HIGH RESOLUTION MAPS OF NITROGEN DIOXIDE FOR THE PROVINCE OF STYRIA, AUSTRIA

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Abstract: Knowledge about the spatial distribution of NO_2 concentrations and its main contributors is beneficial for setting up air quality measurement plans, assessing exposure, or in licensing procedures, where background concentration levels are required. To produce air quality maps with reasonable spatial resolution, a suitable dispersion model is needed. The province of Styria with 16.400 km² and a population of 1.2 million is the second largest in Austria. While the northern part is dominated by the Alps (peak elevation: 2.995 m), the Southeast is much more flat with gentle hills and some larger plains. In order to take topographical effects on the pollutant dispersion properly into account, wind field libraries have been computed using the prognostic non-hydrostatic mesoscale model GRAMM (Graz Mesoscale Model). The chosen horizontal grid resolution of 300 m did not allow to model wind fields for the whole of Styria in one single run; instead the province has been divided into more than 20 overlapping sub-regions. Local observations of wind speed, - direction and estimated stability classes have been used as meteorological input. Subsequently quasi steady state wind fields have been computed and stored for later use in dispersion modelling utilizing the Lagrangian particle model GRAL (Graz Lagrangian Model). In order to capture strong NO_2 concentration gradients in the vicinity of roads, horizontal grid spacing was set 10 m in the dispersion calculations. Building effects on dispersion have been taken into account by applying a simple mass-conservative diagnostic flow field model implemented in GRAL. Modelled annual mean NO_2 concentrations compare well with observations, although in some areas unexpected patterns appear. In some cases these could be reasonably explained by wrong emissions. Apart from correctly assigning some emission sources in space (e.g. tractors, domestic heating), wind field simulations should be further improved. High resolution maps for PM_{10} and B(a)P are foreseen in future, too.

Key words: *GRAL, GRAMM, Air Quality Map, Lagrangian Dispsersion Model, Nitrogen Dioxide*

INTRODUCTION

Air quality maps generated by the help of dispersion models are a valuable supplement to fixed air quality monitoring stations and are recommended by the FAIRMODE (2012) community for the following applications (among others):

- Assessment of air quality levels to establish the extent of exceedances and establish the population exposure
- Source allocation to determine the origin of exceedances and to provide a knowledge basis for planning strategies
- Assessment of plans and measures to control AQ exceedances
- determining the number of fixed monitoring sites that are required
- designing monitoring networks when models are used in combination with monitoring

The modelling efforts depend largely on the complexity of topography. The province of Styria, about 16.400 km² large with a population of 1.2 million, is in its northern part dominated by the Alps (peak elevation 2.995 m), while towards southeast gentle hills and some plains along the river Mur form the scenery. Rather complex flow fields develop on the one hand, and on the other, low wind speed conditions are quite frequent south of the Alpine ridge (e.g. in the city of Graz wind speeds below 2 ms^{-1} occur in about 90 % of a year). Both call for advanced modelling techniques, which are usually quite demanding in computation power. In 2012 the modelling system GRAMM/GRAL, which is widely used in Austria, has been parallelized using OpenMP. Now, simulations for the whole of Styria can be made in a reasonable time. Subsequently the methods, results for NO_2, as well as shortcomings and strengths of the procedure are outlined.

METHODS

Flow field modelling

To account for the influences of the rather complex terrain on the flow fields, the mesoscale prognostic non-hydrostatic model GRAMM (Graz Mesoscale Model) has been utilized. It has been evaluated (Oettl 2000a) according to the suggestions of Schluenzen (1997) and its performance has further been tested by applying it in the MESOCOM (Thunis et al., 2003) and DATE-Graz projects (Almbauer et al. 2000 a,b). The most common way to model air pollution in areas with complex terrain is to compute time series of 3-dimensional wind-, turbulence-, and concentration fields (e.g. Nanni et al., 2002; Finardi et al., 2002, Anfossi et al., 1998; Carvalho et al., 2002; Finardi et al., 2004; Tinarelli et al., 2000; Trini Castelli et al., 2003 and 2004). Models are initialized with outputs of a global scale model or reanalysis data and subsequently nested until the required horizontal resolution is achieved. As the computation times are still rather high using such an approach, scientists sometimes select a subset of periods shorter than one year, which in their ensemble represent the concentration statistics for a whole year. The limitation of this methodology lays in the statistical approach itself, both in the pre-selection of the periods, based on the available observed data not necessarily representative for the whole domain, and in the approximation linked to the finite number of periods considered.

