5A.1 PARTICULATE MATTER DISPERSION MODELING IN ALPINE VALLEYS

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1. INTRODUCTION

PM10 (particulate matter with an aerodynamic diameter of less than 10 µm) is a matter of increasing concern. Comprehensive emission inventories and a dispersion model have been developed to predict the Swiss annual PM10 concentrations. The second version of the Swiss PM10 model (de Haan et al. 2000) aims at improving the modeling prediction capability in the Swiss Alps.

The local wind conditions in alpine valleys are often determined either by the topographic forcing of the meso-scale 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 PM10 concentration throughout the country, but PM10 concentrations from transit highway emissions in alpine valleys were 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 applied dispersion model. For local climatologies and each out of a set of several source configurations (traffic line source, elevated stacks, residential heating, etc.), a dispersion matrix is used.

Local climatologies are derived by statistically analyzing the hourly resolved flow field and turbulence parameter predictions from a year-long simulation by the meteorological pre-processor CALMET. The statistical analysis has a weighted set of meteorological classes as main result. The classes result from the combination of the frequency distributions of wind speed and direction, mixing height and PGT stability class. For each local climatology and each source configuration, a Gaussian plume model is then used to compute the concentration impact on every neighboring grid cell from a source with unit strength located in the center of the grid.

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The dispersion model uses annually averaged dispersion matrices (spatial resolution of 200m x 200m up to 4 km away from the source, 4 km2 resolution up to a spatial extension of 200 km), which are applied to each cell of the different emission inventories. Emissions having distinct source heights are grouped into different inventories. The dispersion matrices are derived from a simple dispersion model and reflect the annually averaged ground concentration impact of a point source with specific source characteristics.

As a second result, the statistical analysis of the CALMET flow fields also gives a map of the entire modeling domain indicating whether orographically induced flow fields exist (i.e., whether a valley-induced wind system is present for most of the year), and, if so, what the main wind directions are. Hence for each grid cell this map gives the set of dispersion matrices that is most representative.

2. PARTICULATE MATTER EMISSION INVENTORIES

The method adopted by the Swiss PM10 model is to treat the primary and secondary particles separately. The emissions originating from Switzerland are modeled with emission inventories with a grid spacing of 1 km2,. For the regional background concentration, parameterizations are being used. The traffic emission inventory takes into account PM10 emissions from tailpipe exhaust (mainly from diesel engines), tire wear, brake dust, and resuspension of particles from road surfaces. Other inventories cover industrial processes, agriculture, forestry and domestic activities (heating, gardening, hobby).

To compute the emission inventory for road transport, the total amount of vehicle-km traveled within Switzerland is attributed the major Swiss roads and to zonal traffic within the agglomerations. The emission factors from the newly released version 1.2 of the „Handbook Emission Factors for Road Transport“ (SAEFL 1999) have been used to determine PM10 emissions from tailpipe exhaust (mainly from diesel engines). All tailpipe emissions are assumed to be PM10 (Kerminen 1997). In addition, emission factors have been taken from literature to compute PM10 emissions caused by tire wear, brake dust, and re-suspension of particles from road surfaces.

The other inventories for emissions of primary particles cover the off-road sector, industrial processes and domestic heating. Secondary PM10 components like nitrate, sulfate, ammonia, and organic matter (OM), which are produced in the atmosphere from precursors in the gaseous phase, use inventories for the precursor concentrations of NO2, SO2 and VOC. Regional background contributions are taken from a European-scale model.

3. METHODS OF CONCENTRATION MODELING

Different applied dispersion models are used for primary and secondary particles. The dispersion model for primary particles (spatial resolution of 4 km2) uses annually averaged dispersion matrixes with a spatial extension of up to 200 km, which are applied to each cell of the different emission inventories. The dispersion model used is a Gaussian model using the TA-Luft stability class definition. 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 representative for the climate at the Swiss Plateau, where the vast majority of the PM10 emissions occur. For 36 different wind flow directions of 10° each, the dispersion is then modeled for the yearly averaged wind speed of 2 m s–1. The dispersion matrixes are then computed by averaged by weighting with a wind direction distribution (wind rose) typical for the Swiss Plateau, and hence give the annually averaged concentration of a unit source at the center of every 1 km2 grid cell over an area of 200 km x 200 km.

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.

The local range dispersion in the vicinity of the source location is modeled in the same way, but using a much finer grid spacing of 200 m x 200 m. This nested grid extends over an area of 4 km x 4 km, the corresponding grid center values of the course grid are set to zero.

The above procedure is done for two different source heights: ground-level for traffic sources, and medium-level for chimneys. All emission inventories from Table 1 are modeled using one of these two annually averages dispersion matrices.

