ISSN: 0001-5113
AADRAY

ACTA ADRIAT,
38 (2): 45-59, 1997

UDC: 551.468 (262.3)
Original scientific paper

Modelling the effect of wind on average circulation and long-term pollutant dispersion in the Gulf of Trieste

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Two methods for the evaluation of the effect of wind for long-term prognostic hydrodynamic (HD) and advection-dispersion (AD) simulations are presented and their efficiency and applicability is studied for the case of the Gulf of Trieste. Both methods are applicable only in cases of homogenous (spatially constant) wind fields. They also both apply common wind roses as the only input, which ensures easy and fast preparation of wind data.

The VERANDA method employs a stochastic approach and is designed for use in non-stationary HD and AD models, while the deterministic VECTRA method is used in both stationary and non-stationary models. Both methods were used to create synthetic time series of wind data which were the input for HD and AD models. Results of simulations using these synthetic winds are compared with results of a reference simulation where wind input was a 1-year measured time series. Comparisons are performed on the basis of concentration fields, velocity fields and point values of concentration and velocity. An acceptable accuracy is found for both methods if they are used in accordance with adopted assumptions.

INTRODUCTION

Wind is one of the most important forcing factors for water circulation and contaminant dispersion, especially in shallow shelf seas and coastal areas. For this reason, its effect is included into every general mathematical hydrodynamic (HD) model. However, modellers are sometimes faced with the problem of determining wind inputs for their prognostic models on the basis of historical data. For short-term simulations, the problem can be avoided by employing some typical winds (e.g. RAJAR *et al*, 1995) which are regularly used for analytical purposes instead of the whole wind rose (STRAVISI, 1977; RAJAR and ČETINA, 1992; BONE, 1993), or fictitious time series, consisting of these typical winds. On the other hand, contemporary long-term water quality (WQ) models use measured meteorological time series from the past (CERCO and COLE, 1993; CERCO, 1995a; LUNG and LARSON, 1995), which are later repeated as probable future time series (CERCO, 1995b; LUNG and LARSON, 1995). Because wind is a regularly measured meteorological parameter, a practical solution for its long-term prediction would be to take a measured time series from a typical year or decade (from the past) and repeat it for as many years or decades (in the future) as needed. From the practical engineer's point of view, this idea is not attractive since it requires time series from many years, from which a typical year or decade can be selected by means of some suitable statistical method. Besides the burden of extensive statistical computations, wind data might not be readily available.

In this paper, two possible alternative methods for the evaluation of the effect of homogenous wind fields on long-term prognostic HD and advection-dispersion (AD) simulations will be presented, along with their application to the real case of the Gulf of Trieste. For both methods, the source of data are wind roses which are the most common form of presenting wind characteristics of a certain area. A consequence of simple input is that the time needed for preparation of synthetic wind data series by suggested methods is at least an order of magnitude shorter than the time spent on the selection of a typical year.

VERANDA: A STOCHASTIC APPROACH

It is known that creating a wind rose results in some averaging, through which much of the information about wind dynamics is irreversibly lost. Therefore, the main concern during our work on the first method was to avoid any further loss, i.e., to extract as much information as possible from an available wind rose.

This method is based on the assumption that wind direction at any timestep is completely independent from the wind direction at the previous timestep. This assumption is not correct, but it will be shown later (with the results obtained from the Gulf of Trieste) that proper selection of timestep length during which the wind is constant can lead to acceptable results for longer simulation periods. By definition, this method is most suitable for cases in which no wind direction is considerably dominant. In the real world, such cases are rare, but in practical work, it is feasible for a skilled expert to separately decide for each case, whether the method might still be applied. At this point, time discretization is one of the most important parameters to vary.

The above idea was realized in a FORTRAN routine named VERANDA, which is an autonomous unit run independently from any HD-AD program. VERANDA's inputs are a wind rose and the parameter "n" - a number of required (direction, speed) data pairs. The output of VERANDA is a time-independent set of "n" pairs, so the user himself must decide whether these are hourly, quarter-daily, daily or some other wind data values.

With the VERANDA method, wind direction series are generated stochastically on the basis of a 16-direction wind rose. When one of the 16 wind directions is chosen, the corresponding average wind speed from the wind rose is automatically adopted as the magnitude of the wind. Before the description of the procedure, the following must be assumed: a circle with r = 1 and its centre at point (0,0) is a representation of a two-dimensional field of potential wind directions; further, let any point (X, Y) inside this circle be a representation of a single direction and let the circle be divided into 16 sectors representing the directions of the wind rose. Generation of a synthetic wind time series then runs by application of the following algorithm:

a) an arbitrary point (direction) is chosen by invoking a uniform random number generator (RNG1) twice - separately for the X and for Y directions of the coordinate system.
b) it is determined in which of the 16 sectors the chosen point (direction) lies.
c) the second uniform RNG (RNG2) is invoked to account for the probability of wind from the sector determined in stage b). The range of RNG2 is from 0 to 1 (value of 1 represents 100 % probability) but the direction from stage b) is accepted only if the generated RNG2 value lies in the range from 0 to p. p is the probability of the wind occuring from direction deter-

mined in stage b), which is taken from the given wind rose.

d) if the condition in stage c) is fulfilled, the new wind direction and the corresponding (average) speed are stored and the whole procedure from stage a) is repeated. If not, the same actions are repeated without storing direction and speed.

e) after every succesful loop, a procedure similar to that in c) is employed to account for the probability of calm (no-wind condition).

