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MODELLING DISPERSION OF AIR POLLUTANTS OVER THE AREA OF DIVERSIFIED RELIEF BASED ON THE CALMET/CALPUFF MODEL

The results of simulations performed using the multi-layer, non-stationary CALMET/CALPUFF model of dispersing air pollutants in the areas of diversified relief for variable meteorological field are presented. The research was carried out in the Bielsko-Biała region, taking into account the real relief of the area. The calculations and their analyses have shown that relief may significantly influence simulation results.

1. INTRODUCTION

The task of modelling the dispersion of pollutants in the air over the areas of diversified relief is particularly difficult. First of all, this is a result of variable meteorological conditions usually prevailing in such areas: varying wind direction and speed, as well as air temperature [1]. These factors significantly influence the transport of pollutants in the air. Simulations of pollutant concentrations performed according to the Gaussian plume model formally recognized in Poland may not yield correct immission values due to the oversimplifying assumptions of a flat area and homogeneous meteorological conditions. Therefore other pollutant propagation models that would take into account variable meteorological conditions are necessary. The Gaussian puff model is one of such models [2], [3].

The concept of the Gaussian puff models consists in splitting the pollutants emitted into smaller portions capable of moving independently according to local meteorological conditions. As a result, air pollutant may be described more accurately. It may be particularly significant when relief of the area involved is complicated, especially when wind – one of the most important factors contributing to the transport of pollut-

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ants – meets the area obstacles like hills or mountains.

2. GAUSSIAN PUFF MODELS

The Calpuff model used in our simulations takes into account the influence a diversified relief may exert on the transport and dispersion of pollutant puffs. The wind field is determined using the Calmet meteorological pre-processor that transports pollutant puffs over the area surface, not changing their altitude. The Calpuff model has several options of taking a diversified relief into account, including an option to perform simulations over flat surfaces. The most important options include: the ISC obstacle resolving method (to remove the area obstacles like hills and mountains, thus facilitating unobstructed movement of pollution puffs), and the "partial plume" method (to account for variable altitude of the area in the path of travelling puffs). The altitude H_p of the puff center point over a hill is given by:

$$H_p = H_{po} \cdot C ,$$

where:

H_p – the altitude of the puff center point over the receptor,

H_{po} – the altitude of the puff center point after an "initial" uplift,

C – the correction factor (0.35 for a stable atmosphere, 0.5 for all other atmosphere states).

CALPUFF is the most advanced option of obstacle resolving. Parameters taken into account include the size of travelling puffs, the altitude of travelling puffs, and interactions of travelling puffs with obstacles that depend on the given obstacle slope angle [4], [5].

3. SIMULATION INPUT DATA

The simulations are based on U.S. Geological Survey data on relief and the area utilization [6]. They covered a 40×40 km area (grid) at a 1×1 km resolution (grid mesh). Meteorological data was supplied by the ground stations in Katowice (12560) and Kraków (12566), and the aerologic station in Warsaw/Legionowo.

A power plant chimney located in Bielsko-Biała (coordinates of 360.3, 5518.1) was the emission source. A 100 m tall chimney is based 420 m asl (above sea level), and its diameter (at the outlet) is 2.0 m. Flue gas velocity was taken as 5.0 m/s; flue gas temperature as 373 K. Sulfur propagation was simulated at a constant sulfur emission of 360 kg/h.

A mixed relief was selected for simulations: flat area in the upper part of the simulation grid, mountains in the bottom part. Altitudes within the flat portion of the area varied from 231 to 287 m asl, whereas altitudes within the mountain portion varied from 343 to 818 m asl. Additionally, two of the mountain ranges in the mountain region were separated by a deep valley, several kilometers wide. A map of the area and two vertical cuts along the 5540.5 coordinate (flat region) and the 5514.5 coordinate (mountains) are shown in figure 1. Calculations have been performed based on the meteorological data for a period of 744 hours in March 2005.

