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Hrvatski meteorološki časopis, 28, pp. 7-17, 1993.

UDK: 551.553
Izvorni znanstveni rad

WIND FIELD SIMULATION IN METEOROLOGICAL APPLICATIONS IN CROATIA

Simulacija polja vjetra u primjeni meteorologije u Hrvatskoj

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Primljeno 1. ožujka 1993, u konačnom obliku 10. kolovoza 1993.

Abstract - This paper describes two numerical models for computing the mesoscale influences of orography, friction and heating on the wind field. The DM1 model is a diagnostic, one-level, primitive equation model and the DM2 is a mass-adjusted, three dimensional wind field model where interpolated three-dimensional mean winds are adjusted in a weighted least-squares sense to satisfy the continuity equation within the volume specified. The models are capable of simulating a broad scale of atmospheric phenomena such as orographic channelling, effects due to changes in atmospheric stability, land and sea breezes, and anabatic and katabatic winds. The main attention is paid to the performed models' applications for different purposes in the Meteorological Service of Croatia. The given application examples illustrate the broad spectrum of applications made possible by the models' flexibility in treating different weather situations and regions.

Key word index: Numerical modelling, wind field, meteorological application.

Sažetak - U radu su pokazane široke mogućnosti korištenja numeričkih modela za simulaciju strujanja u orografski složenim uvjetima. U hrvatskoj meteorološkoj službi primijenjivana su dva numerička modela za simulaciju mezoskalnog utjecaja orografije, trenja i zagrijavanja na polje vjetra: DM1-dijagnostički, jednorazinski model s primitivnim jednadžbama gibanja i DM2-trodimenzionalni model s uključenim uvjetom kontinuiteta mase unutar područja rada modela. Analiza rezultata primjene modela na različitm područjima Hrvatske pokazala je da dobiveno polje vjetra odražava mnoge realne karakteristike strujanja. Ukazano je na neophodnost raspolaganja ovakvim numeričkim modelima, naročito u područjima s rijetkom mrežom meteoroloških mjerenja koja ne omogućava dobivanje dovoljno realne slike strujanja u orografski veoma razvijenim područjima.

Ključne riječi: Numeričko modeliranje, polje vjetra, primjena meteorologije.

INTRODUCTION

Coasts and mountains can greatly modify synoptic scale weather in the lower troposphere. Topographic blocking, deflection and channelling, differential heating and cooling, and differential friction produce mesoscale circulations that greatly influence and even dominate local weather.

The mesoscale and local circulation significantly influence many aspects of human activities such as physical planning and housing; design; agriculture; air, land and water transport; energy resources; environmental protection etc.

Why worry about wind in planning? It is because wind can be man's friend or enemy under different circumstances. The advantages which wind can have in physical planning and housing are numerous: it is a source of power, it ventilates, it evaporates moisture and dries surfaces, etc. As for the disadvantages, wind spreads smoke and odours, it assists snow accumulation and the penetration of water into surfaces, it requires stronger construction to resist it, and so on. If architects are aware of the direction of prevailing winds, they can design accordingly. Planners may site industrial quarters in a way to prevent the winds blowing smoke and other impurities into residential areas.

Layout design also has a marked effect upon air motion. Wind in hot, moist climates is an asset and should be exploited as natural air conditioning, for it tends to reduce temperatures and excessive humidity. In colder regimes, the main effect of the wind is to induce convective cooling and thus lower the sensation of temperature.

Many of the climatic effects on buildings require both macro- and microanalysis. This is particularly true of the role of wind for in many situations local topographic effects give rise to highly specialized conditions. For example, wind channelling through valleys requires special design.

All phases of air, sea and land transport are influenced by atmospheric conditions. The effects are felt at all levels of operation, from the construction of roads, railroads, landing strips to the on route trip and the landing and take-off conditions in air transport. On route, aircraft face many problems. Many of these are concerned with meteorological conditions and include such factors as the selection of an optimum cruise altitude in relation to upper level winds.

Wind also affects plants in many ways. One of the most obvious effect is the physical damage that high wind can cause. Wind speed influences the plant carbon dioxide intake, and transpiration rates increase with increasing wind speed. Local winds often play a very important part in modifying the entire plant cover in regions where they prevail.

During the last several years, interest has increased in the transport, diffusion, and environmental impact of air pollutants in regions of complex land forms such as valleys, hills and mountains. Knowledge of the wind field over complex terrain is a prerequisite for the analysis of pollutant dispersion and transport in the atmosphere.

One possible way to know the mesoscale wind field is to install a dense wind measurement network. This is very expensive and not possible everywhere. The measured wind data available for the mesoscale and local air flow analyses, especially for past weather situations are almost always inadequate or nonexistent. Because of that, in data-sparse areas numerical models are used for wind field simulations which provide as many data as needed for the analysis.

Several models may be used to provide two-or three-dimensional wind fields:

a) dynamic models predict the evolution of the planetary boundary layer and, hence, of temporal and spatial variation of wind velocity, but only at a relatively high computational expense;

b) interpolation techniques reconstruct the wind field on the basis of available measurements. These simple methods are in most cases inadequate, as the provided wind fields in general violate mass conservation;

c) diagnostic wind models are a suitable compromise between computational efficiency and modelling accuracy: an initial interpolation of existing measurements provides an estimate for the wind field which is subsequently adjusted to satisfy given conditions.

In the Meteorological Service of Croatia the diagnostic model has been applied for wind field simulation in different regions of the country and for different purposes.