Due to its stochastic character, this method yields better results for a large number of generations. To improve its accuracy for smaller numbers of generations (e.g., for n < 1000), a correction of wind speed was introduced, following the equation:

$$\frac{P_w(i)\cdot U_{wr}(i)}{P_V(i)\cdot U_V(i)} = 1 \qquad i = 1,2,3, \ldots 16 \qquad (1)$$

which ensures conservation of wind energy for every cardinal point. In this equation, $P_{wr}(i)$ and $P_V(i)$ are probabilities of winds from the wind rose and from VERANDA, respectively. Similarly, $U_{wr}(i)$ and $U_V(i)$ are corresponding wind speeds. The index *i* represents the 16 directions of the wind rose (N, NNE, NE, ...).

VECTRA: A VECTORIAL SUM

In contrast to the stochastic approach, the final result of the second method - which was realized in a FORTRAN routine named VECTRA - is a single deterministic vector which we called *average* (monthly, seasonal, yearly) *wind*. The source of data for this method is again a given wind rose, but in this case, additional averaging is performed which completely blurs the probabilistic character of wind. The algorithm used in this method applies simple vectorial addition of "unit winds" originating from different cardinal points. "Unit winds" are vectors whose lengths are equal to the products of the probabilities and average speeds from the chosen wind rose, while their directions are those of the 16 cardinal points. The word "unit" originates from the fact that the overall scalar sum of the "unit winds" yields the value of average wind velocity for the site which in this case is the "unit". When seeking, for example, a monthly average wind, "unit winds" are taken from the monthly wind rose. The same rule applies for determining seasonal or yearly average winds.

By definition, this method yields the best results when one of the winds of the wind rose predominates over all others. Since in the real world, such a case is as rare as uniform distribution, it is sometimes prudent to combine both methods. An example of such a combination will be presented further on.

GULF OF TRIESTE DATA

The Gulf of Trieste is a semi-enclosed gulf in the north-eastern part of the Northern Adriatic (Fig. 1).

It reaches 25 meters in depth in the SE part, while the average depth is about 15 meters. In the north-eastern part of the gulf there is the inflow of the Soča river (called Isonzo in Italy), which is one of the main sources of pollution in the gulf. Its average discharge is approximately 115 m^3s^{-1} with monthly averages ranging from 70 to 140 m^3s^{-1}. The climate over the gulf is mediterranean but is regularly affected by cold air masses from the nearby alpine (continental) region. Especially in the colder season (late fall to spring), these fronts are very often the main cause for the appearance of a very strong, gusty and catabatic wind (bora), blowing from the NNE to E direction. The second characteristic wind of the area is the less intense but more steady (scirocco), blowing from the SE to SSW direction which is more frequent in spring and autumn. There exists a complete data set of hourly measured wind directions and speed for the period from 1975 to 1990 for Beli Križ station, Slovenia, available from the hydrometeorological service. The station is located on top of a hill above the town of Portorož and counts as a representative site for wind conditions on the southern coast of the

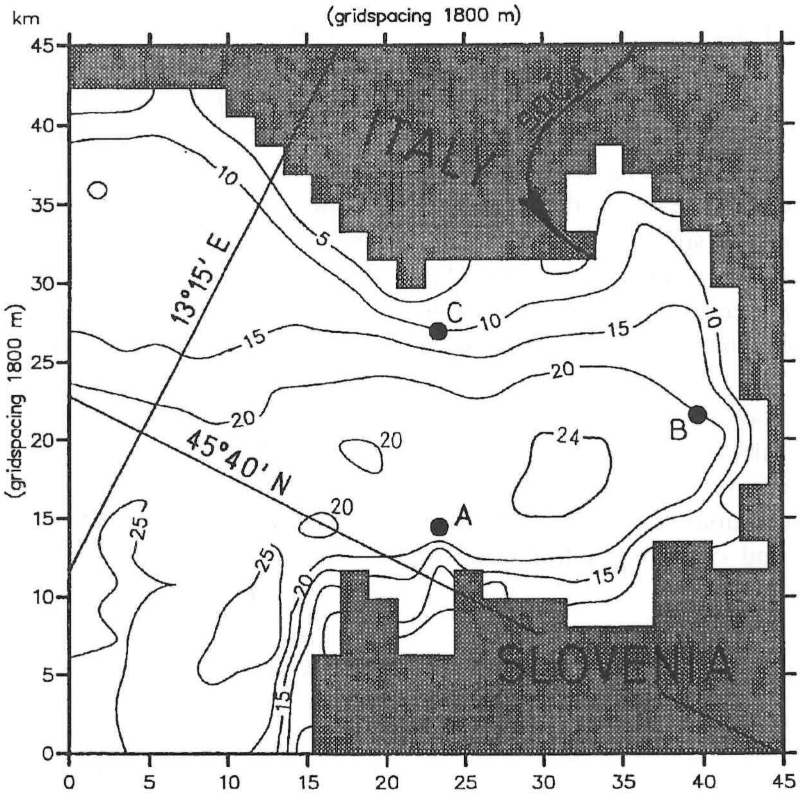

Fig. 1. Gulf of Trieste - situation, bathymetry (depths in meters), model area and locations of characteristic points A, B and C

Gulf of Trieste. The average wind rose for this site is presented in Table 1.

The typical (average) year which was required for verification of the VERANDA and VECTRA methods was selected by comparing quartiles of wind speed data for every single year with the quartiles of a 15-year data set and applying the least-squares method. The year 1988 has been found to be typical (Table 1). For this year only, a complete set of hourly wind direction and wind speed data was made available to the authors.

At the eastern coast of the gulf, in the city of Trieste, Italy, another wind measuring station is located close to the sea, but in an urban environment under a hill, thus some doubt exists about the representativeness of its data for the description of wind conditions in the open section of the gulf. Due to this deficiency and to limited availability of wind data from this station, it was finally decided upon to use the data from Beli Križ for the entire Gulf of Trieste.

