Dispersion Modelling of Cross-Border Air Pollution Transportation in the European Black Triangle

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Abstract: A sensitivity study, where emission characteristics were changed, was conducted on seasonal average concentrations at individual monitoring locations over the complex Krusne Hory (Czech) or Erzgebirge (German) mountain area in the so called European Black Triangle. CALPUFF air dispersion model is used as a tool for simulating air pollution transportion. Several large brown coal-fired power plants in the valley, adjacent to the Krusne Hory, are key sources of sulfur dioxide, nitrogen oxides and particulate matters. Climatology of the air pollution was described by comparing the modelled results, obtained from using upper air data from Prague and Dresden and surface meteorological input from 8 stations on both sides of the border, with real observations at the same surface stations, during the year 1995-1996. High sulfur dioxide episodes on the mountain plateau, recorded by air monitoring stations, were reasonably predicted by the model. The modelled results allow distinctions to be made between seasonal areal distributions of sulfur dioxide in the mountain region. Adjustment to physical stack heights, exit temperatures and exit velocities of the emission sources change the modelled air pollution concentrations significantly.

Keywords: Air dispersion modelling; European Black Triangle; Power plant emission

1. INTRODUCTION

Krusne Hory (Czech) or Erzgebirge (German) is a mountain range located in the so-called European Black Triangle region, the most polluted part of Central Europe. The range lies in a southwest to northeast direction along the Czech-German border (Figure 1). The southern edge is much steeper (300-800m within 10km) than the northern side. The steep slope overlooks a valley where large air pollution sources (brown coal-fired power plants and other industries) are situated. Air pollution has been recorded as a major problem in the area for decades as described by Materna [1989]. Here we focus on the major pollutant, sulfur dioxide (SO_2).

The aim of this study is to employ a modelling system which performed satisfactorily with respect to the field observations – a challenge in an area of such complex terrain. This would then allow an assessment of SO_2 concentrations over the whole mountain range. SO_2 was chosen as the object in this study because the extensive damage to conifer trees were accounted as an effect of it [Kubikova, 1991]. Finally, the model was used to examine the impact from altering some emission characteristics, such as physical stack heights, exit temperatures and exit velocities of the flue gas.

2. AIR POLLUTION DATA AND EMISSION SOURCES

Air pollution monitoring stations were set up on both sides of the border in order to detect air quality improvements following emission controls in the 1990s [Czech Republic Ministry of Environment and German Ministry of Environment, 1998]. For this research, air pollution data were acquired from 8 stations, Flaje, Rudolice, Medenec and Tusimice on the Czech side, and Annaberg, Fichtelberg, Olbernhau and Zinnwald on the German side of the border. (Figure.1).

Characteristics of the 5 major emission sources (incorporating 9 separate units) in the valley, which are considered in this modelling study, are shown in Table 1. In 1995, more than 50,000 tonnes of SO_2 was emitted from each power plant,

Table 1. Power Plants physical characteristics. (Stack height and temperature data are available directly from Prunerov and Pocerady Power Plants; estimates for the other stacks were made on the basis of observations and other reports)

Power plant	Size (MW)	Stack height (m)	Average exit temperature (°C)	Stack Diameter (m)	FGD installation
Chemopetrol	240	100	84.15	3	None
Prunerov I	440	200	84.15	10	Dec 1995
Prunerov II	1050	300	84.15	10	Aug 1996
Tusimice I	330	196	157.55	10	after study
Tusimice II	800	300	157.55	10	Jun 1997
Ledvice I	200	200	157.55	10	None
Ledvice II	330	200	157.55	10	Autumn 1996
Pocerady I	600	200	61.94	10	1996
Pocerady II	400	220	61.94	10	Autumn 1994

except at Chemopetrol and Ledvice which emitted 30,000-50,000 tonnes. Nitrogen oxides emissions were only one tenth of SO_2 and dust emissions were about one tenth those of nitrogen oxides. Emissions of all pollutants started to decrease in 1996 after the fitting of controls; Flue-Gas Desulfurisation (FGD) for SO_2, electrostatic precipitators and ash scrubbers for dust and nitrogen oxides.

