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MEASUREMENT AND ANALYSIS OF NATURAL AMBIENT SOUND LEVELS AND WEATHER PARAMETERS

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ABSTRACT
To assess ambient sound levels a measurement system has been developed to measure sound levels as well as weather parameters such as wind speed and direction, temperature and rainfall, over relatively long periods of time (several weeks). Sample frequency is typically 1 per second and data are saved, usually every 10 minutes, as statistical distributions and averages. With an analysis program the results can be viewed graphically. To reduce the amount of data the distributions can be aggregated statistically correct in intervals or classes. Also selections can be made from all data, based on time or measurement values intervals. Measurements have been made at several locations, of which some results are presented.

1 - INTRODUCTION
Measurements of the 'background' ambient sound level, operationally defined as the 95 percentile (L_{95}) of the sound pressure level, are routinely carried out in the Netherlands for licensing purposes. The L_{95} is the sound level exceeded for 95% of the time, so only in 5% of the time the sound level is less than L_{95}. In environmental licenses the sound level caused by small and medium-sized industries, businesses or enterprises usually is restricted to the L_{95} of the ambient sound, *i.e.* the prevailing sound without the sound caused by the industry, at immission points such as nearby dwellings.
At the Science Shop for Physics a measurement system has been developed to automatically collect sound and weather data. Its original purpose was to measure over relatively long periods of time the sound level in different rural or (semi) natural, non-urban environments and to relate this to variables such as wind speed or direction, tide or time of day. For analysis a computer program has been developed to be able to deal with the statistical data correctly. The result is a quantitative description of the sound level in an area and its relation to time and weather dependent factors. This may be used to assess the audibility or impact of existing or planned noise sources. Important modern noise sources in rural and (semi) natural areas are wind turbines, but levels of other (industrial, recreational, military, traffic) sound sources can also be compared to the ambient levels. For wind turbines the L_{95} has to be established at different wind speeds, in other cases it is usually determined at low wind speeds.

2 - MEASUREMENT SYSTEM
The measurement system consists of sensors to measure sound level, wind speed, wind direction, temperature, rainfall and air moisture. The microphone and one wind meter (speed + direction) are usually placed at a height of about 2 meter, so the wind is measured close to the microphone that is at 'ear height'. The microphone is provided with a rain cap and a cylindrical wind screen of 9 cm diameter; the lower part is in a tubing containing silica grains to keep the microphone (from the lower side) as dry as possible. A second wind meter is in a mast at a fixed reference height of 5 or 10 meter and as much as possible in undisturbed wind, *i.e.* away from obstacles. It is also at some distance from the microphone to prevent whistling caused by wind in the mast rigging to influence the measurements. The moisture sensor is a high-low indicator, based on short-circuiting by moisture from dew, mist or rain. The percentage of time the signal is high ('wet') is stored. The rain sensor is to detect rain by producing

an electric pulse every time 1 mm of rain has fallen. The time between pulses, with a maximum of 99 minutes (corresponding to a very light drizzle), is stored.
All sensors are connected to a case that contains the sound level meter, a palm top computer, a GSM telephone and electronics for the sensors and energy supply. The sound level meter converts the (usually broad band A-weighted) sound level to an electric signal that is connected, as all other measurement signals, to an analog-digital converter (ADC) that is connected to the palmtop. A computer program samples the signal values in intervals of usually 1 second and stores data in intervals ('measurement blocks') of usually 10 minutes. The sample time and block length can be set to values of, respectively, at least 0.1 second and at least 1 minute.
Electric energy is supplied by a 12 volt battery that can be fed by a solar panel. In summer the solar panel supplies enough energy to keep the system working. By means of the telephone remote viewing and controlling the palmtop computer and the transfer of data files is possible.

