SYSTEMS RESEARCH INSTITUTE
POLISH ACADEMY OF SCIENCES

INTERNATIONAL INSTITUTE FOR APPLIED SYSTEMS ANALYSIS

CONTRACTED STUDY AGREEMENT REG/POL/1

"CONCEPTS AND TOOLS FOR STRATEGIC REGIONAL SOCIO-ECONOMIC CHANGE POLICY"

STUDY REPORT

PART 3

APPENDIX: SOFTWARE AVAILABLE

COORDINATOR, IIASA: A. KOCHETKOV
COORDINATOR, SRI PAS: A.STRASZAK

ZTS/ZPZC/ZTSW 1-36/85

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Consisting of 3 Parts

PART 3

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V. COMPUTER MODEL FOR REGIONAL AIR POLLUTION FORECASTING

by Piotr Holnicki and Andrzej Kałuszko

V.1 The mathematical forecasting model

In the paper a computer model for short-term forecasting of air pollution in a region is presented. The model calculates the values related to spatial distribution of pollutant concentration within the forecasting period (in the basic version approximately 1-3 days). The horizontal dimensions of simulated dispersion process are 50 km x 50 km.

The main input data can be divided into the following four groups:

i) independent of time structural data
- the forecasting period - T,
- geometrical dimensions of the domain,
- geometry of urban and industrial areas,
- topography,
- aerodynamic roughness of the terrain.

ii) meteorological forecast
- the mixing layer height - H,
- geostrophic wind components,
- atmospheric stability,
- precipitation intensity.

iii) characteristics of emission sources
- spatial distribution,
- emission intensity.

iv) the initial and boundary conditions.

The physical process of pollutant dipersion in the atmosphere is considered in a rectangular domain $\Omega = L_1 \times L_2$ containing the analyzed region (see Fig.V.1). It is described by

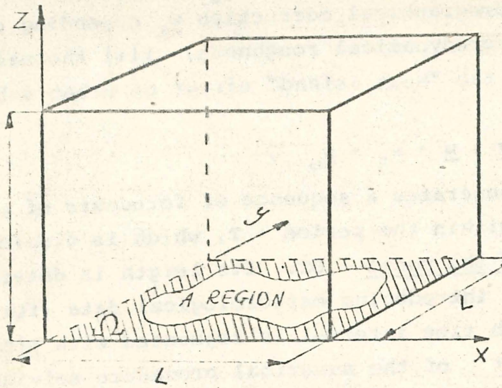

Fig. V.1 The simulated area

two-dimensional (averaged over the mixing height - H) advection--diffusion equation of the form

$$\frac{\partial c}{\partial t} + \underline{w} \cdot \nabla c - K_H \nabla c + \gamma c = \overline{Q} + (E - v_d c)/H \quad \text{in} \, \Omega \times (0,T) \, , \tag{1}$$

along with the boundary conditions

$$\left.\begin{array}{lll} \dfrac{\partial c}{\partial \underline{n}} = 0 & \text{for} & \underline{w} \cdot \underline{n} > 0 \\ c = 0 & \text{for} & \underline{w} \cdot \underline{n} \leq 0 \end{array}\right\} \quad \text{on } \partial\Omega \times [0,T], \tag{2}$$

and the initial condition

$$c\ (0) = c^o \quad \text{in} \ \Omega \ . \tag{3}$$

Here c - denotes a pollutant concentration in [μg/m^3], $\underline{w}$=[u,v] - the wind vector in [m/s], K_H - horizontal diffusion coeficient in [m^2/s]. Q - averaged over H pointwise emission field in[μg/m^{3}s], E - area emission field in [g/m^{2}s], v_d - dry deposition coefficient in [m/s] , γ - wet deposition factor depending on precipitation intensity.

