ADVANCES
in
SIMULATION-BASED DECISION SUPPORT

Volume II

Edited
by

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Canada

Published by

THE INTERNATIONAL INSTITUTE
FOR ADVANCED STUDIES
IN SYSTEMS RESEARCH AND CYBERNETICS

Integration of System Simulation and Geographical Information Processing for the Air-Pollution Emergency Situations Control and Decision Making

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Abstract
Present paper describes integration of air-pollution simulation models and geographical information processing systems for the decision support at the air pollution emergency situations. The Gaussian simulation model of the air pollution dispersion has been implemented and connected to the geographical information processing system. The case study has been prepared and three different simulation scenarios were conducted. Simulation scenarios were based on the real meteorological data considering the wind speed, wind direction and ambient temperature. The case study was used as the test of the concept.
Keywords: simulation, model, air dispersion, emergency situation

Introduction

Control of the emergency situation where the air pollution dispersion is in question is a complex task, where one has to consider the rapid changes of the process, e.g. blast of a tank with poisonous gas, which is related to the, possibly, rapid changes in weather conditions. Therefore the system which would adequately address crisis management in the case of accident air pollution should capture the data from the field in near-real time and besides, provide proper geospatial information to the crisis managers as well as the rescue team on the field. The structure of the GEPSUS (GEPSUS, 2011) system is shown in Figure 2. System input consist of three major automatic inputs from: a) Hydrological and Meteorological Service of Montenegro (HMZCG), b) Center for Ecotoxicological Research of Montenegro (CETI) and c) Real Estate Administration of Montenegro (REA). Another input to the GEPSUS system is user input, which provides the description of the pollutant, such as, location Latitude and Longitude, chemical emission rate, special weather condition parameters, which could not be provided by the automatic input, type of emission, release parameters and thread zones determination. The system should provide proper geospatial awareness to the decision makers which execute the evacuation plans based on the developed simulation models (Škraba et al., 2003).

