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MODELLING DISPERSION OF POLLUTANTS IN LOCAL SCALE FOR REGULATORY PURPOSES WITH A MESOSCALE METEOROLOGICAL MODEL; PART I: SIGNIFICANT WEATHER TYPES CLASSIFICATION

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Abstract: We evaluate an approach of modelling the dispersion of pollutants for regulatory purposes in local scale with a meso-scale meteorological model for representative characteristic weather types. In this first part of the study we focus on classification of characteristic days for which than simulations with a meteorological meso-scale model coupled with a dispersion model can be performed in a very fine resolution. Annual average and annual hourly maximum concentration fields calculated from characteristic days for different classifications are evaluated with the help of simulations performed with a CALMET/CALPUFF modelling system over entire 1 year time period.

Key words: *meteorologicalmeso-scale model, local scale dispersion modelling, clustering, weather types.*

INTRODUCTION

In areas characterized by very complex topography the modelling of pollutant dispersion is extremely challenging due to meso-scale meteorological processes (up- and down-slope winds, thermal heat island circulations, sea breezes, valley channeled winds, temperature inversions), which govern the dispersion of pollutants, but are generally poorly represented by models. Slovenia is characterized not only by complex terrain, but is also located on the southeastern lee side of the Alps, where Alpine barrier blocks westerly and northwesterly flows. Consequently, meteorological situations with weak local winds governing the dispersion of pollutants predominate.

In our study the area of interest is placed over the wider area of Ljubljana basin, a basin in the centre of the country around the capital city of Slovenia. The basin with a bottom at 300 m a.s.l. is almost entirely surrounded by high mountains, reaching and exceeding 2000 m a.s.l. and only towards the SE the hills are lower. So the winds are often – especially during the cool air pool episodes in the basin – rather weak. In (the rather rare) occasions with stronger winds these are strongly orographically modified – with a lot of channellings along the main axes of the basin and along its lateral valleys, with a lot of blockings, etc.. So the reproduction of the reliable 3D wind filed is for this area a very challenging task.

To accurately simulate the dispersion of pollutants for regulatory purposes under such conditions, model must be able to represent the meso-scale meteorological phenomena in complex topography as accurately as possible. When lagrangian type of dispersion models are used for modelling the dispersion of pollutants in local scale, the meteorological conditions (wind field) are usually prepared with a diagnostic wind field model. The problem arises when insufficient number of meteorological measurements is available to accurately reproduce the meteorological conditions with a diagnostic wind field model. In the case of complex terrain and/or geographically diverse area (e.g. combination of urban and rural, or land and sea regions inside domain) and relatively sparse meteorological measurements, that is quite often the case.

In the present study we decided to investigatean approach, where a meteorological meso-scalemodel (e.g. WRF/Chem, Skamarock et al., 2008; Peckham et al., 2008) could be used for local scale dispersion modelling.The advantage of WRF/Chem model is that it includes a state-of-the-art description of physical processes relevant for meteorological meso-scale phenomena, as well as the model enables the assimilation of available meteorological measurements. WRF/Chem model can also be run in a very high spatial resolution (e.g. horizontal resolution up to 100 m).

One of the problems with complex meteorological meso-scale models is that in very high resolution they are generally extremely time consuming. Usually it is not possible to run them in a very fine resolution (e.g. horizontal resolution of 200 meters) for the entire 1 year period (which is the period over which the assessments for regulatory purposes must be made). That is why we decided to study anapproach where simulations with WRF/Chem model are performed only for a number of representative days and results relevant for regulatory purposes are calculated from concentration fields simulated only for representative days. An important part of our study, presented below, was thus to develop and evaluate the procedure for selecting the representative weather types (days) and verify annual average values, daily maximum values and hourly maximum values calculated from representative days.

METHODOLOGY

Characteristic local weather type classification

In classification procedure local weather conditions in Ljubljana basin for every day in time period from January 2005 to March 2011 were represented by wind measurements at Ljubljana station (22 meters above ground level) and hourly stability classes calculated for Ljubljana station. Stability was during the daytime conditions for each day calculated by Bowen method (Bowen et al., 1983), while during the night-time the Pasquill-Turner stability classes were estimated from local measured values of meteorological variables.

