PREDICTING NOX CONCENTRATION IN ALPINE VALLEYS USING APPLIED DISPERSION MODELING

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INTRODUCTION

This paper presents an applied method to model the dispersion of pollutants emitted in the basin of Alpine valleys. Frequency distributions of wind speed and direction, mixing height, and PGT stability class are analyzed for three meteorological stations located in Alpine valley basins. An applied Gaussian plume model is used to produce "dispersion matrices" (i.e., transfer functions), which give the annually averaged concentration impact per grid cell for a source of unit strength located in the center of the matrix. Dispersion matrices are computed for different source configurations and different local climatologies. These dispersion matrices are then used to disperse extensive inventories of NO_x emissions for the whole of Switzerland.

The local wind conditions in alpine valleys are often determined either by the topographic forcing of the mesoscale circulation, or by thermally driven valley breezes. As a result, the circulation exhibits a complex pattern, which is neither homogeneous nor stationary, thus preventing the use of classical Gaussian approaches for modeling pollutant dispersion and the resulting ground-level concentrations.

When modeling pollutant concentrations for entire states (Switzerland has a land surface area of approx. 41 000 square kilometers) using emission inventories, commonly applied dispersion models have to be used. Such dispersion models assume homogeneous and stationary conditions, and often take into account only one generic climatology, as the main goal is the prediction of the annual mean concentration only. This approach worked well in Switzerland for the prediction of annually averaged NO_x concentration throughout the country (SAEFL 1997), but NO_x concentrations from transit highway emissions in alpine valleys were clearly underestimated.

A method has therefore been derived to better take into account the mean local flow patterns in alpine valleys. The main result are so-called dispersion matrices reflecting local climatology for alpine locations, for use within the Swiss PolluMap model, which is described in the next section. For a generic Alpine climatology and for each out of a set of several source configurations (traffic line source, elevated stacks, residential heatings, etc.), a distinct dispersion matrix is used.

THE EMPIRICAL SWISS „POLLUMAP“ DISPERSION MODEL

The empirical PolluMap dispersion model (Heldstab and Künzle 1997) has been applied successfully for regional air pollution management purposes, especially for the present and future situation of the NO_2 and NO_x concentrations (SAEFL 1997). Inputs for the model are detailed emission inventories and actual measurements of concentrations for validation purposes.

The PolluMap dispersion model uses annually averaged dispersion matrices which are applied to each cell of the different emission inventories. The spatial resolution of the dispersion matrices differs. For NO_x modeling, grid cells of 200 m x 200 m are used up to a distance of approx. 8 km away from the source. Concentration impacts caused by transport over more than 8 km is not modeled explicitly; instead, the parameterization of the NO_x background concentration is adjusted such that it accounts for this. The PolluMap modeling approach is also used to model PM_{10} concentrations for the whole of Switzerland. Here, a spatial resolution of 200m x 200m is applied up to 4 km away from the source, and a 1 km^2 resolution up to a spatial extension of 200 km (because of the significant long-range transport of fine particulate matter).

Emissions having distinct source characteristics are grouped into different inventories, i.e. urban and extra-urban emissions, and different source heights. For example, urban and extra-urban traffic sources, residential heating sources, and four different industrial stack heights are distinguished. The dispersion matrices are derived from a simple Gaussian plume dispersion model and reflect the annually averaged ground concentration impact of a point source with specific source characteristics onto each of the neighboring grid cells.

To improve the concentration forecast in alpine valleys, where the dispersion matrices currently being used underestimate the persisting channeling of the flow within the valley, a set of dispersion matrices representing local climatologies in alpine valleys, is used. For that part of Switzerland not being part of the alpine mountain ridge, a single set of dispersion matrices representative for that part of Switzerland is still being used.

ANALYSIS OF HOURLY METEOROLOGICAL DATA

65% of the land surface of Switzerland belongs to the Alp mountains. The main residential and commercial areas are located in the densely populated so-called Swiss

Central Plateau, between the Jura and the Alps mountain ridges. Compared to the Alps, the Swiss Plateau might be regarded as being rather „flat“, although it cannot be compared to really flat terrain like the central U.S. Therefore, we would expect that differences in the meteorology between Alpine and Swiss Plateau sites are present, and that these differences are the reason for the underprediction in the Alps of the first model version.

We therefore compared hourly met. data from Plateau and Alpine sites. The five stations used to represent the Swiss Plateau cover its entire range. All stations are operated by the Swiss national meteorological service on a regular basis. A wide range of parameters can be obtained with an hourly resolution. The three Alpine stations used are situated in those valleys where the major transit routes are.