The reliability of prognostic models strongly depend on the quality of input data, such as soil moisture, soil temperature, snow cover etc. which are often not well known. It might be useful to recall Hanna's (1989) hypothesis regarding model uncertainty: Simple models suffer mainly due to simplifications in physics, while sophisticated models with a comprehensive representation of governing laws are prone to errors due to badly known input data. One may conclude that there might be an optimum model/method for today's scientific knowledge. Such can only be found by comprehensive sensitivity analysis and comparisons. Recent publications on modelling flows in complex terrain with high spatial resolution (e.g. Horvath, et al., 2012; Bianco et al., 2006) applying multiple nesting techniques still report on shortcomings in computing thermally driven flows.

Wind field simulations for the rather complex nocturnal wind field of the city of Graz, Austria, first brought up the idea of a simpler method to compute wind fields in complex terrain with high horizontal resolution (300 m in this case). In the study of Oettl et al. (2000b) the Froude number dependent flow in the Graz basin could successfully be modelled and explained by simply initializing the prognostic non-hydrostatic wind field model GRAMM with a single point measurement of wind and a few assumptions about the vertical wind- and temperature profile. In other words, the wind field model was initialized with a horizontally homogenous wind field and then a quasi steady-state wind field was computed. The most important point is of course to find a monitoring station, which is representative for the large scale wind (e.g. a mountain/valley breeze). Thus, the main disadvantage of this method is the necessity of local representative wind observations, which are sometimes not available. Another disadvantage is that the wind field might be captured only well close to the surface but not in the whole boundary layer. However, provided that one representative point measurement of wind is available, the method offers distinctive advantages compared to the method described before: When using a locally observed atmospheric "stability" parameter then some simple assumptions can also be made about the vertical temperature and wind profiles. This means that the model can already be fully initialized by the use of three locally observed input parameters, namely wind speed, wind direction, and a kind of atmospheric "stability". Due to this limited number of required input parameters it is still possible to establish a simple classification of the meteorological conditions. For instance, when using 36 wind sectors, 5 wind speed classes, and 7 stability classes, the number of meteorological situations representing a full year reduces to some hundreds. As locally observed wind directions and speeds are used as input to the model, the main characteristics of the pollutant advection is already captured (frequency distribution of wind speed, wind direction). The main assumption is that all other parameters in a mesoscale model are of minor importance once the large scale wind is used as input. The subsequent computation of a steady-state flow field for each classified meteorological condition aims mainly at the simulation of local topographical influences (e.g. development of eddies in the wake of mountains, katabatic flows). This method is frequently used in Austria for practical purposes (e.g. Oettl et al., 2003; Oettl et al., 2006), and is increasingly used in Germany, too (e.g. Hasel et al., 2009).

Figure 1 depicts the province of Styria and the chosen model domains. About 80 surface monitoring stations for wind where available providing input data to GRAMM or were used for model evaluation.

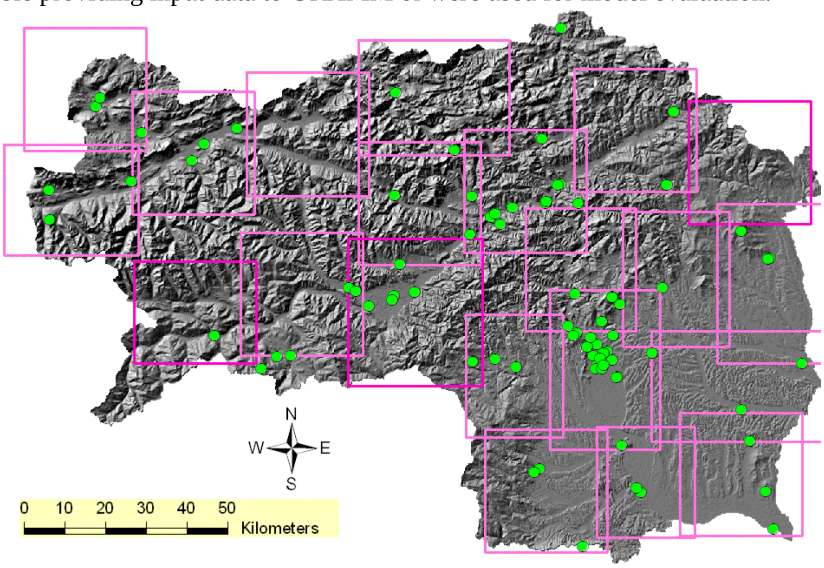

Figure 1. Province of Styria, model domains, and surface wind field monitoring stations

Figure 2 shows an example of observed and modelled wind speeds and -directions at the monitoring stations Voitsberg and Fuerstenfeld. While wind speed distributions are captured in most cases quite well at all monitoring stations, computed wind direction distributions don't fit observed ones everywhere. Most likely, this might be due to improper boundary conditions, erroneous surface energy physics over forests, and/or a result of the simplified initial conditions.