Two stage*k*-means clustering algorithms with Euclidean distance used as dissimilarity measure were used in classification procedure. In the first stage of clustering procedure days were classified based on the daily course of stability. Classification in different number of clusters of similar days (4 to 8 final clusters) were performed and used in the second stage clustering. In the second stage clustering the "quasi-trajectory" was calculated for each day from hourly wind measurements performed 22 m above ground level at Ljubljana station, which is the most representative measuring site inside the modelling domain.

Days from each first stage cluster were then further classified into 4 to 8 sub-clusters based on the Euclidean distance calculated between the each day "quasi-trajectory". Consequently, 25 different final classifications were obtained, for which further analyses and comparisons were performed. As the most representative day of each cluster was chosen a day with the shortest distance from cluster centroid, where cluster centroid was calculated as average over all days classified into this cluster.

Validation of approach based on representative days

To study the suitability of characteristic weather type approach, where annual concentration fields are calculated from concentration fields simulated only for characteristic/representative days, we performed simulations with a CALMET/CALPUFF (Scire et al., 2000a) modelling system for entire 1 year time period (from April 2010 to March 2011). Annual average and maximum hourly concentration fields for all 25 classifications were then calculated both from characteristic days and from results for entire period. The reason why CALMET/CALPUFF instead of WRF/Chem was used in this stage (for evaluation of significant weather types approach), is that CALMET/CALPUFF modelling system is significantly less time consuming. CALMET/CALPUFF consists of a diagnostic mass-consistent meteorological CALMET model, and CALPUFF air quality dispersion model, proposed by US EPA as a guideline model for regulatory applications involving situations where factors such as spatial variability in the meteorological fields, calm winds, fumigation, recirculation or stagnation and terrain or coastal effects may be important.

Model configuration

CALMET/CALPUFF simulations were performed in domain with 125x125 horizontal points and 200 m horizontal resolution (Fig. 1). For the diagnostic wind field calculations in CALMET meteorological measurements at stations S1, S2 and S3, and measurements from one radiosounding site (Fig. 1) were used. Vertical atmosphere structure was represented by 25 vertical levels from 0 to 4000 m altitude and near the ground vertical resolution of 20 m. Characteristics of point source are presented in Tab. 1. Concentration fields of SO_2, NO_x, NO_2 and PM10 were simulated, but only results for SO_2 are presented.

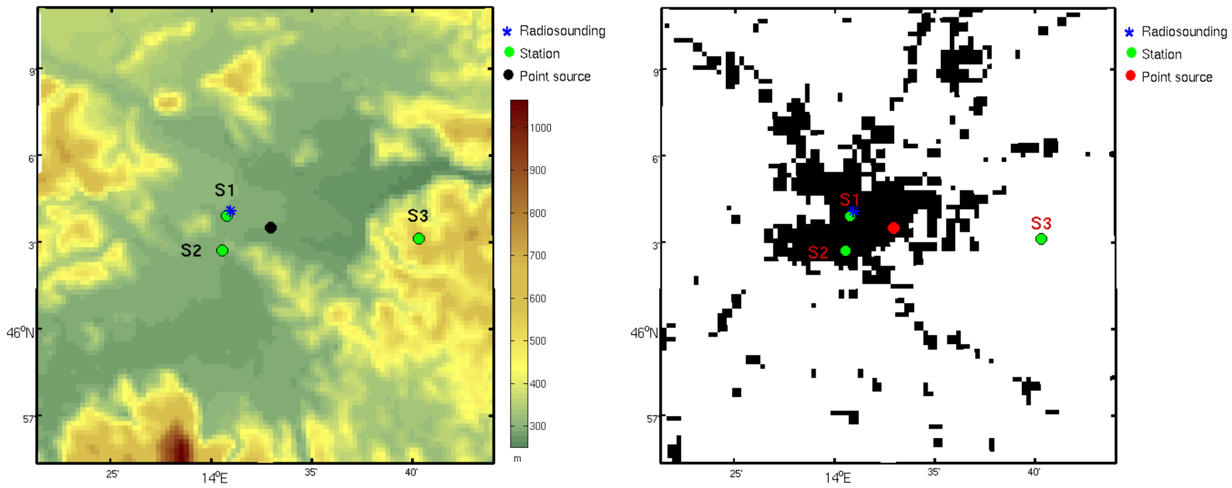

Figure 1: Topography (left) and urban land cover category (right) indicating location of Ljubljana urban area in modelling domain. Shown are locations of three monitoring sites, radiosounding measuring site and point source location.