Figure 1 shows the distribution of wind speeds. The amount of low wind conditions is roughly the same for Alpine and Swiss Plateau sites. The Alpine sites do experience a somewhat higher amount of high wind episodes caused by Föhn conditions. But the average wind speed of the 5 Plateau and the 3 Alpine sites is very close to each other.

The distribution of the well-known Pasquill-Gifford-Turner stability classes, depicted in **Figure 2**, is very similar as well, a result not expected a priori. As one would expect, the amount of very stable conditions is high in Alpine regions. However, it is equally high in Plateau sites. Very unstable conditions are rarely observed in Switzerland at all.

Mixing heights, shown in **Figure 3**, show no significant difference between Plateau and Alpine sites either. The mixing height is often rather low; inversions occur on a regular basis. This is, however, a common feature of both the Alpine regions and of the Swiss Plateau. In the case of inversions of the temperature profile at ground level, the mixing height is not set at zero, but rather set as the level up to where mixing occurs.

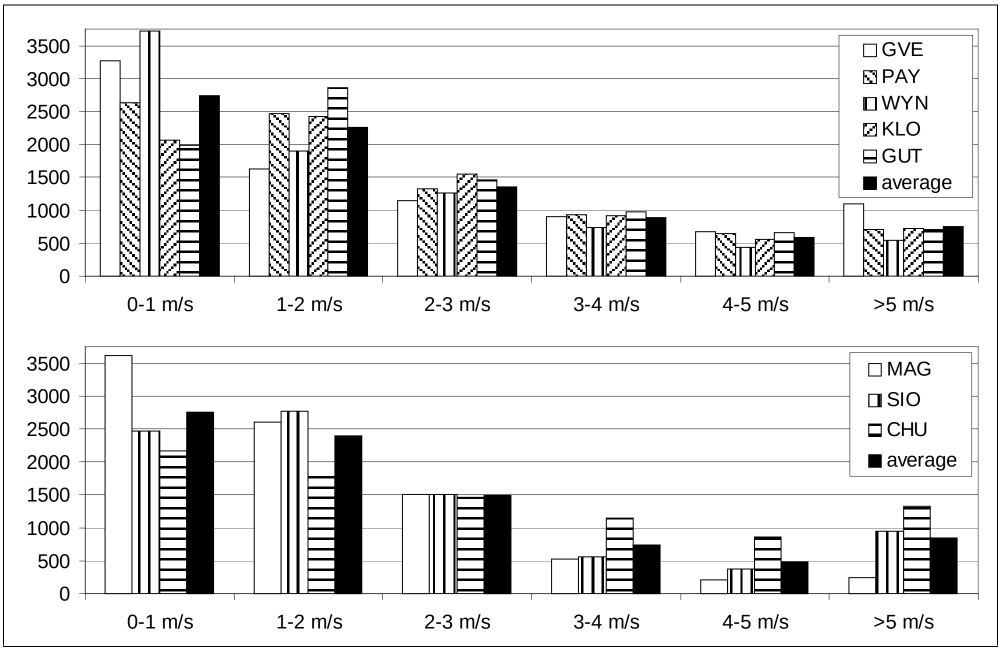

Figure 1. Distribution of hourly wind speed at five Swiss Plateau sites (top) and three Alpine sites (bottom). Data for 1998, 8760 hours.