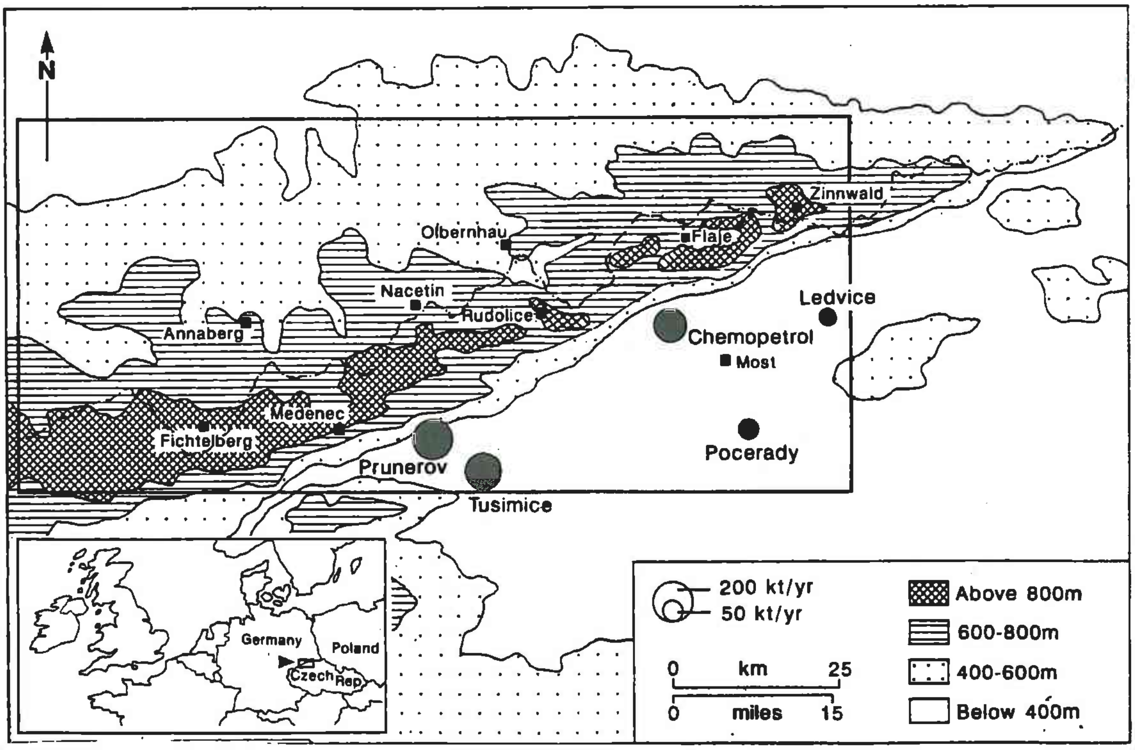

Figure 1. Map of the study area showing locations of 5 key emission sources (circles are proportional to annual SO_2 emission) and monitoring stations (The heavy-lined box is the model receptor area).

Power plant emissions vary seasonally. In fact, some power plant units were shut down during a few summer months due to lower demand. In this work, the emissions were kept constant for modelling purposes. This had the effect of allowing an assessment of the effect of seasonal variations in meteorological conditions on SO_2 concentrations in the mountain range.

In the modelling work, described below, we changed some emission source characteristics to examine if ambient concentrations over Krusne Hory would be significantly affected.

3. MODELLING

CALPUFF, developed by Scire et al. [1990a, 1990b], is a generalised non-steady-state air modeling system which is available from webpage of Earth Tech Inc.[1]. It is chosen as the main tool because of several advantages.

Firstly, it caters for complex terrain, unlike many air dispersion models. Secondly, it has wet and dry deposition and chemical transformation schemes. This makes it possible to investigate a number of key questions, such as the character of the distribution pattern of the air pollution over this complex mountainous area.

CALPUFF comprises 2 main components; a meteorological model, CALMET, and a puff-dispersion model, CALPUFF. We will discuss them in some details.

