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LAGRANGIAN STATISTICS IN ATMOSPHERIC BOUNDARY LAYER DERIVED FROM LES

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1. INTRODUCTION

Lagrangian particle models has recently become an important and widely used tool for studying air pollution dispersion in the atmospheric boundary layer. Advances in computer technology and linking Lagrangian dispersion models to 3-dimensional numerical mesoscale models made it also possible to use this approach in mesoscale and regional air quality studies in complex terrain. However, the main difficulty of this technique is related to the fact that it requires Lagrangian characteristics of turbulence - wind velocity variances and Lagrangian integral times scales - while measurement data or simulated fields are available in Eulerian framework. Only limited information on Lagrangian time scales may be obtained from field studies (e.g., Hanna, 1982) or laboratory experiments (e.g., Sato and Yamamoto, 1987). Another approach for measuring Lagrangian statistics is through numerical simulations of turbulent flows. For this purpose Lagrangian particles are used to sample flow fields obtained from direct numerical simulations (DNS) (e.g., Yeung and Pope, 1989) or large eddy simulation (LES) (Wang et al.,1995).

In this study we are using LES and Lagrangian particles to derive Lagrangian statistics following approach presented by Wang et al., (1995). The previous studies were limited to Lagrangian analysis of turbulent flow at few selected levels within the boundary layer. We are attempting to extend this analysis for the entire boundary layer as well as the atmosphere above it which is important for mesoscale applications of the Lagrangian particle dispersion modeling.

2. NUMERICAL MODELS

For preliminary simulations of atmospheric boundary layer over homogenous terrain, we applied the LES model of Sorbjan (1995). This code was previously used to study the cloud-free convective mixed layer and nocturnal cloud-topped boundary layer (Sorbjan and Uliasz, 1998). A series of simulation of buoyancy- and shear-driven boundary layer flows was performed for the purpose of this study. Currently, simulations are being extended to nonhomogenous terrain with the aid of RAMS (Regional Atmospheric Modeling System) (Pielke, et al., 1992) in the LES configuration with nested grid capabilities. Both LES models are using similar subgrid scale parameterization based on the kinetic energy equation. The Lagrangian particle model used in this study has evolved from a family of particle dispersion models used in mesoscale and regional transport studies (Uliasz, 1994). It is formulated as a subroutine called on each time step of integration of the LES code. All models are implemented and ran on a PC (double processor Pentium 300Mhz).

Each particle in the Lagrangian model is tagged with the time and location of its release, as well as Eulerian wind velocity components at the current particle position. The equation of motion for each particle is integrated by a second-order Runge-Kutta scheme. Resolvable scale wind components from the LES are interpolated linearly to the particle position, taking into account horizontal periodicity of the LES output. Consequently, Lagrangian particles can be tracked in an arbitrary horizontal area, also outside the Eulerian domain of the LES model. Subgrid scale velocity components are generated with the simple random walk scheme. Below the $\Delta z/2$ level, u and v components are derived with the aid of the Monin-Obukhov similarity profiles.

Our procedure for calculating ensemble mean concentration fields from point emission sources under assumption of the flow stationarity and horizontal homogeneity is described by Sorbjan and Uliasz (1998). A similar approach is applied for derivation of Lagrangian statistics from the LES output. After the solution of the LES model has reached a quasi-steady state, Lagrangian particles are continuously being released from randomly selected locations within the entire modeling domain and traced for period of time longer than the expected Lagrangian time scales. Lagrangian velocity autocorrelations are calculated on each step of model integration on a grid: height versus time lag. The uniform kernel estimator (Uliasz, 1994), with bandwidths equal to a half of the assumed grid spacings, is used in these calculations. This method allows us to obtain autocorrelations averaged horizontally over the modeling domain and over certain number of time integration steps.

