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SO_2 BACKGROUND AIR POLLUTION IN THE BAKAR BAY

Temeljna kocentracija SO_2 u Bakarskom zaljevu

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Abstract - A correlation between wind velocity and simultaneous pollutant concentrations at a given locality makes possible to estimate potential background pollution. A simple procedure has been derived which helps to determine the minimum concentration corresponding to a theoretical case when wind velocity approaches infinity. It is applicable to any locality. Such research was carried out in the Bakar bay, on the northern Adriatic coast of Croatia, for simultaneous hourly series of SO_2 concentration and wind velocity. It turned out that the minimum value of SO_2 concentration which could not be cleared away any longer by meteorological factors did not depend upon the change in intensity of the local sea and land breeze circulation and its dispersive potentials. Still, when wind directions were taken into account, the different impact of distant and close emission upon the local background pollution could be detected.

Key word index: estimation of local background pollution, sea and land breeze.

Sažetak - Korelacija između brzine vjetra i simultanih vrijednosti koncentracije polutanata na nekom lokalitetu omogućuje ocjenu lokalnoga temeljnoga onečišćenja - C_b. Izveden je jednostavan postupak koji omogućuje određivanje minimalne koncentracije. Ta vrijednost odgovara teoretskom slučaju kada brzina vjetra teži u neizmjernost. Takvo je istraživanje i ocjena C_b obavljeno za Bakarski zaljev (sjeveroistočna obala Jadrana, Hrvatsko primorje) na temelju satnih vrijednosti brzine i smjera vjetra i koncentracije SO_2, posebno uvažavajući strujanje s kopna, odnosno s mora. Pri tom se pokazalo da je lokalno temeljno onečišćenje osjetljivo na promjenu smjera lokalnih vjetrova, pri čemu dolazi do izražaja razlika između bliskih i dalekih izvora emisije.

Ključne riječi: ocjena lokalnoga temeljnoga onečišćenja, obalna cirkulacija.

1. INTRODUCTION

Background pollution is stationary initial pollution which should be taken into account by all monitoring systems and control strategies. Its definition and, consequently, the methods of its evaluation are not generally adopted. Still, it is supposed to be unaffected by local sources (WMO, 1992) and, therefore, should be determined by means of long-range transport models. Such an approach might imply significant uncertainties (Smith, 1991 and 1992) induced by the changing climatology of weather patterns. For those reasons Szepesi and Fekete (1987) suggest the normalization of air background data by mixing layer heights, degree days or some other relevant meteorological data.

This paper defines the local background pollution as the minimum pollutant concentration which can not be cleared away when wind velocity and turbulent diffusivity approach their maximum. Since in the case of maximum wind velocities, close emission sources cannot be effective in local pollution, our definition agrees with the one of WMO (1992) and implies the dominant role of long-range transport.

The idea of this definition of local background pollution was already presented and discssed at the international conferences (Lončar and Šinik, 1992 and 1993).

We have applied the similarity laws to an analytical solution to the diffusion equation and have derived a method of background pollution determination by means of simultaneous data series of pollutant concentrations and wind velocities. Such an approach has helped to distinguish the various wind direction share in the total value of background pollution in the Bakar bay. It has been found that the greatest background SO_2 concentration is connected with winds blowing from ESE–SSE directions, i.e. with the air streams along the Croatian coast of the Adriatic sea.

2. THE THEORETICAL BASIS

A complete theoretical derivation of this method with all the assumptions and nondimensionalisations used together with the testing by means of data at various localities is being prepared for publication. We are,therefore, presenting only the basic equations with the necessary explanations.

We apply the equation of diffusion to a stationary case of invariant background pollution with constant sources and sinks

$$\frac{\partial \overline{C}}{\partial t} = -\overline{\vec{V}} \cdot \nabla \overline{C} + \overline{\nabla \vec{v}' \cdot c'} = 0 \qquad (1)$$

where $\overline{C}$ and c' are the mean and eddy values of pollutant concentrations and the same holds for the wind vector $\overline{\vec{V}}+\vec{v}'$. Equation (1) is now applied to a vertical crossection (S,Z), Figure 1, over a small region A which is assumed to have horizontally homogeneous fields of wind velocity and turbulent fluxes.

