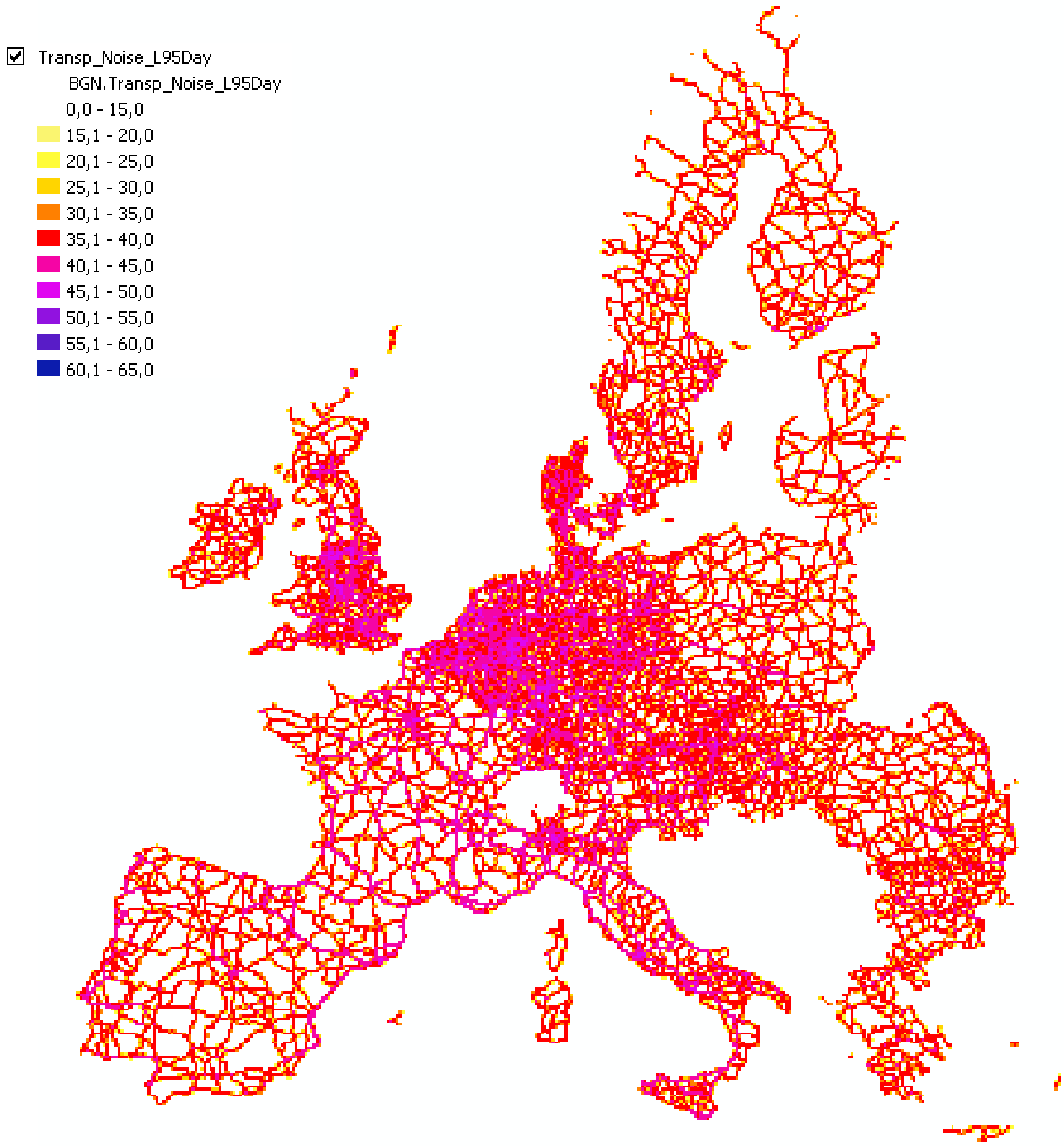


Figure 2- 38. BGN Map in $L_{95,day}$ values for Road Infrastructures

Conclusion:

The Background Noise Map for areas affected by Transport is built considering those cells of the 10 X 10 Km grid with any of the $S_{occupied,\ typei}$ higher than zero.

The algorithm and formulas applied to build these Maps are the following:

- Transport L_{den} Map:

$$L_{denTR} = 10 * \log \left(\frac{\sum_{i=1}^{n} S_{occupied,type1} * 10^{(L_1/10)} + \sum_{j=1}^{n} S_{occupied,type2} * 10^{(L_2/10)}}{S_t} \right)$$

where,

$S_{ocuppied,type\ I}$	is the surface of the cell occupied by any buffer representing the affected area by road type i, This data was created in a Spatial analysis of the data.
S_t	is the total surface of the cell, and
L_1 and L_2	are the noise level assigned to the two type of road defined

- Transport L_{day} Map:
  L_{day} = L_{den} – 3

- Transport $L_{evenning}$ Map:
  $L_{evening}$ = L_{den} – 4

- Transport L_{night} Map:
  L_{nigth} = L_{den} - 10

- Transport **$L_{95,day}$** Background Noise Map:
  $L_{95,day}$ = L_{den} - 12

- Transport **$L_{95,evenning}$** Background Noise Map:
  $L_{95,evening}$ = L_{den} – 21

- Transport $L_{95,night}$ Background Noise Map:
  $L_{95nigth}$ = L_{den} - 15

This process is applied in those cells which area overlaps the buffer of any type of road.

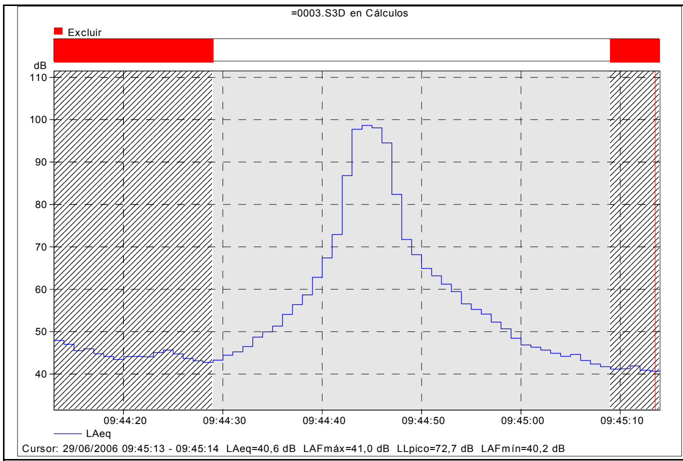
These Maps are combined with Maps generated on other situations to build the BANOERAC Noise Map for each acoustic parameter.

2.1.2.2 Railway

Noise generated by railway lines is composed by several acoustic event caused by train pass bys. Therefore, this type of noise could be considered as intermittent.

The definition of L_{95} parameter stands that it is the sound pressure level exceeded for 95 % of measured time [13]. Therefore L_{95} values depend on the assessment period. As shorter is the assessment period as easier is that an acoustic event occurred during this period affects the L_{95} values of this period.

In the following figure it can be shown that even considering a measurement of an acoustic event caused by a train pass by (measurement time: 40s), the difference between LAeq and L_{95} is very high (25 dB).



L95	42,6
LAeq	87,6

Figure 2- 39. L_{Aeq} of the passing and its L_{95} level

The hypothesis to approach railway noise in the framework of this project is that railway noise does not affect Background Noise levels L_{95} values.

Firstly, this assumption is supported theoretically. In this project the shortest assessment period is the evening (4 hours). Background Noise levels L_{95} values would be affected by railway noise in case it contributes to the global noise in more than 5 % of the sound pressure levels. Considering Slow time weighted noise levels, the hypothesis is not supported in case that among 4 hours of measurement it cannot be found 720 values of 1 second duration without railway noise contribution. It seems that it is quite unusual a railway line with so much frequency of trains passing.

Secondly, to verify the hypothesis in practice, actual measurements of railway lines have been analyzed. The procedure applied is to compare L_{95} values when considering all the noise levels and L_{95} values avoiding the samples affected by train pass bys.

Data used to do this analysis was generated by Labein-Tecnalia. Several measurements of train passing were carried out in Spain in Madrid and Barcelona for acoustical characterization of trains and validation the methodology for Railway Noise Strategic Noise Mapping.

The measurements were made around a Major Railway Line track where many trains circulate. The site was selected avoiding background noise, so without any more sources. The distance from the track to the receiver positions was large (25 m). This means that the acoustic profile in time of the train passing is wider. Measuring time varies from 4 to 9 hours.

Results achieved in the analysis of the measurement data are shown in the following table:

RC num		Time RC	LAeq	LAFmax	LAFmin	LA50	LA90	LA95	LA99
1	Total Noise	7:31:20	68	97	41,2	53,8	49,6	**48,6**	47,1
	Without trains events	6:18:00	59,4	88,8	41,7	52,9	49,3	**48,4**	46,9
2	Total Noise	9:27:54	66,5	99,4	38	52,9	47,5	**46**	44,1
	Without trains events	8:03:00	58,0	89,2	38	52	46,9	**45,7**	43,8
3	Total Noise	4:02:54	66	94,8	38,4	49,9	45	**43,8**	42,4
	Without trains events	3:12:00	54,9	81,1	38,4	48,7	44,5	**43,5**	42,2
4	Total Noise	8:35:47	63,8	94,9	33	45,4	41,4	**40,8**	39,5
	Without trains events	5:56:00	49,0	72,7	36,7	43,6	41	**40,3**	39,3
5	Total Noise	9:32:34	58	91,3	36,4	44,4	41,1	**40,5**	39,7
	Without trains events		47,6	69,8	36,4	43,6	40,9	**40,4**	39,5

Table 2- 12. Analysis of measured railway noise data

As it can be seen in previous table, differences in L_{95} values when considering all the noise levels and avoiding the samples affected by train pass byes are lower than 0,5 dB. So, the hypothesis is considered valid.

Conclusion:

In the framework of this project, it is considered that railway transport does not contribute to Background Noise L_{95} indicator, and therefore it is not considered a specific correction factor for railway infrastructures when building Background Noise Map.

2.1.3 Rural quiet areas

As it is said in chapter 2.1, BANOERAC project proposes a specific consideration for rural quiet areas, defined as extreme situations in the relation between population density and Background Noise. In rural quiet areas natural sound is expected and this could imply a minimum noise level threshold to that estimated when taking into account human presence.

In this section the definition of a threshold noise level to BGN is described. It is also explained the procedure to include this consideration in the general methodology. Therefore, it is established the criteria to apply this correction factor to the BGN Map based on SINTEF algorithm.

Within the WP 2 Anotec carried out measurements of actual noise levels in a number of locations representative for a quiet rural area, with very low levels of background noise from man-made sources. For further information see Parts 2 and 3 of this report.

A total of around 135 hours of background noise measurements has been obtained. These measurements were made at four different test sites, representative for natural parks, agricultural areas and hilly/mountainous regions.

It is considered that the results obtained in these measurement campaigns are valid to define the minimum threshold noise level for the BGN Map. The values obtained referred to different indicators are the following:

Indicator	Natural Parks (level, dBA)	Indicator	Natural Parks (level, L95 dBA)
L_{day}	29	$L_{95,day}$	23
$L_{evening}$	27	$L_{95,evening}$	22
L_{night}	23	$L_{95,night}$	19

Table 2- 13. Values from the Anotec measurement campaign in natural parks

In order to establish the procedure for applying this threshold when obtaining the BGN Map, the criteria to use it is defined in relation to population density and L_{den} values. In that sense, these values of L_{day}, $L_{evenning}$, and L_{night} make a value of L_{den} of 31.2 dBA. And the application of the Sintef algorithm gives for this L_{den} value a population density of 23 inhabitans/km^2.

Therefore it can be drawn the next criteria: when the population density is less or equal to 23 inhabitans/km^2, the L_{den} noise level is 31.2 dBA, instead of the values estimated by the Sintef algorithm.

In the most extreme case, where there is no population density, Sintef algorithm proposes a L_{den} value of 18dBA, but taking into account the measurements made by Anotec, the threshold for the L_{den} value background noise is 31 dBA.

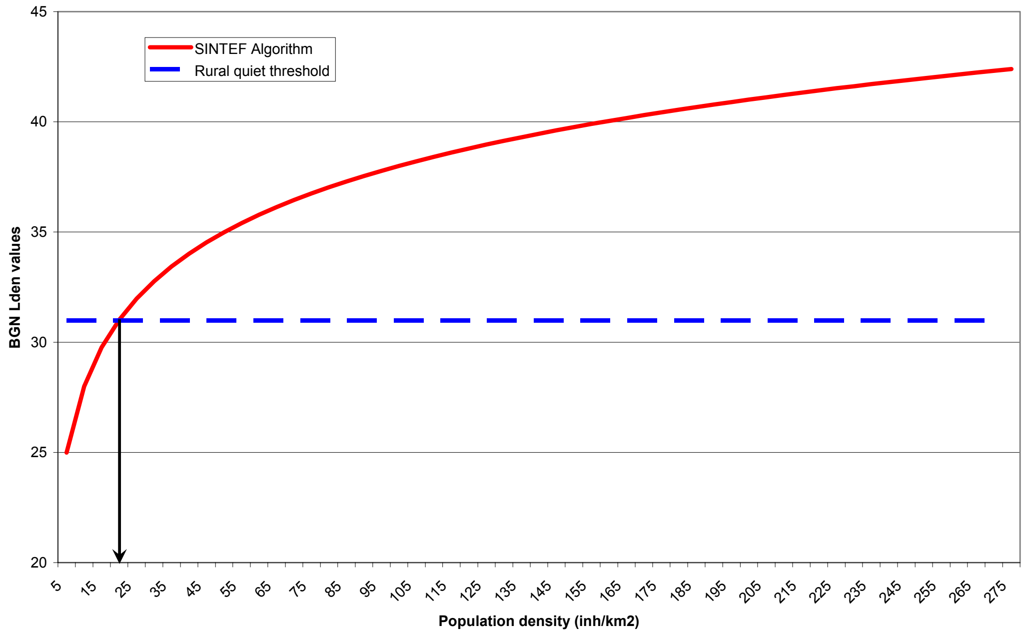


Figure 2- 40. Relationship of minimum threshold noise level for Rural Quiet Areas and the basic L_{den} algorithm

Conclusion:

The Background Noise Map is built considering that the cells of the 10 X 10 Km grid with population density lower or equal to 23 inhabitans/km^2 have the following values to represent the Background Noise estimated for natural sources:

Indicator	BGN Values (dBA)
Lden	31
L_{day}	29
$L_{evening}$	27
L_{night}	23
$L_{95,day}$	23
$L_{95,evening}$	22
$L_{95,night}$	19

Table 2- 14. Noise Level indicators for Rural Quiet Areas

The following figure shows the BGN Map for Rural quiet areas. In this map only the cells that fulfil the requirement for population density are represented.

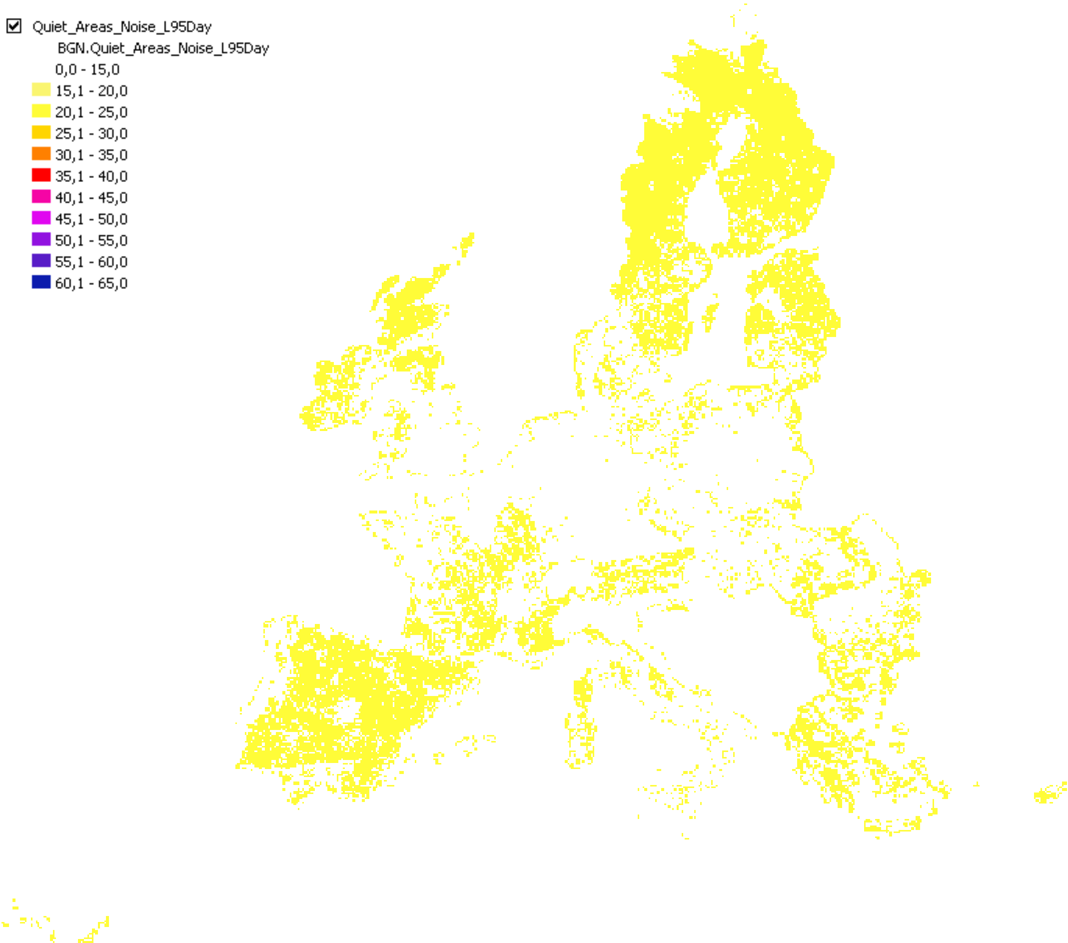


Figure 2- 41. BGN Map for Rural quiet areas, L_{95day}

2.1.4 Methodology main conclusions

Summary of the process to obtain BGN Maps

The application of the methodology defined in previous sections allows building four intermediate BGN Maps.

- Basic BGN Map. It estimates BGN levels considering only population density data.

  L_{den} BGN values are calculated according to the following formula:

  $$\mathbf{L_{denBasic} = 18 + 10 \log (\rho)}$$

  where, ρ is population density

  L_{95} values for each period of the day are calculated by applying the following correction factor to L_{den} values:

  $$L_{95,day,\ Basic} = L_{den} - 9$$
  $$L_{95,evening,Basic} = L_{den} - 9$$
  $$L_{95nigth,\ Basic} = L_{den} - 13$$

  This Map contains all the cells of the Spatial Grid 10x10 Km resolution.

- Agglomeration BGN Map. It estimates BGN levels in urban agglomerations.

  L_{den} BGN values are calculated according to the following formula:

  $$\mathbf{L_{denAg} = 29{,}219 + 7{,}78 \log (\rho) + 0{,}048\ \%IA}$$

  where,

  ρ is the population density of the analyzed cell, and

  %IA is the percentage of the area of the cell that overlaps any polygon of the Population Core. This value was calculated by applying a spatial analysis of the information.

  L_{95} values for each period of the day are calculated by applying the following correction factor to L_{den} values:

  $$L_{95,day,Ag} = L_{den} - 9$$
  $$L_{95,evening,Ag} = L_{den} - 10$$
  $$L_{95nigth,Ag} = L_{den} - 15$$

  This Map contains all cells of the Spatial Grid 10x10 Km resolution which overlaps with any Agglomeration area defined in the Population Core entity. So it is only applied on those cells that have a %IA value higher than zero.

- Transport BGN Map. It estimates BGN levels in areas acoustically affected by major roads.

  L_{den} BGN values are calculated according to the following formula:

$$L_{denTR} = 10 * \log\left(\frac{\sum_{i=1}^{n} S_{occupied,type1} * 10^{(L_1/10)} + \sum_{j=1}^{n} S_{occupied,type2} * 10^{(L_2/10)}}{S_t} \right)$$

  where,

$S_{ocuppied,type\ I}$	is the surface of the cell occupied by any buffer representing the affected area by road type i,
S_t	is the total surface of the cell, and
L_1 and L_2	are the noise level assigned to the Road Type 1 and Road Type 2.

  L_{95} values for each period of the day are calculated by applying the following correction factor to L_{den} values:

  $L_{95,day,Tr}$ = L_{den} - 10
  $L_{95,evening,Tr}$ = L_{den} - 12
  $L_{95nigth,Tr}$ = L_{den} - 21

  This Map contains all cells of the Spatial Grid 10x10 Km resolution which overlaps any buffer defining the acoustical influence area of a major road. So it is only applied on those cells that have $S_{occupied,type1}$ or $S_{occupied,type2}$ higher than zero.

- Rural Quiet BGN Map. It estimates BGN levels in areas with very low population density values. It represents the minimum threshold noise level caused by natural sounds.

  $L_{den,Quiet}$ BGN value is 31 dBA.

  L_{95} values for each period of the day are the following:

  $L_{95,day,Quiet}$ = 23
  $L_{95,evening,Quiet}$ = 22
  $L_{95nigth,Quiet}$ = 19

  This Map contains all cells of the Spatial Grid 10x10 Km resolution with population density values lower than 23 inh/Km^2.

Next table shows a summary of the four types of BGN Maps originated in the project.

Situation represented	Conditions	Lden indicator	L95 indicator
Cells with presence of **Aglomerations (ρ (population density grid 100*100m)>500 inh/Km2)**	%IA (inhabitant area percentage) >0	LdenAg = 29,219 + 7,78 l log (ρ) + 0.48 %IA	Conversion from measurements of monitoring systems and continuous noise registers: L95day = LdenAg-9 L95evening = LdenAg-10 L95night = LdenAg-15
Cells with presence of **roads**	S occupied (area occupied by road buffers type 1 or 2) > 0	$L_{denTR} = 10*\log\left(\frac{\sum_{i=1}^{n} S_{occupied,type1} * 10^{(63/10)} + \sum_{j=1}^{n} S_{occupied,type2} * 10^{(58/10)}}{S_t}\right)$	Conversion from measurements of continuous traffic noise registers: L95day = LdenTR-10 L95evening = LdenTR-12 L95night = LdenTR-21
Cells with popultation density not representative of an Aglomeration structure, and without roads	ρ (population density)>23 inh/km2 %IA = 0 S occupied = 0	Basic Algorithnm LdenB = 18 + 10*log(ρ)	Conversion from measurements in natural parks: L95day = LdenB-8 L95evening = LdenB-9 L95night = LdenB-12
Cells with a population density low or null (**quiet rural areas**)	ρ (population density)<23 inh/km2	Measurements in natural parks: 31,2 dBA	Measurements in natural parks: L95day = 23 L95evening = 22 L95night = 19
BGN			**Max L95 (day)** **Max L95 (evening)** **Max L95 (night)**

Table 2- 15. Summary of the whole methodology

These intermediate BGN Maps should not be considered independently. They give data in every 10x10Km cells to build the final BGN Map. Therefore, the BANOERAC BGN Map is built by combining values from the four intermediate Maps. The criteria to combine those values are crucial. As general rule, the final value of every cell is the maximum value of all existing values coming from any intermediate Map.

2.2 Final BGN Maps

The following figures show the final BANOERAC European BGN Maps.

- L_{den} Basic Map based on population density
- L_{den} Map
- L_{day} Map
- L_{night} Map
- L_{95day} Map
- $L_{95evening}$ Map
- $L_{95night}$ Map

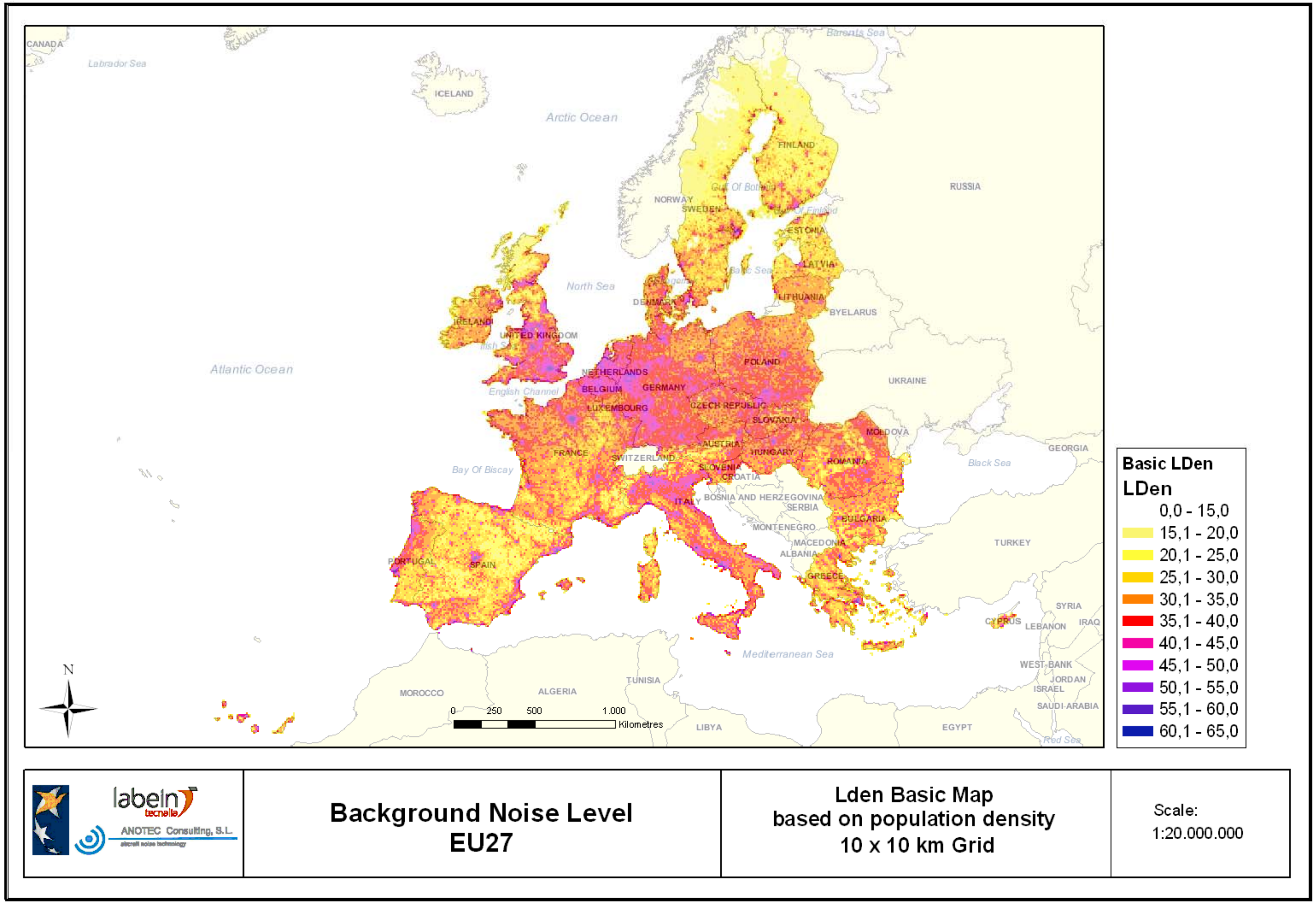
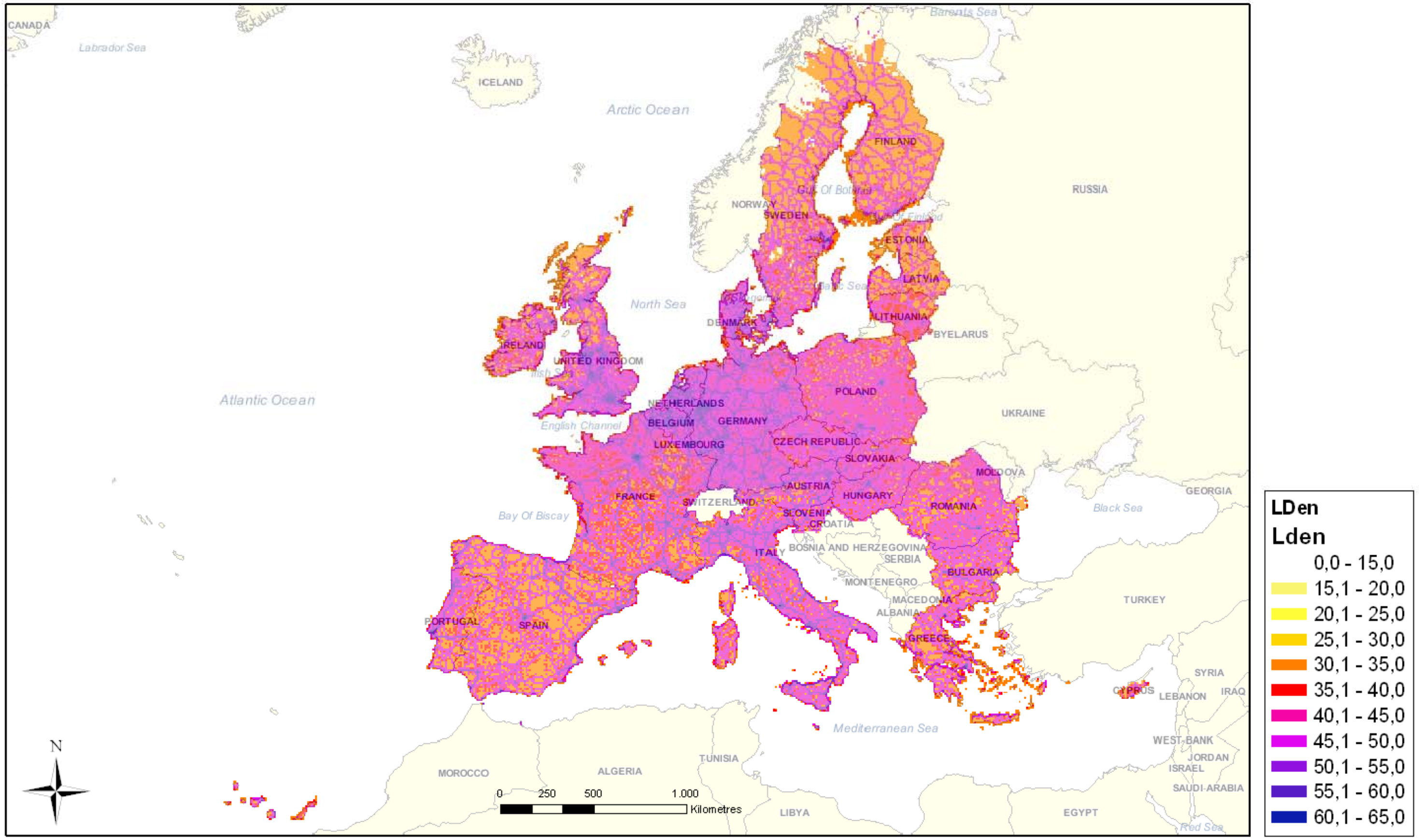


Figure 2- 42. Basic BGN Map, L_{den}



labein tecnalia / ANOTEC Consulting, S.L. aircraft noise technology	**Background Noise Level** **EU27**	**Lden Map** **BANOERAC** **10 x 10 km Grid**	Scale: 1:20.000.000

Figure 2- 43. Final BGN Map, L_{den}

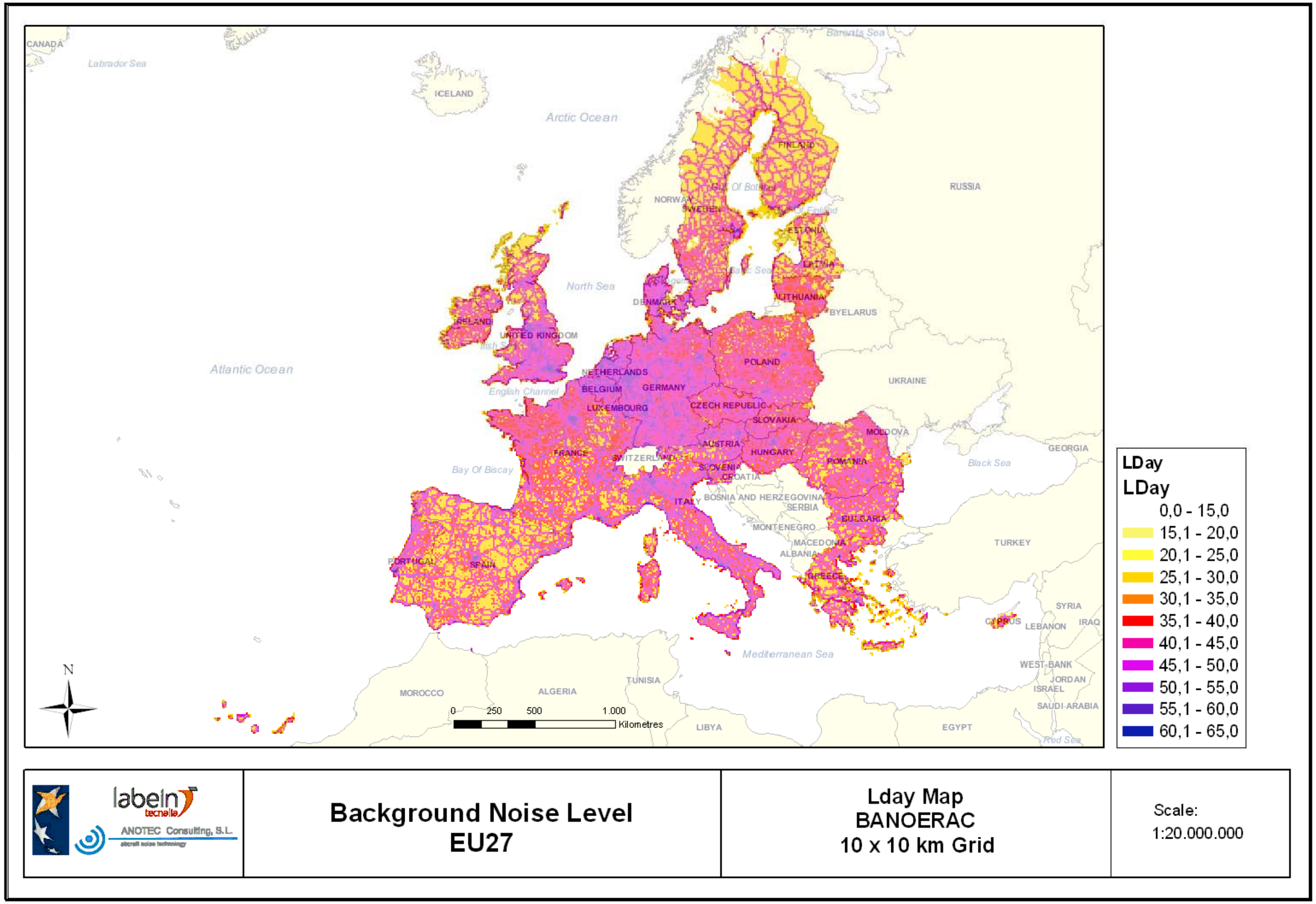
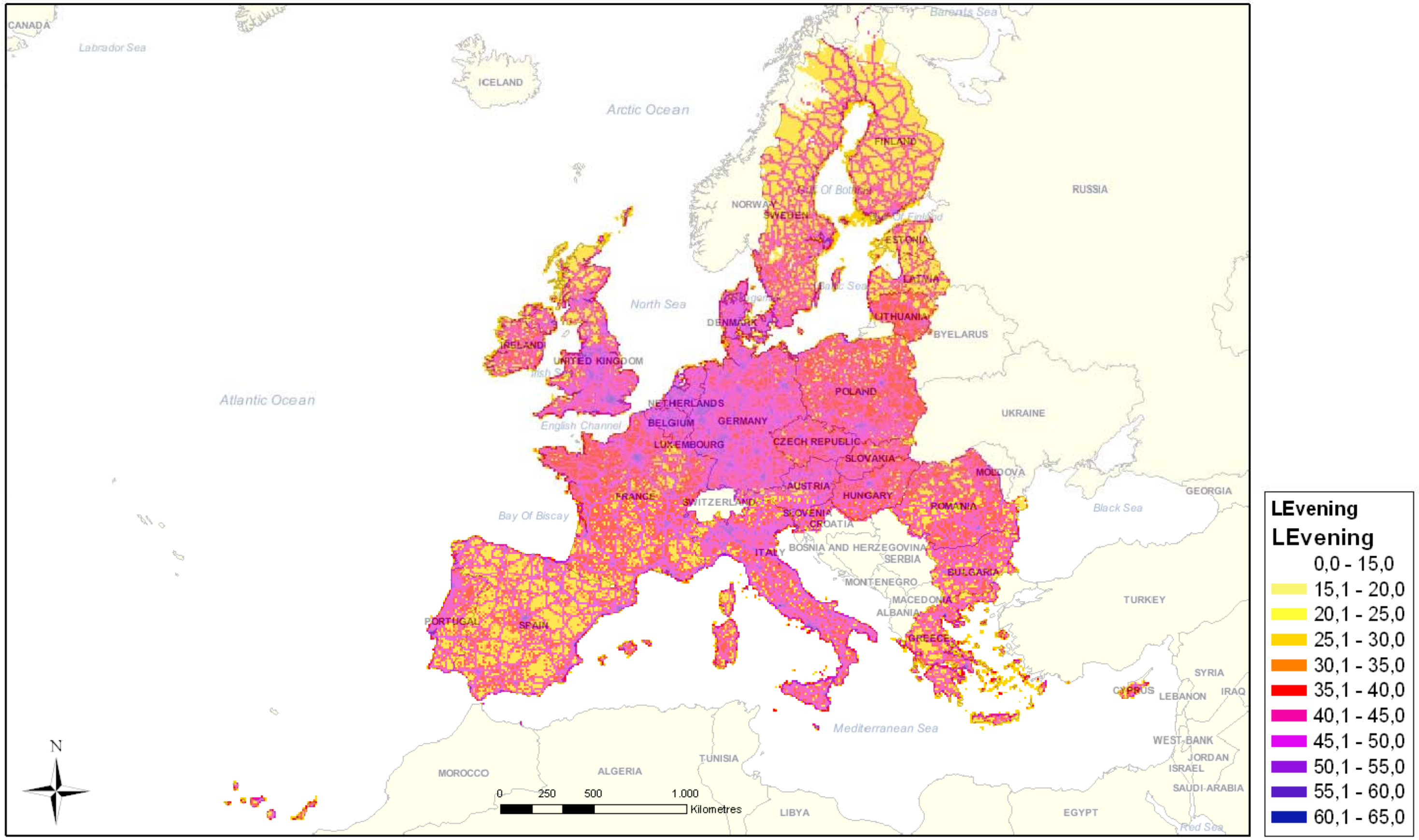


Figure 2- 44. Final BGN Map, L_{day}



labein tecnalia ANOTEC Consulting, S.L. aircraft noise technology	**Background Noise Level EU27**	**Levening Map BANOERAC 10 x 10 km Grid**	Scale: 1:20.000.000

