ARCHIVES OF ENVIRONMENTAL PROTECTION
vol. 34 Special Issue pp. 5 - 21 2008
PL ISSN 0324-8461

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SINZaP – INTELLIGENT AIR POLLUTION MONITORING SYSTEM

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Keywords: Trajectories, back-trajectories. Lagrangian transport and dispersion model, BackTrack, neural network.

Abstract: The paper presents a mature concept of an intelligent monitoring system of air pollution inflow and its realization in the form of a SINZaP system lunched at Institute for Ecology of Industrial Areas (IETU) in 2006. SINZaP is a real time operating system resembling a neural network. It is designed for modeling of pollutant emissions and air pollutants concentrations, addressed to specialists or decision makers responsible for air quality management. For modeling of emission and air pollutants concentrations in SIZNaP system, a back trajectory model – BackTrack has been used, which is based on VLSTRACK model. The essential feature of the BackTrack model is the application of back trajectories in the selection of emission sources influencing a given receptor. For modeling of trajectories BackTrack uses three-dimensional wind fields, friction velocity, Monin-Obukhov length and mixing layer height. SINZaP consists of four main modules: (1) data module including data scanner for reading public data accessible in the Internet, (2) module for preparation of meteorological data, (3) BackTrack module for simulations of pollutants emissions and simulations of air pollutants concentrations, and (4) Trainer module, the task of which is correction of input parameters for adjusting modeling and observed data.

INTRODUCTION

One of the challenges faced by contemporary science is to provide the administration responsible for the air quality protection with tools that would aid or even enable them to fulfill their environmental protection duties. At a national level the administration is responsible, among others, for: controlling whether the air quality meets the existing standards, air quality management by creating the policy of granting permits for air pollutants emissions, the identification of effects resulting from these permits, and where the quality standards are not met – development of environmental protection programs.

The Environmental Protection Act states that if the admissible levels of pollution concentrations have been exceeded within a protection area, i.e. an agglomeration of over 250 000 inhabitants or Powiat (an administration entity including a group of municipalities), a remediation program should be prepared which will include, among others, the identification of responsible sources. In the air quality management it is very important to define clearly which sources of pollution are controlled (e.g. by lowering their air pollution limits), which sources are less controllable (e.g. municipal, traffic and agricultural emission) and which ones are completely out of control (e.g. natural emission). The legislators face this problem when defining the air quality standards for particulate matter. It turns out that the concentration of particulates in the atmospheric air from natural sources is so high that it cannot be neglected in determining the admissible levels of concentrations [12].

A possible way to fulfill the above tasks is an intelligent, real time monitoring system identifying the inflow of pollution to the monitored area and selected receptors in this area. Such a system should:

- enable to retrace the most likely routes (trajectories) of the pollutants inflowing into the monitored area since they entered the area until reaching the receptor points;
- calculate the concentrations of the monitored pollutants at selected points and compare them with the measured concentrations, and based on the obtained results – to identify the most likely emission of pollutants from sources in the monitored area and the most likely levels of pollution concentrations at the boundary of the monitored area.

The first such system was set up at IETU in the mid nineties. It was configured to analyze data coming from the BASKI air quality monitoring system from the Nitrogen Production Plant (Zakłady Azotowe) in Kędzierzyn-Koźle [15, 16]. The system enabled the statistical characterization of concentrations inflowing from various directions and identified the sources that had the most severe impact at a given point.

By juxtaposing the information on the inflow of pollution from two or more monitoring stations, additional information can be generated that should help indicate emission sources having a relatively considerable impact on the air quality in a particular area. This is illustrated in Figure 1.

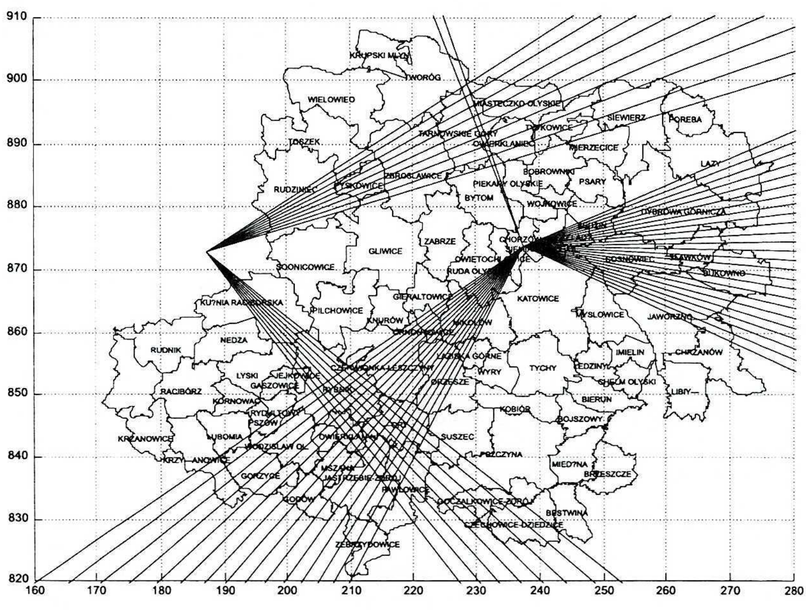

Fig. 1. Sectors of the inflow of elevated PM10 concentrations into the BASKI monitoring station in Grabówka (on the left) and Chorzów monitoring station (on the right)

The figure shows the straight-line trajectories of streams carrying higher concentrations of sulphur dioxide that reached the monitoring stations in Grabówka (near Kędzierzyn-Koźle) and in Chorzów. Analyzing the figure, it can be stated that north of the line connecting the stations in Grabówka and Chorzów, substantial sources of sulphur dioxide exist at the borderline of Tarnowskie Góry and Miasteczko Śląskie. And south of the line the flow streams cross in the area of Rybnik and Żory.

However, the straight-line trajectories used in this system, fail to provide satisfying information on the flow of pollution, since stabile meteorological conditions rarely occur, and thus the number of monitoring stations which can be considered reliable here is limited. Therefore, in order to utilize all available data, it is necessary to employ back-trajectories which take account of the fluctuation of wind directions in the area. The method of back-trajectories is often used to investigate long-distance pollution transports [1, 5–7, 22–24].