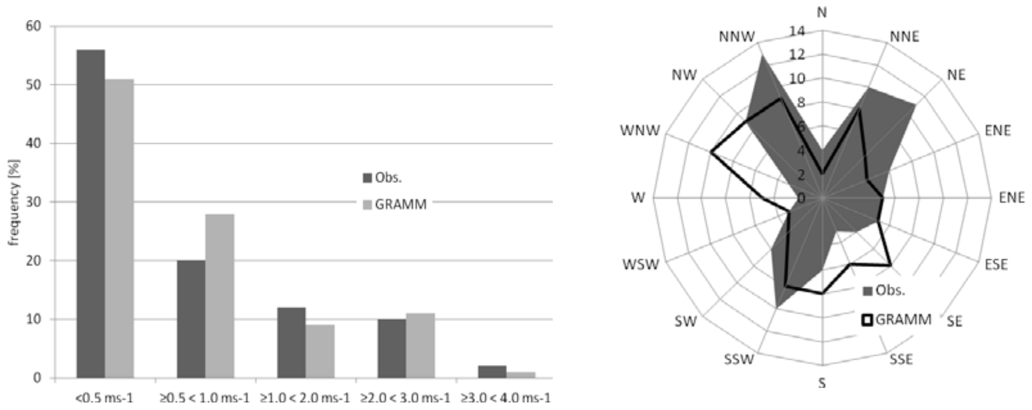

Figure 2. Examples of observed and simulated wind speeds and -directions for 2006 at the monitoring sites Voitsberg (left) and Fuerstenfeld (right)

Emission inventory

Emissions are categorized according to SNAP, with the following main contributors: (i) Energy and Production, (ii) Domestic heating, (iii) Traffic, (iv) Mobile sources, (v) Waste treatment, (vi) Agriculture.

Emissions originating from energy and production are estimated from (i) a survey on working places in Austria in 2001, where the number of stuff in each production branch is multiplied with a corresponding emission factor, and (ii) detailed emission investigations in the frame of environmental inspections of industrial companies falling under the IPPC-, SEVESO-, and/or waste treatment regulations. Up to now, emissions from stacks, mobile offroad equipment, and fugitive dust emissions for roughly 200 enterprises have been compiled. Domestic heating emissions are based on an Austrian survey on heated living spaces categorized by their heating system, fuel, and type of house. As the survey dates back to 2001, and the corresponding emission factors are based on measurements before 1997, these emissions quite uncertain. Traffic emissions are computed with the Network Emission Model NEMO 2.0 developed by the Graz University of Technology (Rexeis and Hausberger, 2005). NEMO requires the annual average daily traffic, the share of HDV, the mean driving speed, and a characterisation of traffic situation. Non-exhaust emissions from traffic (re-suspension, road- and tire wear) were taken from Ketzel et al. (2007) for urban roads, while for all other roads emission factors from Gehrig et al. (2003) were used. There exist several statistics in Austria about the number, and type of offroad machinery, but no information about activity data is available. Thus, emission calculations are based on vaguely estimated fuel consumptions.

Dispersion modelling

Dispersion is calculated with the Lagrangian particle model GRAL (Graz Lagrangian model). A comprehensive description of the model and its evaluation is given in Oettl (2012). GRAL takes into account meandering in low wind speed conditions (Anfossi et al., 2010), and the particular dispersion conditions from road tunnels (Oettl et al., 2002). The horizontal resolution used in GRAL was 10 x10 m². Buildings have been taken into account by using a simple diagnostic wind field model in the vicinity of obstacles, which modifies the 3D wind fields obtained with GRAMM in order to fulfil mass conservation around building structures. A meteorological pre-processor computes all necessary turbulent quantities, such as friction velocity, Monin-Obukhov length, boundary layer height, etc. Steady-state concentration fields and subsequently yearly mean concentrations considering seasonal and daily variations of emissions for the various source groups were computed.

As GRAL is not capable of dealing with chemical reactions, annual mean NO_2 concentrations were estimated via the following empirical relationship derived from observations in Styria over several years:

$$NO_2 = NO_x \cdot \left(\frac{30}{NO_x + 35} + 0.18 \right) \tag{1}$$

RESULTS

Figure 3 depicts the simulated annual mean NO_2 concentrations. The European Air Quality standard of 40 µg m^{-3} is met in most parts of Styria. In Graz, the capital, and along some major roads however, GRAL suggests non-compliance.

