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Studies of sound attenuation depending on meteorological conditions

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Abstract

Previously used standardized calculation methods for sound propagation contain the influence of meteorological parameters just in a very simplified way. But the propagation of acoustic signals over a distance of several kilometers is essentially dependent on the distribution of temperature and wind.

The sound level attenuation maps shown in this work have been calculated with the use of the sound ray model SMART (Sound propagation Model of the Atmosphere using Ray-Tracing). They demonstrate the meteorological influence on the sound attenuation in a distance of up to 15 km from the sound source. SMART takes the current or the predicted state of the atmosphere into account to depict the distribution of sound attenuation near the ground surface. Therefore it is an instrument which is able to estimate sound immission for a current or future moment (sound weather). Applied to meteorological data of longer time periods typical mean sound immissions for individual regions can be derived, which is referred as sound climate. On the one hand these attenuation maps firstly clarify the difference between these two terms. On the other hand they show the dependence of sound propagation on atmospheric conditions on several timescales. Radiosonde data from the years 1990 – 2009 were used for this analysis.

A second part of this study deals with the question whether observational data (radiosonde) can be replaced by model data (COSMO-EU). For this purpose data of the station of Bergen was used for the year 2009.

Zusammenfassung

Bisher verwendete standardisierte Berechnungsverfahren für die Schallausbreitung beinhalten meteorologische Einflüsse nur in stark vereinfachter Weise. Die Ausbreitung akustischer Signale über mehrere Kilometer Entfernung hängt jedoch wesentlich von der Temperatur- und Windverteilung im Gebiet des Emissionsortes ab.

In der Umgebung einer Schallquelle bis hin zu einer Entfernung von 15 km wird in dieser Studie der meteorologische Einfluss auf Schallpegeldämpfungskarten dargestellt, die mit Hilfe des Schallstrahlenmodells SMART (Sound propagation Model of the Atmosphere using Ray-Tracing) berechnet wurden. Das Modell SMART bezieht dabei die beobachteten bzw. prognostizierten meteorologischen Verhältnisse in die Darstellung der bodennahen Schalldämpfungsverteilung ein. Es ist damit ein Instrument für die Abschätzung der Schallimmission zu einem aktuellen oder zukünftigen

Zeitpunkt (Schallwetter). Angewendet auf meteorologische Daten aus längeren Zeitabschnitten sind mittlere, für einzelne Regionen typische Schallimmissionsaussagen ableitbar, was hier als Schallklima bezeichnet wird. Diese Dämpfungskarten sollen zum einen den Unterschied dieser beiden Begriffe verdeutlichen, auf der anderen Seite aber auch die Abhängigkeit beider Zeitrahmen von der Meteorologie aufzeigen. In die Auswertungen gehen Radiosondenbeobachtungen aus den Jahren 1990 – 2009 ein.

Ein zweiter Teil dieser Arbeit befasst sich mit der Frage der Ersetzbarkeit von Beobachtungsdaten (Radiosonde) durch Modelldaten (COSMO-EU). Diese Analyse erfolgt beispielhaft für die Station Bergen für das Jahr 2009.

1 Motivation and Background

Noise is still one of the largest environmental impacts in today’s time. Sound is called noise if the immission is perceived as annoying. The monitoring and forecast of sound immission is thus an important issue in environmental protection.

The background for the following investigations is an assessment of meteorological sound immission conditions near training areas of the Bundeswehr (German armed forces). The Bundeswehr Geoinformation Office (AGeoBw) is requested to make statements about the sound exposure of the population in vicinity of firing ranges. On the one hand an evaluation of the current sound propagation conditions on the basis of the current meteorological conditions (sound weather) must be prepared to protect the population against noise. On the other hand the mean sound immission in a climatological way in areas near those sound sources has to be investigated (sound climate). The sound immission can be derived in general by standardized calculation methods (e.g. ISO 9613-2) which describe the sound level in a distinct distance from the sound source by the sound power level of the sound source and several additive attenuation factors like geometrical attenuation and atmospheric absorption (SALOMONS, 2001). For propagation distances of up to 15 km, atmospheric refraction has large effects on the sound level (PIERCE, 1989). This effect is only partly included into the standardized methods. Therefore, one aim of this study is to demonstrate the meteorological effect on the extended sound propagation using an operationally applicable model (BALOGH ET AL., 2006; ZIEMANN ET AL., 2007).

The calculations for different conditions of sound attenuation are often based on data from radiosonde. To ensure a higher temporal and spatial flexibility it was investigated in this study whether the measurement data can be replaced by model data. To minimize topographic effects first of all, the lowland radiosonde station ‘Bergen’ and its closest model grid point were chosen for this data comparison.

2 Determination of sound attenuation by the model SMART

There are several kinds of acoustical models to investigate outdoor sound propagation (overview e.g. by SALOMONS, 2001). FFP (Fast Field Program, e.g. NIJS and WAPENAAR, 1990) or PE (Parabolic Equation, e.g. GILBERT and WHITE, 1989) methods yield a solution of the wave equation. The computing time increases with increasing frequencies, so the computing time for a complete spectrum is for many cases considerable (SALOMONS, 2001). The most complex models are at present the Euler models, also referred to finite-difference, time-domain (FDTD) models (e.g., BLUMRICH and HEIMANN, 2002). A grid-based algorithm in the spatial domain is derived from the linearized Euler equations. The advantage of these models is their ability to deal with phenomena like scattering or to take the effects of buildings and topography into account (HEIMANN and KARLE, 2006). However a high computational effort is necessary so that these models are only applicable at present for studies with a limited area and lower frequencies.