3. EXAMPLE OF RESULTS

The Sorbjan's LES model was used to simulate convective boundary layer on a $64\times64\times64$ grid with

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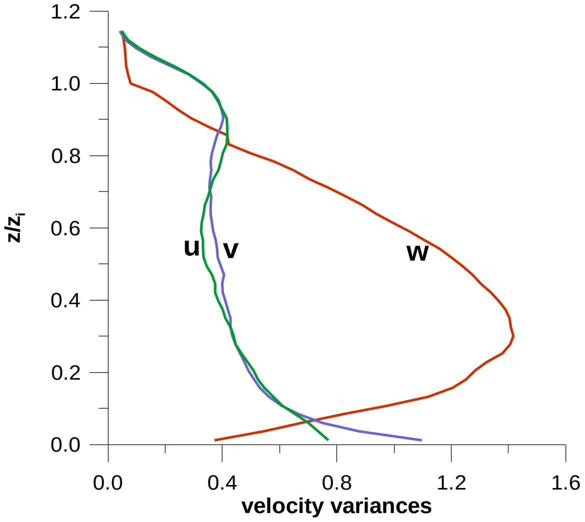

Figure 1. Velocity variances from the LES simulation

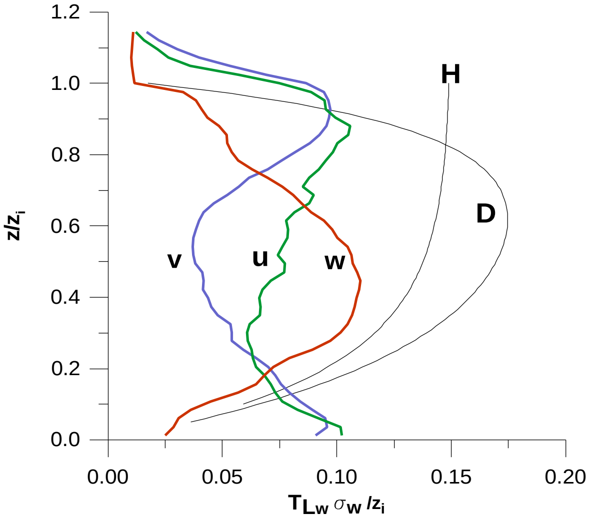

Figure 2. Lagrangian integral time scales for a=u, v, and w velocity components from the LES simulation and for w component from Hanna (1982) - H and Degrazia et al. (1998) - D

spacing $\Delta x=\Delta y=80$ m, and $\Delta z=25$ m with the following input parameters: surface heat flux, $Q_*= 0.24$ $ms^{-1}K$, geostrophic wind velocity $U_g=3$ ms^{-1}. The initial potential temperature profiles was 300 K below an initial boundary layer height of 1000 m; it increases by a total of 8 K across five Δz grid levels, and then increases with the lapse rate of 3 K km^{-1}. The final mixing height, z_I, was 1037.5 m, $u_*=0.31$ ms^{-1}, $w_*=2.01$ ms^{-1}. Figure 1 presents profiles of wind velocity variances obtained from this simulation.

The LES simulation lasted 7538 s. After this time, the Lagrangian particle model was activated and ran for the next 2400 s. Particles were released at the rate of 300 particles per 3 s time step from 5120×5120×1200 m domain during first 1800 s of this period. The Lagrangian autocorrelations were calculated on grid with spacing of 25 m for height and 10 s for time lag and then used to derive Lagrangian times scales.

The obtained profiles of the Lagrangian time scales are shown in Figure 2 as $T_{La}\,\sigma_a/z_I$ (a=u,v,w,). This plot also presents estimations for $T_{Lw}\,\sigma_w/z_I$ derived from measurements by Hanna (1982) and from the spectra of turbulent kinetic energy and Taylor statistical diffusion theory by Degrazio et al. 1998). It should be pointed out that they both applied the same empirical estimation for the peak wavelength of turbulent velocity spectra. Their estimations for horizontal Lagrangian time scales are consequence of assumption that variances of u and v velocity components are equal and constant within the convective boundary layer: $T_L\,\sigma\,/z_I$ is equal to 0.15 and 0.17 according to Hanna (1982) and Degrazio et al. 1998) correspondingly.

4. FINAL REMARKS

The presented results are of preliminary character. Current analysis is focused on explanation of a discrepancy between our results and estimations of Lagrangian time scales provided by Hanna (1982) and Degrazio et al. 1998). We are also comparing our estimations of Lagrangian and Eulerian time scales. Further research will include LES/particle simulations for different flow regimes including the boundary layer over nonhomogeneous terrain as well as testing different formulations for Lagrangian time scales used in Lagrangian particle dispersion models.

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