MODEL AND DATA

Simulations described in this article were performed by the commercial tool MIKE 21, developed by the Danish Hydraulic Institute. MIKE 21 is named "A Modelling System for Estuaries, Coastal Waters and Seas" consisting of several modules from which only the HD module, the AD module and the Pre- and Post-processing (PP) module were used for our task. The theoretical background of MIKE 21 has already been abundantly documented (ABBOT *et al.*, 1973; WARREN and BACH, 1992) but some facts must be reiterated here. The MIKE 21 software package is based on 2D depth averaged description of surface water bodies. The basic module is the HD module which simulates water level variations and flows forced by tide, winds and different sources/sinks. The system solves the full time-dependent non-linear equation of conservation of momentum and the equation of continuity. The solution is obtained by using an implicit ADI finite difference scheme of second-order accuracy. The AD module simulates spreading of conservative pollutants or pollutants decaying at first order rate. In our version of MIKE 21, the AD equation was solved by using the explicit QUICKEST finite difference scheme of third-order accuracy. The PP module provides preparation of data and analysis of results along with the possibility of creating attractive graphic presentations.

With the aim of observing the effects of different wind inputs, only wind data were changed while other data remained unchanged during all simulations and set to values which shall be described in the following. The number of gridpoints was gradually reduced during preliminary simulations to find a grid which would be fine enough to reproduce the basic characteristics of the velocity field as defined by previous authors (e.g. LONGO *et al.*, 1990; MOSETTI and PURGA, 1990; RAJAR *et al.*, 1992) and coarse enough to ensure reasonably fast computations. It was finally concluded to use a very coarse grid with $\Delta x = \Delta y = 1800$ m gridspacing. At the open boundary, a constant-level boundary condition was applied far enough (10 gridpoints) from the area of interest to avoid possible disturbances therein. This protective measure resulted in the overall computational domain of 25 x 25 gridpoints with the inserted 14 x 18 area of interest. Tidal effects were intentionally left out, since the purpose of the study was observation and evaluation of wind effects only. As the HD initial condition, the velocity field at the end of the year 1987 was used which was previously computed by applying a constant yearly average wind of 1.61 ms^{-1} from 73.03° (≈ ENE) direction for the whole year 1987. The wind friction coefficient C_w varied linearly from 0.0016 at speeds over 0 m/s to 0.0026 at speed 24 ms^{-1} to obtain the wind driving force *F* at the water surface, according to the following square law:

$$F = C_w \cdot \frac{\rho_{air}}{\rho_{water}} \cdot w^2$$

where r_{air} and r_{water} are density of air and water, respectively, while *w* stands for the velocity of wind 10 m above the sea level. The source, representing the inflow of the Soča river, had a magnitude of 115 m^3s^{-1} discharging in the direction 105° (from N) and with speed 0.3 ms^{-1}. Concentration of the conservative pollutant at the source was 100 (arbitrary) units and a zero concentration field was used as the AD initial condition. Two further relevant input data were the spatially constant eddy viscosity coefficient of 5 m^2s^{-1} and the uniform Manning's bed-resistance coefficient of 0.033 $sm^{-1/3}$. Simulation time in all cases was 1 year (366 days, as 1988 was a leap year) and the timestep was Dt = 360 s which resulted in a maximum Courant number $C_r = 3.5$. Both HD and AD results were stored every 60 timesteps thus 1464 velocity fields and concentration fields were available after every simulation. Simulations were running on a 486/66 MHz IBM-PC compatible under a Santa Cruz Operation (SCO) Open Desktop (ODT) Unix operating system.

SIMULATIONS

For a convincing comparison of different methods for the evaluation of the effect of wind on HD and AD results, a reference time series of velocities and concentrations in at least 5 charactersitic points of the Gulf of Trieste would be necessary. For the required land scale (about 25 × 25 km) and time scale (1 year) it was impossible to provide a measured time series, thus results of a reference run of the mathematical model were used for comparison. The reference simulation was performed using an actual (measured) time series of hourly wind data from Beli Križ from the year 1988 as an input. From the results of the reference simulation, a yearly average velocity field (Fig. 2a) was constructed by averaging the velocity vectors according to the equation

$$\bar{x}_{i,j} = \frac{1}{1464}\sum_{k=1}^{1464} x_{i,j,k}$$

where *x* represents either *u* or *v* velocities, a pair *i,j* marks the location of an arbitrary computational volume in the grid and *k* is a timestep counter. Using the same equation form, a yearly average concentration field (Fig. 2b) was also

