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Application of the improved version of CONDOR to the Greater Thessaloniki area

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Abstract

A new version of the diagnostic wind model CONDOR [1] for generating mass-consistent, three-dimensional wind fields has been developed by using an interpolation procedure which takes into account the probabilities of various wind directions. Results of this new version of CONDOR are compared with corresponding results of the original model version for the case of locally circulating flows. Specifically, both model versions are applied to the Greater Thessaloniki area for one typical sea breeze day in September 1991. The comparison is based on data collected in the frame of the Thessaloniki 1991 Field Measurement Campaign. The model results reveal the superiority of interpolating wind measurements in a physically more realistic manner.

1 Introduction

The knowledge of the wind field over a region characterized by complex orography is required for different atmospheric studies. Among the most preferred wind field calculation algorithms are the diagnostic models which provide quickly and efficiently three-dimensional wind fields by satisfying only some of the physical constrains. The most important category of diagnostic wind models is that using the variational calculus method. CONDOR, a model of this category, generates a wind field by first interpolating existing measurements and subsequently satisfying the continuity equation [2].

CONDOR has been modified by defining, in the interpolation process, a new weight which considers not only the distance between observation point and interpolation location, but also topographical influence by the aid of wind roses. This is practiced by defining the weight function to depend on both the inverse of the squared separation distance and the frequency of the prevailing wind direction pointing to the given interpolation point.

In the present study the ability of the modified version of CONDOR to initialize wind fields in a physically more realistic manner is tested by comparing the results of the old and the new versions of the model for the case of sea/land breeze system as an example for a locally circulating flow. Specifically, both versions of the model were applied to the Greater Thessaloniki area (GTA) for a day in the midst of the Thessaloniki 1991 Field Measurement Campaign.

2 Wind field interpolation procedure in CONDOR

2.1 Interpolation procedure in the original model version

The initial wind field interpolation in a diagnostic wind model is of paramount importance for the reconstruction of representative wind velocities in regions with complex orography: If the interpolated values of the velocity components do not represent correctly the wind field in the area of interest, the actual atmospheric flow pattern cannot be retrieved by imposing mass conservation. The approach followed for interpolating the measured data onto a regular grid in the original model version assumes the influence of specific measurements to decrease monotonically with increasing distance between interpolation location and observation point. Apparently, such an algorithm simply gives more weight to the measurements of the wind velocity closest to the interpolation location, without taking into account any other characteristics of the wind flow in the study area. In most previous applications of CONDOR the inverse of the squared distance was used as weight function.

In more detail, the interpolation technique used in the diagnostic model of Moussiopoulos et al. [1] is the following: The Cartesian vertical component w is set equal to zero at all grid points and in a next step the interpolation is applied only for the horizontal velocity components. The following interpolation formula is used:

$$\left(u_{ij}, v_{ij}\right) = \frac{\sum_{k=1}^{N} \left(u_k, v_k\right) 1 / r_k^2}{\sum_{k=1}^{N} 1 / r_k^2} \qquad (1)$$

where (u_k, v_k) is the wind velocity at the k-th measuring station in the specified reference height and r_k is the distance from the station k to the grid point (i,j). If necessary, the available ground-level measurements are beforehand extrapolated to the reference height by the aid of the power law. In a next step, the horizontal wind components at all grid locations within the surface layer are vertically extrapolated using the power law. Above the surface layer, finally, the wind components are interpolated linearly between the value at the top of the surface layer and the appropriate wind velocity from available upper air soundings. Obviously, the influence of the ground-level wind measurements decreases with increasing height.

2.2 New interpolation procedure

A shortcoming of the interpolation procedure in the original version of CONDOR is that the weight factor is independent of the gross terrain features (e.g. mountains, valleys). Based on the idea that terrain features influence the local flow either in the form of the prevailing channeling patterns or, if applicable, in the characteristics of occuring local circulation systems, the wind roses valid for each measuring station may be assumed to reflect the local topographical features in the surroundings of the station over a given period of time. The interpolation procedure in the new version of CONDOR takes into account the probabilities of various wind directions as they are manifested by the wind rose.