In order to model the dispersion of secondary PM10 components like nitrate, sulfate, ammonium, and organic matter, which are produced in the atmosphere from precursors in the gaseous phase, are calculated by using inventories for the precursor concentrations of NO2, SO2 and VOC. NH3 is supposed to be abundantly present in the atmosphere, such that every sulfate and nitrate ion is completely neutralized by ammonium ions.

The corresponding conversion of the gaseous precursors into the secondary aerosols ammonium-nitrate and ammonium-sulfate is parameterized as of function of the concentration of NO2 and SO2 , respectively.

The regional background contribution to the PM10 concentrations in Switzerland is estimated from a European-scale model (ca. 11 µg m–3 on the Swiss Plateau). 1 µg m–3 is added for natural PM10 found in Switzerland (mainly wind-blown desert dust). Biological components are neglected for the annual average.

4. THE CALMET/CALPUFF MODELING SYSTEM

The CALPUFF model (Scire et al. 1997) is a non-steady-state Lagrangian puff dispersion model for pollutant transport simulations under inhomogeneous and non-stationary conditions for periods of one year or more with a one-hour time step. Among its main fields of application are pollutant transport simulations for inhomogeneous and non-stationary conditions. Together with the flow fields of its meteorological model, CALMET, CALPUFF is applicable to complex terrain and coastal situations (Carizi et al. 1998). CALMET is a diagnostic flow field model producing mass consistent and diagnostic 3D flow, temperature and turbulence fields on an hourly basis, based on measurements. Evaluation studies of CALPUFF have been done for long range transport distances as well as short to intermediate distances. CALPUFF has also been extended with a short-range puff-particle approach (de Haan and Rotach 1998) to predict near-source concentration fluctuations (de Haan et al. 1998).

The user-defined grid size allows for high-resolution simulation of episodes as well as for runs of one year or more with a one-hour time step for environmental impact assessments, and studies of air quality and pollutant transport on regional scales. By its puff-based formulation, it can account for a variety of effects such as spatial variability of meteorological and dispersion conditions, causality effects, dry deposition, plume fumigation, low wind speed dispersion, pollutant transformation, wet removal, and complex terrain effects. It has various algorithms for parameterizing dispersion processes, including the use of turbulence-based dispersion coefficients derived from similarity theory or observations.

5. ANALYZING CALMET'S FLOW FIELD AND TURBULENCE PREDICTIONS

The analysis of the flow field and turbulence predictions made by CALMET is done by a specialized software package. It reads in the binary formatted CALMET file and processes its hour-by-hour information for any location specified by the user. The user specifies which meteorological variables are to be classified. The flow field, temperature, etc., are predicted by CALMET on a three-dimensional grid. Turbulence parameters (friction velocity, Obukhov length) as well as mixing heights and the Pasquill-Gifford stability class are given on a two-dimensional grid. The output from the software package are histograms of those meteorological variables. For example, it computes how often (on annual average) wind speed was below 0.5 m/s, between 0.5 and 1 m/s, etc. Together with wind direction, this enables to determine the wind rose for any given location, and can thus be compared to data retrieved from a surface met. station.

Within the present project, the software package has been used to compute the average value and frequency distributions for user-specified class bounds for wind speed and direction, mixing height and PGT stability classes. This leads to a weighted set of classes, each with specific wind speed, direction, mixing height and stability, describing the local climatology. These parameters are the main input parameters to Gaussian plume models. However, the software package also offers the possibility to use generic mean values or generic frequency distributions for any of the above parameters. For cases where the year-long CALMET simulation has been conducted in separate runs, or if a twelve-month period is approximated by a one-month simulation for each of the year's seasons, the software package enables the user to compute statistics over more than one CALMET output file.

The software package also computes the mean (annually averaged) flow direction not only for user-specified locations, but for the entire modeling domain, and produces a map indicating for each grid cell in the domain whether a pronounced flow direction is present (i.e., whether the wind rose shows that orographically induced flow pattern like valley winds persist for most of the year) or not, and gives, if pronounced flow directions are present, the angle (i.e., the mean wind directions) of the wind rose. These maps are being read in by the dispersion model. This way the dispersion model knows which of the sets of dispersion matrices is most representative for each location. The software package also allows for a quality assessment and quality control procedure.

6. COMPUTING DISPERSION MATRICES

Another 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 heterogeneity 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 4 km2 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.

7. OUTLOOK

In the near future, the CALMET flow and turbulence fields will also be used as direct input to the CALPUFF model for the simulation of several point sources configurations situated in the basin of alpine valleys. The same source configuration is then modeled using the applied dispersion model using dispersion matrices, following the procedure outlined in this paper. The comparison of the concentration fields will allow to further validate the performance of the combined CALMET/dispersion matrix approach.

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