The first developed version of the diagnostic model was based on the one-level primitive equation model constructed by Danard (1977). Although this model is simple it gives useful informations about the surface wind field. However, the two dimensional wind field turned out not to be sufficient for many applications which required a third dimension, such as an air pollution transport estimate. The incorporation of a third dimension became, therefore, necessary. For that purpose the mass-adjusted three-dimensional wind field model (MATHEW) made by Sherman (1978) was used for construction of second version of the DM2 model.

The second version of the diagnostic model constructed in the Meteorological Service of Croatia (DM2) uses an initial surface wind field obtained by the DM1 model. In the case of a neutrally stratified atmosphere the DM2 model incorporates the channelling effects caused by river valleys in the model domain according to Wippermann's approach (Wippermann, 1984; Bajić, 1984). The third wind component was obtained by including the continuity equation according to MATHEW. The programming code of Sherman's model was made by Rakovec in the Slovenian Hydrometeorological Institute. The final part of the DM2 model is a calculation of air particle trajectories. In such a way, for the first time, several model approaches were implemented in one model. The model begins with measurements at one point of the model domain and ends with three-dimensional trajectories in the whole domain.

The aim of this paper is to give a short description of the DM1 and DM2 models and a review of their applications by the Meteorological Service of Croatia.

THE DM1 MODEL

The first version of the diagnostic model (DM1) applied in our meteorological service was based on the simple, one-level, primitive equation model for the mesoscale effects of orography, friction and heating on surface winds, as constructed by Danard (1977). The model integrates tendency equations for pressure, potential temperature and wind only at the surface and does not demand mass conservation. Changes in surface pressure are determined hydrostatically by parametrized variations in the potential temperature within a layer of topographic influence above the surface. This model has many convenient characteristics such as:

1) The model can be used in data sparse area because it requires little input data. It only requires the following meteorological data at just one point: the sea-level and 850 hPa geostrophic winds, the sea-level pressure, the 850 hPa and 700 hPa heights and tem-

peratures, and the surface temperature sufficiently far inland from the shoreline to be unaffected by the land-water discontinuity.

2) It can be used historically. Suppose one is interested in a past air pollution episode and the wind data, which are essential to explain this phenomenon, are inadequate or nonexistent. It is obviously too late to install a special data network. This model could be applied to such a case.

3) Since the model does not require detailed data it is readily applied to different locations.

4) It is economical, since no special data are needed and computing costs are not high. The model can even be run with a reduced array of grid points on "mini-computers".

The Danard's modelling equations are based on the assumption that physical processes tend to have opposite effects in the upper and lower troposphere with little influence in the mid-level, where the zero-pressure change is specified. This leads to the equation of motion for the surface wind

$$\frac{\partial \boldsymbol{V}_s}{\partial t}=\boldsymbol{V}_s \bullet \nabla \boldsymbol{V}_s+K_m \nabla^2 \boldsymbol{V}_s-$$

$$-(g\nabla h_s+RT_s\nabla \ln p_s)-f\boldsymbol{k}\times \boldsymbol{V}_s+\boldsymbol{F} \qquad (1)$$

and the first law of thermodynamics

$$\frac{\partial \theta_s}{\partial t}=-\boldsymbol{V}_s \bullet \nabla \boldsymbol{V}_s+K_t \nabla^2 \theta_s+Q \qquad (2)$$

where h_s is the terrain height above sea level, θ_s is the surface potential temperature, $\boldsymbol{F}$ represents the surface friction, Q is the diabatic rate of change of θ. K_t and K_m are the thermal diffusivity and horizontal momentum, respectively, and the terms in which they appear represent the effects of subgrid-scale mixing and also help to control computational instability. The influence of atmospheric stability on channelling effects is included in the advection term in Equation (2). The index "s" denotes the surface variables. The term in parenthesis in Equation (1) is the horizontal pressure gradient force at the earth's surface in sigma coordinates $(\sigma=p/p_s)$. If θ_s is affected by the earth's surface, p_s will also be modified. The other symbols have their usual meanings, and the other details of the model can be found in the original paper by Danard (1977). Danard showed, in several cases, that the modelled winds at individual stations were generally more accurate than those produced by a simple balance of the pressure gradient, Coriolis and frictional forces.

Although this model is simple it gives useful information about the surface wind field. The incorporation of the third dimension can be done by the explicit use of the continuity equation in addition to the momentum, thermodynamic and hydrostatic equations.

THE DM2 MODEL

Mass-consistent models are used in situations with a temperature inversion which separates the airflow near the surface from the general airflow at higher altitudes or for the extrapolation of the one-level model results. For these purposes a second version of the diagnostic model DM2 was constructed in the Meteorological Service of Croatia. This model uses an initial surface wind field obtained by the DM1 model and then applies a variational technique incorporating continuity to adjust the interpolated wind field in a least-squares sense so that the mass is conserved. This was done on the basis of the MATHEW (mass-adjusted, three-dimensional wind filed) model (Sherman, 1978). The ability of this model to provide a realistic wind field depends on the quality of the input data, the interpolation scheme, and on whether physical processes such as nonlinear advection, adiabatic warming or cooling or diabatic forcing (which are not explicitly considered in this type of model) are properly represented by their implicit inclusion in the initial wind data.