Definition of the wind rose A 'wind rose' is defined as a diagram designed to show the distribution of wind directions experienced at a given location over an extended period of time. It thus shows the prevailing wind directions. The most usual form consists of numerous (for instance sixteen) lines emanating from a common origin. Each of these lines corresponds to a compass point. The length of each line is proportional to the frequency of winds from that direction. A comparison of wind rose data with the local topography often shows a strong correlation between orography and prevailing wind directions or developing sea and land breezes [3]. A typical wind rose is shown in Figure 1.

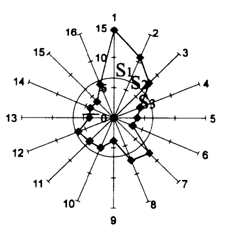

Figure 1: Wind rose

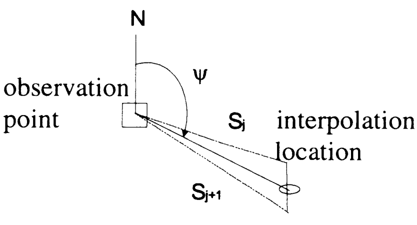

Figure 2: Formulation of the angle

Principle of the new interpolation procedure The principle of the interpolation procedure in the new version of CONDOR is that the weight factor in eqn(1) is modified to reflect the structure of the appropriate wind rose. Specifically, the influence of the individual measurement is assumed to be proportional to the probability that the wind blows in the relevant direction. In the example of Figure 1, maximum influence in the interpolation is assumed to the south, as northerly winds have highest probability. Quantitatively, the surface area of the polygon representing the wind rose is calculated (Appendix) and subsequently, the radius of a circle with a surface area equal to that of the polygon

$$r_{eq} = \sqrt{\frac{F}{\pi}} \quad (2)$$

In case that z compass points are taken into account in the wind rose, the 'factor of directional influence' in the interpolation is defined as

$$f_j = \frac{s_j - z/2}{r_{eq}} \quad (3)$$

The formula is given here in its discrete formulation. In the code a continuous formulation of the factor of directional influence is implemented. This formulation allows defining the factor f for any angle ψ formed by the northerly direction and the line connecting the observation point and the interpolation location (Figure 2). The weight factor is re-defined as

$$W_{k,j} = \frac{f_j^m}{r_k^2} \quad (4)$$

where the recommended value for m is 2 (although it is allowed to take any value between 1 and 2). For large values of f the result of the interpolation for the wind velocity at any grid point is more dependent on measurements at upwind located stations in the directions of the prevailing wind. Hence, this new weight factor gives a physically more reasonable solution to the interpolation problem because it takes into account not only the distance (r) but also the topographical influence by the wind roses (f).

Apparently, by a suitable pre-processing of the available anemological records it is possible to compute the wind direction probabilities which are appropriate for the specific applications (e.g. nighttime pattern, seasonal or monthly situation, only relevant hour).

3 Measuring stations and model inputs

Thessaloniki with its 1.000.000 inhabitants is the second largest city in Greece and exhibits typical characteristics of urban-industrial atmospheric pollution. The Thessaloniki area has complex topography and meteorology. The Thermaikos gulf, the massive of Hortiatis, the beds of Gallikos and Axios rivers and the Lake Koronia surrounding the area produce a relatively complex wind field flow (Figure 1).

A pollution monitoring campaign was conducted in the GTA in the period 15 September to 13 October 1991 [4]. The locations of the stations were selected to ensure that the collected information on the local meteorology and atmospheric pollution is representative for the study area. The positions of the measuring stations in the Thessaloniki area are displayed in Figure 3. Hourly wind speeds and directions were available at 6 observations points

(Angelohori, Neohorouda, Langadas, Panorama, Gallikos and Perea). For the vertical structure two acoustic sounders were operated, one in the University (close to the most polluted area of the city) and one in the industrial area of Sindos, near the Thessaloniki-Athens motorway and close to the Axios river.

