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Nationwide noise mapping across Sweden's green landscape

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ABSTRACT

This research project presents a mapping of noise levels in green areas across all of Sweden, with a particular emphasis on nature reserves, national parks, and other recreational spaces. Utilising the Nord2000 noise prediction method, our study incorporates the following noise sources: road traffic, railway traffic, wind turbines, and airports. Our analysis includes longer propagation distances than typical noise maps (up to 8 km) to account for distant sources, given the importance of low noise levels in pristine natural environments. Weather conditions play a crucial role in long-range sound propagation; therefore, we have integrated ten years of weather statistics (2013-2022) from the ERA5 climate dataset into our assessment. This mapping effort represents one of the first nationwide noise mapping initiatives with a specific focus on low-exposure natural areas. Our findings not only provide valuable insights for policymakers and stakeholders in managing and preserving the acoustic quality of Sweden's green spaces but also offer a foundation for analysing the potential impact of noise pollution on wildlife and biodiversity within these ecologically sensitive areas. The resulting noise map and relevant weather statistics are publicly released and downloadable. Participants from industry, government, and academia cooperated in this environmental monitoring project.

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1. INTRODUCTION

Traditional noise mapping focuses on predicting the noise level from different sources where the noise level is relatively high, and often at locations where the noise level is dominated by one major source. A typical example would be a building with dwellings close to a major road. The methodology focuses on estimating the ground effect and the effects of screening and reflection by terrain, buildings and noise barriers. In some cases longer propagation distances may be important, and some methods for estimating noise propagation do include weather influence such as Harmonoise/Imagine [1,2] and Nord2000 [3], which is of major importance for long distance propagation.

In this project we aim to estimate lower noise levels in natural areas often located relatively far from the noise sources. For a small, forested area more than 2 km from a major road, other factors are important for the prediction of the noise level than for a receiving point on a building in an urbanised residential area 50 meters from the major road. In the second case the noise level varies over time as the strength of the source itself varies (time of day, weekday, holidays…), but the noise level is almost always dictated by the traffic on the major road. In the first case, the remote natural area, the noise level does not only vary with the strength of the source, but also the wind direction, humidity and temperature are very important factors. In some weather situations the major road might not contribute to the total level at all, and instead a local road in another direction determines the noise level.

This research project was funded by Naturvårdsverket, the Swedish environmental protection agency, under their program for monitoring environmental effects on health (HÄMI). The project ends in 2024, and aims at providing a method for calculating noise levels in green areas that can be used to monitor the development of noise exposure in such areas in the future.

2. METHOD

2.1. GIS data

The calculations presented in this paper are based on the method Nord2000 [3] and weather statistics from the ERA5 climate dataset [4]. Since the objective was to calculate noise levels for the whole area of Sweden many adjustments and simplifications from the complete method were necessary, which are described below.

The most demanding noise source is road traffic, since it is distributed across most of the country. After initial experimentation we decided to proceed with a resolution of 500 m. The whole area of Sweden, including Sweden's economic zone in the Baltic sea and North sea, is covered by 2,162,818 squares of size 500 m × 500 m, with a total surface area of more than 540 km^2 (projected area Sweref99 TM, ESPG 3006).

An overview of the GIS datasets we used in the calculations is provided in Table 1. The digital height model and the land cover was downsampled to a resolution of 100 m. For railway lines and roads the sound power was calculated using the relevant Nord2000 source method [5,6] and then summed up in each 500 m square to a point source. The point source was placed in the centre of the square at the corresponding ground height. The source height above ground was simplified to 0.3 m (several source heights between 0.01 m and 4.0 m are used in the detailed source methods).

Table 1: GIS datasets used for the calculation.