The method of back-trajectories was used as a basis for a system developed within the framework of a grant from Committee of Scientific Research [14]. The research resulted in formulating the concept of an interactive modeling system of air pollution, capable of providing the most reliable data for modeling of air pollution concentration in a given area and the generated information would be accessible to clients interested in modeling local air pollution concentrations. Such a system should:

- generate and maintain its information resources regarding:
  - the existing state of emission sources in the monitored area,
  - the air quality state in the monitored area and its vicinity collected from all available sources,
  - meteorological conditions in the planetary boundary layer in the vicinity of the monitored area,
  - dispersion of pollution over the monitored area;
- model, based on the available data, pollution concentrations at selected points, where air pollution is monitored and by using the information adjust its knowledge regarding emission sources;
- create data for modeling pollution concentration accessible from outside.

IMPLEMENTATION OF INTELLIGENT POLLUTION MONITORING SYSTEM

The concept of intelligent pollution monitoring system has been implemented as a computer system SINZaP consisting of: (1) an information base that contains all the facts requisite for the system operation, a module for gathering information regarding meteorological conditions, (2) a set of transport and distribution of air pollution models, (3) a module of data analysis called Trainer and a Web server and a VNC (Virtual Network Computer) server. A diagram of SINZaP is shown in Figure 2.

Knowledge base

The information base constitutes the main part of SINZaP. It consists in collecting, storing and making available all information necessary for the functioning of the system.

The MYSQL server is used for collecting data. The database gathers information on monitoring stations and the meteorological stations METAR that operate in the vicinity of the Voivodeship (province) including the information scanned from the Internet, meteorological data for the monitored area, the concentrations modeled for monitoring stations, impact areas, the most likely pollution concentrations levels at the boundary of the modeled area and other information necessary for the functioning of the system.

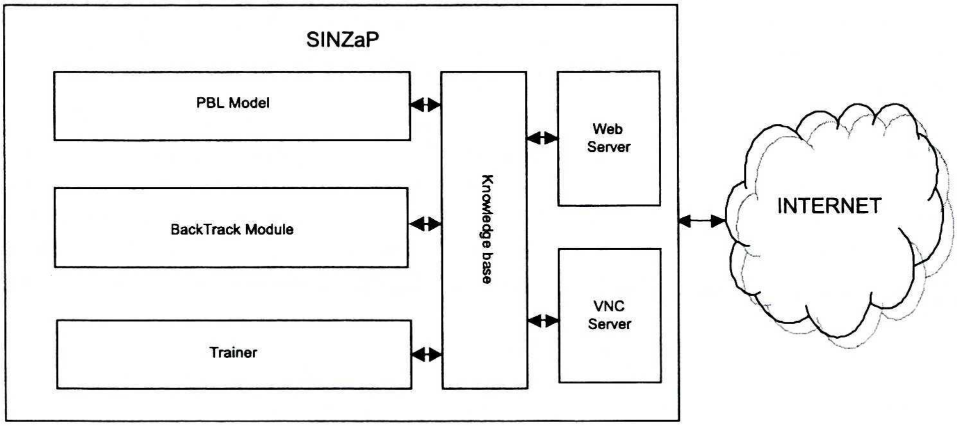

Fig. 2. Diagram of the SINZaP system

Additionally, the database stores data on ca. 3000 point sources existing in the Silesian Voivodeship and the latest data on 40 000 area sources, coefficients of uncovering area that emit particulate matter, data on the texture and type of the areas emitting particulate matter.

The data server is in direct contact with all the system modules, the Web server and external users of the system. The Internet scanner constitutes an integral part of the system. It scans public Internet sites for data on air quality. It scans the sites of Polish air quality monitoring stations in the vicinity of the Silesian Voivodeship every hour, every three hours it scans the Czech Hydrometeorological Institute Webpage, every hour it checks the text files coming from the Finnish Meteorological Institute and every 15 minutes it collects reports from the METAR server. The system checks 54 sites of air quality monitoring stations.

BackTrack Module

The BackTrack model simulates hourly pollution concentrations at selected points. It is based on a Gaussian dispersion model VLSTRACK [3]. The core of the BackTrack Model is the function determining the distribution of air pollution concentrations in a cloud of pollution discharged to the atmosphere from an emission source and moving in the atmosphere along the trajectory determined by meteorological conditions in the planetary boundary layer (PBL).

Let t_0 be an hour (1-hour period) and $\mathbf{m}_{24}(t_0)$ – a set of meteorological conditions at least 24 hour before t_0. The emission of the pollutant p_p, $p = 1, ..., p_n$ (e.g. SO_2, NO_2, PM10 and CO as implemented so far in the SINZaP) from the source e_s, $s = 1, ..., s_n$, during an hour t, $t_0 - 24 < t < t_0$ is calculated by the emission function ϕ_s dependent of the scalar parameters $\bar{\phi}_s$ of the source e_s (e.g. number of boilers in a grid cell e_s) and the emission factors $\hat{\phi}(s,t,p,\mathbf{m}_{24}(t_0))$ for time t and meteorological conditions $\mathbf{m}_{24}(t_0)$:

$$q_{s,p,t} = \phi(s,t,p,\mathbf{m}_{24}(t_0)) = \bar{\phi}_s \cdot \hat{\phi}(s,t,p,\mathbf{m}_{24}(t_0)) \tag{1}$$

It can be stated that the source e_s from which the pollutant p_p, $p = 1, ..., p_n$ has been introduced into the air during t, produces at the receptor r_r, $r = 1, ..., r_n$ a concentration

$\psi(s,r,p,t,\mathbf{m}_{24}(t_0))$. Consequently, the total concentration $c_{p,r}$ of pollutant $\boldsymbol{p}_p$ at the receptor $\boldsymbol{r}_r$ at the time t_0 is the sum of the above-mentioned concentrations at the time $t < t_0$ from all emission sources:

$$c_{p,r} = \sum_{t<t_0}\sum_{s}\psi(s,r,p,t,\mathbf{m}_{24}(t_0)) = \sum_{t<t_0}\sum_{s} q_{s,p,t}\hat{\psi}(s,r,p,t,\mathbf{m}_{24}(t_0))$$