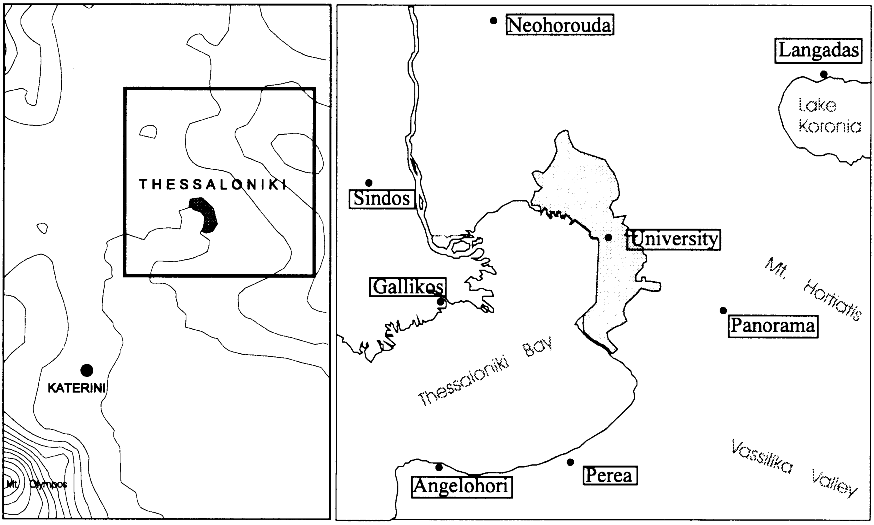

Figure 3: CONDOR model domain (left); the frame indicates the location of the enlargement (right) showing the Thessaloniki urban area (stippled) and the locations of the measuring stations installed during the Thessaloniki 1991 Field Measurement Campaign.

In this study, we analyzed the situation on 30 September 1991, a day with typical sea-breeze conditions. From available meteorological data wind roses were computed and given as input to the modified version of the diagnostic wind model CONDOR. Using the hourly measured wind directions of the 6 observing stations, wind roses were constructed by calculating the frequency distribution for the directions. With the wind directions classified in 22.5° categories, frequencies were obtained for the corresponding directions of the wind.

4 Simulation case

4.1 Description of the sea/land breeze circulation in the GTA

To simulate the sea and land breeze circulation flow, three-dimensional wind fields were calculated by using the old version of the diagnostic wind model CONDOR at 05:00, 09:00, 11:00, 15:00, 19:00 and 24:00 LST (local standard time). For the wind field calculations in the horizontal direction, an equidistant

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numerical grid of 24 × 48 points was applied (horizontal resolution 2.5 km, Figure 4). A non-equidistant vertical grid of 21 layers was used with a minimum grid spacing of 20 m and an upper boundary height of 2000 m.

Figure 4 illustrates the diurnal cycle of the flow field due to the variability of differential heating and cooling between land and sea. At night (between 01:00 and 05:00 LST), a weak NE land breeze was blowing. The flow gradually reversed to a sea breeze in the course of the morning. The sea breeze continued to develop and finally at 11:00 LST a substantial southwesterly flow was attained in almost the whole region. At 15:00 LST the wind velocities were considerably higher than at any other time and a clear southerly wind prevailed through out most of the area. At 19:00 LST a weak westerly flow prevailed and the wind field indicated the transition to the nocturnal land breeze. By midnight the land breeze was dominating and the flow started to turn to SE.

4.2 Comparison between the original and the modified version of CONDOR

The following procedure was followed to evaluate the modified version of CONDOR: Because none of the stations coincided with the grid points, the calculated wind vector at the nearest grid point to each station (test mesh point) was considered as the 'observed wind vector'. The old version of CONDOR was first used taking into account all six measurements. The old and the new versions (m=1,m=2) were then used to calculate the wind vector at all the test mesh points by successively using the other 5 stations around the test station.