3 - ANALYSIS SOFTWARE

All data are collected in measurement blocks that contain the measurement date and time, the statistical distributions of the sound level (in 0.1 dB intervals), wind speeds (0.1 m/s) and wind directions (1 degree), and the average temperature, 'moisture' and 1 mm rain interval time. The time resolution in analysis is determined by the time length of the measurement blocks. In the measurement results presented below the sample time is 1 second and the block length 10 minutes. The analysis software is a self developed program (in Labview) that presents results as graphs where the abscissa is either block number, date, clock time (0-24 hours), or any measurement value, and the ordinate is any measurement value. Measurement values include the equivalent sound level and percentile and average values of all statistical variables. Graphs may be plotted from all data or from selections, where selections are defined by a combination of lower and upper bounds of measurement values or date, clock time or relative tidal amplitude (in case of measurements near sea).
Graphs produced this way consist of up to thousands of points (1 week contains 1008 10-minute intervals) where each point represents a value over the measurement block time length. The number of points can be reduced in a meaningful way by dividing the abscissa in intervals. Then, all distributions of the statistical variables (sound level, two wind speeds and wind directions) belonging to one interval are added to yield one distribution per variable and one graph point (e.g. of a specific percentile level, an average or an L_{eq}) per interval. In this fashion a graph is formed containing as many points as the number of (non-empty) intervals on the abscissa. Figure 1 is an example of measurements in the Horsterwold, a semi-natural area consisting of flat open land and some water, with few trees and low, grassy vegetation near the measurement location. The A-weighted L_{95} is plotted as a function of the median wind speed (v_{50}) at 10 meters height. The separate points are the L_{95}-values of all (appr. 5000) 10-minute measurement blocks. Then the abscissa is divided in intervals of 1 m/s, and the statistical distributions of the sound levels are added, in figure 1 for a specific selection: only the night time period from 23 to 7 hours, from all blocks with $0 < v_{50} < 1$ m/s; from the resulting distribution the aggregate L_5 and L_{95} are determined and plotted as a two points at $v_{50} = 0.5$ m/s. The same procedure is followed for all other intervals ($1-2$, $2-3$, $3-4$ m/s, etc.) and L_5 and L_{95} values are determined for $v_{50} = 1.5$, 2.5, 3.5 m/s, etc. The resulting aggregate values are plotted and connected by lines, resulting in the two line graphs for the night time period in figure 1. The same procedure has been followed for a selection of all daytime (7-19 hours) measurements.

4 - RESULTS

In this section some results of measurements at different locations are presented. All locations are in the northers half of the Netherlands. At all locations the land is flat, with surface levels varying no more than some decimeters with the exception of ditches and dikes. At most locations the vegetation consisted of grass and/or low herbs. At Warffum the measurement spot was on seaside meadow lands near (100 m) the high tide line, at Ameland above flooded mud flats. At Rutten the microphone was close to a dwelling ($1-2$ m) and trees (20 m) to investigate the effect of these obstacles on the wind and sound level. At all locations the reference wind meter and, except for Rutten, the microphone was at least 100 m from elevated objects such as trees, houses, barns, dikes, etc.

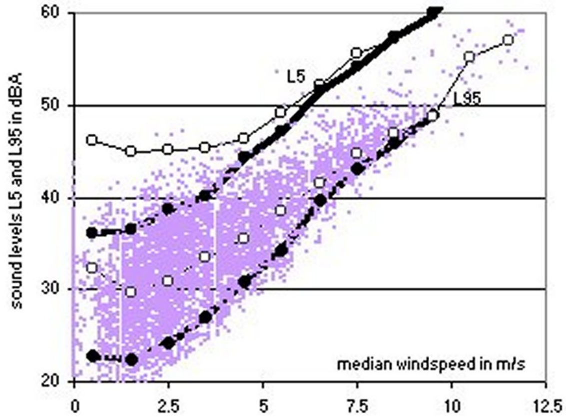

Figure 1: All measured 10-minute L_{95} sound pressure levels (points) at Horsterwold and aggregated L_5 and L_{95} sound levels for daytime (open circles) and nighttime (filled circles).

Location	Type of area	Immediate environment	Measurement		Continuous human sound sources
			Period	time	
Ameland	flooded coastal flats	sand flats, water at high tide	june−aug '99	900 hours	None
Baflo	meadow land	grass, some reed	may−june '98	530	village at 2 km
Blauhuis	meadow land	Grass	dec '95	270	village at 0.5 km
Warffum	coastal plain	Grass, low herbs	july-aug '96	280	road at 4 km
Rutten	arable land	dwellings, garden, trees	dec '98-jan '99	690	highway at 6 km
Horsterwold	low vegetation	low herbs, grass, some reed	nov-dec '98	900	highway at 4 km

Table 1: Measurement locations.

In figure 2 the statistical distribution of all measurements at Ameland is indicated by five percentile levels. These levels have been determined by aggregating all measured sound levels in 1 m/s wind speed intervals. At this location the sound level was not, for a significant amount of time, influenced by human sources and the L_{95} was found to correlate well with the v_{85}, the wind speed percentile about one s.d. below the median wind speed. In figure 3 four statistical distributions are plotted for wind from the four compass quadrants ($0-90$ degrees, $90-180$, etc.) from all measurement blocks with low or moderate wind speeds ($v_{50} < 5$ m/s). It appears that with northerly winds, coming from the island of Ameland at 1 km distance, the sound levels are lower than with southerly winds coming from the Waddensea. This may be caused by the lower sound absorption of the sea surface, the different nature of the sound production over sea, or the different behavior of wind.

At inland locations the sound level is significantly influenced by human activities, especially road traffic. Figure 4 gives a plot of the L_{95} at low wind speeds ($v_{50} < 3$ m/s) to exclude masking by wind induced sounds, aggregated in one hour intervals, as a function of clock time. Also plotted, on a logarithmic scale, is the hourly traffic intensity on the nearest highway, 4 km from the measurement spot. It is clear that the curves correlate well.

