THE PROBLEM OF LIMIT VALUES EXCEEDANCES DETECTION IN COMPLEX TERRAIN USING MEASUREMENT AND MODELS

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Abstract: The present directive 2008/50/EC defines several limit values for human health protection. To determine the concentration of pollutants in the air the directive is clearly suggesting point measurements and modelling techniques: "Information from fixed measurements may be supplemented by modelling techniques and/or indicative measurements to enable point data to be interpreted in terms of geographical distribution of concentrations." The directive is also giving precise advices for data quality in terms of quantity of valid data when aggregating data and calculating statistical parameters.

But when studying air quality over the areas of very complex terrain we have encountered one specific and important problem not yet addressed in the directive: over the complex terrain air pollutants concentrations are not homogenous in space (which is an obvious fact). If point measurements locations are chosen properly they do show the actual concentrations that citizens are exposed to and are also showing properly the exceedances of limit values. But if on the other hand for the same area only modelling techniques are used for air pollution assessment the pollutants concentrations are usually calculated for grid cell of significant size. Most of the models calculate homogenous concentration within the cell. And this is the reason why peak concentrations (that population is actually exposed to) are "smoothed" when the cell size is large enough to cover areas of both very high and low concentrations. Mathematically the described effect is an obvious consequence of assessing the values from fine resolution to the coarse resolution. And it is nothing new, the modellers are aware of it. But we do not discuss enough that due to this implicit "smoothing" that removes actual peaks of concentrations, the resulting modelled concentrations over areas of complex terrain are lower and we do not detect the limit values exceedances properly. Therefore we suggest that this problem should be addressed further and that maybe in the future limit values are lower when used for comparison with modelling results in the areas where large model cells spread over complex non-homogenous areas.

Examples of modelling results over complex terrain will be given to illustrate the problem.

Key words: *limit values, exceedances, complex terrain, measurements, models, satellite observations.*

INTRODUCTION

It is essential to realise with regard to the use of dispersion models for regulatory purposes how well models can illustrate what is actually happening in nature. This was already known two decades ago, when an initiative was launched in Europe to unify these models. In addition to model validation using measurement data sets (Mlakar, P. et al., 2014), we wish to highlight the issue of the proper interpretation of the accuracy of model results when using them for regulatory purposes.

THE EU DIRECTIVE AND THE PROTECTION OF HUMAN HEALTH

Directive 2008/50/EC on ambient air quality and cleaner air for Europe (European Union, 2008) defines limit values for various pollutants, which are not to be exceeded in order to protect the health of the population to the greatest extent possible. The pollutants whose high concentrations have been the most problematic for the European population are ozone, PM_{10} and nitrogen oxides. Though other pollutants are quite problematic as well, this article primarily focuses on the three pollutants listed so that the issue may be presented as clearly as possible. The limit values for these pollutants were determined on the basis of scientific findings and recommendations with regard to the environment and medical research on the effects of pollutants on human health. They have been set so that their observance helps to prevent the most harmful short-term effects of air pollution as well as the long-term effects of prolonged exposure.

It is important in the prevention of long-term harmful effects that average pollutant concentrations do not exceed the limit values for longer periods of time. As regards the prevention of short-term health effects, it is essential to prevent very high concentrations of pollutants in the air that we breathe. But as high concentrations of pollutants nevertheless occur due to industrial activities, residential heating and other human activities as well as weather conditions unfavourable for the dilution of air pollutants, the Directive stipulates that episodes of high concentration should occur as few times as possible within a given year. It is also stressed in the Directive that the essence of a high concentration event is the actual occurrence of high concentrations of pollutants, and not so much the maximum concentration value during the event, assuming, of course, that it exceeds the limit value defining high concentrations. A well-known limit implemented due to exceedances in numerous cities and regions is that the high daily concentrations of PM_{10} (over $50\mu g/m^3$) must not occur more than 35 times per year. The hourly concentrations of nitrogen dioxide must not exceed $200\mu g/m^3$ more than 18 times per year. The limits for other pollutants are set in a similar manner.

In simple terms, it could be said that the Directive introduces counters for exceedances that have harmful health effects.

It is essential when describing such events to accurately determine how exactly the concentration occurred, which enables us to obtain data, either directly or by means of statistical analysis, that show whether or not the limit value was exceeded, such as the daily average value of PM_{10}.

THE DETERMINATION OF EXCEEDANCES OF THE LIMIT VALUES OF POLLUTANTS IN AMBIENT AIR THAT ARE HARMFUL TO HUMAN HEALTH

The Directive stipulates that air-pollution concentrations may be determined by means of measurements as well as modelling techniques. "Information from fixed measurements may be supplemented by modelling techniques and/or indicative measurements to enable point data to be interpreted in terms of the geographical distribution of the concentrations." (European Union, 2008). The Directive furthermore stipulates that the measuring stations must be sited so that the measurements are representative of the air breathed by the population in the area.