The accuracy of the old and the new versions of CONDOR may be estimated by an error defined as follows:

$$\text{error} = \frac{\sum_{i=1}^{N} \sqrt{(u_{im} - u_{ic})^2 + (v_{im} - v_{ic})^2}}{\sum_{i=1}^{N} \sqrt{u_{im}^2 + u_{ic}^2}} \tag{5}$$

where u_{im} and v_{im} are the 'observed wind components' calculated from the old version of CONDOR including the station under comparison and u_{ic} and v_{ic} are the 'observed wind components' calculated from the old and new versions of CONDOR excluding the station under comparison and N=6 in the present application.

4.3 Simulation results

Table 1 shows mean values for the error corresponding to each station, calculated by averaging the errors at 6 different times (05:00, 09:00, 11:00, 15:00, 19:00 and 24:00 LST) for each of the 6 stations. Separate values are provided for the old and the new version of CONDOR, the latter for both exponents m=1 and m=2. For clarity the same information is provided in graphical form in Figures 5 and 6. The displayed results reveal that the modified version of CONDOR reduced significantly the error in the calculation of the wind velocity at all measuring stations except at Gallikos. Interestingly

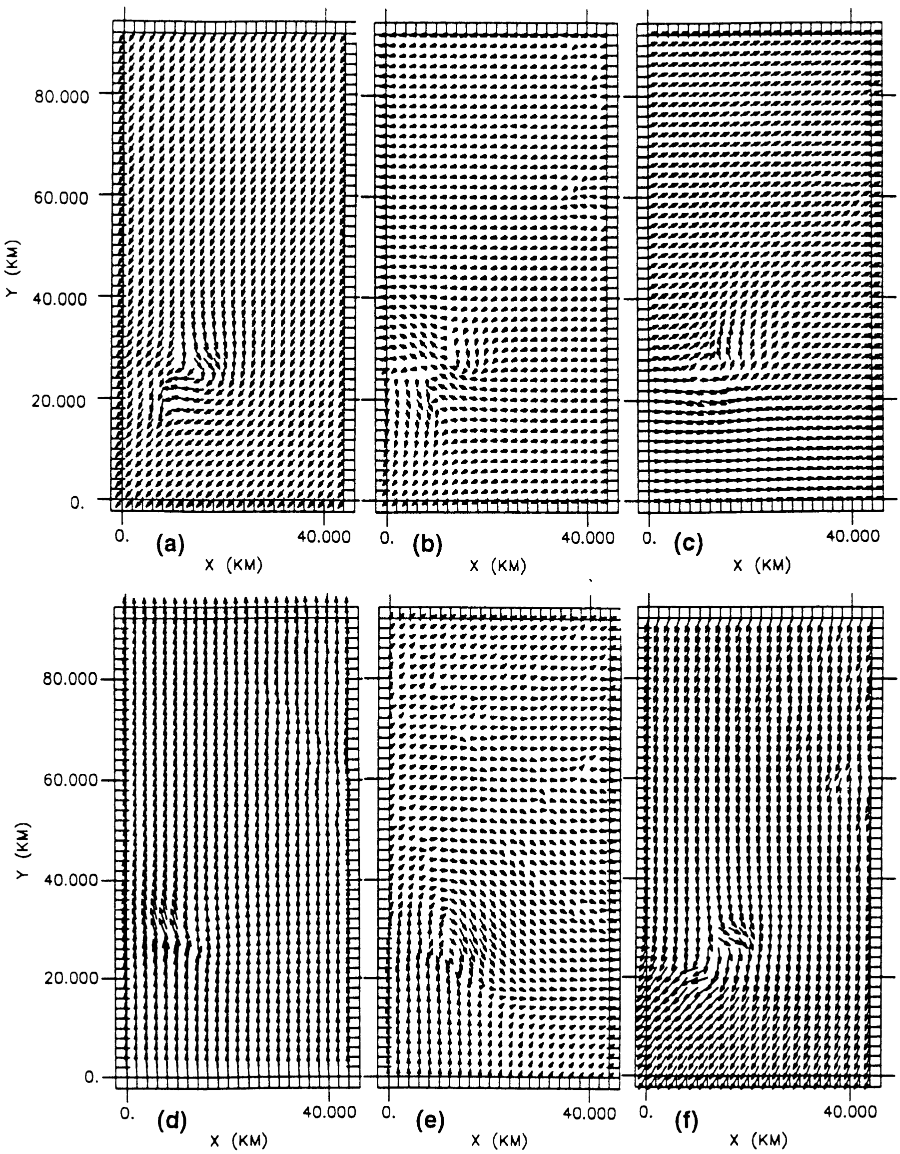

Figure 4: Near ground wind pattern in the Greater Thessaloniki area (domain extension: Figure 3) calculated with the diagnostic model CONDOR for 30 September 1991. Time: (a) 05:00 LST (b) 09:00 LST (c) 11:00 LST (d) 15:00 LST (e) 19:00 LST (f) 24:00 LST. Wind velocity is scaled 2 mm being equivalent to 2 ms^{-1}.