Finally, Equation (1) gets the following form

$$V \frac{\partial \overline{C}}{\partial s} = \frac{\partial}{\partial z} \overline{w' c'} \qquad (2)$$

$$(V = |\overline{\vec{V}}|)$$

which states that in a stationary case pollutant advection along the path s is balanced by the vertical divergence of the turbulent pollutant flux of concentration. This equation can be transformed to its gradient form with a constant turbulent diffusivity K_z in the surface layer, so that

$$V \frac{\partial \overline{C}}{\partial s} = K_z \frac{\partial^2 \overline{C}}{\partial z^2} \qquad (3)$$

We take the following boundary conditions:

$\overline{C} = C_o$ at $s=0$ and $z=0$

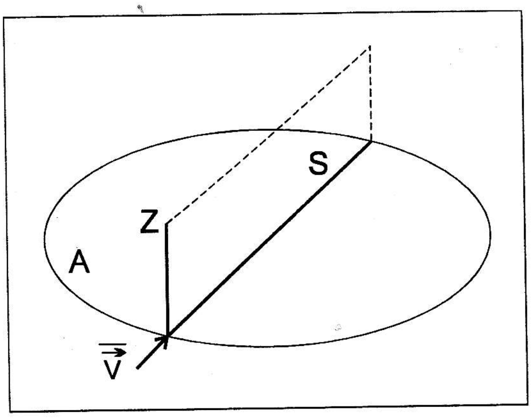

Figure 1. Vertical crossection (S, Z) over region A.

Slika 1. Vertikalni presjek (S, Z) iznad područja A.

and also assume : $\frac{\partial \overline{C}}{\partial s} > 0$ and $\frac{\partial \overline{C}}{\partial z} > 0$. Then an integration of (3) gives:

$$\overline{C} = C_o \exp\left(\frac{s}{V} + \frac{z}{K_z^{1/2}}\right) \qquad (4)$$

where C_o is the constant value of concentration over the vertical area SZ. Finally, we nondimensionalize the exponent in (4) and get:

$$\overline{C} = C_o \exp\left[\frac{u_* s}{VS} + \left(\frac{u_*}{SK_z}\right)^{1/2} z\right] \qquad (5)$$

where the friction velocity

$$u_* = [\,(\overline{u'w'})^2 + (\overline{v'w'})^2]^{1/2}.$$

After applying the surface layer similarity, (5) transformed to

$$\overline{C} = C_o \exp\left[\frac{u_* s}{VS} + \left(\frac{z_*}{kS_z}\right)^{1/2} \Phi_m\right] \qquad (6)$$

where k is von Karman's constant and Φ_m is the universal similarity function. This equation enables us to drive the following definition of background pollution:

$$C_b = \lim_{\substack{V \to \infty \\ \Phi_m \to 1}} C \qquad (7)$$

In relation to the basic Equation (3), condition (7) states that, when $V \to \infty$, K_z obtain a constant value so that $\partial \overline{C}/\partial s \to 0$ (this agrees with the defined time and space over area A and the invariability of background concentration, C_b).

A practical graphical evaluation of (7) has been derived by means of a diagram with the axes $ln\overline{C}$ and u_*/V. Measured simultaneous values of $\overline{C}$ and V are entered into the diagram and straight lines are drown through the points on the diagram. No matter which value of u_* is assumed, the lowest straight line intersects the $ln\overline{C}$ axis at the value lnC_b (corresponding to u_*/V=0). The uppermost straight line interceets the u_*/V=0 axis at the same point lnC_b. In fact all straight lines through points on the diagram should intersect at the lowest concentration i.e. the background concentration C_b. (Only two enveloping straight lines can be drawn and even these are subjected to a certain degree of uncertainty due to measurement inaccuracy, particularly at low concentrations).

3. LOCAL BACKGROUND POLLUTION IN THE BAKAR BAY

This method has been applied to determine the background concentration of SO_2 in the Bakar bay, on the northeastern Adriatic coast of Croatia (Figure 2), by means of simultaneous series of hourly SO_2 concentrations and wind velocities, measured during the period from January 1 to December 31, 1975.