Figure 2- 45. Final BGN Map, $L_{evening}$

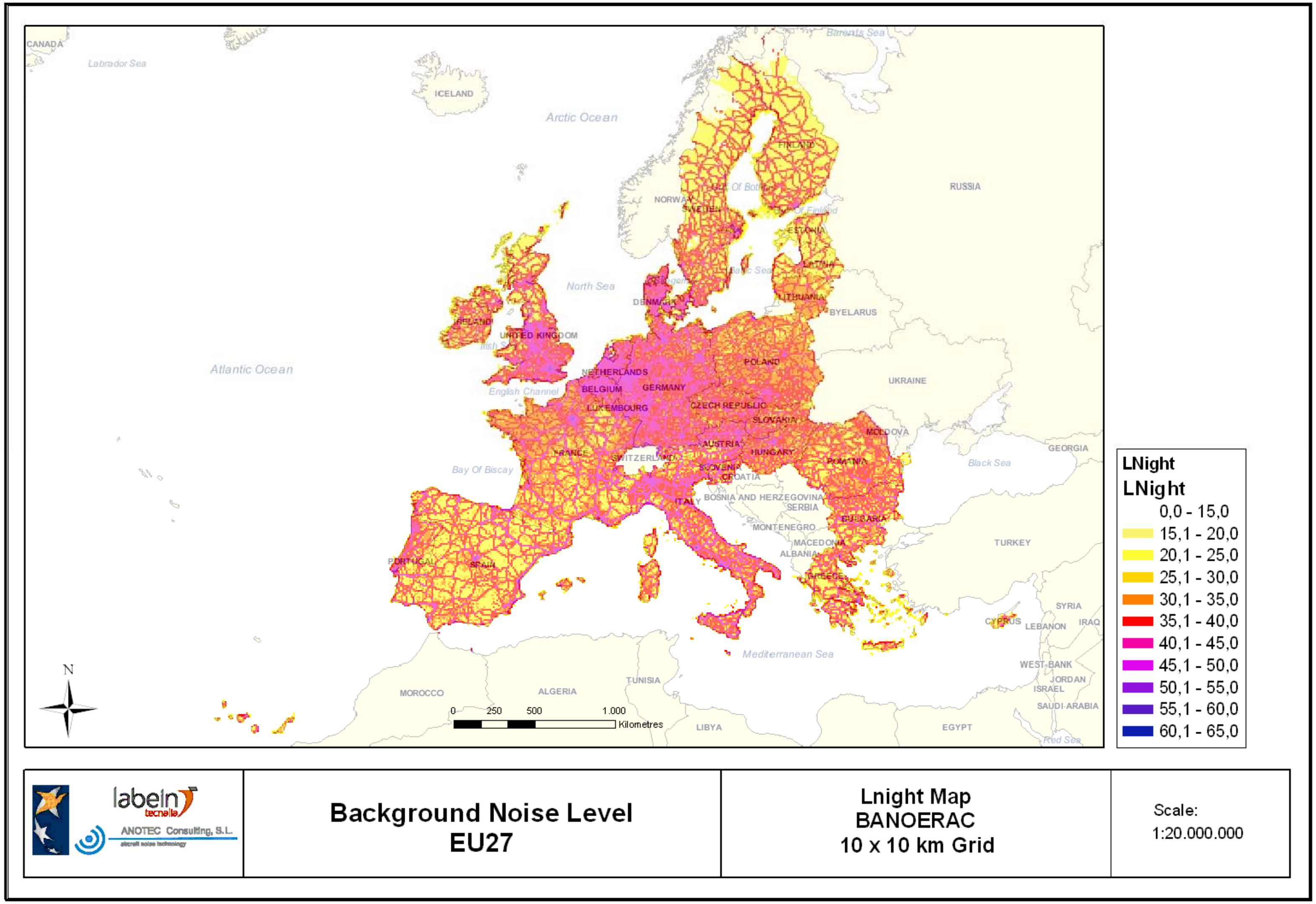


Figure 2- 46. Final BGN Map, L_{night}

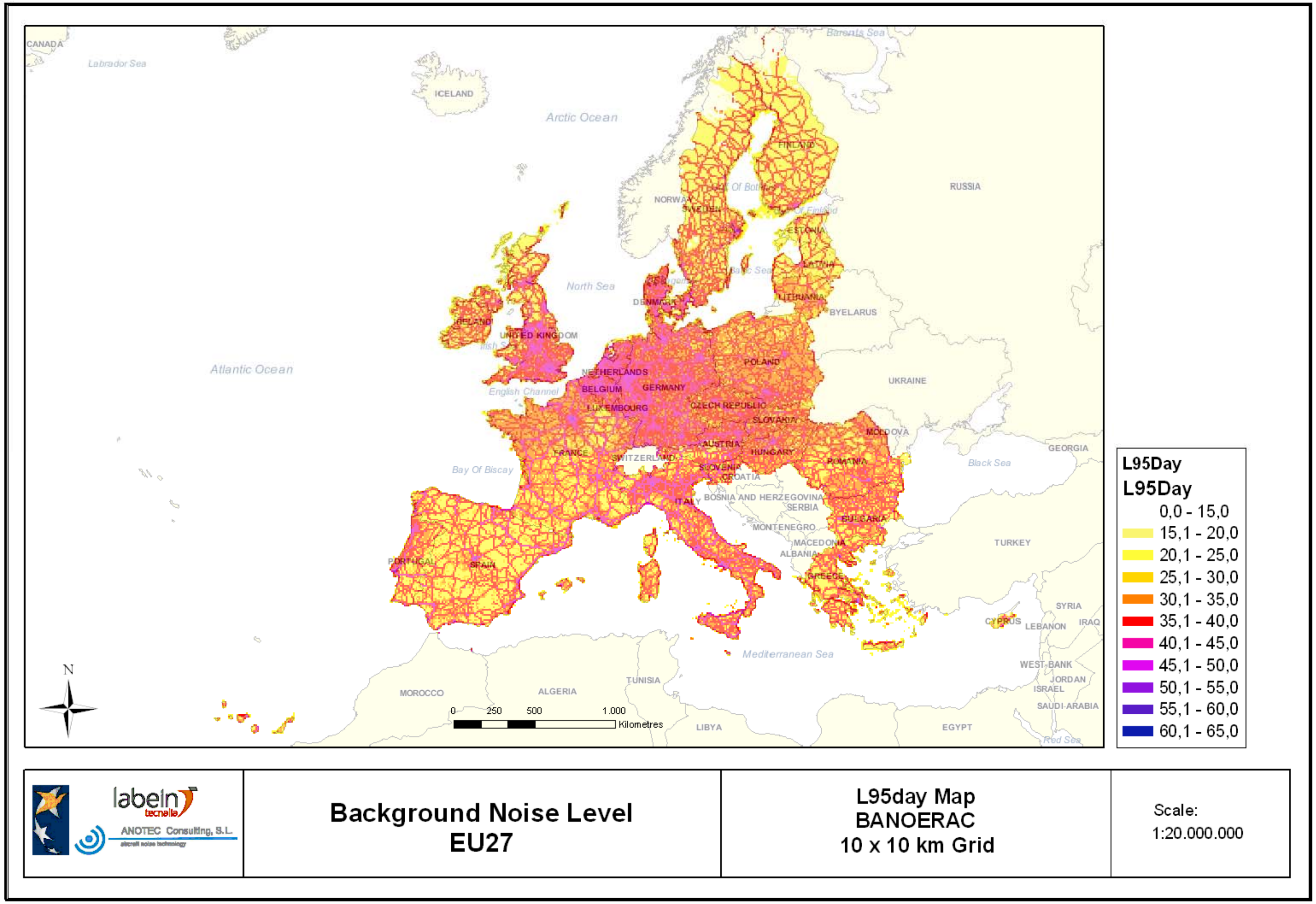


Figure 2- 47. Final BGN Map, L_{95day}

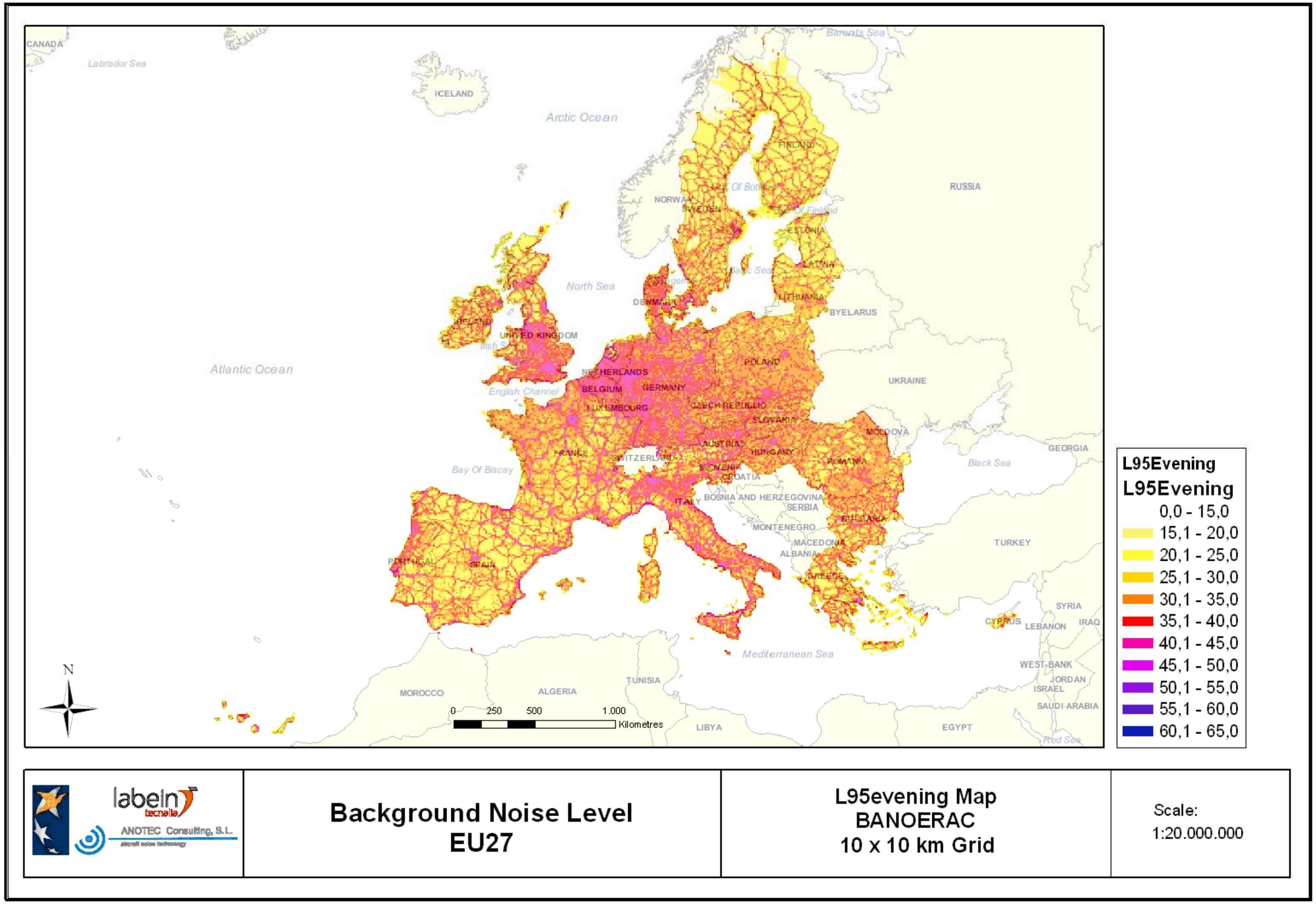


Figure 2- 48. Final BGN Map, $L_{95evening}$

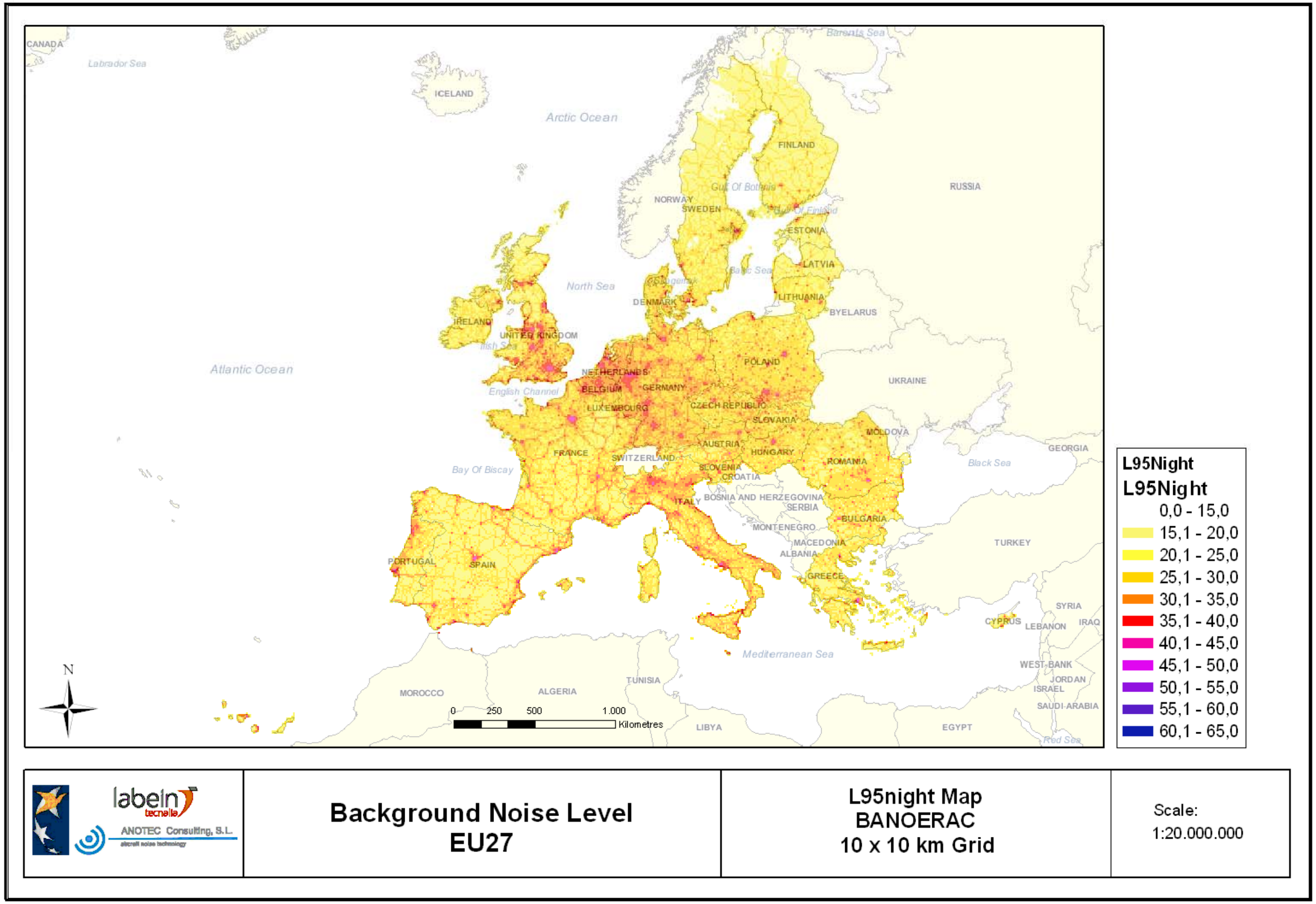


Figure 2- 49. Final BGN Map, $L_{95night}$

2.3 Access to the BGN maps

The BANOERAC methodology has been implemented through a database, linked to a 10 km reference grid for the EU27 countries, which contains both fundamental information for each 10 km cell and the resulting noise data.

Printed maps with the background noise levels have been also provided as plots in DIN A4 paper and as digital files in PDF format.

In the same way, it is also possible to visualize and consult these same maps, as well as other relevant reference information, by means of easy-to-use desktop mapping tools.

Details about this information, provided in three DVD, are given in the next sections and in the appendices 1-1 Background Noise Levels Databases and Spatial Information and 1-2 Delivered Digital Information.

2.3.1 General concepts about mapping data with GIS tools

A Geographic Information System (GIS) is a group of technologies that permit to capture, integrate, store, analyze, manage and display data that are linked to an Earth's location. In a more generic sense, GIS applications may be considered as specialized tools that allow users to create interactive queries, analyze spatial information, edit data, visualize maps and present the results of all these operations.

As a very general and basic approach, GIS are the merging of graphical map entities (points, lines, polygons, cells,…), which usually represent real world objects, and information stored in alphanumeric databases (for example, the ones with noise data). So, if tables in the databases have or are susceptible of having a spatial reference on Earth to be geo-referenced, then may be visualized in form of maps or other graphical representations such as, for example, diagrams.

Although different GIS technologies are used nowadays for showing the information to the user, in this project an easy-to-use and non-cost desktop mapping tool has been chosen to show the results that come from applying the methodology already exposed.

2.3.2 Processing spatial data

The methodology to get Background Noise levels in Europe has taken into account different geographical data sources. From the viewpoint of its spatial processing, some of them have been to be previously treated and adapted to a common projected coordinate system[11] and limited exclusively to the study area (EU27).

Because the developed methodology needs fundamental data, for every 10 km cell, about population density, urban area percentage and area percentage affected by road types, some spatial

[11] ETRS89 Lambert Azimuthal Equal Area has been the chosen projected coordinate system because it is recommended by EEA (http://www.eionet.europa.eu/gis/geographicinformationstandards.html)

processing tools, mainly buffering and overlapping of geo-referenced layers, and statistical methods to summarize data have been applied to obtain them.

Although, as previously stated, much more data have been considered in the development and validation of the methodology, to get this basic information for each 10 km cell, the following data have been taken into account for spatial processing:

1. Population Density Grid with spatial resolution of 100 m, provided by JRC,
2. European Road Network, provided by EUROSTAT, which distinguishes general road types, and
3. Spatial reference grid, 10Km resolution, corresponding to each one of the EU27 countries, available from the EEA Web site[12].

As a result of these spatial processes, new derived data have been generated respectively:

1. a polygon grid with extended values of density population (ρ) and inhabitant area percentage (%IA) for each 10 km cell,
2. a polygon grid with values of occupied area under the influence of roads considered as type 1 ($S_{ocuppied,type1}$) or type 2 ($S_{ocuppied,type2}$) for each 10 km cell, and
3. a single 10 km cell grid for the 27 European countries, obtained after merging spatially all the individual grids, which works as a reference layer to relate both source data and any other derived data from them.

Figure 2- 50. The single 10 km reference grid for the EU27 countries

The tables associated to these new GIS layers have been incorporated into the BGN database, where they take part in a series of numerical processes that will be explained later.

2.3.3 BGN database

The core of the BGN database is a Microsoft Access 2003 database, called EUROPE_NOISE_2009.MDB, which contains the main data referred in the project scope.

Besides the already mentioned fundamental data coming from the spatial processes and other that may be considered as auxiliary, the database also contains derived data about noise levels for each

[12] http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=760

one of the cells in the 10 km grid. These noise data appear referred individually to areas with agglomerations, areas with road transport, quiet areas and areas where Basic algorithm may be applied according to BANOERAC methodology. BGN database also stores global data in the form of total background levels.

Although in the Appendix 1-1 Background Noise Levels Databases and Spatial Information more detailed information about the database tables and their fields may be found, a general description is given next:

- Table AGG_DATA
  Auxiliary table with general data for the main agglomerations.

- Table EU27_POPULATION_CORE
  Auxiliary table with population density for the population core.

- Table AGG_CHAR
  Fundamental table with data about density population (ρ) and inhabitant area percentage (%IA). See Section 2.1.1 for more information about processes in urban agglomerations.

- Table SINTEF_NOISE
  Derived table with noise level in cells where Basic algorithm is applied according to BANOERAC methodology.

- Table AGG_NOISE
  Derived table with noise level due to presence of urban agglomerations.

- Table QUIET_AREAS_NOISE
  Derived table with noise level in quiet rural areas.

- Table TRANSP_NOISE
  Derived table with noise level for cells under the influence of road transport.

- Table TRANSP_CHAR
  Fundamental table with data about occupied area in the cell by roads with “Type 1” ($S_{ocuppied,type1}$) or roads with “Type 2” ($S_{ocuppied,type2}$). See Section 2.1.2 for more information about processes in transport infrastructures.

- Table TRANSP_DATA
  Auxiliary table with data for the main road network.

- Table LDEN_POP_DENSITY
  Derived table with basic L_{den} Noise level only based on population density.

- Table EU27_GRID_LAEA5210_10K
  Auxiliary table with spatial information for each 10 km cell in ETRS89 LAEA projected coordinate system.

- Table EU27_GRID_LAEA5210_10K_CENTROIDS_WGS84
  Auxiliary table with spatial coordinates of the cell central point in the WGS84 coordinate system.

- Table LDEN
  Derived table with L_{den} noise level.

- Table LDAY
  Derived table with L_{day} noise level.

- Table LEVENING
  Derived table with $L_{evening}$ noise level.

- Table LNIGHT
  Derived table with L_{night} noise level.

- Table BGN
  Derived table with background noise level.

The tables belonging to the BGN database and the relations among them may be summarized in Figure 2- 51.

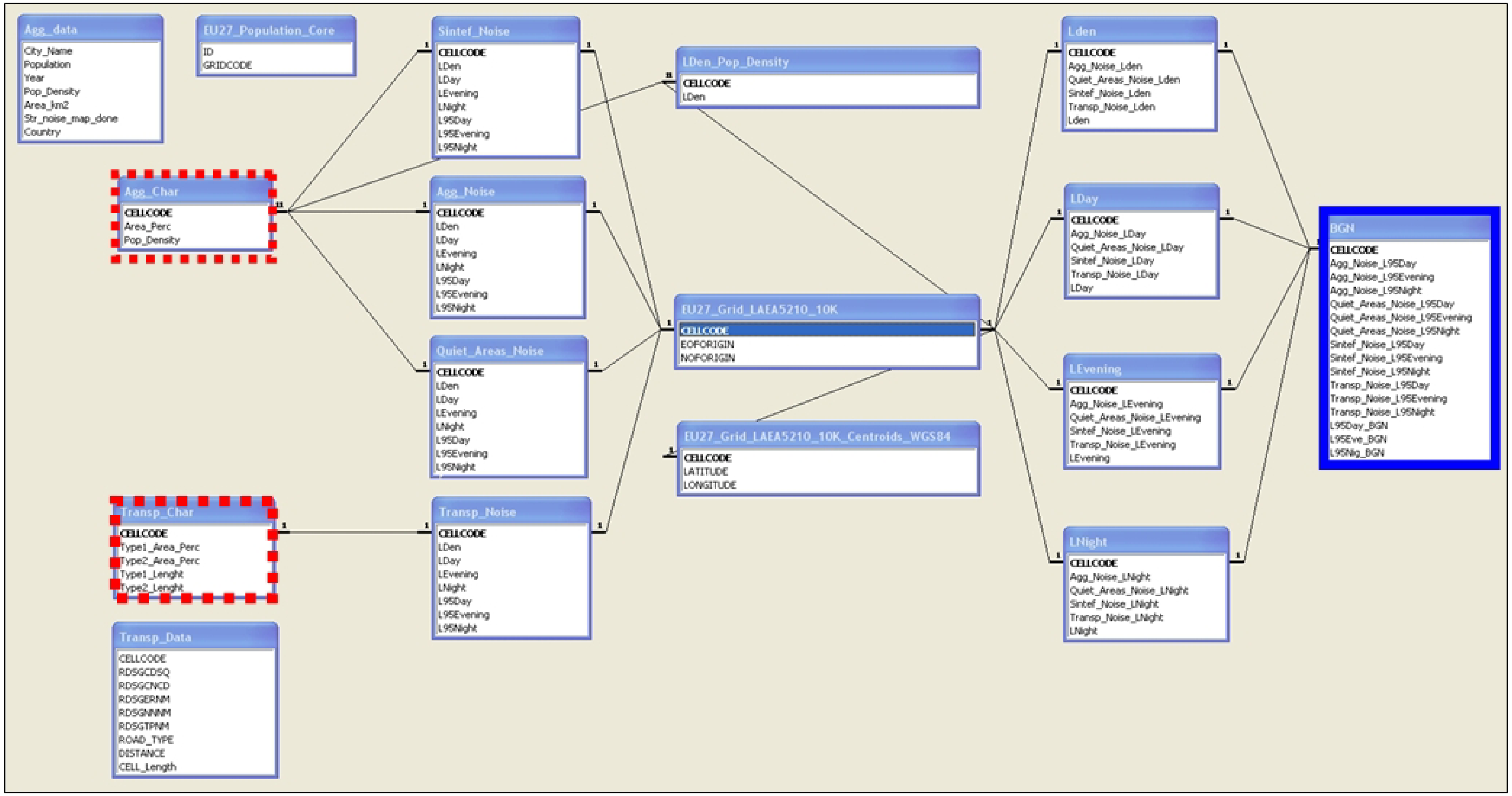


Figure 2- 51. AGG_CHAR and TRANSP_CHAR are fundamental tables with key data for obtaining background noise levels of the BGN table.

BGN database updating tool

The updating of the noise levels in the derived tables by means of numerical calculations of the key data contained in the fundamental tables, AGG_CHAR and TRANSP_CHAR, has been automated through a series of processes, also stored in the BGN database.

These processes consist of ten concatenated database queries that may be launched independently, one by one, or all together from a macro, called UPDATE_NOISE_TABLES.

In a similar way, as it may be appreciated in the following figure, there is also a user form with a button to facilitate the execution of this macro. Although it is not necessary to run it again once derived tables have been populated, the database is designed to permit a future update of the noise levels if fundamental data (ρ, %IA, $S_{ocuppied,type1}$, $S_{ocuppied,type2}$) change. Nevertheless, prior to the numerical calculations, some additional spatial processing would be necessary too.

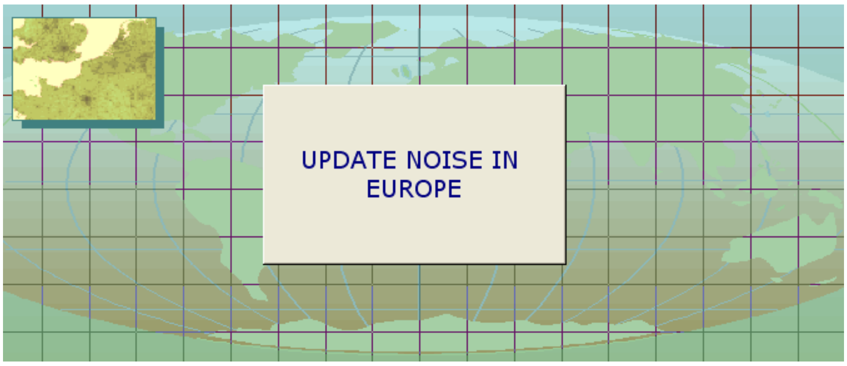


Figure 2- 52. User form to update noise data levels

Although the complete SQL syntax for the database queries may be consulted in the Appendix 1-1 Background Noise Levels Databases and Spatial Information, their main characteristics are the following ones:

- Query Q01A_UPDATE_AGG_NOISE_LDEN
  It calculates L_{den} noise level in urban agglomerations from the table AGG_CHAR where %IA is greater than 0.

- Query Q01B_UPDATE_AGG_NOISE_REST_INDICATORS
  It calculates the rest of noise indicators (L_{day}, $L_{evening}$, L_{night}, L_{95day}, $L_{95evening}$ and $L_{95night}$) in urban agglomerations where %IA is greater than 0.

- Query Q02A_UPDATE_TRANSP_NOISE_LDEN
  It calculates L_{den} noise level in areas with transport infrastructures from the table TRANSP_CHAR where $S_{ocuppied,type1}$ or $S_{ocuppied,type2}$ are greater than 0.

- Query Q02B_UPDATE_TRANSP_NOISE_REST_INDICATORS
It calculates the rest of noise indicators (L_{day}, $L_{evening}$, L_{night}, L_{95day}, $L_{95evening}$ and $L_{95night}$) in areas with transport infrastructures where $S_{occupied,type1}$ or $S_{occupied,type2}$ are greater than 0.

- Query Q03A_UPDATE_SINTEF_NOISE_LDEN
It calculates L_{den} noise level in areas the table from the table AGG_CHAR where ρ is greater than 23 inhabitants/km^2, %IA is equal to 0, $S_{ocuppied,type1}$ is equal to 0 and $S_{ocuppied,type2}$ is equal to 0.

- Query Q03B_UPDATE_SINTEF_NOISE_REST_INDICATORS
It calculates the rest of noise indicators (L_{day}, $L_{evening}$, L_{night}, L_{95day}, $L_{95evening}$ and L_{95nig}) in areas where ρ is greater than 23 inhabitants/km^2, %IA is equal to 0, $S_{ocuppied,type1}$ is equal to 0 and $S_{ocuppied,type2}$ is equal to 0.

- Query Q04_UPDATE_QUIET_AREAS_INDICATORS
It calculates the noise indicators (L_{day}, $L_{evening}$, L_{night}, L_{95day}, $L_{95evening}$ and L_{95nig}) in areas where ρ is less or equal to 23 inhabitants/km^2.

- Query Q05_UPDATE_LDEN_MAX
It calculates L_{den} taking the maximum L_{den} level from the noise tables AGG_NOISE, TRANSP_NOISE, SINTEF_NOISE and QUIET_AREAS_NOISE.

- Query Q06_UPDATE_LDAY_MAX
It calculates L_{day} taking the maximum L_{day} level from the noise tables AGG_NOISE, TRANSP_NOISE, SINTEF_NOISE and QUIET_AREAS_NOISE.

- Query Q07_UPDATE_LEVENING_MAX
It calculates $L_{evening}$ taking the maximum $L_{evening}$ level from the noise tables AGG_NOISE, TRANSP_NOISE, SINTEF_NOISE and QUIET_AREAS_NOISE.

- Query Q08_UPDATE_LNIGHT_MAX
It calculates L_{night} taking the maximum L_{night} level from the noise tables AGG_NOISE, TRANSP_NOISE, SINTEF_NOISE and QUIET_AREAS_NOISE.

- Query Q09_UPDATE_BGN_MAX
It calculates background L_{95day}, $L_{95evening}$ and $L_{95night}$ levels taking the maximum L_{95day}, $L_{95evening}$ and $L_{95night}$ levels, respectively, from the noise tables AGG_NOISE, TRANSP_NOISE, SINTEF_NOISE and QUIET_AREAS_NOISE.

- Query Q10_UPDATE_LDEN_POP_DENSITY
It calculates basic L_{den} noise level for the whole study area from the table AGG_CHAR.

In the Figure 2- 53 there is a general view of the tables and queries involved in the described numerical processes.

Security class	Document ID	Issue no.	Short Title	Issue date	Page
Restricted	PAN074-5-1	3	Final Report - Part 1	06/11/2009	89 of 97

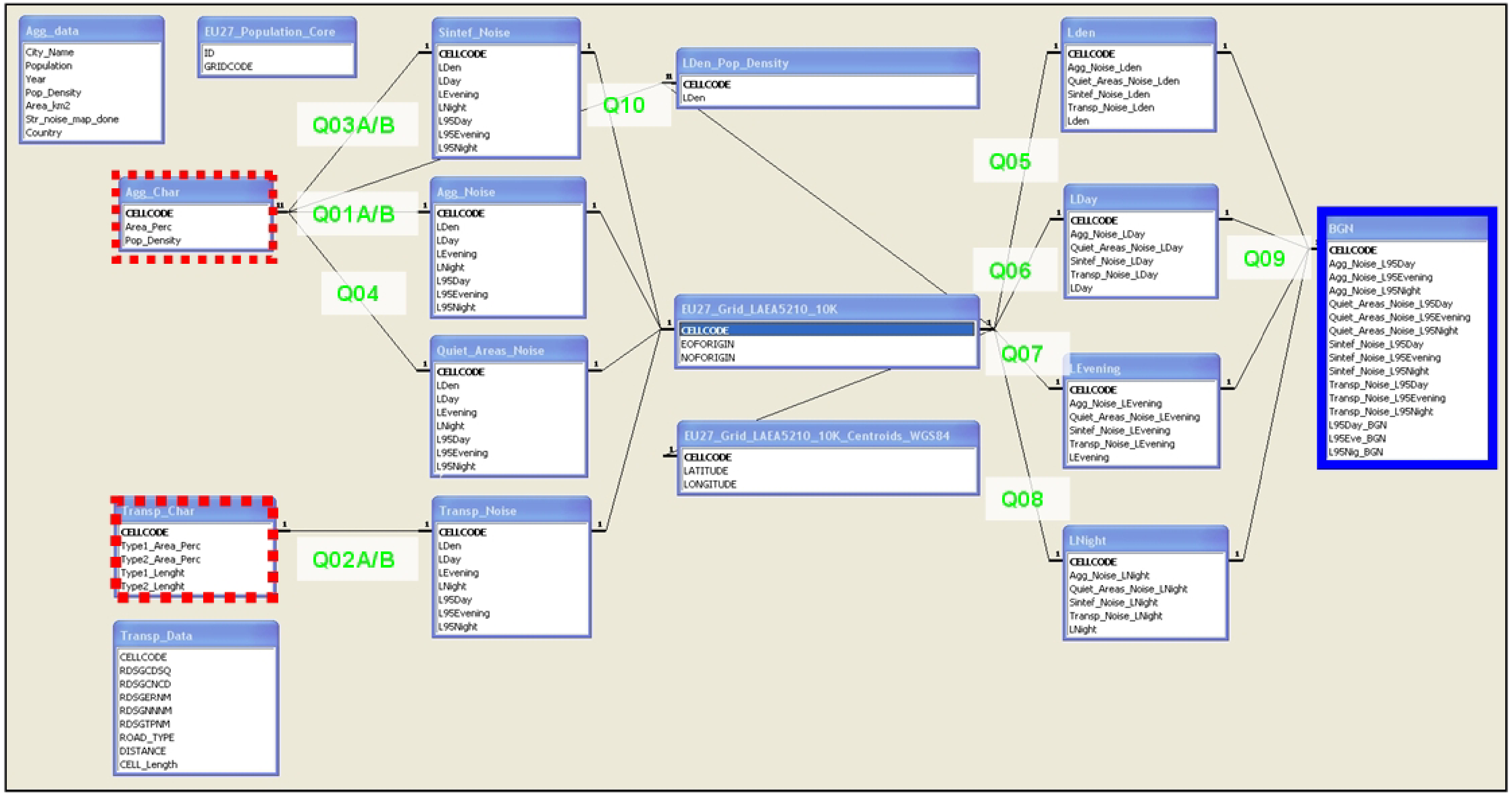


Figure 2- 53. Texts starting with the letter "Q" represent the database queries to calculate partial and total noise levels.

2.3.4 Mapping the results

Once processed the data and populated the noise tables, after running the database queries, any of the resulting data, stored in their corresponding derived tables, may be linked to the 10 km reference grid[13] and be visualized or even printed with common GIS applications, both commercial and free applications, after loading in them.

With the aim of facilitating a quicker way to generate plots of maps in PDF format and a easier access to noise data from mapping tools, some new feature layers have been generated joining the information provided by the 10 km reference grid, mainly the cell code, and the tables from the BGN database that should be printed or visualized in form of maps. These new GIS layers, also provided in the DVD called "BANOERAC_WP1" and in shapefile format, are the following ones:

- EU27_EUROSTAT_ROADS
  Road network for EU27 countries.
- TYPE1_ROADS_PERC
  Percentage of occupied area in the 10 km grid under influence of roads of "type 1".
- TYPE2_ROADS_PERC
  Percentage of occupied area in the 10 km grid under influence of roads of "type 2".
- AGGLOMERATIONS
  Main European agglomerations for EU27 countries.
- 10KM_POPULATION_DENSITY
  Population density in the 10 km grid.
- URBAN_CORE_PERC
  Urban area percentage in the 10 km grid.
- LDEN
  L_{den} noise level in the 10 km grid.
- LDAY
  L_{day} noise level in the 10 km grid.
- LEVENING
  $L_{evening}$ noise level in the 10 km grid.
- LNIGHT
  L_{night} noise level in the 10 km grid.
- L95DAY
  L_{95day} noise level in the 10 km grid.

[13] The 10 km grid is a polygon layer in shapefile format called "EU27_Grid_LAEA5210_10K_Layer"

- L95EVENING
  $L_{95evening}$ noise level in the 10 km grid.

- L95NIGHT
  $L_{95night}$ noise level in the 10 km grid.

- BASIC_LDEN
  L_{den} noise level considering only density population

- BGN_MEASUREMENTS_TEST_SITES
  WP2 measurement test sites.

Full details about the fields which are part of the GIS layers' attribute tables are shown in the Appendix 1-1 Background Noise Levels Databases and Spatial Information.

One aspect to remark is that not only these new GIS layers are suitable in the framework of this project, for printing or visualizing noise data or related with them, but also they might take part in other studies or analyses as, for instance, those which require an overlapping of this information with other coming from strategic noise maps for airports.

Putting together some of the previous GIS layers, a collection of eight map compositions has been created, both printed in DIN A4 paper and in PDF format. These are the maps provided in section 2.2:

- Basic L_{den} based on Population Density
- L_{den} noise level
- L_{day} noise level
- $L_{evening}$ noise level
- L_{night} noise level
- L_{95day} noise level
- $L_{95evening}$ noise level
- $L_{95night}$ noise level

2.3.5 GIS Consultation Tool

Two are the ways the user may choose for visualizing and consulting the noise data. On one hand, If ArcGIS Desktop software is available, the information may be analyzed opening the ArcMap document called BACKGROUND_NOISE_2009_OCTOBER.MXD (version ArcGIS 9.2), which is also provided, together with the GIS layers it links to, in the DVD called "BANOERAC_WP1".

Its main buttons to visualize and consult information are the same than in the case of the mapping tool explained next.

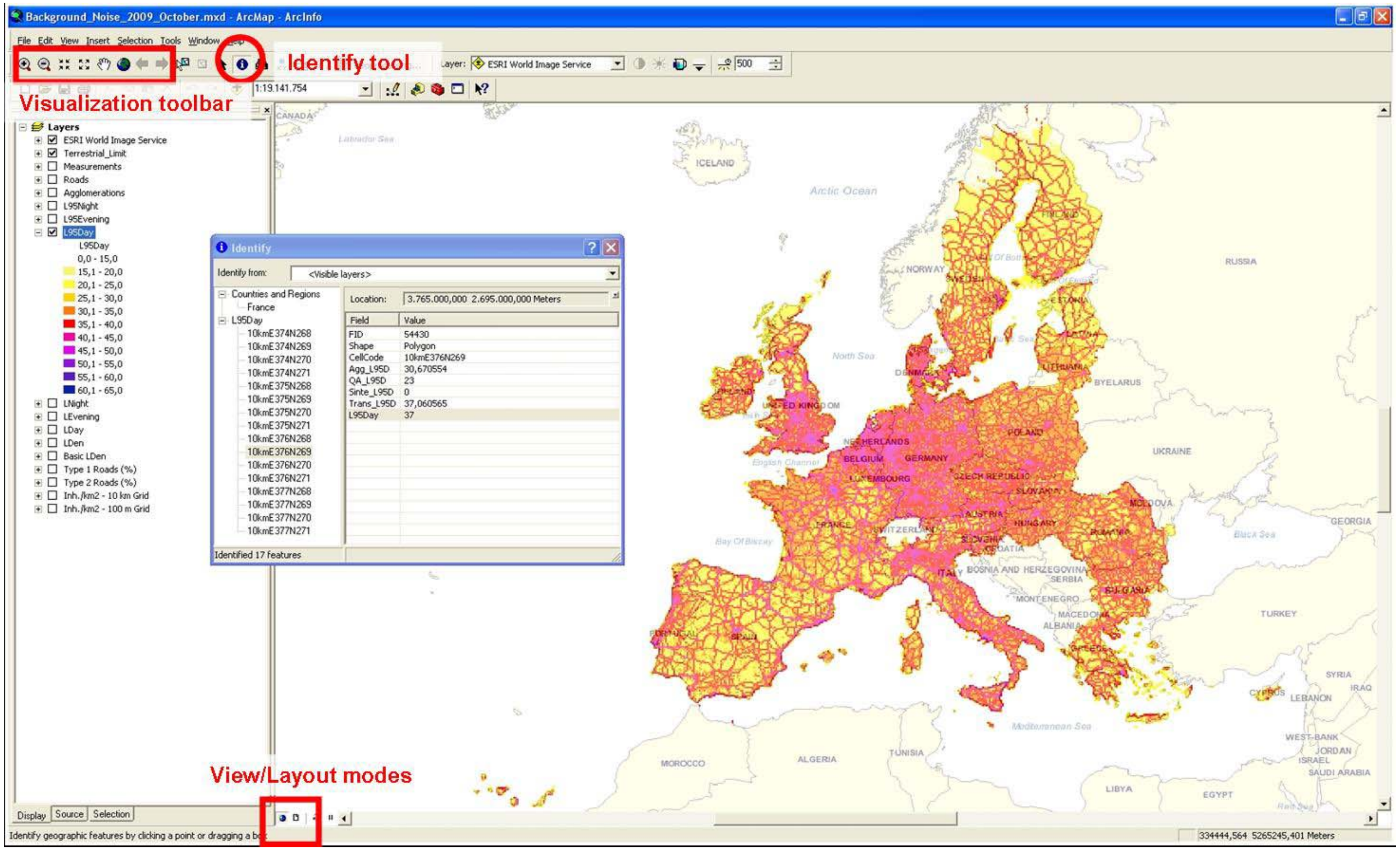


Figure 2- 54. Noise data visualization in the user interface of ArcGIS Desktop. Visualization toolbar, Identify tool and View/Layout switcher are highlighted

Otherwise, if ArcGIS Desktop is not available, then the user also may install a free GIS application provided in the DVD “BANOERAC_MAPPING_TOOL”, named ArcReader, and open with it an already created published map (BACKGROUND_NOISE_2009_OCTOBER.PMF).

In short, ArcReader is a free, easy-to-use desktop mapping application that allows users to view, explore and print published maps documents (in PMF file format) on any printer, including all layers symbology and cartographic map elements; zoom in/out, pan and switch between map (view mode) and page layout view (layout mode). To clarify more what maps in PMF format are, we might think of something analogous to the PDF files, because both are files readable by non-cost applications: ArcReader, in the case of PMF files, and Acrobat Reader, in the case of PDF files.

So, with this very simple mapping tool it is possible to explore zones from the study area with more detail through some buttons placed in a toolbar which is in the top of the application window. The user has the opportunity to work with several buttons, like Zoom In (magnifying glass with symbol “+”), Zoom Out (magnifying glass with symbol “-“), Pan (hand), etc. In any case, it is quite easy to know what a particular button does just moving the mouse over it.

Another very useful tool is the Identify button (the one with a symbol with letter “i”). It gives information of the elements from one or several layers when the user clicks on them with the mouse. Selecting the proper option in the list box that is located in the top of the Identify window, it is also possible to control the layer or layers which will offer the information the user is looking for (top-most layers, visible layers, all layers, a specific layer…). In this way the user may access to any of the different noise data stored in GIS layers.

The mapping tool also provides a quick way of printing simple customized maps, made by checking on and off the GIS layers the user wants to visualize. The buttons to switch between view and layout mode are also highlighted in the Figure 2- 55.

Full capabilities of ArcReader mapping tool may be found in the PDF documents “ARCREADER QUICK-START TUTORIAL” and ARCREADER_TUTORIAL, provided to the user in the DVD “BANOERAC_MAPPING_TOOL”.

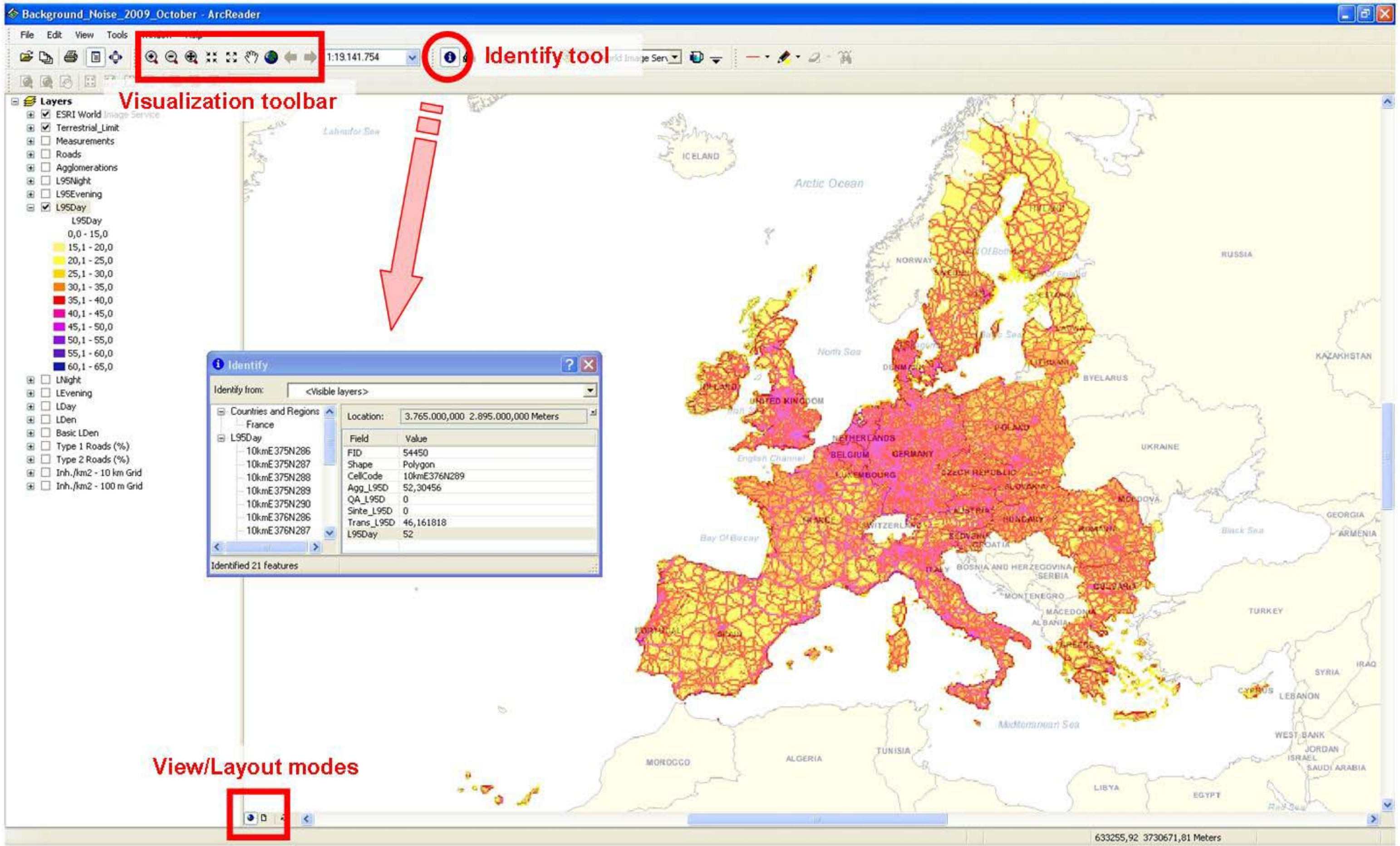


Figure 2- 55. Noise data visualization in the user interface of ArcReader. Visualization toolbar, Identify tool and View/Layout switcher are highlighted

Both opening the MXD file in ArcGIS Desktop and opening the PMF file in ArcReader, the GIS layers the user may visualize and consult are exactly the same:

- L_{den}
- L_{day}
- $L_{evening}$
- L_{night}
- L_{95day}
- $L_{95evening}$
- $L_{95night}$
- Basic L_{den}
- Road Network
- Type 1 Roads (area percentage)
- Type 2 Roads (area percentage)
- Agglomerations
- Inhabitants/km2 in 10 km reference grid
- Inhabitants/km2 in 100 m reference grid
- WP2 Measurements test sites
- Terrestrial limit for the 10 km reference grid

All layers referring to noise data share the same colour symbology in ranges of 5 dB.

Although it is not absolutely necessary, it is advisable to have a connection to Internet because the map documents to be opened by the mapping tools use a remote map service (ESRI World Map Service) as reference information in the map background.

References

[1] EASA
Specifications attached to the Invitation to Tender EASA.2008.OP.14 – BANOERAC
July 2008

[2] Anotec Consulting / Labein-Tecnalia
Proposal for the performance of the BANOERAC project
Anotec Doc OAN074-1-1 – September 2008

[3] SINTEF ICT
Background noise levels in Europe – June 2008

[4] Anotec Consulting
Initial study on aircraft cruise noise levels
Anotec Doc PAN069-1-2 – May 2008

[5] Javier.gallego, JRC
Population density grid of EU-27+, version 4
http://dataservice.eea.europa.eu/dataservice/

[6] Population Density, EEA
http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=1018&i=1

[7] US Environmental Protection Agency, Population Distribution of the United States as a function of outdoor noise level, Report 550/9-74-009, June 1974

[8] Stewart, C. M. Russel, W. A. Luz, G. A. Can population density be used to determine ambient noise levels? Forum Acusticum, Berlin, Germany, March 1999.

[9] Miedema, H. Oudshoorn, C. Annoyance from transportation noise: Relationships with metrics DNL and DENL and their confidence intervals. Environmental Health, vol 109 (4), April 2001

[10] European Transport Networks, Eurostat Institution
http://epp.eurostat.ec.europa.eu/portal/page/portal/gisco/geodata/archives

[11] Strategic noise maps
http://circa.europa.eu/Public/irc/env/d_2002_49/library?l=/strategic_december&vm=detailed&sb=Title

[12] SPATIAL GRID ETRS89 Lambert Azimuthal Equal Area 52N 10E grid, recommended by the EEA
http://www.eionet.europa.eu/gis/geographicinformationstandards.html
http://dataservice.eea.europa.eu/dataservice/metadetails.asp?id=760.

[13] ISO 1996-1 (2003). Acoustics — Description, measurement and assessment of environmental noise — Part 1: Basic quantities and assessment procedures.

[14] European Noise Directive 2002/49/EC of 25 June 2002 of the European Parliament and Council relating to the assessment and management of environmental noise.

ANOTEC Consulting, S.L.
aircraft noise technology

Security class	Document ID	Issue no.	Short Title	Issue date	Page
Restricted	PAN074-5-2	3	Final Report - Part 2	06/11/2009	1 of 37

Project		Document Title
AN074	BANOERAC	D1. Final report Part 2: Measurements

Summary

This report covers the work performed within the BANOERAC project.

In this Part 2, elaborated by Anotec, the background noise and aircraft en-route noise measurements are described.

Document revision

Issue	Date	Affected pages	Modifications
1	15/08/2009	All	First issue
2	14/10/2009	All	Incorporation of EASA comments 21/09/2009
3	06/11/2009	All	Incorporation of EASA comments 06/11/2009

Controlled copies

Anotec	Customer	Other
Lib	EASA (Mr. Franken)	Labein

Approval status

Prepared by Project team	Approved by Head Engineering & Design	Verified by Responsible Airworthiness
Nico van Oosten Victoria Esteban	Nico van Oosten	N/A

TABLE OF CONTENT

List of figures

List of tables

Introduction

Two developments in aviation industry will shortly have reached a phase where actual rulemaking work will have to commence. These developments are the preliminary studies on supersonic business jets and the revived interest in so called 'open rotor' engines. They have a common factor in that they will potentially create non negligible noise levels on the ground, not only when flying in the terminal area around airports but also while the aircraft are climbing, cruising and descending at distance from airports (hereafter referred to as "en-route noise"). If aircraft with such technology would be numerous, this would essentially mean that aircraft noise would be audible literally everywhere. The political discussion and the impact assessment will therefore require factual data on existing so called background noise levels and on actual noise levels of 'classical' aircraft in cruise in Europe and elsewhere. Such data will make it possible to put the noise levels of these new technologies in perspective with the existing situation.

EASA issued an Invitation to Tender (ItT) for a study on “Background noise level and noise levels from en-route aircraft”, with acronym BANOERAC [1]. The contract was awarded to the proposal from the consortium, formed by Anotec and Labein-Tecnalia, both from Spain [2]

Before the present study EASA contracted two pilot studies with direct relation to BANOERAC.

One study, performed by SINTEF [3], concluded that no data is readily available on existing background noise. It was reported however that a first approximation of the background noise levels can be derived from population density. The present project intends to use this concept to establish a detailed database of estimated background noise levels in Europe.

The other study, performed by Anotec [4], concluded that very little and mainly outdated information on en-route noise from aircraft was available, but that it would be possible to collect meaningful information with a measurement campaign. BANOERAC aimed at carrying out such measurements.

The aim of this study is to improve insight in background noise levels in Europe and the en-route noise from aircraft. It is realised though that the scope of the study does not allow to claim that the results would be representative for all of Europe.

According to the proposal the work performed was divided in 3 parts:

Part 1. Calculation of approximation of background noise levels
Calculation of background noise levels based on population density for each EU country, building on the SINTEF report and proposing some correction for extreme situations [3].

Part 2. Actual measurements of background noise and aircraft en-route noise
Measuring of actual noise levels in a number of locations representative for a quiet rural area, with very low levels of background noise from man-made sources.
Noise measurements from actual passages of aircraft that are en-route (i.e. climb, cruise and descent phases).

Part 3. Final analysis and results
Analysis of the measured data and presentation and discussion of the results for both background noise and aircraft en-route noise.

The project has been performed based on the following work breakdown structure:

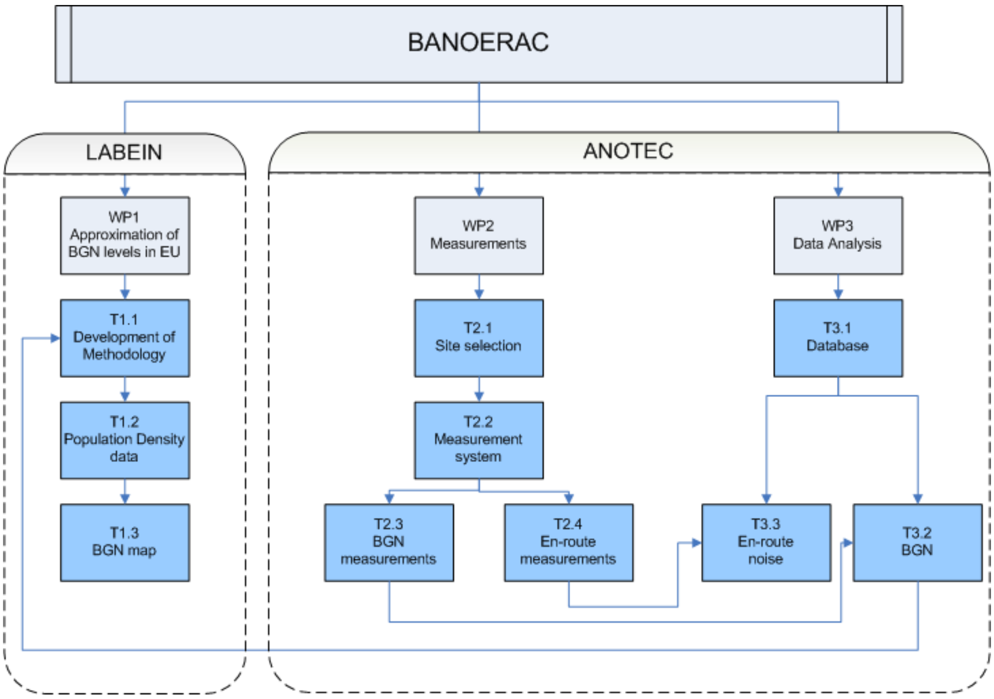


Figure 3- 1 Work breakdown structure

The present document describes the work performed in WP2.