weighting with m=1 leads to better results compared with m=2. The largest reduction occurring at any station was at Langadas, a station in the vicinity of the Lake Koronia to the northeast of the small hills surrounding the city. The improvement diminishes for the other 4 stations in the order Panorama, Neohorouda, Angelohori, Perea, the differences between the old and the new versions of CONDOR being 58%, 46%, 32%, 25% and 14%, respectively. It is noticeable that for the Neohorouda station at 09:00 LST the calculated error in the wind vector using the m=1 weighting is equal to 0. Of the 6 stations an increased error occurred only at Gallikos, a station which caused a lot of problems in the course of the campaign [4].

Table 1. Average of the statistical error for the calculation of the wind field with the old and new versions of CONDOR, in the latter case for two different exponents m.

Thessaloniki Measuring Campaign 30.09.91	Average error old version of CONDOR	Average error new version of CONDOR, m=1	Average error new version of CONDOR, m=2
Angelohori	0.468	0.351	0.422
Gallikos	0.209	0.284	0.514
Langadas	1.124	0.470	0.956
Neohorouda	0.651	0.444	0.546
Panorama	0.327	0.195	0.171
Perea	0.500	0.431	0.547

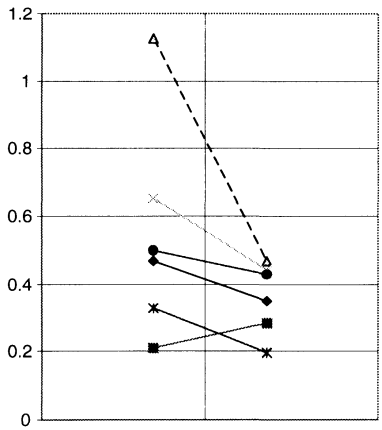

Figure 5: Statistical error of the old and new versions of CONDOR, m=1.

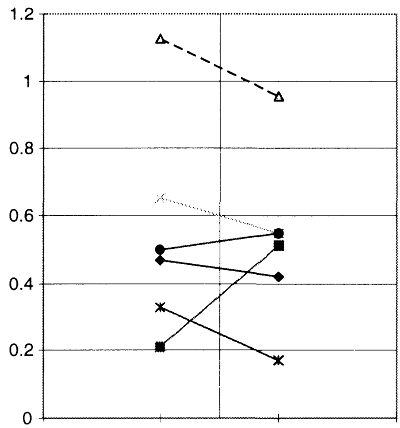

Figure 6: Statistical error of the old and new versions of CONDOR, m=2.

Results of both the old and the new versions of CONDOR for the station University (Figure 1) are compared in Figure 7 with observations available for this station (measurements at the University were not taken into account in the wind field reconstruction). Apparently, the results of the modified version of CONDOR are in better agreement with the observations, especially as far as the wind speed is concerned.

