Sound weather – methods and applications

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ABSTRACT

Weather forecasts are derived from highly sophisticated weather models reliably describing the condition of the atmosphere and its development under continuous correction through measured values from a dense monitoring network. Weather reports condense these results in simple statements that have many applications in daily life. The so-called ‚sound weather’ combines the weather forecast with the sound propagation calculation. It takes advantage of the meteorological weather models providing profile forecasts for wind and temperature and use these profiles with qualified sound propagation models to predict the favorableness of the noise propagation. The sound weather forecast is done with a lead time of 36 hours on an hourly basis.

From long-term time series of the sound weather various information about level distributions can be derived providing new features and applications of the sound weather in many areas of outdoor acoustics and noise assessment. Studies are going on to derive the meteorological correction c_{met} of the ISO 9613-2 used to estimate the long term level from the long term sound weather prediction. This c_{met} can be different for day and night or winter and summer or any combination of such conditions.

Keywords: Sound propagation in the atmosphere, Meteorological factors

I-INCE Classification of Subjects Numbers: 24.0,24.6

1. INTRODUCTION

Weather reports are among the most popular features of news broadcasts. Looking at satellite images, isobars and streamline videos the audience or reader learns about the weather tomorrow and its development for the next few days. A weather report is obviously a successful and attractive mix of entertainment and information reaching many people.

If normal weather conditions are expected the forecast will typically provide temperature, rainfall and sunshine and information on the wind. Under particular conditions, meaning something is not normal, the weather forecast will include information on special themes of current interest such as pollen count, UV index or ozone levels. This paper talks about a new special theme that will be called ‘sound weather’.

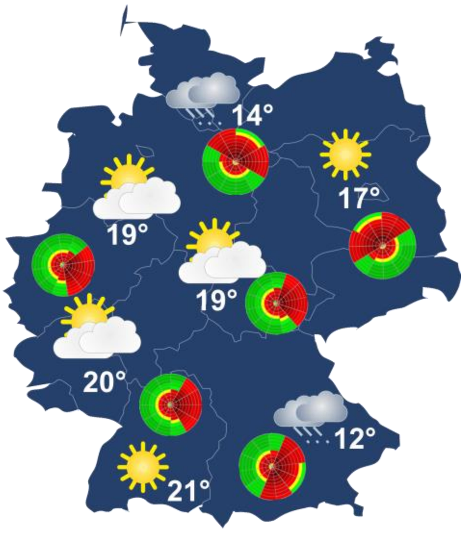

Figure 1 – Noise roses on a weather map

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To be in the news, the sound weather needs a form of presentation that is easy to understand and easy to indicate on a weather map. Such a form of presentation is given by e so-called noise roses, which Figure 1 exemplarily shows besides the symbols of cloudiness on a weather map (1).

A Noise rose as sound weather forecast at dedicated locations - for instance in the vicinity of a noisy factory, highway or airport - is an appropriate tool in the context of professional noise or complaint management system.

Long term recordings of the sound weather can also answer questions like: What are favorable and not favorable sound propagation condition. Does this condition depend on seasons or time of the day? As an example, sound weather is feasible to objectively evaluate the c_{met} of the ISO 9613-2 at a given location for sound assessment purposes (2).

2. Noise roses

A noise rose indicates whether it is more (graded red colors) or less (graded green colors) noisier then normal. The radius of the rose indicates the distance between the source at the center of the rose and a receiver point at the compass angle. To keep it simple for weather maps, the sound weather is given for ranges of distance and angle. Figure 2 uses a distance step of 200 m and an angle step of 30°. The message of the noise rose in Figure 2 is clear: There is a favorable sound propagation to the east, typically the result of westerly winds at day time.

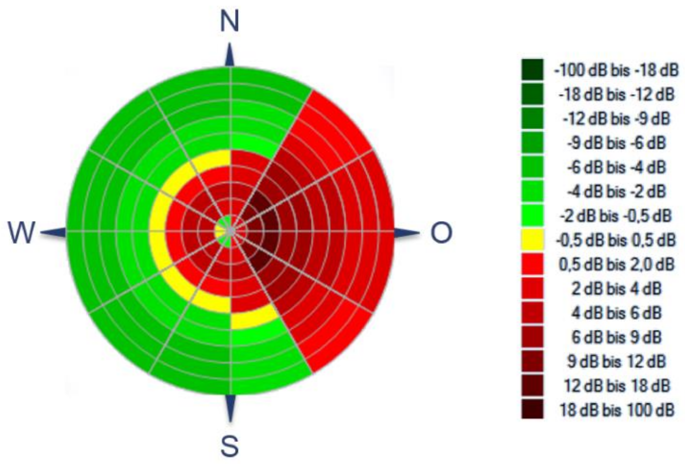


Figure 2 – Noise rose

The discussion of the change of noise roses during a night time inversion will show that noise roses are normally more complex than the noise rose in Figure 2. Time lines of noise roses provides an insight into the influence of refraction of sound rays due to wind and temperature and its interaction.