Definitions

According to Appendix 3 of the ICAO Environmental Technical Manual [6] the following definitions related to background noise apply:

AMBIENT NOISE The acoustical noise from sources other than the test aircraft present at the microphone site during aircraft noise measurements. Ambient noise is one component of background noise.

BACKGROUND NOISE The combined noise present in a measurement system from sources other than the test aircraft, which can influence or obscure the aircraft noise levels being measured. Typical elements of background noise include (but are not limited to): ambient noise from sources around the microphone site; thermal electrical noise generated by components in the measurement system; magnetic flux noise (“tape hiss”) from analog tape recorders; and digitization noise caused by quantization error in digital converters. Some elements of background noise, such as ambient noise, can contribute energy to the measured aircraft noise signal while others, such as digitization noise, can obscure the aircraft noise signal.

POST-DETECTION NOISE: The minimum levels below which measured noise levels are not considered valid. Usually determined by the baseline of an analysis “window”, or by amplitude non-linearity characteristics of components in the measurement and analysis system. Post-detection noise levels are non-additive, i.e., they do not contribute energy to measured aircraft noise levels.

PRE-DETECTION NOISE Any noise which can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, recording / playback, and analysis systems.

In the context of the present project these definitions have been maintained. However, it is necessary to take the following into account when reading the report.

As mentioned in the Introduction, the main objective of Part 1 is to determine the **background noise** levels based on population density for each EU country. For higher population densities (and thus higher noise levels) this will be equivalent to the **ambient noise**, since noise levels will generally be significantly higher than the noise floor of the measurement system. Here it is noted that noise mapping software is predicting **ambient noise**. The measurements performed in quiet areas as part of the present study obviously provide **background noise** levels, since at these low levels instrumentation noise is relevant.

The lower limit of the curve is defined by the noise present in areas with no population at all. Although measurements were made in quiet areas, some population related noise was still present. In order to extract this noise, two additional terms had to be defined:

NATURAL NOISE	The acoustical noise from all non man-made sources, mainly wind and animals. Noise of e.g. barking dogs has been included in this group, recognising that in some cases a direct relationship might exist with human presence.
NON-NATURAL NOISE	The acoustical noise from all man-made sources. This includes noise from any transport system, human beings, spurious noise (e.g. that generated due to a cable problem), etc.

Following these definitions, the background noise defining the lower limit of the curve will thus correspond to the **natural noise**.

The objective of the background noise measurements performed in Part 2 of the study is thus the determination of the **natural noise** at the various test sites. This is done by excluding any **non-natural noise** from the measurements

The metric used to express background noise is L95, whereas L95c[1] is used for describing natural noise only.

[1] L95c is determined in the same manner as L95, except that only the 'natural noise' part of the measurement is used as the basis.

3. MEASUREMENTS

The main objective of Part 2 of the BANOERAC study was the performance of measurements in order to establish actual background noise levels in various environments and also to determine the noise levels of current aircraft types when en-route.

To facilitate the handling of the vast amount of data obtained, 3 levels of detail were defined:
- Session (usually a test day), consisting of various measurements
- Measurement. A continuous recording of usually 30 minutes
- Event. Occurrences during a measurement which might influence the noise level.

In the following sections the selection of the test sites and the measurement system is described. After this an overview is given of the background noise and the aircraft en-route noise measurements.

For a description of the data analysis and final results, one is referred to Chapters 4 and 5 to 6 respectively.

3.1. Test site selection

Due to the expected low noise levels to be measured, the test sites had to be selected carefully. Significant effort was therefore dedicated to the selection procedure and to visiting potential test sites.

For all measurements the following general characteristics were applicable to the test sites:
- sufficiently flat terrain, without obstructions which significantly influence the sound field within 75º from the vertical through the microphone
- quiet rural area
- very low level of background noise from man-made sources:
  - at least 3 km from major motorways, from larger towns, and from major industrial areas
  - at least 2 km from minor motorways and major trunk roads and from the edge of smaller towns
  - at least 1 km from medium disturbance roads (typically more than 10,000 vehicles per day)
  - not exposed to any other major noise sources such as nearby railways, industrial complexes etc.
  - not exposed to noise from windmills (incl. low frequencies and infrasound)

Apart from these general characteristics especially the aircraft en-route noise measurements required specific additional attention with respect to the proper selection of the test sites (underneath major airways).

For practical reasons all test sites were positioned in Spain.

3.1.1. Selection process

The following flowchart reflects the process followed to select the test sites.

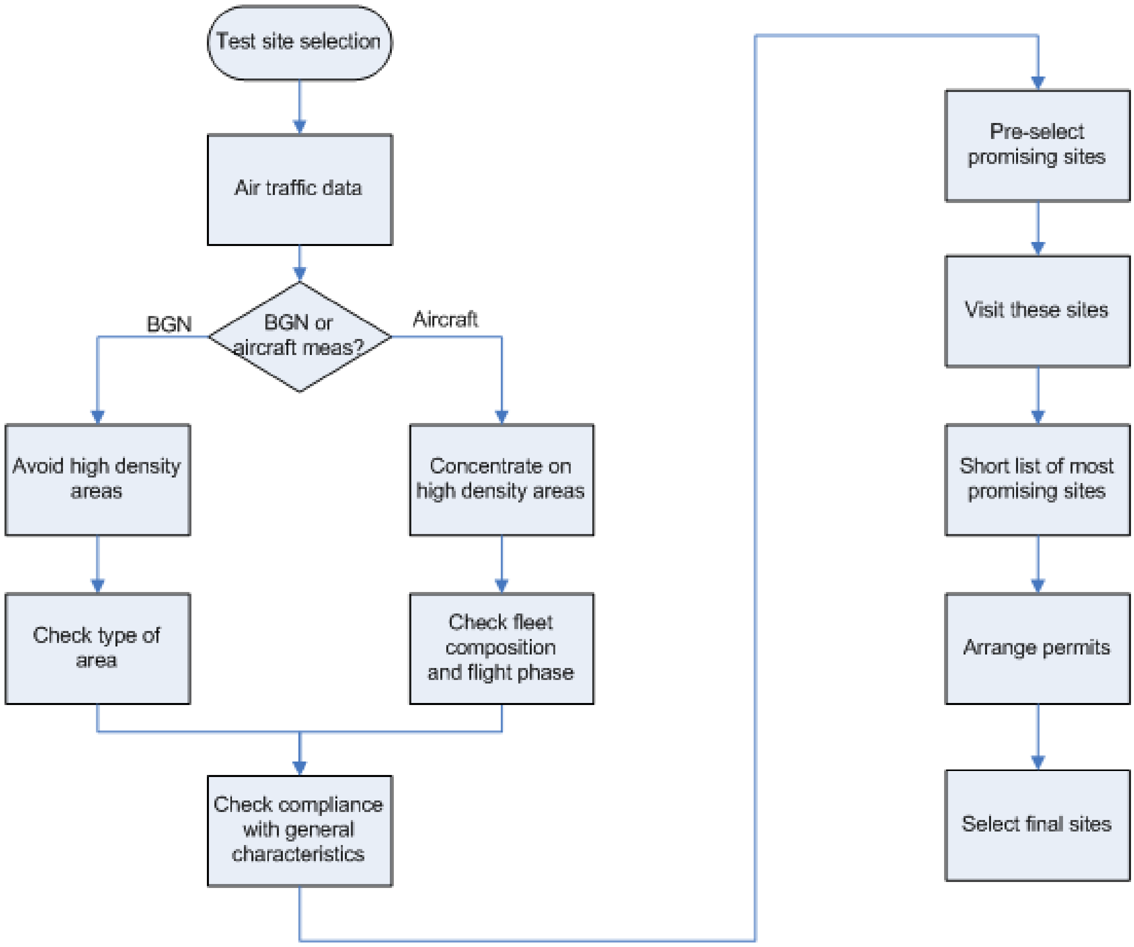


Figure 3- 2 Selection process flowchart

The first step of the process was to compile a comprehensive dataset for air traffic in the area of interest. From Anotec's IBANET noise and trajectory monitoring system traffic data for almost a year was available for the center part of Spain, where most measurements were planned to be performed.

This area was split up in cells of 5x5 km and for each cell the number of aircraft, aircraft types and the average altitude were determined. A colorplot was then generated and subsequently mapped on the earth surface with Google Earth. The following graph is an example of a week of air traffic in the central part of Spain.

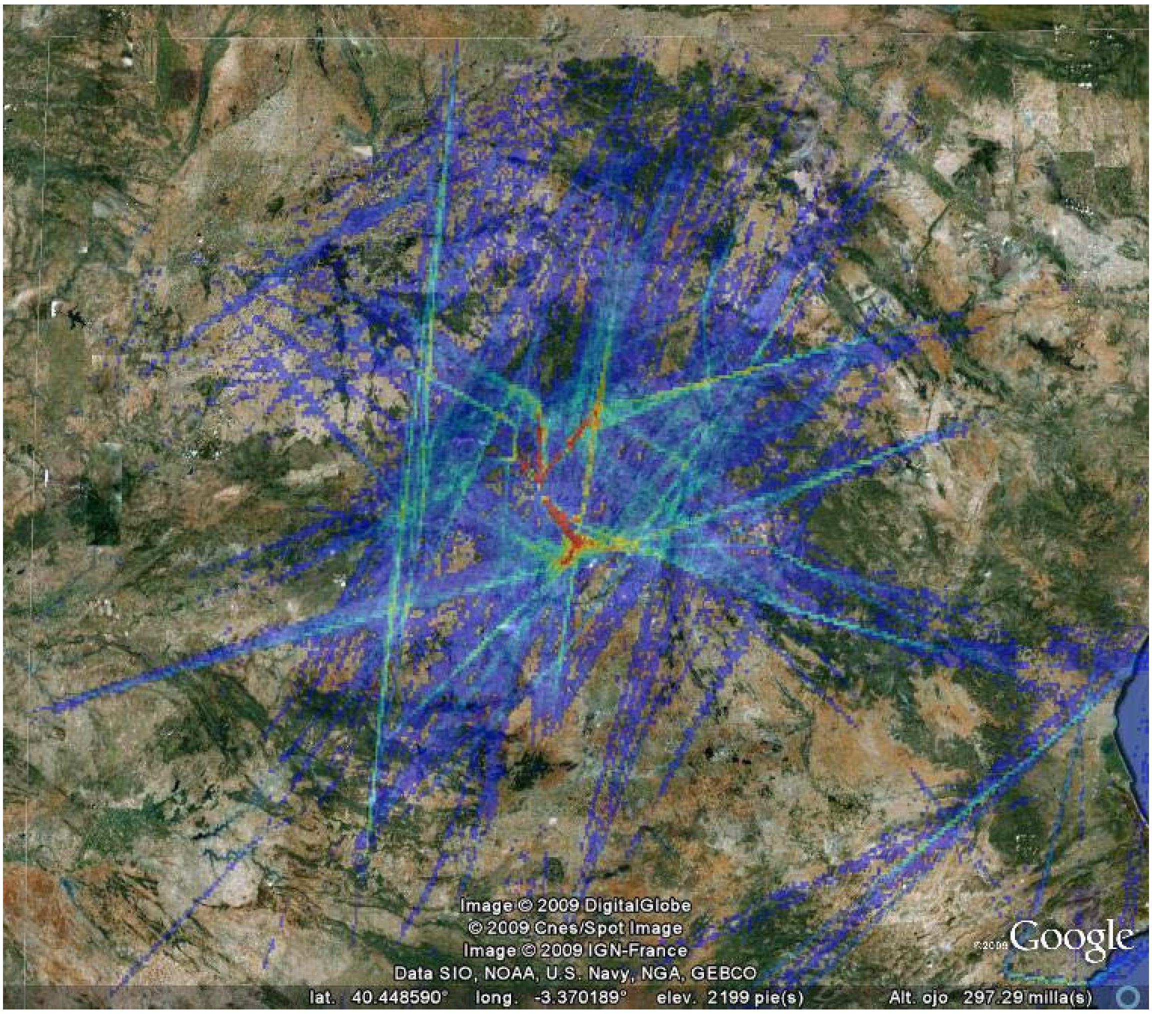


Figure 3- 3 Plot of a week of air traffic in central Spain

The red colored cells in the middle of the graph correspond to arrivals and departures at Madrid-Barajas airport. Apart from this, also clear concentrations can be found in North-South and West-East directions (yellow-orange), corresponding to major airways. However, also a wide spread around these routes can clearly be observed (blue).

From this plot it was clear that the test sites for the background noise measurements had to be sought outside the Madrid region. A dedicated IbaTrack station (see section 3.2) was therefore temporarily installed in various places outside this area, in order to detect more appropriate sites. Apart from being located in none to low traffic areas, the sites for background noise also had to be representative for Natural Parks, agricultural and hilly/mountainous regions respectively.

On the other hand, for the aircraft noise measurements some very interesting points were revealed, at the crossing of different airways. Especially at some points various types of traffic could be expected (i.e. crossing of cruise with arrival and/or departure routes). By filtering the grid data for e.g. aircraft types and/or flight phase, similar plots could be generated in order to anticipate potential specific needs (e.g. only aircraft in cruise, or only long-range quads).

The areas which resulted most interesting from the traffic point of view were then screened on their compliance with the general characteristics, described above. Especially the distance to, and the influence of, residential areas and transport infrastructures was checked in this step.

After this initial filtering a pre-selection of promising sites was then made. These sites were then visited in order to obtain further relevant information, especially on the presence of noise sources like wind mills and on the possibility to access the site.

After these visits a short list of most promising sites was elaborated and, if necessary, an application was made to obtain the permits to access the terrains and perform the measurements. In this phase various very interesting sites had to be eliminated from the list, because of the reluctance to give permission due to fear of forest fire or due to their location in ZEPAs (area of special protection of birds) or National Parks.

From the above process 2 test sites were defined for the dedicated background noise measurement, which were representative for Natural park and agricultural/hilly. For the aircraft en-route measurements 2 sites were considered the most appropriate.

For both types of measurements some sites were placed on a reserve list.

3.1.2. Test sites for background noise sessions

For the background noise sessions the following test sites were finally selected:

Table 3- 1 Test sites for Background noise sessions

Region	Location	WGS84			ETRS89	
		Lat	Lon	Alt (m)	X	Y
Natural park	Diego Alvaro	40.69107º N	5.33420º W	988	3028826.1997	2086229.2579
Agricultural /hilly	Los Tablones	36.76723º N	3.46204º W	268	3115680.1306	1628002.4632

Although originally it was the intention to measure also in a specific hilly/mountainous environment, it appeared that this kind of region was also representative for a natural park or for an agricultural area. Real mountainous areas (not being natural park or agricultural) are scars and usually not accessible to the public by car and/or are exposed to high wind speeds. Considering that also the aircraft en-route noise measurements would provide part of the background noise levels to be obtained and these sites were representative of Natural Park/hilly and agricultural/hilly, it was considered that the combination of the various sites was sufficient to give a representative overview of background noise in all types of quiet rural areas. Especially the Cebreros site is considered representative for a large part of Europe.

Diego Alvaro (Avila)

This test site is representative for natural parks. The surroundings are relatively flat. The flora mainly consists of holm oak trees with limited low shrubs, whereas the fauna ranges from small birds and eagles to wild boar. The ground mainly consists of quite dense soil. The background noise at this site is dominated by noise from birds. In addition significant noise levels, albeit of very short duration, were detected from flies and bees passing by the microphones. Especially the white plate with the inverted microphone appeared an attractive object for these insects. At night some noise from remote cows or bulls and dogs has been detected. In the course of the day, with increasing wind speed, noise of tree leafs becomes more apparent.

Non-natural noise sources mainly consisted of some cars and a limited number of aircraft in cruise phase.

The following photograph shows both microphones at the test site, an open space in between the trees.

Figure 3- 4 Diego Alvaro test site

The following map is a zoom of the topographic map of the area at scale 1:25000 with the measurement position indicate as a red dot and where each blue grid square corresponds to 1 Km x 1 Km. The full map covering an area of 5 km around the measurement position is provided in Appendix 2-1.

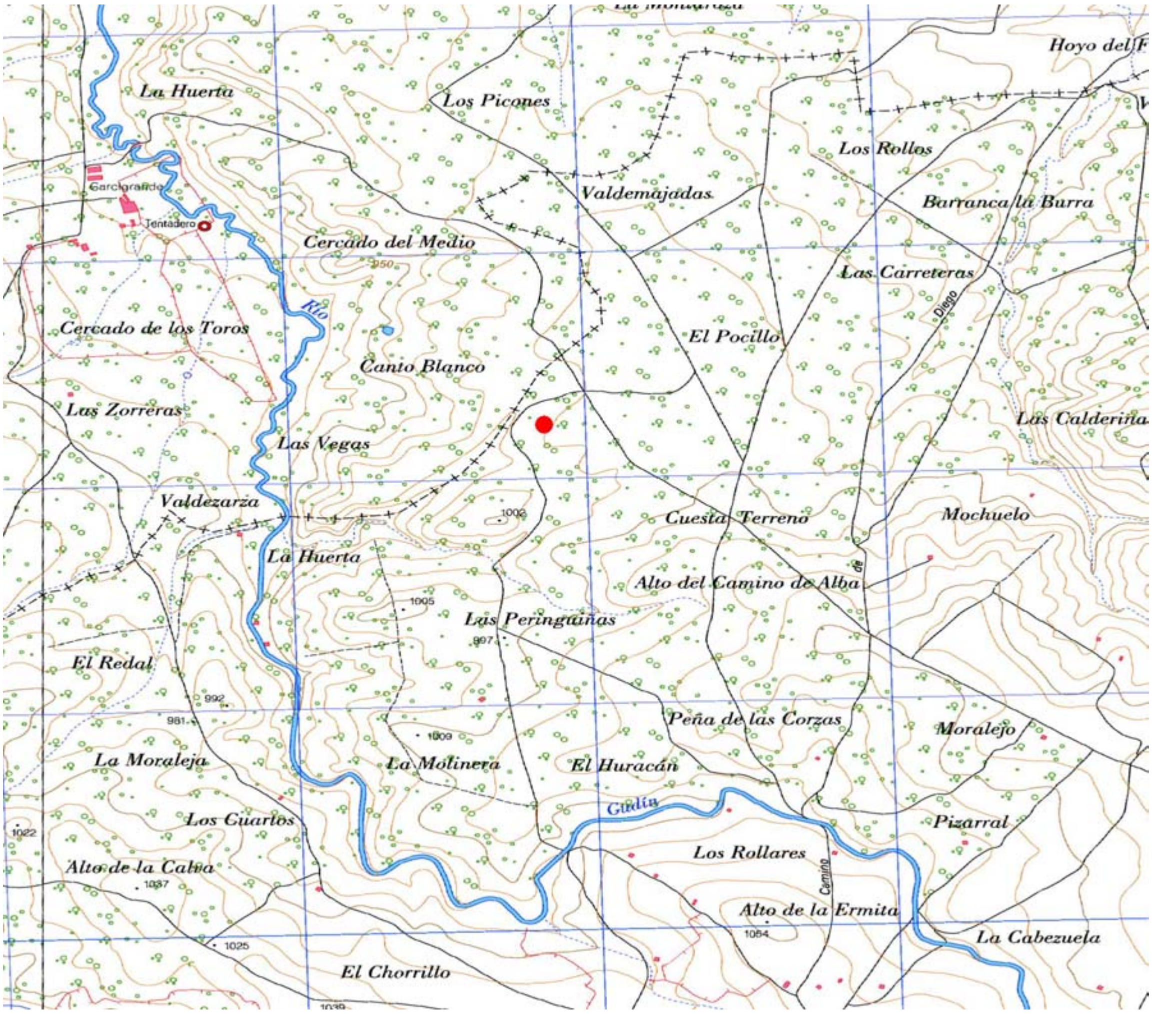


Figure 3- 5 Diego Alvaro topographic map (each blue grid square is 1 Km x 1 Km)

<u>Los Tablones (Granada)</u>

This test site is representative for areas of agricultural use, especially in the Mediterranean region. It is located in an undulating area. After visiting various potential test sites this was strongly preferred, since it was observed that in more flat and open terrain, noise from extraneous noise sources (especially road traffic and tractors, even if far away) would almost continuously be heard and would make the measurements less representative for natural background noise. The flora mainly consists of avocado and fig trees with limited low shrubs. The fauna mainly consists of small birds and insects. The background noise at this site is clearly dominated by the high pitched noise of cicadas ("chicharras"). In addition significant noise levels, albeit of very short duration, were detected from flies and bees passing by the microphones. Especially at night noise of barking dogs was detected. Also some noise from moving cattle (goats) was recorded. During the tests wind speeds were in general very low.

Non-natural noise sources mainly consisted of some motorcycles and cars passing to nearby fields and a very limited number of aircraft in mainly cruise phase.

Figure 3- 6 Los Tablones test site

The following map is a zoom of the topographic map of the area at scale 1:25000 with the measurement position indicated with the red dot and where each blue grid square corresponds to 1 Km x 1 Km. The full map covering an area of 5 km around the measurement position is provided in Appendix 2-1.

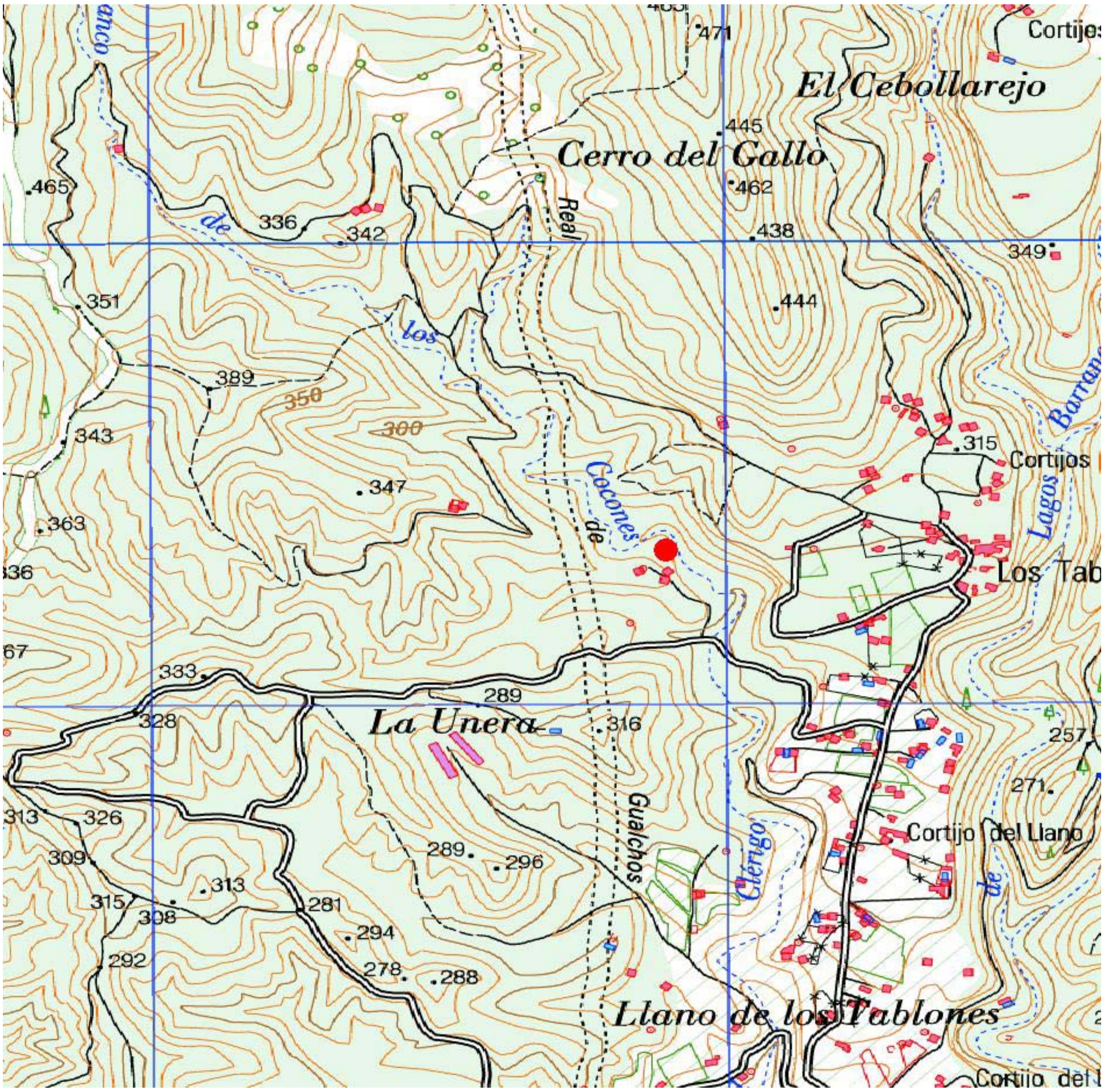


Figure 3- 7 Los Tablones topographic map (each blue grid square is 1 Km x 1 Km)

3.1.3. Test sites for aircraft en-route noise sessions

For the aircraft en-route noise sessions the following test sites were finally selected:

Table 3- 2 Test sites for Aircraft en route noise sessions

Location	WGS84			ETRS89	
	Lat	Lon	Alt (m)	X	Y
Cebreros	40.44945º N	4.36233º W	702	3104935.1110	2043763.5019
Colmenar	40.08658º N	3.40173º W	698	3178801.7192	1989182.8738

Cebreros (Avila)

This test site is located in a privately owned natural park[2]. The area is mountainous, although the direct surroundings of the measurement position are quite flat. The first measurements were made directly on the relatively soft soil, with no vegetation, whereas at the same place later in spring low wheat plants had grown. Some mid size holm oak trees are spread over the area. Natural noise sources were mainly birds and insects. During measurements with higher wind speeds also the noise of tree leafs was audible.

Non-natural ground based sources mainly consisted of cars and motorcycles passing and on some days tractors working on fields not far from the test site. Especially annoying at this site appeared to be the noise generated by general aviation and helicopters. Later in spring also patrol flights of fire-fighters were disturbing.

[2] Access permitted by courtesy of El Quexigal

Figure 3- 8 Cebreros test site

The following map is a zoom of the topographic map of the area at scale 1:25000 with the measurement position indicated with the red dot and where each blue grid square corresponds to 1 Km x 1 Km. The full map covering an area of 5 km around the measurement position is provided in Appendix 2-1.

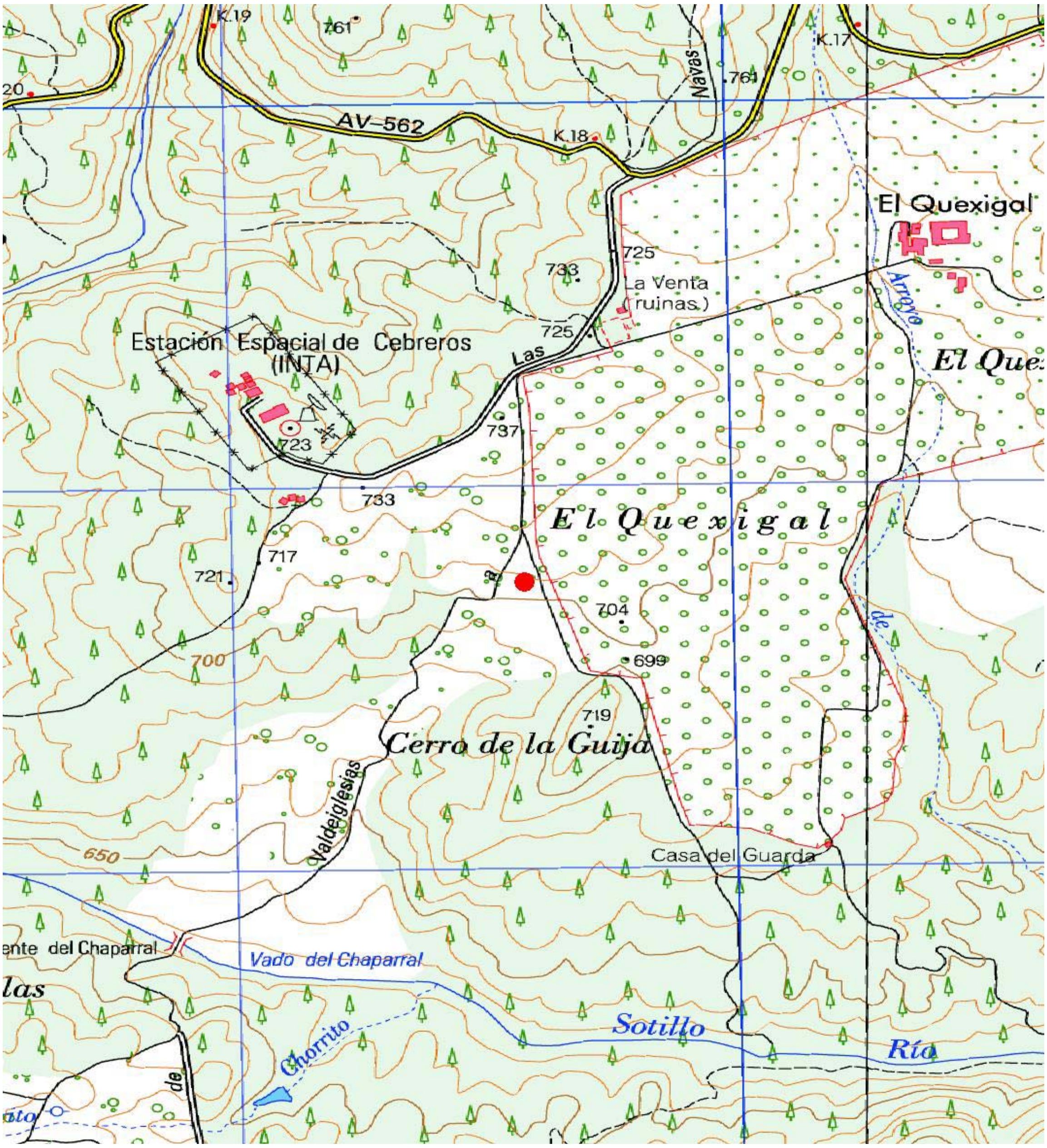


Figure 3- 9 Cebreros topographic map (each blue grid square is 1 Km x 1 Km)

This test site was selected as the best for this kind of measurements, since it was located on the crossing of an airway and some departure and arrival routes of Madrid-Barajas airport. However, due to a recent change in some routings, the traffic was even higher than anticipated, which resulted in a non-negligible number of events close to each other. Especially the presence of general aviation and helicopters invalidated quite a number of events. In addition access to the site was restricted in late spring for environmental reasons (breading period of a protected bird specimen in the area). Therefore an alternative test site was selected from the reserve list.

Colmenar de Oreja (Madrid)

This test site is located in a remote rural area. The ground consists of soft soil with some small stones and without vegetation. Surroundings are somewhat undulating. The measurement position is located in an olive tree plantation, with generally young and low trees. Natural noise sources are mainly birds and insects and, during higher wind speeds, tree leafs. Non-natural sources are some occasional remote road traffic and on one day a tractor on a nearby field. Also some noise from general aviation and helicopters was recorded. In general this test site appeared better than the Cebreros site with respect to the amount of valid events.

Figure 3- 10 Colmenar de Oreja test site

The following map is a zoom of the topographic map of the area at scale 1:25000 with the measurement position indicated with the red dot and where each blue grid square corresponds to 1 Km x 1 Km. The full map covering an area of 5 km around the measurement position is provided in Appendix 2-1.

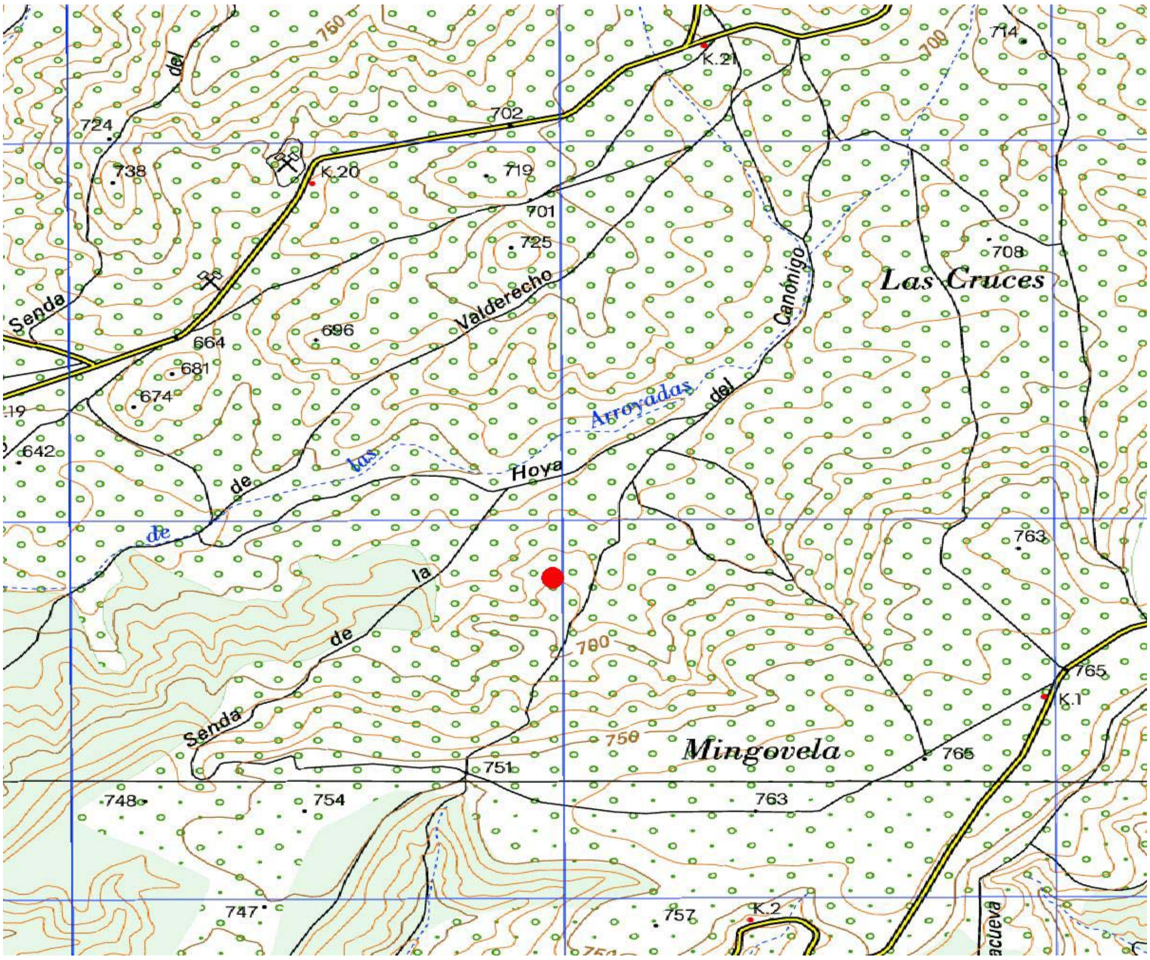


Figure 3- 11 Colmenar de Oreja topographic map (each blue grid square is 1 Km x 1 Km)

3.2. Measurement setup

The measurement system used was the Anotec EMMA system. This system is usually used for aircraft noise flight tests, for both research and certification purposes. It is built around National Instruments data acquisition hardware, controlled by means of a specific application, developed in Labview. This system is modular and comprises of a variety of subsystems. For the purpose of the present project only the noise (NMS), ground meteo (GMS) and time sync (TSS) subsystems have been deployed. This system was installed in a dedicated CPU.

In addition Anotecs IBaTrack system has been used for flight trajectory tracking. This system was installed in a separate CPU.

Data from atmospheric soundings was obtained from an external source.

A specific event logger application was developed in order to facilitate the recording and subsequent processing of the noise intrusions occurring during the measurements, as observed by the operator.

Control of the systems was provided by means of 2 daylight readable touchscreens, each controlling one CPU, with 7 meters extension cables. In this manner the CPUs could be installed inside the van, thus avoiding that the noise from their cooling fans could potentially influence the measurements. This also allowed the operator to be in a position with unobstructed view (and hearing) of the airspace above and the measurement location. To further reduce any noise from the control position the microphones were located at around 50 meters from the van.

Power supply for all systems is based on standard 12 VDC car batteries, allowing for continuous operation during a full day in any remote environment and for easy replacement in case of failure.

The following drawing gives a schematic overview of the measurement system.

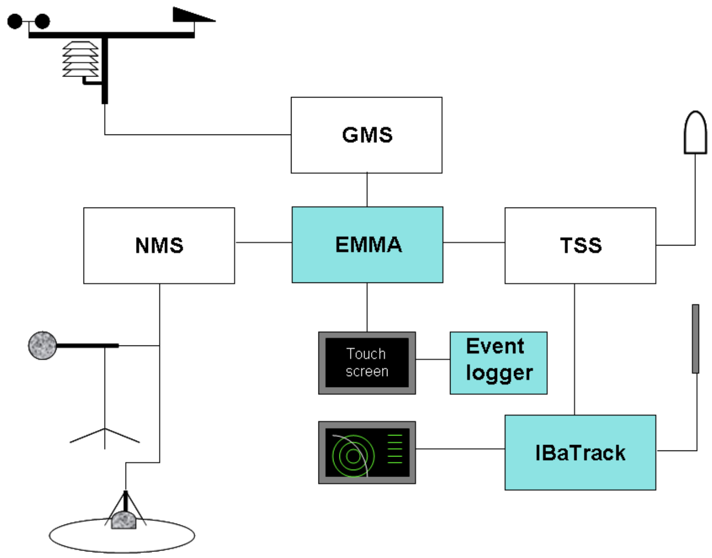


Figure 3- 12 Schematic overview of the measurement system

The following photos show the control position at the Cebreros test site.

Figure 3- 13 Control position at Cebreros

Figure 3- 14 Control position operator

All systems were duly calibrated before the start of the measurements.

3.2.1 Noise Measurement System (NMS)

The NMS subsystem used for the noise measurements within the present project comprises of the following elements:

Table 3- 3 Noise measurement equipment

Equipment	Type	Manufacturer	Serial nº
Pistonphone	42AA	GRAS	74560
Microphones	40AD	GRAS	40628 + 73512
Preamplifier for 40AD	26CF	GRAS	75641 + 75628
Windscreens 90mm	1434	Norsonic	-
Low noise cables (100m)	RG59	Eurocable	-
Data acquisition card CGS	PCI-4474	National Instruments	P10078405
Real-time analyser	Labview	National Instruments	-

All equipment fully complies with the specifications for aircraft noise certification as laid down in ICAO Annex 16, Appendices 2 and 6 [5]. Apart from being used for aircraft noise certification and research, this equipment has also extensively been used for noise impact measurements of electrical power plants, high speed trains and highways and has proved its robustness under a wide variety of conditions.

Special attention has been paid to the specific requirements of the present project. Very low noise levels were to be expected, especially in the higher frequency range (mainly due to atmospheric absorption). For this reason the 26CF pre-amplifier was chosen, since it provides a 20 dB gain option. Together with the 24 bit high performance 4474 card this allows for accurate noise measurements at low noise levels. Figure 3-15 provides spectra recorded with the measurement chain in a very low noise environment (semi-anechoic chamber) for both gain settings.

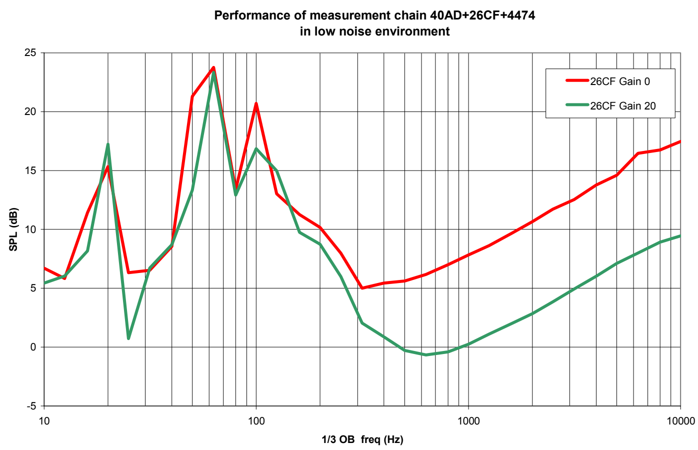


Figure 3- 15 Measured spectrum in very low noise environment

It can be seen that above a certain frequency (around 500 Hz for 0 dB gain and 1 kHz for 20 dB gain) the spectrum is dominated by the electrical noise of the system (post-detection noise). In this frequency range the presented values correspond to the noise floor. In the lower frequency range some noise from external sources was present. In this frequency range it was thus not possible to establish the noise floor of the measurement chain. However, the A-weighted overall noise level of the spectrum is fully dominated by the high frequency part, which thus determines the overall noise floor. From this figure it could be determined that the noise floor of the system with a 20 dB gain is 17 dB(A), which was considered sufficient for the purpose of this project.

Although in the initial plan a special wind screen was to be designed, the development had to be abandoned since the person in charge left unexpectedly. In the kick-off meeting it was decided that the measurements could be performed without this special screen, since the one actually applied already complies with certification standards.

Although the ItT [1] only required measurements to be taken with an inverted microphone on a 40 cm metal plate, simultaneous measurements were performed with a microphone at 1.2m above ground. This was considered of added value for various reasons:

- Little has been published on the effect of microphone height on background noise levels, whereas this effect might not be negligible.
- Very few of the known background noise measurements have been performed with an inverted microphone. These additional measurements allow for a better correlation of existing datasets with those obtained in this project.
- For aircraft en-route noise it provides an additional dataset, which could be used in potential future studies on e.g. correlation with results from ‘normal’ flight tests or to support the extension of the ANP database for en-route noise purposes.
- This substantial additional dataset could be obtained at a negligible additional cost

Both microphone systems are shown in the following pictures.

Figure 3- 16 Microphone setup

The NMS subsystem was controlled through a touch screen with a long extension cable, which allowed the user superior flexibility and thus optimal selection of his/her position during the measurements.

An example of one of the NMS screens is shown here. The real-time spectra and time histories are presented for all active channels.

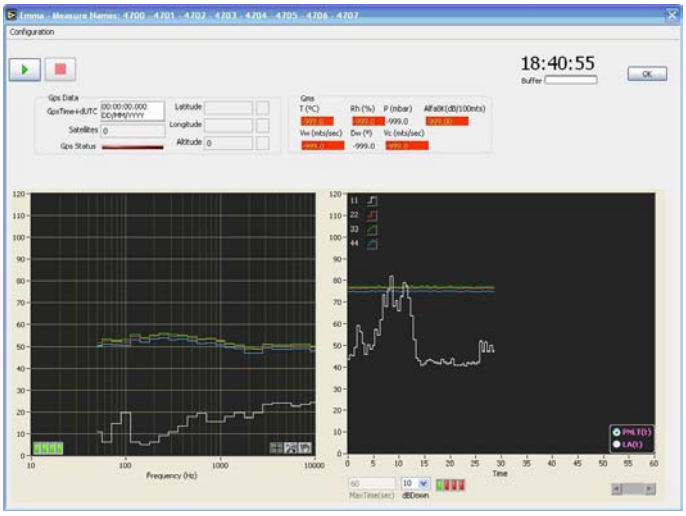


Figure 3- 17 Screenshot with Real-time spectra and time histories

When the GMS system is active, also the current meteorological conditions are displayed here, including an indication if any applicable limit is being exceeded (see also hereafter)

For each measurement (each with a unique ID), the system generates ASCII text files with 1/3 octave spectra and overall levels (dB(A) and OASPL) for each time instant. The raw pressure-time signal is stored in a standard 32 bit .wav file, which can later be reproduced in the laboratory for re-analysis and/or listening. To this end also a so-called .inf file is generated with all required information (such as sensitivity). The name of the files contain the measurement id. All files are set to read-only once they have been generated, thus protecting the file(name) from unintentional changes.

3.2.2 Ground Meteo System (GMS)

The standard Anotec GMS system was used. Normally this system is used on a 10 meter mast, but for the purpose of this project it was located at 1.8 m height[3]. It is equipped with sensors measuring temperature, relative humidity, wind speed and –direction and atmospheric pressure. These sensors are connected to a data-logger with 3 2-channel modules. The equipment used is given in the following table.

[3] In the original plan 1.2m. However 1.8m was necessary in order to be able to use a more robust tripod. In the kick-off meeting it was decided that this was allowable since it was considered a more restrictive case.

Table 3- 4 GMS equipment

Equipment	Type	Manufacturer	Serial nº
Wind speed sensor	8352.1OP	Lufft	0602100
Wind direction sensor		Lufft	0602099
Temperature/Humidity sensor	TFF10	Lufft	001.0400.9302.5.4.1.00
Pressure sensor	ED510	Haenni	68883/0102
Data-Logger	OPUS 200	Lufft	1302+1304+1306

Through the GMS module of EMMA the data-loggers are configured and controlled and the internal clock is maintained synchronised with the GPS time. All measured parameters are transferred in real-time to GMS, where they are stored in an ASCII text file, under the same measurement ID as the noise recording. These data are also used to indicate on the touchscreen if environmental conditions during the run are inside the applicable limits. This allowed the operator to make a well-founded decision on whether or not to continue the measurements if atmospheric conditions were becoming adverse.

Figure 3- 18 Ground meteo system

Due to a failure in the communication module of the datalogger with the pressure sensor, the pressure data could not be sent to the pc. Since this parameter is only varying very slowly with time and does not have any limit to comply with, it was considered acceptable to just read the pressure from the datalogger screen at the beginning of each measurement and manually record it on the log sheets.

3.2.3 Atmospheric Measurement System (AMS)

To obtain information on the meteorological conditions from test site to cruise altitude, atmospheric soundings are required. Performance of these measurements was considered beyond the scope of this project, both due to the related cost and the logistic challenges it poses (e.g. permits). A good alternative has been found in the data published on http://weather.uwyo.edu/upperair/sounding.html by the University of Wyoming which freely provides data from radio soundings every 12 hours for a significant amount of airports worldwide, among which several Spanish airports. For each test session the soundings of the following stations were downloaded from the above website in text format:

Table 3- 5 Position of sounding stations

ID	Name	Lat	Lon	Alt (m)
1	LECO (La Coruña)	43.36	-8.41	67
2	LEMD (Madrid)	40.5	-3.58	633
3	LEZG (Zaragoza)	41.66	-1.01	258
4	LELC (Murcia)	38	-1.16	62
5	LPPT (Lisbon)	38.76	-9.13	105
6	LEXJ (Santander)	43.48	-3.8	59
7	LXGB (Gibraltar)	36.15	-5.35	4

3.2.4 Aircraft data (IBaTrack)

As part of the IBANET airport noise monitoring system, Anotec developed the flight trajectory system IBaTrack. This system provides all relevant information of aircraft movements in a wide area around its receiver. Mode-S id, call sign, 4-D position (i.e. time-space) and speed are received through the ADS-B signals emitted by almost all current aircraft. The Mode-S id is then used to retrieve the aircraft model and tail number from specific databases, generated by crossing publicly available databases[4]. Here it should be noted that the relation between Mode_S id and aircraft model will not change since it is assigned only once. The databases containing this relationship are therefore reliable. Information like tail number and operator obviously might change over the lifetime of an aircraft. Therefore these databases are updated regularly in order to reflect as accurate as possible the current situation in this respect. All data was shown on the second touchscreen the operator had available, to see in real time the details of all aircraft in a wide area around the test site.