A clear way to model sound propagation is ray tracing using the geometrical acoustics (ATTENBOROUGH et al., 1995). This approximation is applicable if the sound wave length is smaller than the typical length scale of the structures which are influenced by the sound wave. Ray-tracing is also used in acoustic particle models (HEIMANN and GROSS, 1999) which partly overcome difficulties of classical ray models in the vicinity of caustics or in sound shadow zones.

Advantages of ray models are the relative simple incorporation of refraction effects due to an inhomogeneous atmosphere and the very small computational requirements. Therefore, ray-tracing is applicable for the operational use in forecasting the sound weather or to calculate the sound climate of an area based on large meteorological data sets. Thus, the geometrical sound propagation model SMART is used in this study to include on one side the vertical state of the atmosphere adequately and to minimize on the other side the computing time compared with physically and numerically more sophisticated models. Thereby, we turned our main attention to the important influence of refraction (PIERCY et al, 1977) in a stratified atmosphere.

In case of the two-dimensional sound ray model SMART (ZIEMANN ET AL., 2007) sound propagation of a sound ray bundle, which originates of a sound source at the surface, is traced using a refraction law for moving media (OSTASHEV, 1997). The version of the sound ray model SMART applied for this work (BALOGH ET AL., 2006) simulates the propagation of sound with a sound-reflecting surface. This leads to a worst case assumption regarding noise protection, i.e. a maximum amplification of sound intensity for multiple surface reflections.

Input data for SMART are radiosonde observations of wind (amount and direction) and air temperature profiles up to a height of 750 m. Provided that the radiosonde for a distinct time observed at least 5 values within this air layer, the data were used for the further sound immission propagation. Prior to the calculations of sound propagation a linear interpolation between the measured values was carried out. Based on this interpolation, the model SMART uses a very high vertical and an adequate horizontal resolution to show the influence of a vertical inhomogeneous structure of the atmosphere on the sound propagation (WILSDORF ET AL., 2009).

From the place of a monopole sound source sound rays with different elevation angles from 17.8° to 89.998° (with increasing resolution from 0.1° to 0.001°) are traced and their propagation throughout the atmosphere is calculated. If the rays reach the surface they also can be reflected back to the atmosphere. The sound rays contribute to the sound immission at a specific location, if they pass through a height level of 2 m above the ground. The geometrical parameters of all sound ray paths that reach this place are used to determine the sound attenuation in the immission level and for a distinct horizontal range (ZIEMANN ET AL., 2007). The sound rays in this model are emitted in 36 different directions to create a horizontal map of sound pressure attenuation level (with respect to a sound pressure level in distance of 1 m to the sound source).

If a corresponding input data set of meteorological data is used, SMART is able to numerically reproduce the analytical solution of ray-tracing equations for simple vertical profiles (WILSDORF ET AL., 2009; FISCHER AND ZIEMANN, 2009). But the sound ray model has also the ability to simulate the sound propagation and calculate sound attenuation for several distances from the sound source, if complex vertical profiles of temperature and wind vector are used. The sound attenuation is derived for several horizontal intervals. Thereby, SMART uses an arithmetic mean of all attenuation values for one distance interval. This leads to a realistic smoothing of the attenuation and approximates the effect of sound scattering. Finally an assumption for the sound attenuation within the sound shadow was used, based on the distance-dependent attenuation due to divergence of spherical waves and an additional constant attenuation of 20 dB, to generate a more realistic sound attenuation in the geometrical sound shadow zone (SALOMONS, 2001).

3 Classification of sound propagation conditions

The use of meteorological data from different regions with a climatologically relevant time span, offers the possibility to separate a widespread area into smaller, sound climatologically 'similar' regions (i.e. regionalization, see WILSDORF ET AL., 2010). In each of those individual regions the same data basis is used to make statements about sound weather for an area of immission. The reason for this regionalization is the incomplete overlap of radiosonde stations (Germany: only 13 – 15 stations). Often there is no corresponding station near the location where the meteorological profiles are needed to calculate the sound immission. The use of measurement data would be obsolete if the radiosonde data could be replaced by data of a weather model. But this replacement cannot be made without an appropriate proof that both data sets (radiosonde and model) result in a comparable distribution of sound immission at a corresponding time.

Radiosonde has the advantage that they can capture the real atmospheric state at the place of investigation. But their disadvantage is the incomplete temporal availability of data and the horizontal offset with increasing height in comparison to the starting point. A further, even more essential disadvantage is the small amount of stations which are gathering radiosonde data. This leads to difficulties in a spatial analysis of atmospheric states and sound immissions. A possibility to overcome these problems would be the use of model data as data basis. The advantage of model data is a homogenous distribution of grid points, small distances between the grid points and a temporal completeness of data. The remaining uncertainty relates to the advantage of radiosonde data: How accurate describe the model data the real atmospheric state especially of the atmospheric boundary layer near the ground surface.