3. Sound weather

3.1 Definition

As pointed out in the previous chapter, the sound weather is basically a level difference. Equation 1 gives the formulation of any sound weather typically evaluated for an arbitrary hour.

Let denote $L_{sw,n}(r,\varphi)$ the sound weather level at the distance r and the compass angle φ for a certain hour n. Let denote L_I any relevant receiver level of interest at the given point r,φ. The index ‘ref’ indicates the level of the normal propagation situation whatever is appropriate to be termed as ‘normal’.

$$L_{sw,n}(r,\varphi) = L_{I,n}(r,\varphi) - L_{I,ref}(r,\varphi) \tag{1}$$

It is clear that the sound weather requires a weather forecast for all relevant features of the atmosphere that influence the sound propagation. The second requirement is a sophisticated sound propagation model to predict the receiver levels around a source up to the distance of interest and at all directions considering the weather forecast.

3.2 Profile forecasts

It is well-know that close to the source the ground weather is sufficient to make reliable level prediction. The wind direction yields the most import influence. This is because in such cases the sound propagates close to ground. For typical noise sources and receiver heights, relevant sound rays of the direct transmission and of the ground reflections will not reach a height above ground where the change of wind speed or temperature plays an important role. However, if it comes to larger distances, the rays will reach heights where these features take over. Hence, the profiles – the height dependency – of wind speed, wind direction, temperature and humidity are the important meteorological input parameters of the propagation models. Forecasts of the sound weather requires forecasts of these profiles.

The forecast of profiles is not a standard theme of weather models. For sound weather purposes, MeteoGroup (3) developed such a profile forecast as a special service using their sophisticated weather models to make that prediction. For a given location, this service provides a profile forecast for the upcoming next 36 hours on an hourly basis. The following discussion relies on such forecasts every 12 hours.

3.3 Sound propagation model

Technical sound propagation schemes are widely used for noise assessment purposes. They do not take into account weather profiles and do not apply to the current weather situation. They are designed and restricted to average sound levels and to close range propagation using a simple decibel adjustment to account for favorable, neutral or unfavorable sound propagation conditions. The ISO 9613-2, for example, introduces a correction called c_{met} to adjust its downwind propagation level to a long term prediction level.

For sound weather purposes, a sophisticated propagation model is needed that considers the profiles of wind speed and temperature and that is capable to predict the height dependent refraction due to the resulting sound speed profile. The sound weather in the present paper uses a sophisticated ray tracing model that fulfill these basic requirements.

The meteorological profile forecast gives hourly average values of the wind speed and temperature at selected heights. The sound refraction however does not depend on these parameters but on their change with height. This change is an orthogonal information. For example, even if the average wind speed does not change with height, it does not mean that there is no refraction. Let’s assume for a moment that the radius of curvature has a symmetric Gaussian distribution around the radius of curvature of 0 m, which is the average radius of a not – on the average – changing profile. In addition, let’s assume that the level predictions depend linearly on the radius of curvature than the whole effect is not really important. However, the second assumption does not hold.

As a conclusion, an hourly averaged sound weather needs level averaging and not the averaging of weather conditions. Therefore, the sound weather discussed here is the result of level prediction based upon the averaging of a distribution of single prediction levels as a result of varying input parameters each based on a reasonable estimation of its relevant range of uncertainty.

The sound weather depends, of course, on some general settings. The scenario under consideration is given in Table 1. The source radiates a pink noise in the frequency range of 100 Hz to 8 kHz. Source and receiver heights are both set to 4 m above the overall plane ground. The ground is something like grass given here as flow resistance to meet the requirements of the used propagation model. The air humidity is not taken from the profile forecast but introduced as a scenario parameter.

Table 1 also indicates the range of uncertainty for each parameter to perform the level averaging. Of course, the level averaging includes the distance and compass angle ranges for each value of the noise rose. In the present paper, the level predictions of the model for a non-refracting atmosphere are used as reference levels in Equation 1.