The system generates a specific binary file which content is uploaded to the database for its use in the final analysis (see section 4).

3.2.5 Time Synchronisation System (TSS)

All systems are synchronised to GPS (UTC) time by means of a Meinberg GPS169/PCI time server. Originally the GPS161/SDA time server was proposed due to its form factor (external box with serial port). However, since the time of submission of the proposal new 12 VDC computerboards have become available which allowed for use of the GPS clock PCI card already available at Anotec. Since both clocks are from the same manufacturer and are equivalent in performance, this change was considered acceptable.

3.2.6 Additional information (Event Logger)

Apart from the above equipment specific event logger software was used in this project. Although in the proposal this software was planned to provide a series of functions, during some initial testing this appeared not to be practical. The operator had to provide too much information through the touchscreen whereas the time available between two subsequent events sometimes was very short. In order not to loose valuable events due to this, it was decided to limit the functionality of the event logger to simply mark the begin and end time

[4] http://www.gatwickaviationsociety.org.uk ; http://www.airframes.org/ ; ICAO Doc 8643

instants of each event by pressing a 'start' and 'stop' button on the touchscreen. Additional information was then recorded by hand in paper log sheets, a common practice during certification flight tests. Afterwards this information was passed to the database with an off-line tool. This resulted a much more practical way and allowed the operator to concentrate on the observation of the events.

3.3. Test procedure

On each test day the procedure as described hereafter has been followed for both types of measurement (background and aircraft en-route noise).

The full measurement system was deployed and checked for proper operation (i.e. also in bgn measurements including the IBaTrack system, for any possible aircraft en-route events).

The (unique) session number was defined and session details were recorded in the session log sheet.

Before the measurements, both noise measurement chains were calibrated with a pistonphone, adjusting the sensitivity of the channels accordingly. The calibration signal was recorded. The sensitivity was stored in a so-called .inf file together with the .wav file, for potential future re-analysis of the recordings.

The system was set to monitoring mode, which means that automatic measurements, with a user defined duration, are made sequentially. For the purpose of these tests a duration of 30 minutes was chosen, in order to maintain the datafiles (especially the wav files) within manageable size and avoid the loss of too much data in case of a system failure. The system automatically starts a new measurement (with a new and unique id) directly after stopping the former one, without any noteworthy time lag. The real-time analyser was set to:

- Exponential averaging with SLOW response
- 1/3 octave filtering from 10Hz to 10 kHz
- A-weighting
- 1 s time interval for background noise measurements
- 500ms time interval for aircraft en-route noise measurements

During the measurements the operator continuously monitored the touchscreens and listened to the ambient noise. When a noise originating from a non-natural source was detected the start button of the event logger was pressed and the event was recorded in the measurement log sheet. Information on the noise source(s) was added to this sheet. Once the noise source was not detectable anymore the stop button of the event logger was pressed.

If the noise source was an aircraft, the callsign of the flight and the flight phase[5] were recorded in the log sheet. Also an indication was given if the aircraft was audible or not. In the case of coinciding aircraft passes, the event markers were given at the moments where a clear change of noise was perceived, especially in combination with the visually available position of the aircraft. In general it appeared quite well possible to distinguish the events in this manner. However, if this change was not perceived no new event was given. In the case of an aircraft with no ADS-B transponder, the aircraft type (or at least class) was visually determined by means of a binocular, whenever possible. This limited the detection of this type of events to those aircraft passing with a relatively small lateral deviation from the measurement position. Usually the flight phase could easily be established by comparison of its nominal course with that of other aircraft which passed earlier.

The same procedure was in general applied to noise from natural sources, although this was more difficult to strictly follow, due to the high occurrence rate of some noises. However, this was not considered a problem since these natural events are not used in the final analysis and will thus not influence the final results.

After the measurements, both noise measurement chains were calibrated again with the same pistonphone, but now without changing the sensitivity. The calibration level was compared with the level before the measurements, in order to detect any possible drift. A maximum difference of 0.5 dB between both readings was allowed. None of the measurements performed failed on this criterion.

After each test day all data stored in the datafiles generated by the complete measurement system were uploaded to the central database for further analysis.

[5] The flight phase is determined directly by the software which is provided with the ADS-B receiver. This is based on the rate of climb parameter, derived from the change in aircraft position (altitude) over time. The graphical interface plots the trajectories in different colours, depending on the flight phase, which facilitated the monitoring and logging.

3.4. Overview of performed background noise measurements

3.4.1. Introduction

At the start of the project it was planned to perform first several sessions of the more challenging aircraft noise measurements, since this would allow for the detection of any problems as soon as possible. In addition it was envisaged that certain periods of these measurements could be used for the determination of the background noise. After this, dedicated background noise measurements were envisaged. After 11 aircraft noise sessions at the Cebreros test site an analysis was made in order to guide the following steps in the project. Hereafter the main results of this preliminary analysis are presented.

Use of measurements made during aircraft noise sessions for background noise purposes

Due to the high air traffic volume at the Cebreros site no single 30 minute interval was available without any aircraft noise. Therefore the use of the corrected L95 metric was studied. This L95c metric is calculated in the same manner as L95, except that in stead of the whole 30 minute interval, only the time outside the logged non-natural events is taken into account. The following chart plots the difference between L95 and L95c as a function of the fraction of 'only natural noise' time available.

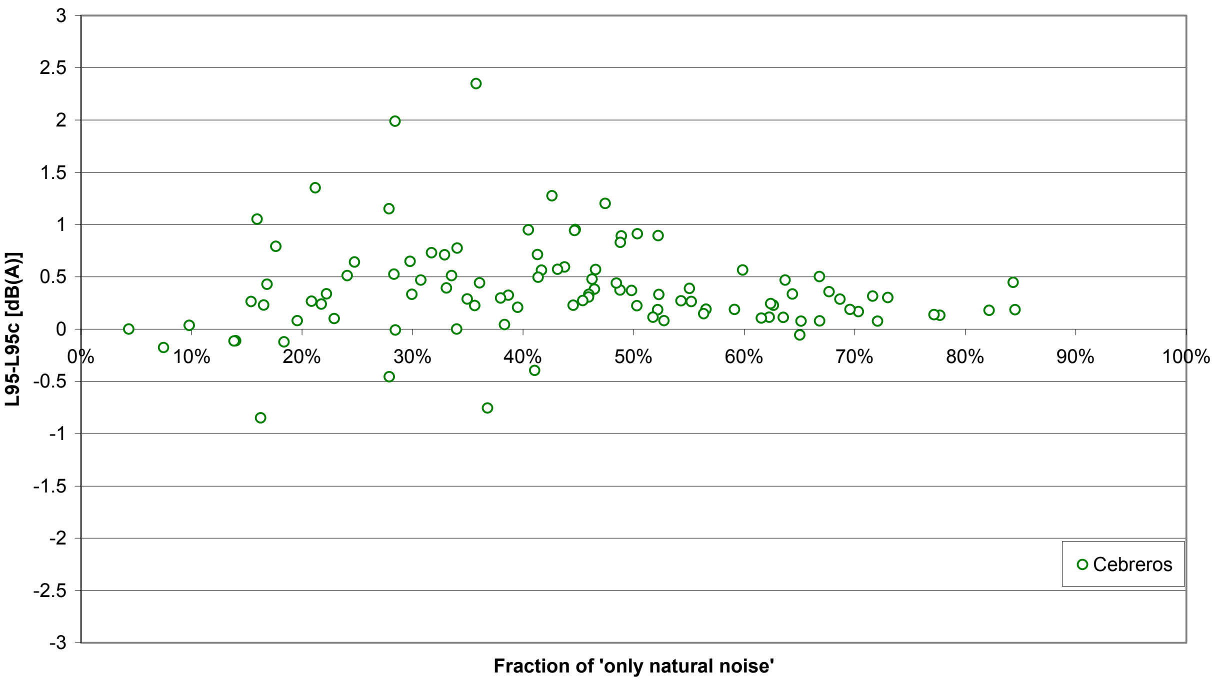


Figure 3- 19. L95-L95c versus fraction of 'only natural noise' time for the first 11 sessions

It can clearly be seen that for those measurements in which at least half of the time only natural noise was detected, the difference between L95 and L95c is less than 1 dB(A). At the end of all measurements this analysis was repeated in order to verify that this conclusion holds for all test sites. Figure 3-20 shows that this is indeed the case.

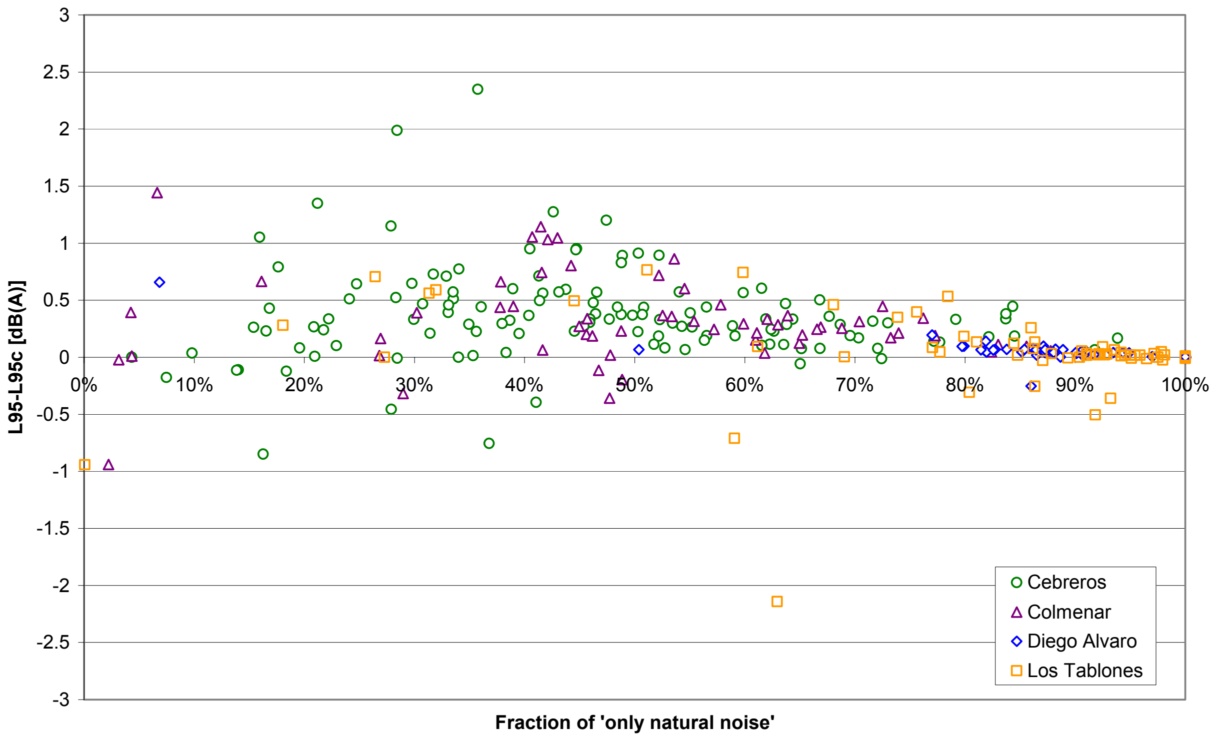


Figure 3- 20. L95-L95c versus fraction of 'only natural noise' time for all test sites

It was concluded that for the measurements where at least half of the time only natural noise is present, the natural noise (L95c) and background noise (L95) can be considered equivalent within sufficient accuracy and that therefore these measurements could be used in the final analysis of background noise levels in Part 3.

<u>Change of plan for background noise sessions</u>

The 11 sessions at Cebreros were realized from the end of February 09 until the end of April 09, thus covering winter and spring. This allowed to get an indication of the variation of background noise over significantly different seasons. As mentioned in 3.1.3 the ground cover had also changed in this period. In the following graph the L95c level is plotted as a function of the session number.

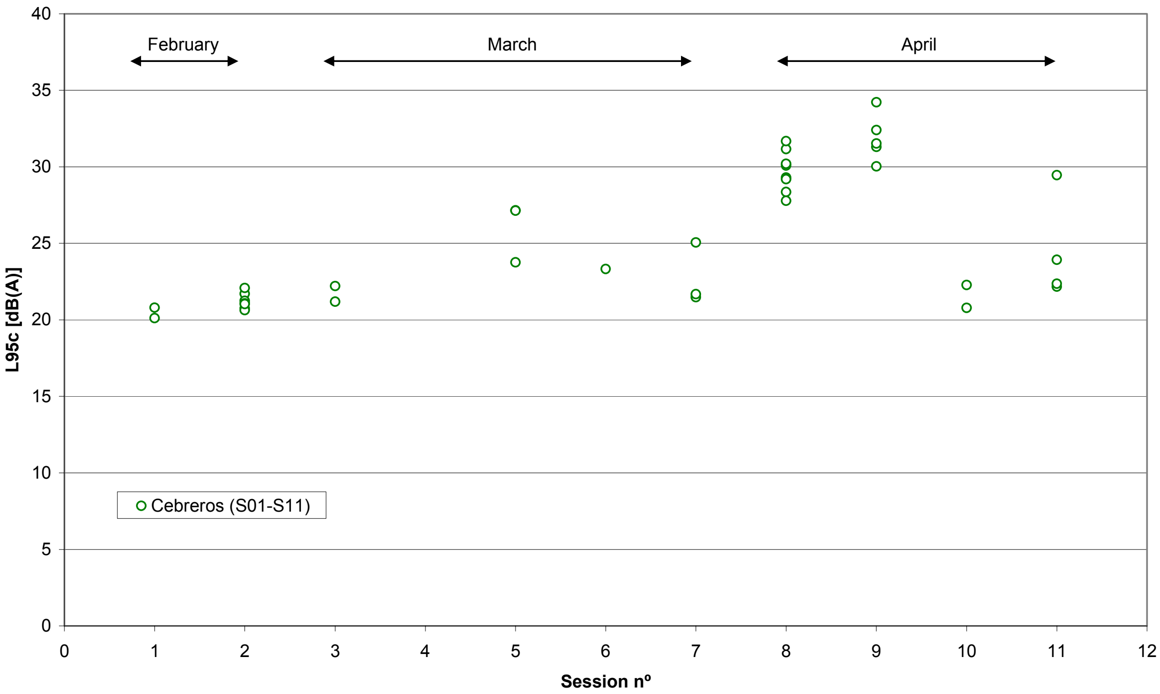


Figure 3- 21 L95c as a function of session

Significant differences can be observed between the various sessions, in extreme cases reaching almost 15 dB(A). However no clear trend can be found when considering the season. On the other hand a 5 dB(A) variation on a single day can also be seen.

The sessions with the highest noise levels (8 and 9) appeared to be those which were performed with relatively high wind speeds. As will be shown in Section 5, indeed the wind appeared to be a main contributor to the observed higher levels.

Considering that:

- background noise levels can be estimated by using L95c of the aircraft noise measurements, thus serving as an additional source of information
- significant hour-to-hour and day-to-day scatter in L95c levels can be observed
- no clear trend is found with regard to season-to-season scatter
- wind seems to be an important contributor to background noise levels
- for Part 1 of the study information was required for the day, evening and night period
- the original plan envisaged measurements mainly during the day period

it was concluded that within the budget available for the background noise measurements (90 hours) more useful information would be obtained if, in stead of visiting the test sites two times in different periods, at both test sites continuous measurements would be made during a 24 to 48 hours period.

Since the season-to-season scatter appeared of less importance and in any case was covered by data obtained during the aircraft noise sessions, the dedicated background noise tests were delayed in order to allow full dedication to the aircraft noise measurements, which appeared quite challenging due to the relatively high rejection rate.

Once the aircraft measurements were finished the dedicate background noise measurements were performed.

3.4.2. Measurements

The dedicated background noise sessions performed at the two test sites are listed in the following table. Further details on each measurement are provided in section 5.

Table 3- 6 Summary of dedicated background noise sessions

Test site	Session	Date	Time	Nº meas
Diego Alvaro	19	18/07/2009	14:00 – 24:00	20
	20	19/07/2009	00:00 – 21:30	43
Los Tablones	21	27/07/2009	15:00 – 24:00	18
	22	28/07/2009	00:00 – 24:00	48
	23	29/07/2009	00:00 – 15:00	31
Total	**5**	**5 days**	**79.5h**	**160**

As explained in 3.4.1, for those aircraft noise measurements for which at least half of the measurement time only natural noise was present, the L95c metric could be used to estimate the background noise level with good accuracy. The following table gives an overview of those aircraft noise measurements which thus can be used to obtain background noise. A total of 55h of background noise has been recorded during these measurements. For further details on these sessions one is referred to section 3.5.

Table 3- 7 Summary of Background noise measurement from dedicated aircraft noise sessions

Ses	Meas	bgn (s)	Ses	Meas	bgn (s)	Ses	Meas	bgn (s)	Ses	Meas	bgn (s)	Ses	Meas	bgn (s)
1	3	2242	8	1	2628	12	1	2229	14	6	1994	17	9	2477
1	7	2532	8	2	2778	12	4	1965	14	7	2637	17	10	2300
2	2	2216	8	4	2155	12	5	1830	14	9	2408	17	11	2743
2	4	2036	8	5	2505	12	6	3013	14	10	1929	18	1	2988
2	5	1899	8	6	2293	12	7	2120	14	11	2610	18	3	2348
2	6	2726	8	7	2405	12	10	1946	15	2	2199	18	4	2782
2	7	2594	8	8	3036	12	11	2297	15	3	3160	18	6	2534
2	8	2797	8	9	2341	12	12	2035	15	6	2663	18	11	1963
2	9	2255	9	3	1863	12	13	3304	15	7	2081			
2	10	1882	9	6	3042	12	14	3014	15	8	2156			
3	4	2028	9	7	1811	12	15	2607	15	9	2225			
3	6	2406	9	8	1812	12	16	2850	15	10	2233			
5	6	2287	9	9	2472	12	17	3379	15	11	1879			
5	7	1878	10	4	2128	13	2	2215	16	1	2396			
5	8	2317	10	7	2958	13	4	1825	16	2	3081			
6	10	2246	11	1	1982	13	5	1924	16	4	2059			
7	6	1988	11	4	1880	14	2	2966	16	6	2268			
7	9	1954	11	8	2578	14	4	2338	17	6	1891			
7	11	2345	11	9	2436	14	5	2195	17	8	1921			

From Table 3-8 it can be seen that the total time available for the analysis of background noise is 134.5 hours, almost 50% more than the budgeted 90 hours. This time has been spread over 4 test sites and 22 days, covering a 5 months period.

Table 3- 8 Total nº hours of background noise measurement per test site

Test site	Nº hours
Diego Alvaro	31.5
Los Tablones	48
Cebreros	35
Colmenar de Oreja	20
Total	**134.5**

3.5. Overview of performed aircraft en-route noise measurements

3.5.1. Introduction

In the original plan 2 single operator sessions of around 7-8 hours each were envisaged. However, several issues made it impossible to follow this plan:

- due to the quite demanding attention the operator had to pay to monitor the tests (especially the aircraft events), a single operator was not able to perform at sufficiently high level of concentration during more than around 2 hours
- the test sites are located in remote areas, with practically no human presence and without cell phone coverage. For reasons of personal safety it was therefore necessary to perform the measurements with 2 team members.
- A significant reduction of air traffic was found after around 2 PM, only resuming late in the afternoon, with too short time left until dawn to justify remaining at the test site, especially in the early months of the measurements.
- In general wind is becoming marginally acceptable in the early afternoon, even in early spring.

It was therefore decided that a more practical way to proceed was to perform measurements in the morning and with 2 operators.

Although it was intended to perform all tests at the Cebreros site, it appeared necessary to move to the Colmenar site to avoid coinciding non-natural noise events, especially the presence of general aviation and helicopters, apart from the restrictions to continue due to environmental protection reasons (see section 3.1.3). A total of almost 1200 aircraft events was recorded during 18 sessions. A preliminary analysis of the data indicated that about 20% of the events would have to be rejected due to coincidence with other noise events of non-natural origin. Assuming that during the dedicated background noise levels also some aircraft events would be recorded, it was concluded that the objective of 1000 valid aircraft events would probably be covered. Therefore it was decided to discontinue the aircraft noise measurements and further concentrate on the background noise measurements, described above.

3.5.2. Measurements

The aircraft noise sessions performed at the various test sites are listed in the following table. Further details on each measurement are provided in section 5.

Table 3- 9 Summary of dedicated aircraft noise sessions

Test site	Session	Date	Time	Nº meas	Nº valid events		
					Detected IbaTrack	Not detected	Total
Cebreros	1	26/02/2009	13:15 - 16:45	7	28	17	45
	2	27/02/2009	11:18 - 16:49	11	41	18	59
	3	09/03/2009	09:23 - 13:59	10	48	23	71
	4	10/03/2009	09:20 - 13:58	9	36	15	51
	5	11/03/2009	08:55 - 13:08	9	42	14	56
	6	12/03/2009	09:31 - 14:13	11	42	30	72
	7	13/03/2009	09:24 - 14:00	11	44	17	61
	8	21/04/2009	08:38 - 13:38	10	56	12	68
	9	22/04/2009	09:20 - 13:51	9	56	9	65
	10	23/04/2009	10:40 - 14:10	7	36	15	51
	11	24/04/2009	09:17 - 13:47	9	46	7	53
	12	18/05/2009	08:47 - 17:18	17	83	10	93
	13	19/05/2009	09:22 - 12:28	7	26	9	35
Colmenar de Oreja	14	02/06/2009	09:46 - 14:47	11	37	13	50
	15	03/06/2009	08:49 - 14:20	12	45	14	59
	16	11/06/2009	08:47 - 13:59	11	51	14	65
	17	30/06/2009	09:00 - 14:33	11	38	9	47
	18	01/07/2009	08:56 - 14:31	11	47	8	55
Total	**18**	**18 days**	**88h**	**183**	**802**	**254**	**1056**

Apart from these dedicated sessions also some aircraft events have been recorded during the background noise sessions.

Table 3- 10 Summary of Aircraft noise events from dedicated background noise sessions

Test site	Session	Date	Time	Nº meas	Nº valid events		
					Detected IbaTrack	Not detected	Total
Diego Alvaro	19	18/07/2009	14:00 – 24:00	20	9	4	13
	20	19/07/2009	00:00 – 21:30	43	17	11	28
Los Tablones	21	27/07/2009	15:00 – 24:00	18	1	8	9
	22	28/07/2009	00:00 – 24:00	48	3	3	6
	23	29/07/2009	00:00 – 15:00	31	3	3	6
Total	**5**	**5 days**	**79.5h**	**160**	**33**	**29**	**62**

A total of 1118 valid aircraft events has thus been obtained, which is well above the target of 1000 valid events. More details on these aircraft events and their distribution over the flight phases and aircraft classes is provided in section 5.

References

[1] EASA
Specifications attached to the Invitation to Tender EASA.2008.OP.14 – BANOERAC
July 2008

[2] Anotec Consulting / Labein-Tecnalia
Proposal for the performance of the BANOERAC project
Anotec Doc OAN074-1-1 – September 2008

[3] SINTEF ICT
Background noise levels in Europe – June 2008

[4] Anotec Consulting
Initial study on aircraft cruise noise levels
Anotec Doc PAN069-1-2 – May 2008

[5] International Civil Aviation Organisation (ICAO)
Annex 16 to the convention on international civil aviation,
Volume I, Aircraft Noise, Fourth Edition - July 2005

[6] International Civil Aviation Organisation (ICAO)
Environmental Technical Manual on the use of procedures in the noise certification of Aircraft (Third Edition – 2004) - ICAO Doc 9501

ANOTEC Consulting, S. L.
aircraft noise technology

Security class	Document ID	Issue no.	Short Title	Issue date	Page
Restricted	PAN074-5-3	3	Final Report - Part 3	06/11/2009	1 of 70

Project		Document Title
AN074	BANOERAC	D1. Final report Part 3: Data Analysis and Results

Summary

This report describes the work performed within the BANOERAC project.

In this Part 3, elaborated by Anotec, the data from the background noise and aircraft en-route noise measurements are analysed and the results discussed.

Document revision

Issue	Date	Affected pages	Modifications
1	15/08/2009	All	First issue
2	14/10/2009	All	Incorporation of EASA comments 21/09/2009
3	06/11/2009	All	Incorporation of EASA comments 06/11/2009

Controlled copies

Anotec	Customer	Other
Lib	EASA (Mr. Franken)	Labein

Approval status

Prepared by Project team	Approved by Head Engineering & Design	Verified by Responsible Airworthiness
Nico van Oosten Victoria Esteban	Nico van Oosten	N/A

TABLE OF CONTENT

LIST OF FIGURES

LIST OF TABLES

Introduction

Two developments in aviation industry will shortly have reached a phase where actual rulemaking work will have to commence. These developments are the preliminary studies on supersonic business jets and the revived interest in so called 'open rotor' engines. They have a common factor in that they will potentially create non negligible noise levels on the ground, not only when flying in the terminal area around airports but also while the aircraft are climbing, cruising and descending at distance from airports (hereafter referred to as "en-route noise"). If aircraft with such technology would be numerous, this would essentially mean that aircraft noise would be audible literally everywhere. The political discussion and the impact assessment will therefore require factual data on existing so called background noise levels and on actual noise levels of 'classical' aircraft in cruise in Europe and elsewhere. Such data will make it possible to put the noise levels of these new technologies in perspective with the existing situation.

EASA issued an Invitation to Tender (ItT) for a study on “Background noise level and noise levels from en-route aircraft”, with acronym BANOERAC [1]. The contract was awarded to the proposal from the consortium, formed by Anotec and Labein-Tecnalia, both from Spain [2]

Before the present study EASA contracted two pilot studies with direct relation to BANOERAC.

One study, performed by SINTEF [3], concluded that no data is readily available on existing background noise. It was reported however that a first approximation of the background noise levels can be derived from population density. The present project intends to use this concept to establish a detailed database of estimated background noise levels in Europe.

The other study, performed by Anotec [4], concluded that very little and mainly outdated information on en-route noise from aircraft was available, but that it would be possible to collect meaningful information with a measurement campaign. BANOERAC aimed at carrying out such measurements.

The aim of this study is to improve insight in background noise levels in Europe and the en-route noise from aircraft. It is realised though that the scope of the study does not allow to claim that the results would be representative for all of Europe.

According to the proposal the work performed was divided in 3 parts:

Part 1. Calculation of approximation of background noise levels
Calculation of background noise levels based on population density for each EU country, building on the SINTEF report and proposing some correction for extreme situations [3].

Part 2. Actual measurements of background noise and aircraft en-route noise
Measuring of actual noise levels in a number of locations representative for a quiet rural area, with very low levels of background noise from man-made sources.
Noise measurements from actual passages of aircraft that are en-route (i.e. climb, cruise and descent phases).

Part 3. Final analysis and results
Analysis of the measured data and presentation and discussion of the results for both background noise and aircraft en-route noise.

The project has been performed based on the following work breakdown structure:

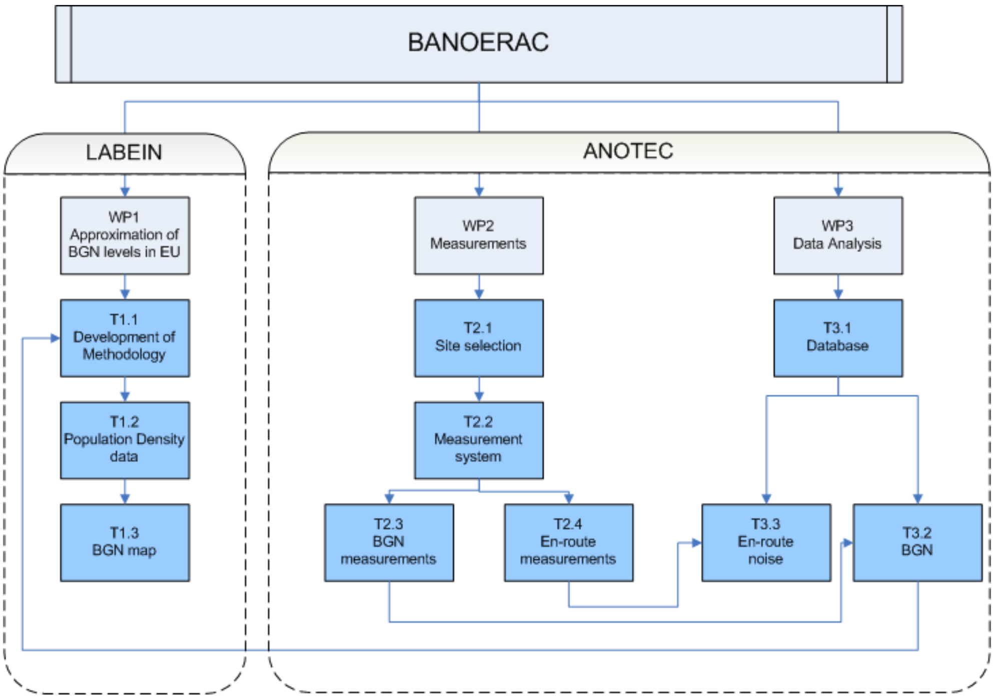


Figure 4- 1 Work breakdown structure

The present document describes the work performed in WP3.

Definitions

According to Appendix 3 of the ICAO Environmental Technical Manual [6] the following definitions related to background noise apply:

AMBIENT NOISE	The acoustical noise from sources other than the test aircraft present at the microphone site during aircraft noise measurements. Ambient noise is one component of background noise.
BACKGROUND NOISE	The combined noise present in a measurement system from sources other than the test aircraft, which can influence or obscure the aircraft noise levels being measured. Typical elements of background noise include (but are not limited to): ambient noise from sources around the microphone site; thermal electrical noise generated by components in the measurement system; magnetic flux noise (“tape hiss”) from analog tape recorders; and digitization noise caused by quantization error in digital converters. Some elements of background noise, such as ambient noise, can contribute energy to the measured aircraft noise signal while others, such as digitization noise, can obscure the aircraft noise signal.
POST-DETECTION NOISE:	The minimum levels below which measured noise levels are not considered valid. Usually determined by the baseline of an analysis “window”, or by amplitude non-linearity characteristics of components in the measurement and analysis system. Post-detection noise levels are non-additive, i.e., they do not contribute energy to measured aircraft noise levels.
PRE-DETECTION NOISE	Any noise which can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, recording / playback, and analysis systems.

In the context of the present project these definitions have been maintained. However, it is necessary to take the following into account when reading the report.

As mentioned in the Introduction, the main objective of Part 1 is to determine the **background noise** levels based on population density for each EU country. For higher population densities (and thus higher noise levels) this will be equivalent to the **ambient noise**, since noise levels will generally be significantly higher than the noise floor of the measurement system. Here it is noted that noise mapping software is predicting **ambient noise**. The measurements performed in quiet areas as part of the present study obviously provide **background noise** levels, since at these low levels instrumentation noise is relevant.

The lower limit of the curve is defined by the noise present in areas with no population at all. Although measurements were made in quiet areas, some population related noise was still present. In order to extract this noise, two additional terms had to be defined:

NATURAL NOISE	The acoustical noise from all non man-made sources, mainly wind and animals. Noise of e.g. barking dogs has been included in this group, recognising that in some cases a direct relationship might exist with human presence.
NON-NATURAL NOISE	The acoustical noise from all man-made sources. This includes noise from any transport system, human beings, spurious noise (e.g. that generated due to a cable problem), etc.

Following these definitions, the background noise defining the lower limit of the curve will thus correspond to the **natural noise**.

The objective of the background noise measurements performed in Part 2 of the study is thus the determination of the **natural noise** at the various test sites. This is done by excluding any **non-natural noise** from the measurements

The metric used to express background noise is L95, whereas L95c[1] is used for describing natural noise only.

[1] L95c is determined in the same manner as L95, except that only the 'natural noise' part of the measurement is used as the basis.

4. FINAL ANALYSIS

The main objective of Part 3 of the BANOERAC study is the analysis of the data obtained during the measurements of WP2, in order to establish actual background noise levels in various environments and also to determine the noise levels of current aircraft types when en-route.

As a first step all data from the measurements are stored in a central database and supplementary information is added with an off-line application. After this the data for background noise and aircraft en-route noise are processed and final results are derived.

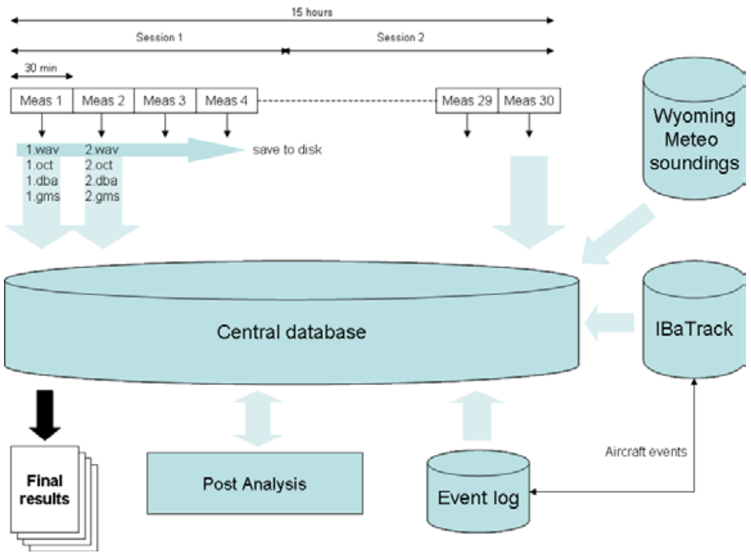


Figure 4- 2 Final analysis process

A more detailed description of the analysis procedures is given hereafter.

The final results are given in Section 5.

4.1. Description of the database

A central database was created where all data from the measurements are stored, together with the results of the analysis. This centralised storage greatly facilitates final analysis and reporting, allowing for various levels of aggregation.

The structure of this database reflects the various levels in the total procedure:

- Session data
- Measurement data
- Event data (noise and aircraft)

For all levels some data come from the measurements performed, whereas another part is provided during the final analysis.

The data stored in this database is given in Tables 4-1 and 4-2.

Table 4- 1 Data stored in database (Session and Measurement level)

Level: Session		
Provider	**Parameter**	**Description**
Log sheets	Session_ID	Unique identification of the session
	SessionType	Background noise or aircraft en-route noise measurement session
	Location	Test site name
	NMS1	Identification of Noise Measurement System 1
	Mic_Lat1	Latitude microphone 1 (decimal degrees WGS84)
	Mic_Lon1	Longitude microphone 1 (decimal degrees WGS84)
	Mic_Alt1	Altitude microphone 1 (ft)
	NMS2	Identification of Noise Measurement System 2
	Mic_Lat2	Latitude microphone 2 (decimal degrees WGS84)
	Mic_Lon2	Longitude microphone 2 (decimal degrees WGS84)
	Mic_Alt2	Altitude microphone 2 (ft)
	Operator	Name of operator
	Date	Date of session
	Ts_s	Start time of session (sec after midnight)
	Ts_e	End time of session (sec after midnight)
	tOffset	Difference in clocks of CPUs for noise and track due to non-sync (s)
Wyoming	Sounding_ID[i,j]	Unique identification of sounding for station i at time j
	Dates[i,j]	Date of atmospheric sounding for station i at time j
	Ts[i,j]	Time of atmospheric sounding for station i at time j (hour ZULU)
	T[i,j] (h)	Temp as a function of height for station i at time j (ºC)
	RH[i,j] (h)	Rel hum as a function of height for station i at time j (%)
	P[i,j] (h)	Pressure as a function of height for station i at time j (hPa)
	Dw[i,j] (h)	Wind dir as a function of height for station i at time j (º)
	Vw[i,j] (h)	Wind speed as a function of height for station i at time j (kts)
Post analysis	Sounding_ID	Id of the sounding representative for the atmospheric conditions during the measurements

Level: Measurement		
Provider	**Parameter**	**Description**
EMMA	Meas_ID	Unique identification of the measurement
	Session_ID	Identification of the session in which the measurement was performed
	Tm_s	Start time of measurement (sec after midnight)
	Tm_e	End time of measurement (sec after midnight)
NMS	SPL(ch,f,t)	1/3 oct spectra (10-10kHz) as a function of time for each channel (dB)
	LA(ch,t)	Instantaneous A-weighted noise level as a function of time for each channel (dBA)
	LA1k(ch,t)	Same as LA(ch,t), but with 1kHz cut-off (dBA)
	OASPL(ch,t)	Instantaneous linear noise level as a function of time for each channel (dB)
	OASPL1k(ch,t)	Same as OASPL(ch,t), but with 1kHz cut-off (dB)
GMS	T(t)	Temp at 1.8m as a function of time (K)
	RH(t)	Rel hum at 1.8m as a function of time (%)
	P	Pressure at 1.8m at beginning of measurement (mbar)
	Dw(t)	Wind dir at 1.8m as a function of time (º)
	Vw(t)	Instantaneous wind speed at 1.8m as a function of time (m/s)
	Vw30(t)	30 sec averaged wind speed at 1.8m as a function of time (m/s)
Post analysis	Valid(ch)	Measurement valid (Y/N) for each channel
	ReasonReject(ch)	Reason why measurement is not valid for each channel
	LAeq(ch)	30 min. equivalent noise level (A-weighted) for each channel (dBA)
	LAeqc(ch)	30 min. equivalent noise level (A-weighted), corrected for noise intrusions (incl. aircraft) (dBA)
	LAeq1k(ch)	Same as LAeq(ch), but with 1kHz cut-off (dBA)
	Leq(ch)	30 min. equivalent noise level (linear) for each channel (dB)
	Leqc(ch)	30 min. equivalent noise level (linear), corrected for noise intrusions (incl. aircraft noise) (dB)
	Leq1k(ch)	Same as Leq(ch), but with 1kHz cut-off (dB)
	L95(ch)	95% percentile of the full 30 min. measurement for each channel (dBA)
	L95c(ch)	95% percentile of the full 30 min. measurement, corrected for noise intrusions (incl. aircraft) (dBA)
	L951k(ch)	Same as L95(ch), but with 1kHz cut-off (dBA)
	L50(ch)	50% percentile of the full 30 min. measurement for each channel (dBA)
	L50c(ch)	50% percentile of the full 30 min. measurement, corrected for noise intrusions (incl. aircraft) (dBA)
	L501k(ch)	Same as L50(ch), but with 1kHz cut-off (dBA)
	nSc	Total nº of samples with only natural sound
	T	Average temp during the measurement (based on GMS data) (K)
	RH	Average rel hum during the measurement (based on GMS data) (%)
	P	Average pressure during the measurement (based on GMS data) (mbar)
	Dw	Average wind dir during the measurement (based on GMS data) (º)
	Vw	Average wind speed during the measurement (based on GMS data) (m/s)

It should be noted that at event level two parts are distinguished to simplify the database structure: the noise event and the aircraft event. A noise event is defined as any acoustical event (intrusion), caused by one or more noise sources (natural or non-natural). An aircraft event is generated when an aircraft is passing by the microphone. In this context an aircraft event is geometry related. One or more aircraft events may be the cause of, and thus assigned to, of a single noise event. However, an aircraft event can only be responsible for a single noise event.

Table 4- 2 Data stored in database (Event level)

Level: Noise event		
Provider	**Parameter**	**Description**
Event logger + off-line check	Event_ID	Unique identification of the noise event
	Meas_ID	Identification of the measurement in which the event occurred
	Te_s	Start time of event (sec after midnight)
	Te_e	End time of event (sec after midnight)
Log sheets + Off-line check	AC	Event contains at least one aircraft with known callsign (Y/N)
	noIDT	Aircraft class for non-identified aircraft (i.e. no ADS-B) (None/class(i))
	noIDP	Flight phase for non-identified aircraft (i.e. no ADS-B) (None/CL/CR/DE)
	Heli	Noise from helicopter was audible during the event (Y/N)
	GA	Noise from general aviation (small prop aircraft) was audible during the event (Y/N)
	Car	Noise from motorised vehicle was audible during the event (Y/N)
	Voices	Voices were audible during the event (Y/N)
	OtherNN	Other non-natural noise sources were audible during the event (Y/N)
	Wind	Wind noise was audible during the event (Y/N)
	Birds	Birds were audible during the event (Y/N)
	OtherNat	Other natural noise sources were audible during the event (Y/N)
	Obs	Any observation relevant for the event (if any)
Post analysis	SEL(ch)	SEL of event (if possible) for each channel (dBA)
	SEL1k(ch)	Same as SEL(ch), but with 1kHz cut-off (dBA)
	LAmax(ch)	Max A-weighted level of the event for each channel (dBA)
	LAmax1k(ch)	Same as LAmax(ch), but with 1kHz cut-off (dBA)
	Lmax(ch)	Max linear level of the event for each channel (dB)
	Lmax1k(ch)	Same as Lmax(ch), but with 1kHz cut-off (dB)
	TendB(ch)	10-dB down interval detected (no:-1 / yes:1) for each channel
	Vw30_av	Average 30 sec averaged wind speed during event (m/s)
	Vw30_max	Max 30 sec averaged wind speed during event (m/s)
Level: Aircraft event		
Provider	**Parameter**	**Description**
Log sheets + off-line check	Audible	The aircraft event was audible (Y/N)
	Event_ID	Noise event to which this aircraft event is assigned
IBaTrack	Air_ID	Unique identification of aircraft event
	Mode-S	Mode-S identifier of aircraft
	CallSign	Call-sign (flight number) of aircraft
	Sign	Registration number of aircraft
	Manuf	Manufacturer of aircraft
	Model	Aircraft model
	Flight_phase	Flight phase (Climb, Cruise, Descent)
	T_cpa	Emitted time at closest point of approach (CPA) (sec after midnight)
	Trec_cpa	Received time at closest point of approach (CPA) (sec after midnight)
	Lat	Aircraft Latitude @CPA (decimal degrees WGS84)
	Lon	Aircraft Longitude @CPA (decimal degrees WGS84)
	Alt	Aircraft Altitude @CPA (ft)
	Dist	Distance (slant range) from mic1 to CPA (m)
	Dist_H	Horizontal distance from mic1 to CPA ("lateral deviation") (m)
	e	Vertical distance from mic1 to CPA (m)
	Elev_angle	Elevation angle of aircraft rel. mic1 @CPA (º)
	ROC	Rate of Climb around CPA (ft/min)
	Track	Nominal track of aircraft during event (true heading) (º)
	Speed	Aircraft speed @CPA (kts)
Post analysis	Valid	Event can be used for final analysis (Y/N)

4.2. Improvements to the original analysis procedure

During the initial analysis it became apparent that some improvements to the proposed analysis procedure were required in order to guarantee the level of quality to be expected from the present study. In addition they would allow for an extension of the exploitation of the final results and for the provision of valuable information for potential future studies.

Hereafter these improvements are described in more detail.

4.2.1. Use of an additional noise metric

According to the original plan, the analysis should be based on intrusions, defined as those events with a LA level 5 dB(A) or more over L95. The following graph shows a typical measurement, with in light green the LA level as a function of time. It can clearly been seen that no useful information can be obtained from this signal.

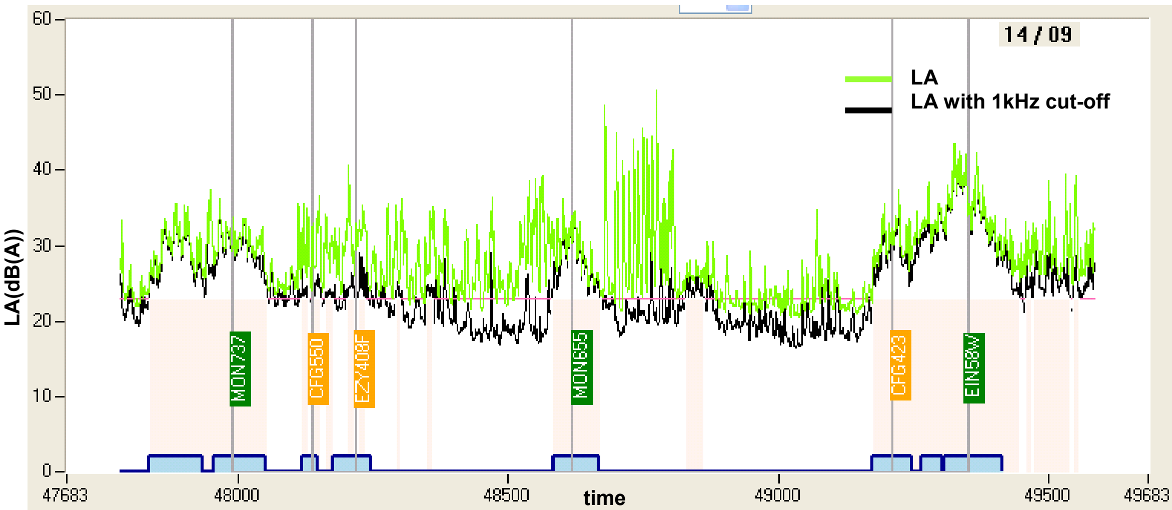


Figure 4- 3 Typical measurement

A more detailed analysis, including replay of the original wav file, revealed that this behaviour was completely due to the high frequency noise generated by birds as shown in the following instantaneous spectrum.

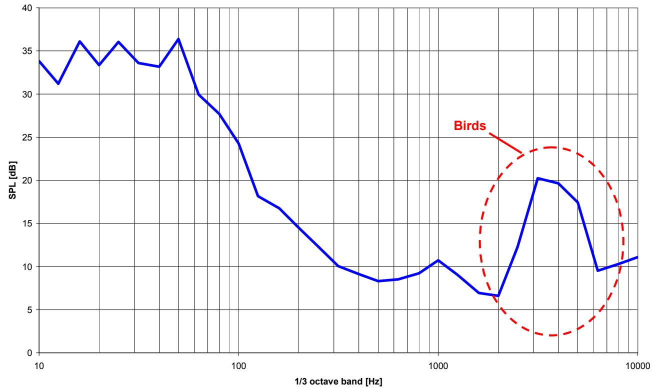


Figure 4- 4 High frequency noise generated by birds

During the measurements it was observed that the recorded aircraft noise does not have any relevant frequency contents above 1 kHz, due to atmospheric absorption.

Based on this another metric was investigated, the so-called LA1k metric, which is the overall level of the A-weighted spectrum, from 10 to 1000 Hz. The higher frequency part is thus not taken into account in this metric. Figure 4-3 shows this metric in black. It can be seen that now the various aircraft events clearly appear.

A perfect case to proof the validity of this proposed metric was found in an event of an A-340 flying at night over the Diego Alvaro site. Background noise at that instant was very low, close to the system noise. The following graph presents the time history of the corresponding measurement.

