AN APPLICATION OF CALPUFF DISPERSION MODEL TO A NON-STANDARD PROBLEM

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Abstract: Pulp and paper mill situated in the complex terrain of northern Slovakia, in the close vicinity of the city of Ružomberok, continuously releases to atmosphere 30 kg of water vapor per second. Impressive clouds above the industrial complex have given rise to concerns from the side of local citizens, suspecting the emissions to be responsible for the local increase in precipitation. Therefore, a complex study has been initiated, including model simulation of the dispersion of water vapor from the paper mill focused on the domain of 8 x 7 km in close vicinity of the paper mill.

Phase conversions of water vapor in the atmosphere are a complex thermodynamic process involving many factors. However, we found out that for some practical applications a simplified approach is sufficient to assess the magnitude of the above mentioned effects. A combination of CALMET-CALPUFF models were applied to compute hourly concentrations of water vapor added to the atmosphere by emissions from the paper mill; these were compared to the hourly absolute humidity values as measured by the meteorological stations in the region, which are not supposed to be affected by the paper mill. The interest was focused on those hours in which the "background" absolute humidity was below saturation value, but additional vapor from the paper mill would bring the value to or above the saturation point.

Winter periods of two years (2005, 2006) were modeled and analyzed, during which 66 hours occurred when the additional water from the paper mill caused the humidity to exceed the saturation point, compared to 478 hours with 100% background relative humidity, when the additional vapor from the mill could possibly strengthen the icing effect which would occur anyway.

The study concludes that the contribution of the paper mill to total precipitation is negligible even in the close vicinity of the factory. However, in certain cases it can cause icings on a nearby E50 road communication; although these cases are not frequent, they can lead to fatal outcomes.

The uncertainties associated with the study method are also discussed.

Keywords: *CALPUFF, precipitation, paper mill, environmental impact.*

1. INTRODUCTION

Environmental impacts of large industrial complexes have always been a matter of concerns of local citizens and authorities. Pulp and paper mills usually emit large quantities of water vapor, often producing impressive clouds which are commonly associated with potential precipitation – all this giving rise to suspicions of having positive effect on precipitation in their close vicinity.

Pulp and paper mill operated by Mondi SCP in the city of Ružomberok (population of 30 000), Central Slovakia producing 30 kg of water vapor per second, has been a subject of such concerns for many years. In 2006, the managers of the company initiated a study in order to accommodate the debate.

It is necessary to note that the development of a cloud and droplet/ice particle growth is an extremely complex process depending on many factors (Wallace and Hobbs, 2006). Urban or industrial complexes can affect those processes by emitting cloud condensation nuclei (CCN), moisture and heat, the effects of which are not straightforward, but their final impact can be positive or negative depending on many other factors – both geographical and physical - as documented in a comprehensive review of current investigations focused on urban-induced rainfall by Shepherd (2005). Studies by Rosenfeld and Givati (2004, 2006) on urban and industrial impacts on precipitation in western US and Israel show negative effect on precipitation upslope the mountain ranges downwind of the industrial areas and positive effect on downslope side.

However, it is necessary to differentiate between an industrial sources in general and industrial sources emitting large quantities of water vapor, such as, e.g., paper mills, which produce all - vapor, heat and particles. Studies related to the effects of mills on precipitation are rather sparse in literature. In the 70-ties, Hindman, Hobbs, and Radke conducted some experiments and published a series of articles on large CCN effects produced by a large paper mill in Port Towsend, Wash., US (Hindman et al., 1977). They also performed some theoretical computations based on a model, and concluded that large and giant CCN emitted by the mill should not significantly affect rainfall from non-sheared warm cumulus clouds, but with combination with the emitted heat and water vapor may be responsible for the increased precipitation in the vicinity of the paper mills in Pacific Northwest, US. Mather (1991) reports a positive effect on the precipitation enhancement in certain large multicell storms in the vicinity of a paper mill in South Africa. Shepherd (2005) also analyzed modeling efforts undertaken in order to characterize the physical processes involved in the urban precipitation. He found that a relatively few number of numerical model studies had existed in the literature. He attributes this to several factors, among which the most important are probably the over-simplified or inadequate representation of wet microphysical processes in most models, their lack of capacity to adequately represent aerosol fields, and limitations in computing capabilities for fully coupled atmosphere-land modeling systems with explicit microphysical, dynamical, aerosol and land surface processes.

