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WIND FIELD OVER COMPLEX TERRAIN AND AIR QUALITY MODELING

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1. Introduction

The wind field is the second component in the chain: Source - Propagation - Object, and plays an important role in the atmospheric pollution processes. But determining the exact wind field for numerical air pollution modeling always is a difficult problem. In the numerous codes the semi-empirical model based on Gaussian or Berliand conceptions and using the uniform wind field in combination with observational and measurement data [1, 2] is applied to simulate the pollutant transport due to convection and its dispersion due to turbulence. In fact, this kind of model, which requests statistical meteorological information, is simple, easy to use, but normally applicable for small spatial area (small scale, some kilometers from pollutant emission sources). In the area with complex terrain, for example, mountain and coastal zones the wind field changes from time to time and usually has non-uniform distribution. Therefore in those cases the simplified model listed above will lead to a significant error.

In the paper the mesoscale wind field simulation and air quality modeling results using three dimensional numerical package LADM [3] and the influence of complex terrain (raising mountain and coastal line) on the wind field and pollutant propagation for some examples such as north-east (Hai phong, Quang ninh) and central (Dung quat) provinces of Vietnam are presented. All calculations are implemented on PC Pentium 100 at the Institute of Mechanics - NCNST (Hanoi).

2. Mathematical models

2.1. Wind field model

Governing equations

In order to simulate the atmospheric turbulent motion the basic equations of thermo- and hydrodynamics taken into account of astronomical and meteorological conditions such as the short wave radiation (changing from time to time during the year and depending on the astronomical angle), Coriolis force, cloud (cloud type, level cover and etc.) and influence of the thermo-hydrodynamical processes, surface properties and etc. are used and closed by the K-theory.

In general, the system of equations, including the equation of mass conservation, impulse conservation in vector form, energy conservation in the form of the thermal conductivity equation and equation for humidity change, has the following form:

$$\frac{D\rho}{Dt} + \rho(\nabla \cdot \overline{v}) = 0 \tag{2.1}$$

$$\frac{D\,\overline{v}}{Dt} + [\overline{\Omega} \times \overline{v}] = -\frac{1}{\rho}\,\mathrm{grad}\,p - g\overline{k} + (\nabla \cdot K_d\nabla)\overline{v} \tag{2.2}$$

$$\frac{D\theta}{Dt} = (\nabla \cdot K_\theta\nabla)\theta + q_r \tag{2.3}$$

$$\frac{Dc_h}{Dt} = (\nabla \cdot K_h\nabla)c_h \tag{2.4}$$

where the symbols are used traditionally and, respectively, ρ, p, $\overline{v}$ are a density, pressure and vector velocity; θ is a temperature potential; K is a diffusion coefficient; q_r is a thermal flux due to radiation; c_h is a humidity and g is the gravitational coefficient.

The temperature T can be presented through θ in the following manner:

$$T = \theta\left(\frac{p}{p_*}\right)^{R/C_p} \tag{2.5}$$

where R is the gas constant; C_p is a heat capacity at constant pressure; p_* is the standard pressure and equal 1000 mbar.

In order to integrate numerically the system of equations (2.1)-(2.5) is transformed using hydrostatic assumption into the system of coordinates $(x, y, \sigma = p/p_s)$ where p_s is surface pressure.

Boundary conditions

- Lateral:

The wind field calculation is implemented using "nest" techniques. In the framework of this techniques the wind field is simulated for the nests one smaller another. The first calculation is mplemented for the biggest nest with the zero-gradient conditions at the boundary. The calculation results are used as boundary conditions for the next smaller nest, and the process is continued until the smallest nest which we are interested in. Normally the biggest nest has the size of 800 km × 800 km, and every the next nest has the half size of the previous nest.

- Surface:

The wind velocity at the surface is zero. The thermal, dynamical and moist conditions are given depending on the surface material properties such as water, soil (clay, sand, rock etc.) and covering flora (soil-canopy). For the temperature the equation of the soil thermal conductivity is solved.

- Upper:

The height of the simulation box is 19700 m above the sea level. With this height the non-reflection of upward propagating waves from the top of model is assumed.