The theoretical basis for this model was developed by Sasaki (1958, 1970). The general variational analysis formalism defines an integral function whose extreme solution minimizes the variance of the difference between the observed and analyzed variable values subject to physical constraints which are satisfied exactly or approximately by the analyzed values. For the DM2 model a functional is needed to minimize the variance of the difference between values subject to the strong constraint of the three-dimensional analyzed wind field being nondivergent. The specific functional used in the model is:

$$J=\oint_V \Big[\alpha_1{}^2(u-u_0)^2+\alpha_1{}^2(v-v_0)^2+\alpha_2{}^2(w-w_0)^2$$

$$+\lambda\left(\frac{\partial u}{\partial x}+\frac{\partial v}{\partial y}+\frac{\partial w}{\partial z}\right)\Big]dx\,dy\,dz \qquad (3)$$

where x, y are the horizontal directions; z is the vertical direction; u, v, w are the adjusted velocity components in the x, y, z directions, respectively; u_0, v_0, w_0 are the corresponding observed variables; $\lambda(x,y,z)$ is the Lagrange multiplier; and values of α_1, α_2 are Gauss precision moduli.

The first guess of adjusted horizontal velocity components u_0 and v_0 are obtained by using the DM1 model and the vertical wind component w_0 was calculated according to the relation

$$w_0=u_0\frac{\partial h}{\partial x}+v_0\frac{\partial h}{\partial y} \qquad (4)$$

The associated Euler-Lagrange equations whose solution minimizes Equation (4) are:

$$u = u_0 + \frac{1}{2\alpha_1^2}\frac{\partial\lambda}{\partial x} \quad (5)$$

$$v = v_0 + \frac{1}{2\alpha_1^2}\frac{\partial\lambda}{\partial y} \quad (6)$$

$$w = w_0 + \frac{1}{2\alpha_2^2}\frac{\partial\lambda}{\partial z} \quad (7)$$

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} + \frac{\partial w}{\partial z} = 0 \quad (8)$$

$$\frac{\partial^2\lambda}{\partial x^2} + \frac{\partial^2\lambda}{\partial y^2} + \left(\frac{\alpha_1^2}{\alpha_2^2}\right)\frac{\partial^2\lambda}{\partial z^2} = -2\alpha_1^2\left(\frac{\partial u_0}{\partial x} + \frac{\partial v_0}{\partial y} + \frac{\partial w_0}{\partial z}\right) \quad (9)$$

The equation for λ is derived by differentiating Equations (5-7) and substituting into Equation (8) giving Equation (9).

The details of the model, its initial and boundary conditions can be found in the Sherman (1978) and Dickerson (1978) papers.

In the case of a neutrally stratified atmosphere the model incorporates the channelling effects caused by river valleys in the model domain according to Wippermann's approach (Wippermann, 1984; Bajić, 1984).

SIMULATION OF BORA AND SCIROCCO IN THE NORTHERN AND MID-ADRIATIC

The local wind regime along the Adriatic coast has been a research subject for many years in the Croatian meteorological service (Jurčec, 1981; Vučetić, 1985). Bora and scirocco are very frequent and often very strong (even severe) meteorological phenomena (Bajić, 1989) which can affect land and sea transport, tourism, human activities etc. It is, therefore, important to use all available methods to analize weather situations with such winds. In order to examine to what extent the orographic influence and the land-sea difference in friction could explain this local wind circulation along the Adriatic coast the DM1 model was run on the northern and mid-Adriatic (Jurčec and Bajić, 1982; Jurčec, Bajić and Pandžić, 1986). The simulation of the wind field was done on the northern Adriatic in a domain with a

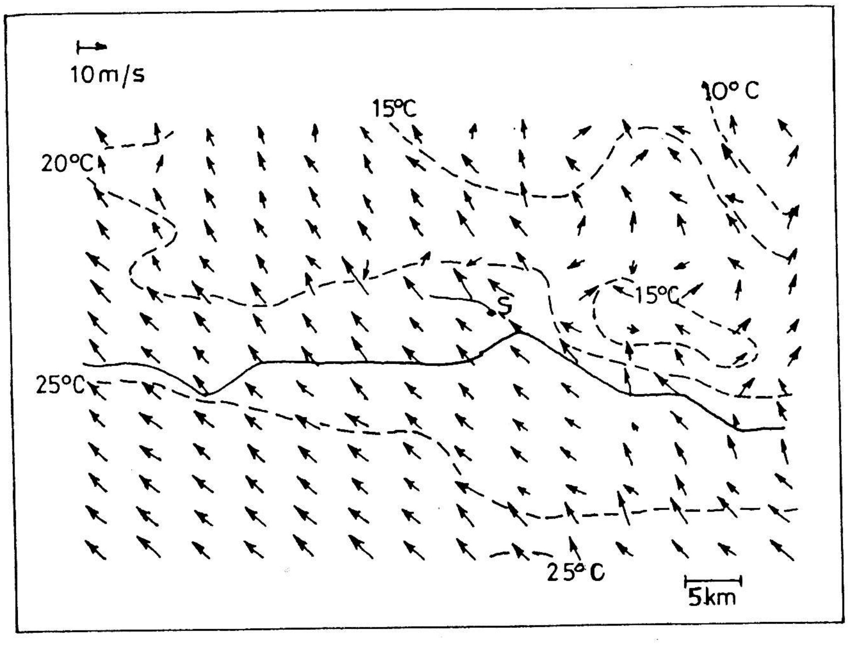

Figure 1. Simulated scirocco on the mid-Adriatic. The surface wind field after 20 DM1 integration time steps, superposed on the surface temperature field. S-Split location

Slika 1. Simulirano jugo na srednjem Jadranu. Polje vjetra nakon 20 koraka integracije modelom DM1 superponirano na polje temperature u istom vremenu. S označuje položaj Splita.

horizontal resolution of 10 km 18×18 grid points network (with Senj as the input data point), and on the mid-Adriatic with a finer resolution of 5km (nearly centered in Split). The model atmosphere was adiabatic, under the influence of orography and friction in the surface boundary layer. The input data were chosen so as to represent typical bora or scirocco situations. The strongest bora and scirocco appear in zones with steep orography close to the coastline, where a low level jet, besides strong frictional convergence, causes anticyclonic relative vorticity on the continental side, and cyclonic vorticity offshore (Fig. 1).