Due to the orientation of the bay and the surrounding mountains, air streams from NE and from SW prevail. Northeasterly winds (from land toward sea)

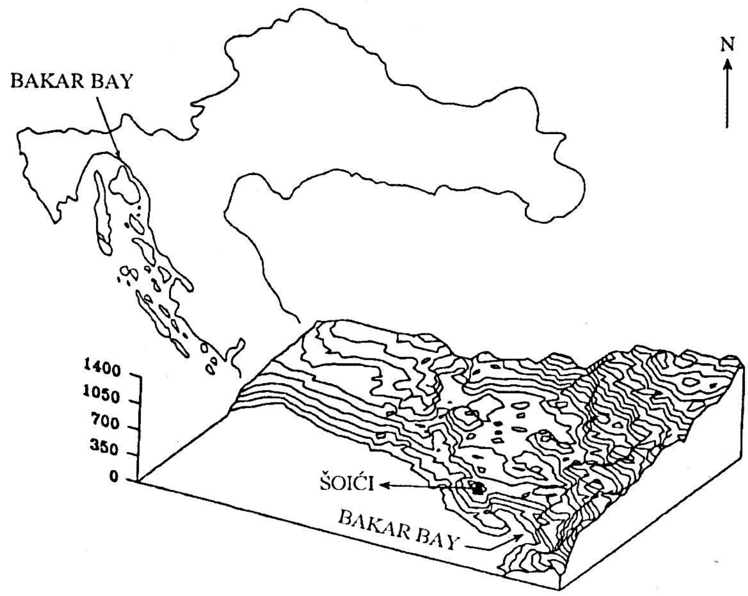

Figure 2. The Bakar bay with the northern Adriatic surroundings.
Slika 2. Karta Bakarskog zaljeva sa okolišem N–Jadrana.

are usually strong and have a ventilating effect in this region. On the other hand, southwesterly winds (from sea toward land) are usually light and persist on days when local circulation dominates synoptic circulation.

These facts suggest that it should be possible to estimate potential background pollution in relation to the main wind directions. In accordance with the method, both concentration of SO_2 and wind velocity have been translated to the $ln\overline{C}$ against u_*/V diagram. We have chosen $u_*=0.2$ for the winds blowing from the land and $u_*=0.5$ for the on-shore winds. In fact, repeated calculations proved that the choise of u_* did not influence the results, since C_b, being a theoretical limit, did not depend upon the way in which u_*/V approached zero.

For the most probable NNE–E wind directions, a practical evaluation of local background air pollution has been illustrated in Figure 3. The enveloping straight lines intersect the ordinate $u_*/V=0$ (which corresponds to $V \rightarrow \infty$) at $lnC_b=1.4$, which means $C_b=4\,\mu gm^{-3}$.

Background pollution for other, not so frequent, wind directions has been estimated on the same way. So, for:

- NW–N directions $C_b = 3\,\mu gm^{-3}$
- ESE–SSE directions $C_b = 9\,\mu gm^{-3}$

ESE to SSE winds follow the dominant direction of the Adriatic coast line and can, therefore, bring to the Bakar bay pollutants from distant emission sources along the shore.

Still, besides the possible inaccuracy of measured data, the possibility to draw the enveloping straight lines and to determine their inclination depends greatly upon the number of points on the diagram. It was, therefore, rather easy to determine lnC_b for NNE–E and NW–N directions. On the other hand, the enveloping straight lines in Figure 5 are drawn very roughly. Such a degree of subjectivity is to be eliminated, or at least lessened, in the further development of the method.

However, when applied to the sea breeze (S–W), which in the Bakar bay appears to be fairly light (velocities less than 3 ms^{-1}), the method "fails" since such light winds can in no ways approximate condition (7). Figure 6 presumably descrabes a pollutant transport from emission sources close to the Bakar bay, since concentrations of SO_2 increase with wind speed. Still, even in this case, the background SO_2 concentration would be determined as a theoretical limit if there were more points on the diagram) i.e. a greater enssembly of data).

4. CONCLUSION

Finally, it may be concluded, that local background pollution in Bakar bay is sensitive to coastal circulation. This approach to local background pollution makes it possible to determine C_b in general or with respect to wind directions. Besides, it helps to detect the different role of distant and close emissions upon local background pollution.

As to the method itself, it certainly needs theoretical improvement in many details – and also testing at various localities. Research is in progress and the results so far appear very encouraging. Since its application relies upon the measured data series accuracy, an

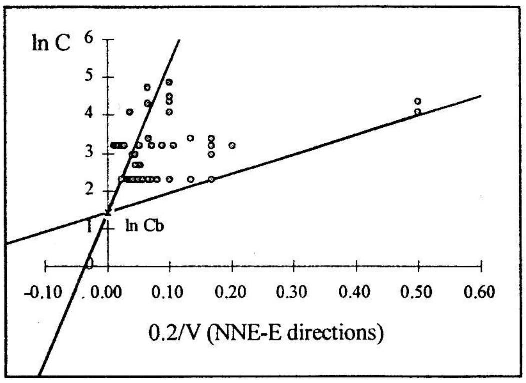

Figure 3. Practical evaluation of local background SO_2 concentrations for NNE–E wind directions.