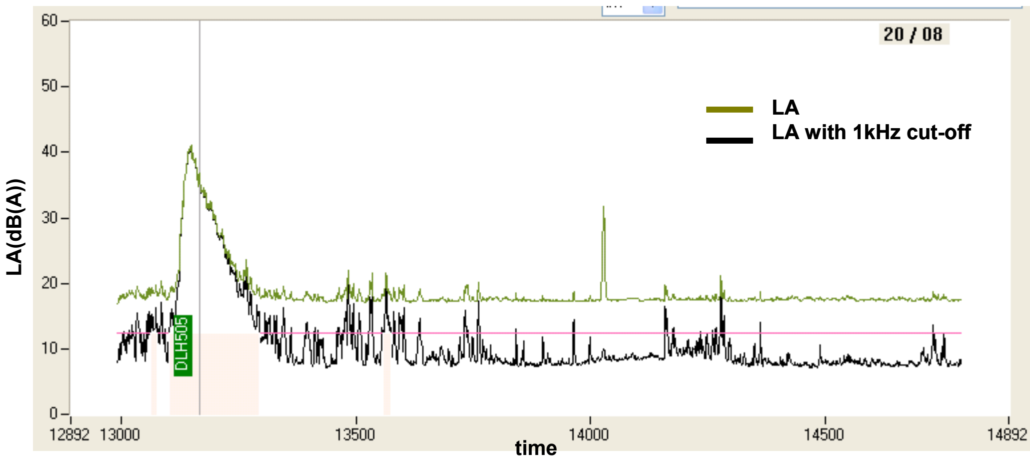


Figure 4- 5 Standard LA metric and LA1k metric.

The green line represents the standard LA metric, whereas the black line corresponds to the LA1k metric. Obviously outside the event the LA level remains higher (at 17 dB(A)) due to the system noise at high frequencies. The following graph zooms in on the aircraft event. It can be clearly seen that during the event both metrics fully coincide.

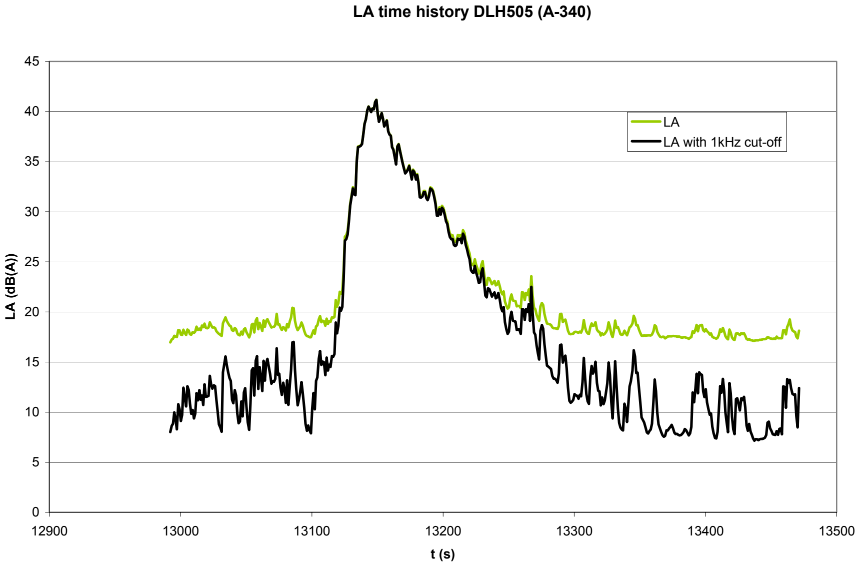


Figure 4- 6 Coincidence of LA and LA1k metrics during the event

The following graph shows the same measurement, but now expressed in linear weighting. The green line shows the OASPL based on the whole spectrum, whilst the black line represents the OASPL1k (i.e. based on the spectrum from 10 to 1000 Hz). Both time histories fully coincide.

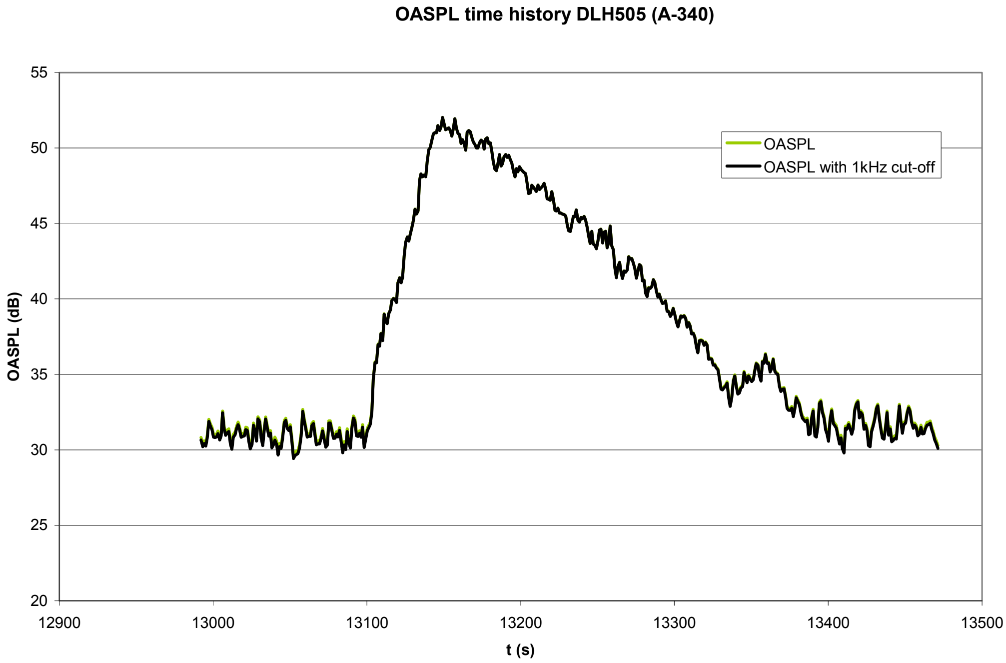


Figure 4- 7 Coincidence of OASPL and OASPL1k during the event

The instantaneous 1/3 octave spectra at LAmax and the 10 dB down points are plotted in the following graph.

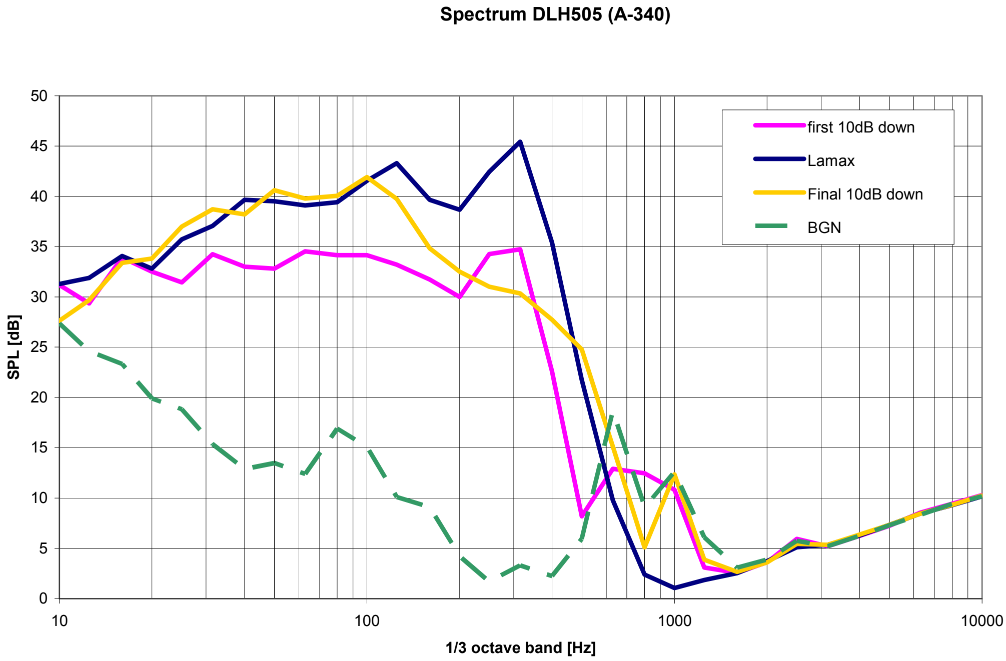


Figure 4- 8 Instantaneous spectra at various time instants

It can indeed be seen that above 1 kHz the recorded noise is almost equal to the system noise. Replay of the event revealed that the noise at mid frequencies was due to a barking dog far from the test site. The instantaneous spectrum of a time instant far from the aircraft event confirms that this noise is not aircraft related.

To further illustrate the equivalency between both metrics for aircraft en-route noise purposes, the following metrics have been calculated for the above event:

Table 4- 3 Equivalence between metrics

Metric	Microphone	
	Inv	1.2m
SEL	55.38	53.22
SEL1k	55.25	53.08
LAmax	41.18	38.65
LAmax1k	41.17	38.63

The very small difference of 0.1 dB(A) in SEL can be explained by the observed noise from the dog. LAmax and LAmax1 can be deemed equal.

In Appendix 3-1 a more theoretical approach is followed to further demonstrate the equivalency between LA and LA1k for aircraft en-route noise.

It is concluded that the LA and LA1k based metrics will give equivalent results under low background noise conditions. The advantage of the improved metric, however, is that it can be used in environments with significant high frequency background noise like that encountered during the present tests.

For the analysis of the aircraft en-route noise measurements the LA1k based metric will be used. For background noise the standard LA will obviously be used. However, for potential future studies both LA and LA1k based metrics are included in the database for all cases.

4.2.2. Improved procedure to detect intrusions

In the original plan the analysis was intended to be based on the concept of intrusion, the definition of intrusion being a noise event with levels above the L95+5dB threshold. The following graph shows a typical measurement, with the intrusions as defined above indicated with the salmon shaded areas.

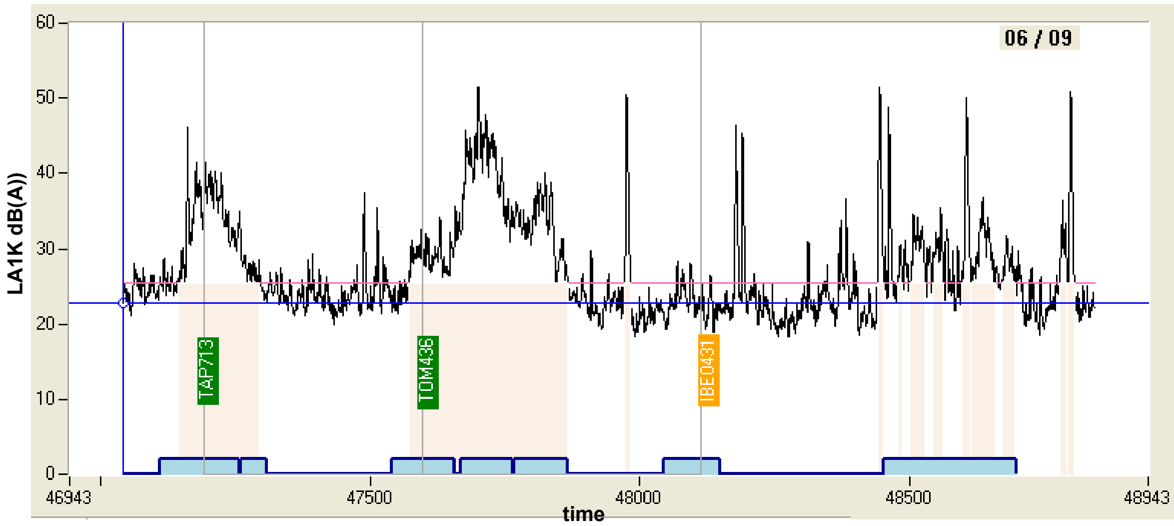


Figure 4- 9 Detection of intrusions

The pink horizontal line is the L95+5 threshold, above which an intrusion is detected. All intrusions with a duration of less than 10 seconds have been removed (thus avoiding pass-by noise of bees, etc.). When analysing the detected intrusions we can observe the following.

It can be seen that the first aircraft event (TAP713) is covered correctly. However, the second intrusion in reality is a combination of several events: first TOM436, then a firefighter aircraft and finally a non-identified aircraft in cruise (all according to the log sheets). Later in the measurement the opposite occurs: a single aircraft event (a small GA aircraft) is distributed over 7 intrusions, since its level crosses the threshold several times.

The events, logged during the measurement by the operator, are plotted at the bottom of the same graph, in blue. Each step represents an event. This may be an aircraft pass-by, a car, or any other noise the operator considers relevant. Indeed the actual occurrences during the measurement are covered well with these events.

Based on the above, it was considered necessary to determine the intrusions based on the events logged during the measurements, rather than on the originally planned L95+5 threshold. An off-line tool was developed with which the user could manually/visually adjust the start and end time of the events. With the additional information provided by the plots and the replay of the recording, the user was thus able to correct possible operator errors and to add new events, if so required, thus offering great flexibility to get the optimum description of the event.

The calculation of final noise levels (LAmax, LAeq, SEL, etc.) is based on this final set of events.

4.2.3. Separation of noise events

A non-negligible amount of aircraft events appeared to coincide in the same time frame with other non-natural sources (aircraft or other). In order to maximise the usability of the information gathered, these events were split up, if possible, so as to contain a single aircraft each. The following graph shows the pass-by of 8 aircraft in a period of 30 minutes. Two of these aircraft events (EZY1924 and MON013) appear to be quite close in time.

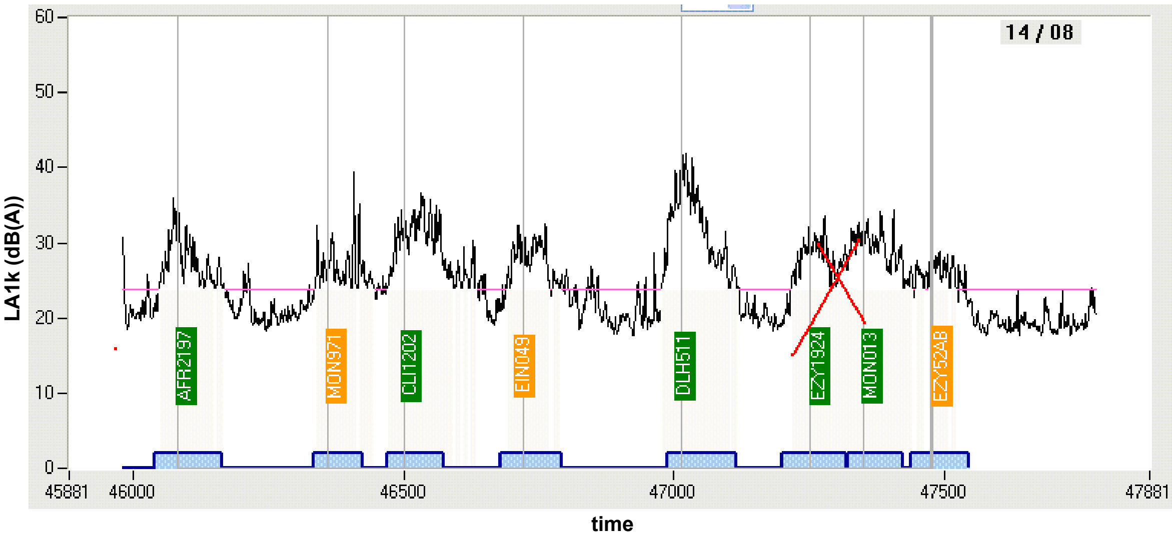


Figure 4- 10 Separation of noise events

First the time history of EZY shows a maximum, after which noise reduces, until the following aircraft enters and increases the noise again. Obviously the lack of a distinct 10dB down period results in difficulties to determine integrated metrics like SEL. However, the LAmax of both aircraft can be determined with good accuracy, since the noise from the other aircraft (approximated by the red line) is more than 10 dB below the maximum, thus not contributing significantly to the maximum level.

The validity of this visual separation can be shown by the indicated events (blue steps at the bottom of the graph), logged by the operator during the tests. During the measurements it was frequently possible to audibly distinguish the noise from two aircraft by its spectral contents and also by the direction it came from, together with the visual position information. In these cases the operator was instructed to start a new event, when the noise clearly shifted from one to the next aircraft. In the above graph it can be seen that these events coincide very well with the visual separation described earlier.

During the final analysis the above procedure has been used to separate nearby events.

4.2.4. Extension of the range of elevation angles

In the original plan only events within a +/- 30º cone above the microphone (i.e. elevation angles > 60º) were to be considered. However, during the measurements in the field it was noticed that the noise from aircraft well beyond this constraint was clearly audible.

Since the main objective of this study is to obtain measured data of actual noise levels from aircraft en-route as received on the ground, it seems sensible to include all relevant data, even if this is originating from points beyond the original, quite arbitrarily set, limit. In addition, by allowing datapoints with lower elevation angle, the information obtained would also facilitate a wider future exploitation of the dataset (e.g. long range propagation modelling).

In order to be able to set a reasonable limit which takes into account the audibility of the signal received, the following investigation was done.

The following chart presents the datapoints of all aircraft detected within a distance of less than 20 km from the microphone, expressed in elevation angle as a function of distance. Aircraft flying at less than 3000ft above the microphone are considered not to be in the en-route phase. These have been removed from the dataset. The group on the right side represents aircraft in cruise (the use of Flight Levels can clearly be seen there). The group at the left represents aircraft in descent or climb. Since one of the test sites was not too far from Barajas airport, low elevation angles can be found, mainly representing approaches.

A third dimension was added to this plot by indicating the audibility of the aircraft event. During the measurements the operators were instructed to note in the log sheets if a detected event was audible or not. This information was passed to the graph. The events which were labelled as audible are plotted in green, whereas the red points indicate that the event was not audible.

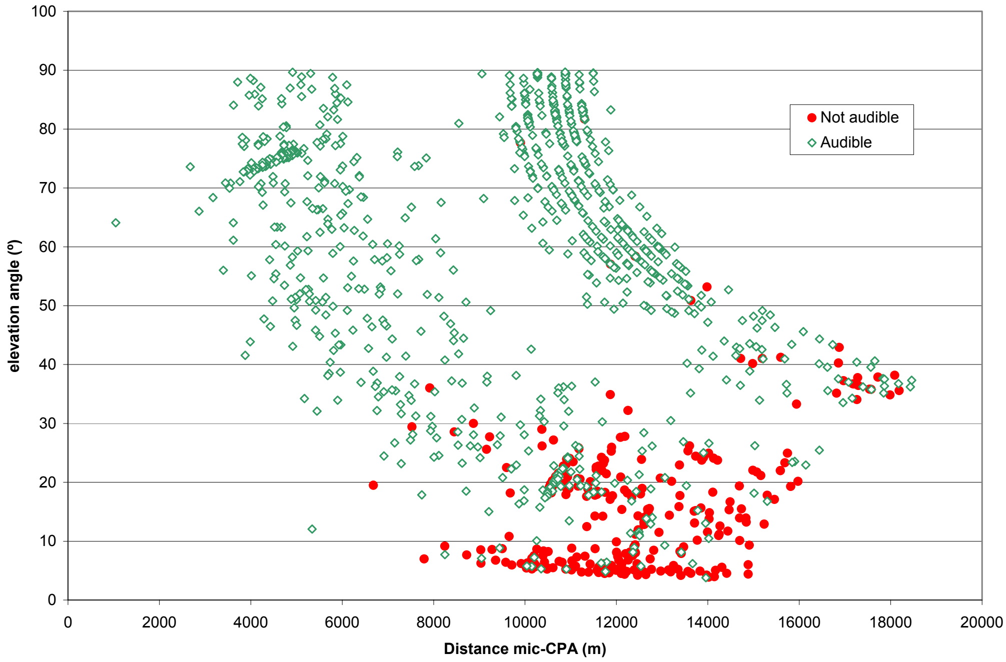


Figure 4- 11 Audibility related to distance and elevation angle

A clear trend can be observed in which the audibility reduces with reduced elevation angle. In order to link the audibility to elevation angle the following graphs have been derived from the same dataset. Six groups of elevation angles, each 15º wide, were defined. The following graph shows the percentage of the events in each group which were audible. It can be seen that from 15º onwards, at least half of the events is audible.

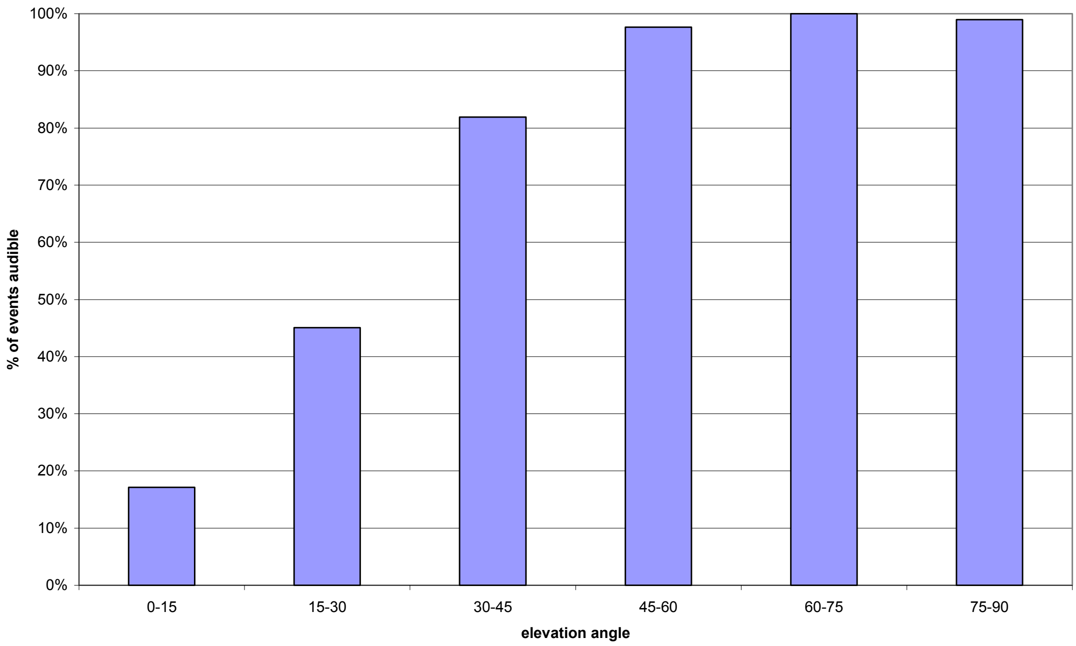


Figure 4- 12 Percentage of audible events per elevation angle interval

Another manner in which this data can be viewed is by plotting the percentage of the total number of audible points which is covered above a certain limit. Here it can be seen that for a lower limit of 30º around 85% of all audible points is taken into account, whereas for a limit at 15º this amount rises to 97%.

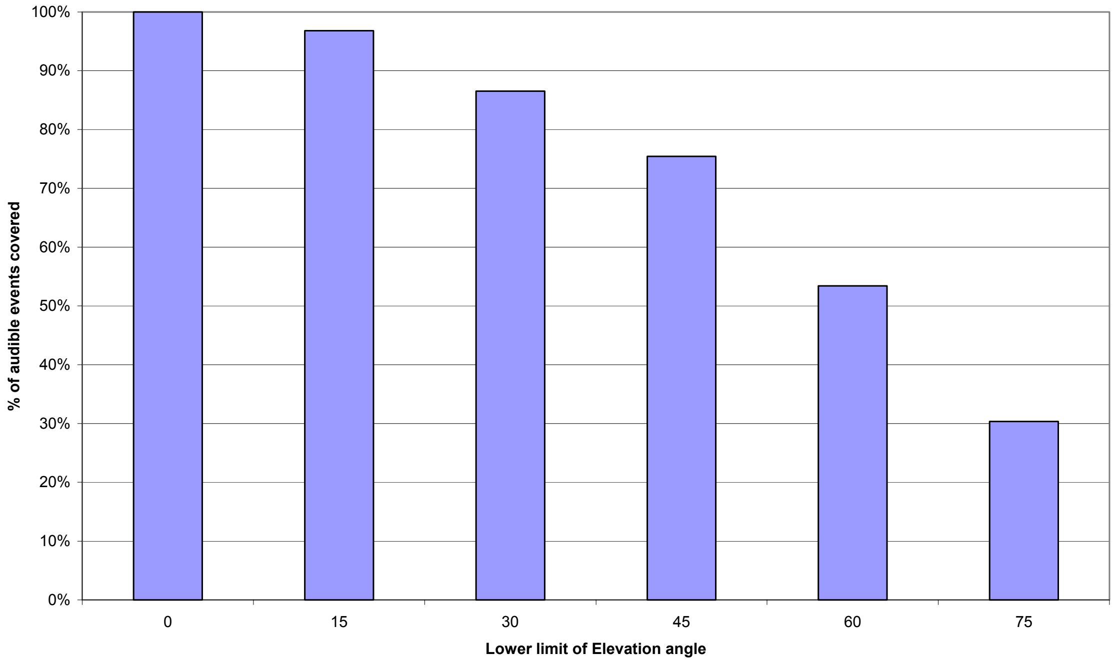


Figure 4- 13 Percentage of audible events covered per lower limit of elevation angle

From SAE AIR-5662, adopted by ECAC in Doc29 3rd edition, it can be deduced that for elevation angles above 30º the lateral attenuation will be limited to less than 1 dB, whereas for 15º the lateral attenuation will be at most 2 dB.

Considering the above and also anticipating on the scatter observed over the whole range of datapoints (see section 5), it can be concluded that a 15º limit to the elevation angle appears to be reasonable, corresponding well with the audibility as observed during the tests.

In the final analysis this limit of 15º has been applied. It should be noted that all events above this limit (both audible and not-audible) have been considered in the analysis, in order to avoid a biased result.

4.3. Analysis procedure

The analysis procedure is the same for the background as for the aircraft en-route noise measurements. The following flowchart provides a schematic overview of the various steps followed during the analysis. These steps are further described hereafter.

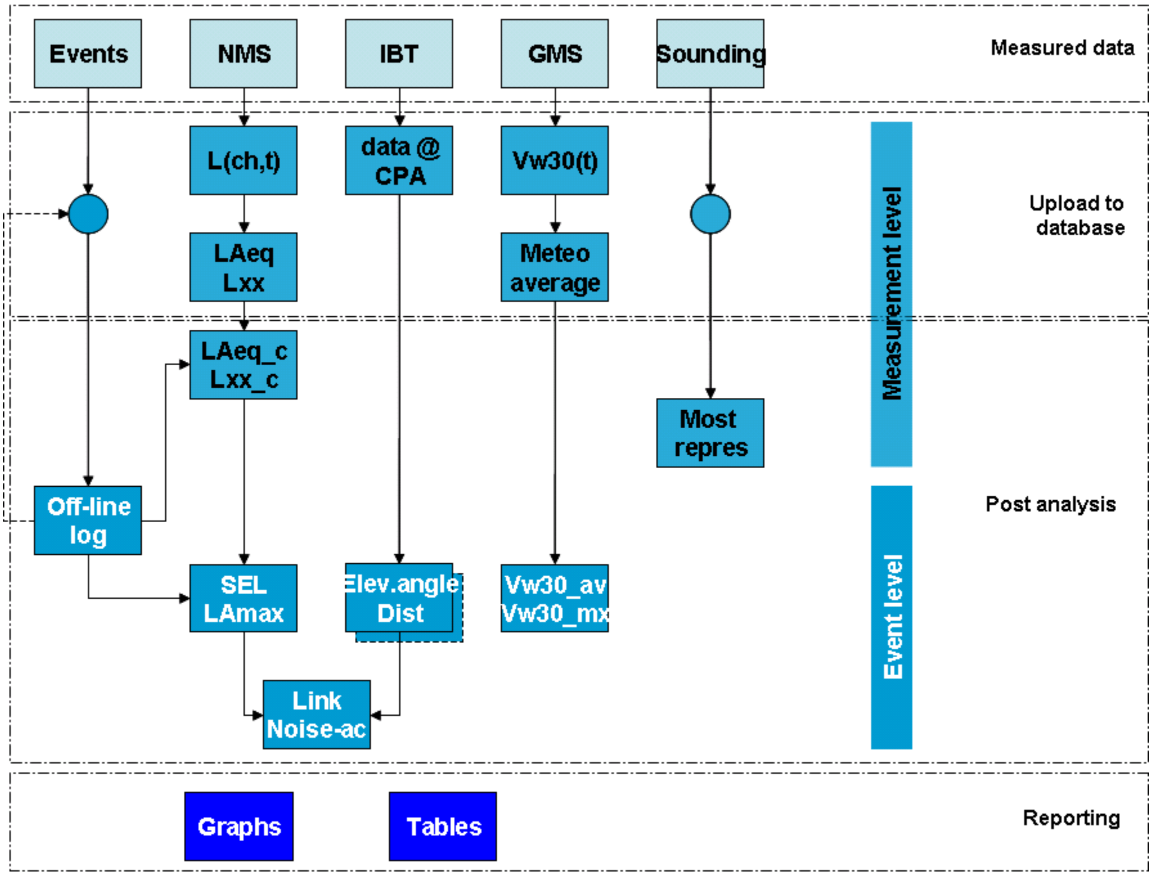


Figure 4- 14 Analysis procedure flowchart

4.3.1. Upload to the database

All measured data was uploaded to the central database by a specific tool. Apart from storing the as measured data in their corresponding tables, also some additional parameters were calculated and stored in this step.

The data from the events logged during the measurements with the event logger (i.e. start and end time and id of each event) were stored directly in the database.

For the noise measurements the LA, LA1k, OASPL and OASPL1k levels were calculated for each time instant of the measurement and for both channels. Based on these time histories the time averaged LAeq, LAeq1k, Leq and Leq1k were calculated for each measurement, together with the corresponding percentiles L95, L951k, L50 and L501k.

The aircraft data from the IBaTrack system was reduced by first filtering only those events which were within a radius of 20 km from the measurement position and at an altitude of more than 3000 ft above airport elevation. For each of the resulting events the point where the aircraft was closest to the inverted microphone was then determined (closest point of approach or CPA). At this CPA the relevant geometrical parameters like elevation angle, slant distance, horizontal distance, height above the microphone, etc. were calculated. Also the average of other parameters like speed, rate of climb and track around this CPA and the flight phase were determined. A record was then added to the database with all relevant information of the aircraft event (identification + geometrical and other info at CPA). The following figure illustrates the geometrical parameters obtained.

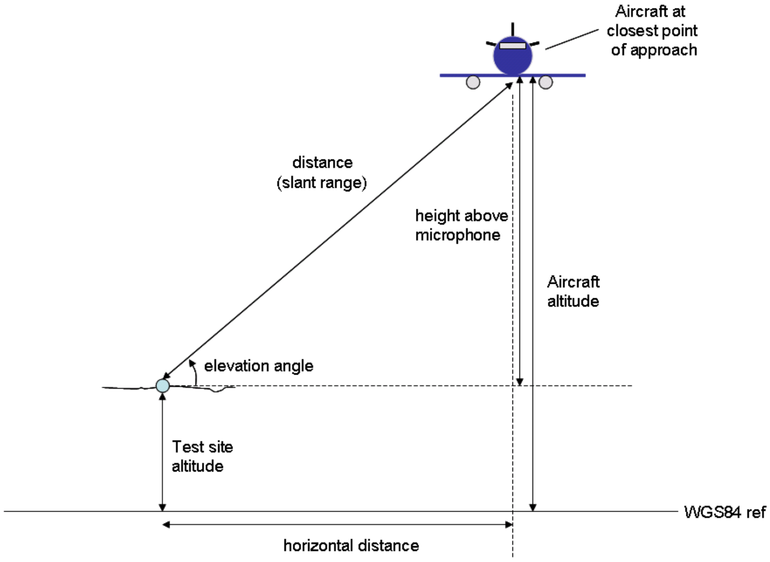


Figure 4- 15 Definition of geometrical parameters

The measured ground meteo data contains instantaneous wind speed. During the upload of these data to the database the 30 second averaged wind speed was added for each time instant. During the upload process also the average values for each measurement were determined. These average values were checked against the applicable limits:

- relative humidity not higher than 95 per cent and not lower than 20 per cent
- ambient temperature not above 35°C and not below 2°C;

The limit check on wind speed is done at event level, rather than at measurement level.

The sounding data downloaded from the Wyoming site was directly stored in the database.

4.3.2. Post analysis

After the initial storage of the data into the central database and the addition of the parameters as described above, supplementary data was obtained during the post analysis phase.

The first step in this phase was the check on the events and, if deemed necessary, the adjustment of the event interval and/or the addition of an event. Also in this stage the data recorded by the operator in the paper log sheet was added. This data is mainly referring to the identification of the source(s) responsible for a certain noise event. In the case of doubt, the recording could be replayed so as to enable the user to get also an auditive impression of the event and thus to improve the interpretation of the measurement.

To facilitate this labour intensive task, a specific dataviewer tool was developed. Screen shots of this application were used in section 4.2.

Once all additional data of each event was provided and the event intervals fully defined, these were then stored in the database together with the already available data from the former step (4.3.1).

Since now the characteristics of each event are known, some additional noise parameters could be calculated. For each measurement the noise of each event of non-natural origin was removed and for the remaining part the corrected LAeqc, Leqc, L95c and L50c were calculated. Also the total duration of the remaining part was determined.

For each session the most representative sounding was determined by considering the average wind direction over the session, the time of day and the position (direction and distance) of the sounding stations relative to the measurement position. For the sessions at Cebreros and Colmenar de Oreja always the soundings of the Madrid station were used due to its vicinity to both test sites (65 and 45 km resp.). For the background noise sessions, which were performed at locations not close to any sounding station, the closest upwind station was used. By coincidence this always appeared to be the Gibraltar station. It is noted that the data of all sounding stations has been stored in the database, independent of the selection of the most representative sounding as presented here.

At this stage all data at measurement level has been determined. The analysis of the background noise measurements finished here.

From here the analysis continued on event level for the measurements with aircraft events.

For each noise event the SEL, SEL1k, LAmax, LAmax1k and Lmax were calculated for each channel, based on the time interval defined earlier and the noise-time histories stored in the first phase. If the 10 dB down interval could not be determined during the SEL calculation, this is indicated in the database.

For each noise event the corresponding aircraft event(s) were then determined. If a noise event was shared by 2 or more aircraft events this is indicated in the database and these aircraft events were labelled invalid. If the aircraft event was assigned to a noise event which contains other noise sources of non-natural origin which affect the final aircraft noise levels, the aircraft event was also labelled not-valid. In all other cases the event was deemed valid.

For each noise event the average and maximum of the 30s averaged wind speed over the event interval were determined and checked against the limit of 19km/h (10 kts or 5.14 m/s). If this limit is exceeded, the corresponding aircraft event was labelled not valid.

The valid aircraft events were then used for the determination of the final results as part of the reporting phase (see section 5).

4.4. Resulting data

All measurements were analysed in the manner described above. The results from this analysis are provided in tables in the following Appendices:

- App. 3-2. Final data on measurement level
- App. 3-3. Final data on noise event level
- App. 3-4. Final data on aircraft event level (only aircraft detected with IbaTrack)
- App. 3-5. Final data on aircraft event level (aircraft not detected with IbaTrack)

4.5. Dataviewer

A dataviewer application was developed to facilitate the visualisation of the data. This software is provided on the DVD. The user manual is provided in Appendix 3-9.

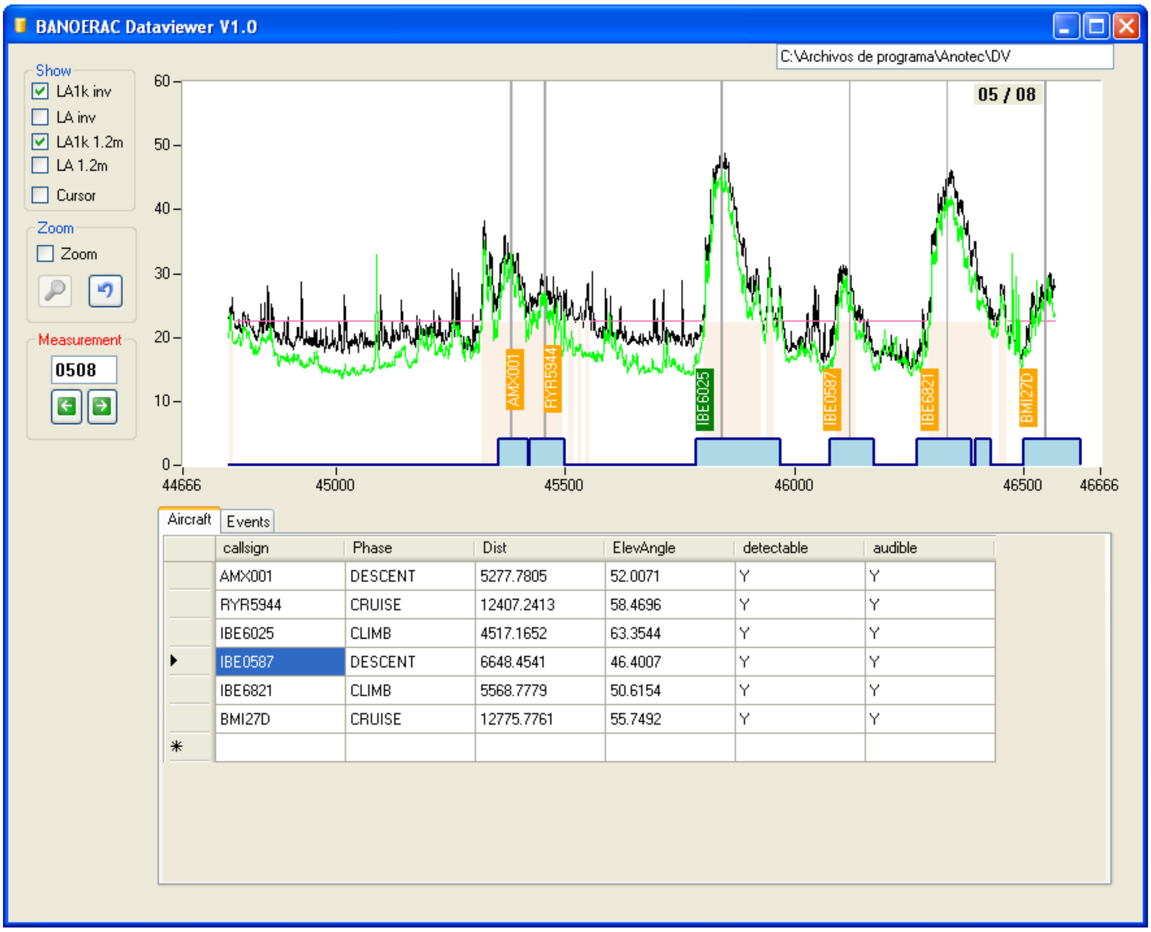


Figure 4- 16 Screenshot of Dataviewer

5. RESULTS FOR BACKGROUND NOISE

The results for the background noise measurements are based on the data provided in Appendix 3-2.

5.1. Measurement results

For each measurement made during the dedicated background noise sessions, the average meteo conditions and all relevant noise levels have been calculated according to section 4.3. Hereafter these data are presented for both tests sites visited.

5.1.1. Meteo

The meteo conditions as monitored during the tests are provided for both test sites.

Diego Alvaro (sessions 19 and 20)

During the almost 32 hours of measurements at this test site the meteo conditions were within the limits. The temperature on the first day was moderate, whereas on the second day it had increased by about 5ºC. Between day and night a difference of more than 20ºC was observed, which is typical for the continental climate at this test site.

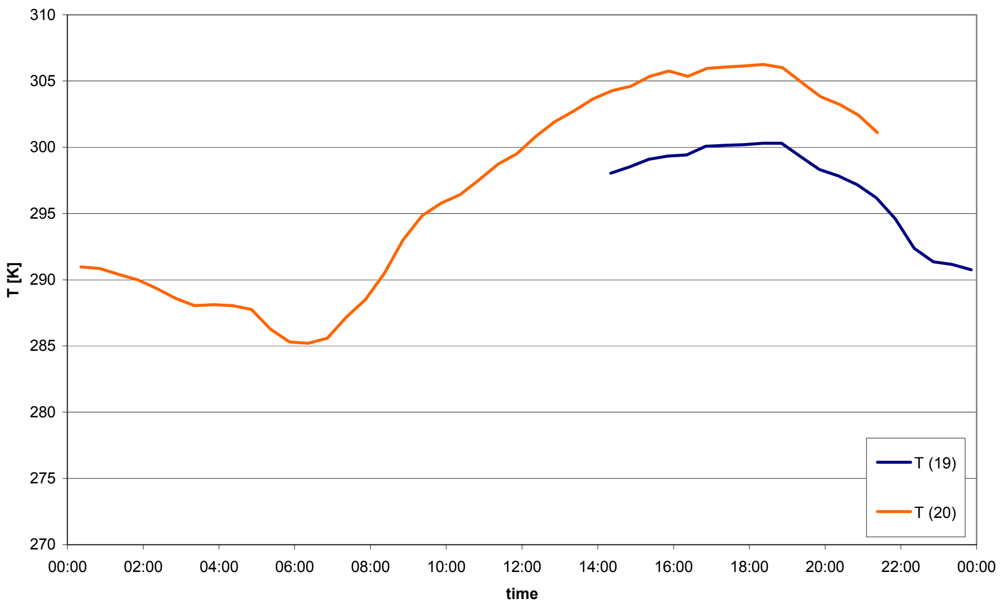


Figure 5-1 Diego Alvaro. Temperature at 1.8 m

The relative humidity ranged from just over 20 to 50%, in phase with the ambient temperature.

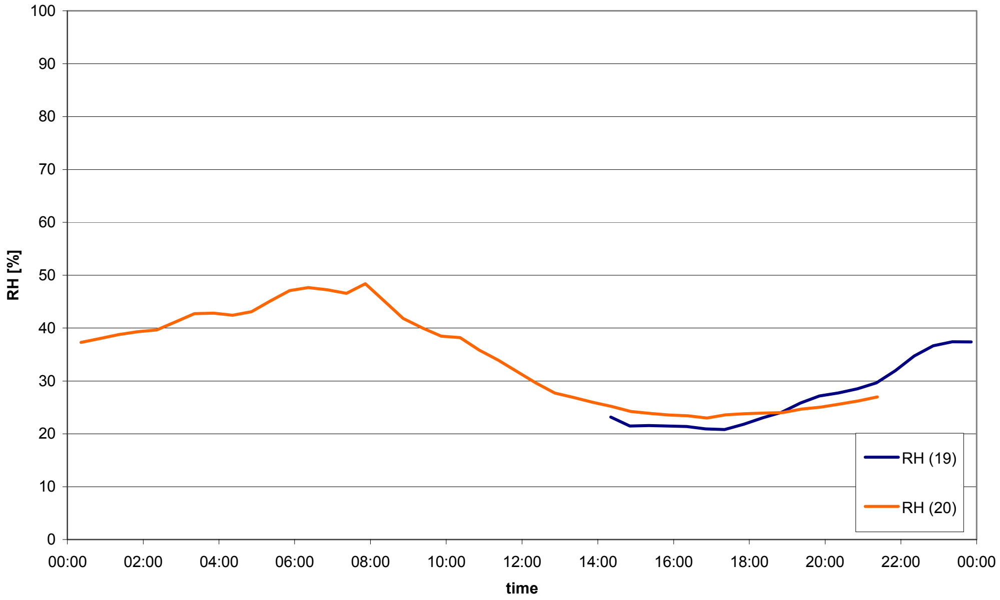


Figure 5- 2 Diego Alvaro. Relative Humidity at 1.8 m

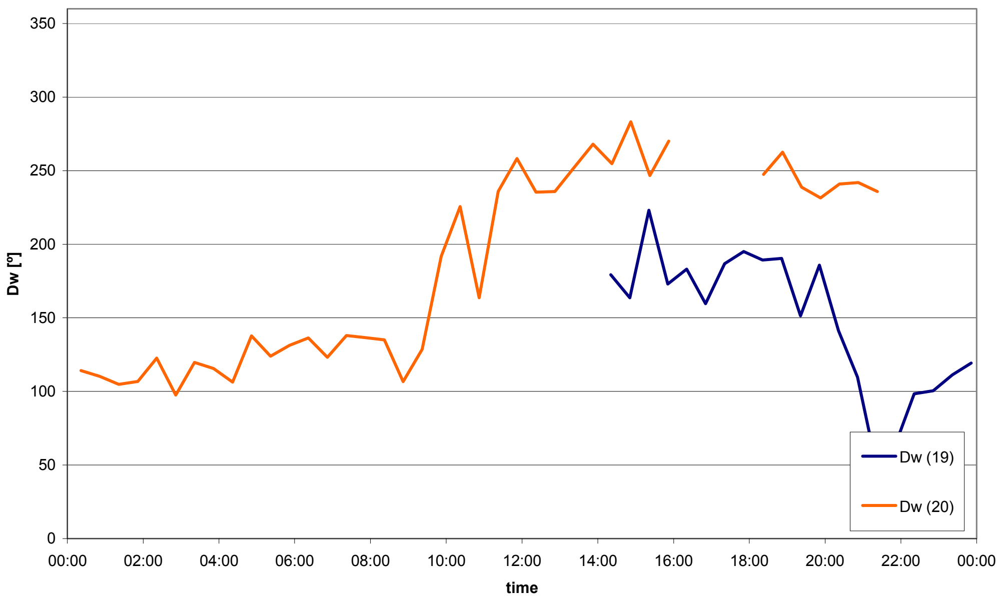


Figure 5- 3 Diego Alvaro. Wind direction at 1.8 m

Wind during night was almost zero, whereas during the day some south-westerly wind was present due to heating up of the atmosphere. During a very short period in the afternoon of the second day a tornado type event happened at very small scale, which damaged the cabling of the wind sensor. After repair the measurement of wind speed and direction was resumed. It is interesting to see that the evolution of wind speed over time on the two days coincide very well.

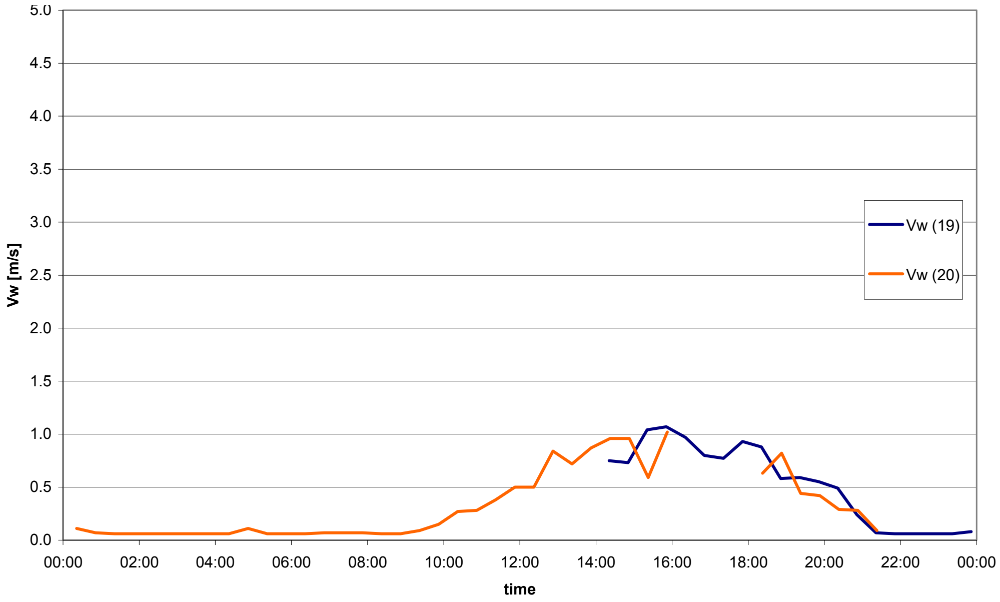


Figure 5- 4 Diego Alvaro. Wind speed at 1.8 m

<u>Los Tablones (sessions 21 to 23)</u>

During the 48 hours of measurements at this test site the meteo conditions were within the limits, although especially on the second day the temperature was approaching the upper limit. The first and third day the temperature remained somewhat lower.