Table 1 – Scenario parameters and its uncertainties for the sound weather evaluation

Input parameter	Mean	lower limit	Upper limit
Noise	Pink noise 100 Hz to 8 kHz	No variation	
Source height	4 m	3,8 m	4,2 m
Receiver height	4 m	3,8 m	4,2 m
Ground	400 kPa s/ m²	200 kPa s/ m²	600 kPa s/ m²
Relative humidity	70%	50%	90%

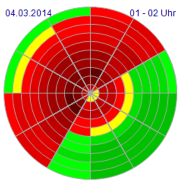
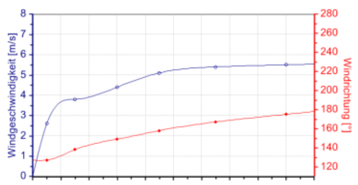
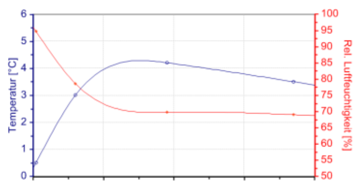
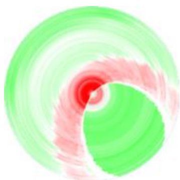
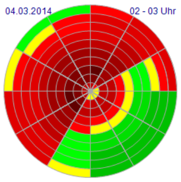
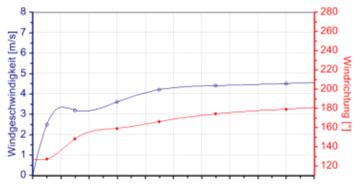
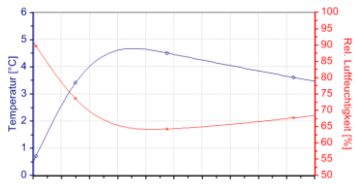
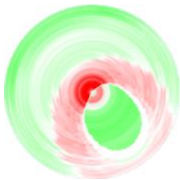
The calculation of the sound weather is realized using look-up tables for the scenario. Note that the sound propagation model will still have a significant range of uncertainty. However, the sound weather only relies on the level difference of two predictions. Therefore, any systematic errors will not be relevant in zero order. This is the reason why the source needs no source strength but only a source spectrum.

Sound weather also depends on the choice of the type of receiver level under consideration. In this paper an A-weighted sound level is used. Using a different scenario, for instance impulse noise and an A-unweighted exposure level for a single event as receiver level, the sound weather will change. For aircraft noise or in particular for noise from wind turbines the sound weather yields complete different results with respect to the meteorological correction c_{met} of the ISO 9613 -2, s. (2).

4. A night with inversion

To highlight the power of the idea of the sound weather, Figure 3 shows the series of noise roses for a night time inversion. The noise roses in the second column of Figure 3 follow the setting for the noise rose in Figure 2. The noise roses in the right most column are noise roses with a (10 m/1°)-resolution up to a distance of 5 km.

The columns in between the noise roses indicate the profile forecasts for each hour. The x-axis each is the height above ground scaled in meters from 0 m to 200 m. The left diagram shows the wind profile. The left y-axis refers to the wind speed (blue line) in meters per second and is always scaled from 0 m/s to 8 m/s. The compass wind direction (red line) is assigned to the right y-axis scaled in degrees from 110° to 280°. The right diagram indicates temperature (blue line, left y-axis scaled in degrees centigrade, 0 °C to 6 °C) and the relative humidity (red line, right y-axis, scaled in percent from 50% to 100%).

Time of day	Noise rose standard resolution up to 2 km	Wind speed (blue) and wind direction (red) profiles *labels given in German*	Temperature (blue) and humidity (red) profile *labels given in German*	Noise rose high resolution up to 5 km
01 to 02 am				
02 to 03 am				

Time of day	Noise rose standard resolution up to 2 km	Wind speed (blue) and wind direction (red) profiles *labels given in German*	Temperature (blue) and humidity (red) profile *labels given in German*	Noise rose high resolution up to 5 km