So, for t_0 concentration $c_{p,r}$ is a linear function of $\bar{\phi}_s$:

$$c_{p,r} = \sum_{t<t_0}\sum_{s}\bar{\phi}_s \cdot \hat{\phi}(s,t,p,\mathbf{m}_{24}(t_0))\hat{\psi}(s,r,p,t,\mathbf{m}_{24}(t_0)) \qquad (2)$$

Trainer Module

For each hour t_0 the model (2) can be regarded as a three-layer neural network [2] which includes the layer of emission sources, the layer of pollutants emitted in time periods t_0, t_0 - 1, ..., t_0 - 24 and the layer of pollution concentrations at receptors. The Figure 3 shows an example of the traffic emission sources affecting different receptors at the same time. The figure presents two overlying back-trajectory beams for monitoring station in Katowice and Dąbrowa Górnicza, which were modeled for 2007-05-22, 4:00 PM. In this example the areas represented by the back trajectory beams determine the emission sources which directly influence the pollutant concentrations measured at monitoring stations.

Pollutant concentrations at a given monitoring station are calculated taking into account only emission sources which are inside the back trajectory beam area. These modeled concentrations are compared with concentrations observed at a given monitoring station. The obtained error is used for proportional modification of emission parameters of all sources located in the back trajectory beam area. This operation is repeated for each pollutant and each monitoring station until the minimization of the total error is obtained.

It can be noticed that at the time t_0 only a part of the emission sources affects the receptor $\boldsymbol{r}_r$. By S_r we denote the set of these sources. We can assume that the concentration of the pollutant $\boldsymbol{p}_p$, $p = 1, \ldots, p_n$, at receptor $\boldsymbol{r}_r$, $r = 1, \ldots, r_n$ is equal:

$$c_{p,r} = \sum_{t<t_0}\sum_{s\in S_r}\bar{\phi}_s \cdot \hat{\phi}(s,t,p,\mathbf{m}_{24}(t_0))\hat{\psi}(s,r,p,t,\mathbf{m}_{24}(t_0))$$

These modifications of emission parameters are carried out for any monitoring station and any time period. Those modifications are carried out by computational module called Trainer. To minimize the difference between modeled and observed concentrations the Trainer modifies the emission parameters ϕ_s for each hour. The Trainer works like a neural network which uses the above formula. As a result, it recommends an adjustment of parameters of emission sources which at the time t_0 affected the level of modeled concentrations. The connections of the Trainer with other modules of the BackTrack model are presented in Figure 4.

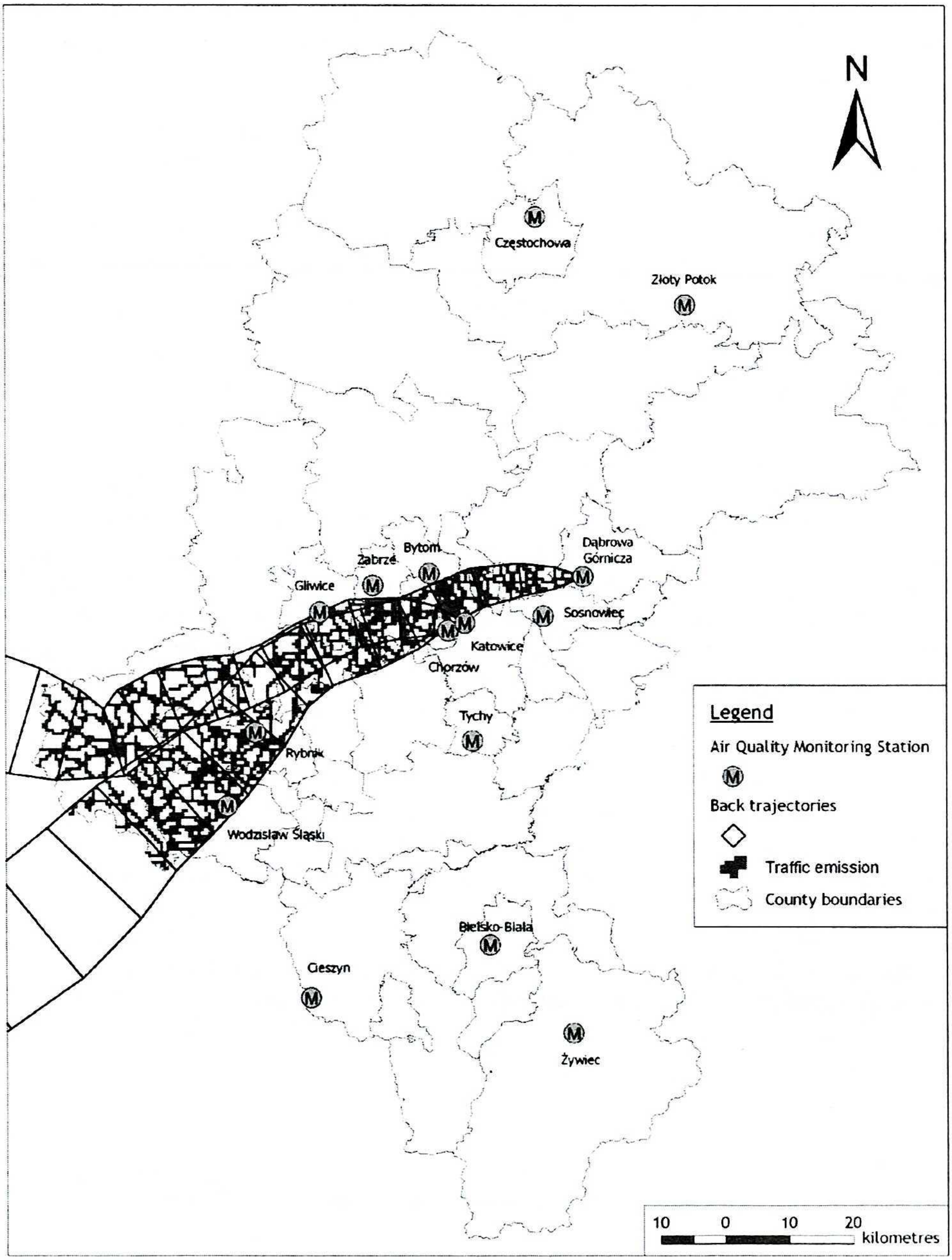

Fig. 3. An example of the overlying back-trajectory beams for two monitoring station in Katowice and Dąbrowa Górnicza at 2007-05-22, 4:00PM