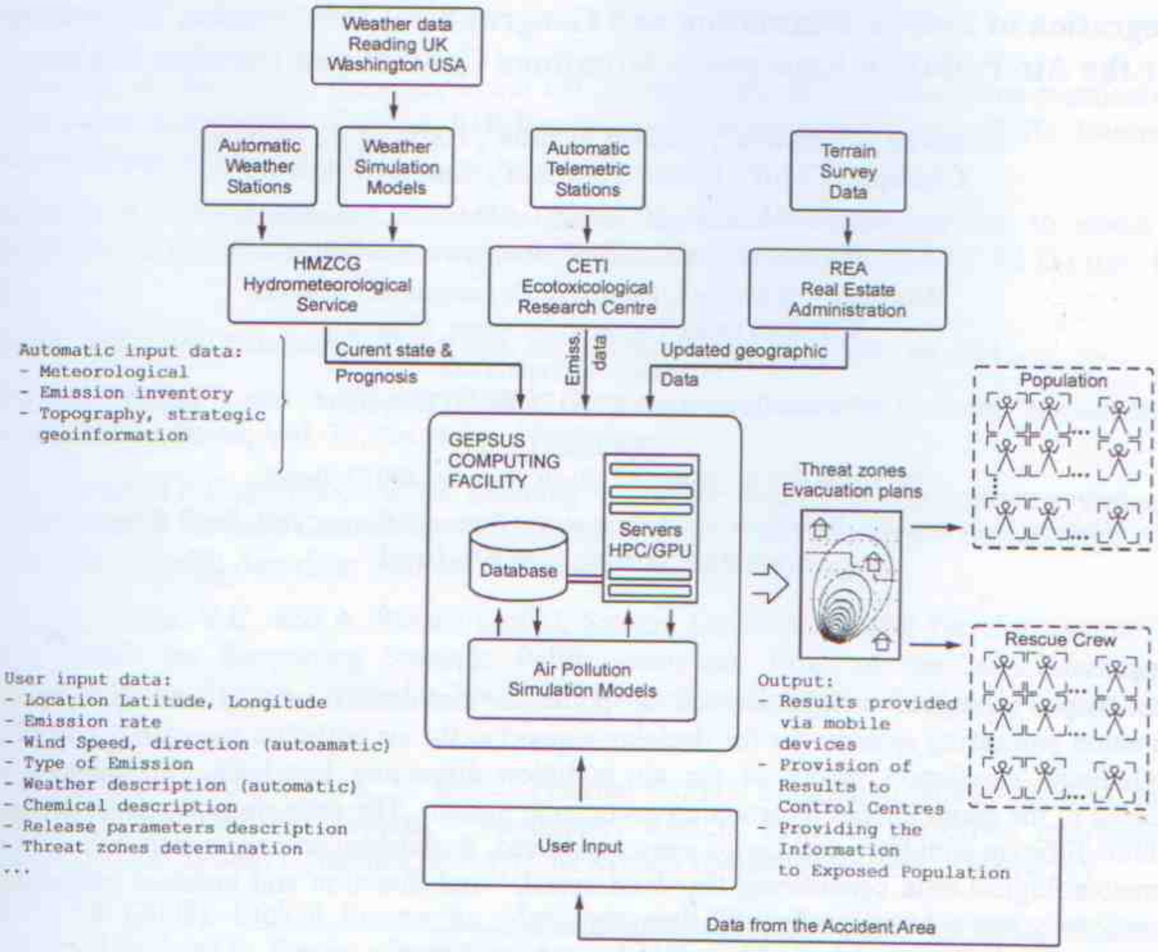

Figure 2: Structure of the GEPSUS system

The outputs of the GEPSUS system are the threat zones, which are equipped with exact concentration levels, threat classes and geolocation.

Air Pollution Dispersion Modelling

There are several approaches to the description of the air pollution dispersion process: Lagrangian model, Box model, Eulerian model, Dense gas model and other new approaches (Grašič, 2008; Osalu et al. 2009). For the demonstration of the system functionality the Gaussian Dispersion model will be applied which is build on the Gaussian probability distribution of the wind vector which determines the pollutant concentration (Holzberger, 2007; Tiwary, 2010;). The idea of modeling the pollution dispersion by Gaussian model is to imagine the instantaneous release i.e. puff of a pollutant from a point source which then moves in downwind (x) direction. If one neglects the diffusion in horizontal direction the following differential equation is obtained for three dimensional case:

$$\frac{\partial c}{\partial t} = \frac{\partial}{\partial y} D_y \frac{\partial c}{\partial y} + \frac{\partial}{\partial z} D_z \frac{\partial c}{\partial z} - v \frac{\partial c}{\partial x} - \lambda c \tag{1}$$

where D_y and D_z represent the diffusivity in y and z direction and λ represents the decay rate of the process. Diffusion equation is expanded for the case of double reflection with the effect of the reflection from the inversion; here the height in the analytical solution is considered as $(2H_i\text{-}H)$:

$$c(x,y,z) = \frac{Q}{2\pi v \sigma_y \cdot \sigma_z} e^{\frac{-y^2}{2\sigma_y^2}} \left(e^{\frac{-(z-H)^2}{2\sigma_z^2}} + e^{\frac{-(z+H)^2}{2\sigma_z^2}} + e^{\frac{-(z-2H_i+H)^2}{2\sigma_z^2}} + e^{\frac{-(z+2H_i-H)^2}{2\sigma_z^2}} + e^{\frac{-(z-2H_i+H)^2}{2\sigma_z^2}} \right) \tag{3}$$

where H*i* is the height of the inversion or the top of the atmospheric boundary layer. The exponential terms represent various effects of reflection from the ground and inversion as well as the direct effect. The values of σ_y and σ_z depend on the state of the atmosphere where the empirical approach is usually considered (Turner, 1970).

Application of the Simulation Model on Observed data

In order to test the technical part of the GEPSUS system, the developed models of air pollution which were realized in MATLAB, were tested against the real data from the field (Stojanović et al., 2011). The data was provided by the HMZCG (Hidrometeorološki zavod Crne Gore, 2011). The MATLAB has also been applied in other air-pollution modeling tasks due to its practical application value (Fatehifar 2006). The parameters which were prepared for three different simulation scenarios are shown inTable 2. Results of the simulation for the first run are shown in Figure 3. Here we have x and y distance while on the z axis the concentration is shown. Here one could observe the concentration level above $2\text{x}10^{-3}$.

Parameter	Scenario 1 (9:00h)	Scenario 2 (12:00h)	Scenario 3 (12:00h)
Emission rate Q [g/s]	76.3	76.3	76.3
Height H [m]	37	37	37
Wind welocity [m/s]	2	3.2	2
Wind direction [deg]	180	285	270
z [m]	0	0	0
Stack x [m]	100	100	100
Stack y [m]	200	200	200
x min [m]	1000	1000	1000
y max [m]	400	400	400
W. condition [A-F]	'A'	'A'	'A'
T [C]	28.5	28	28.7
Real time of simulation execution	5.6.2011 9:00	5.6.2011 9:00	5.6.2011 12:00

Table 2: Table of parameter values for three different scenarios based on real data (Scenario 1 and Scenario 3) and prognosis data (Scenario 2) considered as the concept test