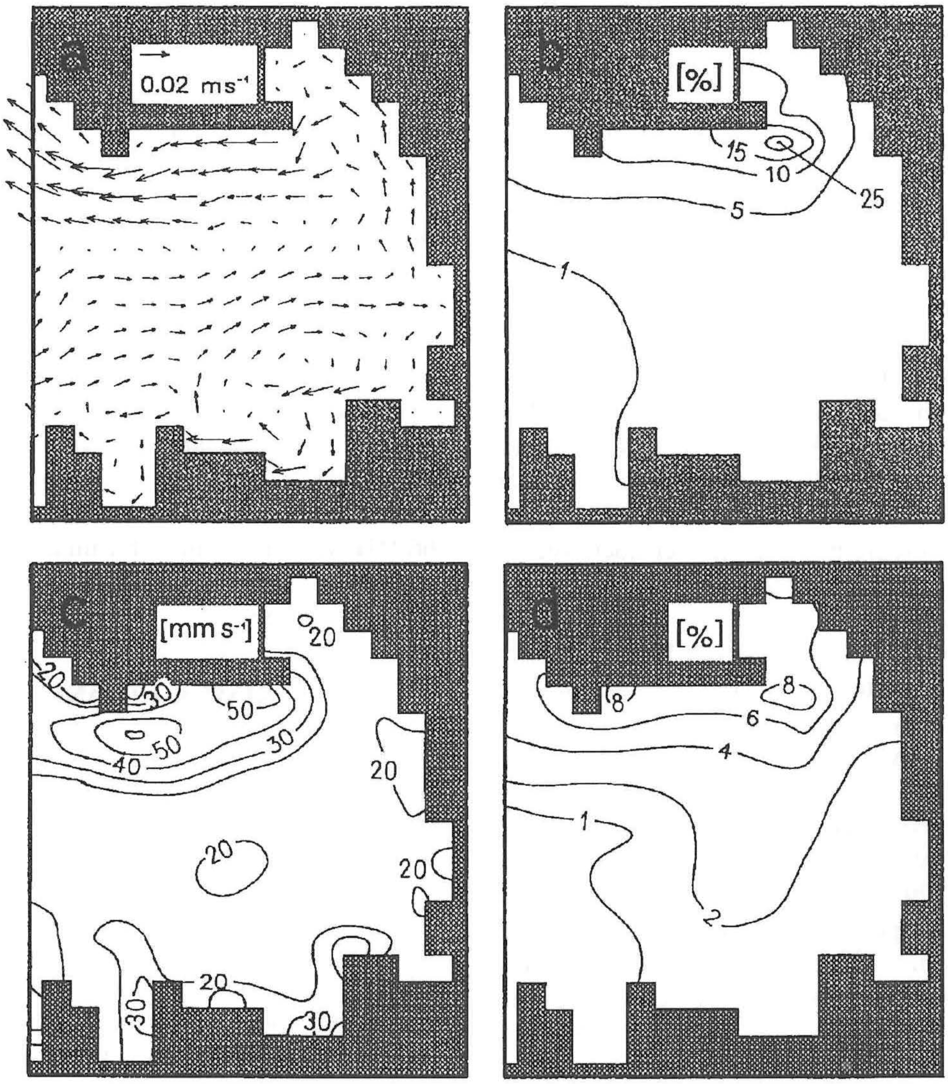

***Fig. 2.** Results of the reference simulation; average velocity field (a), average concentrations (b), standard deviations of velocities (c) and standard deviations of concentrations (d)*

obtained by averaging the corresponding concentrations in computational volumes.

Fields of the standard deviations of current velocities (Fig. 2c) and the standard deviations of concentrations (Fig. 2d) were also obtained by applying the equation

$$\sigma_{i,j}^{2} = \frac{1}{1464}\sum_{k=1}^{1464} x_{i,j,k}^{2} - \bar{x}_{i,j}^{2}$$

where x stands either for the magnitude M of the velocity which is defined by $M^2 = u^2 + v^2$ or for the concentration C. Respectively, $\sigma_{i,j}$ represents either the standard deviation of the velocity or the standard deviation of the concentration in the computational volume at location i,j. In addition to those plots an animation of pollutant spreading has been made which offers the most illustrative survey of seasonal changes due to different wind regimes during the year.

The efficiency of the VERANDA and VECTRA methods was tested using the results of three additional 1-year simulations, where a measured time series from a reference simulation was replaced first by a synthetic series

Table 1. Average (1975-1990) and yearly (1988) wind roses for the Beli Križ station

Wind roses for the Beli Križ station				
	average 1975-1990		year 1988	
direction	probability	speed	probability	speed
[-]	[%]	[ms^{-1}]	[%]	[ms^{-1}]
N	2.9	2.4	2.9	2.2
NNE	7.9	2.5	8.7	2.5
NE	27.8	5.3	27.4	5.1
ENE	8.3	5.5	7.5	5.5
E	1.2	2.4	0.7	2.5
ESE	1.9	1.9	2.1	1.8
SE	9.1	2.6	9.5	2.5
SSE	11.4	4.1	13.8	4.3
S	5.4	4.7	5.4	4.7
SSW	4.8	4.3	5.6	4.3
SW	2.9	3.0	2.3	2.8
WSW	3.9	2.5	4.7	2.5
W	1.8	2.2	1.4	2.3
WNW	2.7	2.4	3.1	2.3
NW	2.5	2.4	2.1	2.3
NNW	2.7	2.6	2.8	2.3
CALM	2.8	-	0.0	-

generated by VERANDA, second by a set of 12 monthly average wind vectors obtained by VECTRA and finally by a set of wind data obtained by combining VERANDA and VECTRA.

Input for the first simulation was a time series of 366 daily wind data pairs generated by VERANDA on the basis of the average wind rose (Table 1). A timestep of one day was chosen because there are mainly daily or even weekly changes in wind direction and speed during winter (frontal winds) while during the summer changes occur in 6- to 8-hour intervals (thermal winds). Since the summer period is relatively short (4 months), advantage was finally given to the winter regime with daily changes of wind. Results of the simulation applying wind data from VERANDA were worked out in the same way as for the reference simulation (Fig. 3).

As the second alternative to the measured wind data series, 12 monthly average winds were applied as the driving force (Table 2).

Table 2. Monthly average winds as computed by VECTRA (directions in ^{o} from N, clockwise)

Monthly average winds		
month	direction	speed
[-]	[β]	[ms^{-1}]
JAN	68.9	1.92
FEB	59.4	2.84
MAR	75.2	1.89
APR	90.7	1.55
MAY	114.8	1.06
JUN	105.5	0.74
JUL	57.3	0.74
AUG	53.2	1.17
SEP	79.4	1.30
OCT	78.5	1.86
NOV	65.4	2.60
DEC	67.8	2.34

They were computed by VECTRA from the average wind rose (Table 1).

All other computational details remained as described in the previous section. Results of the simulation based on VECTRA wind velocities are given in Fig. 4.

During the verification of VECTRA an additional simulation was also performed by applying only 4 seasonal average winds. The main conclusion of this task was that the resulting average velocity field and average concentration field were practically identical to the fields obtained by using 12 winds.