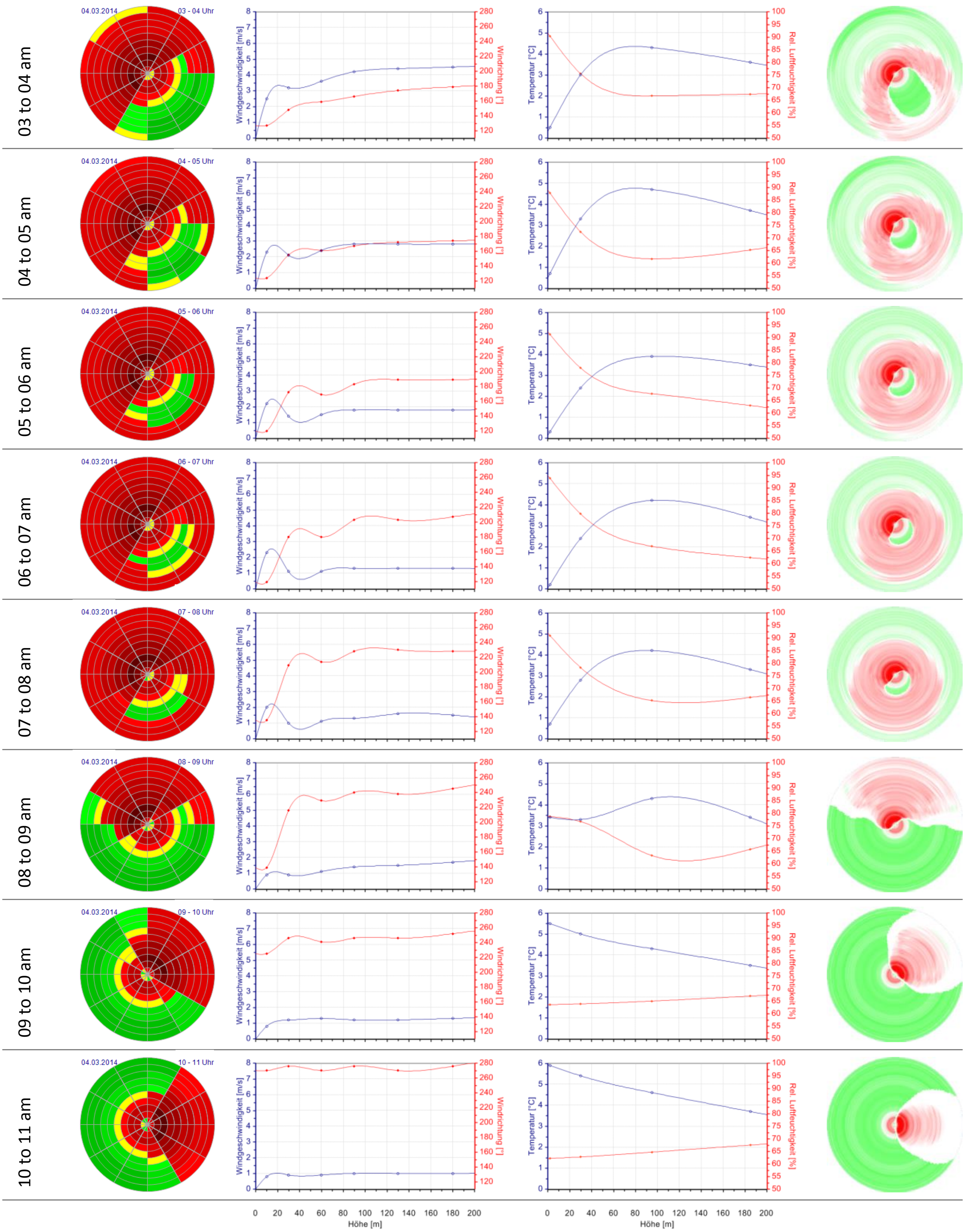


Figure 3 – Time line of noise roses for a night with temperature inversion

At the beginning of the time line the inversion is already there but due to the still blowing easterly winds increasing with height the sound levels only react at the northeast and southwest direction. These are the ‘neutral’ directions if it would be a pure wind driven regime. Due to the decreasing wind along with the proceeding night the sound weather indicates the transition into a clear inversion regime during the early morning hours. At 8 am the inversion disappears, beginning at the ground and ending up with a normal downwind propagation to the east due to the freshening westerly winds.

This is what the noise roses up to 2 km indicate. The noise roses up to 5 km are telling a slightly different story complementing the picture for larger distances. The noise rose for the first hour in the time line points out that the downwind regime applies not to a sector but to a region that is more or less an elliptical ring.

People who are living in the south of the source may be in a ‘shadow’ if they are close enough; at greater distances they experience high levels during that hour. In addition, the downwind regime to the northwest stops at roundabout 2 km distance from the source entering a weak shadow zone. The upcoming inversion is a more or less local phenomenon in this case; there is no inversion above 100 m and only a weak change in wind speed. Further interpretation is left to reader.