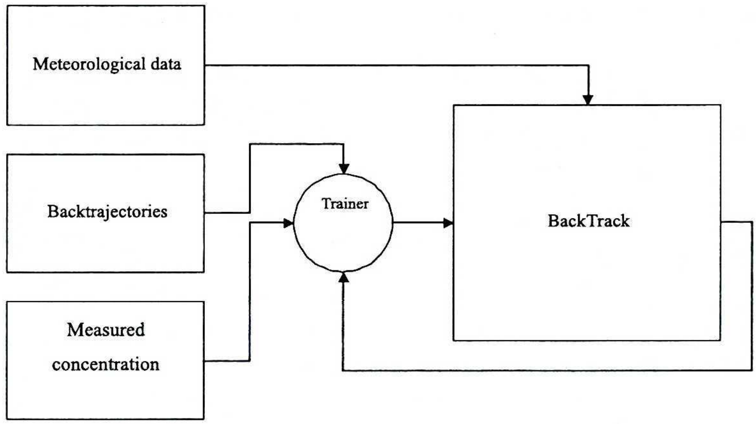

Fig. 4. Modular diagram of the BackTrack model

Planetary Boundary Layer Model

For modeling of the pollutant transport in the atmosphere and air pollutant concentrations VLSTRACK uses the following parameters: three-dimensional wind field, friction velocity, Monin-Obukhov length, mixing layer height.

In order to obtain the above mentioned data various meteorological models such as MM5, COAMPS, OMEGA and HIRLAM can be used. The operating version of SINZaP uses the meteorological parameters from HIRLAM model [9, 18, 21].

Dispatches containing: 36-hour forecasts of the temperature, wind velocity and direction (at the altitude: 10, 30, 90, 165, 250, 350, 460, 740, 1360 and 1860 m above the ground), Monin-Obukhov length, hourly rainfall, mixing layer height, friction velocity and long as well as short-term radiation intensity, are sent between 4–5 and 16–17 o'clock UTC by the Finnish Meteorological Institute. The data are stored temporarily in the server from which the data scanner sends them to a database that verifies the files.

SINZaP additionally utilizes public domain meteorological data from the aviation meteorological reports METAR. Every 15 minutes the scanner retrieves meteorological reports from http://weather.noaa.gov/pub/data/observations/metar/stations/.

In the Silesian region and its neighborhood there are 12 meteorological stations which provide METAR reports.

Web Server

In order to enable a direct access to the data generated by SINZaP, an Internet server has been set up (link by IETU homepage – http://www.ietu.katowice.pl). Current information on monitoring stations and the results of pollution concentrations modeling are made available here to the interested parties. The server also provides 24-hour forecasts of air pollution concentrations.

BACKTRACK MODEL

BackTrack is a software for modeling of air pollution concentrations at a given time and place, based on VLSTRACK model [20]. For operation it requires information about meteorological conditions, emission sources from the monitored area and the air quality data collected from inside and from outside of the monitored area during the preceding 24-hour period.

VLSTRACK is the Lagrangian transport and pollution dispersion model, which utilizes a Gaussian puff method. In this method the Monin-Obukhov's similarity theory is used for modeling of the planetary boundary layer and Pasquill's and Gifford's stability classes – for describing the atmospheric stability.

In the BackTrack model back-trajectories are of great importance. They are employed to indicate area with potential sources that in the preceding 24-hour period affected the pollution concentration at a given point. The input data for the BackTrack model consist of data on pollution concentrations at the area's boundary from the preceding 24-hours and data on emission sources, as well as simulation hour, meteorological data from the preceding 24-hours in the vicinity of the point, 3D wind field, friction velocity, Monin-Obukhov length, mixing height – for trajectory simulation, and temperature field, rainfall and solar radiation intensity – for other simulations.

Back-Trajectories

A trajectory is a line $\mathbf{x}(t)$ in space, along which an air particle moves. The trajectories of air particles are determined based on 4-dimensional wind field. The position at the time $t + \Delta t$ of a particle which at the time t was at the point of space $\mathbf{x}(t)$ moving at the velocity $\mathbf{v}(\mathbf{x}, t)$ is determined in two steps. Firstly, a likely position of the particle after the time Δt is calculated based on information regarding the velocity $\mathbf{v}(\mathbf{x}, t)$:

$$\mathbf{x}'(t+\Delta t) = \mathbf{x}(t) + \mathbf{v}(\mathbf{x},t) \cdot \Delta t$$

then, the final position of the particle is calculated based on the following formula:

$$\mathbf{x}(t+\Delta t) = \mathbf{x}(t) + \frac{\mathbf{v}(\mathbf{x},t) + \mathbf{v}(\mathbf{x}',t+\Delta t)}{2} \cdot \Delta t$$

A series of points $\mathbf{x}(t_1)$, ..., $\mathbf{x}(t_n)$ is generated which delineate a trajectory at the time from the moment $t_1 = 0$, ..., $t_n = T$. Trajectories can have a forward direction, when $\Delta t > 0$, or a backward one, when $\Delta t < 0$.

The altitude $z(t)$ of trajectory $\mathbf{x}(t) = (x(t), y(t), z(t))$ is expressed by the formula:

$$z(t) = \min(0.5 \cdot z_b, z_c + 0.6 \cdot \sigma_z(t)) \tag{3}$$

where z_b is the mixing layer height, z_c is the initial altitude of the trajectory (the altitude of the cloud at the beginning of emission), and $\sigma_z(t)$ – the coefficient of vertical turbulence diffusion (see (5)).

Wind vector $\mathbf{v}$ can be regarded as a random vector variable of which constituents u, v, w are normal random variables.