In figure 5 the relation of the L_{95} with the median wind speed at 10 m height is plotted for all locations. The slope of the lines is typically 4 dB per ms^{-1}, except for Rutten (1.8 dB/ms^{-1}).

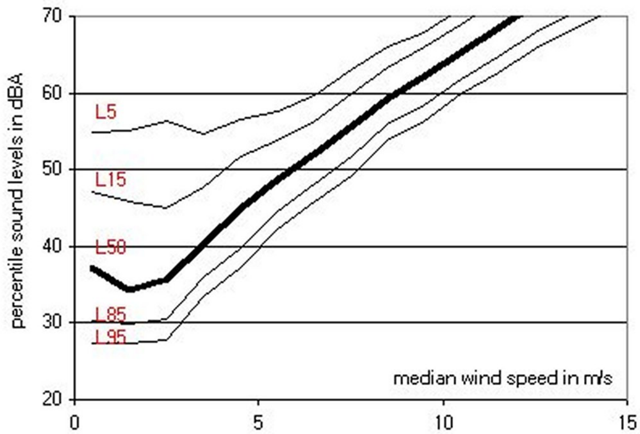

Figure 2: Aggregated percentile sound levels L_5, L_{15}, L_{50}, L_{85} and L_{95} in 1 m/s wind speed intervals of all measurements at Ameland.

5 - CONCLUSION

With data collected over prolonged periods of time (several weeks) it is possible to investigate the dependence of the ambient sound level on wind speed and other weather parameters (wind direction, rainfall), or the influence of time related sources such as traffic intensity or tide. In this paper only very few results can be presented; many others are available in reports from the Science Shop for Physics (in Dutch; see http://www.phys.rug.nl/scienceshop.physics). A next step we now consider is the addition of another dimension, *viz.* the spectral distribution of the measured sound levels.

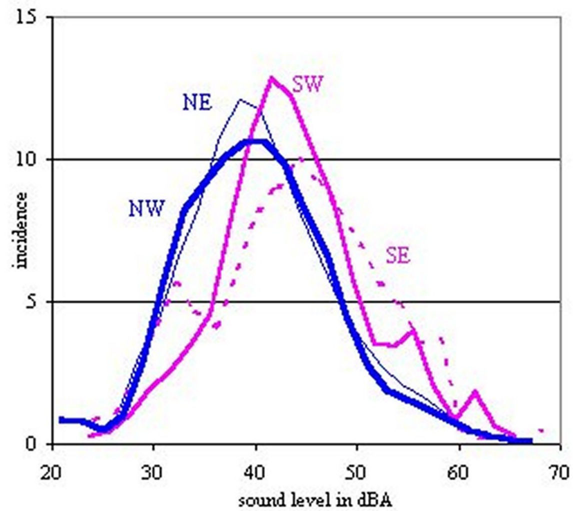

Figure 3: Sound pressure level distributions in 2 dB intervals at Ameland, at low/moderate wind speeds ($v_{50} < 5$ m/s) for wind from four compass quadrants.

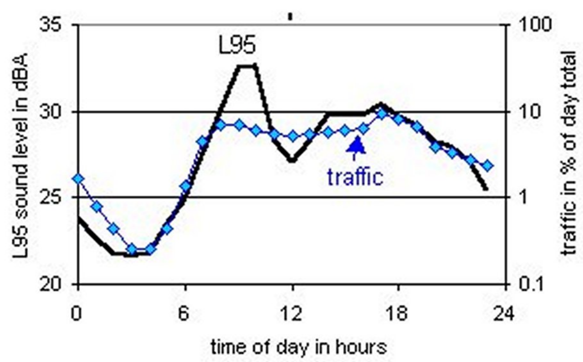

Figure 4: L_{95} sound level at Horsterwold and traffic intensity on highway at 4 km at low wind speeds ($v_{50} < 3$ m/s) as a function of clock time.

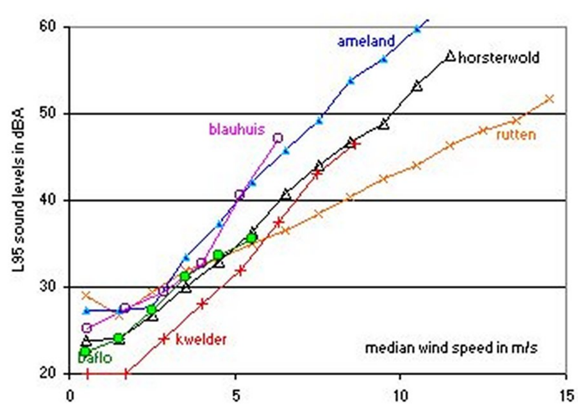

Figure 5: L_{95} sound levels, aggregated in 1 m/s wind speed intervals, from all measurements at all locations.