Dataset	**Provider**	**Base resolution**
ERA5 climate	Copernicus, ECMWF	15 arcseconds
NMD land cover	Naturvårdsverket	10 m
Ground elevation 50+	Lantmäteriet	50 m
Road traffic flow	Trafikverket	~20 m
Railway traffic	Trafikverket	~20 m
Takeoffs/landings	Transportstyrelsen	
Wind turbines	Energimyndigheten	~10 m

For wind turbines and airports no summation of sources was necessary since there are so few in comparison to the road and rail network, and their exact location was used in the calculations. The source height above ground was set to 50 m, 100 m or 150 m depending on whichever was closest to the actual hub height of the wind turbine. The sound power of the wind turbines was also adjusted depending on hub height; for 70 m and lower we assumed an A-weighted sound power of 101 dB, which was then linearly increased up to a maximum of 105 dB for a hub height of 130 m or higher. We used the hub height as a proxy of sound power since the database did not have any information on sound power, and other relevant information such as manufacturer, rated power output and similar was often missing. We used a standard 1/3 octave spectrum for all wind turbines, which was a smoothed version of the spectra used in [7].

For aircraft noise close to airports we used statistics on number of takeoffs and landings on the 39 airports where official statistics was available [8], small local airstrips and military airbases were not included. Neither was military flight operations from civilian airports. In order to estimate the sound power of starting and landing aircraft we used the reverse engineering method from Imagine [2] on aircraft noise data from EASA [9]. Only aircraft operations close to the airport was included, up to about 1800 m (6000 feet).

The ground effect was estimated by classifying the ground cover data [10] in one of the impedance classes B (very soft, code > 63), D (soft, code < 44) and H (hard, all other codes). The impedance class was averaged over each 100 m square, which contained 100 sub-squares (10 m) with ground cover information as a code, except for water surfaces which were assumed to be acoustically hard.

2.2. ERA5 weather statistics

We used “hourly reanalysis” dataset from the ERA5 climate data provided by Copernicus/ECMWF [11]. For the period 2013 – 2022 we downloaded the variables in Table 2.

Table 2: ERA5 variables used to calculate the weather statistics for 2013 – 2022.

Variable	**Use**
10m u-component of wind	Refraction
10m v-component of wind	Refraction
2m dewpoint temperature	Absorption
2m temperature	Absorption and refraction
Total cloud cover	Refraction
Friction velocity	Refraction

The downloaded dataset contained 87,648 hours in a latitude/longitude grid of 15 arcseconds (0.25 degrees), which corresponds to approximately 10 km × 28 km in the north part of Sweden and 16 km × 28 km in the south part. Apart from the variables in Table 2 we also needed the sunrise and sunset times for each grid cell which was calculated using pyEphem [12].

Nord2000 normally operates with 25 different weather classes [3] divided into propagation directions of 10 degrees, but in order to reduce the calculation time needed we instead adapted the suggested 4 weather classes suggested for use in Denmark [13], and used eight propagation directions (N, NE, E,…) corresponding to an angular resolution of 45 degrees. The classes are denoted M1, M2, M3 and M4, where M1 corresponds to upward refraction propagation (lowest noise levels) and M4 is strong downward refraction propagation (highest noise levels). M2 is then neutral atmosphere and M3 slight downwards refraction. The concept is illustrated in Figure 1.