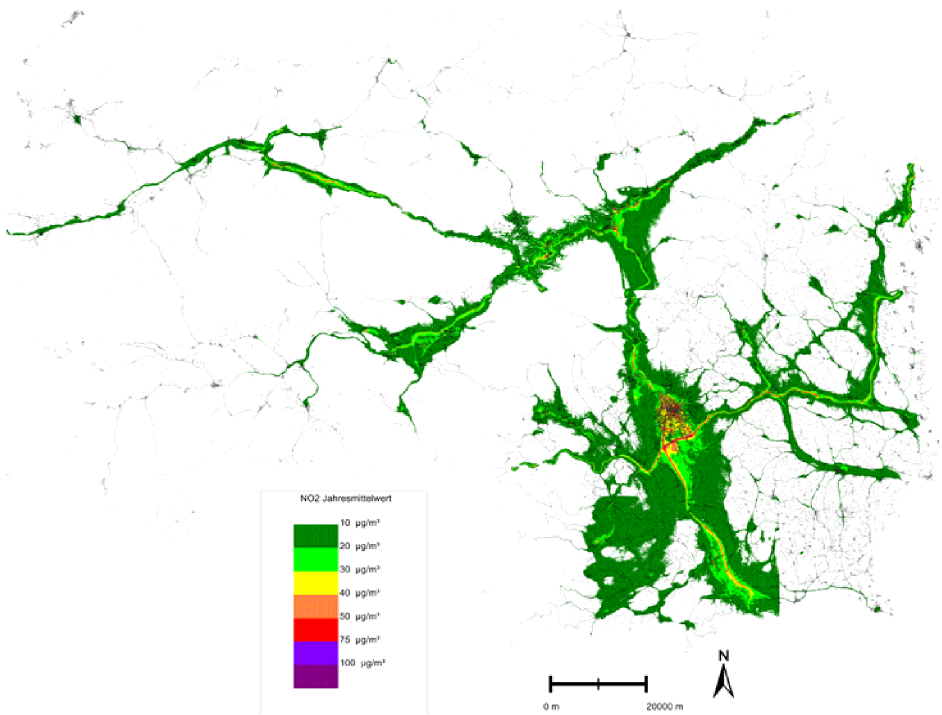

Figure 3. Modelled yearly average NO_2 concentrations

To evaluate model results, the DELTA3.2 tool developed by Thunis et al. (2013) has been utilized. For annual mean values it provides two statistics: (i) a scatter plot, and (ii) the so-called summary report. The DELTA software is thought to serve as future tool to assess model performance within the EU. The model quality objective (MQO) for annual means is based on the bias, and it is expected to be fulfilled by at least 90 % of the available stations. The second raw in the summary report provides information on the number of stations fulfilling the performance criteria; green for above 90 % of the stations, orange between 75 and 90 %, and red below 75 %. GRAL obviously fulfils the requirements of the Air Quality Directive (AQD), but improvements could be made concerning the normalized bias. In fact, in some cases underestimations of concentrations are due to missing emissions. For instance, in some district capitals traffic data for several major roads aren't available yet. Other shortcomings of the emissions inventory, that were identified based on the model results, concern emissions from offroad machinery, such as tractors, or equipment used in industrial facilities. The corresponding emission modelling is currently under revision.

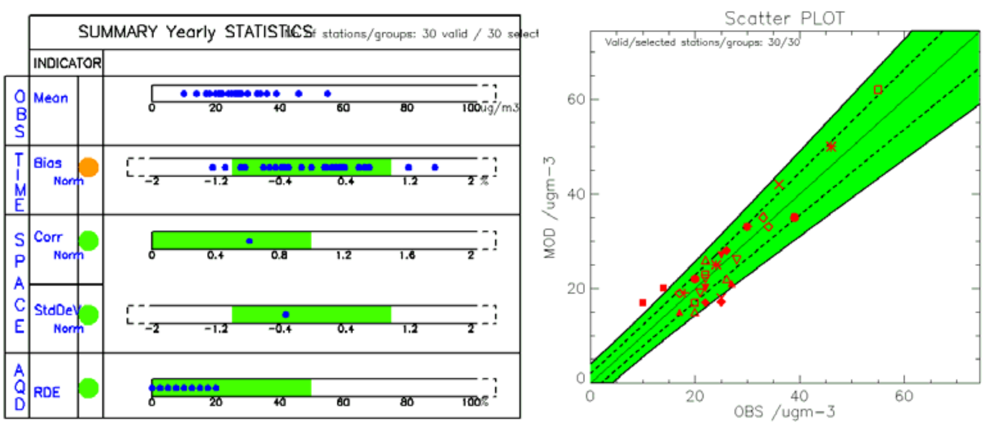

Figure 4. Summary report (left) and scatter plot (right) for annual mean NO_2 concentrations in Styria for 2006 using DELTA3.2

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