Thus, the wind vector $\mathbf{v}$ at the point $\mathbf{x}$ and at the time t is a vector random variable as $\mathbf{v}(\mathbf{x},t) + \hat{\sigma}(\mathbf{x},t)$, where $\mathbf{v}(\mathbf{x}, t)$ represents the vector of the mean velocity at the averaging time Δt, and $\hat{\sigma}(\mathbf{x},t)$ is a random vector of mean 0 and constituents of standard deviation $\hat{\sigma} = (\hat{\sigma}_u, \hat{\sigma}_v, \hat{\sigma}_w)$ representing the local fluctuations of the wind vector in times $(t, t + \Delta t)$.

To determine the wind vector fluctuations, the similarity theory of Monin-Obukhov is employed. The standard deviations of the wind vector fluctuations are expressed, similarly as in the VLSTRACK model, by Saucier formulas [19], dependent on the friction velocity u_*, the mixing height z_b and Monin - Obukhov length L.

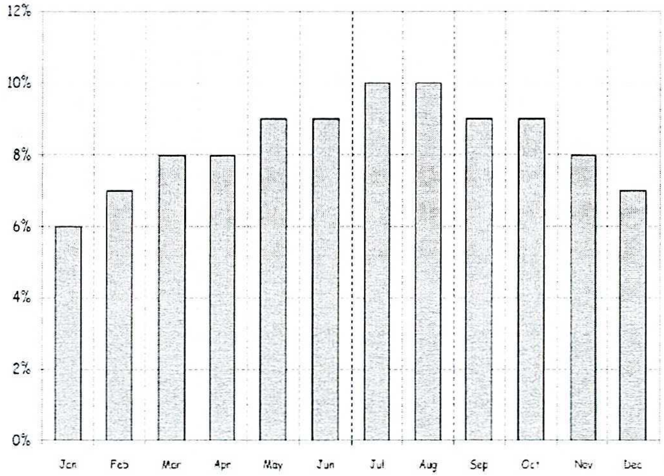

Fig. 5. Distribution of the monthly traffic emission in annual emission from traffic

The standard deviations of the turbulence horizontal fluctuations of wind represented by σ_u, σ_v are functions of the friction velocity u_*

$$\hat{\sigma}_u = \hat{\sigma}_v = b \cdot u_* \tag{4}$$

where

$$b = (12 - z_b / L / 2)^{1/3} \qquad L<0,$$

$$b = 2.1 \qquad L \geq 0,$$

The fluctuations of the vertical constituent w of wind σ_w are expressed as follows:

$$\hat{\sigma}_w = 1.3 \cdot w_* \tag{5}$$

where:

$$w_* = u_* \cdot (1 - 3 \cdot z_b / L)^{1/3} \qquad L<0,$$

$$w_* = u_* \qquad L \geq 0,$$

The wind fluctuations disperse the cloud of pollutants released to atmosphere at the time t_0. The centre of the cloud moves along the trajectory $\mathbf{x}(t) = (x(t), y(t), z(t))$, $t > t_0$. At the same time the cloud disperses. Let's assume that the concentration of pollution has 3-dimentional Gaussian distribution:

$$\frac{1}{\sigma_x(t)\sqrt{2\pi}} e^{-\frac{(x-x(t))^2}{2\sigma_x(t)^2}} \frac{1}{\sigma_y(t)\sqrt{2\pi}} e^{-\frac{(y-y(t))^2}{2\sigma_y(t)^2}} \frac{1}{\sigma_z(t)\sqrt{2\pi}} e^{-\frac{(z-z(t))^2}{2\sigma_z(t)^2}} \tag{6}$$

at the point $\mathbf{x}(t) = (x(t), y(t), z(t))$ with the standard deviation $\sigma(t) = (\sigma_x(t), \sigma_y(t), \sigma_z(t))$.

Variances of pollutant concentration in the time t are expressed by the formulas resulting from Taylor's statistical model [20]:

$$\sigma_x(t)^2 = 2\cdot T_u \cdot \int_{t_o}^{t} \hat{\sigma}_u(\tau)^2 \cdot \left(0.6\cdot e^{-0.6\tau/T_u} \cdot \left(\frac{\tau}{T_u} - \left(1-e^{-\frac{\tau}{T_u}}\right)\right) + \left(1-e^{-0.6\frac{\tau}{T_u}}\right)\cdot\left(1-e^{-\frac{\tau}{T_u}}\right)\right) d\tau$$

$$\sigma_y(t)^2 = 2\cdot T_v \cdot \int_{t_o}^{t} \hat{\sigma}_v(\tau)^2 \cdot \left(0.6\cdot e^{-0.6\tau/T_v} \cdot \left(\frac{\tau}{T_v} - \left(1-e^{-\frac{\tau}{T_v}}\right)\right) + \left(1-e^{-0.6\frac{\tau}{T_v}}\right)\cdot\left(1-e^{-\frac{\tau}{T_v}}\right)\right) d\tau \quad (7)$$

$$\sigma_z(t)^2 = 2\cdot T_w \cdot \int_{t_o}^{t} \hat{\sigma}_w(\tau)^2 \cdot \left(0.6\cdot e^{-0.6\tau/T_w} \cdot \left(\frac{\tau}{T_w} - \left(1-e^{-\frac{\tau}{T_w}}\right)\right) + \left(1-e^{-0.6\frac{\tau}{T_w}}\right)\cdot\left(1-e^{-\frac{\tau}{T_w}}\right)\right) d\tau$$

where T_u, T_v, T_w are parameters of Lagrangian time scale (Tab. 1).

Table 1. Lagrangian time scales

Stability class	Lagrangian Time Scale [s]	
	T_u, T_v	T_w
A	400	400
B	400	400
C	400	400
D	400	200
E	400	100
F	400	50

Now let us define a function $\wp$, so called puff-function corridor, which describes distribution of particles in the moving and dispersing cloud of pollution:

$$\wp(t) = (\mathbf{x}(t), \hat{\sigma}(t), \hat{\sigma}(t)) \quad (8)$$

where:

$\mathbf{x}(t) = (x(t), y(t), z(t))$ are the coordinates of the trajectory at the time t,

$\hat{\sigma}(t) = (\sigma_u(t), \sigma_v(t), \sigma_w(t))$ is local wind fluctuation (4, 5),

$\sigma(t) = (\sigma_x(t), \sigma_y(t), \sigma_z(t))$ turbulence diffusion coefficient (7).