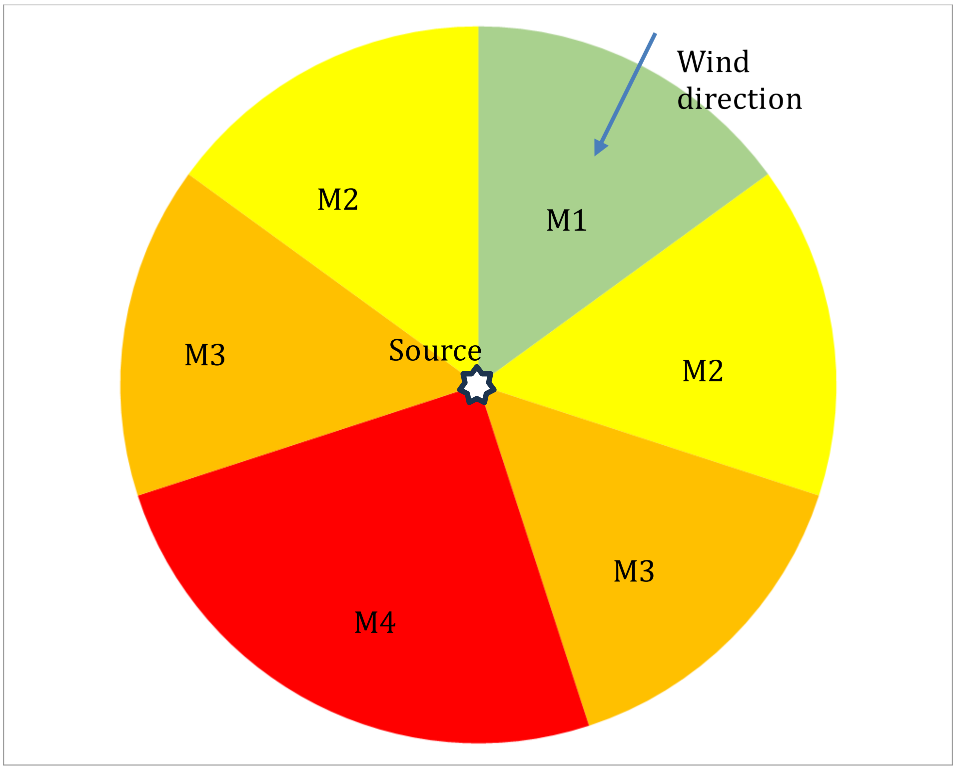


Figure 1: Example of weather classes M1 – M4 in different propagation directions for a certain wind direction.

For every grid cell and every hour in the dataset we then determined which weather class was dominant in each propagation direction using the formulas from [13], with the exception of friction velocity that we did no need to estimate indirectly via wind speed, since it was already calculated for us in the ERA5 dataset. The process of classifying the weather is also very well described in [14]. From this large dataset of weather classes, we then created statistics for every grid cell (location), month and period (day, evening and night). An example map is given in Figure 2.

But not only refraction is important for long range propagation, absorption becomes more and more important as the propagation distance increases. We converted the humidity and temperature to propagation attenuation for each 1/3 octave band using the standard ISO 9613 formulas [15], including frequency correction terms for high attenuation and high frequencies [1,3].