To compare the two different data sets a classification scheme of meteorological profiles, developed at the Leipziger Institute for Meteorology (LIM), is used to classify meteorological sound propagation conditions (see e.g. ZIEMANN ET AL., 2001). This classification is based on the assumption that every possible vertical wind and temperature profile within specified limits can be related to a specific profile class. Afterwards a sound immission distribution, calculated by the model SMART, can be related to the respective profile class. Different profile classes are separated according their sound attenuation distributions. Each point of one sound attenuation map (for one profile class) was compared with the same point for another sound attenuation map (for another profile class). Two profile classes are different from each other when 30% of all points of a sound attenuation distribution for one profile class differ from another one whereby the points must differ numerically by a value of at least 3 dB. In this way the sensitivity of the chosen classification scheme was studied and adapted.

As a result of the sensitivity study a classification was made, based on the gradients of air temperature (5 classes), wind speed (13 classes) and wind direction (24 classes).

The classification of temperature profiles is carried out by using different vertical gradients in three different height layers (0 m – 50 m, 50 m – 250 m, 250 m – 500 m or 750 m for temperature inversion). For the definition of the wind speed classes the increasing wind speed with height was taken into account. Wind speed classes were also related to the wind speed near the surface. Usually higher wind speed gradients can be expected at higher wind speeds. The profiles of wind direction classes were defined according to the corresponding prevalent wind direction at the surface and the turning of the wind (change in wind direction) in the 2nd layer (50 m – 250 m).

With this subdivision one is able to relate all imaginable and plausible distributions of the meteorological parameters temperature, wind speed and wind direction over a certain height level to the entirety of the developed classes: 1551 profile classes. Until now all the currently determined profiles (either radiosonde observations or model data) could be brought in agreement with one specific class (see WILSDORF et al., 2010).

4 Results

4.1 Sound attenuation as sound climate and sound weather based on radiosonde observations

The calculation of sound attenuation was conducted with the model SMART. A calculation of sound attenuation for a discrete time is shown in Fig.1 (the radiosonde observation is taken into account up to a height of 750 m above the surface). This and further figures have to be interpreted in the following manner: at a certain time or over a time span the sound level is attenuated (in comparison to a sound level in a distance of 1 m away from the sound source which is located in the middle of the figure) by a certain value (dB). Thereby the sound attenuation includes the effects of spherical wave

divergence, atmospheric refraction as well as sound reflection at the hard ground surface into account. If sound attenuation would be calculated according to spherical wave divergence alone, concentric circles of sound attenuation contour lines would be visible in the figure. Deviations of the circularity can be traced back to a meteorological influence (change of wind speed, wind direction and temperature with increasing height). Unfortunately, the resulting attenuation maps have not yet been validated by measured values due to dimensions of the investigated area. The model SMART was however compared with measured data (BALOGH et al., 2006, ZIEMANN et al., 2007)
The sound attenuation calculated at a specific time can be taken as a snapshot of the atmosphere. This can also be referred to as sound weather. Outgoing from a data set of radiosonde ascents at 0 UTC and 12 UTC for different radiosonde stations in Germany within the period of many years a data base of sound attenuation maps was calculated describing the meteorological influence for single situation (sound weather) but also the averaged situation for a longer time period (sound climate).
In Fig. 1 (left side) such a meteorological situation is shown. The dependence of the thermal stratification and especially the mean wind direction (MWD) result in different sound attenuation maps from time to time and from location to location.