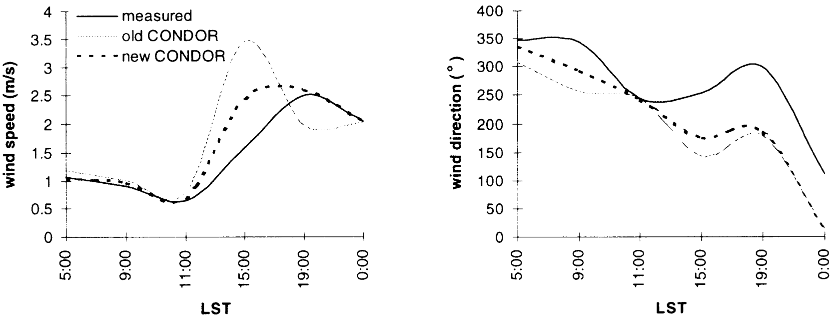

Figure 7: Results of wind velocities and directions of both versions of CONDOR compared with observations at the station University on September 30, 1991.

Results of the wind field reconstruction with both the old and the new versions of CONDOR were compared with predictions of the nonhydrostatic prognostic mesoscale model MEMO [5]. It could be shown that the results of the new improved version are in better agreement with the predictions compared to those of the old version [6].

5 Conclusions

A new interpolation procedure has been introduced in the diagnostic wind model CONDOR which allows reconstructing three-dimensional mass-consistent wind fields. This new interpolation method uses wind roses to include the influence of gross topographical features on the wind field reconstruction. Both the old and the new versions of CONDOR were tested by calculating the wind field for a typical sea-breeze day in the Greater Thessaloniki area. The statistical analysis performed shows that the new version of CONDOR is capable of providing significantly improved wind fields compared to the old version. Hence, it appears that the application of the new weighting approach leads to greater accuracy when reconstructing wind fields in regions with complex terrain.

References

1. Moussiopoulos, N., Flassak, Th. & Knittel, G. A Refined Diagnostic Wind Model, *Environ. Software* **3**, 85-94, 1988.

Transactions on Ecology and the Environment vol 6, © 1995 WIT Press, www.witpress.com, ISSN 1743-3541

2. Moussiopoulos, N. & Flassak, Th. Two vectorized Algorithms for the Effective Calculation of Mass-Consistent Flow Fields, *J.Clim.Appl. Meteor.* **25**, 847-857, 1986.
3. John, G. Rau & David, C. *Wooten Environmental Impact Analysis Handbook*, McGraw-Hill book company, 1980.
4. Moussiopoulos, N. & Kaiser, G. *Thessaloniki '91 Field Measurement Campaign*, Scientific series of the International Bureau, Forschungszentrum Juelich GmbH, vol.18, 232 pp, 1992.
5. Kunz, R. & Moussiopoulos, N. Simulation of the wind field in Athens using refined boundary conditions, *Atmos. Envir.*, 1995, in press.
6. Megariti, V. Diagnostic analysis of wind fields over complex terrain, *ph.D thesis*, 1995, in press.

Appendix: Calculation of the surface area of a polygon

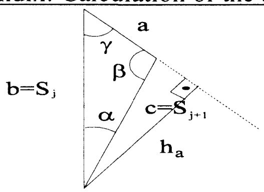

Figure A_1: A triangular subregion of the polygon representing the wind rose.

The polygon is divided into z triangular subregions. In the example z=16, this is equivalent to an angle $\alpha = 22.5°$. The area for each triangular subregion may be calculated as follows: In a triangle with angles α, β and γ and opposite sides a, b and c, respectively (Figure A_1) the area is given by

$$F_j = \frac{1}{2} a h_a \qquad (A_1)$$

where h_a is the height of the triangle on the side a. The height h_a is computed by

$$h_a = c \sin\beta \qquad (A_2)$$

Consequently, the area can be computed by the following formula

$$F_j = \frac{1}{2} a c \sin\beta \qquad (A_3)$$

The unknown side of the triangle may be calculated by the aid of the cosine theorem, i.e.

$$a = \sqrt{b^2 + c^2 - 2bc\cos\alpha} \qquad (A_4)$$

where α is equal to $22.5°$. The unknown $\sin\beta$ follows from the sine theorem

$$\sin\beta = \frac{b}{a} \sin\alpha \qquad (A_5)$$

The surface area of the entire polygon is obtained by summing over j, i.e.

$$F = \sum_{j=1}^{z} F_j \qquad (A_6)$$