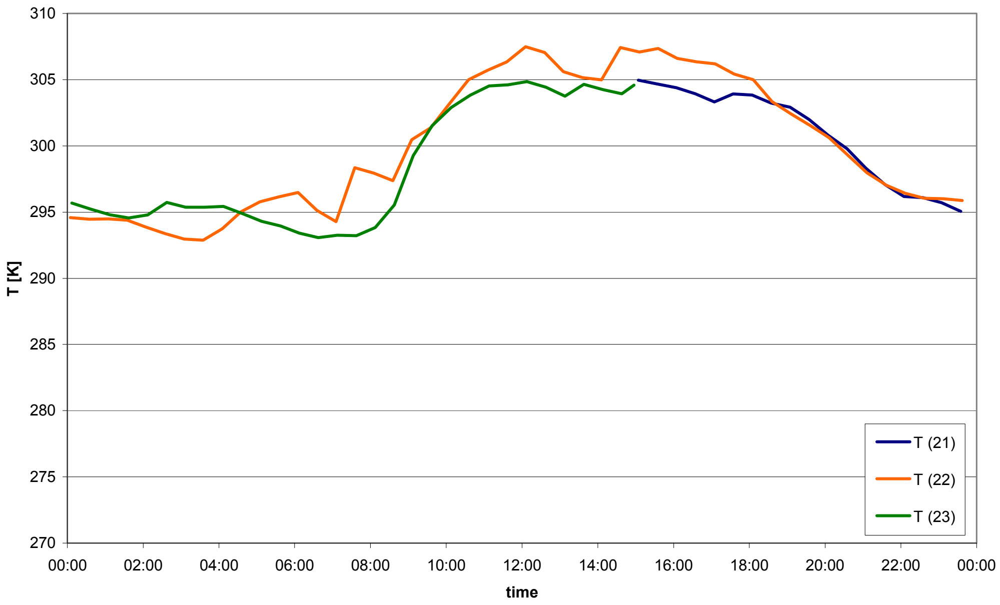


Figure 5- 5 Los Tablones. Temperature at 1.8 m

Between day and night a difference of about 12ºC was observed, which is normal for a Mediterranean climate. At night the humidity was around 80%, falling to 50% at midday.

Between the first and second day a significant difference was found between the time of day at which the humidity dropped. During the night and at midday irrigation took place in the field where the equipment was installed. It was observed that in the night between sessions 22 and 23 this irrigation lasted longer. Apart from a high humidity this also caused problems with the connectors of one of the microphone cables.

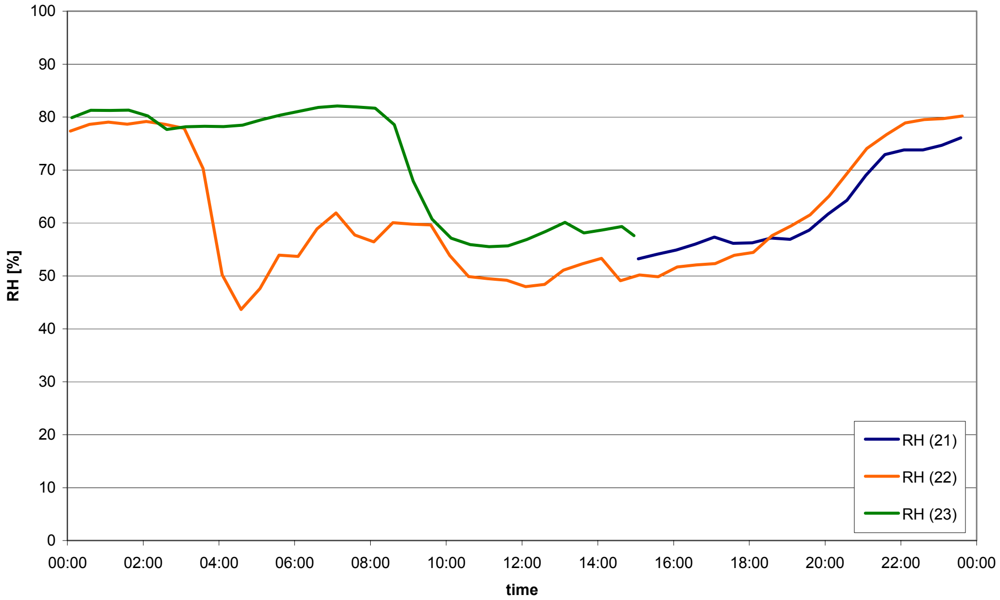


Figure 5- 6 Los Tablones. Relative humidity at 1.8 m

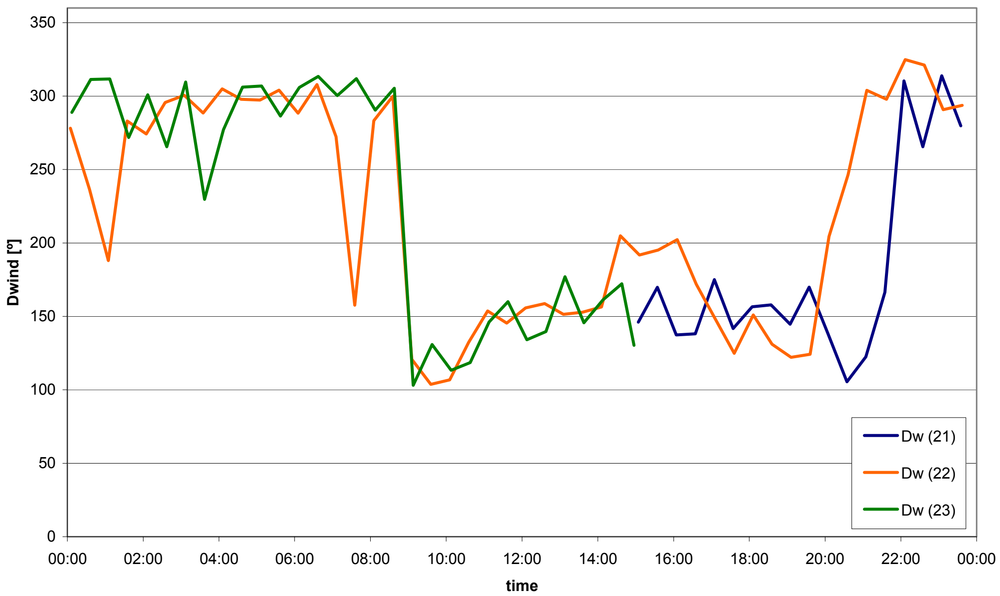


Figure 5- 7 Los Tablones. Wind direction at 1.8 m

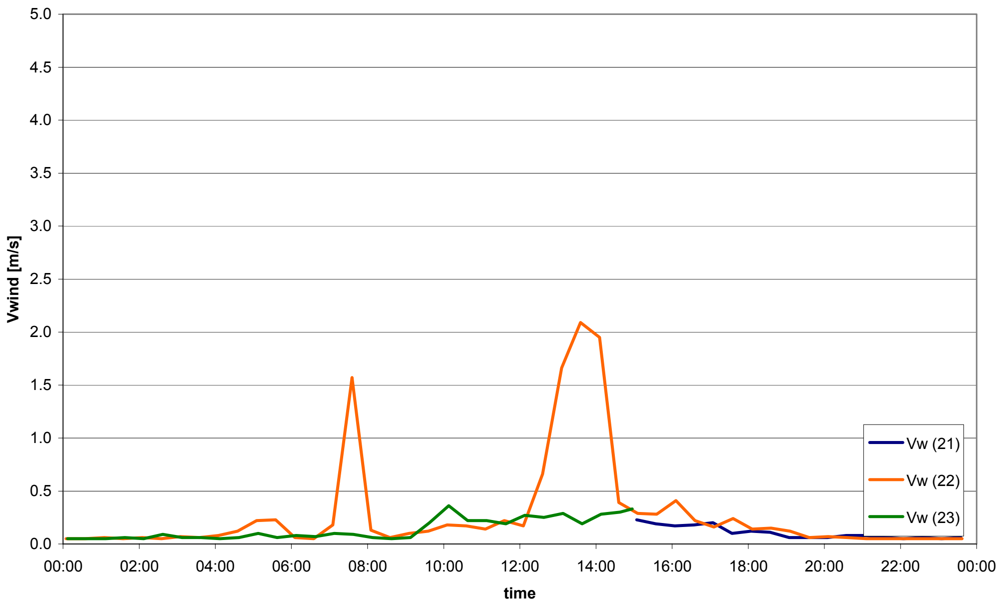


Figure 5- 8 Los Tablones. Wind speed at 1.8 m

Wind speed was generally very low during the sessions, except for two periods during the second day. In the morning suddenly wind started to blow during half an hour, after which it dropped to almost zero again, until midday, when during around 2 hours wind was relatively high, although well within the limits. In this period wind was southerly.

5.1.2. Noise

Graphs of the evolution over the test days of the various noise metrics calculated for both microphones and for each measurement (LAeq, LAeqc, Leq, Leqc, L95, L95c, L50, L50c) are given in Appendix 3-6.

Diego Alvaro (sessions 19 and 20)

From the graphs corresponding to this test site it can clearly be seen that after 1 AM noise drops significantly down to very low levels. At around 6 AM it starts to rise again until it reaches a more or less constant value for the rest of the day. Although this is true for all A-weighted metrics, the linear Leq level does not stay as constant, with a peak at around 16h. This indicates that around that time a low frequency phenomenon occurs. The relationship with wind speed (which has the same evolution over time), will be investigated hereafter.

The following graphs are examples of some measurements at this test site, the first taken at midnight, the second in the afternoon, with some wind. The olive green line is LA of the inverted microphone, whereas the black line represents the LA1k metric, in order to reduce the masking of bird noise. The light green line is the LA1k metric for the 1.2m microphone. The spikes are insects passing by the microphone. In the second plot (with wind) the LA and LA1k appear to be close, which indicates the presence of a low frequency source (e.g. wind), as already observed above.

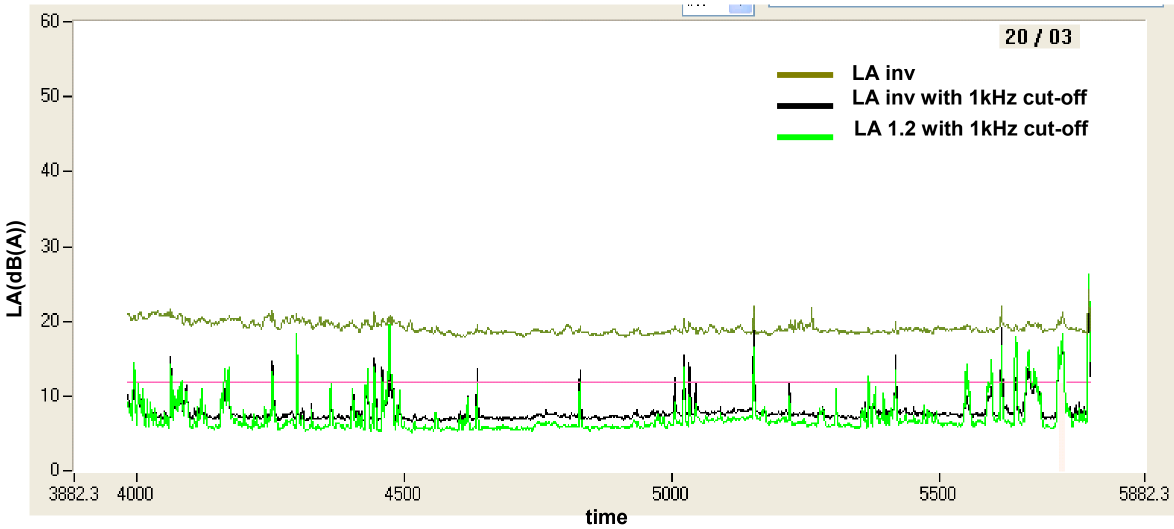


Figure 5- 9 Example of night-time measurement at Diego Alvaro

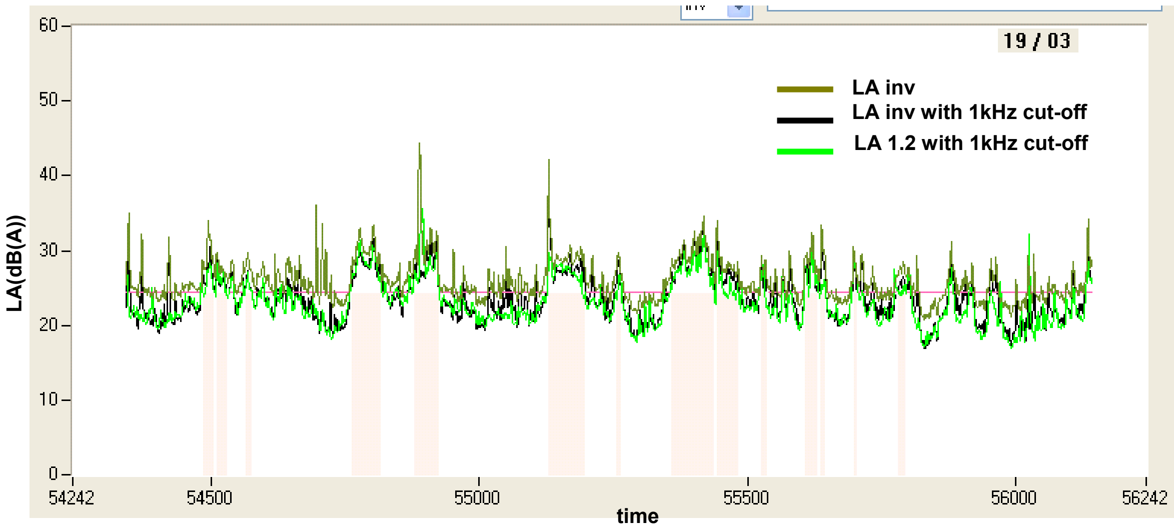


Figure 5- 10 Example of day-time measurement at Diego Alvaro

From the graphs in the Appendix it can also be seen that very little difference exists between the metrics for the total measurement and the corrected one (i.e. non-natural noise sources removed). This indicates that at this site only very few non-natural sources existed and thus that this site was indeed very good for background noise measurements.

Los Tablones (sessions 21 to 23)

The graphs corresponding to this test site also show a period during which noise is lower and another with higher noise levels. However, the time of the day in which noise rises and falls are quite different from those observed at the first test site. Also the significantly higher noise levels are apparent. The following plots correspond to some measurements at this site, the first at night time, the second at day. It can clearly be seen that at night noise is quite low, although not as low as in Diego Alvaro. This appears mainly due to the noise of insects and (like in the least part of the measurement) barking dogs.

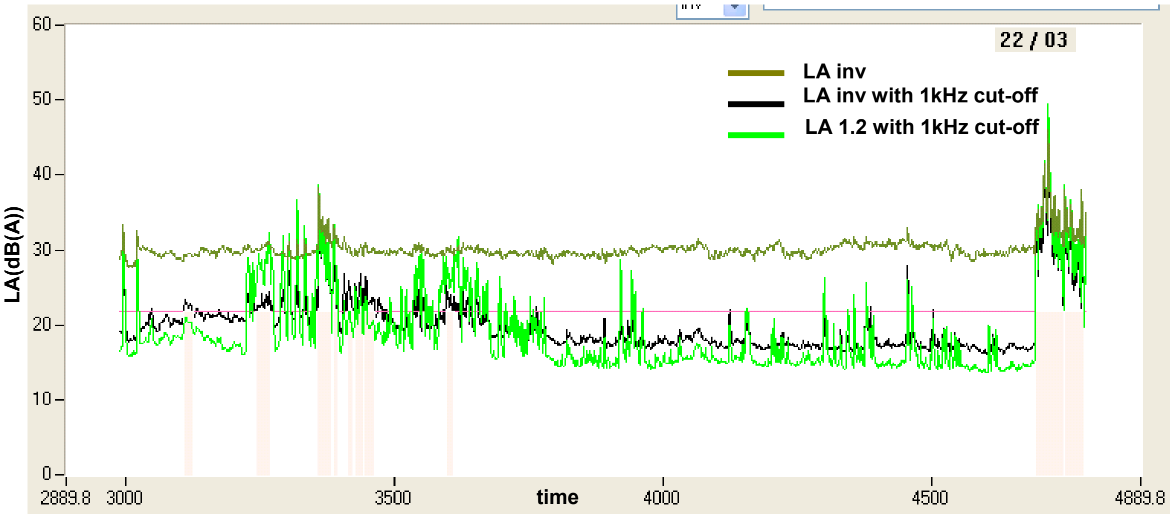


Figure 5- 11 Example of night-time measurement at Los Tablones

The next graph is typical for the day time at test site 2. The significant LA levels are fully due to the dominant cicadas. It can clearly be seen how this level changes when the cicada interrupts the noise generation. The significant difference between the LA and LA1k level is a clear indicator for the predominance of high frequency noise.

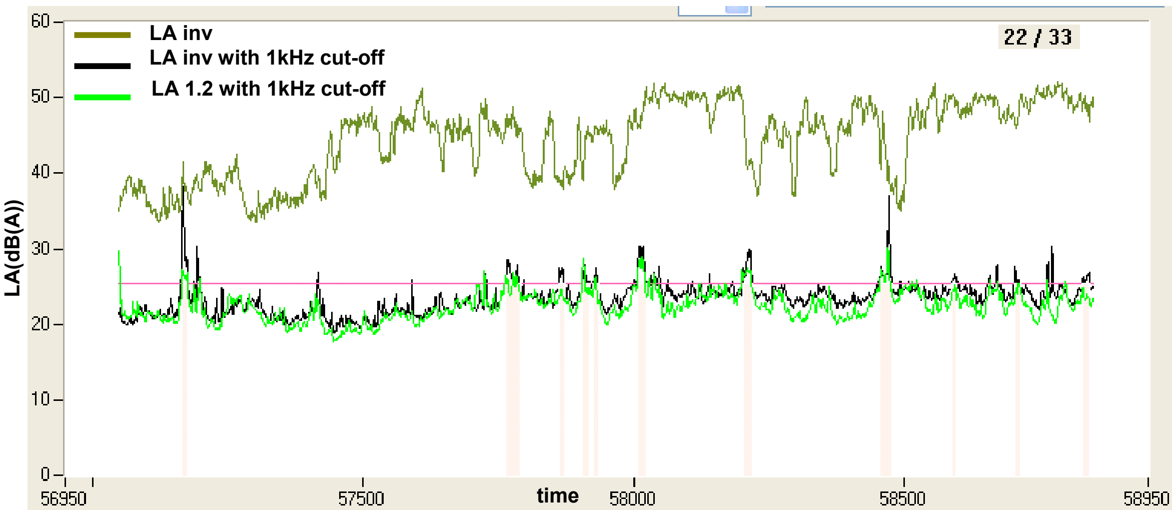


Figure 5- 12 Example of day-time measurement at Los Tablones with cicadas

The evolution of noise over the day as observed in the graphs in the appendix follows the evolution of the cicada noise, which is dominant during the whole day.

From the graphs it can also be seen that at night big differences were found between LA and LAc. This is due to the fact that in this period the irrigation in the field affected some connectors in the cable of the inverted microphone and electrical noise was introduced and some spikes were recorded. These were labelled as events with non-natural cause and thus removed in the calculation of LAc.

Apart from these peaks, the evolution of noise over the two full days appears to be remarkably repetitive.
Although it is recognised that the noise recorded at this test site is not representative for large parts of (especially middle and northern) Europe, it will be for the whole Mediterranean region. In fact it highlights a topic which is not taken into account presently in the formula proposed by SINTEF and adapted by Labein. It appears that some regions might have specific situations, maybe during specific periods of the day or the year, which strongly influence the background noise, due to which the general formula presented in Part 1 of this study might not be valid. Obviously it is not possible to include this directly in the noise map as determined in Part 1, since no information is available on the geographical distribution of these types of noise sources. Probably the inclusion of an additional coefficient, representing the local situation would be a way forward. How to determine the value of this coefficient is considered beyond the scope of BANOERAC.

5.2. Determination of background noise level

Considering the measurement results as discussed above, it was decided to use the measurements of the Diego Alvaro test site for the determination of the background noise level, required for WP1.

To this end the measured LAeqc and L95c levels of the inverted microphone were plotted as a function of the time of day.

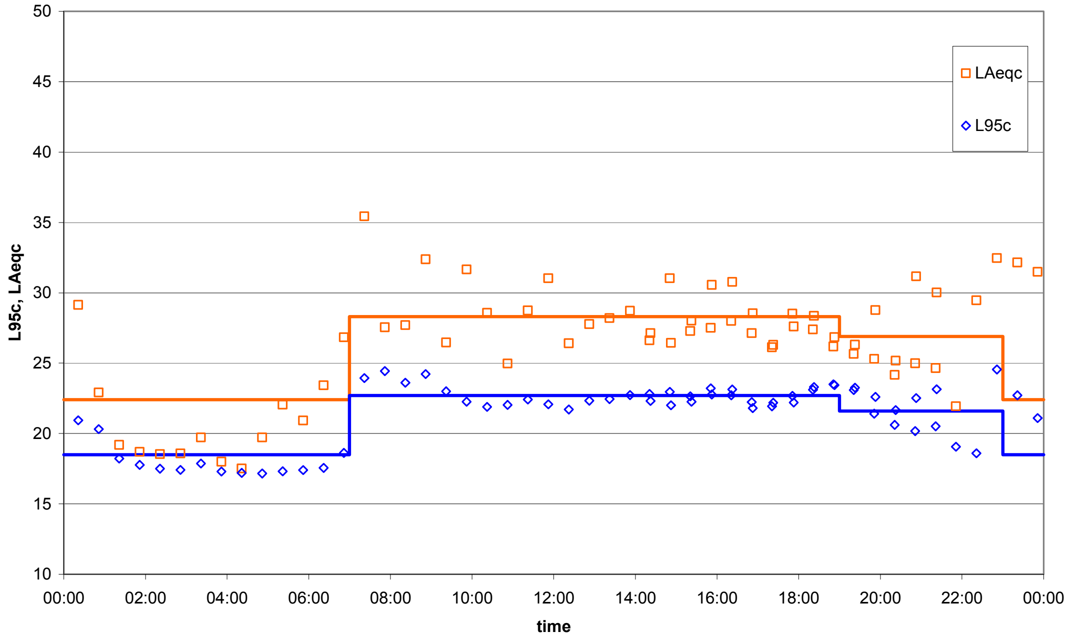


Figure 5- 13 Evolution over Day-Evening-Night at Diego Alvaro

This plot also contains the average values for the 3 periods Day (7-19h), Evening (19-23h) and Night (23-7h) of LAeqc and L95c, which are as follows:

Table 5- 1 Average values for the 3 periods of day

	Inverted mic		1.2m mic	
Period	**LAeqc**	**L95c**	**LAeqc**	**L95c**
D	28.3	22.7	28.9	22.8
E	26.9	21.6	26.9	22.0
N	22.4	18.5	23.4	18.9

These values were passed to Labein for their inclusion in WP1.

5.3. Background noise from the aircraft sessions

Part of the background noise to be studied here was acquired during the aircraft noise sessions at the Cebreros and Colmenar test sites. The measurements where at least half of the measurement time remained after removing the events originating from non-natural noise sources could be used, as was explained in section 3.4 (Part 2). The L95c level for these measurements was determined and plotted together with the datapoints from the background noise sessions.

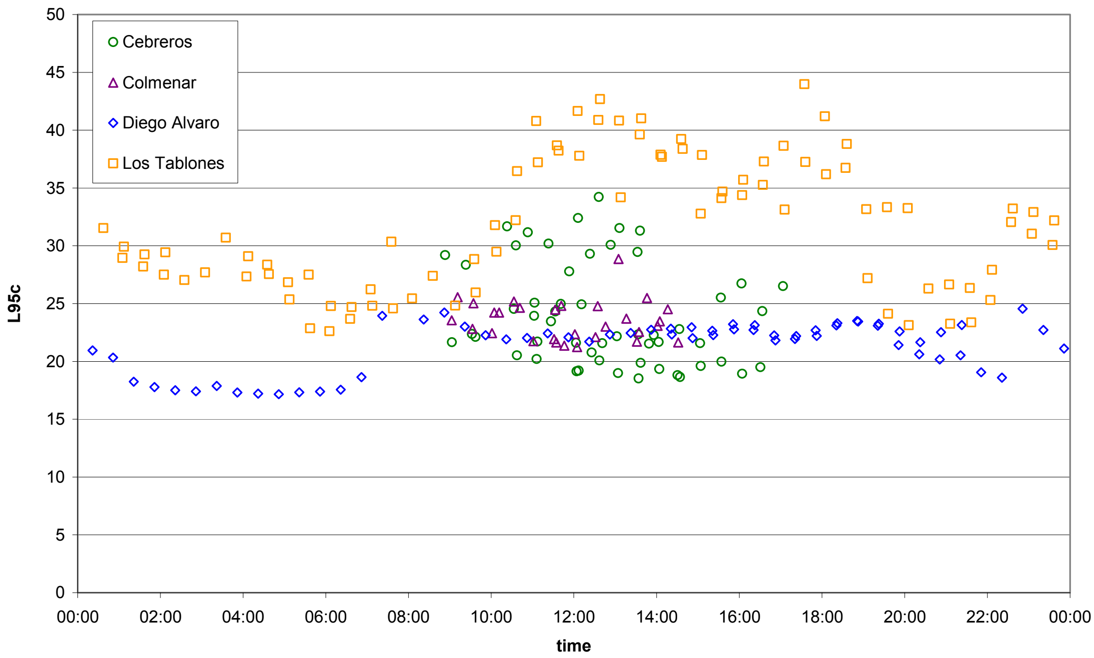


Figure 5- 14 Evolution of L95c levels over the day (all test sites)

From figure 5-14 the influence of the cicadas on the background noise level can clearly be seen. When suppressing the cicada noise by limiting the L95c calculation to the 1 kHz band (thus eliminating all high frequency noise), the background noise levels (L95c_1k) at all sites appear to coincide quite well, except some points for Cebreros at midday (see Figure 5-15).

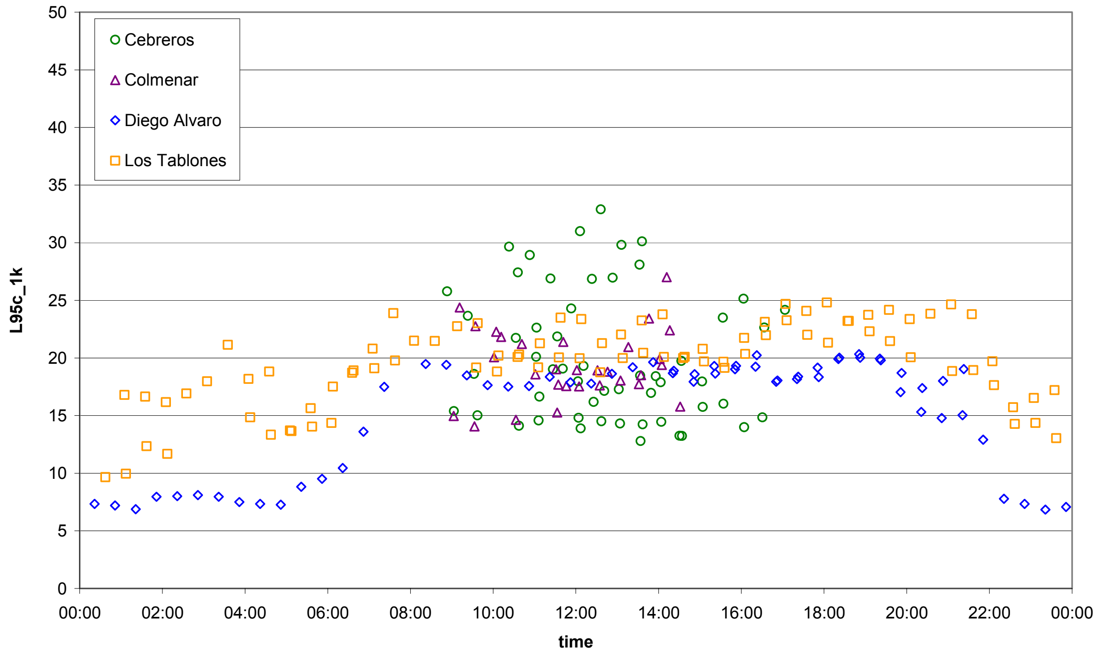


Figure 5- 15 Evolution of L95c_1k levels over the day (all test sites)

5.4. Observations

5.4.1. Effect of wind on background noise levels

In the former section it was observed that some datapoints were considerably higher than the majority within the same dataset. There were indications that this was due to wind. This is further investigated here.

To this end the same plot as in Figure 5-14 is used, but where now the datapoints with an average wind speed of 1.75 m/s or higher are indicated.

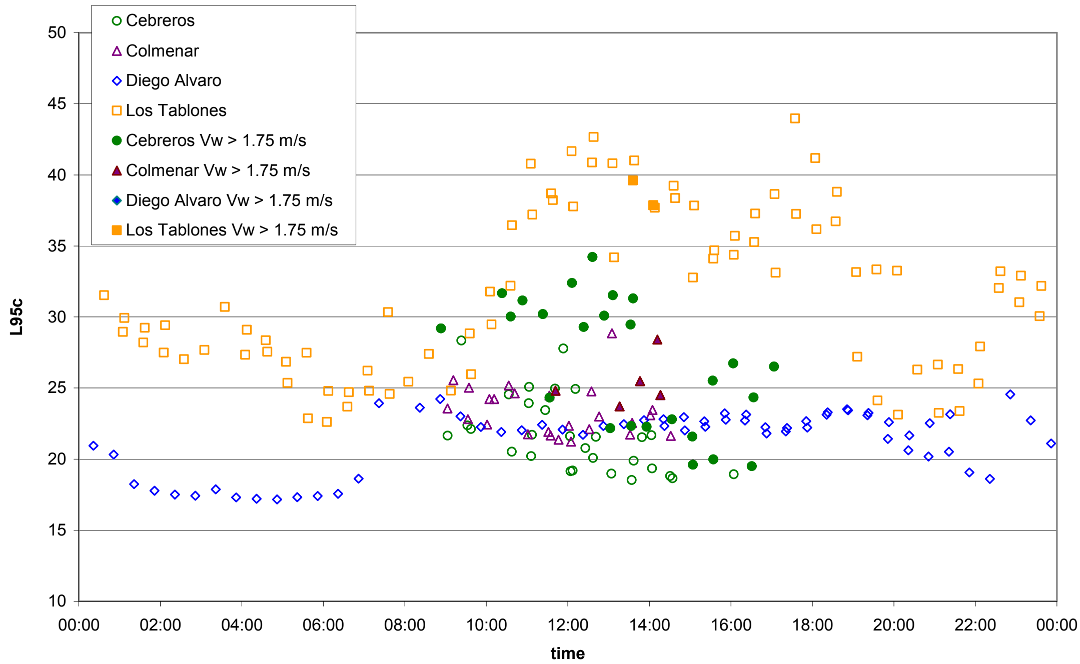


Figure 5- 16 Background noise and wind at test sites

Indeed the highest points appear to be those with higher wind speed. However, also some of the points with lower levels appear to have high wind speeds. This indicates that also other (unknown) phenomena might contribute to the higher noise levels.

This can also be seen from a more general plot of various noise metrics as a function of the average wind speed during the measurement.

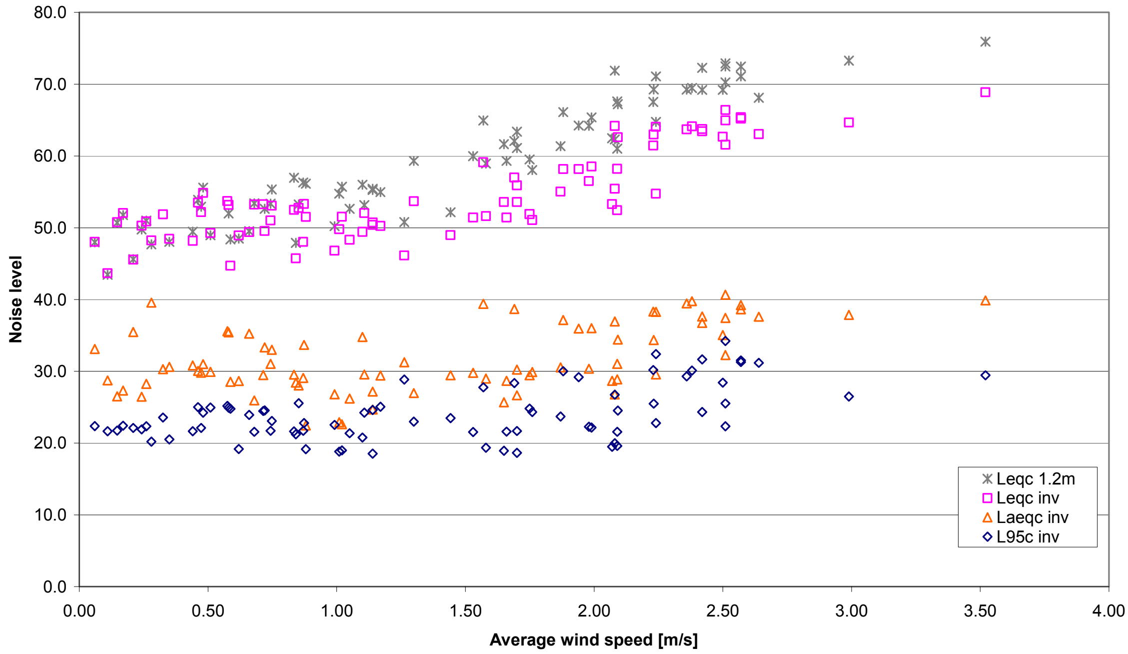


Figure 5- 17 Effect of wind on noise

The A-weighted metrics LAeqc and L95c show a slight increase of noise with increased wind speed, starting at about 1.5 m/s. However, this effect is very evident in the case of Leq, where an increase of noise level of about 15 dB can be observed for even moderate wind speeds of 2.5 m/s. The behaviour of Leq as observed in 5.1.2 can thus indeed be explained by the effect of the wind speed. For this metric also the data for the 1.2m microphone is plotted. It can be seen that here the effect is even more pronounced and reaches around 20 dB.

In general wind has 3 effects on the noise recorded at a microphone:

- Noise propagation
- Noise of moving tree leafs, etc
- wind induced noise at the microphone itself

For background noise measurements with no non-natural sources the first topic is not considered relevant. The noise of leafs has been noticed during the measurements and certainly contributes to the increased levels. This is considered part of the natural noise. For moderate wind speeds the wind induced noise at the microphone is expected to be low.

A more detailed investigation into this subject is considered beyond the scope of BANOERAC.

5.4.2. Effect of microphone height

For aircraft noise measurements it is well known that the difference in noise level between an inverted microphone and one at 1.2m height is somewhere between 2.5 and 3 dB(A). However, during some measurements Anotec performed some years ago it was observed that the difference between the 2 microphone during background noise measurements was not as clear. Hereafter the results for both microphones are compared for the measurements at all test sites.

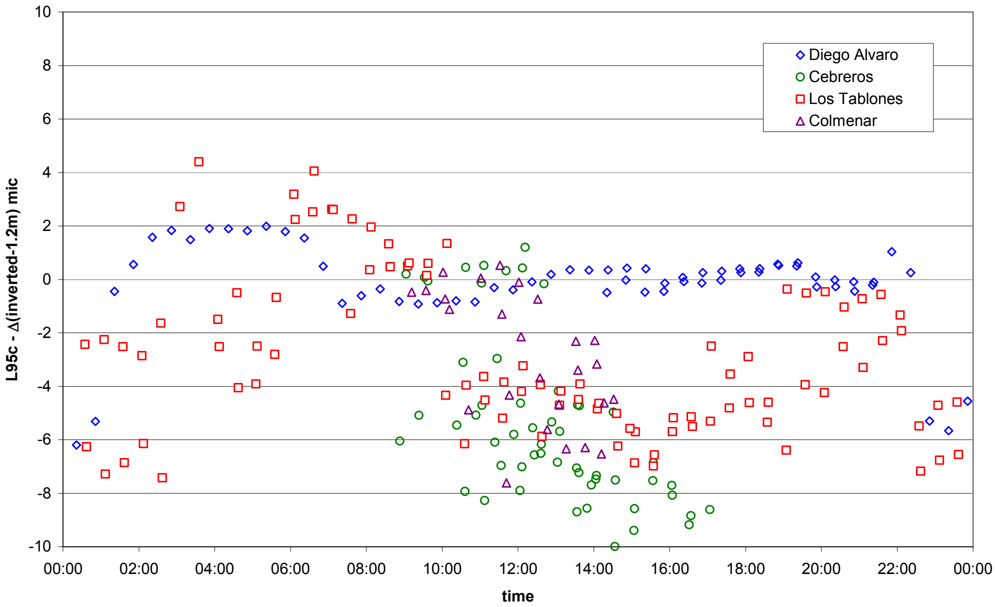


Figure 5- 18 Effect of microphone height on L95c

It can be seen that indeed the difference is not the same as for aircraft noise measurements. At Diego Alvaro, during almost the whole day the difference is almost zero. Only at night, with lowest noise the difference is about 2 dB(A). The -6 dB(A) difference was found to be due to some insects close to the 1.2 m microphone during a significant time. Some of the datapoints for Cebreros and Colmenar coincide with the zero difference at day time. Many points appear to be much lower, which is consistent with the findings with respect to the wind speed, which appeared to be higher at these points.
In Los Tablones a wide spread can be found. This is due to the fact that the noise levels here are completely dominated by the noise from cicadas and depending on the relative position of the insect to both microphones the difference between them may vary considerably. A small exercise with plotting L95c1k instead, revealed that the difference between both microphones was very small, which is consistent with the other test sites.

In general it can be concluded that the effect of microphone height on background noise does not seem to be large if the ambient noise is dominated by randomly distributed sources.

6. RESULTS FOR AIRCRAFT EN-ROUTE NOISE

The results for the aircraft en-route noise measurements are based on the data provided in Appendices 3-2 to 3.5. Hereafter a description is given for the different levels of aggregation considered in this study.

6.1. Measurement level

For each measurement made during the first 18 sessions, dedicated to aircraft en-route noise, the average meteo conditions and all relevant noise levels have been calculated according to section 4.3. Hereafter these data are presented as a single dataset for all 18 sessions. In this manner a good overview is obtained of the range of meteo conditions covered by these sessions. With respect to noise the wide spread in noise levels is evident.

6.1.1. Meteo

The meteo conditions were monitored during the tests. The tests were stopped when the conditions were such that the limits would be exceeded.

As can be seen from the following graph, the temperature range covered is wide, from 10ºC up to almost 34ºC. Usually during a test day the temperature varied by around 10ºC.

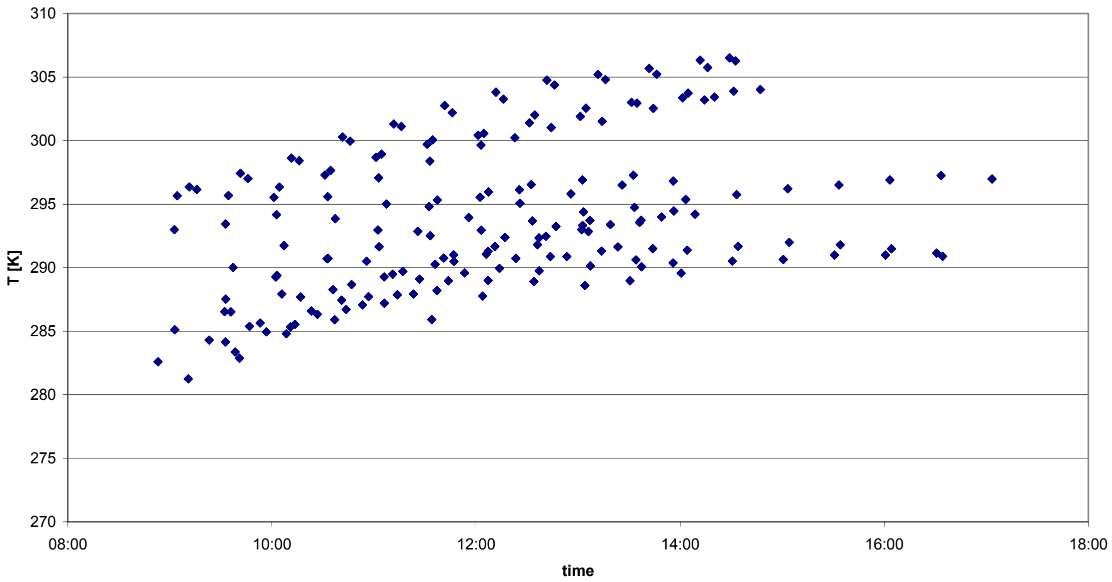


Figure 6- 1 Aircraft noise sessions: Temperature at 1.8 m

Due to the location of the test sides in the central part of Spain, quite low relative humidities were observed (between 20 and 60%), as can be seen from the next plot. During a test day the humidity usually reduced by about 10 to 20%.

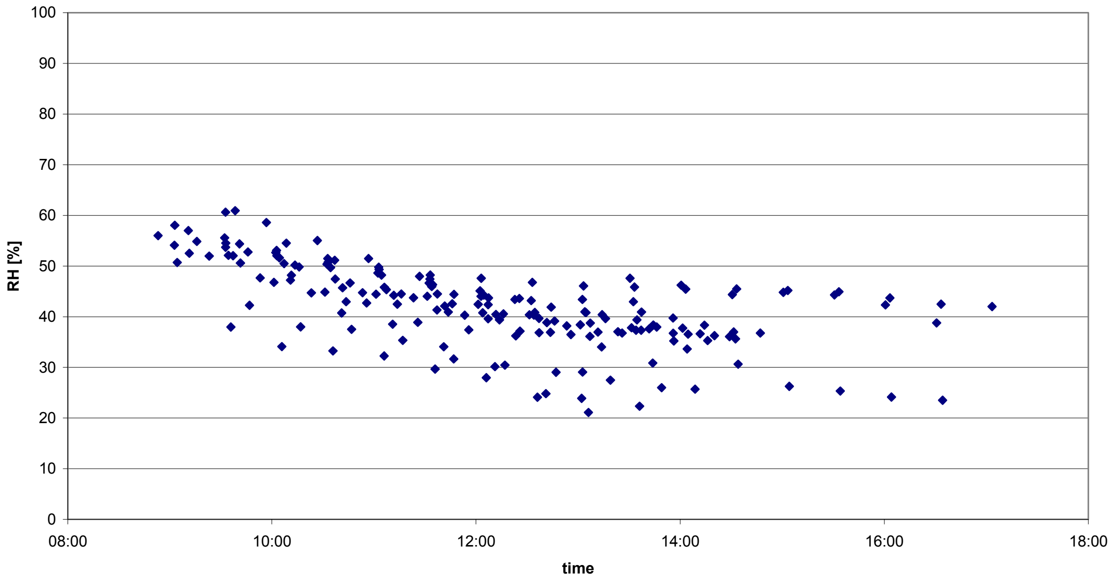


Figure 6- 2 Aircraft noise sessions: Relative humidity at 1.8 m

The wind direction during a test day usually stayed quite constant. The measurements were predominantly made with southerly winds. On some days westerly winds were present.

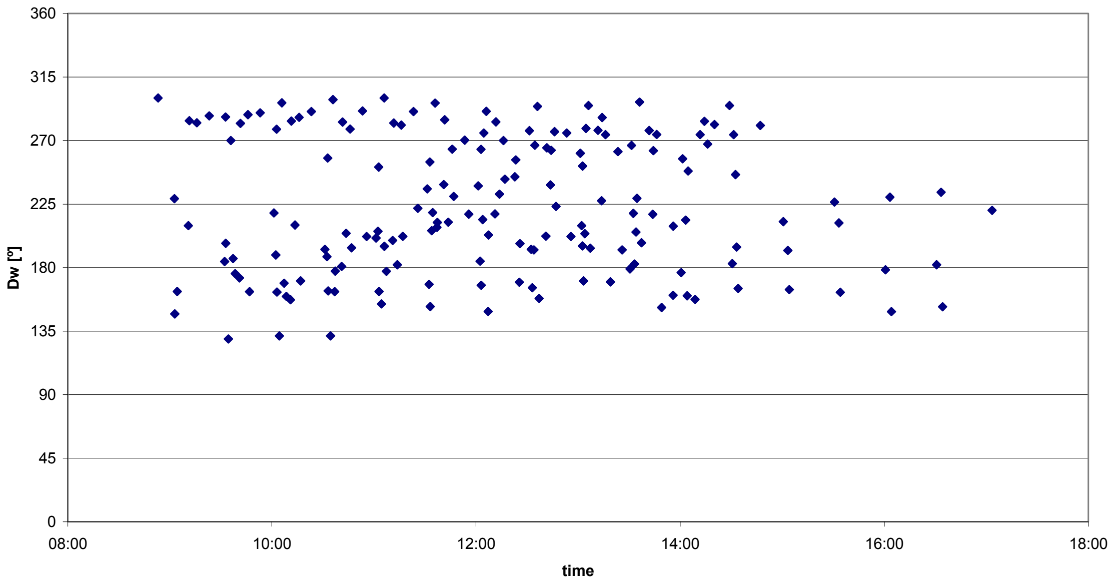


Figure 6- 3 Aircraft noise sessions: Wind direction at 1.8 m

Usually in the morning at the start of the tests wind speeds were very low. During the day the wind speed usually increased considerably as can be seen from the following plot. Some sessions were performed during relative high wind conditions during the whole day.

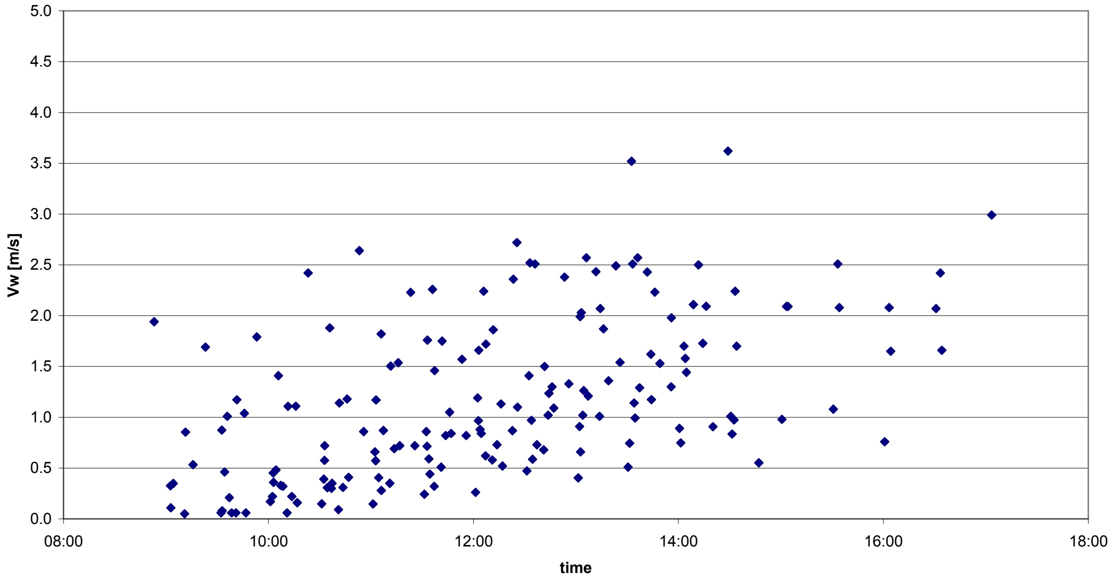


Figure 6- 4 Aircraft noise sessions: Wind speed at 1.8 m

6.1.2. Noise

Graphs of the evolution over the test days of the various noise metrics calculated for both microphones and for each measurement (LAeq, LAeqc, Leq, Leqc, L95, L95c, L50, L50c) are given in Appendix 3-7.