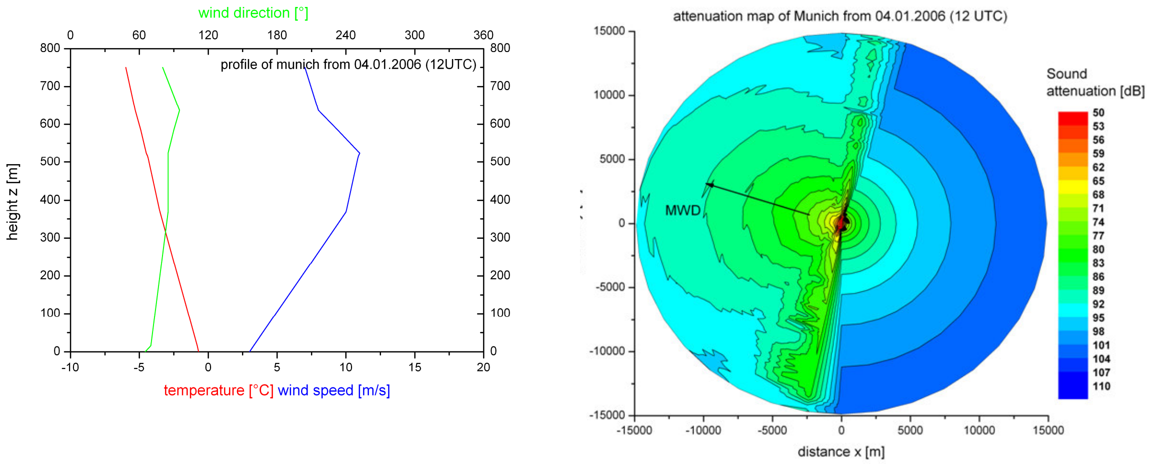
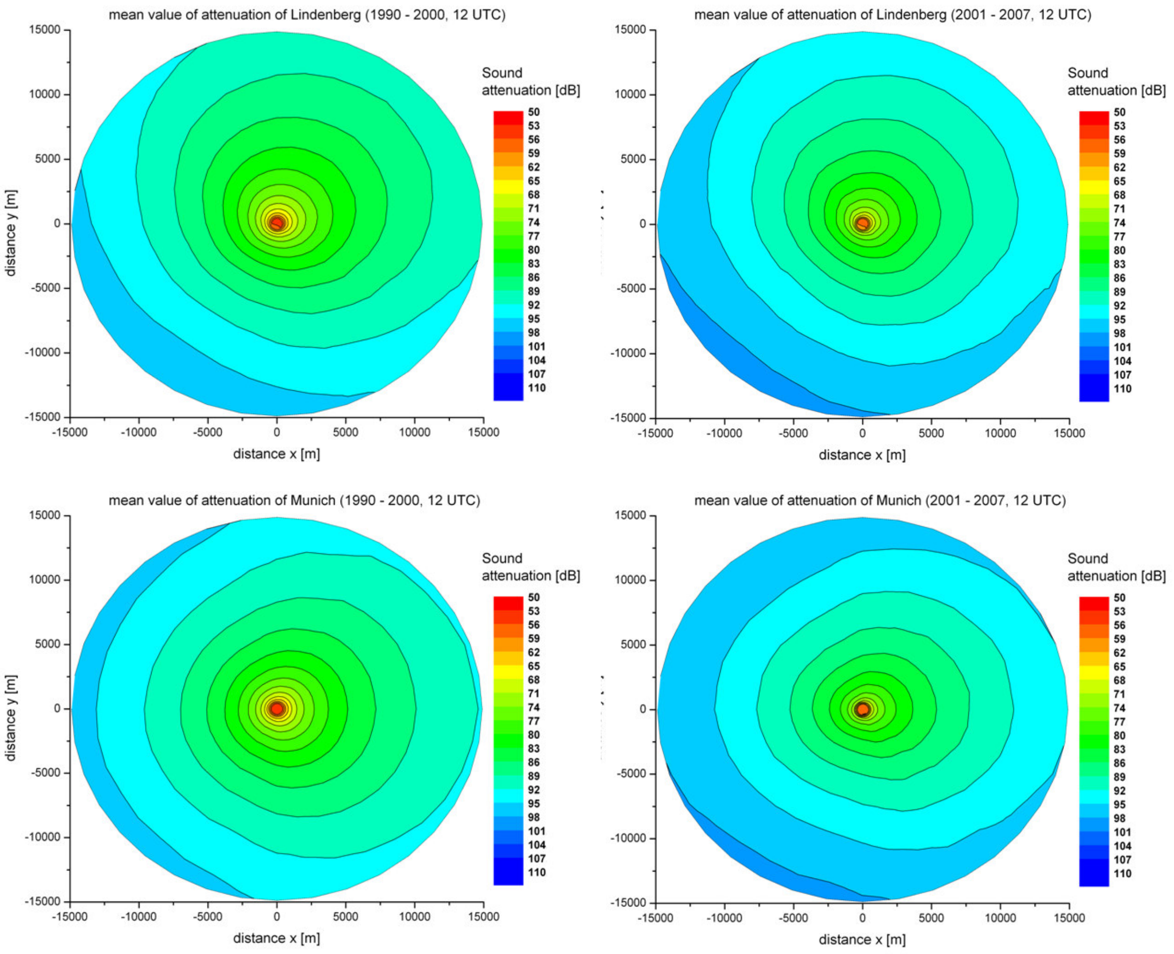


Figure 1: Meteorological profiles of one individual radiosonde ascent for the station Munich on 01.04.2006 at 12 UTC (left) and the corresponding sound level attenuation map at a height level of 2 m (right).

In an upward refracting atmosphere (Fig. 1, sound attenuation map, right side, upwind direction) a so called sound shadow zone develops where no sound rays arrive (see section 2). The sound attenuation in this geometrical shadow zone is high but due to the effects of diffraction and scattering it is finite (SALOMONS, 2001). The sound shadow in upwind direction is therefore approximated by using of sound attenuation due to spherical wave divergence plus a constant value of 20 dB.
A major finding of this study is the fact that the influence of meteorology on both, sound weather, i.e. on current forecast situations, as well as on sound climate (long-term average statements) can be found.

This discrete (current) situation at the example of Munich (Fig.1, right side) describes the so called ’sound weather’. This term can be interpreted as a specific sound propagation situation based on the current measured or forecasted weather data, like this special sound propagation situation on 04.01.2006 at 12 UTC.

This situation is characterized by a distinctive sound shadow east of the sound source and by an area with a lower sound attenuation (mean wind region) west to the sound source in the middle of the picture. This area is the noise pollution area due to increased sound immission based on the influence of the atmosphere state in this specific case.


mean value of attenuation of Lindenberg (1990 - 2000, 12 UTC)

mean value of attenuation of Lindenberg (2001 - 2007, 12 UTC)

mean value of attenuation of Munich (1990 - 2000, 12 UTC)

mean value of attenuation of Munich (2001 - 2007, 12 UTC)

Figure 2: Sound level attenuation of the station Lindenberg (above) and Munich (below) averaged over different periods (1990-2000: left and 2001-2007: right).

In addition to the term sound weather the term ’sound climate’ can be defined when different sound propagation situations over a climatologically relevant time span are averaged. In Figure 2 Two examples for different geographical and climatologically sites: a station of the North-east German Plain (Lindenberg) and a station in Alpine Foothills (Munich). Therefore, the sound climate can be interpreted as a mean sound propagation situation at a specific location over a long time.