Table 1: Point source characteristics.

Latitude	Longitude	Stack height	Stack diameter	Velocity	Temperature	SO_2 mass flow
46.05833 ºN	14.5495 ºE	100 m	6 m	2.8 ms^{-1}	401 K	54.4 kgh^{-1}

RESULTS

With the first stage clustering procedures days were classified in clusters with similar daily courses of stability. Example of cluster mean stability courses (stability courses for cluster centroids) are for the first stage classification in N_{stab}= 4 and N_{stab}= 8 clusters shown in Fig. 2. In both classifications the most numerous cluster is cluster with the most stable days (neutral conditions between approximately 9 a.m. and 16 p.m., and very stable conditions otherwise), confirming frequent meteorological conditions with weak local winds. When each of these first stage clusters is then further classified into subclusters by the daily courses of measured wind speed and direction, we finally have clusters of days with similar daily stability course and similar wind characteristics (similar prevailing wind speed and direction). Example of wind trajectories for days included in each cluster is shown in Fig.3 for classification with N_{stab}=4 stability clusters and N_{traj}=8 trajectory subclusters (altogether 4x8=32 final clusters of similar days). After the classification procedures are performed for each final cluster (each subcluster) the most representative day can be chosen. In our case as the most representative day was selected a day with the minimum distance form cluster centroid, where distance was calculated as mean of Euclidean distances from cluster centroid for daily stability course and for measured wind trajectory. The question now arises if with these representative days we are able to estimate annual concentration fields required for regulatory purposes.

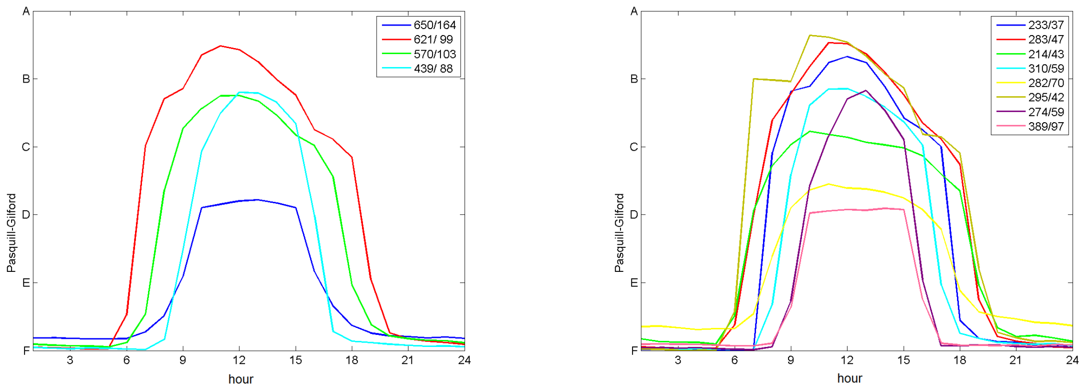

Figure 2: Average daily stability courses (in Pasquill-Guilford classes) for clusters of similar days, calculated with first stage classification in 4 (left) and 8 (right) stability clusters. In legend number of days in each stability cluster from entire classification period (January 2005 – March 2011) and from 1 year time period (April 2010 – March 2011) is shown.

