Available online at www.sciencedirect.com
SCIENCE DIRECT®

Physica A 354 (2005) 88–94

PHYSICA A

www.elsevier.com/locate/physa

Representing intermittency in turbulent fluxes: An application to the stable atmospheric boundary layer

Haroldo F. Campos Velho[a,*], Reinaldo R. Rosa[a], Fernando M. Ramos[a], Roger A. Pielke Sr[b], Gervásio A. Degrazia[c]

[a]Laboratório Associado de Computação e Matemática Aplicada (LAC), Instituto Nacional de Pesquisas Espaciais (INPE), Cx. Postal 515, 12201-970– São José dos Campos (SP), Brazil
[b]Department of Atmospheric Science, Colorado State University (CSU), Fort Collins, CO, USA
[c]Departamento de Física, Universidade Federal de Santa Maria (UFSM), Santa Maria, RS, Brazil

Received 20 March 2004; received in revised form 21 January 2005
Available online 31 March 2005

Abstract

A new formulation for eddy diffusivity is derived from Taylor's statistical theory on turbulence and from a generalized turbulent spectral equation for energy in the inertial subrange. The latter aspect is taken into account for considering the intermittency phenomenon within turbulence model. The approach is used for a stable atmospheric boundary layer parameterization.

Keywords: Eddy diffusivity; Intermittency; Taylor's theory; Atmospheric turbulence

1. Introduction

Intermittency concept has been proposed to explain some theoretical and experimental discrepancies from Kolmogorov's theory on turbulence [1]. Parisi

*Corresponding author. Fax: +55 12 3945 6375.
E-mail address: haroldo@lac.inpe.br (H.F. Campos Velho).

0378-4371/$ - see front matter
doi:10.1016/j.physa.2005.02.039

and Frisch [2] used a multifractal approach to model intermittency, where the second Kolmogorov's hypothesis (self-similarity) is replaced by the assumption that "*turbulent flow is assumed to possess a range of scaling exponents* $b \in (b_{\min},\ b_{\max})$" [1]. Here, a generalized Kolmogorov's law for inertial sub-range is used to represent the intermittency and also to derive a new formulation for eddy diffusivity.

Many approaches in turbulence start assuming Reynolds' hypothesis, where the turbulence is described as a sum of a mean stream plus a fluctuation term (with zero mean). The turbulence contribution in momentum, energy, and mass equations is constituted by the product between fluctuations. These terms represent new unknowns in the equations. The system of equations can be closed using the K-theory, where the turbulent fluxes are represented by the gradient of the mean stream multiplied by an eddy diffusivity. In this paper new formulations for these parameters are derived based on the Taylor's statistical theory of turbulence [3] and by an analytical model for the energy spectra. This model of turbulence can be applied for many physical systems, such as combustion, solar physics, pollutant diffusion, and geophysical fluid dynamics.

Our approach is applied to the atmospheric turbulence, since it is a permanent feature in the planetary boundary layer (PBL), a thin layer in direct contact with the ground. In a recent paper, a similar formulation was used for convective atmospheric boundary layer to derive eddy diffusivities and counter-gradient term [4]. In the present work the intermittency is represented in a parameterization for stable boundary layer (SBL). In this PBL, turbulence comes from a delicate balance between heat flux from the atmosphere to the ground (weakening the turbulence) and the shear of the wind (production term of the turbulence).

2. Representing intermittency in the eddy diffusivity

The starting point for the new formula for the eddy diffusivity is to consider a modified or generalized Kolmogorov's energy spectra in the inertial subrange

$$E(k) = c_2\, \varepsilon^{2/3}\, k^{-(1+\zeta_2)} \tag{1}$$

c_2 being a constant, ε is the dissipation function, and k is the wavelength. For $\zeta_2 = \frac{2}{3}$ the Kolmogorov's law is recovered and there is no intermittency.

Taylor's statistical theory on turbulence [3] states that the variance of the position of a particle is related to the velocity variance according to

$$\sigma_\alpha^2 = 2\sigma_i^2 \int_0^t (t-\tau)\, \varrho_{L_i}(\tau)\, \mathrm{d}\tau \quad \text{with} \quad \begin{cases} \alpha = x, y, z\,, \\ i = u,\ v,\ w\,, \end{cases} \tag{2}$$

where ϱ_{L_i} is the correlation coefficient and satisfies $\varrho_{L_i}(0) = 1$, and the subscript L is a reference to Lagragian correlations. Assuming stationary behaviour for turbulent velocity field, the relation between the correlation function and the spectra is