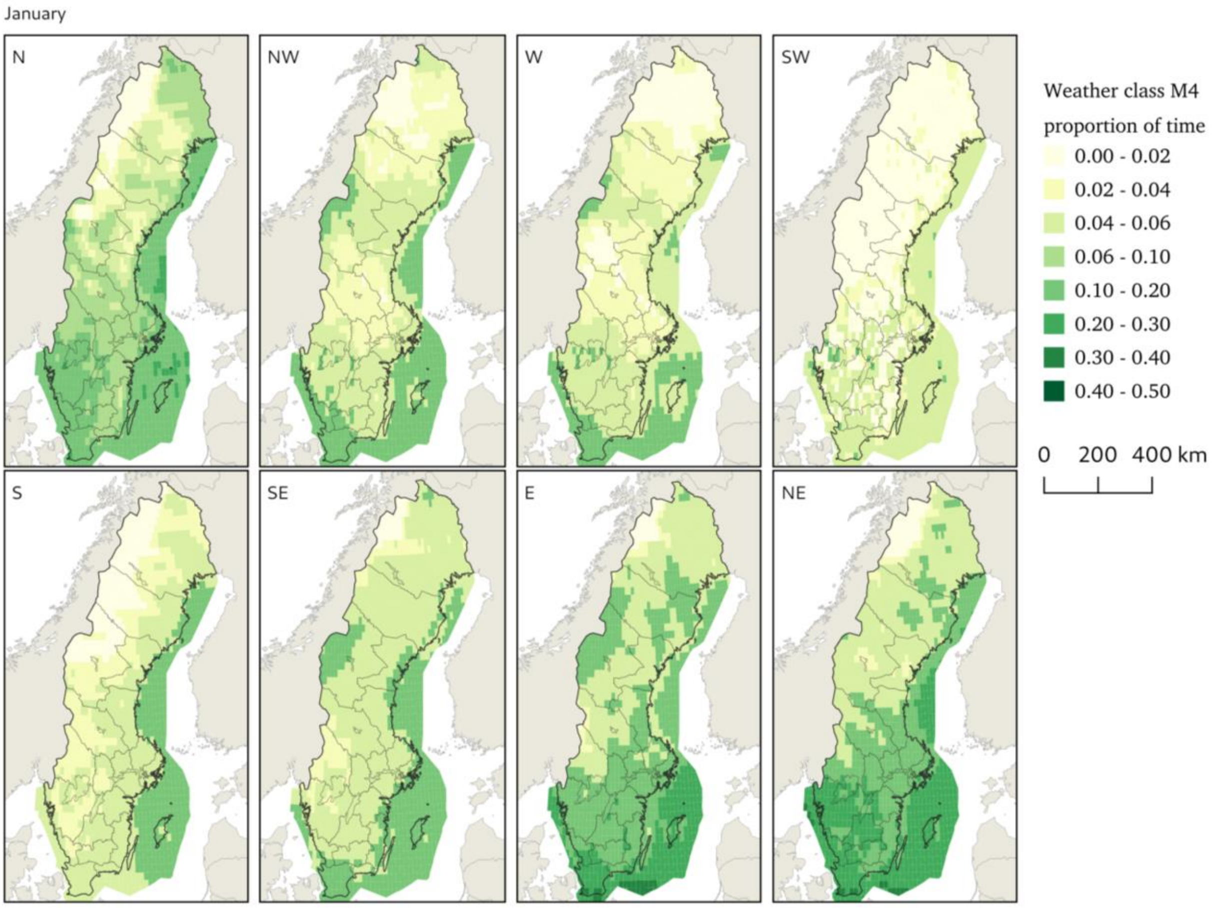


Figure 2: Proportion of time (1.0 = 100%) with weather class M4 for January, daytime (06 – 18). Each map represents a different propagation direction. Mean over ten years (2013 – 2022).

The most important parameter for the calculation time required is the maximum source to receiver distance considered. After experimenting with different values on the maximum distance we finally used a maximum of 8 km between source and receiver, this gave a reasonable balance between calculation time and the lowest levels that could be estimated, which for the day/evening level is about 5 – 10 dB. In order to accurately estimate levels lower than that in the future, sound propagation over longer ranges must be taken into account.

2.3. Nord2000 propagation

The weather statistics gives us the proportion of time for the different weather classes and the humidity and temperature. Ground impedance and terrain height is determined as described above, and sound power is calculated using the source specific methods. For each combination of source and receiver we need four Nord2000 calculations for that transfer path, one for each weather class. To calculate with the full method for each path over the whole of Sweden is very computationally expensive, therefore we used precalculated transfer functions stored in a database and used the best fit for the terrain and ground impedance to speed up the calculations.

The propagation database contains more than 6.6 million transfer paths and took about 48 hours of computation time to create on a processor with 12 physical cores (AMD Ryzen 9 5900X). Every path stored the free field transfer function in 1/3 octave bands, geometrical spreading and air absorption was not part of the database, it was instead calculated individually for each combination of source and receiver based on temperature and humidity.

Initially we calculated for a number of typical receivers every hour in a two-year period (2020 – 2022), including hourly variation in sound power for road traffic (linear sources) and wind turbines (point sources). Using these calculations, we estimated a procedure to calculate using fewer time steps. Our final method used one calculation per month, period of day (day, evening and night) and propagation direction (8 directions), for a total of 288 calculations per receiver point and source type.