It is certainly clear that measurements at a sampling point (measuring location) indicate directly what is in the air that we breathe, assuming, of course, that the measurement is carried out in full compliance with the requirements. The time series of the measurement results thus enable us to directly determine whether or not the limit values for high concentration events have been exceeded.

THE ISSUES OF DETECTING HIGH CONCENTRATION EVENTS USING MODELS

When models are used instead of measurements to assess events defined as exceedances, an often-overlooked problem arises in relation to interpretation. If the actual air-pollution concentration field at ground level, i.e. in the air breathed by the population, in the observed domain that is non-homogeneous, the concentration peaks can be smoothed with an adequate cell size by averaging multiple concentrations to the extent that exceedances within smaller areas cannot be detected at all using the model results.

In other terms, when using models for complex terrain, where concentrations are often not locally homogeneous due to the pollution dispersion mechanisms, concentrations can be smoothed with a large enough model cell size to the extent that exceedances are actually not detected at all.

Though the solution to this problem may appear simple, i.e. using a model cell small enough to allow the assumption that the concentrations are homogeneous, this is normally very difficult to actually achieve over very complex terrain despite the sophisticated modelling tools available today and the sincere efforts of modellers to obtain results that reflect the actual situation.

While it is possible to assume that certain air pollutants (such as ozone in coastal regions and over large cities) are relatively homogeneously distributed at ground level within cells with sides measuring several kilometres, it is conversely not possible to assume that air pollutants such as nitrogen dioxide emitted by motor vehicles are homogeneously distributed at ground level, as the pollution patterns are predominantly dependent on the network of high-traffic roads.

It has been proved by means of measurements from a number of densely distributed measuring stations that the conditions over very complex terrain, such as in most of Slovenia, can differ significantly even at distances of only one kilometre or even a few kilometres. One example of this, i.e. the model validation data set obtained in the Šoštanj measurement campaign of 1991, is described in more detail in our presentation at this conference (Mlakar, P. et al., 2014). We have published a number of publications in the course of our work over the years that explain the local non-homogeneity of concentrations over very complex terrain on the basis of measurements and modelling (Božnar, M. Z. et al., 2012a, Božnar, M. Z. et al., 2012b, Elisei, G. et al., 1992, Grašič, B. et al., 2008a, Grašič, B. et al., 2008b, Grašič, B. et al., 2011, Mlakar, P. et al., 2012).

The reason for the extremely pronounced non-homogeneity over very complex terrain lies in the complex meteorological conditions as well as the physical shape of the hills and valleys and the different locations of the settlements. It is obviously impossible to assume that the concentration of the air pollutant under study is homogeneous within a cell measuring several kilometres, which is standard when using models for an entire country, given the mere fact that the cell covers multiple hills and valleys, since we know from experience that they each have their own separate sources of air pollution and local meteorological dilution mechanisms.

The interpretation of high concentration events within such areas using relatively large model cells would constitute an improper application of model results.

We must therefore find a way to obtain accurate data on the exposure of the population to harmful concentrations of pollutants in ambient air even when using modelling techniques that do not yet enable the use of adequately small cells over complex terrain. We present our proposal for a solution to this problem in the conclusion to this article. Before the conclusion, however, we have provided an illustrative fictional example of how exceedance events can be erased by enlarging cells. This example is not included because researchers would require clarifications of the mathematical bases, but for the sole purpose of shedding light on this often-ignored fact.

We have also included a brief section on satellite measurements, which are increasingly used in the analysis of air pollution for large areas and, like models, provide information on the geographical distribution of pollutants.

AN ILLUSTRATION OF EXCEEDANCES UNDETECTED DUE TO THE ENLARGEMENT OF THE HORIZONTAL DIMENSIONS OF A GROUND-LEVEL MODEL CELL

The first figure shows an illustration of concentrations within cells at ground level over a hypothetical complex terrain that results in non-homogeneous concentrations, which clearly shows exceedances at individual locations within the domain under observation. These events are then literally erased by gradually enlarging the horizontal dimensions of the cell in two steps.

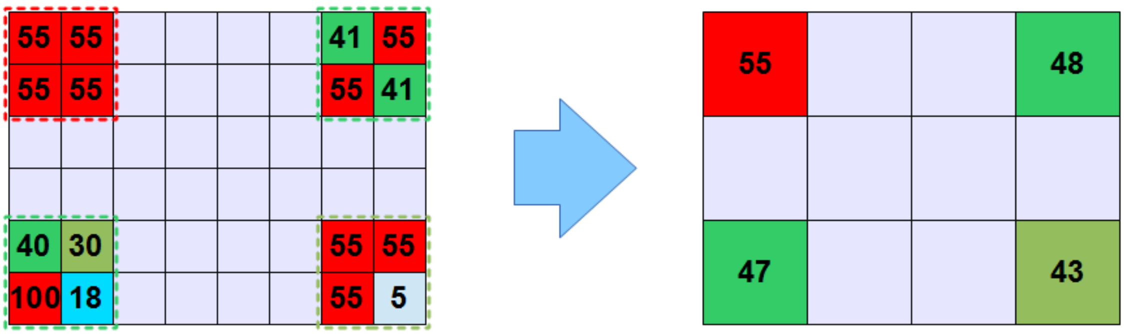

Figure 1. Results of modelling on different grids – using of air pollution concentration smoothing to hide exceedances (pink and red indicate exceedances, green and blue indicate no exceedances)