Even if the averaging time span expands over years, there are still meteorological influences on the sound immission. The mean wind direction has a formative impact on the sound propagation over long averaging periods and leads to the deviations of the attenuation maps of the circular form of contour lines due to spherical wave divergence. First recognize the main wind direction in Figure 2 (southwest for Lindenberg and west for Munich). Furthermore, a slight increase in attenuation in long-term means is to determine.

These maps still differ from location to location. A classification of the areas with respect to different climatologically sound conditions can be conducted based on the local specifications (see WILSDORF ET AL., 2010).

4.2 Substitutability of radiosonde by model data for the presentation of sound immission distributions

In a first approach, the question of replace ability was investigated with help of radiosonde observations from Bergen because the topographic influence on profile data is relatively low. Therefore the radiosonde measurements of this station were compared to model data of the nearest grid point of the weather model COSMO-EU. The regional model COSMO-EU forms the core of DWD’s (German Weather Service) numerical weather prediction system. It is based on the full Euler equations without any scale-dependent approximations, i.e. it belongs to the non-hydrostatic models which solve a prognostic equation for the vertical velocity. The grid resolution of COSMO-EU amounts to 7 km and is significantly higher than that one of radiosonde stations.

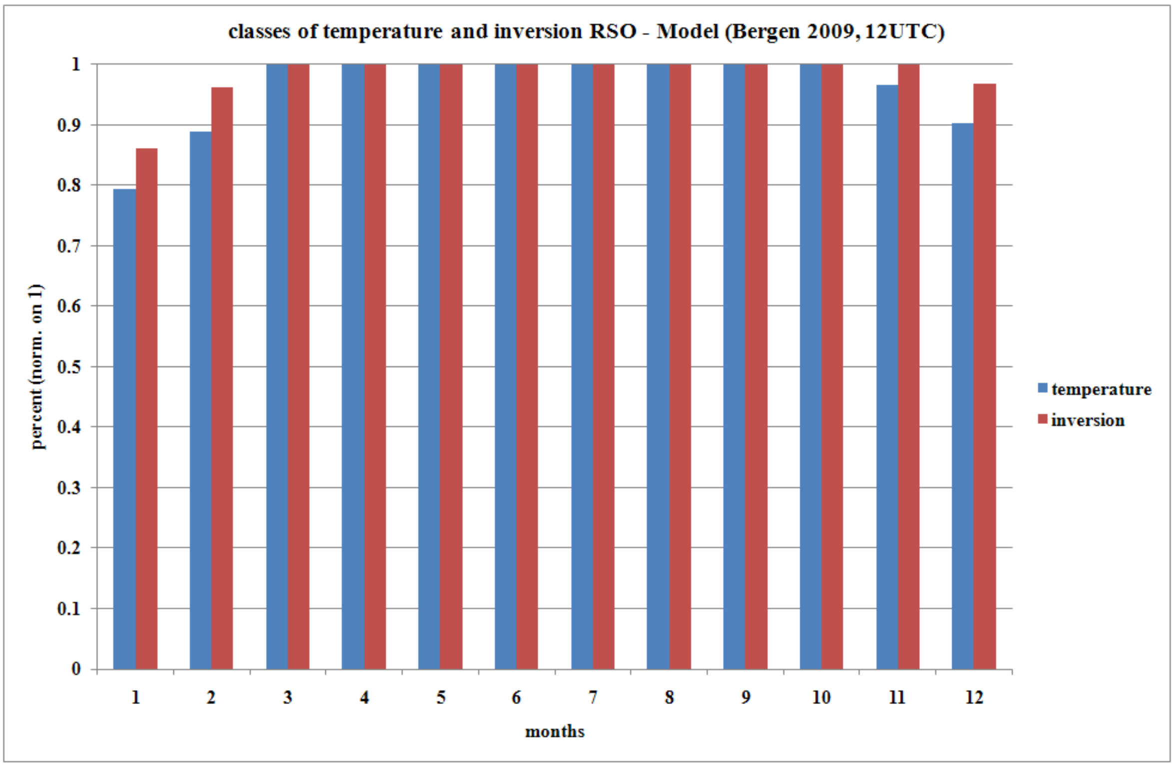


Figure 3: Comparison of determined classes of temperature (blue) and temperature inversion (red) between the simulation (model COSMO-EU) and measurement (radiosonde - RSO) of

station Bergen for 12 months in 2009 (radiosonde ascents at 12 UTC): Fraction of coincident profile classes of temperature and temperature inversion depending on the month.

The classification scheme (see section 3) for meteorological profiles developed by the LIM (see RAABE et al., 2000 and ZIEMANN et al., 2002) was used to classify the wind and temperature profiles.

Then, every profile (from radiosonde observations or model data) that has been recorded at 0 UTC and 12 UTC has been classified and analyzed. Due to the character of the profile an assignment to temperature-, inversion-, wind speed-, wind profile- as well as wind direction class was made. Finally all sub classes result in their entirety in a meteorological class which describes the profile (total: 1551 classes).

The main result was basically that there are only small differences between radiosonde and model by the sub-classification according to temperature gradients and a possible inversion. The COSMO-model is able to reproduce the temperature distribution and the occurrence of inversions that can be measured in a real atmosphere. This is depicted in Figure 3.