Using these 288 calculated noise levels at each receiver position we can estimate the distribution function for hourly levels over the year. Based on this we can then estimate many different noise level indicators, for example L_{AEq24h}, L_{10}, L_{den} and so on. After discussion we decided to use the equivalent level over the day and evening periods which we denote $L_{06\text{-}22}$, since it is a straightforward equivalent level with a focus on daytime when most of the visits to green areas would occur. In our calculations it represents a true yearly average based on weather statistics and hourly variation of sound power. As such it is mostly determined by periods with relatively high noise levels, i.e. downward refraction, low atmospheric absorption and wind from the main source towards the receiver.

3. RESULTS

The project produced three main results; weather statistics, noise maps with 500 m resolution and as statistics of the noise maps evaluated for every nature reserve and national park in Sweden. The weather statistics are downloadable and available as maps similar to those in Figure 2 [16]. An overview of the road traffic and wind turbine noise estimates for the yearly average equivalent noise level 06 – 22 ($L_{06\text{-}22}$, day and evening) are presented in Figure 3. The maps show levels in the range between 5 dB and 45 dB, lower levels are transparent in the colour scheme and higher levels are truncated to show 45 dB and above. The nationwide maps for railway traffic noise and airport noise are work in progress when the paper was submitted but will be available before the conference in August 2024.

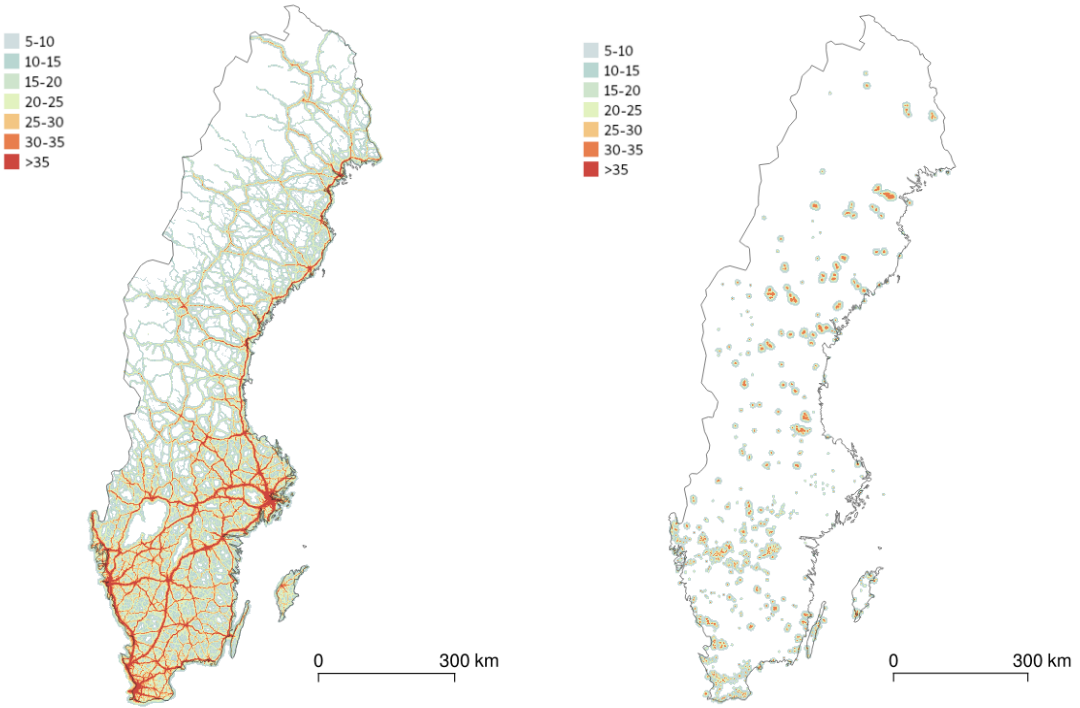


Figure 3: Map of noise levels ($L_{06\text{-}22}$) in Sweden from road traffic (left) and wind turbines (right) with a resolution of 500 m.