These turbulent vorticities are more expressed in the case of bora. Orographic channelling effects are more marked in the model with the finer horizontal resolution over the mid-Adriatic, which means they influence the strong bora at Split. The same effects are not simulated in the coarse grid network of the northern Adriatic, where their presence in reality causes the strongest bora at Senj (Jurčec and Bajić, 1982).

These results helped to understand the dynamics and the spatial distribution of the wind field in regions with sparse data, especially in estimating the orographic influence on airflow in the Dinaric Alps region.

SIMULATION OF THE WIND FIELD IN THE VICINITY OF THE CEMENT FACTORY IN PODRUTE

Before building factories which might produce air pollutants, meteorological conditions need to be examined in the specified region in order to estimate future influence on air quality and to find an optimum location for the factory. An example of such work is the analysis of possible future influence on the environment which a cement factory to be built in the northwestern part of Croatia could have.

The planned factory location is in relatively complex terrain between the Ivanščica (1060m above sea-level) on the west northwest and the Kalnik (640m above sea-level) mountain on the southeast. Such orography influences the local circulation regime in many ways; wind experiences marked channelling effects; nocturnal cooling of the earth's surface and a resulting temperature difference between the elevated terrain and the free air at the same altitude generates downslope winds. Lack of measured wind data made the analysis of the local and mesoscale circulation and, consequently, the estimation of a possible influence on air quality very difficult. Therefore, an air flow simulation

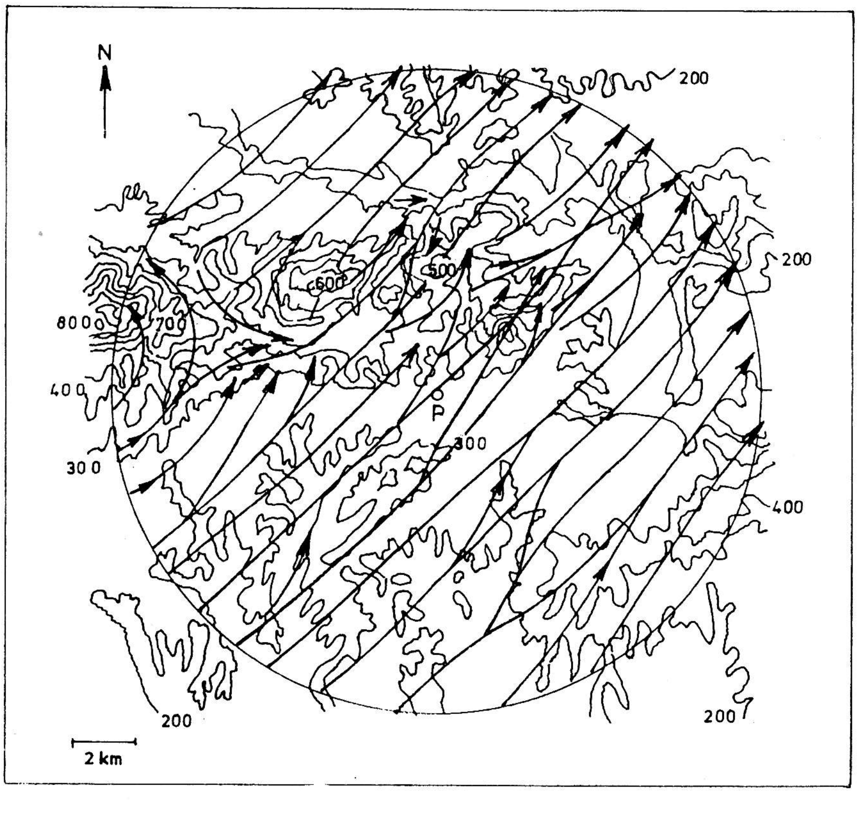

Figure 2. Numericaly obtained streamlines 10 km around Podrute (P) in a neutraly stratified atmosphere for a SW initial wind field.

Slika 2. Numerički dobivene strujnice na području radijusa 10 km oko Podruta (P) u neutralno stratificiranoj atmosferi za SW početno polje vjetra.

with the numerical model had to be performed.

The DM1 model has been run in a 1 km grid distance in 18x18 km region around Podrute in a case of neutrally stratified atmosphere according to the Pasquille categories (the most frequent stability in that region, Lončar et al, 1985) for 8 initial wind directions. The results of the run with SW-SE initial geostrophic wind emphasized the zones of convergence and divergence (Fig. 2) which are very important for the air pollution problem. This means that the air coming from the factory will accumulate in the convergence region for a longer time and may cause an essential increase in pollution. Such air behavior could not be quantitatively estimate without knowing the wind field in the whole area, i.e. without a diagnostic numerical model.

SIMULATIONS OF THE WINDS AT THE LOCATION OF OVERHEAD LINES IN GORSKI KOTAR

The electric overhead lines, being very elongated construction, are exposed to additional burden due to constant wind influence. Therefore, a knowledge of the wind field along the overhead line route is necessary for its design, building and exploitation. For that purpose, special wind measurements have to be organized and the collected data compared with the wind data measured at regular meteorological stations. However, overhead lines are usually very long and they may go through orographically developed regions where spatial and temporal variabilities of wind velocity and wind direction are very great. Therefore, special measurements in few weather situations and a small number of meteorological stations (which are usually non-representative of the overhead line route) can not give all the necessary information about the wind regime along the entire route. This problem can be solved by using the numerical model for wind field simulation.

