Geophysical Research Abstracts
Vol. 14, EGU2012-12439-2, 2012
EGU General Assembly 2012

A nonlinear subgrid-scale closure for large-eddy simulation of the atmospheric boundary layer

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Subgrid-scale (SGS) modeling is a critical component in large-eddy simulation of the atmospheric boundary layer. After the encouraging performance of a recently introduced nonlinear SGS stress model (Lu and Porté-Agel, 2010), here we extend it and propose a nonlinear SGS scalar flux model. The complete closure is based on the Taylor expansion of the exact SGS terms, and employs the local equilibrium hypothesis to evaluate the SGS velocity scale and the SGS scalar concentration scale. The two model coefficients can be specified based on theoretical arguments, which are strictly valid only in the inertial subrange of high-Reynolds-number turbulence. It is therefore questionable if this closure, with two universal constants, can model effectively the variety of phenomena present in complex flows. To avoid this issue, we develop and implement a dynamic SGS procedure, which is used to optimize the value of the model coefficients based on the statistics of the resolved turbulence. As a result, the model coefficients are computed dynamically rather than input a-priori or ad-hoc. We find that the two dynamically-calculated coefficients have mean values that are approximately constant throughout the turbulent boundary layer, and their fluctuations follow a near-lognormal distribution. Results from large-eddy simulations of a neutral atmospheric boundary layer and a stable atmospheric boundary layer using the new closure show good agreement with reference results, including well-established theoretical predictions as well as experimental and numerical results. For instance, the closure can deliver the expected surface-layer similarity profiles.