In Figure 4 a more zoomed in large scale map is presented where it is easier to see the details of the noise map. In this map the border of the official nature reserves in the area are indicated in green. Most of the noise impact on the nature reserves are from road traffic but some are also exposed to wind turbines or both sources.

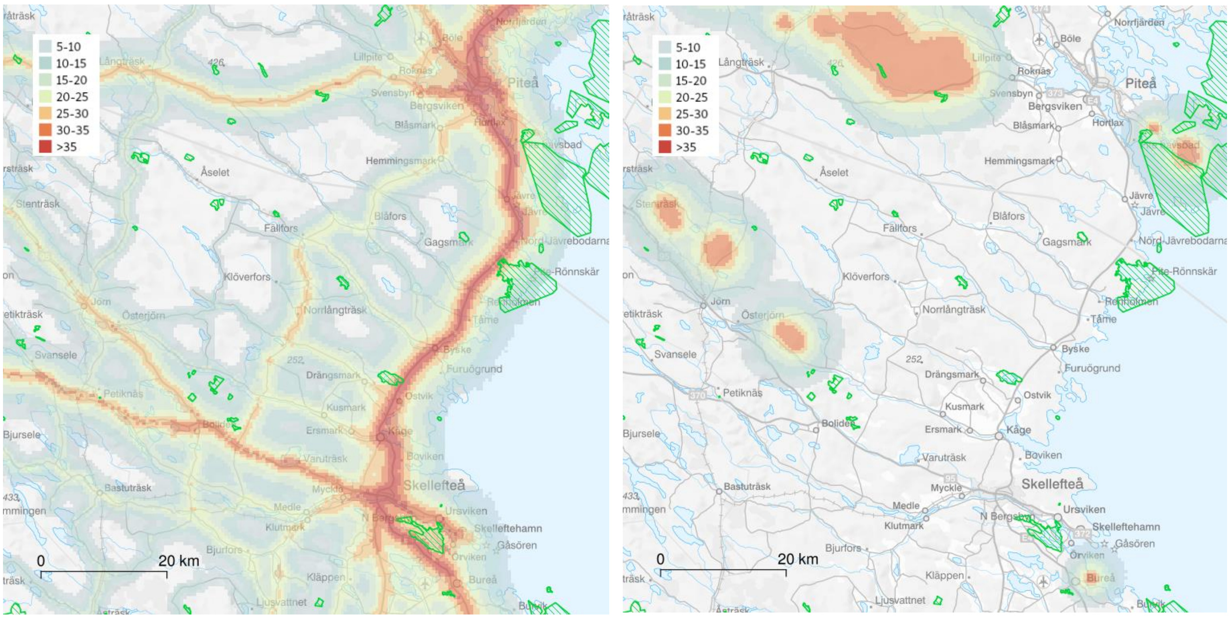
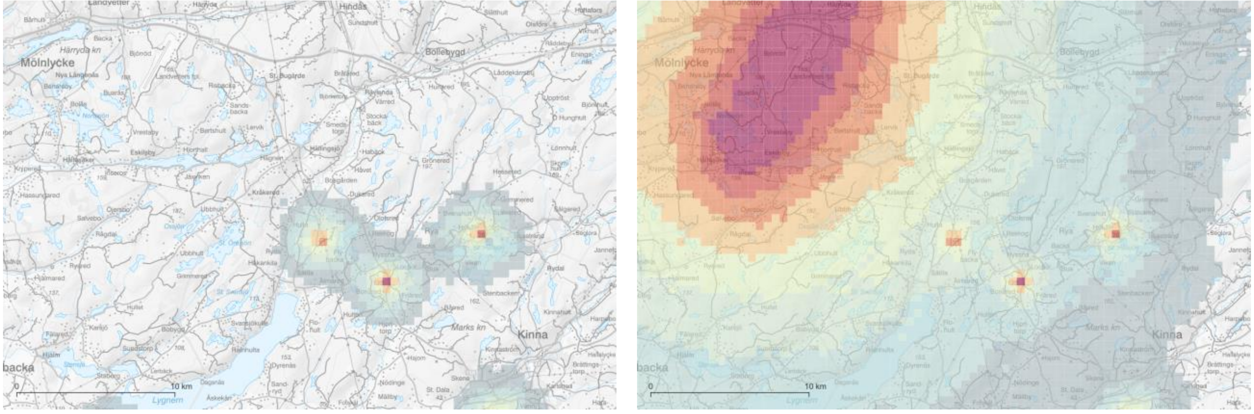