Such DM1 model application has been done in the 74x42 points region with a 1 km grid distance and with the 40 km long overhead line route Meline-Vrbovsko as its central part (Bajić, 1986). The complexity of the terrain configuration can be seen in Figure 3.

Wind measurements were available along the route for a number of weather situations which made possible a verification of the results. A comparison between the measured and numerically obtained wind vectors for 17 March 1985 (Fig. 4) showed a 17° mean difference in wind direction and a 2.8 ms^{-1} average difference in wind velocity.

The orographycally complex terrain caused great spatial variability in the resultant wind field (Fig. 5) along the overhead line route. The simulated wind field provided all the necessary information we needed for the design, building and exploitation of the overhead line considered.

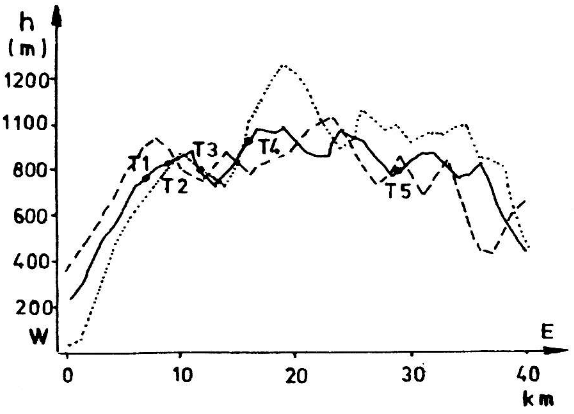

Figure 3. Terrain profile along the overhead line route (solid line), 2 km to the north (dashed line) and 2 km to the south (dotted line). T1 - T5 are the locations of wind measurements.

Slika 3. Profil terena duž pretpostavljene trase dalekovoda (puna linija), 2 km sjevernije (isprekidana linija) i 2 km južnije (točkasta linija) od trase. Sa T1 do T5 označene su točke na kojima su postojala mjerenja smjera i brzine vjetra.

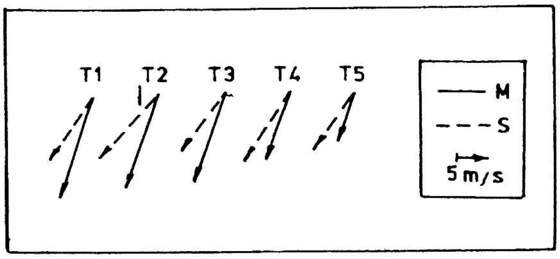

Figure 4. Simulated and measured surface wind vectors on T1 - T5 locations.

Slika 4. Izmjereni i modelom simulirani vektori prizemnog vjetra u točkama mjerenja označenim na Slici 3.

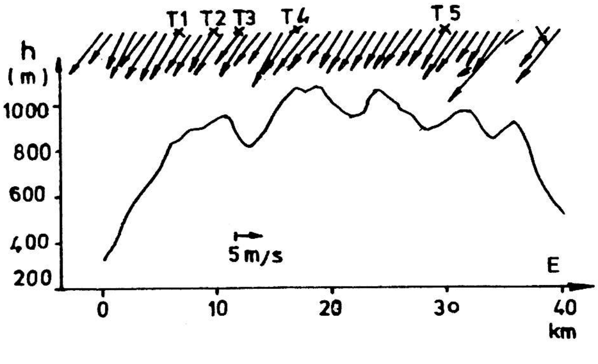

Figure 5. Simulated surface wind vectors along the overhead line route.

Slika 5. Modelom simulirano polje prizemnog vjetra duž trase dalekovoda.

CALCULATION OF AIR PARTICLE TRAJECTORIES IN THE VICINITY OF THE KRŠKO NUCLEAR POWER PLANT

Air particle trajectories in orographically developed regions are of special interest in the air pollutant transport analysis. In order to determine these trajectories wind data in a dense three-dimensional network are necessary. Such data can be relatively easily obtained using a three-dimensional numerical model for wind field simulation such as the DM2 model. When we have wind vectors in all grid points, the particle movement from the source point and its location in time t can be obtained by using the relation:

$$x_t = x_{t-1} + u_{t-1}\Delta t \qquad (10)$$

x_{t-1} is the particle position in the previous time step, u_{t-1} is the wind component in time $t-1$.

The y_t and z_t positions are calculated analogically. The new particle coordinates x_t, y_t and z_t usually don't coincide with the model's grid point. Therefore, spatial interpolation is needed. For the air particle trajectory analyses performed in the Meteorological Service of Croatia the Dickerson (1978) interpolation method was used.

During the planning and building of the nuclear power plant in Krško our task was to calculate and analize the trajectories of air particles originating in Krško. In order to do that the DM2 model was developed and used in the nuclear power plant surroundings (Fig. 6).

The model was run in several weather situations. One of them was on 17 March 1982 with the initial wind and temperature data given on Figure 7. The model domain contained 25×25 grid point in horizontal dimension and 15 vertical levels at 100 m distance. The simulated surface wind field showed the greatest orographycal influence on the initial uniform air flow near the steep mountain ranges. Maximum wind speed reached 16.4 m s^{-1} in the northeastern part of the domain. The simulated wind in Krško was SW with a 4.7 m s^{-1} horizontal and 0.2 m s^{-1} vertical wind velocity (Fig. 8). The regions with the strongest descending (ascending) motion were in accordance with the continuity equation divergence (convergence) regions. Simulated wind vectors (6 selected grid points are presented on Figure 9) indicate the vertical motion resulting from the terrain features and the wind shear present in the vertical profile. Such vertical wind profile is more realistic than a simply linearly interpolated one.