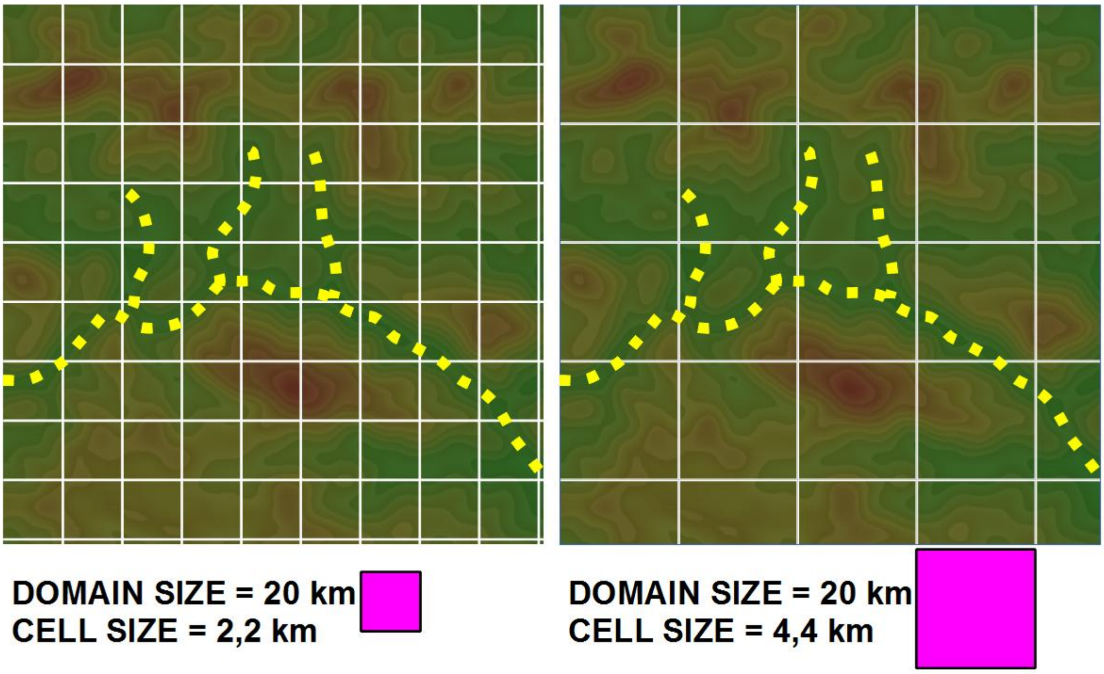

Figure 2. Effect of doubling cell size on Zasavje region case, an example of very complex terrain, yellow dotted lines represent the main valleys, bigger cells show how two valleys and a hill between can fall into the same cell and therefore give misleading results

SATELLITE MEASUREMENTS

Remote satellite measurements are becoming an increasingly prominent source of data for initialising models, namely for meteorological variables and ambient air pollutant concentrations, and even more so for general purposes in meteorological observations. However, as the air-pollution concentration values measured and processed by satellites for areas over complex terrain, as well as areas where air-pollution concentrations are known not to be locally homogeneous for other reasons, are available to the end user in the form of locally averaged values for large areas, the same interpretation problem arises in relation to these results as that described for the model results (Božnar, M. Z. et al., 2013).

The same issue of the non-detection of high air-pollution concentrations also arises with certain other satellite meteorological measurements, where users receive the results in the form of local averages. Satellite data on the solar energy received per unit of the planet’s surface are becoming more and more widely used for purposes in relation to energy utilisation. As the final data are given in the form of local averages for relatively large areas, they can be very misleading when used, for instance, in choosing the location of solar power plants within an area with complex terrain. More focus should be placed on the proper interpretation of data in this area as well. We also raised this issue at an invited lecture in Munich (Božnar, M. Z. et al., 2013).

IN LIEU OF A CONCLUSION – A PROPOSAL FOR A SOLUTION TO THE ISSUE OF THE INTERPRETATION OF MODEL RESULTS FOR AREAS WITH HIGHLY NON-HOMOGENEOUS CONCENTRATIONS

The local smoothing of air-pollution concentrations integrated in the interpretation of the model results actually prevents the detection of high concentration events within the area observed. To avoid this and ensure the proper interpretation of results, we propose the introduction of a mandatory corrective factor that would downscale the limit values determining the occurrence of high concentration events in inverse proportion to the size of the model cell. The factor would thus only equal one when adequately small ground-level model cells are used so that it can be assumed with certainty on the basis of expert knowledge of the area and its specific air-pollution dispersion mechanisms that the air-pollution concentrations are actually homogeneous within individual ground-level cells in reality.

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