3.1 CALMET

Fourteen layers of diagnostic meteorological fields (hourly wind and temperature) were simulated, using the divergence minimization method of Goodin et al. [1980], and two-dimensional fields of mixing height, surface characteristics and dispersion properties were generated on 140 x 60 square kilometres grid.

The input surface meteorological data were from 3 stations (Annaberg, Olbernhau and Most; Figure 1) or 5 stations (Annaberg, Olbernhau, Fichtelberg, Most and Nacetin; Figure 1), subject to data availability. Upper air data from Prague (80 km SE of the valley) and Dresden (40 km NE of the valley) were utilised. The cell face heights are at 0, 20, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100, 1200 and 1300 metres above ground level (terrain-following coordinates) for meteorological field simulation in summer months (JJAS) and are at 0, 20, 50, 100, 200, 300, 400, 500, 600, 700, 800, 900, 1000, 1100 and 1200 metres for those in winter months (NDJF).

3.2 CALPUFF

For all runs, we used an hourly timestep and turned on options in CALPUFF, such as partial plume path adjustment and transitional plume rise. Only the physical characteristics of emission sources were changed between runs (see below).

There were constant emissions of SO_2, NO_2 and particulate matter, of which values were extrapolated from Prunerov and Pocerady power plants. This was done by weighting the emissions by size of the power plants.

The chemical scheme used is RIVAD ARM-3 of Morris et al. [1988] which is best suited to non-urban areas. The dry deposition processes were in gaseous phases for SO_2, NO and NO_2, while sulfate, nitrate and PM10 were deposited as particles.

3.3 Characteristics of Emission Sources

Key characteristics of the stacks for modelling considerations are: stack height, stack diameter, exit velocity and exit temperature. In modelling, the exit velocity is assumed to be 8 to 10 m/s according to the temperature of flue gas indicated by the Prunerov boiler house records (125-200°C). The exit temperature at the top of the stacks is estimated to be lower by 20°C.

4. RESULTS AND DISCUSSION

Here we evaluate how well CALPUFF can simulate SO_2 in this complex and highly polluted environment. There are occasions when the model predicts episodes well. An example is shown for SO_2 at Rudolice (Figure 2).

In the early morning of January 11, 1996, the model predicted peak concentration at the right time, 04:00hrs, but with higher magnitude (2500 $\mu g/m^3$, compared to the observed 1300 $\mu g/m^3$). A drop in wind speed and a marked lowering in mixing height coincided with the start of the episode. Wind direction was southerly, indicating transport from the valley.

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[1] www.src.com/calpuff/calpuff1.htm

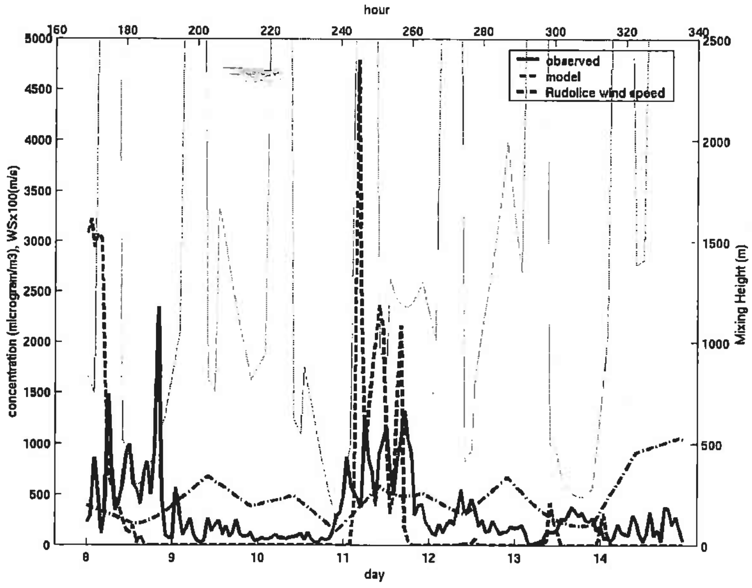

Figure 2. Time series plot of observed and modelled hourly SO_2 concentrations at Rudolice for 04:00 January 8 to 03:00 of January 14, 1996. Also shown are wind speed and mixing height (lightest line).