Concurrently the function $\wp$ describes particle trajectories and the dispersion parameters of particles along the trajectory.

The back-trajectory of the point $\mathbf{x}_0$ at the time t_0 determines potential positions of points (sources) at which the trajectories had begun and reached the point $\mathbf{p}_0$ in the time t_0. Such a back-trajectory enables selection of the emission sources that affect the point $\mathbf{p}_0$. The information base contains the recorded sequences of trajectory parameters for each monitoring station and modeling period. The information can be utilized for selecting the emission sources affecting the level of concentration at this point and for modifying the parameters of these sources.

Pollution Emission Module

This module facilitates modeling pollution emission from point and area sources (flats and small buildings, transport sources, agricultural sources and sources of particulate matter). The information contains data on over 3000 stationary sources of air pollution from Silesian Voivodeship including the three-month mean emissions from these sources.

Based on the above the emission generator determines emission and its parameters for every hour.

The information base includes 40 000 area sources from the Voivodeship. Area sources are represented by squares of land (squares of the mosaic map) of 0.5 x 0.5 km area. Area sources are attributed with the number of flats heated by stove or by district system, the length of roads of different quality, the area of reservoirs emitting particulate matter, etc.

Pollution emission from home stoves and boilers results from utilizing fuels for heating purposes. The demand for heat of a single flat is determined by meteorological conditions. Thus, the pollution emission from coal stoves and boilers from the area source s_s, is the function $\phi(s,p,t,\mathbf{m})$ of meteorological conditions $\mathbf{m}$, stored in the information base regarding the number of flats heated by the boiler and stove and the related pollution emission rates.

The following data from the information base are utilized in calculating the emission from transport sources: (1) the length of roads existing within the boundary of an area source: national, provincial and other made-up roads, (2) traffic density on these roads, (3) emission rates from these roads.

The yearly emission determined for a road fragment is recalculated into hourly emission based on a set of factors that characterize traffic fluctuation on yearly, weekly and 24 hours basis.

The emission of a pollutant p from the type of road k of area source e_i, in the time t is expressed by the formula:

$$\phi(s,p,t,\mathbf{m}) = l(s,k)\cdot u_m(t)\cdot u_w(t)\cdot u_d(t)\cdot er(k,p)$$

where:

$l(s, k)$ – the length of road of type k in the grid $\mathbf{s}_s$,

$u_m(t)$, $u_w(t)$, $u_d(t)$ – monthly (Fig. 6), weekly (Fig. 7) and 24-hour proportions (Fig. 8),

$er(k, p)$ – emission rate of pollutant p (per kilometer) from the road type k.

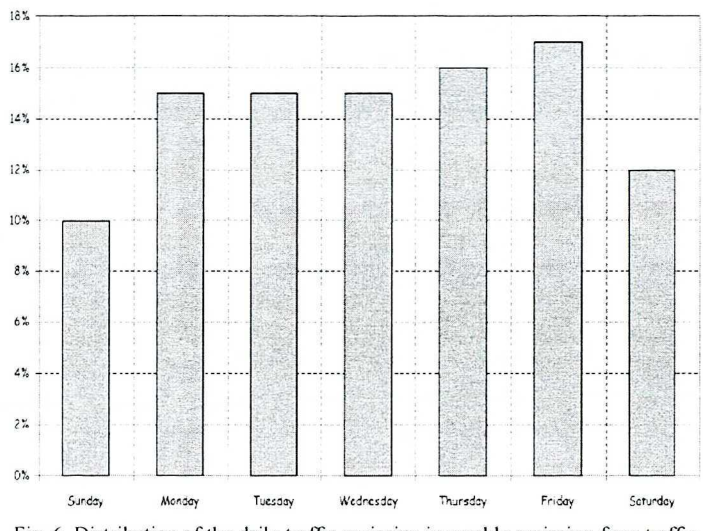

Fig. 6. Distribution of the daily traffic emission in weekly emission from traffic

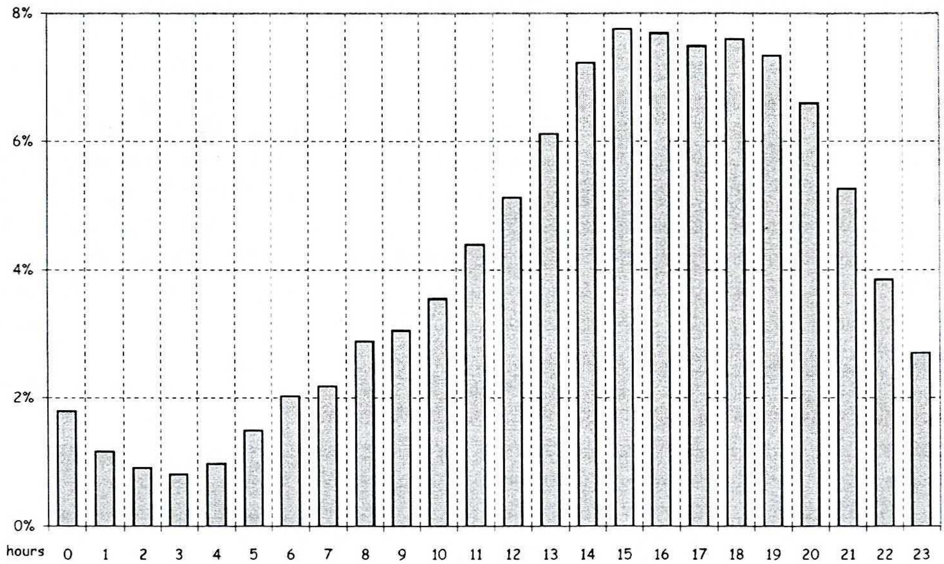

Fig. 7. Distribution of the hourly traffic emission in daily emission from traffic