Small differences are visible in the winter months where inversions occur more often. But even here, the agreement ratio is not lower than 79%.

The assignment to the wind direction classes, with a class width of 30°, was more difficult. The model was just able to reproduce the conditions measured by radiosonde in 25% - 50% of all cases (Fig. 4, blue).

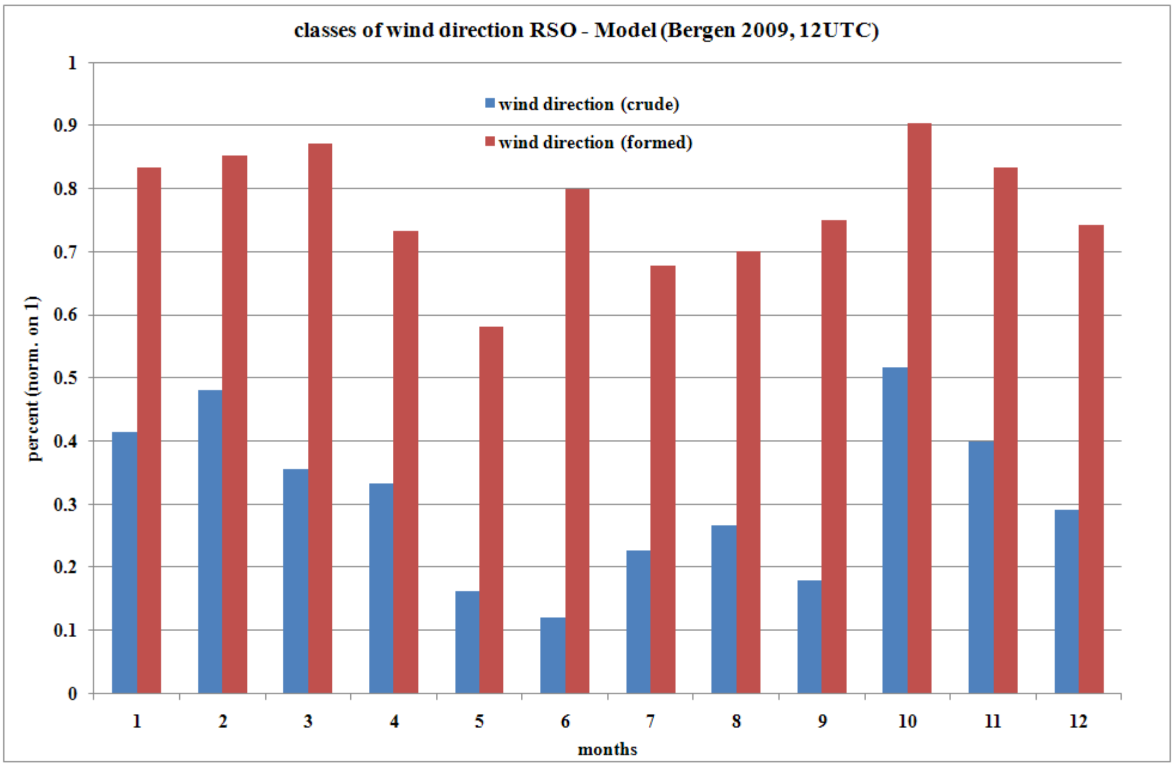


Figure 4: Comparison of determined classes of wind direction between model and RSO of station Bergen 2009 (12 UTC) for original classification (blue) and for formed classification (red).

On the base of the low success rate, the direction class width was enlarged to 90°, so that not only the main sector, but also the sectors left and right of the main sector lead to an agreement. If the model produces a wind direction class, which is one class higher or lower than the original one, this is treated as an agreement. Cause could be that the wind direction class is indeed formed at the ground, and there the influence of the local conditions (difference between RSO station and grid point) are greatest.

The achieved agreement increased from a former average of 30% to an average of 70%. This can be taken as a hint that a substitutability of radiosonde by model data could be possible.

The problems for the wind speed class assignment (Fig. 5) were comparable to those of the wind direction assignment. The agreement of radiosonde and model data reached values from 40% to 65% at the given wind speed classification. This is also shown in Fig. 5. The classification was basically denoted by a division in three blocks: 0-3 m/s, 3-7 m/s und > 7 m/s. If this division is reduced from three to two blocks, so that the resulting blocks span from 0 – 5 m/s and >5 m/s, then the agreement rises to 70% - 80%.

As a first result one can state that an adequate alignment of radiosonde and model is possible for certain characteristic attributes (temperature, wind vector).