Initial data

Besides elevation of the terrain above sea level, also needed are vertical profiles of wind and emperature at a point near the study region center. The wind profile must reflect the synoptic-scale pressure gradients and obtained from mean ground-level pressure charts and geopotential height charts at 1000 hPa, 850 hPa, 700 hPa, 500 hPa and etc. The initial data should be representative of the study region and applied at all grid columns.

The obtained system of equations (2.1)-(2.4) is solved by the finite difference method using the Arakawa C-grid, fractional time steps and the sweep procedure. The model run usually begins at midnight to allow the wind to adjust to the terrain and to allow time for drainage flow to develop before diurnal heating begins at sunrise. It is also advisable to run the model for 48 hours and more, and compare predictions to observations during the second 24 hours, thus allowing time for he formation of mesoscale pressure gradients from the diurnal heating of the previous day.

2.2. Pollutant dispersion

In order to simulate the pollutant propagation process within the Lagrange conception the quation for the particle position determining is used:

$$x_i(t+dt) = x_i(t) + [v_i(t) + v_i''(t)]dt \tag{2.6}$$

where v'' is turbulent component of velocity determined by Langevin equation

$$dv_i'' = a_i dt + (C_0\epsilon)^{1/2} dw_i \tag{2.7}$$

and Fokker-Planck equation:

$$\frac{\partial a_i P_E}{\partial v_i''} = -\frac{\partial v_i''}{\partial x_i} + \frac{1}{2} C_0 \epsilon \frac{\partial^2 P_E}{\partial v_i''^2} - \frac{\partial P_E}{\partial t} \tag{2.8}$$

Here a_i is an acceleration, dv_i'' is a change in turbulent velocity over the time interval dt, ε is the rate of dissipation of turbulent kinetic energy, C_0 is a universal constant; dw_i is a random variable which has a Gaussian distribution (mean 0, variance dt) and P_E is the probability density function representing the turbulence.

In convective (unstable) conditions for the top of the mixed layer and surface the condition used is the skewed memory reflection. The only boundary condition employed in stable conditions is at the ground where perfect reflection of a particle's velocity and position is assumed to occur. The height, at which particles are released through the simulation period, is determined from the bent-over plume rise equations.

The initial concentration is a font concentration. As the input data, the dispersion model uses the wind fields and turbulence parameters, obtained from the model presented in 2.1, to advect and diffuse the particles. These values are updated every ten minutes. For the pollutant source, it is necessary to specify emission characteristics needed for the plume rise calculations, such as the emission (stack) height, flue gas speed and temperature, pollutant contains and etc.

The more detailed mathematical description of models and results of its verification (analysis of case studies and comparison with observations) can be seen in [3]. Note that for a single mountain the influence of the terrain on the wind field, maximum surface concentration and etc. can lead to a significant effect normally when the slopes are typically greater than 1:10.

3. Wind field over some complex terrains

The terrains structure is digitized and kept in the form of data file on a PC. For example, in Figs 1-5 the terrain structure maps of north east (Figs 1-4) and central (Fig. 5) provinces of Vietnam are presented. The iso-level contours indicate the heights with interval of 100 m.