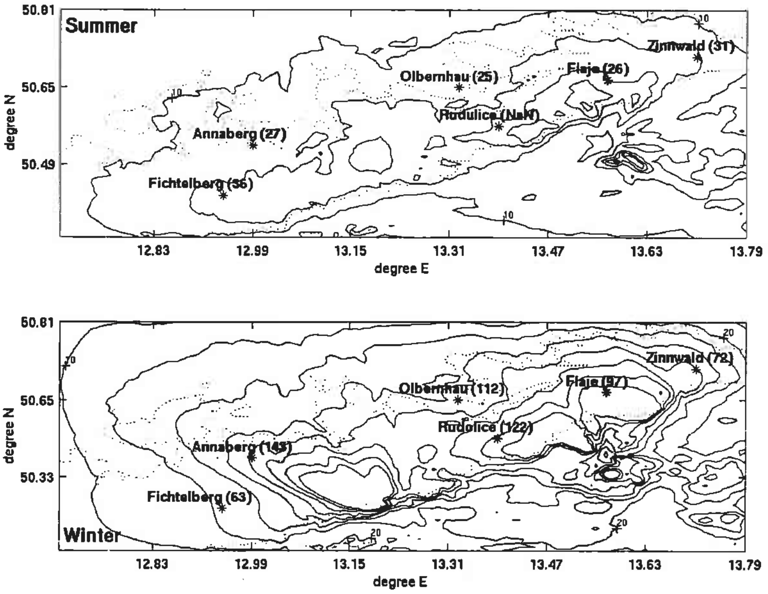

Figure 3. Modelled seasonal average of SO_2 isopleths (interval 10 $\mu g/m^3$) for the summer (upper) and winter (lower). The outer isopleth in each plot is 10 $\mu g/m^3$; the highest values in the vicinity of Flaje in summer is 50 $\mu g/m^3$, in winter is 80 $\mu g/m^3$. The values in brackets after the station names represent observed values. The dotted line represents the 600 m contour. ("NaN" refers that the data is not available during the period)

Averaging over longer time scales, the model results are generally satisfactory. Figure 3 shows the distribution of SO_2 for summer (JJAS) and winter (NDJF). In summer, we see that the modelled SO_2 concentrations are within range of the observations. For example, at Flaje, the modelled concentration distribution lies between the 20 $\mu g/m^3$ and 30 $\mu g/m^3$ isopleths while the observed value is 26 $\mu g/m^3$. This is seen as an acceptable performance.

The concentration pattern in winter is different to that of summer, with higher concentrations on the mountain ridge (Figure 3). The model performance is less satisfactory in winter, with underpredictions at all stations. For example, the observed concentration at Flaje was 97 *µg/m³* while the model predicted between 50-60 *µg/m³*.

Figure 4 summarises the winter and summer model performance for Flaje and Annaberg. The underprediction at Annaberg is particularly pronounced in winter. The middle bar, in all 4 plots indicates that, if exit velocities are reduced by 5 m/s and exit temperatures are lowered by 50°C, the model predictions are better in winter at Flaje and better in summer at Annaberg. The Flaje summer concentration is overpredicted. The 4th bar in all plots shows that increasing all stack heights by 50 m slightly reduces the concentrations. Increasing the temperature by 50°C and the exit velocity by 5 m/s (5th bar in all plots) reduces the modelled concentration further.

The underprediction for all seasons, and all trial adjustments, may suggest additional sources near Annaberg. For example, the report of Czech Republic and German Ministries for the Environment [1998] suggests that the power plants in Chemnitz, a city situated about 20 km. to the north of Annaberg, might also contribute as SO_2 sources. It is also suspected that domestic and traffic emissions could be significant in this area. We intend to take area sources into account in future runs of CALPUFF.