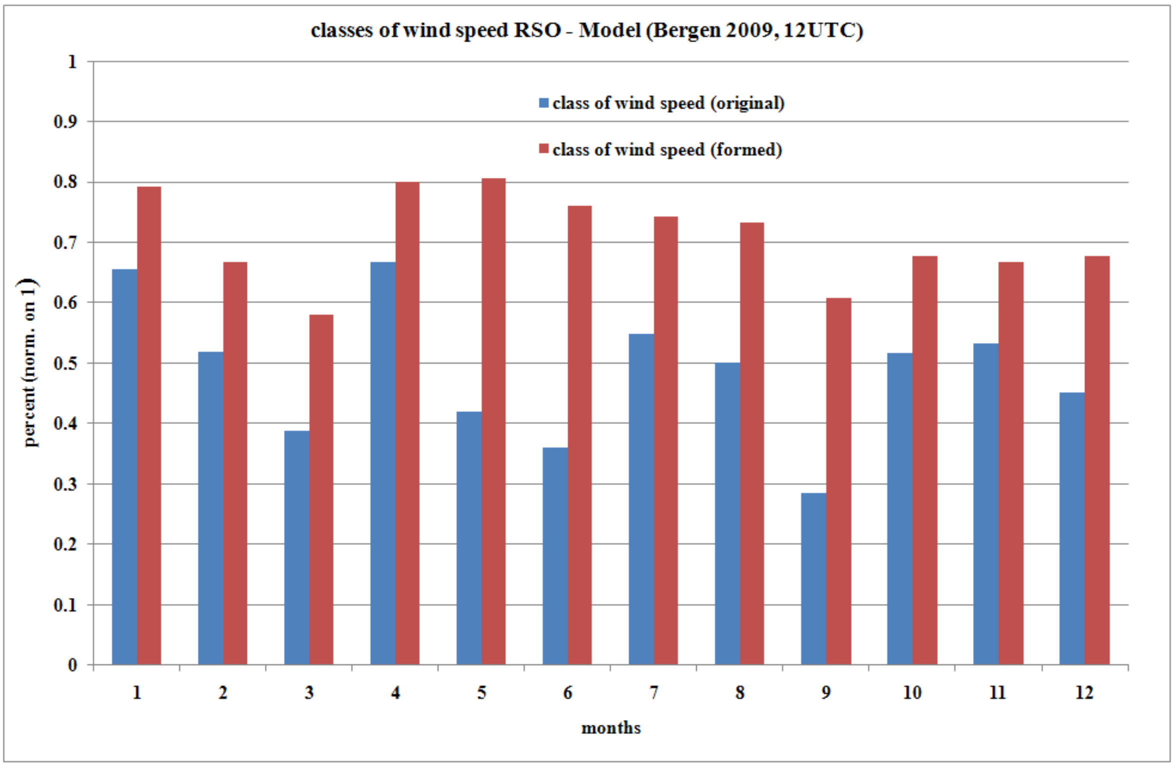


Figure 5: Comparison of determined classes of wind speed between model and RSO of station Bergen 2009 (12 UTC) for original classification (blue) and after treatment (red).

At a high rate of percentage one could replace the radio sonde by COSMO-EU without problems because both profiles are either the same or can be assigned to very similar profile classes. But a full agreement could not yet be determined, especially when the single attributes (temperature, wind speed, wind direction) were combined into one of the 1551 profile classes.

Supportingly this conclusion, the daily observation and model data were taken as an input for SMART and the particular attenuation distributions were calculated. The comparison (Fig. 6) shows that the sound attenuation distributions are not identical. Both have basically the same mean wind direction, but in general the sound levels using the data of the model are more attenuated than that one using the radiosonde observation.

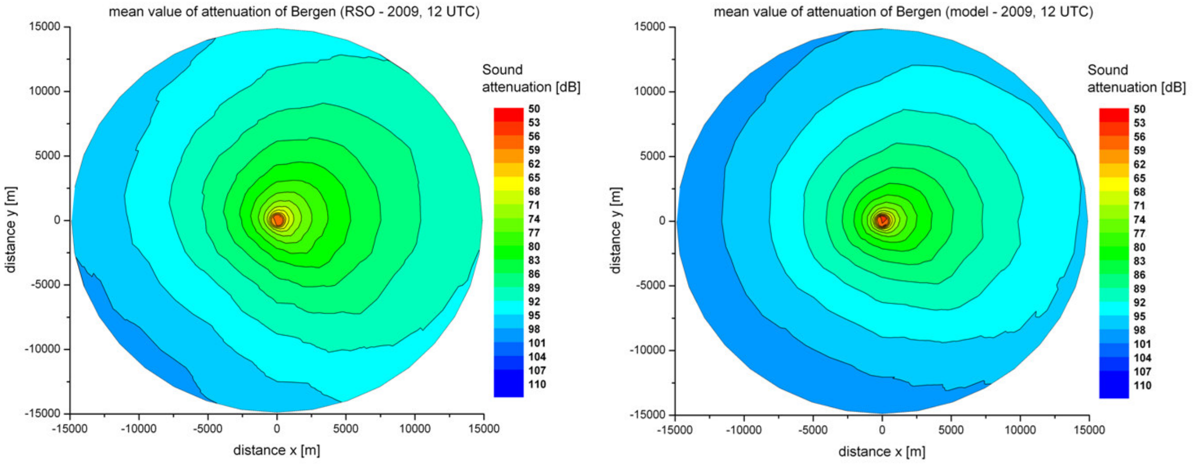


Figure 6: Sound level attenuation in the mountains surrounding the station Bergen as an annual average based on radiosonde data (left) and due to model data (right) for 12 UTC.

A mean deviation of the model from the radiosonde of about 3 dB can be found in a qualitative consideration of the attenuation calculation. This deviation is approximately distributed uniformly over the whole area.