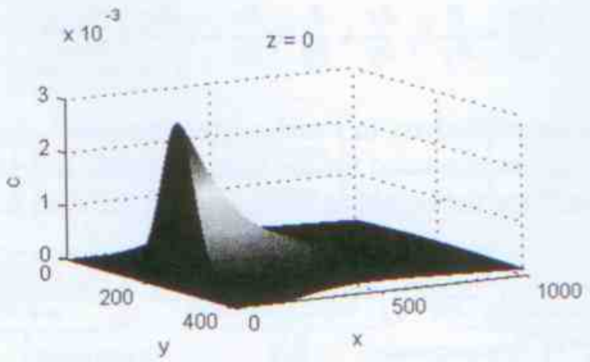

Figure 3: Concentration graph for the first scenario

Determination of the Incident Location and Representation of the Results in GIS

For the purpose of the test case, the location of the gas emission will which is the plume at location of the KAP Aluminium Production Plant, Lat.: 42.389000, Lon.: 19.218797. The GIS representation of the data has a significant importance for the decision makers, response crew as well as the population in order to increase geospatial awareness (De Amicis et al., 2009). In our case we have prepared the kml files for the Google Earth (Google Earth, 2011; Daly, 2008).

The results of the simulation runs put on the Google Earth GIS are shown in Figure 4. One could observe extreme change in the direction of air pollutant spread which occurred in the period of three hours. Actual wind change was from 180° (A) at 9:00h to 270° (C) at 12h. The predicted wind direction (B) was 285° and missed for 15°. Due to the larger predicted wind speed of meteorological prognosis, one could observe larger expected perimeter in the predicted run (B).

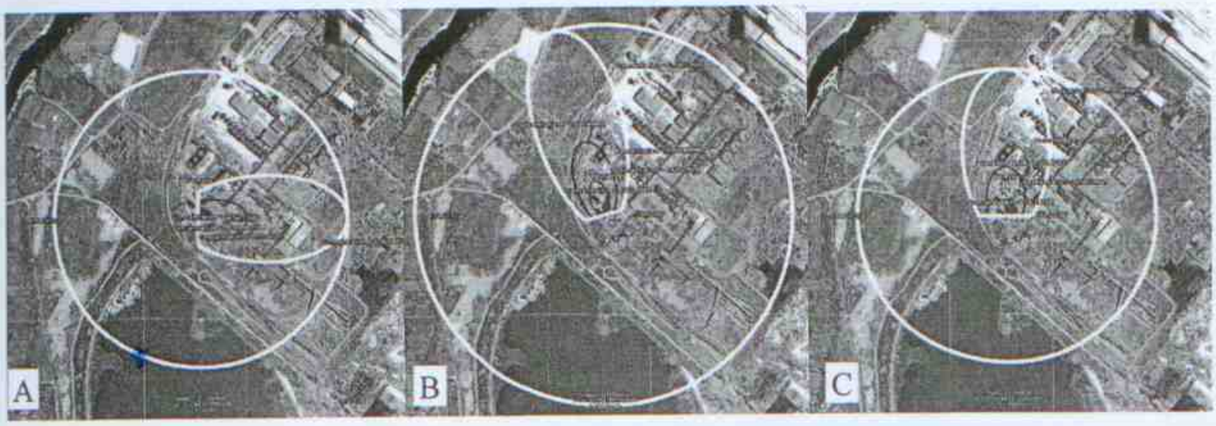

Figure 4: Results of three simulation runs at KAP Aluminium Production Plant, location: Lat.: 42.389000, Lon.: 19.218797; A: concentrations of pollutant on 5.6.2011 at 9:00 h, based on the real data on wind direction (180°), wind speed (2m/s) and temperature 28.5°C, B: anticipated concentrations of pollutant on 5.6.2011 at 12:00h, based on the prognosis of wind direction (285°), wind speed (3.2m/s) and temperature 28°C and C: concentrations of the pollutant on 5.6.2011 at 12:00 h based on the real data on wind direction (270°), wind speed (2m/s) and temperature 28.7°C. One could observe extreme change in the direction of air pollutant spread which occurred in the period of three hours.

Conclusion

By the presented test case one could gain better overview of the system complexity at the air-pollution emergency control. Important aspect that emerged in the course of our study is the integration of major governmental institutions which have to provide the input data to the system as well as the response by acting on the field. For the test case the Gaussian model of air pollution dispersion was adequate to show the major characteristic of the particular crisis situation. Several crucial parameters were taken from the real observations and by this the system proved its core functionality to predict the air pollution incident dynamics. However, there are issues of model validation (Ames et al., 2002), real-time data input and decision making which still have to be addresses. In this early stage, the rapid prototyping with the MATLAB™ showed to be efficient for model application as well as putting data to the standard output format. The application of Google Earth as the initial GIS system contributed to the better process of system development, since the end results of the simulation models could be observed in its final form which will be put to the decision makers and emergency response teams.

Acknowledgement

This research is sponsored by: a) NATO's Public Diplomacy Division in the framework of "Science for Peace" project GEPSUS SfP 983510, b) Ministry of Education and Science, Montenegro and Slovenian Research Agency ARRS within Program No. BI ME / 10—11—12 and c) ARRS Program No. UNI-MB-0586-P5-0018.

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