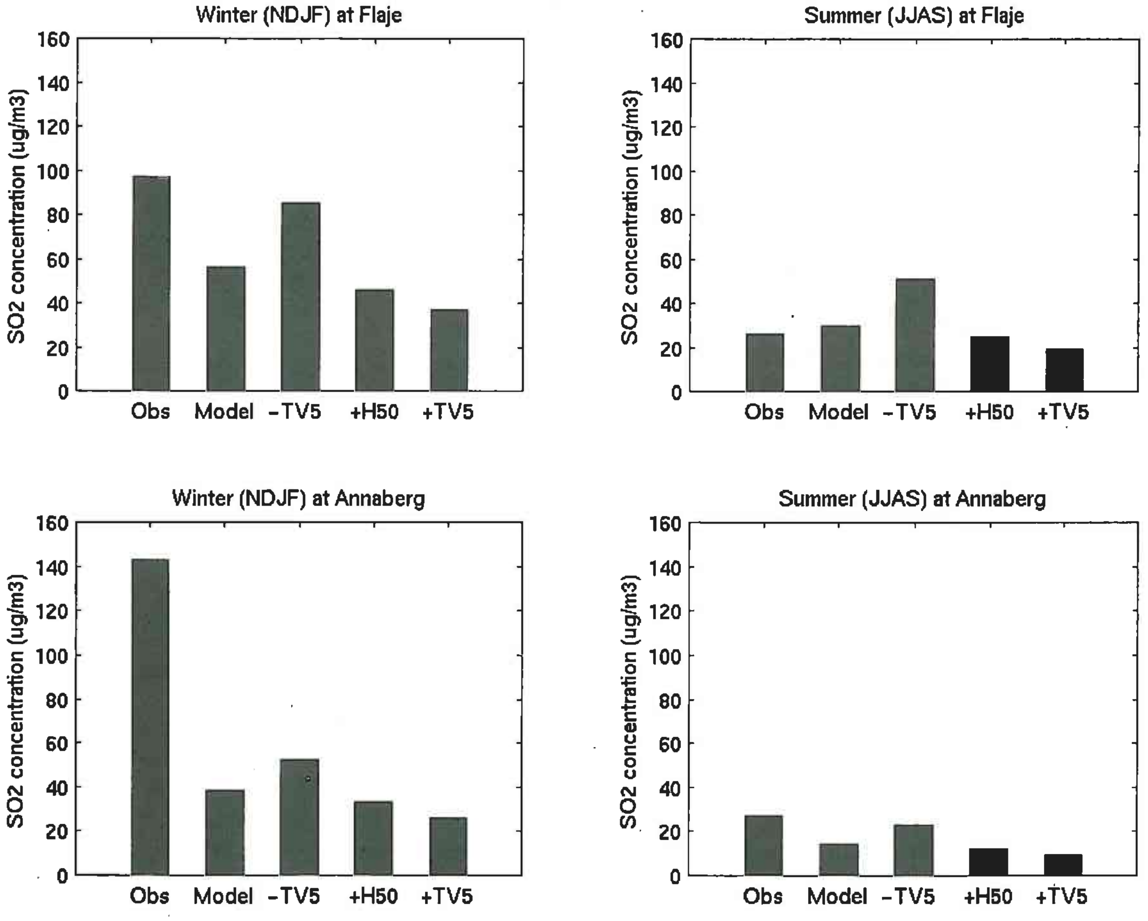

Figure 4. Bar plot of seasonal averaged SO_2 concentrations at Flaje and Annaberg comparing observations (Obs) with modelled results when using real stack characteristics (Model); reducing exit temperature by 50°C and velocity by 5 m/s (-TV5); increasing stack height by 50 m (+H50); and increasing exit temperature by 50°C and velocity by 5 m/s (+TV5).

5. CONCLUSION

With constant emission from the major point sources, the CALPUFF model shows markedly different SO_2 distribution patterns over the mountain in summer and winter. Underprediction in winter for all stations, especially in Germany, suggests additional contributions from sources other than the major power plants. The model predictions are better in summer, although a general overprediction at most stations may reflect the seasonal reductions in emissions.

Adjustment to physical characteristics of the emission sources change the modelled air pollution concentrations on the mountain. Exit temperature and exit velocity have a more important influence than the physical stack height.

Details of the mechanistic link between meteorology and air pollution need further careful investigation, especially during winter.

6. ACKHOWLEDGEMENT

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