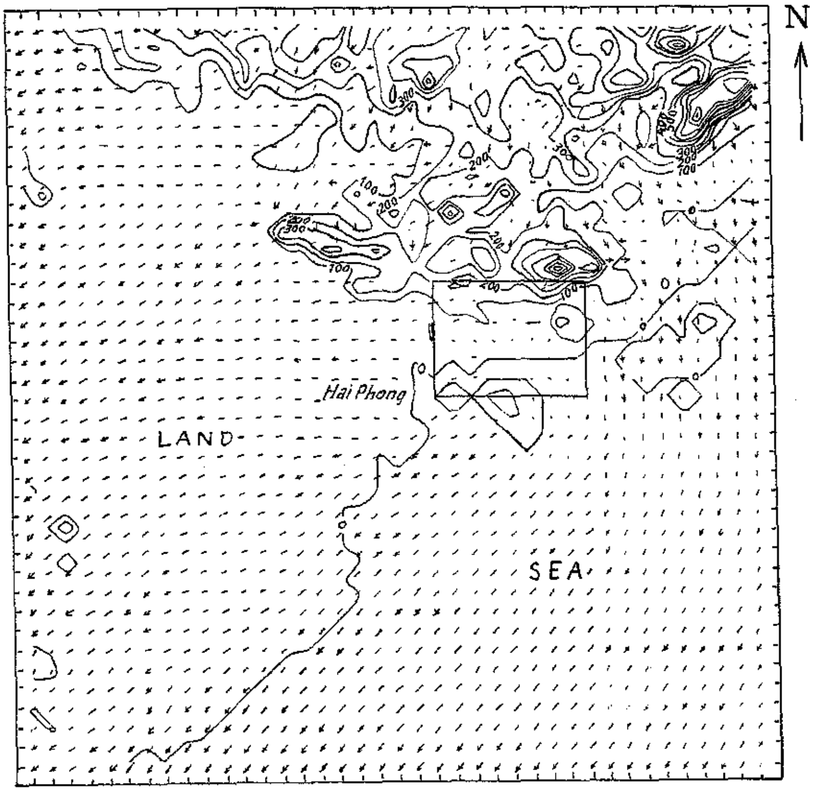

Fig. 1. Modeled wind fields - 06h - 10m - Winter ⟶ 10. m/s

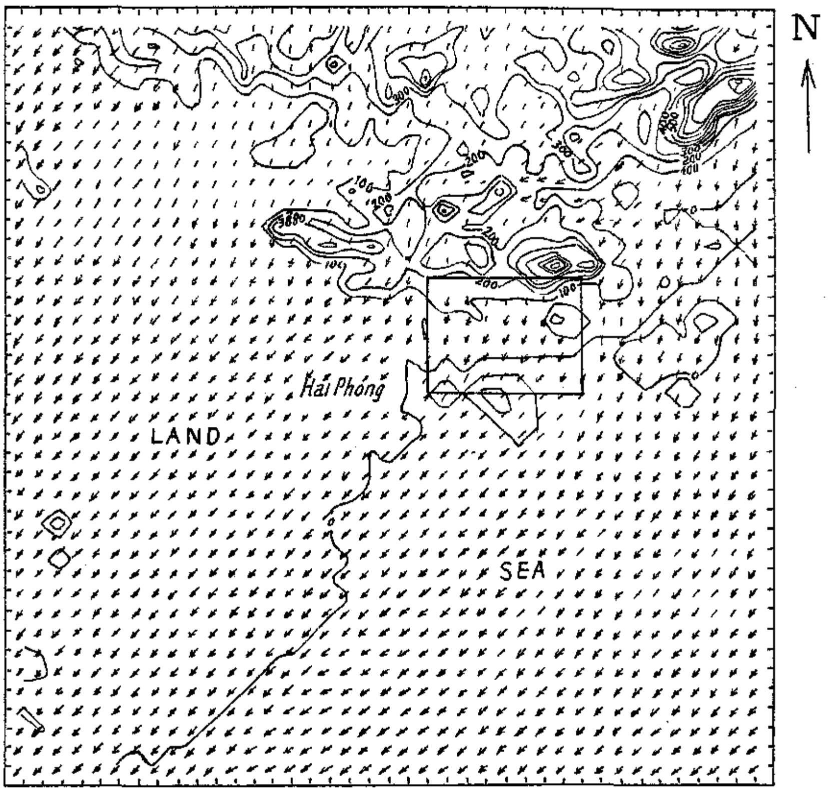

Fig. 2. Modeled wind fields - 11h - 10m - Winter ⟶ 10. m/s

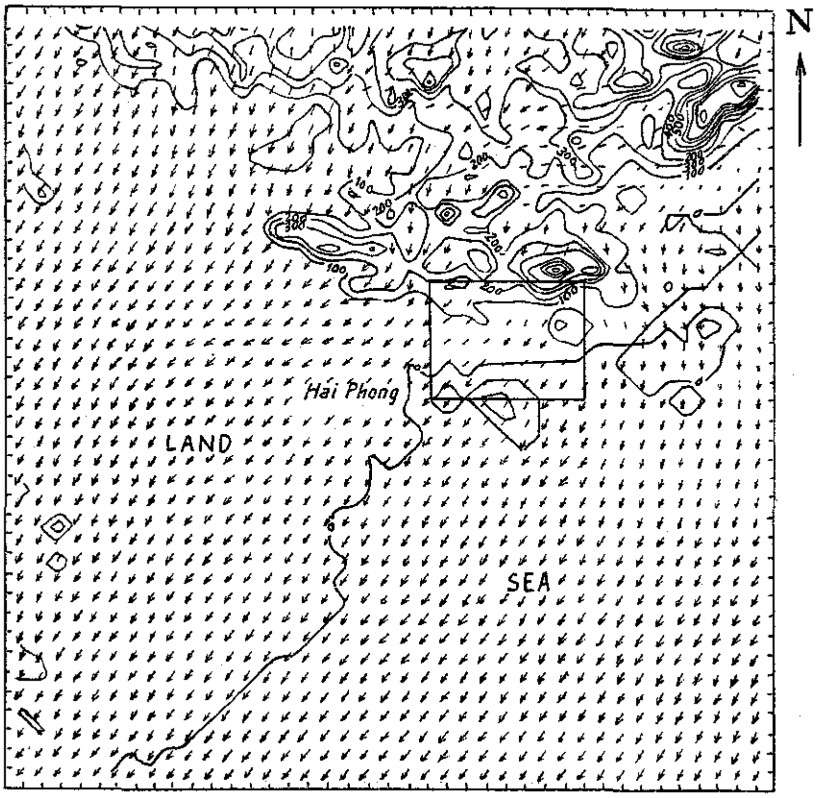

Fig. 3. Modeled wind fields - 19h - 10m - Winter ⟶ 10. m/s

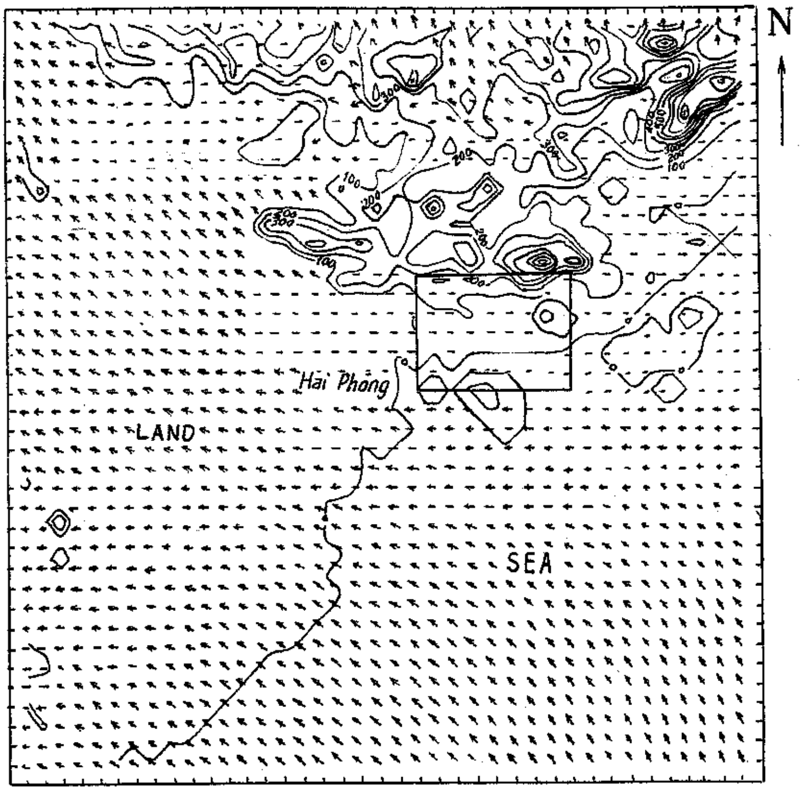

Fig. 4. Modeled wind fields - 06h - 10m - Summer → 10. m/s

In order to investigate the wind field over complex terrain and pollutant propagation, 3 case studies (simulations) have been carried out accordingly to the following initial conditions:

Case study 1 (Figs 1-3)

Level (hPa)	Height (m, Ground surface-hPa)	Wind direction -Wind speed (m/s)	Temperature (°C)	Specific Humidity (g/kg)	Relative Humidity (%)
Ground surface	1022.0	E-2	25	20.0	100
1000	10	SE-2	26.4	19.9	90
850	1436	SW-2.5	20.8	15.5	87
700	3090	WSW-5	10.8	11.4	98
500	5830	NW-7	-3.9	5.6	100
300	9710	NE-30	-27.7	0.9	95
200	12490	NE-10	-48.5	×	×
100	16690	ENE-22	-73.3	×	×