The last simulation was performed by using wind data prepared by a combination of VERANDA and VECTRA since we wanted to take advantage of both methods. A time series was prepared in which 8 average monthly winds were used except for May, June, July and August. For these months, values of winds from VERANDA were applied which were based on the average summer wind rose. Since during summer months winds from different directions are mutually more equivalent than during the rest of the year, such a division was justifiable. There were no other changes in the data in comparison with the reference simulation. Results of the combined method are given in Fig. 5.

RESULTS AND DISCUSSION

Efficiency of the methods described in previous sections will be discussed on the basis of three groups of results: 2D concentration fields, 2D velocity fields and the values of concentrations and velocities at three characteristic points of the computational area. For ease of referencing, names of the methods used for the evaluation of winds were sometimes used for the HD-AD simulations where those winds were applied.

Concentration fields

Observing only the average concentration fields (Fig. 3b), the VERANDA method appears to be very successful. Concentration isolines in the vicinity of the source are well in agreement with the isolines of the reference simulation (Fig. 2b). A more important difference is noticed only in the shape of the 1% isoline in the southern part of the gulf. Maximum average concentrations, according to VERANDA and to the reference simulation, which appear close to the source are 24.6 % and 25.3 %, respectively, thus being in excel-

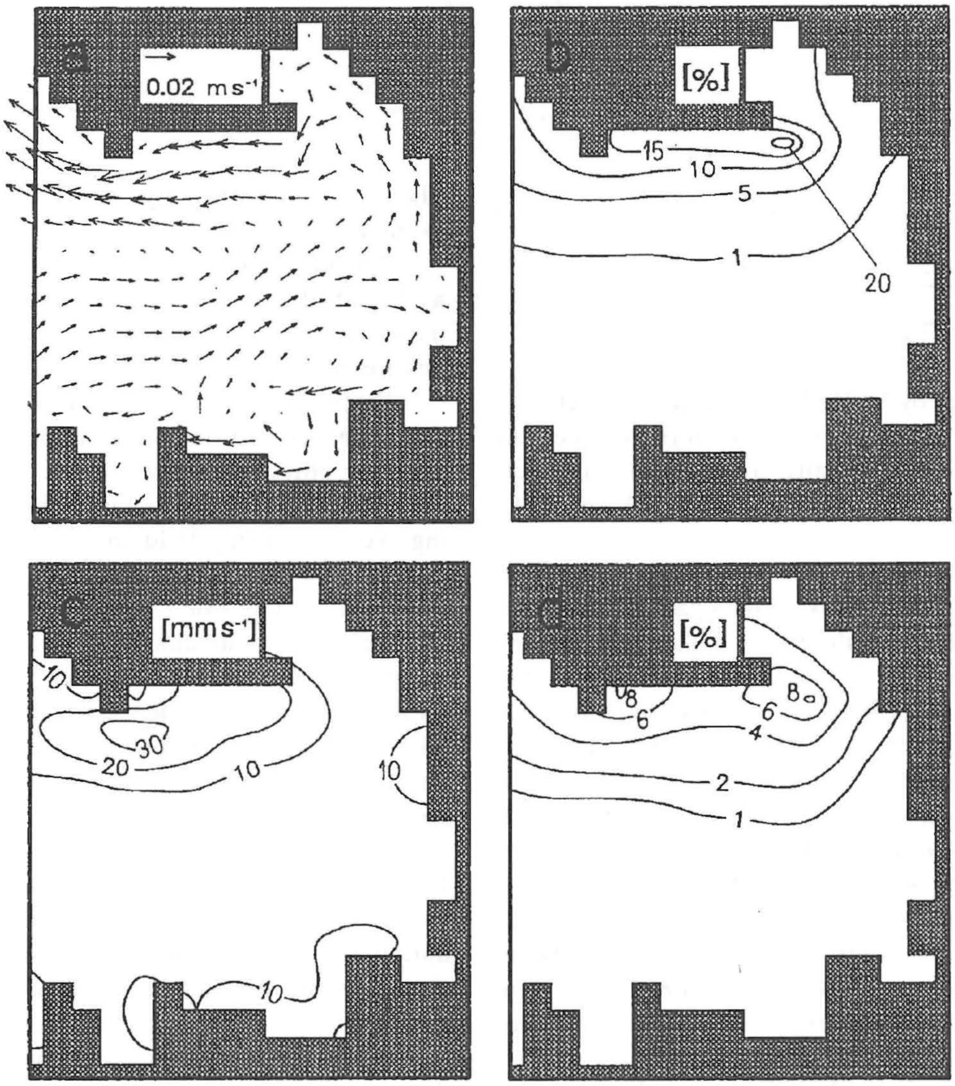

Fig. 3. Results of the simulation applying winds from VERANDA; average velocity field (a), average concentrations (b), standard deviations of velocities (c) and standard deviations of concentrations (d)