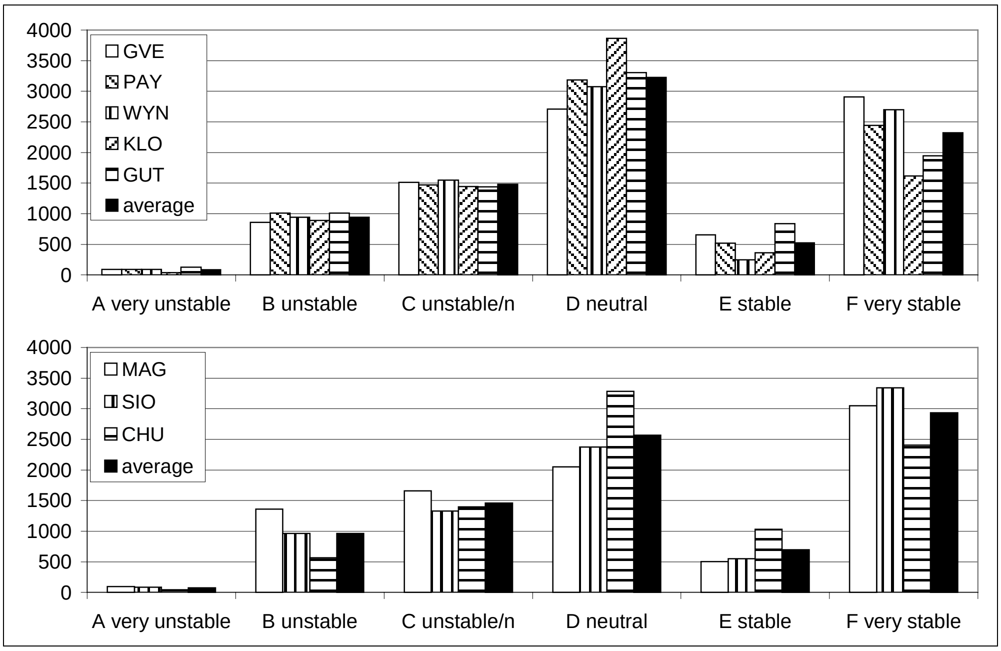

Figure 2. As **Figure 1**, but for PGT stability classes.

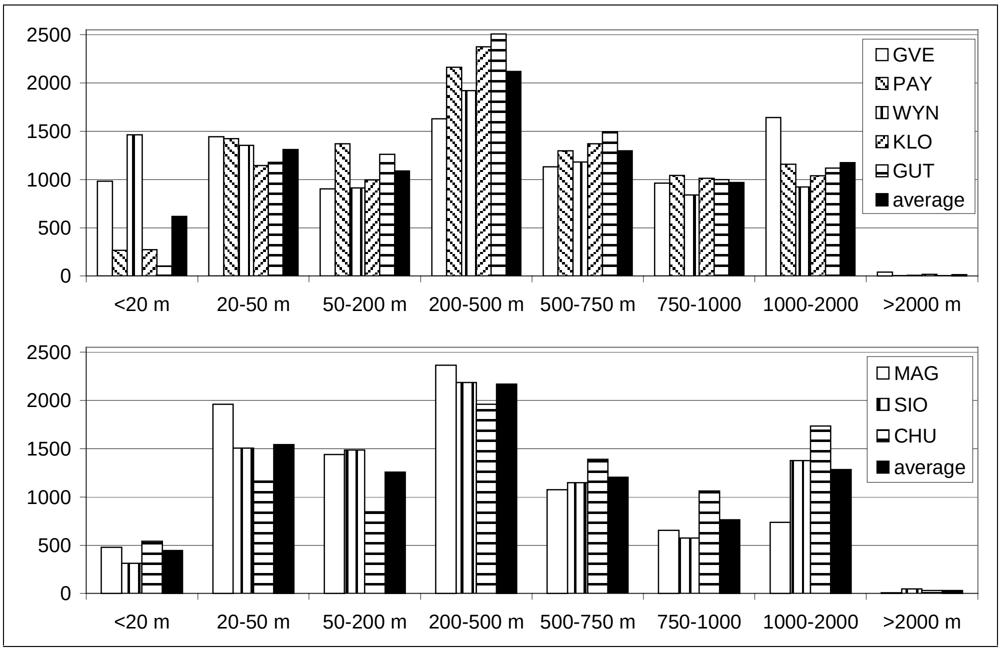

Figure 3. As **Figure 1**, but for mixing height.

COMPUTING DISPERSION MATRICES

A software package has been developed for the computation of dispersion matrices. Such dispersion matrices give the annually averaged concentration impact to each cell of the matrix for a source of unit emission strength, located in the center of the matrix (i.e., the grid). For each type of source (urban, non-urban, ground-level and elevated source, etc.), and for each local dispersion climatology, a different dispersion matrix results.

The Gaussian plume dispersion model being used employs the stability class definitions from the German regulatory model TA-Luft. It assumes homogeneity and heterogenity throughout the modeling domain. Only meteorology for the source location itself is used. The software package enable to compute nested dispersion matrices as well (i.e., a 1 km^2 grid, with a finer 200 m x 200 m grid nested in the center).

A total of six mirror sources are placed beneath the ground and above of the mixing height to preserve mass conservation. To compute the dispersion matrixes, the dispersion of a point source with unit emission strength is computed for a stability class distribution. For 36 different wind flow directions of 10° each, the dispersion is then modeled for different wind speed classes. The dispersion matrices are then computed as the weighted average, and hence give the annually averaged concentration of a unit source.