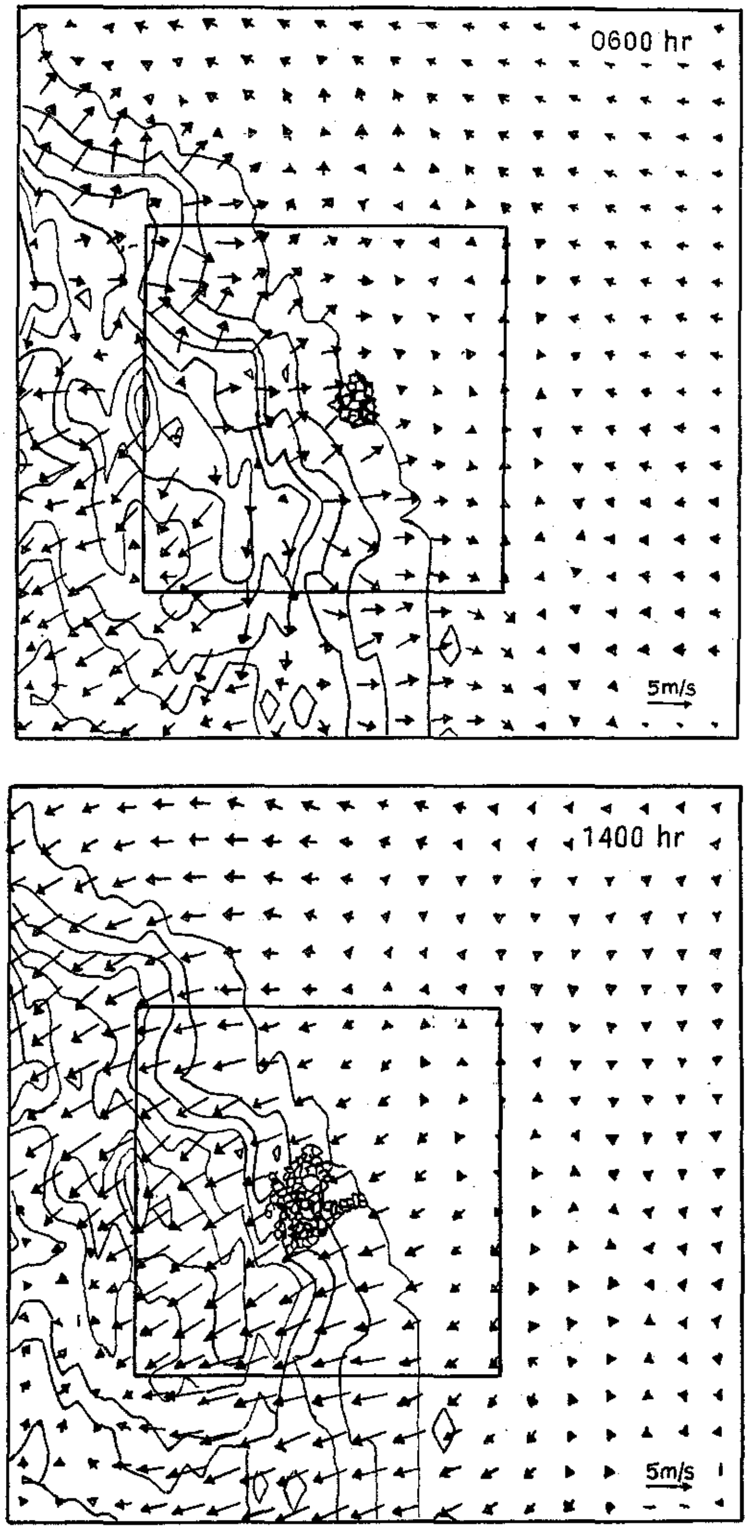

Fig. 5

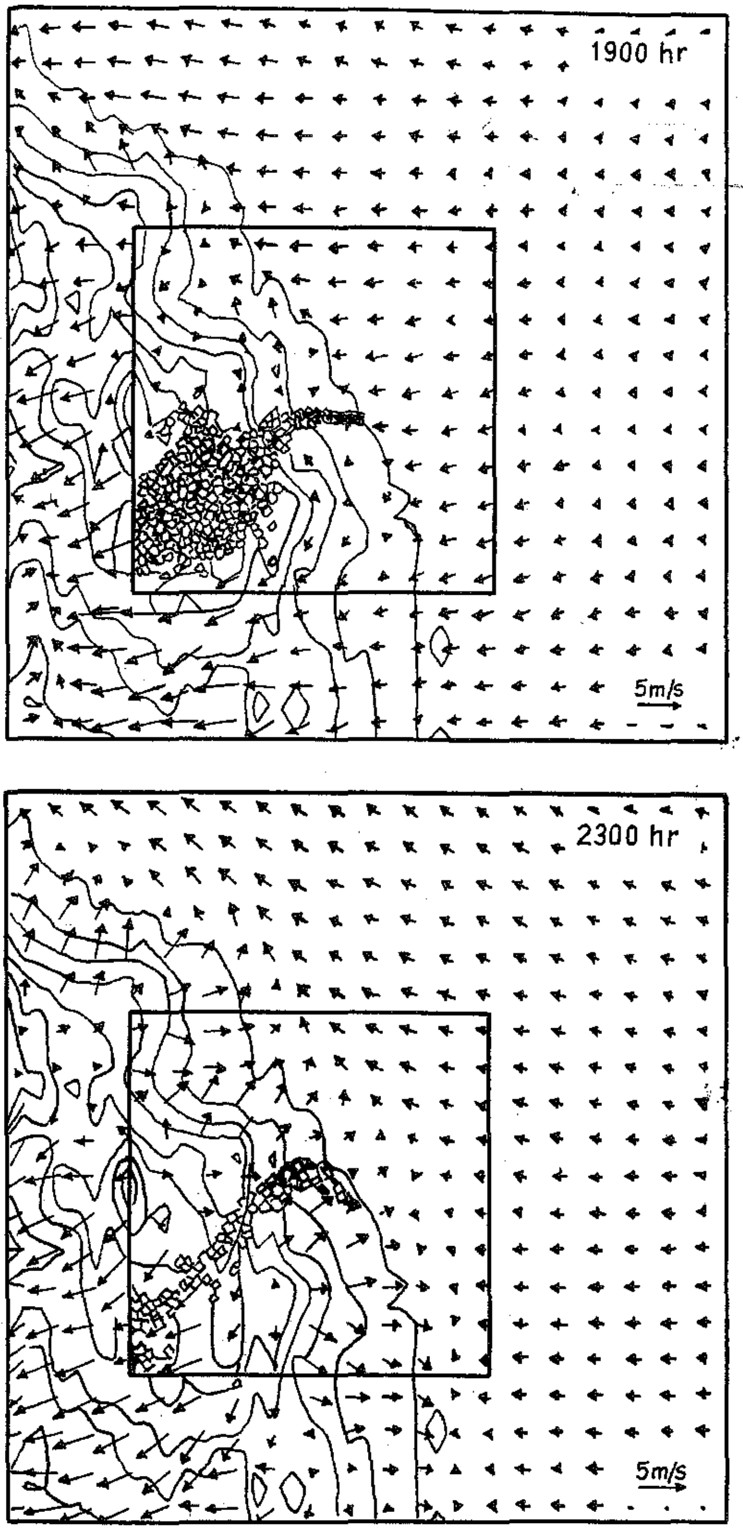

Fig. 5 (continued)

Case study 2 (Fig. 4)

Level (hPa)	Height (m, Ground surface-hPa)	Wind direction -Wind speed (m/s)	Temperature (°C)	Specific Humidity (g/kg)	Relative Humidity (%)
Ground surface	1022	NE-2	14	9.3	85
1000	183	NE-2	12.2	8.2	82
850	1545	N-4	10.2	8.7	90
700	3140	W-7	7.4	6.6	80
500	5860	WSW-17	-8.7	1.1	30
300	9650	WSW-30	-28.9	0.3	38
200	12440	WSW-30	-48.3	×	×
100	16670	SW-12	-76.9	×	×

Case study 3 (Fig. 5)

Level (hPa)	Height (m, Ground surface-hPa)	Wind direction -Wind speed (m/s)	Temperature (°C)	Specific Humidity (g/kg)	Relative Humidity (%)
Ground surface	1012	SE-2	26	20.6	95
850	1512	ENE-5	16.1	12.7	96
700	3142	E-5	7.9	6.6	80
500	5849	ESE-5	-5.9	1.1	30
300	9660	S-5	-31.9	0.3	38
200	12394	S-7.5	-54.1	×	×
100	16546	ESE-5	-79.1	×	×

These case studies are rather typical for the winter (case 2) and summer (case 1 and 3) seasons in Vietnam.