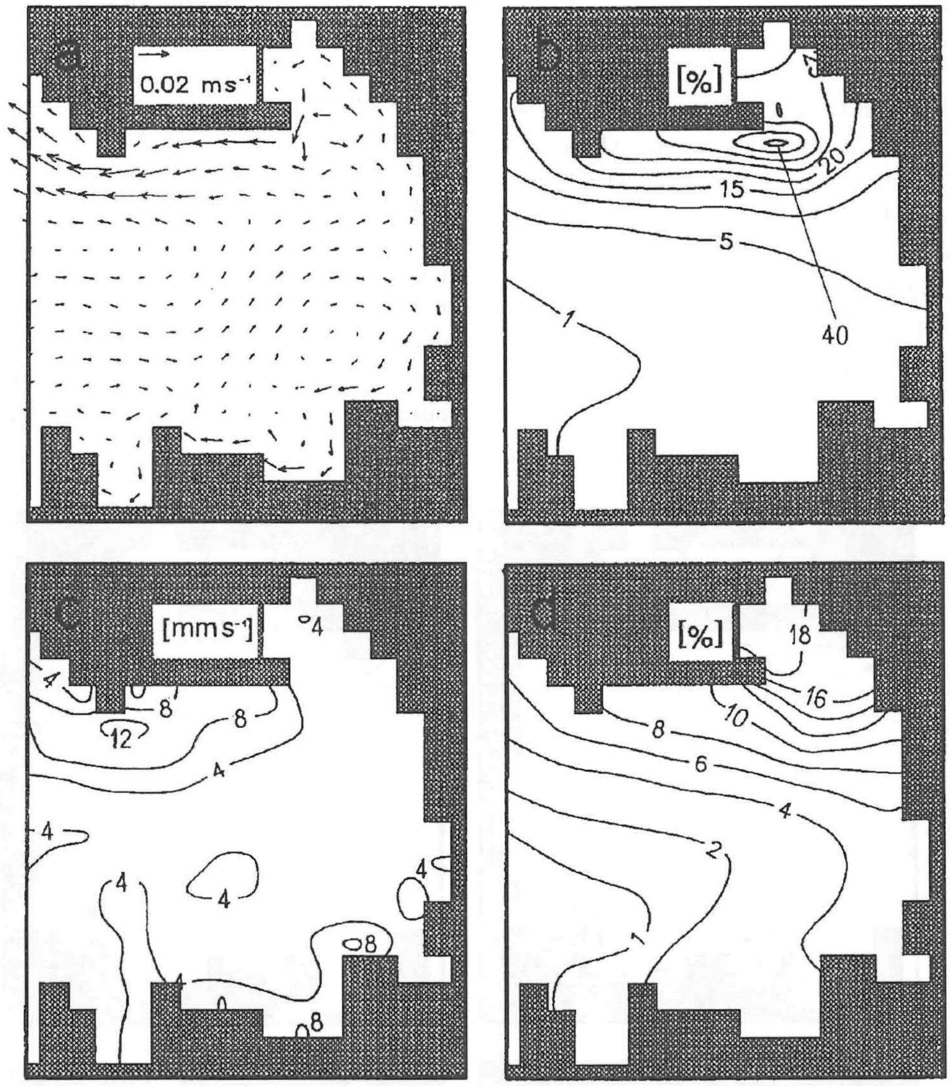

Fig. 4. Results of the simulation applying winds from VECTRA; average velocity field (a), average concentrations (b), standard deviations of velocities (c) and standard deviations of concentrations (d)

lent accordance. The fields of standard deviations of concentrations also show good agreement: except for the detail in the southern part of the gulf, isolines are shifted in comparison to the reference field, only about 1 % having lower values using VERANDA. The maximum values of standard deviation of concentration are 8.5 % and 9.7 % using VERANDA and the reference simulation, respectively.

As for the field of average concentrations, VECTRA (Fig. 4b) was less successfull than VERANDA. Maximum concentration was 42.7 %, and in comparison with the reference simulation there is a shift in isoline position which ascends from 5 % in areas far from the source to 15 % close at the source. The only advantage of VECTRA over VERANDA is the 1 % concentration isoline, which in the case of VECTRA fits the reference 1 % isoline much better. Standard deviation isolines fit the reference isolines acceptably only at values of 1 % and 2 % in the southern part of the gulf, while close to the source their VECTRA value is even as high as 19.5 %.

Results of the combined method (Fig. 5) are a conjunction of results obtained by VERANDA and VECTRA alone. The maximum concentration was 33.2 % while the isolines were shifted about 5 % in the whole area. The 1% isoline shows a trend of extending to the south. The maximum value of standard deviation of concentration is 8.3 % and the isolines are very similar to those of VERANDA alone except for the small shift of 1 % and 2 % isolines towards the south.

Velocity fields

Comparison of the average velocity field obtained by winds from VERANDA (Fig. 3a) and the velocity field from the reference simulation (Fig. 2a) shows perfect agreement. There are only some minor differences in vector lengths of a typical scale of 10 % and some differences of up to 5^{o} in vector directions. The comparison of the standard deviations of current speeds is less favourable since values obtained by VERANDA are only 1/2 to 1/3 of

