Detection of Turbulence Structures and Their Interactions with a Flat Gas-Liquid Interface in Fully-Developed Turbulent Flow

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ABSTRACT
This study proposes a proper scaling of a vortex indicator for practical identification of coherent structures (CS) in a turbulent flow with a gas-liquid interface. The Laplacian of the pressure is scaled by its time-space average and root-mean-square value to introduce a new parameterization for effective identification of CS. Numerical turbulent flow realizations with the gas-liquid interface obtained by a direct numerical simulation technique are employed to confirm suitability of the proposed scaling. The results of this study indicate that the newly proposed scaling is advantageous in separating all the essential CS from disorganized turbulent background using a unique threshold level, especially in the region adjacent to the gas-liquid interface.

KEY WORDS: Coherent Structures, Turbulence, Gas-Liquid Interface, Direct Numerical Simulation, Vortex Identification

INTRODUCTION
Interest in identification of coherent structures (CS) from fluid turbulence has been maintained in the last several decades by speculation that CS play an important role in sustaining turbulence, momentum, heat and mass transport, the turbulence energy cascade, and many other phenomena. Identification of CS near a gas-liquid interface is particularly useful for investigating physical mechanisms and processes relevant for multiphase transport phenomena between air and water in turbulent flow (Kim, 2003; Adrian, 2007; Wallace, 2009). The author has investigated the relation between turbulence and heat and mass transport mechanisms at a non-sheared gas-liquid interface, (Nagaosa and Handler, 2003) and at a weakly sheared gas-liquid interface (Enstad et al., 2006). This study focuses on identification of CS near the flat gas-liquid interface in turbulence. Turbulent flows under the interface with mass transfer have been realized by a direct numerical simulation (DNS) technique. An extraction of CS from fluid turbulence using these DNS data has been attempted, in order to model turbulent heat and mass fluxes at the interface based on easily measurable turbulence quantities. Three numerical criteria for identification of CS have been applied to the turbulent flows to achieve an exact diagnosis of CS in fluid turbulence. First is the criterion based on the discriminant of the characteristic equation of the velocity gradient tensor (Chong et al., 1990; Blackburn et al., 1995; Chong et al., 1995; Chacin and Caantwell, 2000). Second is the criterion using the second eigenvalue of the symmetric tensor, $H_\beta = \Sigma_\alpha \Sigma_\beta - \Omega_\lambda \Omega_\beta$, where $\Sigma_\alpha$ and $\Omega_\beta$ are the symmetric and anti-symmetric parts of the velocity gradient tensor, $G_\eta = (\Sigma_\eta + \Omega_\eta)/2$ (Jeong and Hussain, 1995; Jeong et al., 1997). The final criterion is based on the second invariant of the velocity gradient tensor $G_\eta$, which is equivalent to the Laplacian of the pressure (Tanaka...