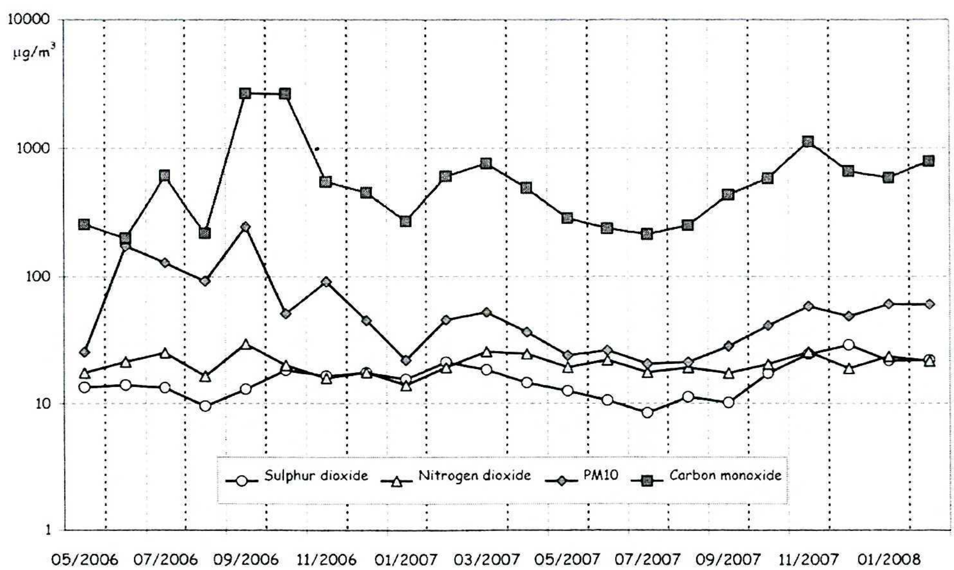

Fig. 8. Graph of the monthly root mean square error between the 1-hour modeled and observed concentrations of sulphur dioxide, nitrogen dioxide. PM10 and carbon monoxide

The emission of pollutants from agriculture is determined similarly as the transport emission but the main parameter of the emission is the length of unmade-up roads and the area of arable lands in the grid. The function u_m, of monthly proportion takes account of the specificity of agricultural work.

The model produced in the NatAir project [12], calculating emission of particulate matter, is utilized to determine PM emission from the surface. The model of PM emission is based on algorithms developed in [17]. It determines hourly PM emission $\phi(s,p,t,\mathbf{m})$ from the area source e_s as a function of the granulometric characteristics of PM reservoirs existing in this area source, the type of ground surface emitting PM, variable green coverage of the surface and meteorological conditions **m**.

Pollution Concentration Model

In Gaussian models such as BackTrack the distribution of pollutant concentrations of the unit mass in a cloud moving along the trajectory corridor $\wp$ and without interaction of the cloud with bounding planes, is 3D Gaussian distribution (6), with its centre at the point $\wp_{\mathbf{x}}(t) = \mathbf{x}(t) = (x(t), y(t), z(t))$ and diffusion parameters $\wp_{\sigma}(t) = \sigma(t) = (\sigma_x(t), \sigma_y(t), \sigma_z(t))$.

The ground surface constitutes a barrier to the migration of a cloud. Some particles of pollution touching the ground get stuck in it; others bounce off the ground and enter the atmosphere again. The likelihood that a particle rebounds is described by the parameter α. In VLSTRACK it is assumed that 98.5% of pollutant particles in contact with the ground rebound and return to the atmosphere. In general, the rebound coefficient of a particle depends on the kind of pollutant and the ground. In pollution dispersion models used in Poland for suspended matter, the rebound coefficient is $\alpha = 0$

Consequently, the unit mass of pollutant $\mathbf{p}_p$ which flows along trajectory $\wp$ produces the following concentration in point $\mathbf{x}$ at time t:

$$\hat{\psi}(\mathbf{x},t,\wp,p) = \frac{1}{2\pi\sqrt{2\pi}\sigma_x(t)\sigma_y(t)\sigma_z(t)} e^{-\frac{(x-x(t))^2}{2\sigma_x(t)^2}-\frac{(y-y(t))^2}{2\sigma_y(t)^2}} \left(e^{-\frac{(z-z(t))^2}{2\sigma_z(t)^2}} + \alpha(p)\cdot e^{-\frac{(z-z(t))^2}{2\sigma_z(t)^2}} \right) \quad (9)$$

Vertical migration of pollution may be hindered by the size of mixing layer height. In the BackTrack model the blocking effect of vertical migration is described by modifying the altitude $z(t)$ (see (3)).

Transformation of a pollutant affects the level of the pollutant concentration and its transport in the atmosphere. Due to a relatively short time of transport, as assumed in the BackTrack model, the chemical transformation formulas are simplified.

Transformation of SO_2

According to [10, 11] the rate of irreversible loss of sulphur dioxide in the air is ca. 5% an hour. Thus, the concentration of SO_2 in a moving cloud after the time t is:

$$\psi(\mathbf{x}, q_{SO_2}, t, \wp, SO_2) = q_{SO_2} \cdot 0.95^t \cdot \hat{\psi}(\mathbf{x}, t, \wp, SO_2)$$

where: q_{SO_2} is SO_2 emission.

Transformation of NO_x, NO_2

During the movement of the pollutant cloud, nitrogen oxides undergo slow transformation. According to [10, 11] within an hour ca. 1% of nitrogen oxides vanish from the moving cloud. Additionally, as a result of various impacts of environmental factors, especially resulting from the impact of UVB radiation, a reversible transformation of nitrogen oxides into nitrogen dioxide occurs. The investigation of the balance of nitrogen oxides and nitrogen dioxide is presented in the studies [8, 13]. The projects investigated the dependence of NO_2, NO_x and O_3 concentrations in plumes from industrial sources and roads.

In the BackTrack model of NO_2 concentrations, it is assumed that NO_2 concentration at the point *(x, y, z)* is the function of nitrogen oxides concentration at the point $\mathbf{x} = (x, y, z)$ at the time *t* and the intensity of short-term solar radiation $s_r(\mathbf{x}, t)$. Therefore, the concentration of nitrogen dioxide after the time *t* can be expressed as follows:

$$\psi(\mathbf{x}, q_{NO_x}, t, \wp, NO_2) = q_{NO_x} \cdot 0.99^t \cdot e^{-\left(b - c \cdot s_r(\mathbf{x},t)\right)^2} \hat{\psi}(\mathbf{x}, t, \wp, NO_x)$$

where: $b = 0.43$, $c = 0.03$ and q_{NO_x} is NO_x emission.