In Figs. 1-4 the calculated wind field on the height of 10 m from the ground at moment 6h00 (Figs 1, 4) 11h00 (Fig. 2) and 16h00 (Fig. 3) are presented. The inner square domain has a pollutant source at the center. The similar pictures for the central provinces around Dung Quat are presented in Fig. 5. In Figs 1-4 the vector fields are depicted with spatial interval of 5 km, and in Fig. 5 - of 10 km. From the figures it can be seen the place where the wind field is influenced by terrain. The calculation results show clearly that in the place far from the elevated terrain the wind field is relatively uniform and changes gradually from time to time. In the mountain area the wind field has non-uniform structure and change strongly (in direction and in value) from time to time. In this case to choice the common characteristic wind velocity for a big enough area is the question. This means the application of simplified models based on the stationary or pseudo stationary hypothesis can lead to considerable errors.

Comparing figures one with another indicates also the influence of sea breeze on the wind field distribution. In general this influence depends on different factors and in many cases plays significant role in the area of some tens km from the coastal line.

From the presented above figures we can see that although the synoptic wind is strong enough, the wind field changes significantly in both direction and values by terrain.

The calculation results show that the wind field in the complex terrain areas is relatively chaotic. The velocity vectors of the neighboring points can be strongly different in directions and values. And even in the 5 km radius area the wind can have opposite directions. In this and similar cases using simplified model based on Gaussian or Berliand conception even with modification is questionable.

