Two-equation turbulence closure for quantitative description of boundary layers

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The introduction of the prediction equations for more and more turbulence quantities is that more physics is taken into account and the various complex turbulence phenomena can the be described [1,3,7]. Now the two-equation turbulence closure which includes the equations of kinetic turbulent energy(TKE) , dissipation rate(epsilon), Kolmogorov-Prandtl and Smagorinsky relationships for vertical and horizontal turbulent exchange has by far achieved the popularity for practical aims as an alternative to use Yamada-Mellor method[2,4,5,6]. Let's emphasize that the aim of described turbulence closure is the reconstruction of 3D distributions of atmospheric transfer and the characteristics of the turbulence in ABL for the service of the ecological monitoring [1]. Now the quantitative description of the air and water pollution problem uses the turbulent diffusion equation in the framework of vertical and horizontal coefficients of turbulence. In considered performance the turbulent closure method has to give a possibility of the definition of the coefficients of the vertical and horizontal turbulent exchange. The expediency of using the equation for TKE is now recognized, but the using equation for epsilon has been criticized because the process of the dissipation is associated with the small-scale turbulence. However, the energy amount dissipated is controlled by the energy fed from the large- scale motion. In this case, the spectral cascade of energy as a flow from the region of energy- carrying eddies determines the absorption of energy in a “dissipative tail”. At the same time, in cascade transfer mechanism the viscosity adjusts itself to the spectral flow by regulating the scale of turbulent eddies. Strictly, the dissipation used in the closure scheme is the rate of energy passed on by the large scales for absorption at smallest scales. Therefore the value of dissipation may be considered as a parameter characterizing the large-scale motion. Using equations for TKE and epsilon it can be possible to describe, at first, the extension of eddies which provides a cascade transfer of energy over the spectrum of scales, the sequential subdivision of eddies and a reduction of their sizes, second, the dissipation destroying the smallest eddies and thereby effectively increasing their characteristic scale.

Thus, the connection of equations for turbulent kinetic energy and for dissipation rate, Kolmogorov-Prandtl relationship are physically well-founded and acceptable closure method for vertical turbulent exchange.

Unlike the coefficient of vertical turbulent exchange, the coefficient of horizontal turbulent exchange is a parameter connected with the scale of division between mean and fluctuation motions, and in this sense it depends on a spatial resolution of the numerical scheme. The definition of horizontal coefficient is based on (1) the division of the motions into large-scale and subgrid scale, (2) the calculation of the kinetic energy production using the horizontal coefficient of turbulence and modulus of deformation, (3) the determination of kinetic energy transfer from large-scale to subgrid-scale motions. These considerations are the basis of Smagorinsky relationship for the horizontal coefficient of the turbulent exchange.

The merit of the closure method is that physically justified boundary conditions are formulated for TKE and epsilon. Equilibrium of the production and dissipation of the turbulent kinetic energy in the roughness sublayer allows to obtain the vertical boundary condition for the turbulent parameters at the roughness level. The turbulent fluxes of TKE and epsilon are given as a small values at the upper level of the calculation domain. The turbulent parameters are calculated with the sufficient accuracy at the lateral boundaries by neglecting the advective terms in the equations of turbulent kinetic energy and of dissipation rate.

At the initial time 3D distribution of the turbulent parameters is reconstructed by hydrodynamical interpolation procedure which represents the solution of 1D stationary equations for turbulent kinetic energy and dissipation rate .

The semi-implicit numerical integration method used the finite difference equations obtained by the forward -differencing scheme for integration in time, the central differences for the terms of advection and centered-in-space differences for the turbulence diffusion terms. The implicit treatment concerns the vertical turbulent exchange terms in the equations and adjusts the small vertical spacing required to resolve the internal structure of boundary layer without drastically reducing the time step as would be with more usual explicit scheme. The use of centered-in-vertical implicit scheme results in a tri-diagonal matrix which is solved by the factorization methods. The linear and finite-difference forms of TKE and epsilon equations are constructed in such way that the solution for TKE and epsilon have to be positive. It concerns the buoyancy and dissipation terms in the turbulence closure equations. If the finite-difference approximation is applied to linear forms of the TKE and epsilon equations constructed the criteria of stability and positive numerical solution are fulfilled.

The above considerations show that the potentialities of described turbulence closure is far from exhausted and can be successfully used to solve the tests of air and water pollution and other applied problems.

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