The values of the wind field vector $\underline{w}$ (x,y,t) in domain are generated by a special procedure which calculates succesively: i) the averaged over Ω value $\underline{w}_\Theta$ basing on meteorelogical forecast, ii) topographical correction $\underline{w}_t$ depending on the ground topography and aerodynamical roughness, iii) thermal correction $\underline{w}_\Theta$ depending on the "heat island" effect of urban subregion. Finally we have

$$\underline{w} = \underline{w} + \underline{w}_t + \underline{w}_\Theta \quad , \tag{4}$$

The model generates a sequence of forecasts of pollutant concentrations within the period - T, which is discretized with <u>time interval of the model</u> - DT. Its length is determined by the frequency of introducing meteorological data (for example DT = 6 hrs). Each time interval is segmented with <u>time discretization step - τ</u> of the numerical procedure solving the advection-diffusion equation (see Fig.V.2). All the time-dependent

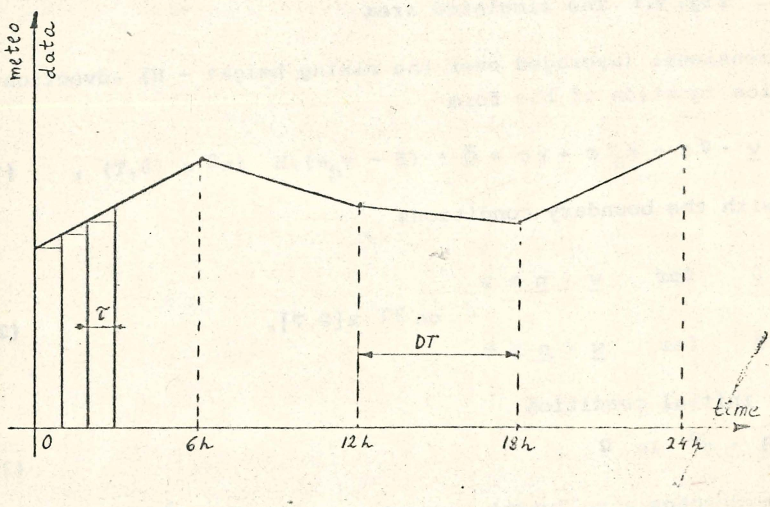

Fig. V.2 The time discretization

data at the inner points of the interval DT are linearly interpolated. The initial-boundary value problem (1) - (3) is numerically solved by an effective finite element-characteristics procedure, Holnicki et. al. (1983), Holnicki and Żochowski (1985).