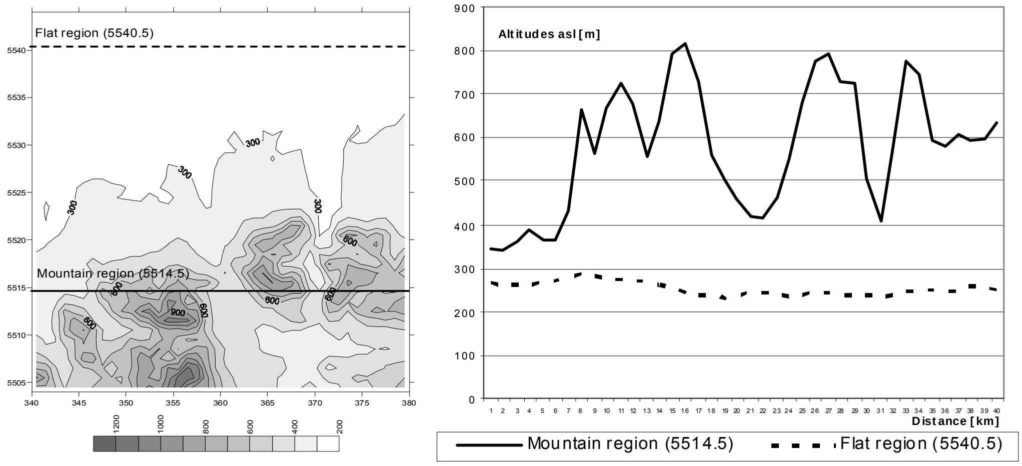

Fig. 1. The area selected for simulations. The solid line is a vertical cut along the line shown at the bottom of the contour map to the left (mountains). The dashed line is a vertical cut along the line shown at the top of the map (flat terrain)

Pollutant dispersion was simulated for both types of relief indicated in the simulation area map (5514.5 coordinate – mountains, and 5540.5 coordinate – flat area). The maximum one-hour SO_2 concentrations calculated using various options of the Gaussian plume model are shown in figure 2.

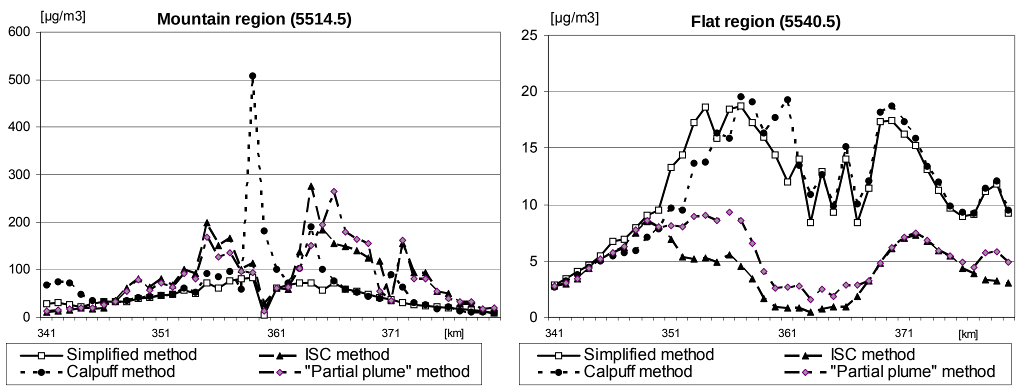

Fig. 2. Maximum one-hour SO_2 concentration along the 5514.5 line routed through the mountain region of the simulation area (left) and along the 5540.5 line routed through the flat region of the area (right). Concentration calculated based on various model options is expressed in μg/m^3

Statistics of the data plotted in figure 2 is presented in the table. For the sake of comparison, the data calculated using the simplified method are also shown.

Table

Statistics of one-hour SO_2 concentration data calculated using the simplified dispersion model and various options of the Gaussian plume model (μg/m^3)

Concentration	Simplified method*	ISC method	"Partial plume" method	Calpuff method
Mountains (5514.5)				
Minimum	4.3	10.1	12.5	8.0
Maximum	83.4	276.7	265.1	508.9
Average	42.8	85.6	80.8	71.0
Standard deviation	21.6	62.4	60.8	81.3
Flat area (5540.5)				
Minimum	2.8	0.5	1.6	2.7
Maximum	18.7	8.4	9.3	19.6
Average	11.6	4.2	5.5	11.6
Standard deviation	4.5	2.3	2.3	4.9

* Relief is not taken into account.