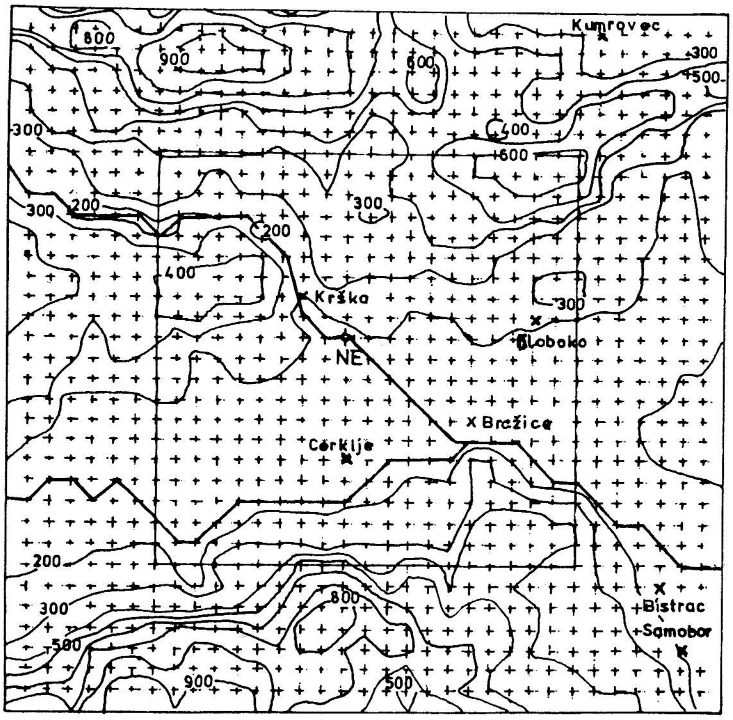

Figure 6. The DM2 model domain with the power plant Krško (K) in the center.

Slika 6. Područje primjene DM2 modela s nuklearnom elektranom Krško (K) u centru.

The calculated trajectory started from Krško at 50 m above the surface. Its steps for every 5 minutes are given in Table 1.

Table 1. Calculated above sea-level altitudes (SLA in m) and displacement of air particles (PAD in m) at every 5 minute time step with the starting point at 50 m above Krško for 17 March 1982.

Tablica 1. Proračunata nadmorska visina (SLA u m) i pomak u svakom vremenskom koraku (PAD u m) od 5 minuta zračne čestice s početnom točkom u Krškom na visini 50 m nad tlom.

Time	SLA (m)	PAD (m)
5	1401	268
10	1753	267
15	1326	283
20	1625	316
25	2006	375
30	2324	434
35	1641	371
40	2337	349

The importance of the three-dimensional mass consistent wind field modeling can be seen from the difference between the simple rectilinear two-dimensional trajectory and the trajectory obtained by running the DM2 model (Fig. 10).

The simulated wind field makes it possible to detect locations in a mountainous region where one should expect more (or less) pollution.

CONCLUDING REMARKS

The relatively simple, one level, sigma coordinate model (DM1) described above could be used to diagnose the surface wind field in mountainous and coastal regions. The cases of its application possibility presented here, as well as several additional cases which have not been described in this paper, indicate that this model can diagnose many details of the mesoscale flow in complex terrain. Thus it has proven to posses much of the essential physics that determines the low-level flow. Therefore, the DM1 could be applied to many different geographical locations and synoptic situations. In addition to the described application examples, there are many other possible applications of the model including aviation terminal forecasting, predicting air pollution potential, air flow in the vicinity of

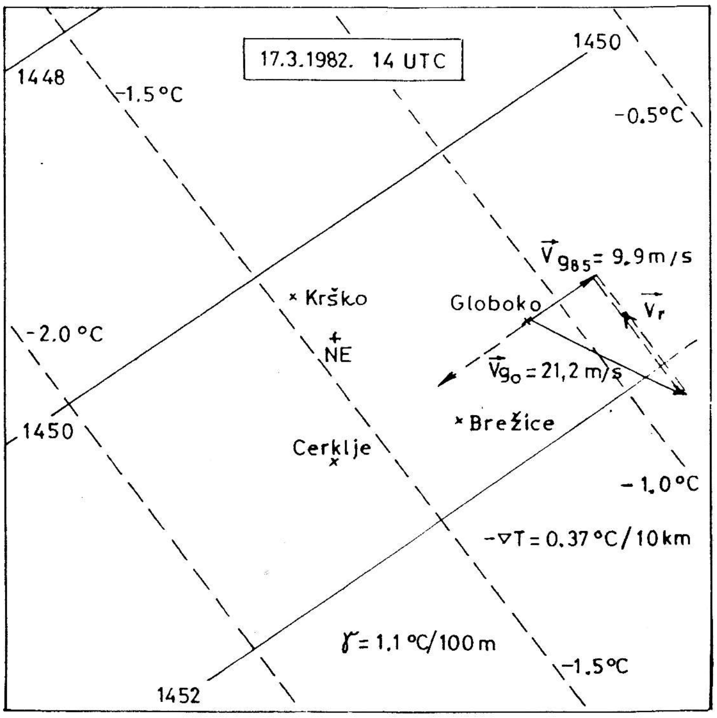

Figure 7. Initial meteorological data for the DM2 model run in the situation on 17 March 1982.

Slika 7. Početna polja meteoroloških elemenata za DM2 model u situaciji 17. ožujak 1982.