Figure 4: Noise map ($L_{06\text{-}22}$) for road traffic (left) and wind turbines (right). Green areas indicate natural reserves. Background map from Lantmäteriet open data 2024.

Figure 5 illustrates the sum of wind turbine, airport and road traffic noise by adding them together consecutively. In this example the road traffic is the dominant source by far, which is often but not always the case. Using a yearly average of equivalent levels for day and evening is a very course indicator though. In some wind directions and at certain times a wind turbine could still be the dominant audible source, for example a late weekend evening. And even far from the airport in some occasions a passing aircraft might be the dominant source, even if the road traffic dominates the yearly equivalent level.

a) Wind turbines

b) Wind turbines + airport



c) Wind t. + airport + road traffic

c) only road traffic

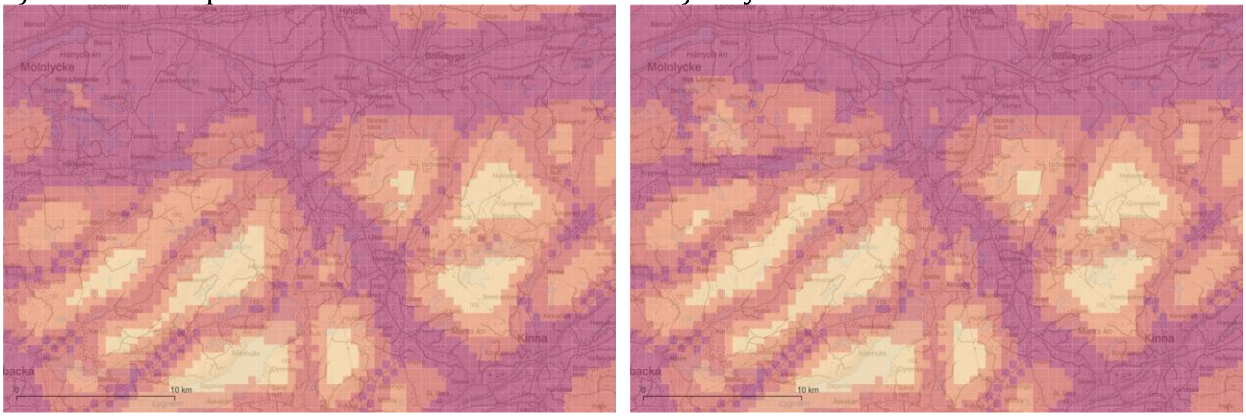


Figure 5: Maps showing an example of combination of sources ($L_{06\text{-}22}$).

4. DISCUSSION

The main limitations of our national noise mapping are related to its scale, it is not useful for estimating noise levels at highly exposed small areas, for example a small garden close to a major highway, for such positions a traditional short range noise map is better suited. Another weakness is that many noise sources important in green and recreational areas are not included in our noise map due to difficulties related to gathering information on activity and useful source strength descriptions. Examples of such sources are snowmobile traffic, air traffic in remote areas related to skiing and hiking, and coastal use of jet skis.

The strengths of our mapping effort are mainly the large scale, and that we use a relative long maximum distance between source and receiver (8 km). Another positive aspect is that the method is fully described and repeatable, which facilitates following time trends regarding noise exposure in green areas in the future. All of the noise maps created within the project will be openly published online without restrictions which facilitates the use in urban planning, research, education and for general use by the public. A final URL linking to the project results is not yet available, but it will most likely be accessible via the web map “skyddad natur” (translation: protected nature) [17].

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