4. RESULTS

The analysis of the simulation results obtained yields the conclusion that relief clearly influences SO_2 concentration levels. Maximum concentration simulated for the mountain region varied significantly, depending on the model used. The greatest concentration differences were obtained for simulations performed according to the Calpuff method for the mountain region. Maximum SO_2 concentration (508.9 μg/m^3) was obtained for a narrow valley between two high mountain ranges. The results obtained using other methods did not indicate any concentrations as high. On the contrary, the values of SO_2 concentration calculated for the regions inside the valley were clearly lower than the values calculated for the regions outside the valley. For the mountain region, the greatest differences in results were observed between the Calpuff method and the ISC/partial plume method. A characteristic feature of the latter results is high SO_2 concentration in the vicinity of hill peaks. Maximum concentrations simulated by means of the simplified method (any terrain relief is not taken into account) were several times lower than the results obtained using other methods.

For the flat area, the results obtained using the simplified method strongly correlate with those obtained using the Calpuff method (0.90 correlation coefficient). Both the highest and the lowest concentrations appeared at similar points, and the average values were identical (11.6 $\mu g/m^3$). However, the maximum and average concentrations obtained using the two other methods were clearly too low, as they did not reach 50% of the values simulated using the Calpuff method or the simplified method. This result raises doubts about the reliability of the ISC and the "partial plume" methods. This concern is only intensified by the fact that in principle every method should yield similar results in simulations regarding a flat area. A clear similarity exists between the results produced by the ISC and the "partial plume" methods, regardless of the relief. The correlation coefficients calculated on the basis of 40 values amounted to 0.87 (mountains) and 0.82 (flat area).

The above analysis yields the conclusion that relief may significantly influence simulation results. The task of modelling dispersion of pollutants in the air over the area of diversified relief turns out to be very difficult. The results obtained may be quite different, depending on the model applied. It seems that further studies are needed to develop a proper methodology of simulating dispersion of air pollutants over the area of diversified relief.

BIBLIOGRAPHY

[1] ZWOŹDZIAK J., ZWOŹDZIAK A., SZCZUREK A., *Meteorologia w ochronie atmosfery*, Wrocław, Oficyna Wydawnicza Politechniki Wrocławskiej, 1998.

[2] MARKIEWICZ M.T., *Podstawy modelowania rozprzestrzeniania się zanieczyszczeń w powietrzu atmosferycznym*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2004.

[3] SZCZYGŁOWSKI P., MAZUR M., *Zastosowanie modelu Calmet/Calpuff do obliczeń poziomu stężeń zanieczyszczeń pochodzących z wysokich emitorów punktowych*, Inżynieria Środowiska, 2005, t. 10, z. 2, 195–205.

[4] Environmental Protection Agency, 2000, *A User's Guide for the CALPUFF Dispersion Model*.

[5] Environmental Protection Agency, 1995. *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models*, Volumes I–III.

[6] http://edc.usgs.gov/

MODELOWANIE ROZPRZESTRZENIANIA SIĘ ZANIECZYSZCZEŃ W POWIETRZU WEDŁUG MODELU CALMET/CALPUFF W WARUNKACH ZRÓŻNICOWANEJ RZEŹBY TERENU

Podano wyniki obliczeń przestrzennego rozkładu zanieczyszczeń w warunkach zmiennego pola meteorologicznego i zróżnicowanej rzeźby terenu przeprowadzonych z wykorzystaniem wielowarstwowego, niestacjonarnego modelu Calmet/Calpuff. Badania wykonano dla rejonu Bielska-Białej, uwzględniając rzeczywiste ukształtowanie terenu. Na podstawie przeprowadzonych obliczeń i analiz stwierdzono, że ukształtowanie terenu znacząco wpływa na wyniki modelowania.