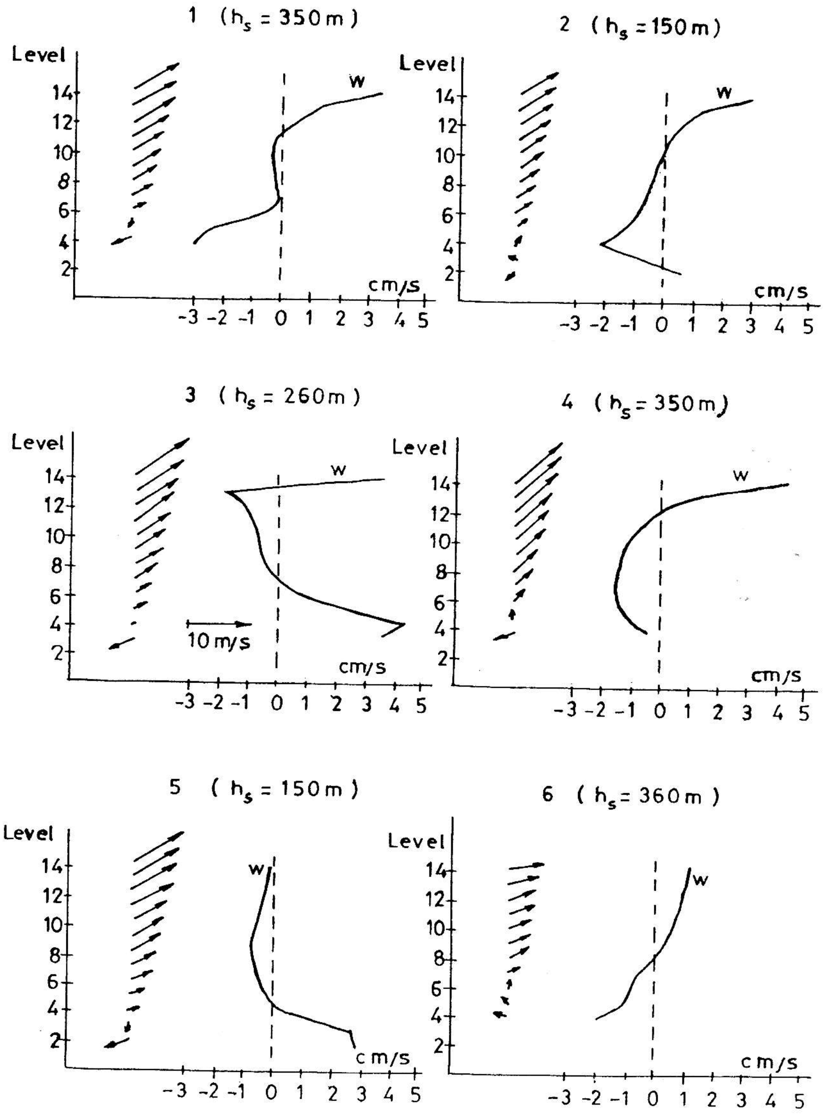

Figure 8. Simulated vertical profiles of wind vectors and vertical wind component in 6 locations of the model DM2 domain in the situation on 17 March 1982.

Slika 8. Simulirani vertikalni profili vektora vjetra i vertikalne komponente vjetra u 6 točaka područja primjene DM2 modela u situaciji 17. ožujak 1982.

inicipient forest fires in complex terrain (provided the heat source is not so great as to invalidate the hydrostatic approximation), wind-generated waves, assessing relative safety of harbors during the strong winds, and many others.

The mass-adjusted, three-dimensional wind field model DM2 has even greater application possibilities. The variational analysis technique as implemented in the DM2 has been an effective procedure for calculating three-dimensional wind fields in complex terrain. The ability to use commonly available meteorological data has made this model practical for many purposes including real-time assessment of environmental effects of toxic atmospheric releases.

In general, both the DM1 and DM2 models have a potential for diagnosing important details of the wind field during various weather conditions and on many locations and have proven to be a useful analysis tool in regions of complex terrain.

There are several ways to improve the models: a better parametrization of the depth of the layer of topographic influence, a better parametrization of diabatic effects and surface friction; allowing the currently unchanging "free atmosphere" lapse rate to vary in space, etc. We believe that such odifications could improve the models' verification in most cases.

Acknowledgement: This research is based on the projects supported by the Croatian National Fund for Scientific Research.

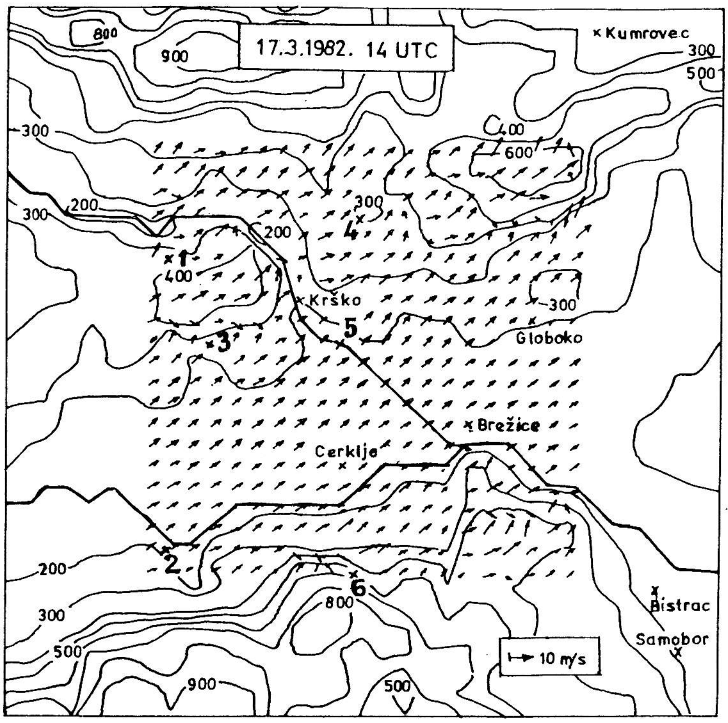

Figure 9. Simulated surface wind field on 17 March 1982.