2. METHOD AND TOOLS

Studies cited above covered the influence of aerosols on precipitation processes in clouds. The process of forming and growing of cloud droplet to the stage when it can fall down to the ground as precipitation takes some time, during which the cloud necessarily moves further in the direction of the prevailing wind. However, the stakeholders in our study have been interested in the impact at close vicinity of the mill, up to 5-10 km. Following the theory (Wallace and Hobbs, 2006), precipitation from clouds is unlikely to develop in such short distance. Therefore, our study will focus on hydrometeors which may form near the ground when the atmosphere is cooled isobarically to saturation point, such as rime, drizzle, etc.

There is no software and hardware means available in Slovakia, which would allow dynamical simulation of precipitation-forming processes with sufficient resolution. An alternative approach, which turned out to be sufficient to achieve the practical goal of the study, was modeling the emission of water vapor as a classical non-reactive pollutant using an air dispersion model. As the paper mill is situated in a complex mountainous terrain, CALPUFF (Scire et al, 2000b) lagrangian puff model coupled with CALMET (Scire et al, 2000a) meteorogical model has been implemented on a domain of 8 x 7km, with the horizontal resolution of 250m, with 7 vertical layers.

Studying the problem of water vapor dispersion, one have to realize that the atmosphere contains rather large amount of natural water – the absorption of which strongly depends on the ambient temperature; the saturation point varies from approx. $2gm^{-3}$ in winter up to approx. $30gm^{-3}$ in summer. The atmosphere is unsaturated most of the time. It naturally saturates mostly in morning hours especially in winter, which is usually demonstrated in the form of fog, drizzle, dew or rime. The contribution of the mill emissions to the total atmospheric water concentrations is several orders lower than the natural.

The analysis of the water vapor concentrations differs from the usual air pollution dispersion analyses due to the nature of the effect of interest. We are interested in cases when the vapor concentration from the mill causes naturally unsaturated atmosphere to become saturated and subject to possible creation of hydrometeors; this is not necessarily when the maximum concentrations from the paper mill occur.

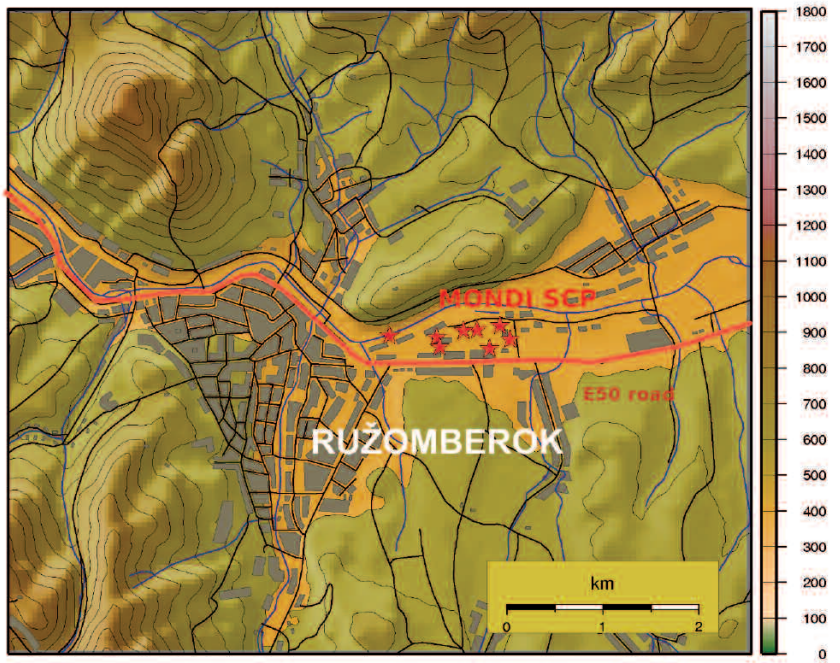

Figure 1. Modeling domain, including the E50 road. Stars represent the paper mill water vapor sources.