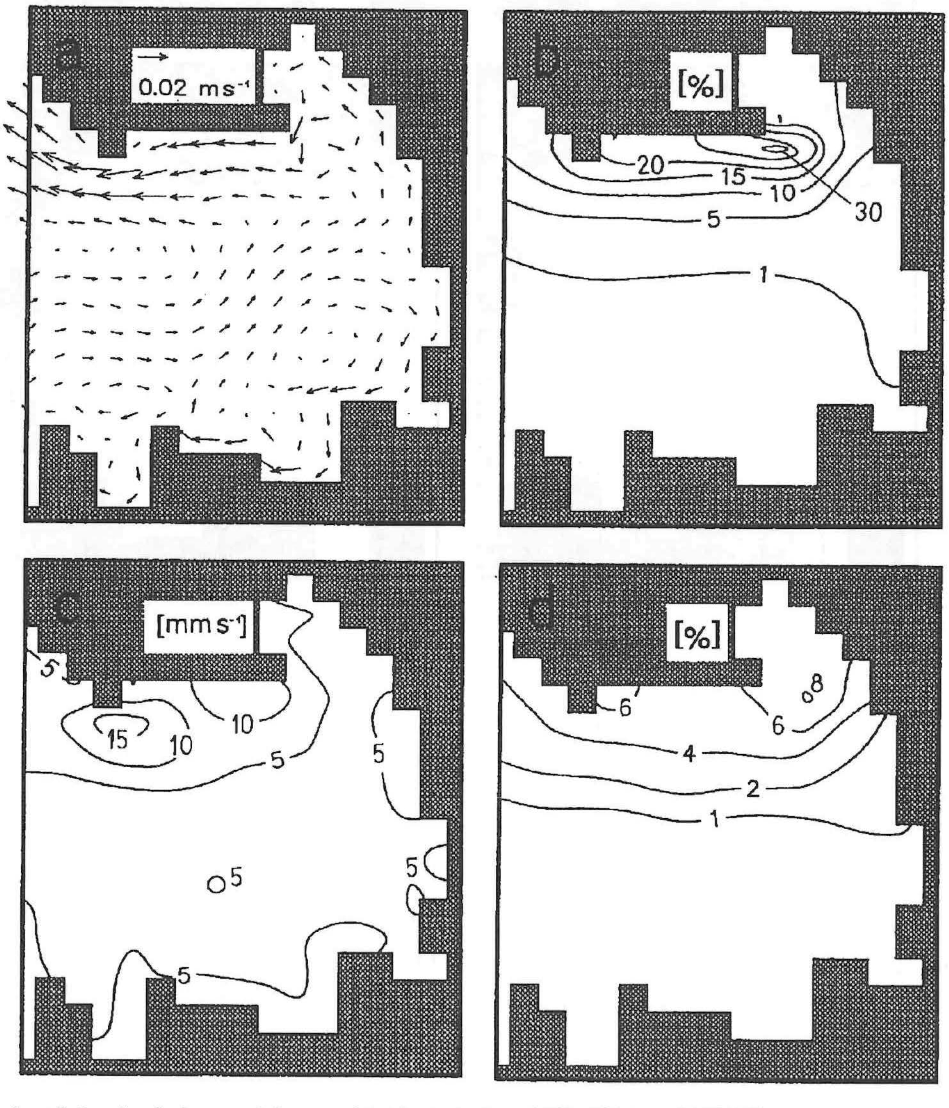

Fig. 5. Results of the simulation applying combined winds from VERANDA and VECTRA; average velocity field (a), average concentrations (b), standard deviations of velocities (c) and standard deviations of concentrations (d)

the values of the reference method. There are also differences in maximum velocities: they equal 0.2 -0.3 ms^{-1} in the reference simulation while they reach only 0.1 to 0.2 ms^{-1} in VERANDA.

The average current velocities obtained by the application of VECTRA (Fig. 4a) are typically about 50 % lower than those obtained from VERANDA. There are also some major changes in vector directions in the central part of the gulf. Further comparison also reveals appreciable discrepancies in standard deviations of current velocities: the differences between VECTRA and the reference simulation is of an order of magnitude, with values being lower for VECTRA. The same conclusion applies to the comparison of maximum velocities.

For the combined method, the average velocity field results are between the two extremes represented by VERANDA and VECTRA, but the general appearance of the velocity field is closer to that of VECTRA. Thus, the combined method was less successful than VERANDA alone regarding only HD results.

Point values

Probably the most illustrative comparison of efficiency of the applied methods was based on values of concentration and current velocities (in two directions of the coordinate system) at three characteristic points of the computational area: A (13,8) in the southern, B (22,12) in the eastern and C (13,15) in the northern part of the gulf (Fig. 1). The values are displayed in Table 3 for concentrations and in Table 4 for velocities. For every point, efficiency of the three methods is evaluated by marks: "a" stands for the best absolute approximation of the reference value and "c" for the worst. On the right edge of every table, marks are summed up separately for every method.

Regarding concentrations, i.e., results of the AD model (Table 3) alone, the most promising seems to be the combined method. From the other two methods, VERANDA was more succesful regarding average concentrations while VECTRA was better at predicting maximum concentrations. Hereby, it must be stressed that for VECTRA, the maximum concentrations can last for almost a month since after introduction of a new wind at the beginning of a month, almost steady state is established already after some days. These long-lasting concentration peaks are, of course, not realistic thus the descriptive advantage can again be given to VERANDA which simulates the dynamics of concentration changes more accurately.

Review of the point velocities (Table 4) reveals the absolute superiority of VERANDA for HD purposes. It is much better at achieving maximum and minimum velocities and only slightly worse at average velocities. In all three categories, the combined method is ranked second and VECTRA third.

Table 3. Values of $C_{average}$ and C_{max} at points A, B and C as obtained by different wind inputs

Point values of concentration					
value	wind input	A	B	C	ranking
	measured	0.7087	2.5405	5.1632	reference
$C_{average}$	VERANDA	0.0960 (c)	0.5974 (b)	5.3707 (a)	abc
	VECTRA	0.9170 (a)	5.2058 (c)	11.1797 (c)	acc
	combined	0.2016 (b)	1.2156 (a)	8.1435 (b)	abb
	measured	2.5413	8.8082	20.7627	reference
C_{max}	VERANDA	0.3127 (c)	2.5750 (c)	16.9637 (c)	ccc
	VECTRA	2.2167 (a)	14.3446 (b)	20.1922 (b)	aab
	combined	0.5144 (b)	3.3686 (a)	17.9637 (b)	abb

Table 4. *Average, maximum and minimum current velocities at points A, B and C as obtained by different wind inputs*