Slika 3. Praktična ocjena temeljne koncentracije SO_2 za vjetar iz smjerova NNE–E.

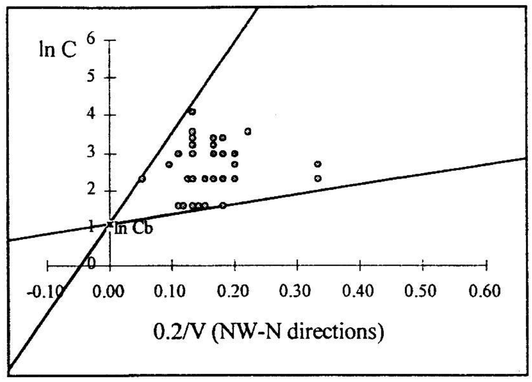

Figure 4. Practical evaluation of local background SO_2 concentrations for wind NW–N directions.

Slika 4. Praktična ocjena temeljne koncentracije SO_2 za vjetar iz smjerova NW–N.

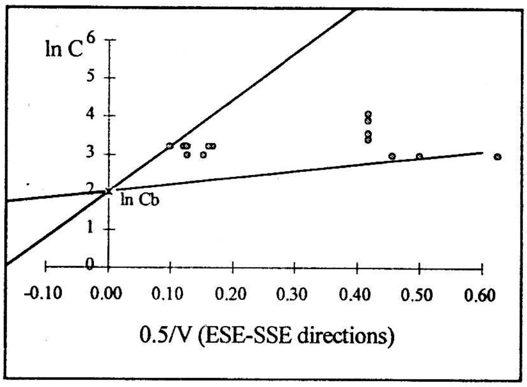

Figure 5. Practical evaluation of local background SO_2 concentrations for wind ESE–SSE directions.

Slika 5. Praktična ocjena temeljne koncentracije SO_2 za vjetar iz smjerova ESE–SSE.

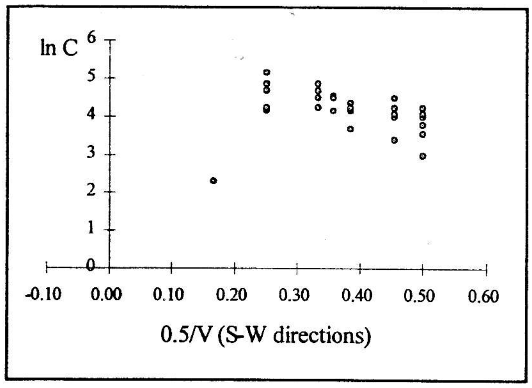

Figure 6. $ln\overline{C}$ against u_*/V for S–W wind directions. A practical evaluation of local background SO_2 concentrations is impossible.

Slika 6. Odnos $ln\overline{C}$ i u_*/V za vjetar iz smjera S–W. Praktična ocjena temeljne koncentracije SO_2 nije moguća.

additional mechanism should be derived to improve the method's effectivness.

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REFERENCES

Lončar, E. and N. Šinik 1992: Winter Daily Temperature Minimums, Wind Velocity and SO_2 concentrations Correlation in the Center of Zagreb, Proceedings "*Geophysics nad environment: Background air pollution*", Rome, 16–18. June 1992, 319–326.

Lončar, E. and N. Šinik 1993: Local Background Air Pollution in Response to Coastal Circulation, *20th International Technical Meeting on Air Pollution Modelling and its Application,* November 29 – December 3, 1993, CEAM Valencia.

Smith, F.B. 1991: Regional Air Pollution with Special Emphasis on Europe. *Q.J.R.Meteorol.Soc.* **117**, 657–683.

Smith, F. B. 1992: Emission Reduction to Meet Deposition Criteria. *Atmospheric Environment* **26 A**, 609–624.

Szepesi, D. J. and K. E. Fekete 1987: Background Levels of Air and Precipitation Quality for Europe. *Atmospheric Environment* **21**, 1623–1630.

WMO 1992: International Meteorological Vocabulary. Geneva, No. **182.** 68 pp.