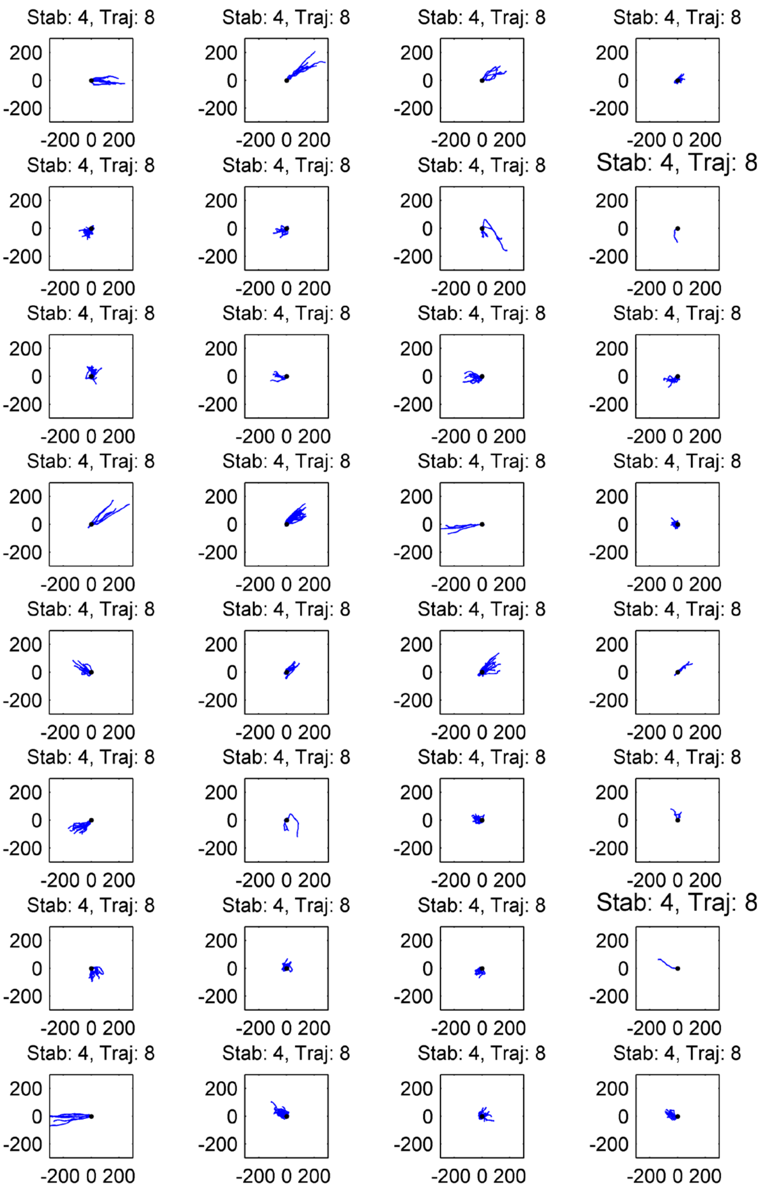

Figure 3: Quasi-trajectories in 200 km x 200 km domain for all cluster days, example is shown for classification with 32 final clusters, obtained with first stage classification in 4 stability clusters (N_{stab}=4) and second stage classification in 8 wind trajectory subclusters (N_{traj}=8).

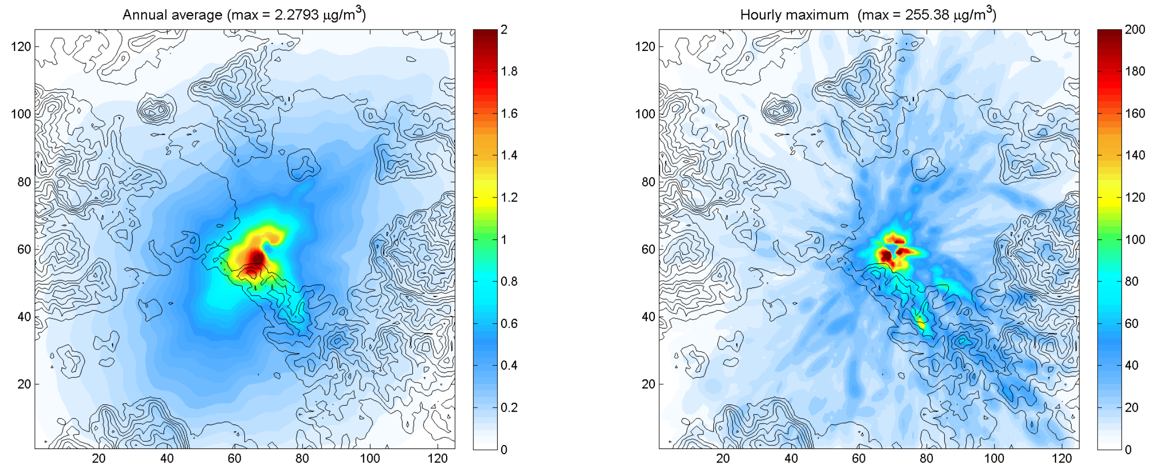

Figure 4: Annual average and hourly maximum SO2 concentration field calculated from model results simulated over entire 1 year period.