Point values of current velocities [cms^{-1}]					
value	wind input	A	B	C	ranking
	measured	1.00	0.53	-3.00	reference
$u_{average}$	VERANDA	1.07 (a)	0.61 (c)	-3.45 (b)	abc
	VECTRA	0.58 (c)	0.49 (a)	-2.23 (c)	acc
	combined	0.76 (b)	0.59 (b)	-2.73 (a)	abb
	measured	0.14	0.37	-0.10	reference
$v_{average}$	VERANDA	0.03 (a)	0.00 (a)	-0.07 (a)	aaa
	VECTRA	-0.23 (c)	-0.28 (b)	0.005 (c)	bcc
	combined	-0.21 (b)	-0.28 (b)	0.002 (b)	bbb
	measured	15.70	7.71	13.25	reference
u_{max}	VERANDA	5.38 (a)	2.62 (a)	9.12 (a)	aaa
	VECTRA	1.46 (c)	1.00 (c)	0.00 (c)	ccc
	combined	3.76 (b)	2.13 (b)	4.93 (b)	bbb
	measured	10.87	5.60	6.05	reference
v_{max}	VERANDA	4.04 (a)	2.99 (a)	2.49 (a)	aaa
	VECTRA	0.14 (c)	0.17 (b)	0.27 (c)	ccc
	combined	2.10 (b)	1.65 (b)	1.61 (b)	bbb
	measured	-7.84	-5.46	-29.77	reference
u_{min}	VERANDA	-3.45 (a)	-2.13 (a)	-18.21 (a)	aaa
	VECTRA	0.00 (c)	0.00 (c)	-4.74 (c)	ccc
	combined	-1.24 (b)	-0.69 (b)	-11.76 (b)	bbb
	measured	-6.56	-2.62	-5.39	reference
u_{min}	VERANDA	-2.40 (a)	-2.83 (a)	-2.30 (a)	aaa
	VECTRA	-0.80 (c)	-0.71 (c)	-0.36 (c)	ccc
	combined	-1.55 (b)	-1.59 (b)	-2.00 (b)	bbb

CONCLUSIONS

Two methods for the evaluation of wind forcing effects at long-term prognostic HD and AD simulations have been developed which were named VERANDA and VECTRA. Both methods are applicable only in cases of homogenous (spatially constant) wind fields. For their validation, a non-stationary HD-AD simulation with a measured wind input data has been performed first, which was adopted as a reference. After that, three additional simulations were done, applying a synthetic wind time series as an input. These time series were generated by VERANDA, VECTRA and a combination of both. On the basis of performed simulations, the following conclusions can be drawn:

The VERANDA method, which applies a stochastic approach for determination of wind direction is dedicated to use in non-stationary (time-dependent) HD and AD models since it provides wind data at regular time intervals. According to the performed simulations, it was found to be absolutely superior method for HD simulations as it was capable of reproducing most actual dynamics: average, maximum and minimum velocities and even the standard deviations of current velocities. As to the AD simulations, it provided results which were in general slightly better than those obtained by a combination of VERANDA and VECTRA and by VECTRA alone. This conclusion was brought on the basis of excellent agreement between VERANDA and reference simulation at high concentrations close at the source which is considered to be more important than their less favourable agreement in the 1 % isoline far from the source. Since only results after one year were compared for all methods it is possible that, due to VERANDA's stochastic character, its results would even be better after a longer period while VECTRA would not show further improvement. It would also be possible to improve VERANDA by application of a stochastic description of wind speed which is presently accounted for deterministically. For such an improvement, a wind rose would be required for which velocity classes (according to magnitude) should be given instead of average velocities.

The deterministic VECTRA method is less precise as it performs additional averaging of (already averaged) wind rose data. On the other hand, it is more widely applicable since it can also be used in stationary models. This is especially important when we want to describe non-stationary processes with steady-state solutions and by applying some interpolation procedures among them. This is often the case for WQ models where time consumption can be reduced by an order of magnitude by such approximations. At least for the Gulf of Trieste, no obvious difference was noticed between results obtained by 12 (monthly) and 4 (seasonal) VECTRA winds.

In addition to the "pure" VERANDA and "pure" VECTRA simulations, a combination of both was applied as the third option. Thereby, no considerable improvement over the use of VERANDA alone was achieved for the Gulf of Trieste. Despite this fact, for every specific site, a potential user should first determine the prevailing character of a wind rose (uniform, unidirectional or mixed) and then decide whether to use a single method or a combination of both to best reproduce the real wind dynamics.

ACKNOWLEDGEMENTS

Creation of the wind roses displayed in Table 1 and the selection of a typical year for Beli Križ was performed by Mrs. Alenka GERJEVIČ from the Hydrometeorological Service of the Republic of Slovenia. The first author would like to express special thanks to Simon ŠIRCA for his valuable suggestions for developing the basic code of VERANDA.

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Accepted: 15 September 1997

Modeliranje utjecaja vjetra na prosječnu cirkulaciju i dugotrajnu disperziju polutanata u Tršćanskom zaljevu

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SAŽETAK

Opisane su dvije metode za evaluaciju utjecaja vjetra u dugoročnim, prognostičkim hidrodinamičkim (HD) i advekcijsko-disperzijskim (AD) modelima. Njihova uspješnost i upotrebljivost studira se na primjeru Tršćanskog zaljeva. Obje su metode upotrebljive samo u primjerima homogenog polja vjetra. Jedini podatak, koji zahtjevaju obje metode je ruža vjetrova, što osigurava jednostavnu i brzu pripremu ulaznih modelskih podataka za vjetar.

U metodi VERANDA, koja je namijenjena primjeni u nestacionarnim HD i AD modelima, upotrebljen je stohastički pristup. Druga predstavljena metoda, zvana VECTRA, je deterministička i upotrebljiva je tako u nestacionarnima kao i u stacionarnima modelima. Pomoću ovih dviju metoda su kreirane sintetičke serije podataka za vjetar, koje su ulazni podatak za HD i AD modele. Rezultati simulacija sa sintetičkim serijama vjetra se uspoređuju sa rezultatima referentne jednogodišnje simulacije, u kojoj je podatak o vjetru bio mjeren. Promatraju se razlike u prosječnim poljima koncentracija i brzina te u diskretnim vrijednostima koncentracija i brzina na nekoliko lokacija. Na kraju se zaključuje, da su obje metode dovoljno točne, ako se pri njihovoj primjeni uzimaju u obzir preuzete pretpostavke i neki praktički aspekti modeliranja.