The main idea of the methodology used for the assessment of the mill influence on local ground-level humidity is as follows:

- using CALMET/CALPUFF model compute ground-level water vapor concentration field for the above mentioned domain for winter periods (we used years 2005 and 2006); select several receptors where the average seasonal and/or short-term values reach maxima.
- analyze hourly values of absolute humidity (water vapor concentration) measured at meteorological stations outside the Ružomberok area, which are close enough to represent background humidity, and at the same time

they are not impacted by the paper mill. Fig. 1 illustrates the domain and the meteorological stations used for determination of background humidity.

- compare the series of hourly values of background water vapor concentration with the complete hourly values of concentrations computed by CALPUFF model at the most impacted receptors, with the focus on cases when the vapor contribution from the mill caused that saturation point has been achieved or exceeded.

3. RESULTS

Maximally impacted receptors with highest mean and short-term average vapor concentrations from the mill were identified to be located south of the paper mill area on and around a frequented road which is part of the E50 European road network.

Fig. 2 summarizes the results of the analysis. In winter periods (January-March, October-November, 2 x 4368 hours in total) of 2005 and 2006, there were 66 hourly occurrences of cases when the vapor from the mill converted originally unsaturated air to saturated or over-saturated. In additional 478 cases the atmosphere was saturated naturally, so any added humidity from the paper mill did not play a crucial role in potential precipitation formation. All cases occur late afternoon, at night and early morning, when the temperature drops and the relative humidity naturally increases, sometimes up to the point of saturation.

The contribution of vapor from the paper mill is below 5% of background vapor concentration in most cases, in many cases it is several orders lower.

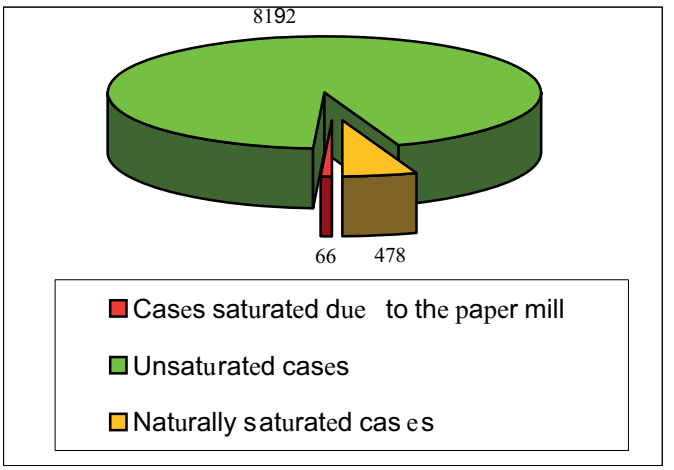

Figure 2. Hourly cases of atmospheric saturation near the E50 road in 2 winter periods (2005, 2006).

4. DISCUSSION

From the above it can be concluded that:

- In winter periods in evening, night and early morning hours and rarely during the day, when the natural humidity is near saturation point, there is certain potential for the water vapor from the paper mill to cause some solid or liquid precipitation (rime, dew) form on exposed surfaces in the vicinity of the paper mill, which may be visually distinguished as, e.g., whiter areas on trees, plants, ground and other surfaces in the direction of plum transported from the paper mill. One of the most exposed areas is the E50 road, and the paper mill is probably responsible for a portion of the cases when icing occurs on it.
- The contribution of the paper mill to the local annual precipitation amount is negligible, as great majority of the annual precipitation amount originates in clouds.
- Based on current state of knowledge published in scientific literature, the impact of the paper mill on cloud precipitation in Ružomberok and its close surroundings is impossible. However, it can affect the cloud processes and so the precipitation amounts and intensities further away; unfortunately, currently available data and computing means do not allow us to perform such studies, so these effects cannot be proved.

The assessment of the impact of water vapor from the sources of Mondi SCP paper mill as performed in this study involves many uncertainties, associated with data (e.g.,insufficient network of meteorological stations in very complex terrain of the region, insufficient information on some of the emission sources) and modeling method (modeling water vapor as a passive substance, ignoring thermodynamics of phase transformations, excluding the influence of aerosols, among others). Bearing this in mind, a conservative approach has been taken to data and model parameters. As there is no official neither unofficial record on icing occurrences in the city and on the E50 road in the vicinity of the mill, the findings of the study cannot be verified. However, judging from the subjective observations

of the local people, the the findings appear to be reasonable. Still, they should be treated as a best approximation which is feasible to achieve in current conditions using currently available data, modeling and computer means.

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