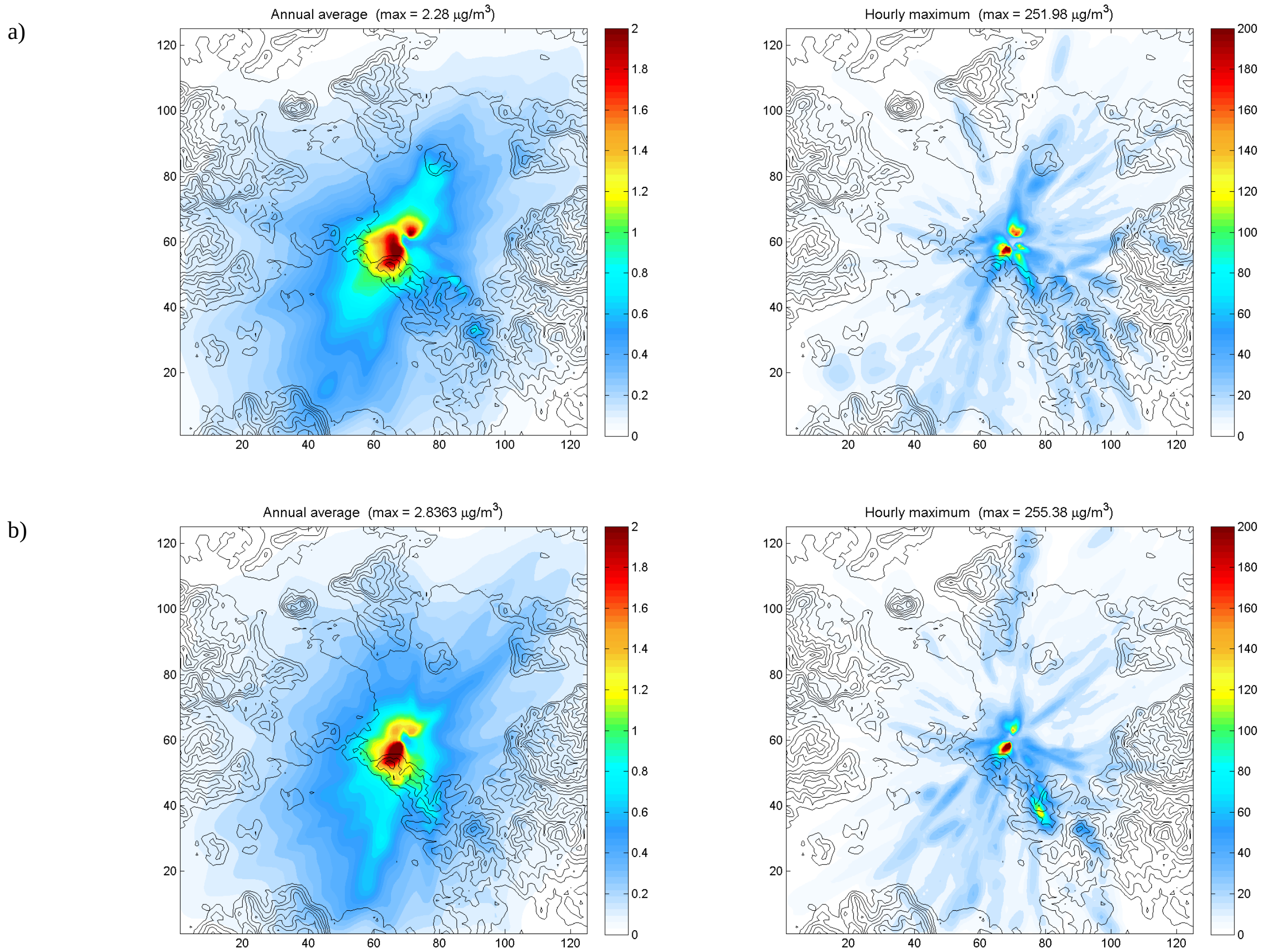

Figure 5: Annual average and hourly maximum SO_2 concentrations fields calculated from representative days for two different classifications in 32 final clusters: a) N_{stab}=4, N_{traj}=8 , b) N_{stab}=8, N_{traj}=4.

Figure 4 shows annual average and hourly maximum concentration field for SO2 calculated from CALMET/CALPUFF simulation results performed for entire 1 year time period – these concentration fields are thus supposed to present "the exact results" for the purpose of our study. For two different classification in 32 clusters (Nstab=4, Ntraj=8 and Nstab=8, Ntraj=4) these two concentration fields are for the same 1 year time period calculated from representative days, where simulation results for representative days are weighted with the factor representing cluster frequency in the analysed 1 year time period.

For classifications in different final number of clusters results for maxima in annual average and hourly maximum field are compared in Tab. 2 and 3. These results show that if approach with representative days was used the maximum in field of hourly maxima concentrations was either detected, or at least the maximum in hourly maximum field was very close to the "true maximum" (Tab. 2). There was only one classification with a slightly larger deviation from exact maximum of hourly concentration field (230 μgm^{-3} compared to exact value of 255 μgm^{-3}). Nevertheless, the comparison of results for hourly maxima in Fig.4 and 5 shows, that areas of the highest hourly values are reduced if approach with representative days is used, which was expected, because variability inside clusters of similar days is lost if only representative days are taken into account.

The comparison of annual average concentration fields for two classifications in 32 final clusters in Fig. 5 show quite a good agreement with the "truth" presented in Fig.4. Nevertheless, this cannot be concluded in advance for all classifications, which is obvious also from results shown in Tab. 3, where maxima in annual average concentration fields are compared with the exact value. In some classifications deviation in maxima of annual average can be as high as 1 μgm^{-3}, but still for the majority of classifications results obtained from representative days are close to the exact value.