Concentration (SO2) - 11h - Winter - Microgram/m^3

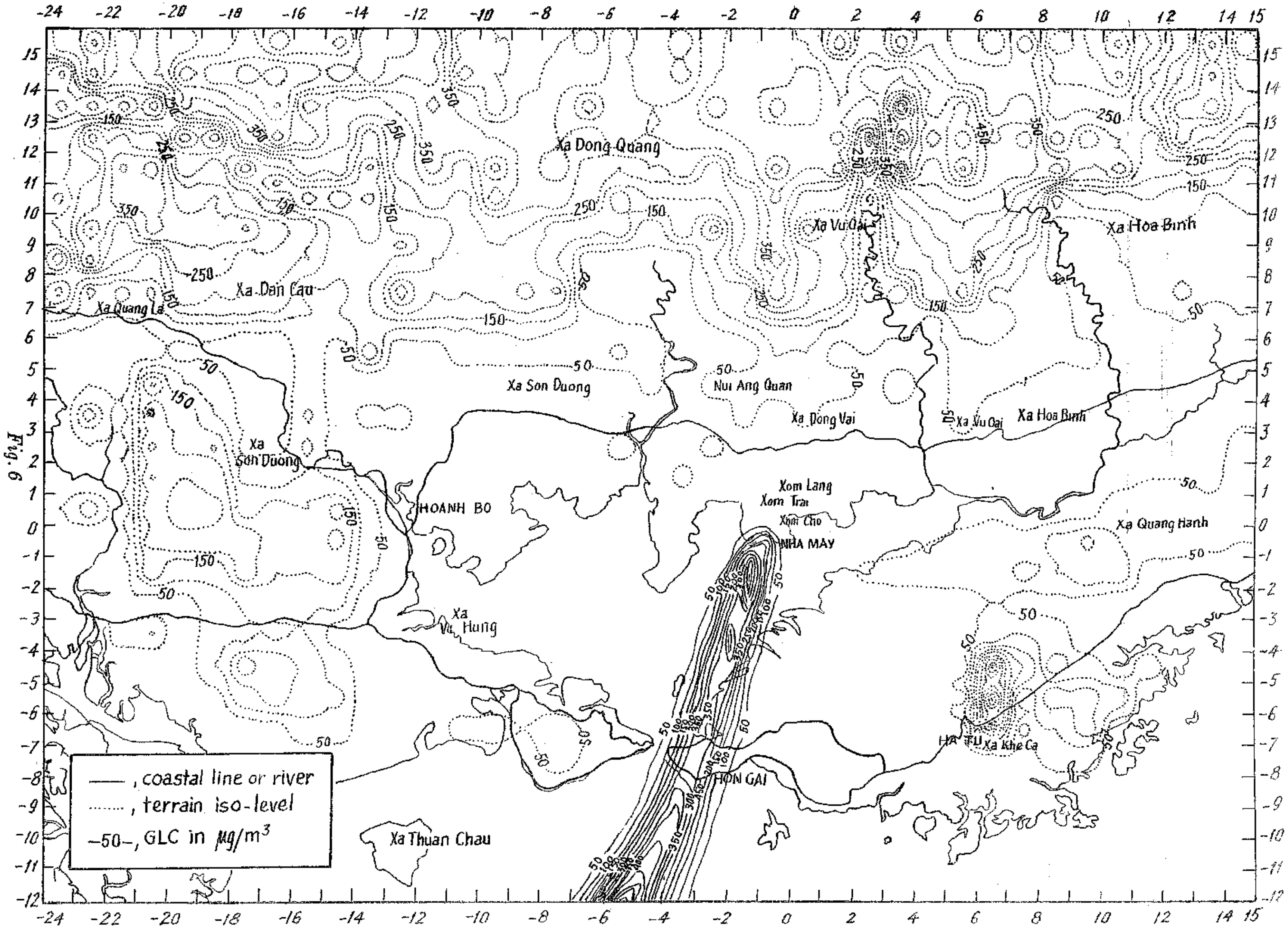

Fig. 6

4. Pollutant propagation

Based on the obtained in 3 wind field the pollutant propagation in the air can be calculated and predicted.

As an example, in Fig. 6 the GLC (ground level concentration) distribution of SO_2 for case study 1 is presented. In this case the proposal plant assumed has two stacks with a height of 100 m, inside diameter of 3.96 m and volumetric flow of 14000 m^3/min at 165°C. The flue gas contains about 500 mg SO_2 per a normal cubic meter. Because the wind field is simulated at any time moment, accordingly the pollution map can be obtained at any time and normally this map will change from time to time. The simulation results are necessary not only for environment pollutant assessment, but especially useful for designing and predicting purposes. In Fig. 5 all the particle release (with the view from the top) is presented for another case (case study 3) with following parameters: the stack height $h_s = 100\,\mathrm{m}$, the inner radius of stack $r_s = 2\,\mathrm{m}$, flue gas speed $v_s = 15\,\mathrm{m/s}$; the flue gas mass flow $q_s = 1\,\mathrm{kg/s}$, $T_s = 100°\mathrm{C}$. The plant site is near Dung Quat gulf (N. 15.5, E. 108.7).

It should be noted that the numerical package LADM simulates the three dimensional turbulent atmospheric motion (LADM-M) and pollutant transport and dispersion (LADM-P). It is a big simulator requested strong PC (Pentium 100 and later with 32 Mb RAM and hard disk memory $\geq$ 2Gb) with a long running time ($\approx$ 20-30 hours/1 case study). The package has the Graphical Information System convenient for presentation of the simulation results in a form of 1-D, 2-D and 3-D pictures.

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TRƯỜNG GIÓ VÙNG ĐỊA HÌNH PHỨC TẠP VÀ MÔ HÌNH HÓA CHẤT LƯỢNG MÔI TRƯỜNG KHÔNG KHÍ

Trường gió là thành phần thứ hai trong chuỗi: Nguồn - Tải - Đối tượng và đóng vai trò quan trọng trong các quá trình ô nhiễm khí quyển. Tuy nhiên việc xác định được chính xác trường gió để sử dụng trong các mô hình số về ô nhiễm không khí luôn là một vấn đề khó, đặc biệt đối với những vùng có địa hình phức tạp như vùng núi hay vùng chịu ảnh hưởng gió biển. Trong bài báo trình bày một số kết quả mô phỏng trường gió 3 chiều và tính toán chất lượng môi trường không khí sử dụng mô hình dòng rối khí quyển và tán xạ theo quan điểm Lagrange cho một số tỉnh ở đông bắc (Hải Phòng, Quảng Ninh) và miền trung (Dung quất) Việt Nam trong một số trường hợp nghiên cứu. Kết quả tính toán được thu nhận trên máy tính Pentium 100 với 32 Mb RAM.