Slika 9. Simulirano prizemno polje vjetra 17. ožujka 1982.

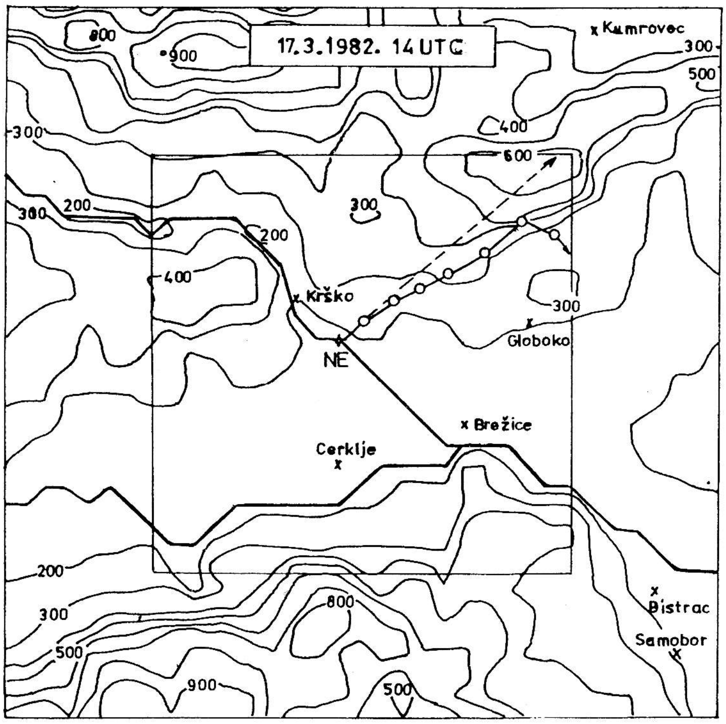

Figure 10. The simple rectilinear air trajectory (dashed line) and air trajectory calculated using the DM2 model (solid line) with a starting point at 50 m above Krško.

Slika 10. Pravocrtna (isprekidana linija) i modelom DM2 proračunata trajektorija zračne čestice s početnom točkom na 50 m visine iznad Krškog.

REFERENCES

Bajić A. (1984) Strujanje u gornjem dijelu doline Save prema modelu Wippermanna. *Razprave* **28(1)**, Ljubljana, 1-46.

Bajić A. and Jurčec V. (1985) Effects of topography on velocity distribution in the atmospheric boundary layer. *XII International Conference on Carphatian Meteorology*, Beograd, 50-53.

Bajić A. and Jurčec V. (1985) Proračun trajektorija zračnih čestica. *Zbornik radova s VII znanstvenog skupa PPPR*, Zagreb, 341-347.

Bajić A., Jurčec V. and Rakovec J. (1985) Trajektorija zračnih čestica za potrebe NE Krško. *Republički hidrometeorološki zavod SR Hrvatske i Republički hidrometeorološki zavod SR Slovenije*, 112 pp.

Bajić A. (1986) Numerička simulacija strujanja na trasi dalekovoda. *Energija* **6**, 455-459.

Bajić A. (1989) Severe bora in the northern Adriatic. Part I: Statistial analysis. *Rasprave (Papers)* **24**, 1-9.

Danard M. B. (1977) A simple model for mesoscale effects of topography on surface winds. *Mon. Wea. Rev.* **105**, 572-581.

Dickerson M. H. (1978) MASCON - A mass consistent atmospheric model for regions with complex terrain. *J. Appl. Meteor.* **17**, 241-253.

Jurčec V. (1981) On mesoscale characteristics of bora condition in Yugoslavia. *PAGEOPH* **119**, 640-657.

Jurčec V. and Bajić A. (1982) Simulacija bure i juga mezomodelom. *Zbornik radova s IV znanstvenog skupa PPPR*, Stubičke Toplice, 539-544.

Jurčec V., Bajić A. and Pandžić K. (1986) Simulacija bure i juga na srednjem Jadranu. *Hidrografski godišnjak* 1984-1985, 59-71.

Lončar E., Šinik N., Bajić A., Jurčec V., Koračin D. and Cvitan L. (1985) Studija utjecaja na okolinu buduće cementare T.C. - Podrute (meteorološki aspekti). *Republički hidrometeorološki zavod SR Hrvatske*, 45 pp.

Rakovec J. (1985) Wind field modelling in a complex terrain. *XII International Conference on Carpathian Meteorology*, Beograd, 182-185.

Sasaki Y. (1958) An objective analysis based on the variational method. *J. Meteor. Soc. Japan.* **36**, 77-88.

Sasaki Y. (1970) Some basic formalisms in numerical variational analysis. *Mon. Wea. Rev.* **98**, 875-883.

Sherman C.A. (1978) A mass-consistent model for wind fields over complex terrain. *J. Appl. Meteor.* **17**, 312-319.

Vučetić V. (1985) Karakteristike bure u lokalnim i mezorazmjerima. *Rasprave (Papers)* **20**, 11-20.

Wippermann F. (1984) Air flow over and in broad valleys. Channeling and counter current. *Beitr. Phys. Atmosph.* **57**, 92-105.