Quite a significant spread in noise levels can be observed for all metrics (although L95 and L50 somewhat less then LAeq and Leq). Whereas LAeq, L95 and L50 remain quite constant over the day, Leq seems to increase somewhat. Later in this section it will be investigated if this is related to the wind speed.

These graphs do not provide much information on aircraft noise levels, for which an analysis at event level is required.

6.2. Noise event level

Appendix 3-3 provides tables with data on noise event level, more specifically on the noise source(s) responsible for each noise event and on the average and maximum wind speed during the event. These tables contain all recorded noise events with non-natural origin, including those recorded during the background noise sessions. It is noted that these are not only aircraft related, since they also include events like the pass-by of a car. A total of 1569 non-natural noise events were detected, of which 1369 (almost 90%) at least had the noise of an aircraft. This confirms that the test sites were properly selected with respect to the absence of other non-natural noise sources.

6.3. Aircraft event level

Appendix 3-4 provides tables with data on aircraft event level for all aircraft detected with the IbaTrack system and assigned to those noise events where the aircraft noise was not affected by other noise sources. Aircraft identification and geometrical information is provided, together with the event noise levels for both microphones (SEL, SEL1k, LAmax, LAmax1k and Lmax).

Appendix 3-5 contains similar information, but for those aircraft events which the IBaTrack system could not detect. These events were detected and logged by the operator during the measurements. Aircraft identification was based on its class, rather than specific aircraft model, visually determined by the operator. Obviously no geometrical information is available for these events.

The following analysis is based on these Appendices.

6.3.1. Classification of aircraft

In order to facilitate the analysis and the presentation of the results the aircraft events are classified by model, according to the following table:

Table 6- 1 Classification of aircraft models

Code	Class	Typical Models
RJ1	Regional Jet (Gen1)	F70/F100 BAE146/Avro RJ
RJ2	Regional Jet (Gen2)	CRJ, ERJ
MR1	Medium Range (Gen1)	MD80/90 B737-200
MR2	Medium Range (Gen2)	A318-A321 B737-300…800
LR2	Long Range Twin	A-300, A-310, A330 B757, B767, B777
LR4	Long Range Quad	A340, B747
Prop	Heavy Prop	ATR, ATP, DH8, F50
BJ	Business Jet	Gulfstream
GA	Small propeller	Cessna, Beechcraft
Heli	Rotorcraft	EC135, A-109
MIL	Military jet aircraft	Eurofighter

Apart from the aircraft class the events are also grouped according to the 3 en-route flight phases:

- Climb (above 3000ft)
- Cruise
- Descent (above 3000ft)

For classes like GA, Heli or MIL it is usually difficult to establish the flight phase. These classes are considered to belong to cruise, since the test sites were relatively far from any airfield where these aircraft could operate.

6.3.2. Number of aircrafts events and their distribution

The valid events have been distributed over their corresponding classes and flight phases, with the following result:

Table 6- 2 Number of events for each aircraft class

	Number of aircraft events								
	Detected by IBaTrack			Detected by operator			Total		
Class	**Climb**	**Cruise**	**Descent**	**Climb**	**Cruise**	**Descent**	**Climb**	**Cruise**	**Descent**
RJ1	3	14	0	0	1	1	3	15	1
RJ2	0	0	0	4	14	4	4	14	4
MR1	0	0	0	5	21	6	5	21	6
MR2	126	405	125	2	29	1	128	434	126
LR2	6	34	41	2	5	1	8	39	42
LR4	54	8	17	3	3	0	57	11	17
Prop	0	0	0	8	4	0	8	4	0
BJ	1	0	1	0	0	0	1	0	1
GA	0	0	0	0	112	0	0	112	0
Heli	0	0	0	0	13	0	0	13	0
MIL	0	0	0	0	4	0	0	4	0
Unknown	0	0	0	0	39	1	0	39	1
							214	**706**	**198**
							19%	63%	18%
							1118		

A total of 1118 valid aircraft events has been obtained, which is well above the minimum of 1000 events, set as the objective of the tests.

In the original plan a distribution of around 25/65/10 for Climb/Cruise/Descent was envisaged. This was based on the assumption that the noise in Descent would not be audible and that around 10% of the events would be enough to demonstrate this. During the tests, however, this assumption appeared not to be valid. Noise in the descent phase appeared lower than the noise in climb, but it was still clearly audible, even at considerable distances. Therefore a redistribution was sought, equalising the events over both phases. The finally obtained distribution matches very well this objective.

Some aircraft classes have only few datapoints. Since the aircraft in these classes do not have an ADS-B transponder on-board, it resulted impossible to find a test site where these aircraft types could be measured in sufficient concentration. The data available for these classes should thus only be used as a first indication of the levels to be expected. This is considered acceptable, since these aircraft types constitute only a small proportion of the current European aircraft fleet.

With respect to the elevation angle, 59% of the valid events as presented in Appendix 3-4 had an elevation angle of 60º or higher, 33% between 30º and 60º and only 8% between 15º and 30º, which is considered a very acceptable distribution.

6.3.3. Noise for each aircraft class

In a first step, the events contained in Appendix 3-4 have been grouped according to the flight phase. Figures 6-5 and 6-6 show the noise levels of each flight phase, independent of aircraft type, as a function of distance from microphone to aircraft at CPA. The 1kHz cut-off SEL1k and LAmax1k are plotted. The data for the standard SEL and LAmax are available through the Appendices.

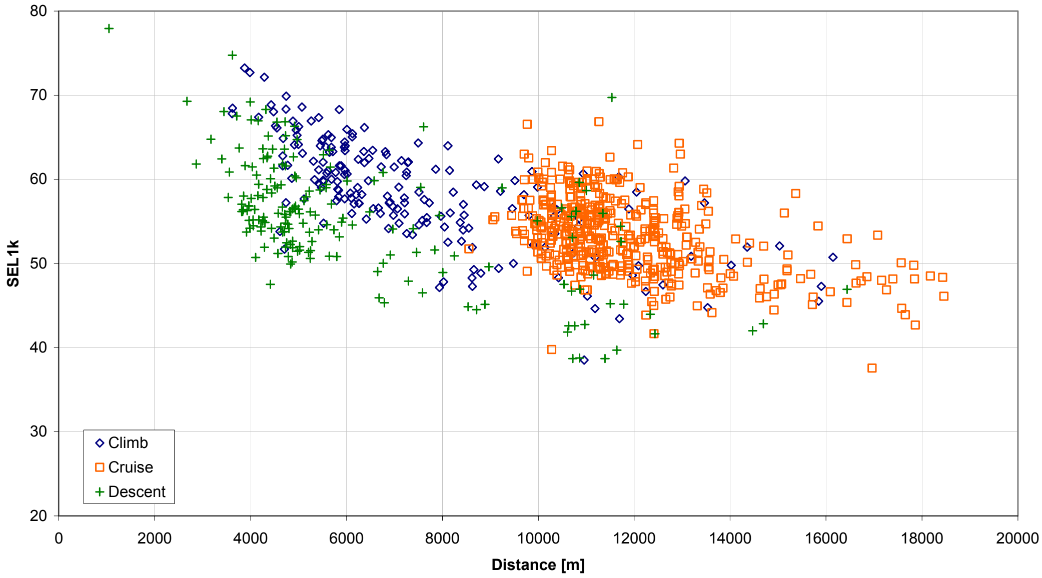


Figure 6- 5 Aircraft en-route measurements: SEL1k – inverted mic

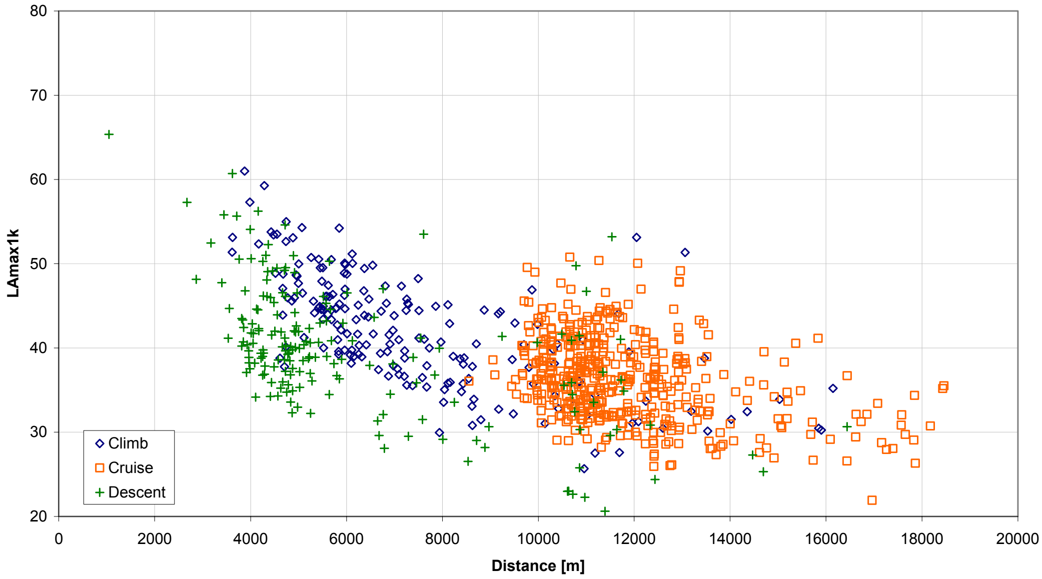


Figure 6- 6 Aircraft en-route measurements: LAmax1k – inverted mic

The valid events have been grouped by aircraft class and flight phase and the corresponding graphs are provided in Appendix 3-8.

In these graphs also the aircraft events of Appendix 3-5 (i.e. those not detected by IBaTrack but by the operator) have been plotted on the left side of the graphs (at an arbitrary default distance, since no geometrical data are available for these events). It can be seen that the measured levels for these aircraft are in the same range as those for the detected aircraft, as was to be expected.

For each aircraft class and flight phase all noise levels were grouped together and the average level, standard deviation and minimum and maximum levels were then determined. Also the average distance is provided. The following tables present the results of this statistical analysis for both microphones for the 3 phases.

Table 6- 3 Statistical analysis for both microphones for CLIMB

CLIMB				Inverted mic			1.2 m mic		
Class	nEv	Param	Distance	SEL1k	LAmax1k	Lmax	SEL1k	LAmax1k	Lmax
RJ1	3	Av	7497	59.5	41.7	63.9	56.4	38.5	63.8
		σ	2582	5.2	6.4	4.9	5.9	6.4	9.9
		min	5310	53.6	34.3	59.1	49.6	31.1	55.7
		max	10345	62.9	45.5	69.0	60.2	42.6	74.8
RJ2	4	Av	N/A	48.9	34.6	61.7	44.7	27.9	64.0
		σ		2.3	5.2	3.7	4.6	5.3	9.5
		min		46.8	30.1	56.2	38.4	21.1	52.8
		max		52.1	41.5	63.8	49.3	33.1	72.3
MR1	5	Av	N/A	61.2	46.1	66.4	58.8	44.3	69.8
		σ		5.5	4.9	4.6	5.1	3.9	5.5
		min		53.2	39.0	62.1	51.0	39.6	61.4
		max		67.6	50.7	73.9	64.8	48.2	76.9
MR2	128	Av	7628	57.7	40.9	62.0	55.2	38.6	64.5
		σ	2662	5.8	6.4	6.9	5.7	6.2	9.2
		min	3876	38.5	25.7	48.8	36.0	22.0	49.9
		max	16143	73.2	61.0	79.9	70.0	56.9	86.5
LR2	8	Av	10483	55.8	40.0	62.2	53.5	37.9	64.0
		σ	3566	7.1	7.4	5.2	6.3	7.1	8.0
		min	5488	46.7	31.1	56.6	44.0	26.4	55.3
		max	15029	64.6	48.1	73.0	61.8	45.8	80.0
LR4	57	Av	6841	61.3	45.4	65.9	58.0	41.8	68.1
		σ	2127	6.4	6.9	6.4	6.5	7.1	7.9
		min	3616	44.8	30.0	54.1	41.6	23.1	52.6
		max	13531	72.9	60.9	80.7	69.7	56.7	83.9
Prop	8	Av	N/A	61.6	47.6	66.7	57.6	43.7	65.3
		σ		5.6	5.1	4.2	5.8	5.8	6.6
		min		56.2	38.9	60.8	52.5	35.4	58.1
		max		71.9	57.2	73.5	67.7	54.0	78.0
BJ	1	Av	12048	58.5	53.1	68.5	53.8	39.3	59.3
		σ							
		min							
		max							
GA	0	Av							
		σ							
		min							
		max							
Heli	0	Av							
		σ							
		min							
		max							
MIL	0	Av							
		σ							
		min							
		max							

Table 6- 4 Statistical analysis for both microphones for CRUISE

CRUISE				Inverted mic			1.2 m mic		
Class	nEv	Param	Distance	SEL1k	LAmax1k	Lmax	SEL1k	LAmax1k	Lmax
RJ1	15	Av	11294	51.1	35.2	58.3	49.0	33.1	61.4
		σ	2278	6.7	6.9	7.4	6.8	5.5	7.9
		min	9676	39.8	27.0	51.1	37.0	25.6	48.0
		max	17159	63.0	49.0	74.3	61.2	44.7	79.7
RJ2	14	Av	N/A	49.3	32.3	58.1	47.7	31.1	61.4
		σ		3.2	3.4	5.3	3.8	4.8	9.6
		min		42.6	25.0	48.2	39.7	24.5	45.4
		max		53.1	37.0	67.6	54.1	38.0	77.3
MR1	21	Av	N/A	54.7	38.1	59.6	52.6	36.1	61.2
		σ		5.9	6.3	8.0	6.4	6.9	9.2
		min		45.3	29.0	47.0	42.6	24.4	45.8
		max		67.1	50.4	75.1	65.3	50.1	80.0
MR2	434	Av	11803	53.1	36.1	58.8	50.7	33.7	62.1
		σ	1730	4.3	4.8	7.2	4.5	5.1	9.4
		min	8553	35.6	21.9	45.8	32.5	17.3	44.3
		max	18460	66.8	50.8	80.9	64.4	53.7	84.1
LR2	39	Av	12248	54.2	37.6	58.6	50.0	33.7	61.9
		σ	2084	4.3	5.1	6.6	9.2	7.4	13.3
		min	9526	42.7	26.3	50.1	0.0	0.0	0.0
		max	18433	64.1	50.0	78.4	61.8	47.1	84.9
LR4	11	Av	12168	54.4	37.6	59.8	53.3	37.1	60.5
		σ	1275	4.5	5.0	7.8	3.2	3.6	11.4
		min	10080	44.0	25.2	52.0	49.2	30.6	49.5
		max	14408	60.8	43.6	74.0	57.7	42.1	80.5
Prop	4	Av	N/A	54.1	40.1	60.8	52.0	38.2	60.6
		σ		2.6	2.9	5.2	1.0	2.1	8.8
		min		51.5	36.6	56.4	51.1	36.6	52.6
		max		56.7	43.1	68.2	52.9	41.1	72.4
BJ	0	Av							
		σ							
		min							
		max							
GA	112	Av	N/A	52.3	37.3	60.3	49.9	34.2	62.1
		σ		10.1	10.1	8.3	9.8	9.8	9.3
		min		35.6	21.9	43.1	33.1	18.6	46.3
		max		76.2	61.8	83.0	72.9	58.0	88.6
Heli	13	Av	N/A	52.7	38.2	61.8	51.5	36.2	63.5
		σ		7.3	9.5	7.7	7.3	9.9	9.3
		min		43.8	28.1	50.2	42.6	23.4	50.9
		max		69.2	58.2	77.8	67.3	55.0	77.4
MIL	4	Av	N/A	60.0	45.0	59.1	58.0	42.4	63.0
		σ		12.3	13.4	5.9	11.3	12.9	8.9
		min		44.4	27.4	53.2	43.8	25.9	52.6
		max		72.2	58.2	66.2	69.3	54.6	73.2

Table 6- 5 Statistical analysis for both microphones for DESCENT

DESCENT				Inverted mic			1.2 m mic		
Class	nEv	Param	Distance	SEL1k	LAmax1k	Lmax	SEL1k	LAmax1k	Lmax
RJ1	1	Av	N/A	60.7	41.7	63.9	56.4	38.5	63.8
		σ							
		min							
		max							
RJ2	4	Av	N/A	50.2	35.4	59.8	47.0	32.1	67.5
		σ		6.5	6.9	8.2	6.9	7.9	7.4
		min		42.8	27.4	52.5	39.4	21.4	62.1
		max		56.9	41.4	71.2	54.3	38.5	78.1
MR1	6	Av	N/A	57.8	42.5	59.0	55.2	39.9	63.1
		σ		6.6	7.4	8.0	6.5	7.5	9.8
		min		54.8	36.5	54.7	52.0	33.8	52.2
		max		64.0	50.0	63.7	61.7	45.7	72.6
MR2	126	Av	6485	54.0	38.4	59.3	51.7	35.9	62.3
		σ	2853	6.3	7.0	8.1	6.1	7.1	10.0
		min	3535	38.7	20.6	45.8	37.2	19.2	45.4
		max	14693	69.7	56.2	84.7	66.8	54.7	82.8
LR2	42	Av	5106	59.2	43.3	62.9	56.6	41.3	64.5
		σ	2276	7.1	8.2	7.4	7.0	8.0	9.0
		min	1046	45.9	29.6	52.4	43.8	25.5	51.0
		max	16439	77.9	65.3	79.2	75.4	62.9	82.7
LR4	17	Av	5701	58.9	43.9	63.1	56.1	40.9	64.5
		σ	2407	6.8	6.5	8.5	6.8	6.8	11.1
		min	3443	39.7	30.3	40.2	35.8	22.9	41.3
		max	11638	68.1	55.8	76.0	65.0	52.8	82.6
Prop	0	Av							
		σ							
		min							
		max							
BJ	1	Av	5901	54.9	38.7	68.8	52.8	37.0	70.2
		σ							
		min							
		max							
GA	0	Av							
		σ							
		min							
		max							
Heli	0	Av							
		σ							
		min							
		max							
MIL	0	Av							
		σ							
		min							
		max							

It is noted that for some aircraft classes few datapoints were available due to which an unrealistically low spread in the noise levels is found.

The differences between the various classes for climb are apparent, which is logical, considering that this phase is performance based and changes in e.g. weight will influence the distance and powersetting, and thus the noise received.

For cruise the differences between the classes representing turbofans are remarkably small. As can be seen in Table 6-4 the average distance was almost the same for most classes. For turboprops too few data are available to derive a conclusion, although it is noted that during the measurements none of these aircraft where flying really overhead. It can thus be expected that noise levels for this group will be higher than those indicated here. General aviation and rotorcraft are about 10 dB(A) noisier than the rest of the classes. Obviously these types fly at lower altitudes, but since this is part of their normal operational practice, the indicated noise levels are representative for their en-route noise. During the measurements also the very long duration of the events caused by these classes appeared very annoying.

In descent differences between the turbofans are again greater. Long range twins seem to be somewhat noisier than the other classes. The average distance for this group was somewhat lower, but this can not fully explain the difference observed.

6.4. Observations

6.4.1. Comparison of final result with the pilot study

In [4] an estimate was made for the cruise noise levels for various aircraft groups. In the following table these estimates are compared with the results of BANOERAC, as derived above.

Table 6- 6 Comparison of cruise noise levels from pilot study and BANOERAC

Aircraft Class	Estimated LAmax		BANOERAC
	INM	Lit [6]	LAmax1k_inv
LR2	21-40	35-53	29-43
LR4	29-31	35-53	38
MR2	28-33	35-53	29-51
Prop	36-40	40-60	37-43
Heli	40-58	-	28-58

It can be seen that the INM based estimates of [4] are significantly too low. In [4] it was already observed that using INM for this purpose has serious drawbacks. With respect to the estimates found in [6], it should be noted that the indicated values are valid for distances between 27 and 35 kft (8.2 to 10.7 km), whereas the distances found in BANOERAC are generally higher, especially for the long-range types. For a good comparison only the BANOERAC data in the same interval were taken. For the LR4 class only one datapoint was found in this range (at 10 km), the rest being at greater distances. For the LR2 and MR2 classes a shift towards lower noise levels is apparent. For LR4 and

Prop not sufficient points are available to draw conclusions. Helicopter levels seem to coincide quite well. It should be noted that it is not clear for what microphone height the levels in [6] are valid. If they appear to be valid for a 1.2 m microphone, the differences observed will increase by around 3 dB (see 6.4.4). It is also noted that the above table should not be used to estimate cruise noise levels of current air traffic, since the distance interval for which they are valid appear not to be representative for the operations observed in BANOERAC (where higher cruise altitudes were generally found).

Another study of interest for comparison is the one elaborated by FFA in 1986 in Sweden [7]. This study was quite extensive and covers mainly chapter 2 aircraft. Data for cruise and climb are provided, for a ground plane microphone. The distances found in [7] for cruise range from 11 to 37 kft, again significantly lower than those observed in BANOERAC. When grouping all aircraft types together and taking only the common range of distances (30-37 kft), the following table can be elaborated for LAmax:

Table 6- 7 Comparison of cruise noise levels from FFA study and BANOERAC

Phase	FFA [7]	BANOERAC
Cruise	38-54	28-51
Climb	58-78	37-59

Also here a shift towards lower noise levels in cruise is observed. For climb a very significant reduction of about 20 dB(A) is found in current aircraft types with respect to the Chapter 2 types of the 80's. Obviously this is due to the introduction of the high by-pass ratio powerplants, which significantly reduced jet noise, the dominant source at take-off and climb. Again, also this table should not be used to estimate cruise noise levels of current air traffic, since the distance interval for which they are valid appear not to be representative for the operations observed in BANOERAC (where higher cruise altitudes were generally found).

6.4.2. Scatter

Even though the measurements were made with high quality equipment, in compliance with and even beyond certification standards, and under good weather conditions (i.e. within certification meteo limits), a significant scatter is found in the data within an aircraft class. Standard deviations are found to be in the order of 5 to 7 dB(A). This is comparable to the scatter found in other studies (e.g. [7]). In section 6.5 hereafter this is further investigated.

6.4.3. Empirical model for the prediction of en-route noise

It would be of interest to take advantage of the huge amount of data available to develop an empirical model for the prediction of en-route noise. Since this is beyond the scope of the present study, here just a first step is made. Since a large dataset is available for the MR2 class, the development is based on this group.

The following very simple model is proposed:

$$\mathbf{LAmax = A_{ij} – B \cdot log(Dist)}$$

where $\mathbf{A}_{ij}$ a constant, depending on aircraft class and flight phase and **B** an overall constant.

Applying this formula to the MR2 data (inverted mic) the following coefficients are found:

Table 6- 8 Coefficients of empirical model

Phase	A	B
Climb	167.4	33
Cruise	170.9	33
Descent	162.0	33

The following chart shows this model for the 3 phases of the MR2 class.

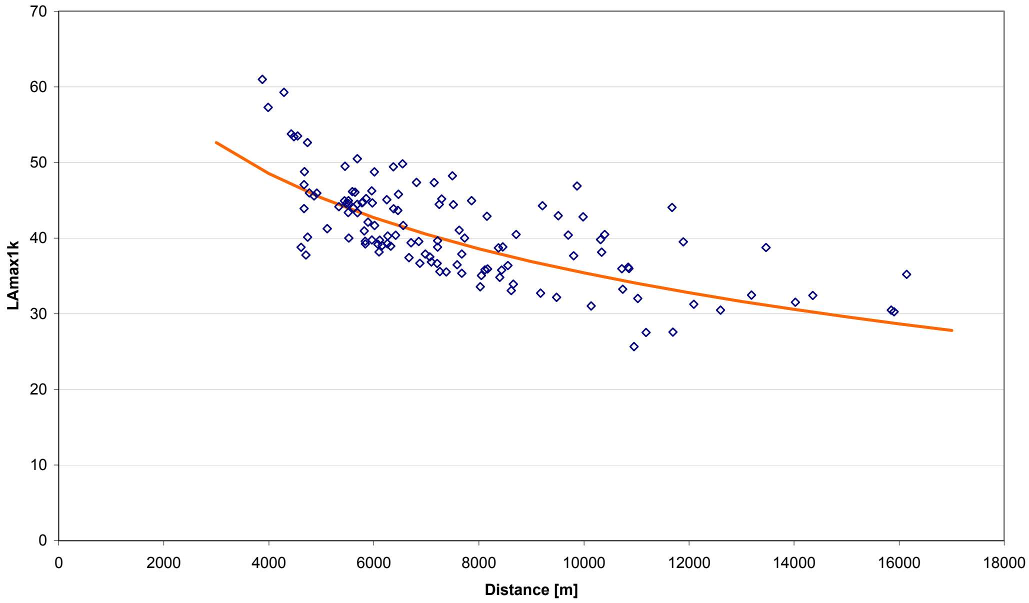


Figure 6- 7 Emperical model for MR2 – Climb – LAmax1k inverted mic

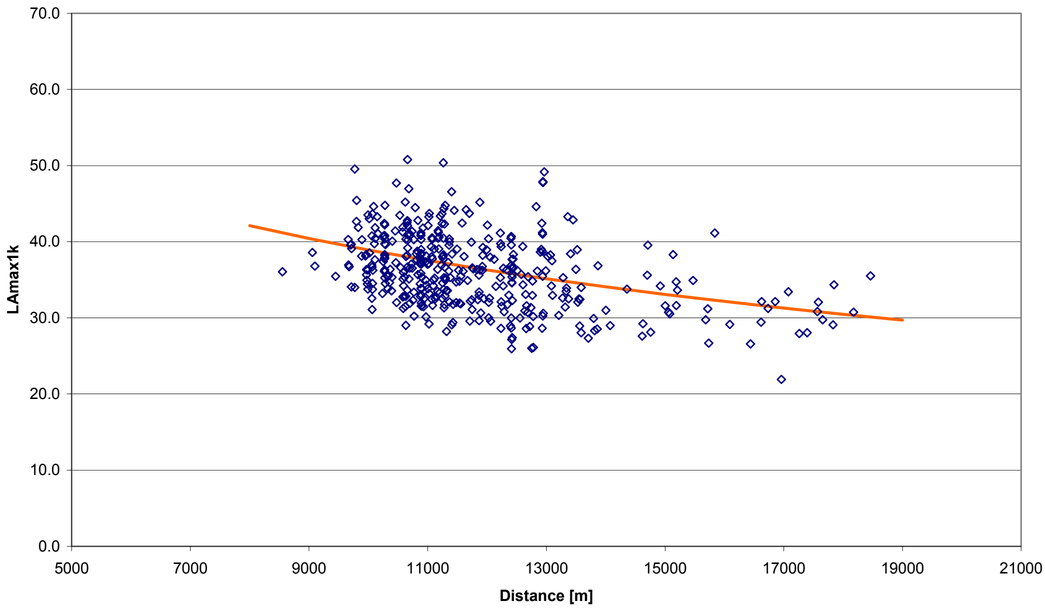


Figure 6- 8 Emperical model for MR2 – Cruise – LAmax1k inverted mic

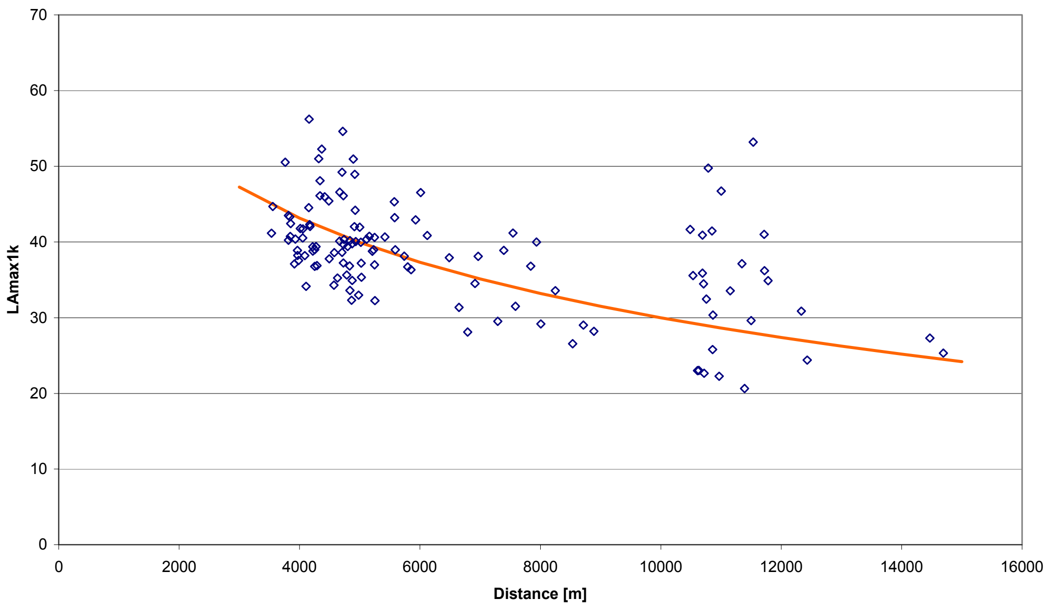


Figure 6- 9 Emperical model for MR2 – Descent – LAmax1k inverted mic

A first check indicates that the value of 33 for B also holds for the other classes. However, since this development is beyond the scope of the present project, no attempt is made to establish the constants for the other classes or for other noise metrics.

It is recognised that this is a very simple model which would need improvements and validation, but as mentioned before, it is just a very first step towards an empirical model.

6.4.4. Effect of microphone height

To obtain an indication of the effect of the microphone height on aircraft en-route noise levels the difference between the noise level of both microphones has been determined for all valid aircraft events, presented in Appendices 3-4 and 3-5. The following graphs show the results for SEL1k and LAmax1k respectively.

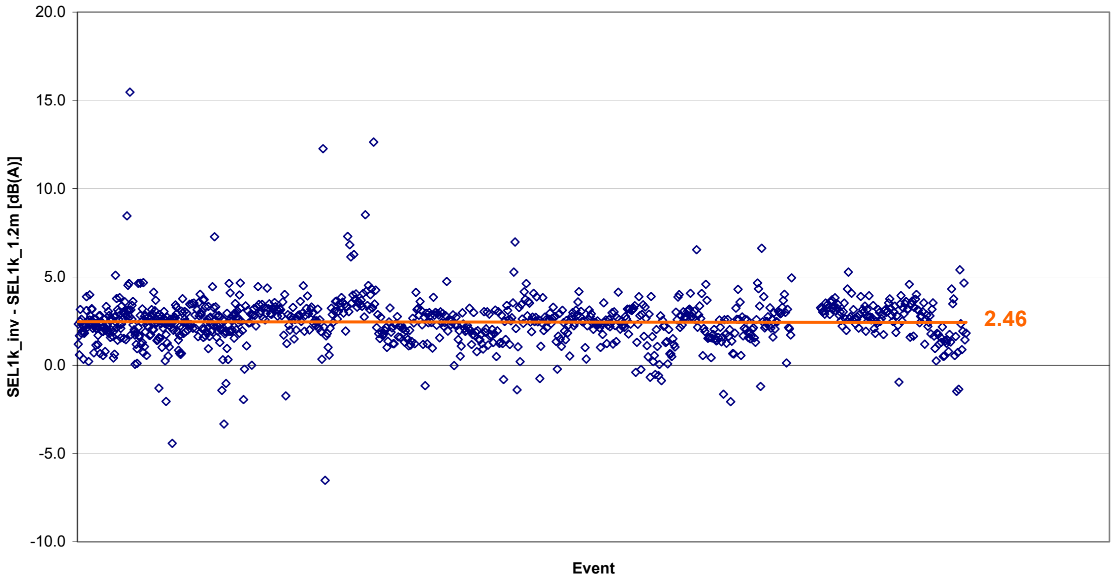


Figure 6- 10 Effect of microphone height on SEL1k

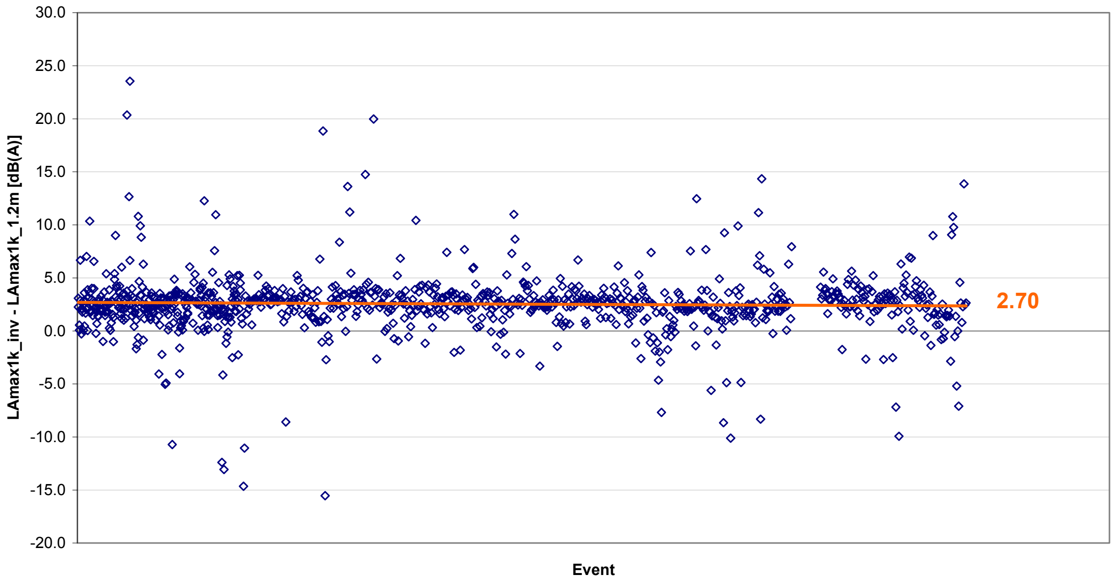


Figure 6- 11 Effect of microphone height on LAmax1k

It can clearly be seen that the differences are concentrated around a constant value, being 2.46 dB(A) for SEL1k and 2.70 dB(A) for LAmax1k. These are values which could be expected and which have been reported in the literature (e.g. [7]). However, also unexpected very large differences can be found. In the following section this phenomenon is further investigated.

6.5. Further investigation of observed phenomena

In the above various phenomena have been observed which deserve further investigation. Especially the scatter found in the aircraft noise levels appears to be an important issue. Therefore hereafter some excursions are made in order to investigate possible causes of this scatter.

6.5.1. Extraneous differences between both microphones

As observed in 6.4.4 in various events large differences have been found between the noise levels of the inverted and 1.2m microphone.

For one of the datapoints with a large positive difference the spectrum is plotted at the time instant of maximum noise at the inverted microphone. The spectrum of the 1.2m mic at the same time is also drawn. A clear difference can be seen between both. For further information the spectrum of both microphones some seconds before the maximum is also shown. For the 1.2m mic almost no change has occurred, whereas at the inverted mic a huge increase in the SPL above 100 Hz is found. From the replay of this event it appeared that this increase was fully caused by the pass-by of an insect (fly or bee).

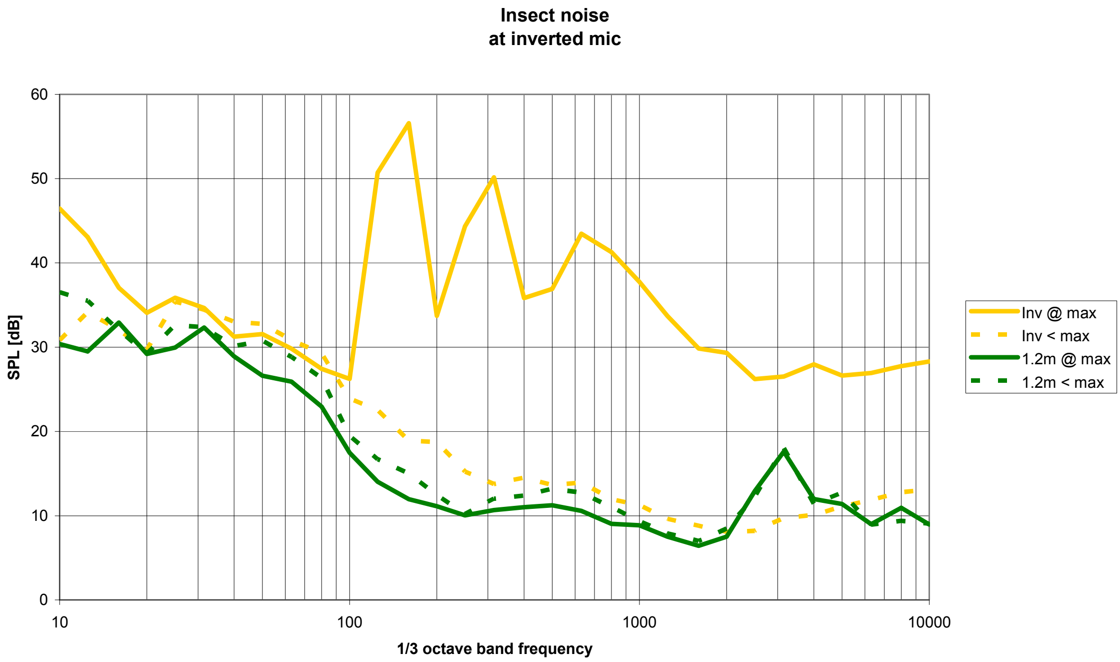


Figure 6- 12 Insect noise at inverted mic

The following graph shows a similar case, but at a datapoint with a big negative difference between inverted and 1.2m microphones.

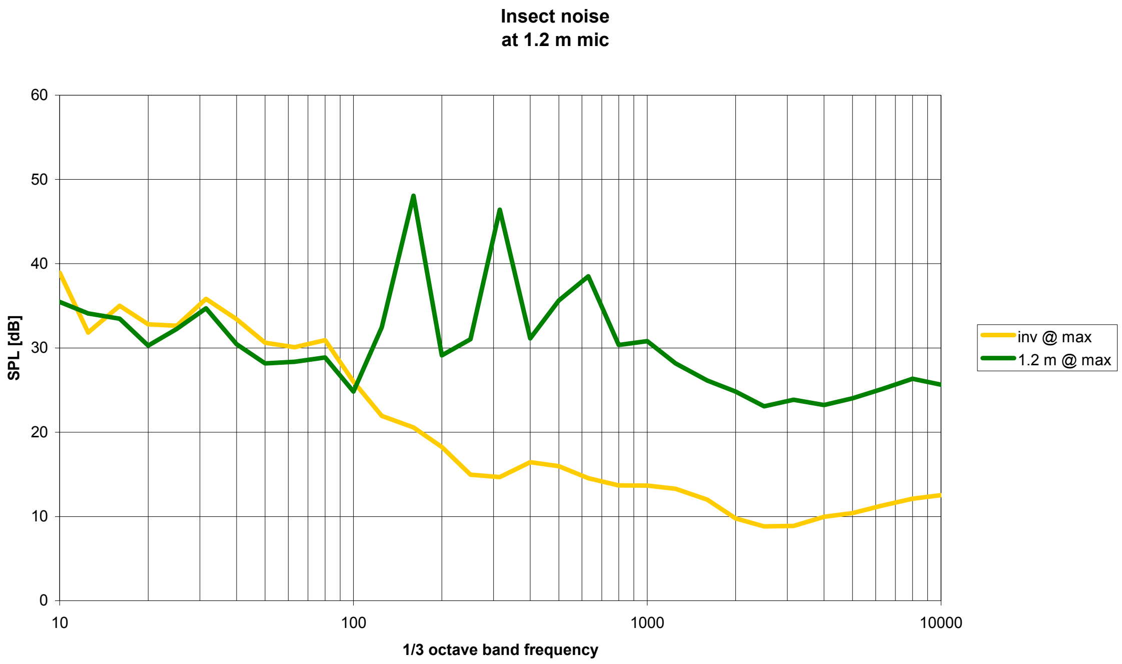


Figure 6- 13 Insect noise at 1.2 mic

A very similar situation took place here, but now at the 1.2 m microphone. Replay of the recording confirmed that also here an insect passed and was fully responsible for the peak and thus for the difference between both microphones.

From the rather complex noise generated by the insects (several tones and broadband) it is clear that no simple correction algorithm can be found.

Considering that the difference between both microphones is about 2.7 dB(A), in a first step all datapoints where the inverted microphone level is more than 5 dB(A) higher than the 1.2m level (i.e. 2.3 dB(A) higher than may be expected) are highlighted in the dataset of MR2 in cruise and climb in the following graphs.

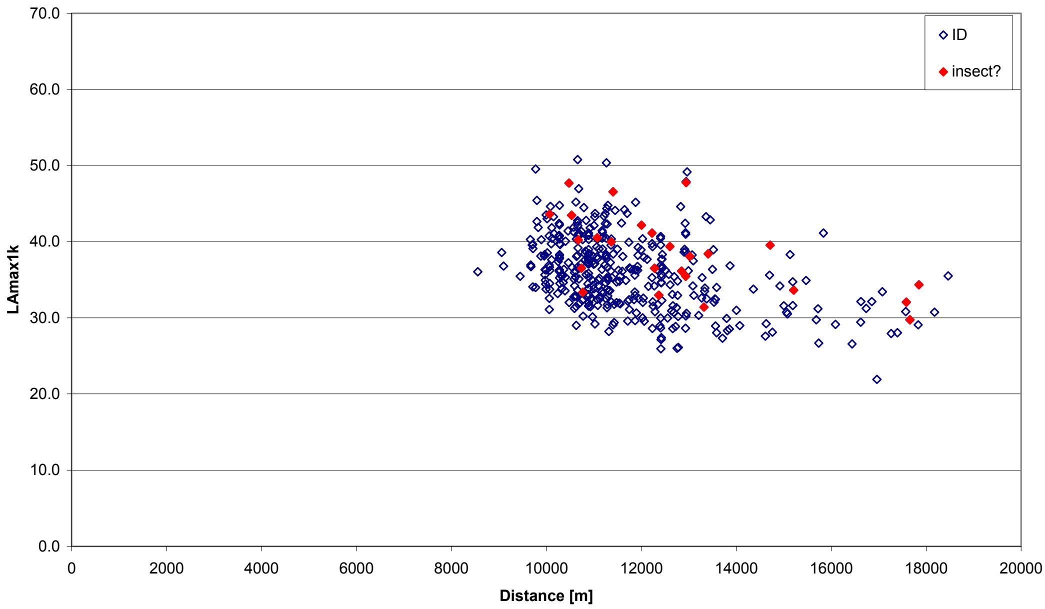


Figure 6- 14 Insect noise: MR2-Cruise-LAmax1k inverted mic

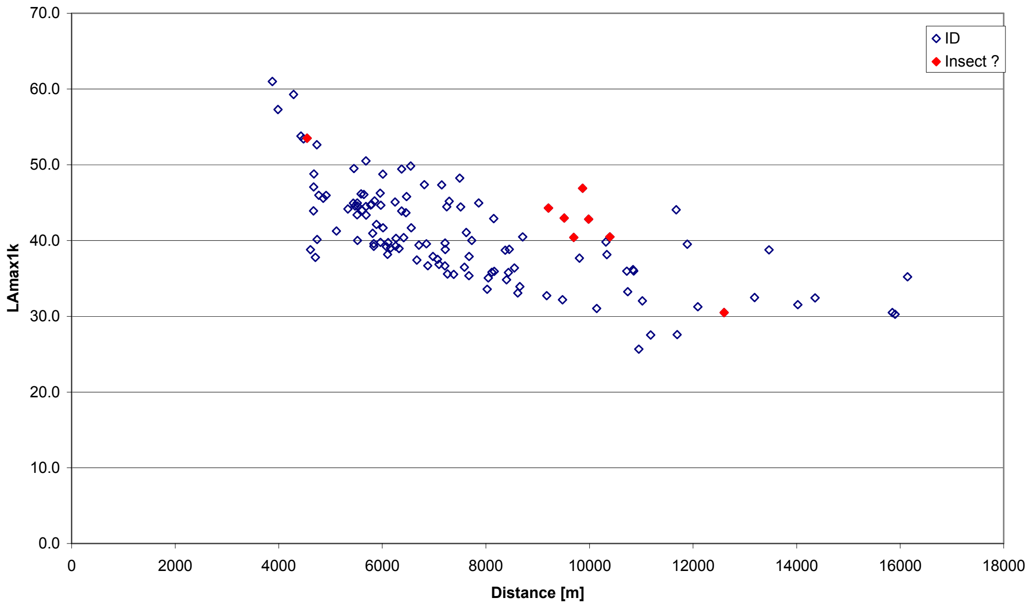


Figure 6- 15 Insect noise: MR2-Climb-LAmax1k inverted mic

It can be seen that indeed quite some datapoints in the higher part of the graphs are detected in this manner, but clearly not all. Obviously this detection method is very basic and gives just a first order result. It is considered beyond the scope of BANOERAC to further investigate this issue.

The main conclusion of this excursion is that indeed the noise of insects is a contributor to the scatter found.

The use of 2 or more microphones is certainly recommended in this type of measurements, in order to at least detect these events. A device might be designed with which insects are not able to approach the microphones, but this might result unpractical during field deployment. Also painting the plate in e.g. blue colour might help to repel insects (at least more than the actual white plate, which seemed quite attractive).

6.5.2. Effect of not reaching 10 dB down

For a significant amount of events the 10 dB down interval could not be determined, mainly due to the low noise levels involved. To investigate if this has an effect on the scatter, hereafter the points for which the 10 dB down interval could not be determined are indicated in a similar manner as before. Obviously this is only of interest for the SEL and SEL1k metrics.