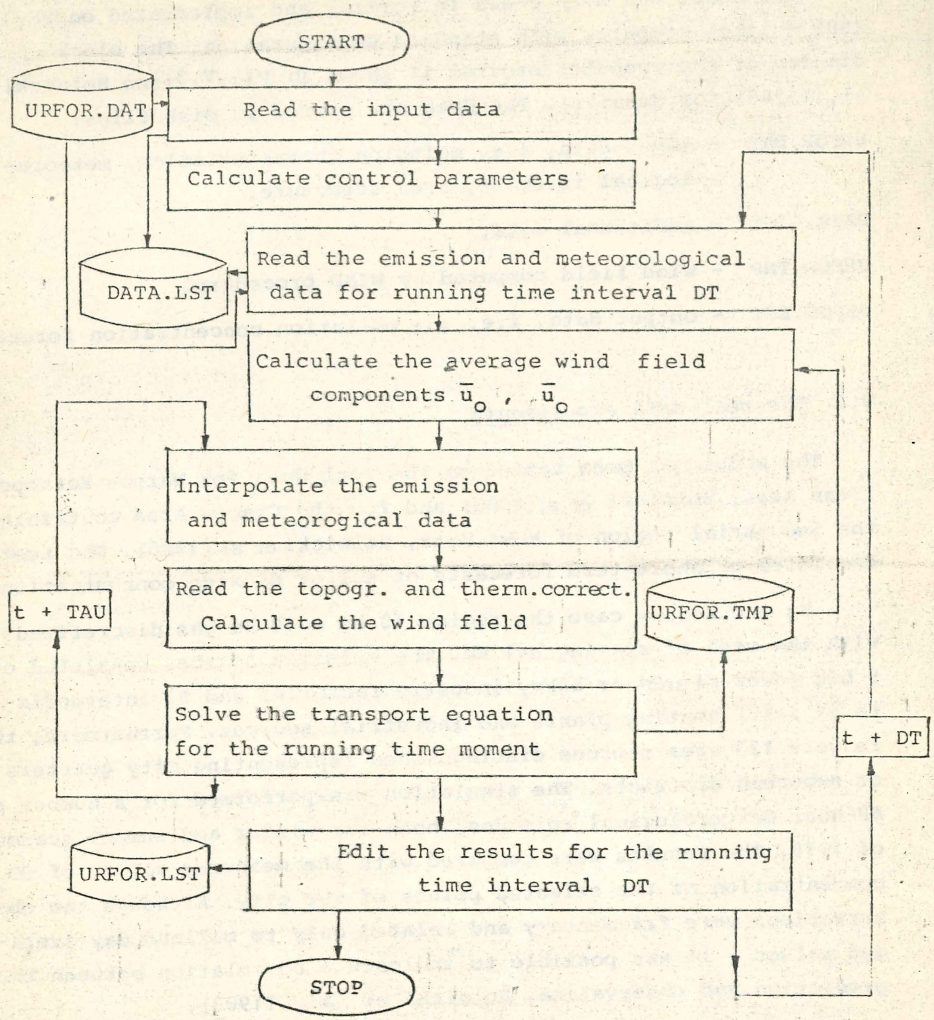

Fig. V.3 Flow diagram of the program.

The model has been coded in Fortran and implemented on SM-4 (PDP - like) computer with standard configuration. The block diagram of the computer program is shown in Fig. V.3 (see Holnicki et al. (1983) for details). The data are stored in disk files:

URFOR.DAT - input data, i.e. emission charakteristics, meteorological forecast, area structure.

DATA.LIST - additional data.

URFOR.TMP - wind field computed by WIND procedure.

URFOR.LST - output data, i.e. air pollution concentration forecast

V.2 The real data experiments

The model has been tested on the real data for Warsaw Metropolitan Area, Holnicki et al(1983) and for the Cracow Area containing the industrial region of Nowa Huta, Holnicki et al.(1985). The tests consisted of short-term forecasts of sulfur dioxide concentration.

In the Warsaw case the region 40 km x 40 km was discretized with the mesh of spacing h=1 km. The emission sources consisted of 5 big power plants or heavy industry factories and 83 intermediate or small heating plants and industrial sources. Furthermore, there were 123 area sources distinguished representing city quarters or suburban districts. The simulation was performed for a number of 48-hour meteorological episodes, both for winter and summer seasons of 1978. The results were compared with the measured values of SO_2 concentration at the selected points of the city. Although the observations were fragmentary and related only to maximum day-averaged values - it was possible to indicate a correlation between the prediction and observation, Holnicki et al. (1983).

The Cracow - case experiment was based on a complex, spatial and temporal observation of SO_2 concentrations and full meteorological data covering February of 1984. The model was examined for 5 selected 24-hours episodes. The emission characteristics of industrial and residential sources were considered. The correlation of the model forecast with the measurement values was, in general, satisfactory, Holnicki et al. (1985).

The run time of the program for both these cases is about 10 minutes for 24 hours forecast and for the standard space discretization.

V.3 Possible applications to regional environmental policy.

Although the model was designed for other applications, it can be also used to analysis and formation of regional environmental policy. The following groups of applications are possible:

1. Evaluation of the environment deterioration in the region related to:
   - local emissions in the region and extremal inflow of pollutants,
   - population density and urban geometry,
   - forest areas and their geometry,
   - agricultural areas and their geometry.
2. Simulation (forecasting) of the extremal environment deterioration situations caused by:
   - extremely unconvenient meteorological conditions,
   - extremely high emission intensity.
3. On-line emission control in order to minimize environment deterioration costs subject to economical and technological constraints. It can be achieved by:
   - fuel quality control,
   - control via redistribution of the emission within existing power plants system.
4. Evaluation of the industrial (including power plants) investments from the environment protection point of view.
5. Design of the optimal funds allocation for:
   - new investment, i.e. determination of the location and the production capacity.
   - modernization of existing industrial plants subject to environment protection and economical constraints.

It can be achieved by the time rescaling of the model.

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