5 Conclusions

The sound attenuation calculations, related to a specific time, are suited for the evaluation of sound weather and so for the investigation of individual sound events, e.g. annoying or dangerous sound exposure. The averaging method applied here (sound climate) is suitable to determine the longer-term sound propagation at specific areas. However, the relatively small number of radiosonde stations for regional considerations of sound is only suitable entries. If there would be a possibility to replace the radiosonde observations by simulated data of a numerical weather forecast model, then a synthetic, but complete data set would be available. On base of this data set the relevant sound propagation conditions at a dense grid of specific locations could be studied continuously.

In this work a simple comparison between both data sources on the basis of a classification of meteorological parameters was conducted. As a first result one can conclude, that for specific characteristic attributes an agreement between radiosonde and model is possible. In many cases the radiosonde observation could be replaced by COSMO-

EU model data, because both profiles could be assigned to the same or a similar profile class. A total agreement of radiosonde observations and model data could not yet be shown, especially if the single attributes were combined to a meteorological profile class.

6 Acknowledgments

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7 References

ATTENBOROUGH, K., S. TAHERZADEH, H.E. BASS, X. DI, R. RASPET, G.R. BECKER, A. GÜDESEN, A. CHRESTMAN, G.A. DAIGLE, A. L'ESPÉRANCE, Y. GABILLET, K.E. GILBERT, Y.L. LI, M.J. WHITE, P. NAZ, J.M. NOBLE, H.A.J.M. VAN HOOF, 1995: Benchmark cases for outdoor sound propagation models. – J. Acoust. Soc. Amer. 97, 173–191

BALOGH, K., ZIEMANN, A. and DANIEL, D., 2006: Influence of atmospheric refraction on pulse propagation over flat ground surface. Acta Acustica unidet with Acustica Vol. 92, p. 848-852

BLUMRICH R., D. HEIMANN, 2002: A linearized Euler sound propagation model for studies of complex meteorological effects. – J. Acoust. Soc. Amer. 112, 446–455.

FISCHER, G., ZIEMANN, A., 2009: Untersuchung des Einflusses der variierenden urbanen Grenzschicht auf die Schallausbreitung. Wiss. Mit. aus dem Institut für Meteorologie der Universität Leipzig, 45, S. 57-68

GILBERT, K.E., M.J. WHITE, 1989: Application of the parabolic equation to sound propagation in a refracting atmosphere. – J. Acoust. Soc. Amer. 85, 630–637

HEIMANN, D., G. GROSS, 1999: Coupled simulation of meteorological parameters and sound level in narrow valley. – Appl. Acoust. 56, 7–100

HEIMANN, D., R. KARLE, 2006: A linearized Euler finite difference time-domain sound propagation model with terrain-following coordinates. – J. Acoust. Soc. Amer. 119, 3813–3821

ISO 9613-2, 1996: Acoustics — Attenuation of sound during propagation outdoors — Part 2: General method of calculation

NIJS, L., C.P.A. WAPENAAR, 1990: The influence of wind and temperature gradients on sound propagation, calculated with the two-way wave equation. – J. Acoust. Soc. Amer. 87, 1987–1998.

OSTASHEV, V. E., 1997: Acoustics in Moving Inhomogeneous Media. E & FN SPON.

PIERCE, A. D., 1989: Acoustics-An Introduction to Its (Physical Principles and Applications. by Acoustical Society of America.

PIERCY, J.E., T.F.W. EMBLETON, L.C. SUTHERLAND, 1977: Review of noise propagation in the atmosphere. – J. Acoust. Soc. Amer. **61**, 1403–1418.

RAABE, A., ARNOLD, K. und ZIEMANN, A., 2000: Berücksichtigung atmosphärischer Schallausbreitungsbedingungen bei Messungen und Prognose von Schießlärm. Abschlußbericht zum Auftrag E/F360/X5144, 46 S.

SALOMONS, E. M., 2001: Computational atmospheric acoustics. By Kluwer Academic Publishers.

WILSDORF, M., FISCHER, G. und ZIEMANN, A., 2009: Einfluss der vertikalen Auflösung der Eingangsprofile bei einem Schallstrahlenmodell. Wiss. Mit. aus dem Institut für Meteorologie der Universität Leipzig, 45, S. 45-56

WILSDORF, M., ZIEMANN, A., BELITZ, H.-J. und RAABE, A., 2010: Ein Bewertungsverfahren für Schallimmissionsprognosen unter Berücksichtigung der Meteorologie, Lärmbekämpfung 5/2010, Springer Verlag.

ZIEMANN, A., ARNOLD, K. und RAABE, A., 2001: Berücksichtigung atmosphärischer Schallausbreitungsbedingungen beim Lärmschutz. Wiss. Mit. aus dem Institut für Meteorologie der Universität Leipzig 24, S. 35-49

Ziemann, A., 2002: Zum Einfluss vertikaler Gradienten meteorologischer Größen auf die Laufzeit von akustischen Signalen zwischen Schallquellen und Schallempfängern in der bodennahen Atmosphäre, Wiss. Mit. aus dem Institut für Meteorologie der Universität Leipzig 26, S. 31-42

ZIEMANN, A., ARNOLD, K. und RAABE, A., 2002: Berücksichtigung atmosphärischer Schallausbreitungsbedingungen bei Messungen und Prognose von Schießlärm. Zwischenbericht zum Auftrag E/F360/X5144, 74 S.

Ziemann, A., BALOGH, K. and ARNOLD, K., 2007: Modelling and measuring the atmospheric excess attenuation over flat terrain during night time conditions. Meteorol. Zeitschrift 16, S. 429-441

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