For medium-range transport distances, the concentration impact at the center of the grid cell is assumed to be representative for the entire grid cell. The local range dispersion in the vicinity of the source location uses a much finer grid spacing within each of the 200 m x 200 m grid cells, in order to obtain the correct cell averaged concentration impact. Different sampling grids for point, line and area sources ensure a correct estimation of the cell-averaged concentration impact even for grid cells in the vicinity of the source location.

RESULTING DISPERSION MATRICES

The main result from the present study is shown in Figure 4 (dispersion matrix for Plateau meteorology) and Figure 5 (Alpine meteorology). The Gaussian model described in the previous section has been used, and all hourly met. data from all sites (i.e., 3 times 8760 hours for the Alpine matrix, and 5 times 8760 hours for the Plateau version). The dispersion matrices correspond to a source emitting 1 ton per year of NO_x. Time series are used to reflect the daily, weekly and seasonal cycle of the emission strength.

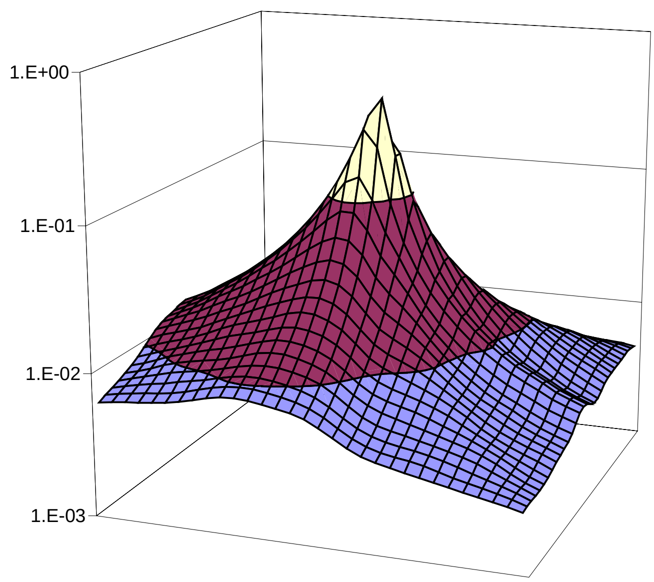

Figure 4: Dispersion matrix with Plateau meteorology for a source located in the center, 20 m above ground (emission: 1 t/a of NO_x). Horizontal axes extend over a square of 6 km by 6 km, each cell is 200 m x 200 m. Vertical axis in µg/m^3.

The main outcome is that no pronounced difference in concentration impact can be seen. Both the near-source peak concentration as well as the decrease of the concentration for increasing distances are comparable. The Alpine matrix is different only because of the more pronounced channeling of the wind directions. This means that for a single point source, the total impact on its surroundings is comparable to a Plateau site. This indicates that the Plateau has to be regarded as a complex terrain region as well. The underprediction of NO_x concentrations in the vicinity of Alpine transit routes, as observed in the first model version, does not occur with the new dispersion matrices anyway. The more pronounced channeling of the wind leads, because of superposition, to higher concentrations in the vicinity of line sources, as long as the line source runs in the same direction as the valley itself.

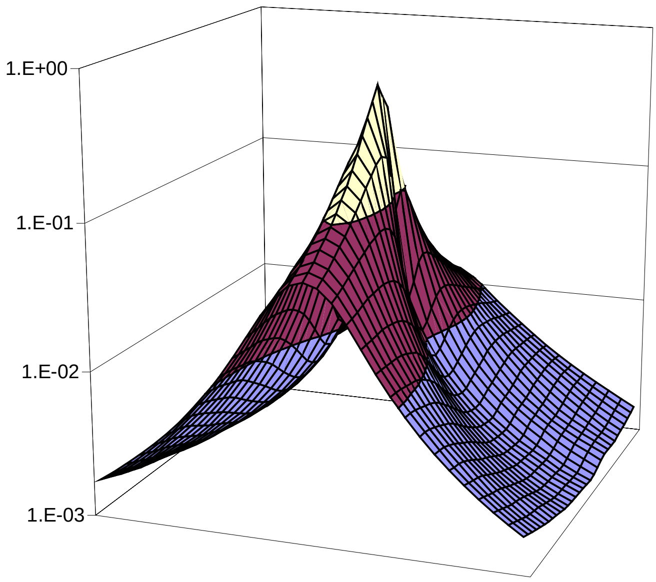

Figure 5: As Figure 4, but for the generic Alpine meteorology.

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