PM10 absorption by the surface

In BackTrack it is assumed that PM10 does not undergo any transformation and does not rebound from the ground ($\alpha = 0$). It should be noted that a large quantity of PM falling to the ground returns to the air due to conducive atmospheric conditions.

SYSTEM VALIDATION

In validation of the BackTrack model 24-hours forecast concentration of air pollutants was used. The goodness of the model was expressed by root mean squared error (RMSE) of the differences between hourly modeled and observed concentrations calculated for all monitoring stations.

The learning procedure adopted in the BackTrack Model reduces considerably the root mean squared error of modeled PM10 and CO concentrations for the period of system operation (between May 2006 and February 2008).

For the entire time of system operation the RMS error for PM10 is 91 $\mu g/m^3$. Monthly RMSE decreased from 125 $\mu g/m^3$ at the beginning of the system operation to about 40 at the current period. The smallest RMSE was observed in the summer 2007 (Fig. 7).

For the same time RMS error for CO is 840 $\mu g/m^3$. Monthly RMSE of CO decreased from 2600 $\mu g/m^3$ in autumn 2006 to 800 $\mu g/m^3$ at the current period.

In the case of SO_2 and NO_2 the RMS error does not change so significantly.

For the entire time of system operation the RMS error for SO_2 is 17 $\mu g/m^3$. Monthly RMSE increased in last months reaching recently 22 $\mu g/m^3$.

With respect to NO_2 the RMSE for the same period was 21 $\mu g/m^3$ and it does not change significantly.

The results of the BackTrack modeling were also compared with the results of modeling conducted within the CITY-DELTA project focused on air pollution monitoring stations in Silesian Voivodeship. CITY-DELTA [4] project, which constituted a part of the European Project – CAFE (Clean Air for Europe), aimed to create a platform to compare effectiveness of various models of transport and dispersion of air pollution. The following models were tested for Silesian Voivodeship: (1) CAMx – Agenzia Milanese Mobilita e Ambiente, Milan, (2) LOTOS – TNO-MEP, Apeldoorn, (3) CALGRID TCAM – Universita degli studi di Brescia, Brescia, (4) CMAQ – Technical University of Madrid and (5) CHIMERE – CNRS LMD, Paris. Table 2 shows the results of comparisons of the

BackTrack Model with other models. Analyzing this table we can conclude that SINZaP generates similar results in comparison with other dispersion models.

Table 2. Root mean square error between the modeled and observed concentrations of the BackTrack model and the models analyzed in the project CITY-DELTA

Pollutant	Average time	Model name					
		SINZAP	CAMx	LOTOS	CALGRID TCAM	CMAQ	CHIMERE
SO_2	1-hour	17.49	–	–	–	–	–
NO_2	1-hour	21.19	23.98	32.79	22.29	17.45	16.75
CO	1-hour	838.77	–	–	–	–	–
PM10	1-hour	91.73	–	–	–	–	–
SO_2	24-hours	11.55			–	–	–
NO_2	24-hours	15.21			–	–	–
CO	24-hours	468.33			–	–	–
PM10	24-hours	27.74			33.69	45.77	43.61

CONCLUSIONS

Traditional pollution monitoring systems contain many shortcomings. They tend to generate incomplete information; they are late in obtaining information relevant to air quality management; they are ineffective in utilizing information.

A system based on the so-called concept of an intelligent monitoring system is free of the above drawbacks. According to the concept, an intelligent monitoring system should:

- utilize the latest information on the air quality from the Internet,
- be capable of recognizing and assessing the pollution sources that affect the monitoring stations,
- interpret available monitoring data and based on them – identify the behavior of air pollution emission sources.

The complete set of the above traits add aspect of intelligence into the system, at the same time, ensuring many other effects that improve the quality of information provided to end users. One of the most important characteristics of an intelligent monitoring system is a more efficient utilization of the monitoring data, accompanied by a higher quality of output data, and first and foremost – incurring no additional costs. Traditional monitoring networks operate in connection with expert teams analyzing, simultaneously or ex post, the monitoring data and providing reports to relevant authorities. An interactive air pollution monitoring system considerably minimizes the demand for such services, thus reducing the cost of the whole system. The above-mentioned advantages make such systems more attractive which finally results in superseding the traditional solutions.

The SINZaP system developed by IETU according to the concept of the intelligent air pollution monitoring system has been operating efficiently since 2006. The system is also used to prepare 24-hour forecasts of sulphur dioxide, nitrogen dioxide, PM10 and carbon oxide. The results from modeling of air pollution concentrations conducted by SINZaP are similar to the monitoring results obtained in other European countries and the neural network approach implemented in the system considerably reduces forecast uncertainty.

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SINZaP – INTELIGENTNY SYSTEM MONITORINGU ZANIECZYSZCZEŃ POWIETRZA

Artykuł przedstawia koncepcję inteligentnego systemu kontroli napływu zanieczyszczeń powietrza oraz implementację systemu zwaną SINZaP, uruchomioną w IETU w 2006 r. SINZaP jest działającym w czasie rzeczywistym systemem do modelowania emisji zanieczyszczeń i stężeń zanieczyszczeń powietrza, podobnym do sieci neuronowej, przeznaczonym dla specjalistów w zakresie zarządzania jakością powietrza. W SINZaP do modelowania emisji i stężeń zanieczyszczeń powietrza wykorzystano model trajektoryjny BackTrack bazujący na modelu VLSTRACK. Cechą BackTrack jest wykorzystanie trajektorii wstecznych do selekcji źródeł oddziałujących na receptor. Do modelowania trajektorii BackTrack wykorzystuje trójwymiarowe pole wiatru, prędkość dynamiczną, długość Monina-Obuchowa oraz wysokość warstwy mieszania. SINZaP składa się z czterech głównych modułów: (1) modułu danych w tym skanera danych o jakości powietrza udostępnionych w internecie, (2) modułu przygotowania danych meteorologicznych, (3) modułu BackTrack do symulacji emisji zanieczyszczeń i symulacji stężeń, (4) modułu modyfikującego parametry źródeł w oparciu o analizę wyników modelowania i wyników monitoringu.