Table 2: Maximum value (in μgm^{-3}) of annual average concentration field for SO_2, calculated for different local weather type classifications. N_{stab} – number of first stage classification clusters calculated from daily stability courses. N_{traj} – number of second stage classification subclusters calculated from daily "quasi-trajectories" for each stability cluster. Exact maximum value of SO_2 annual average in this case is 255 μgm^{-3}.

$N_{stab}\backslash N_{traj}$	4	5	6	7	8
4	255	255	255	252	252
5	255	252	252	252	255
6	255	255	255	252	255
7	255	255	252	252	252
8	255	255	230	252	252

Table 3: Maximum value (in μgm^{-3}) of hourly maximum concentration field for SO_2, calculated for different local weather type classifications. N_{stab} – number of clusters from first stage classification calculated from daily stability courses. N_{traj} – number of second stage classification subclusters calculated from daily "quasi-trajectories" for each stability cluster. Exact maximum value of SO_2 hourly maximum in this case is 2.28 μgm^{-3}.

$N_{stab}\backslash N_{traj}$	4	5	6	7	8
4	2.66	3.64	2.38	2.00	2.28
5	1.76	2.20	1.60	1.81	2.47
6	1.78	2.15	2.50	3.03	2.63
7	3.28	2.72	2.34	2.55	3.24
8	2.84	2.95	2.26	2.69	3.18

CONCLUSIONS

Results of our study show that approach with modelling the dispersion of pollutants for regulatory purposes with representative days can under certain conditions be useful and accurate enough. First, the appropriate clustering procedures with appropriate meteorological data which enable the classification into representative clusters of days with similar local meteorological conditions must be applied. And second, even when the clustering procedures with representative meteorological data are carefully applied, the selection of the final number of clusters plays an important role. In our case classifications with 32 clusters gave reasonable results, as did also some (but not all) classifications with lower (and higher) number of final clusters.

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