5. *c_{met}*

The sound weather can help to decide what the level difference is between favorable and long term average level. It was mentioned above that the ISO 9613-2 introduces the adjustment c_{met} which is just this difference. Let *N* denote the number of hours (and *n* as one particular hour out of *N*) in the time period that is representing one sample of the so-called ‘long-term’ time period in ISO 96113-2. Let *M* denote the number of hours (and *m* as one particular hour out of *M*) for which it is assumed that favorable propagation conditions apply. Hence, c_{met} is the difference of the sound weathers for a given location and a given scenario for the two relevant time periods, Equation 2.

$$C_{met} = 10\lg\left(\frac{1}{M}\sum_{m} 10^{0,1\,\tilde{L}_{sw,m}}\right) - 10\lg\left(\frac{1}{N}\sum_{n} 10^{0,1\,L_{sw,n}}\right) \quad (2)$$

Normally the hours *M* are part of the hours *N*. The condition whether or not an hour *n* belongs also to *M* is not clear. However, the distribution of the hourly sound weather offers an objective criterion to specify this condition. It is possible to say that all hours belonging to *M* must have sound weather levels L_{SW} greater than the mean value of the distribution or – as another example - greater than the energy average of the sound weather of all *N* hours. These are only two reasonable criteria. The second is used in Figure 4.

It is obvious that the hours *N* can be also any selection out of a larger ensemble. *N* can only contain the hours for the assessment time day or evening or night or even only the hours of the nighttime in winter. Hence, sound weather is an appropriate tool to investigate meaning, the reliability and the uncertainty of such corrections.

Figure 4 shows two examples of a so-called ‘c_{met} rose’. The left c_{met} rose indicate the distance and angle dependent c_{met} if *N* covers all hours of a year and *M* covers only the hours for which the sound weather exceeds the energy averaged sound weather of *N*. The right c_{met} rose shows the results if the *M* hours in the left rose are restricted to the assessment time ‘night’, that is from 10 pm to 6 am of the next day. Obviously, the meteorological corrections differ depending on the time of day.

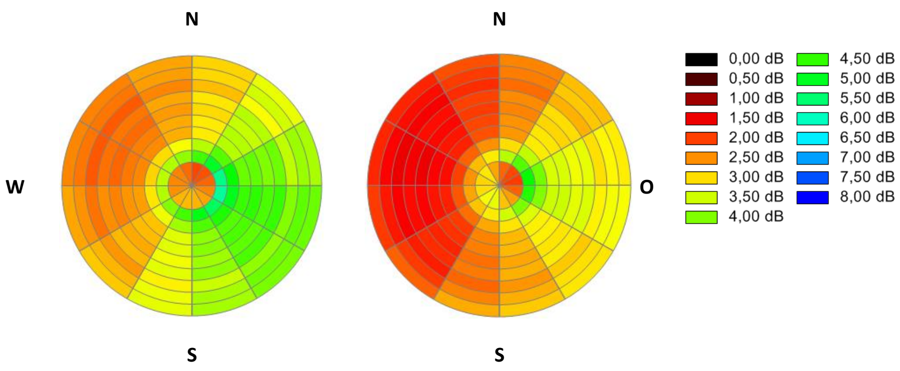


Figure 4 – c_{met} roses
favorable condition: L_{SW} greater than the energy average
left: for all hours of a year, right for all hours 10 pm to 6 am next day

6. Fields of application

The basic feature of the sound weather is that it predicts sound levels for the current weather condition during a given hour. Hence, it is an hourly forecast and not a long term average prediction. This feature yields new fields of application for noise management and noise assessment. The following list briefly itemizes some aspects.

- The operator of an installation can take into account the sound weather forecast to avoid noisy operations during favorable propagation conditions at the direction of the relevant neighborhood and therefore reduce complaints.
- Sound measurement campaigns outdoors can use the sound weather to adapt the measurement plan to the forecast of sound propagation conditions.
- The variation in the level series of long term monitoring systems around an installation will correlate to the sound weather up to a certain extent and can support the analysis in case of complaints.
- Daily sound weather - on a web page of an installation for example - will document that the management of the installation takes care of the noise load of its neighbors. This reduces complaints because the neighbor can understand that sometimes the management cannot avoid high levels due to most unfavorable weather conditions.
- Social studies can account for the time history of sound levels and possibly reduce the variance in the analysis by taking into account the particular propagation conditions during the survey.
- The meteorological correction can be objectified and differentiate into particular assessment times or seasons.
- Sound weather may be a ‘nice to have feature’ for weather reports: The message “Tonight will be a noisy night for all who are living to the south of high way.” may be just as interesting as the message of a high pollen counts or ozone levels.

7. Conclusion

Sound weather is introduced as a tool to predict the sound propagation conditions on the basis of meteorological forecasts of wind and temperature profiles. Noise roses are an appropriate way to present the basically complex results of the sound weather. The discussion of the time line of noise roses during a night with temperature inversion gives an insight into the transition of a downwind regime to an inversion regime and backwards.

Sound weather is an appropriate tool for the noise management and the complaint management at noisy installations. It can support the analysis and understanding of annoyance providing hourly forecasts for sound propagation conditions.

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