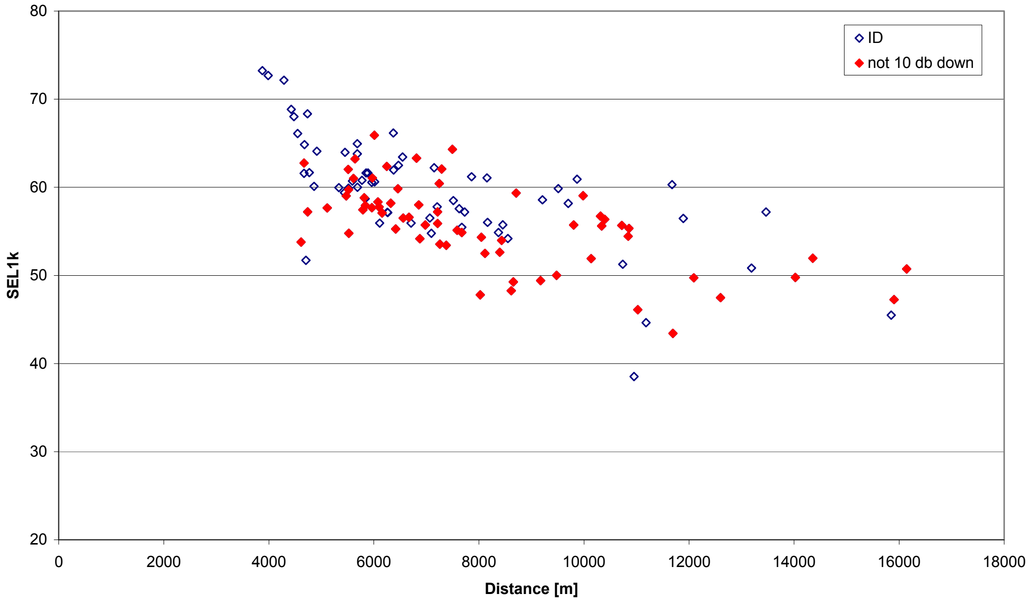


Figure 6- 16 Effect of 'Non 10 dB down': MR2-Climb-SEL1k inverted mic

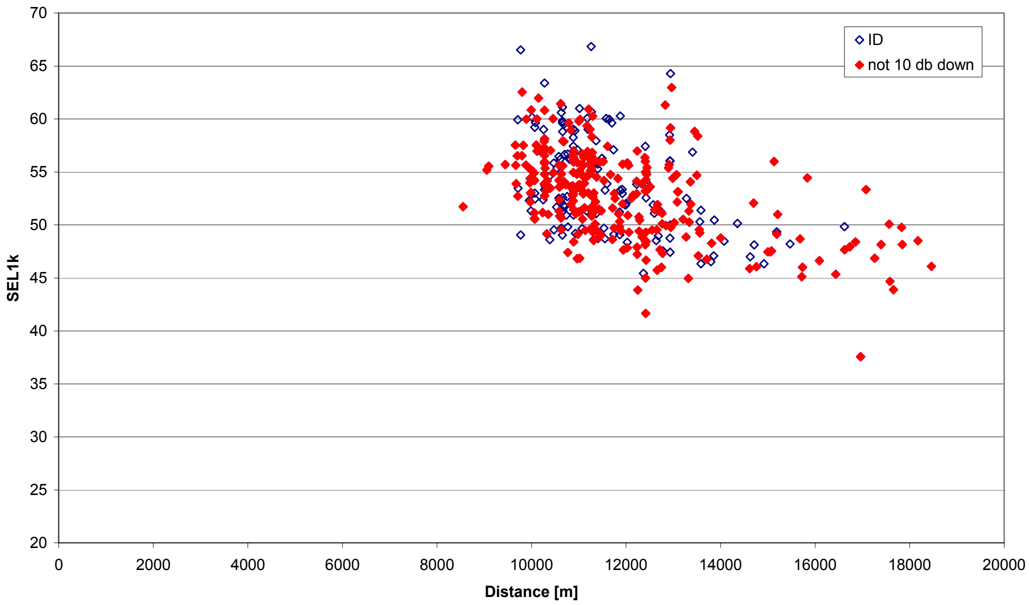


Figure 6- 17 Effect of 'Non 10 dB down': MR2-Cruise-SEL1k inverted mic

Obviously in cruise more points are found with no 10 dB down interval established than in climb. In climb a light tendency to the lower part of the datapoints is found, which was to be expected. However, for cruise this tendency can not be observed.

The fact that the 10 dB down interval can not be reached does not seem a contributor to the scatter found in SEL.

6.5.3. Effect of elevation angle

A similar excursion can be made by detecting the points for which the elevation angle was quite low. In the following graphs for MR2 climb and descent, where this case is most relevant, the datapoints with an elevation angles below 30º are indicated.

Obviously the majority of these points are found at the higher distances. For climb the scatter in this area is around 15 dB(A), which is almost the same as the one found at much lower distances, with high elevation angles.

For descent the scatter in this area appears higher than that in other areas with higher elevation angles. Especially in the upper right corner there seems to be a group of points quite far outside the general tendency of the data. Further investigation revealed that all these points had relatively high wind speeds (although always within the limits). In the following section this is further detailed.

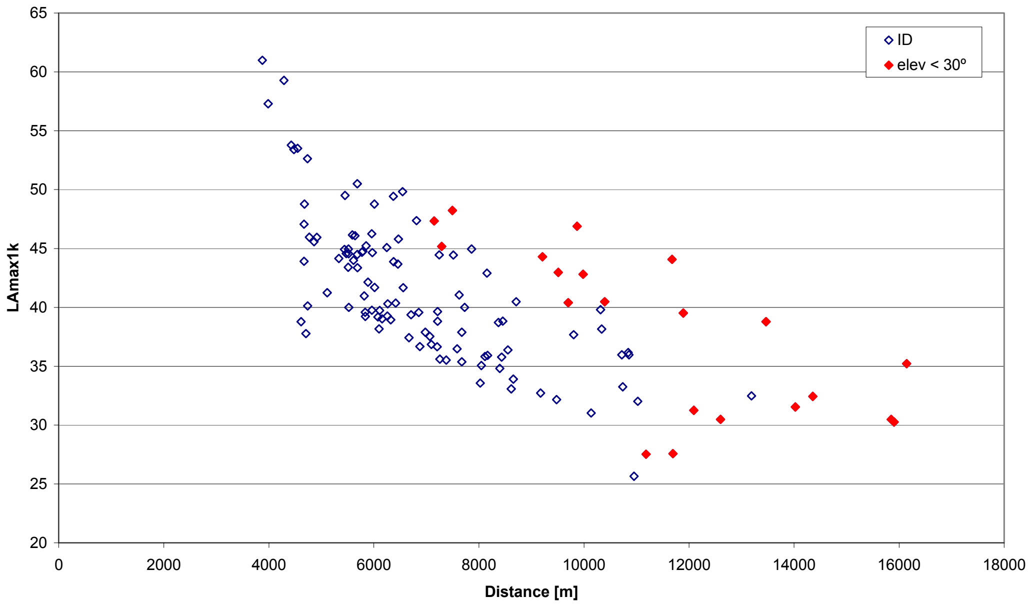


Figure 6- 18 Elevation angle: MR2-Climb-LAMAX1k inverted mic

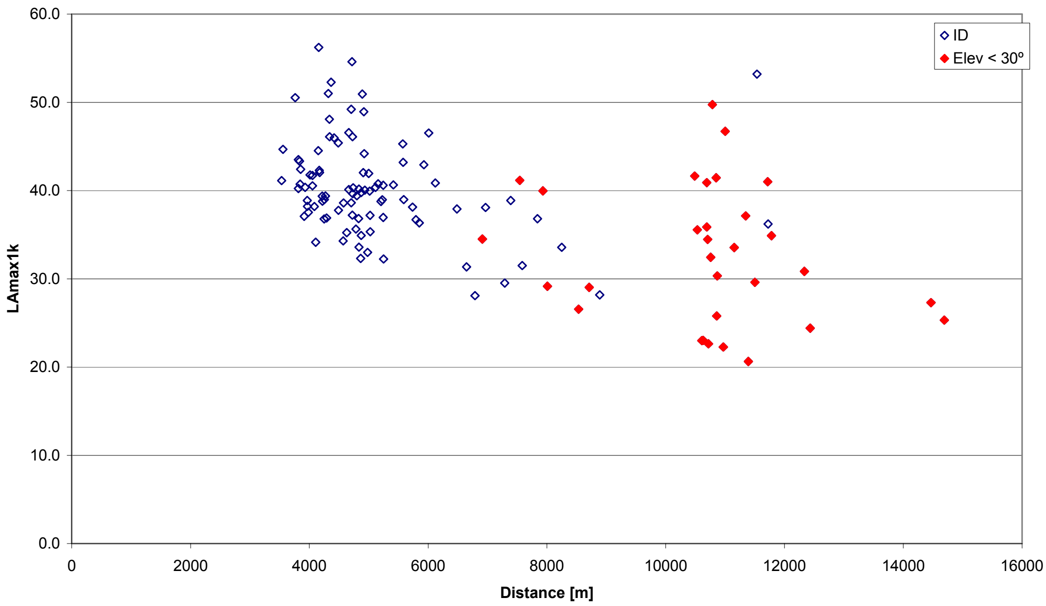


Figure 6- 19 Elevation angle: MR2-Descent-LAMAX1k inverted mic

It seems probable that the combination of low elevation angles with high wind speeds influences the received noise levels. Many projects have been and are dedicated to sound propagation for this kind of situations and this subject is considered beyond the scope of BANOERAC.

6.5.4. Effect of wind speed

During the analysis of the background noise measurements it was already observed that above a certain wind speed noise levels start to increase. In the following graph the points where the maximum wind speed (Vw30_max) was higher than 1.5 m/s are indicated.
For the lower distances a slight tendency to higher noise levels can be detected, although very weakly. However, for the larger distances and lower elevation angles all points detected in the former section appear to have higher wind speeds. If these points would be taken out of the dataset the scatter in this range would decrease significantly and the remaining points would follow the general tendency of the rest of the dataset.

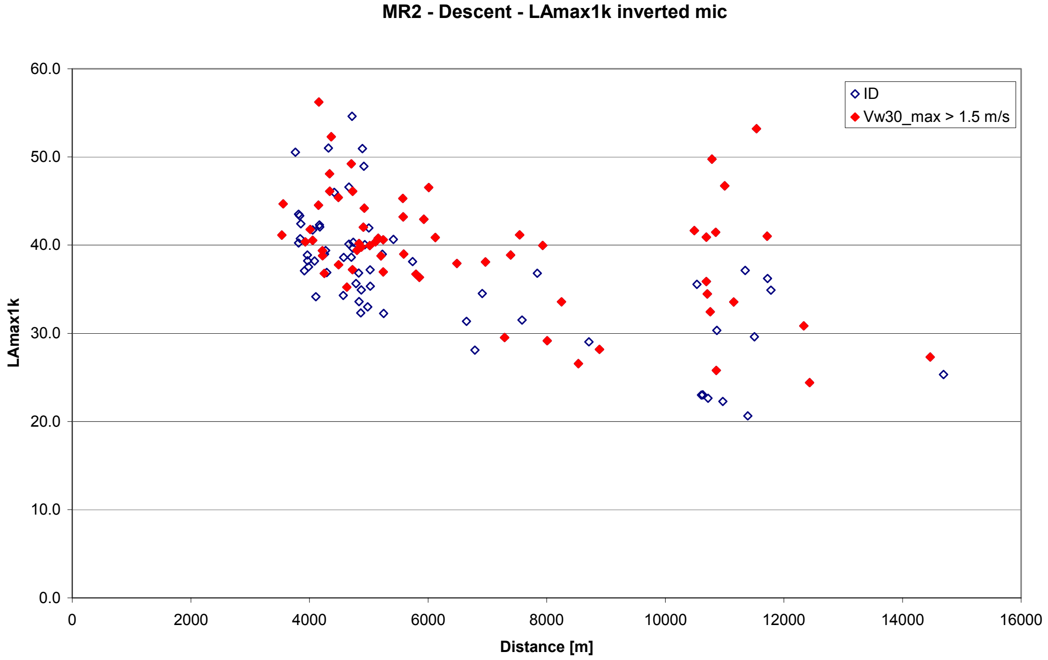


Figure 6- 20 Wind speed: MR2-Descent-LAMAX1k inverted mic

The remaining points at the higher distances have an elevation angle below 30º and they appear perfectly valid. The observation made in the former section about the combination of relatively high wind speed and low elevation angle thus seems correct. It should be noted that a wind speed of 1.5 m/s is still far below the limit of 5 m/s.

6.5.5. Sound propagation

In the former sections some aspects of sound propagation were already mentioned. In the literature the observed scatter is usually attributed to changes in the propagation of the sound through the atmosphere over long distances, especially refraction. As was already mentioned in 6.1.1 the measurements were performed over a range of atmospheric conditions and cover several seasons and different periods of the day. In this large sample of data a variety of propagation conditions will thus have been present. It is considered beyond the scope of BANOERAC to investigate the effect the actual conditions had on the recorded noise levels. However, since the atmospheric conditions in several points around the test site were obtained from soundings as described in section 3.2.3 (Part 2 of this report), providing temperature, humidity and wind speed and direction for heights up to cruise level, an important dataset is available for possible future studies on this topic.

In any case it should be observed that the main objective of BANOERAC was to obtain the actual noise levels received on the ground. The measurements were made under a variety of conditions and can thus be considered representative for the day to day level one can expect.

6.5.6. Effect of grouping of aircraft types

The analysis performed in this study is based on aircraft classes rather than on aircraft types. Obviously within a single class several aircraft types are present and not all will have the same acoustic characteristics. Therefore hereafter the MR2 class is split up into the individual aircraft types.

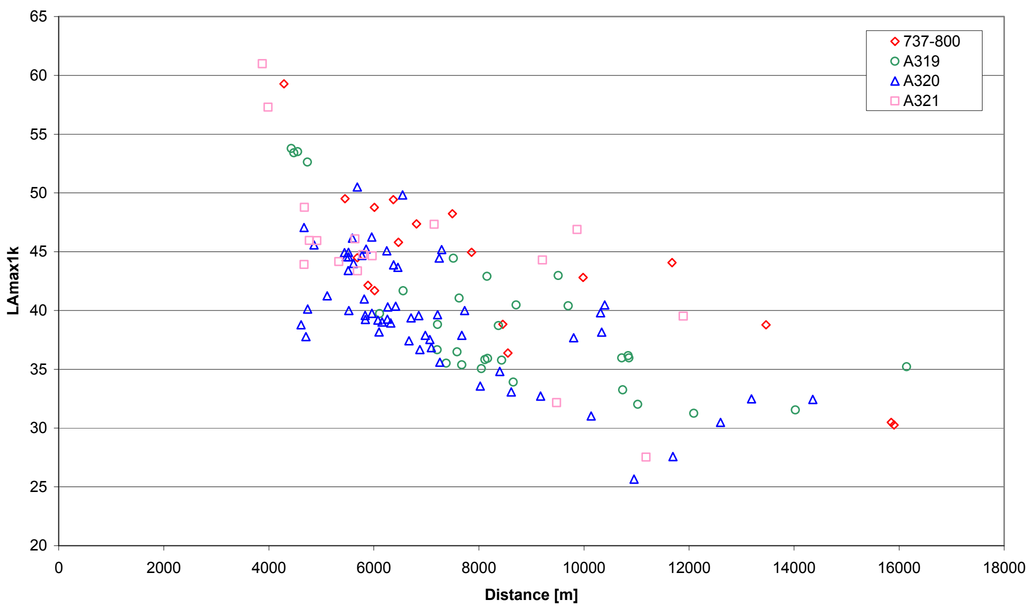


Figure 6- 21 Grouping of aircraft: MR2-Climb-LAMAX1k inverted mic

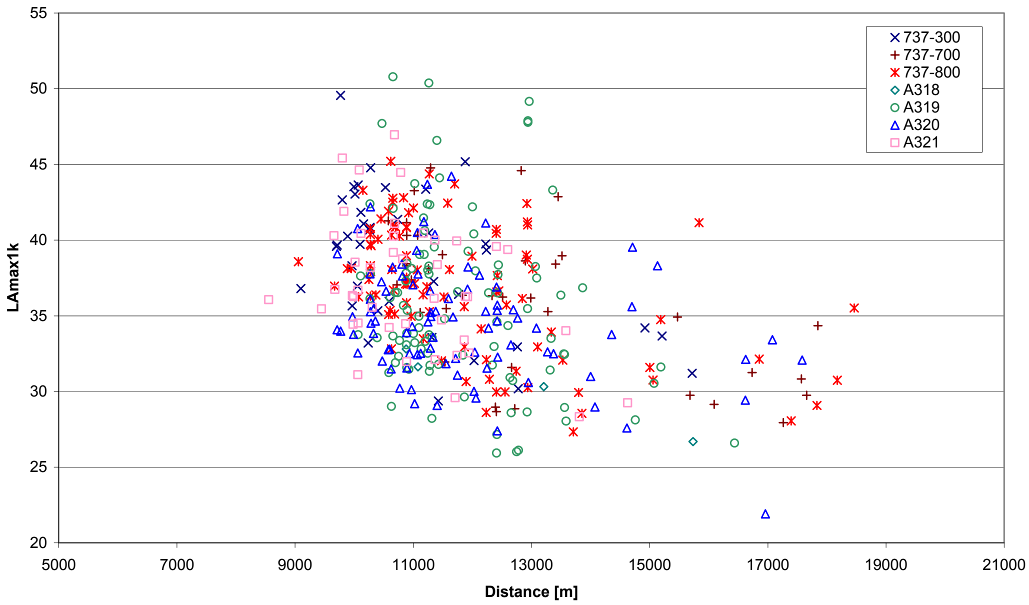


Figure 6- 22 Grouping of aircraft: MR2-Cruise-LAMAX1k inverted mic

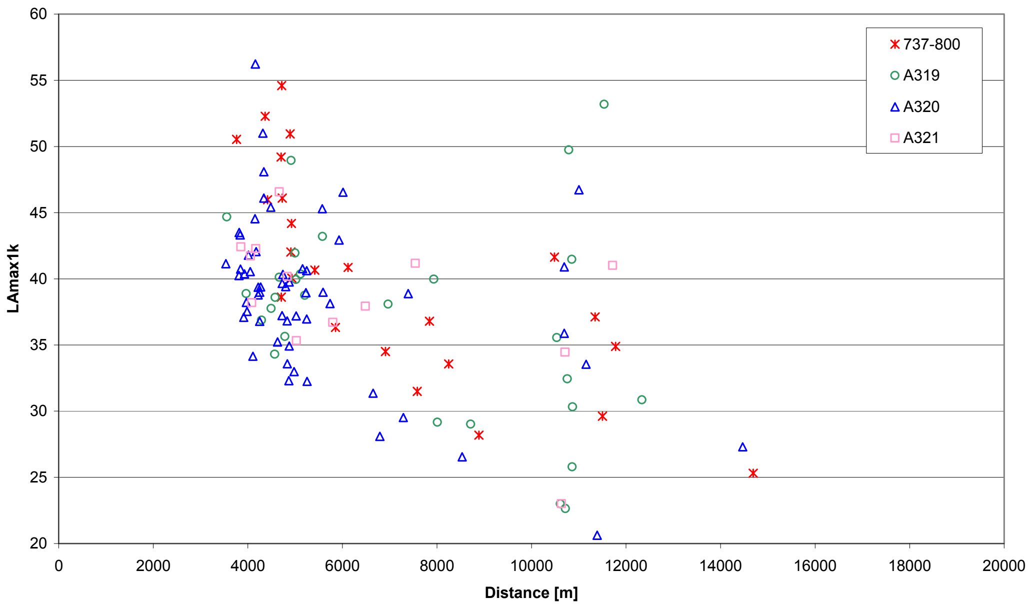


Figure 6- 23 Grouping of aircraft: MR2-Descent-LAMAX1k inverted mic

The noise levels for the various aircraft types are scattered all over the datasets and no tendency towards a ‘quieter’ or ‘noisier’ aircraft is apparent. This confirms that the analysis on the aggregate level of aircraft class, as carried out in this study, is sufficient.

6.5.7. Combined effect of wind speed and noise of insects

In the former sections some effects have been detected which appear to contribute to the observed scatter, especially wind speed and noise of insects. Since both mentioned effects can be considered independent, it is of interest to see if there combined effect indeed is (co-)responsible for the scatter in the datasets. To this end the LAmax1k level (inverted mic) of all valid aircraft events has been plotted for the three flight phases (see figures 6-24 to 6-26). In the same graphs the datapoints for which the average wind speed exceeds 1.5 m/s and/or the difference between inverted and 1.2m microphone level exceeds 5 dB(A) have been indicated in red. If these points are excluded from the datasets, it can be seen that indeed the scatter will be reduced significantly.

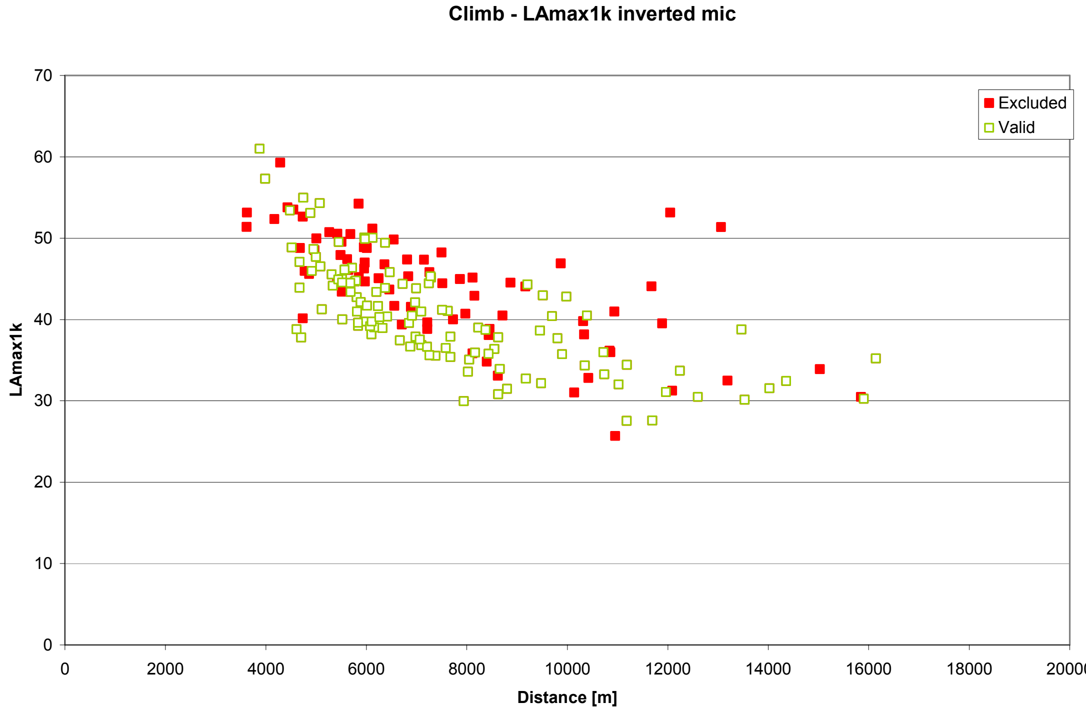


Figure 6- 24 LAmax1k for all valid aircraft events (CLIMB phase)

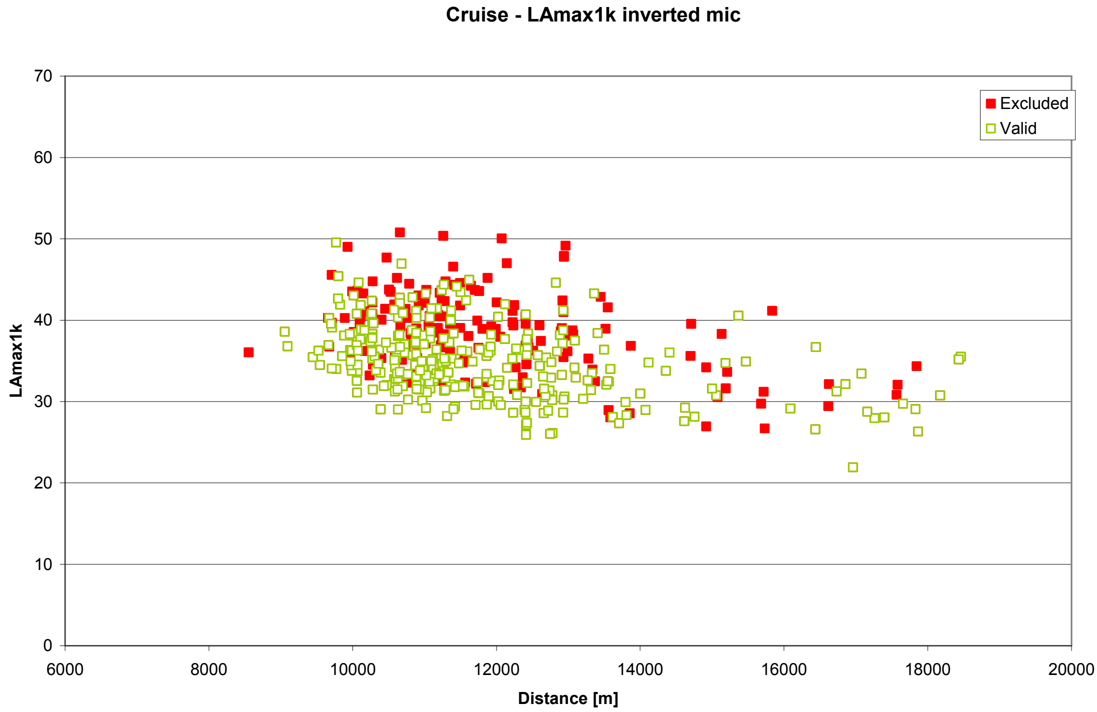


Figure 6- 25 LAmax1k for all valid aircraft events (CRUISE phase)

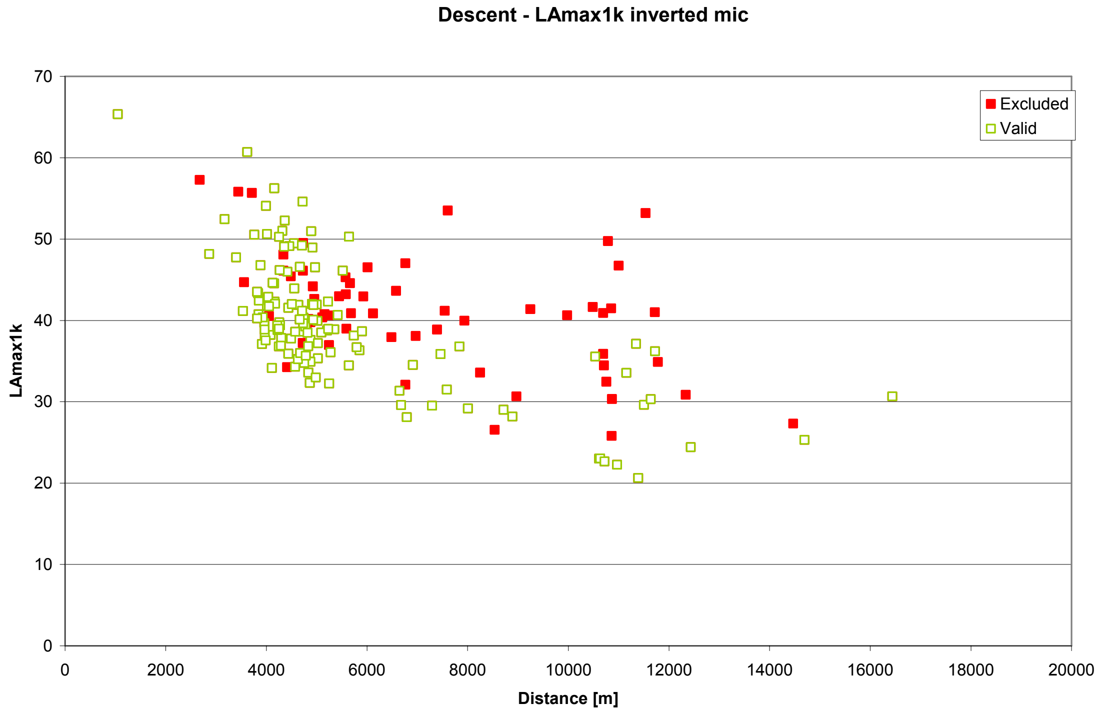


Figure 6- 26 LAmax1k for all valid aircraft events (DESCENT phase)

6.6. Final datasets for aircraft en-route noise

In section 6.5.7 it was found that excluding those points contaminated by wind and/or insects significantly improves the quality of the datasets. Figures 6-27 to 6-29 present these filtered datasets for LAmax1k(inverted mic) as a function of distance for the three flight phases, together with the corresponding regression line:

$$LAmax1k = A - B \cdot \log(distance) \qquad \text{(distance in m)}$$

where:

Table 6- 9 Regression coefficients

Flight phase	A	B
Climb	178.88	35.889
Cruise	158.52	30.405
Descent	168.18	34.659

These coefficients are not far from those derived for the simple empirical model in 6.4.3. It is noted that no distinction is made here between aircraft classes. It should also be noted that the resulting dataset does not include any propeller aircraft, since for these types no geometrical data is available (no ADS-B).

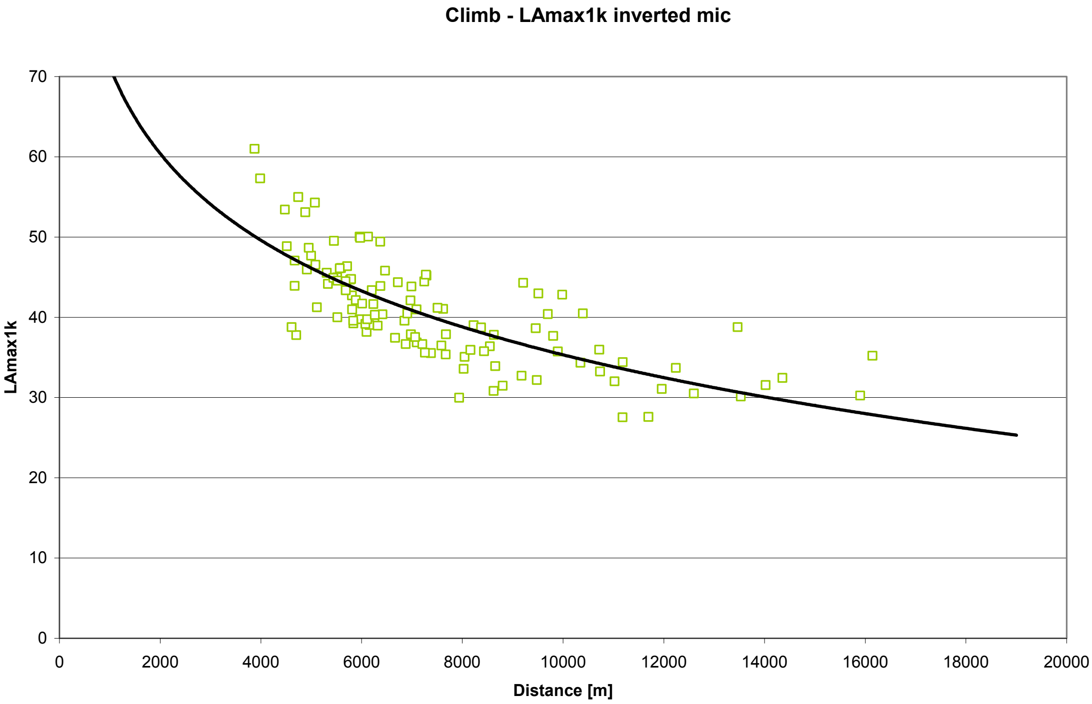


Figure 6- 27 LAmax1k for all valid jet aircraft events - filtered (CLIMB phase)

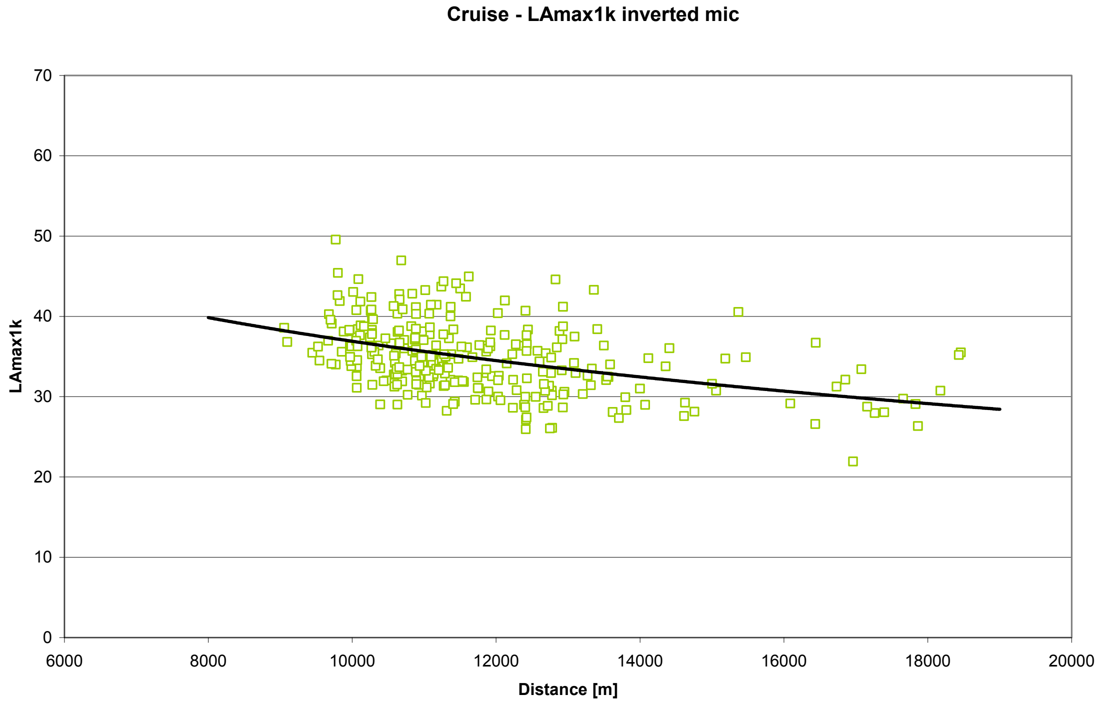


Figure 6- 28 LAmax1k for all valid jet aircraft events - filtered (CRUISE phase)

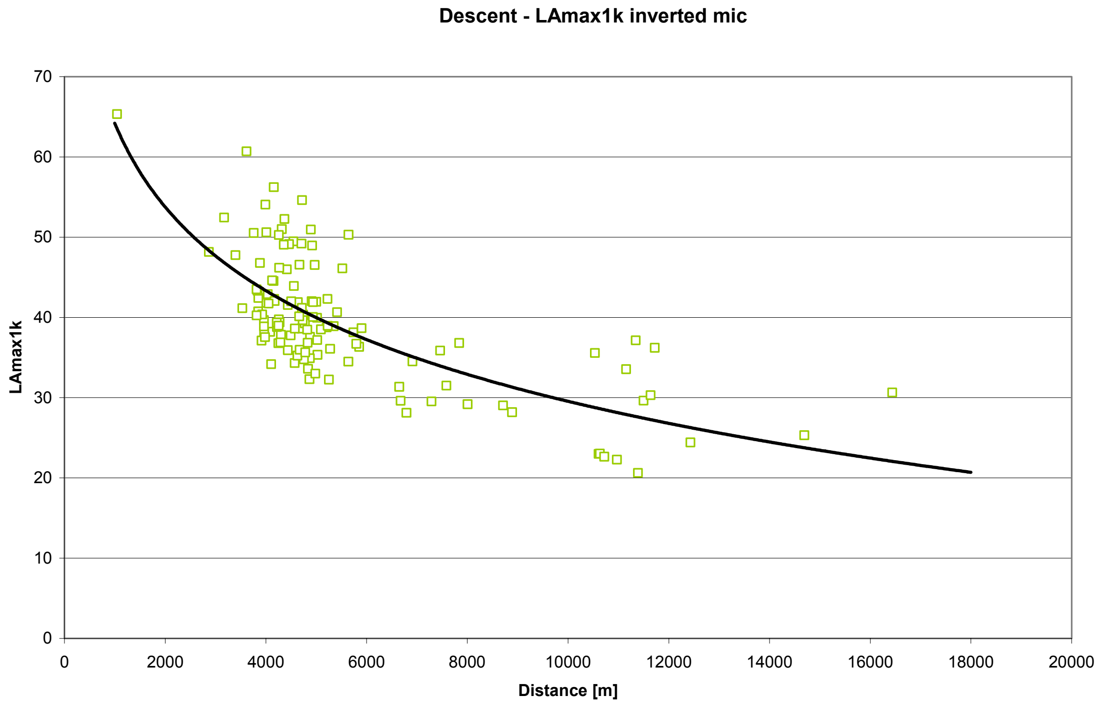


Figure 6- 29 LAmax1k for all valid jet aircraft events - filtered (DESCENT phase)

The following table presents the resulting noise level at an arbitrary reference distance (5 km for climb and descent, 10 km for cruise), following the regression curves derived above.

Table 6- 10 Average noise level at reference distance (inverted mic)

Flight phase	Ref. dist (m)	$LAmax1k_{ref}$	Standard deviation*
Climb	5000	46.1	4.3
Cruise	10000	36.9	4.0
Descent	5000	40.0	5.4

* when all datapoints collapsed to the reference distance by using the regressions curves

It should be noted that these levels are an average level for all jet aircraft types at the indicated distance. Deviations of up to ±10 dB(A) from this average have been observed.

7. CONCLUSIONS

In general it can be concluded that the objectives as set at the beginning of the project have been fully achieved.

7.1. On background noise

A total of around 135 hours of background noise measurements has been obtained. These measurements were made at four different test sites, representative for natural parks, agricultural areas and hilly/mountainous regions.

Dedicated measurements were made during 32 to 48 hours continuously in order to obtain a good view on the change of the levels over a day. The change over day appeared to be remarkably repetitive.

Other measurement data were obtained during the aircraft noise sessions.

Very low noise levels were observed at one of the test sites. These levels were used in the elaboration of the background noise map of Europe, derived in Part 1.

Observed (L95c) background noise levels in quiet areas ranged from 17 dB(A) at night to around 25 dB(A) at day. Significantly higher levels were found in specific situations (e.g. high wind speeds or presence of insects like cicadas).

An extension of the formula derived in Part 1 might be necessary in order to take into account local effects.

Wind speed appears to have an important effect on background noise levels, even at moderate wind speeds, well below certification limits. From the study it could not be deduced if this is mainly due to the increase in noise from e.g. moving tree leafs or due to wind induced noise at the microphone itself. The 1.2m microphone appears to be more sensitive to wind speed than the inverted microphone.

The effect of the microphone height on background noise levels appears to be very small, when randomly distributed noise sources are dominant. When localized sources are dominant, the difference might become considerable and unpredictable.

7.2. On aircraft en-route noise

An extensive dataset on aircraft en-route noise has been obtained through high quality measurements. These measurements were performed at four different test sites over a six month period, covering winter to summer. Some measurements have been made at night. This dataset thus covers a variety of environmental conditions which makes it representative for the noise levels of current aircraft when en-route, which was the main objective of BANOERAC.

For different aircraft classes the noise levels in climb, cruise and descent phase were obtained. A wide range of distances is covered by the dataset.

Against initial expectations, noise in the descent phase is clearly audible.

A specific metric was used in the form of an A-weighted overall noise level (LA), but with a cut-off at 1KHz. It was shown that this allows for the proper description of aircraft events, even in environments with dominant high frequency noise sources like birds.

A first step towards an empirical prediction model for aircraft en-route noise was made.

Comparison of the results with similar studies performed in the past, confirmed that current aircraft types are quieter in all phases of flight. Based on these studies it was also noted that at present cruise altitudes appear to be higher than in the past, thus also contributing to a reduced noise level on the ground.

The scatter in the data was in the same order of magnitude as found in earlier studies. Although probably the influence of atmospheric conditions is very important for the noise propagation and thus the received noise levels, this was certainly not the only contributor to the observed scatter.

The noise of insects passing by the microphone at very short distance appeared quite important. The use of two microphones resulted very useful to detect these events.

Although wind speeds were always well within the established limits, it was found that the combination of even relatively low wind speeds with low elevation angles appears to give rise to an increased scatter in the data.

When excluding the datapoints contaminated by noise of wind and/or insects, the following average LAmax1k levels at the indicated (arbitrary) reference distance can be found for all jet aircraft types together (inverted microphone):

Flight phase	Ref. dist (m)	$LAmax1k_{ref}$
Climb	5000	46.1
Cruise	10000	36.9
Descent	5000	40.0

References

[1] EASA
Specifications attached to the Invitation to Tender EASA.2008.OP.14 – BANOERAC
July 2008

[2] Anotec Consulting / Labein-Tecnalia
Proposal for the performance of the BANOERAC project
Anotec Doc OAN074-1-1 – September 2008

[3] SINTEF ICT
Background noise levels in Europe – June 2008

[4] Anotec Consulting
Initial study on aircraft cruise noise levels
Anotec Doc PAN069-1-2 – May 2008

[5] International Civil Aviation Organisation (ICAO)
Annex 16 to the convention on international civil aviation,
Volume I, Aircraft Noise, Fourth Edition - July 2005

[6] Report of tests: En route noise of turboprop aircraft and their acceptability – W. Held
Paper presented at the FAA/NASA En route noise Symposium – NASA CP-3067 – September 1989

[7] Measurement of noise from aeroplanes travelling at heights 3500-11000m – M. Linde et.al. FFA TN 1986-21, March 1986

Appendix 3-1

Use of a 1 kHz cut-off for aircraft events

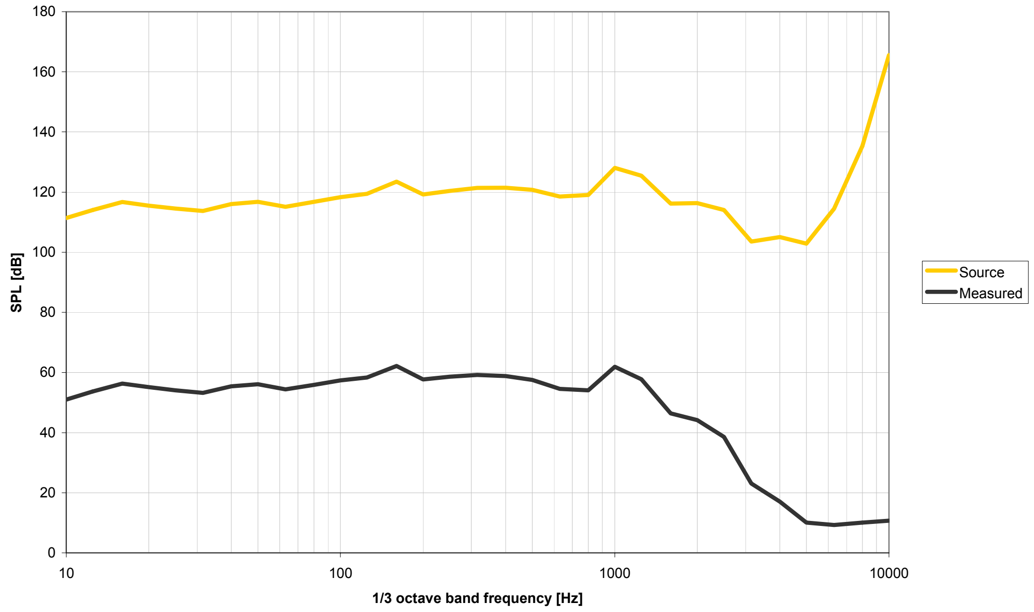
A.3.1-1 Introduction

Due to the presence of noise from birds in the measurements it appeared impossible to obtain any useful information from the LA metric. In section 4.2.1 it was shown that the use of a cut-off at 1kHz (i.e. not taking into account the frequencies above 1 kHz in the calculation of LA) drastically improves this situation. It was empirically demonstrated that for an aircraft event recorded in a very low background noise environment the resulting SEL1k and LAmax1k metrics are equivalent to the standard SEL and LAmax.

In this Appendix this equivalency will be demonstrated by means of a more theoretical approach. Based on a theoretical source spectrum the received spectrum will be calculated for a range of distances, taking into account the corresponding atmospheric absorption.

A.3.1-2 Source noise

No information was found on source noise spectra for current aircraft types in en-route conditions. Therefore it was necessary to derive one from the measured data. The best measurement available for this was aircraft event nº 150203, since the aircraft (an Airbus Beluga) passed the microphone at only 1046 m height, due to which also meaningful noise levels in the higher frequency bands (upto 5 kHz) were recorded. The spectrum at LAmax was then corrected to a distance of 1 m by adding corrections for spherical spreading and atmospheric absorption, thus obtaining the spectrum at the source. The following graph shows both the measured spectrum as received on the ground and the derived source spectrum.



It can be seen that the source spectrum is more or less flat over the whole frequency range upto about 2500 Hz. The sharp increase above 5 kHz is due to the limiting noise floor in the measured spectrum.

Based on the above, it was considered a conservative approach to perform the theoretical study with a flat source spectrum. The level of the source noise was set at 120 dB. It is noted that the final result of this exercise is independent of this value, since only the difference between LA and LA1k will be judged.

A.3.1-3 Atmospheric absorption

In order to be able to determine the atmospheric absorption first the atmospheric conditions have to be known. Both temperature and relative humidity vary with height and it was considered appropriate to work with a layered atmosphere. To facilitate the calculations, layers of 2500m thick were established, in which the temperature and relative humidity were assumed constant.

To assign a temperature and relative humidity to each layer the measured values of the soundings for the Madrid station for each layer have been averaged, with the following result:

Layer	height (m)	Temp (ºC)	Rel.hum (%)
1	0 - 2500	15	32
2	2500-5000	1	21
3	5000-7500	-18	21
4	7500-10000	-37	24

The atmospheric absorption coefficients are calculated with SAE ARP 866A. This standard limits the validity of its results to a lower temperature of 1ºF (-17ºC). In order to be able to use this standard within its valid range, the temperature of the layers from 5000m onwards has been set to -17ºC. It is recognised that this will introduce an error, but it is considered more appropriate than using the standard beyond its stated limits.

A.3.1-4 Calculation of the received spectrum

Assuming the source at a height H above the microphone the spectrum received at the microphone position will be :

$$SPL_{rec}(k) = SPL_{source}(k) - 20 \cdot \log(H) - \sum \alpha(i,k) \cdot \Delta L(i)/100$$

where

$SPL_{rec}(k)$ = sound pressure level of 1/3 octave band k as received on the ground
$SPL_{source}(k)$ = source noise level at 1/3 octave band k
H = height of source above microphone (m)
$\sum \alpha(i,k) \cdot \Delta L(i)/100$ = total atmospheric absorption, composed of the contributions of the various layers below the source
$\alpha(i,k)$ = atm. absorption coefficient for layer i and 1/3 octave band k (dB/100m)
$\Delta L(i)$ = thickness of layer i, to be taken into account (m)[1]

[1] E.g for a source height of 6000 m layer 1 and 2 are to be used in full, whereas only 1000m of layer 3 is to be taken into account

In this manner the received spectra were calculated for heights from 1 km to 10 km. For each spectrum the corresponding overall levels LA and LA1k were then calculated, with the following result:

H (m)	LA (dBA)	LA1k (dBA)
1000	62.89	62.34
2000	53.62	53.51
3000	46.23	46.23
4000	40.23	40.23
5000	35.86	35.86
6000	32.41	32.41
7000	29.27	29.27
8000	26.27	26.27
9000	23.41	23.41
10000	20.76	20.76

From this table it can be concluded that from a distance of 3000m onwards the LA and LA1k levels are equal or, which is the same, from this distance onwards the noise above 1 kHz does not contribute to the overall LA level.

Based on this result it can be concluded that for the distances considered in the present project the LA and LA1k based metrics are equivalent and that thus the use of LA1k instead of LA to describe the aircraft events is justified.