Japan Geoscience Union Meeting 2011
(May 22-27 2011 at Makuhari, Chiba, Japan)

AAS022-03 Room:104 Time:May 25 09:00-09:15

Insight into filter-size effect on SGS turbulence structure in the neutral-surface layer with wind-tunnel experiment

Yasuo Hattori[1*], Chin-Hoh Moeng[2], Hitoshi Suto[1], Hiromaru Hirakuchi[1]

[1]CRIEPI, [2]NCAR

A better understanding of structural characteristics of sub-grid scale (SGS) turbulence in the atmospheric surface layer is of practical interest for developing large-eddy simulation (LES) techniques with numerical weather forecasting models. Such LESs have become a powerful tool for studying atmospheric turbulence (e.g. Takemi and Rotunno 2003, Michioka and Chow 2008, Catalano and Moeng 2010, Hattori et al. 2011). However, the surface-layer turbulence is still poorly resolved, especially near the ground, in the simulations, and thus, the improvement of SGS modeling remains a topic of interest (Wyngaard 2004, Chow et al. 2005, Moeng et al. 2007). To tackle this problem, some observation projects were carried out to firmly grasp the characteristics of SGS motion of the surface-layer turbulence (e.g. Sullivan et al. 2003), but the details of spatial, especially vertical, structure of SGS fields have not been clarified yet, because of the difficulty in obtaining multi-point simultaneous velocities in observations.

On the other hand, we have recently developed an experimental approach to mimic the neutral surface-layer turbulence in a test section of wind tunnel (Hattori et al. 2010); by adding large-scale flow disturbances, the scale of which is much large compared with the scale of shear turbulence of the boundary layer, with an active grid technique, we obtained the fully developed logarithmic layer, which consist of a turbulent flow that has similar characteristics to those typically observed in the atmospheric surface layer.

In this study, by using this approach, we have carried out PIV measurement and discussed the SGS motions in the streamwise-vertical plane of the logarithmic layer; the velocity at the centerline of the test section was set to 5 ms-1 and the measuring location was fixed at the distance x = 4180 mm downstream from the active turbulence grid; the logarithmic layer height, hs, was 0.07 m. The velocity vectors were measured with a PIV technique. Particle-containing flow images with a physical size of 88.4x88.4 mm2 were captured by a CCD camera, and then, the velocity vectors were calculated using a cross-correlation method with interrogation windows of a size of 1.4x1.4 mm2. After removing incorrect velocity vectors with a median filter, we decomposed the instantaneous velocity fields into two, grid and sub-grid, scales by the application of a top-hat spatial filter (Sullivan et al. 2003, Inagaki and Kanda 2010) with the filter width, Df. The statistics were calculated from velocity vectors obtained with about 3000 image pairs. Turbulence statistics obtained with the PIV agreed excellently with the hot-wire measurements (Hattori et al, 2010).

Fist, we examined the change in the contribution of the SGS motions to the turbulence intensity with Df, which properly corresponds to observations in the near-neutral atmospheric surface layer (Sullivan et al, 2003); e.g., the contribution of SGS motions increases with Df and becomes dominant for Df/hs$>$0.2. The probability density function distributions (PDF) of SGS velocity also changed with Df. The wider filter width suppresses the low speed fluid motions, implying that SGS motions for Df/hs=0.5 [such filter width is often used in the LES's with numerical weather prediction models (Sullivan et al. 2003)] relate to coherence structures, which include large-scale fluid motions, such as sweep events.

Then, we examined the coherence structure of SGS fluid motions with a proper orthogonal decomposition. The packet like flow patterns (Adrian 2000) appear for Df/hs=0.5, whereas vortex structures become dominant for Df/hs$<<$1, corresponding to discussion about PDF distributions. Also, we checked the correlation between a SGS flux and a grids-scale deformation tensor, which is apparently weak, suggesting that conventional SGS model might have some problems for estimating instantaneous SGS fluxes of the surface-layer turbulence.

Keywords: coherence structure, LES, surface layer, turbulence, wind-tunnel experiment