Large-eddy simulation of a stratocumulus cloud

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Stratocumulus clouds form near the surface, covering about 20% of the Earth's surface, and typically appear as a lumpy cloud layer. Stratocumulus have a large effect on the Earth's energy balance because they strongly reflect incoming solar radiation. Climate projections are sensitive to the amount of cloud cover and small variations in the stratocumulus area coverage can produce energy-balance changes comparable to those due to greenhouse gases [1].

Large-eddy simulation (LES) can be used to gain insight into the cloud physics and the factors controlling the cloud amount. LES is challenging, requiring very fine grid resolutions because of the sharp inversion (temperature increase) at the cloud top and the fine-scale forcing of buoyant convection that drives the turbulent flow. Turbulence is mainly generated by shear near the surface, (positively) buoyant plumes rising from the surface, and (negatively) buoyant fluid created near the cloud top by radiative cooling.

The simulation corresponds to the conditions of the DYCOMS II campaign [2]. The computational domain is $5.12^2 \times 1.5$ km in the horizontal and vertical directions, and the grid resolution is 1.25 m with $4096^2 \times 1200$ grid points. The simulation utilizes the buoyancy adjusted stretched-vortex subgrid scale (SGS) model [3]. The LES model and the case details are described in Ref. [4].

The images correspond to a snapshot from the LES and show the complex multiscale structure of turbulence in the atmospheric boundary layer. The panels show horizontal (Fig. 1) and vertical (Fig. 2) cross sections of total water mixing ratio [$q_t = (\text{mass of water vapor} + \text{liquid})/\text{mass of dry atmosphere}$]. The total water mixing ratio is an active scalar and the main component of buoyancy. Near the surface, shear dominates the turbulence structure with streaks aligned with the mean wind direction. Higher up in the subcloud layer turbulence transitions to the cellularlike structure that is

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FIG. 1. Horizontal planes of total water mixing ratio. Triangles denote the locations of the x - z vertical cross sections of Fig. 2. DOI: <https://doi.org/10.1103/APS.DFD.2016.GFM.P0012>

characteristic of buoyant convection. The distinctive lumpy or cellular structure of the cloud becomes well defined within the cloud layer. The highest horizontal plane ($z = 850$ m, $z/h = 1$) shows the structure of the turbulent-laminar interface at the top of the boundary layer (i.e., cloud top).

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FIG. 2. Vertical x - z planes of total water mixing ratio (colored contours). The white contour denotes the cloud boundary. Triangles show the locations of the horizontal cross sections of Fig. 1. DOI: <https://doi.org/10.1103/APS.DFD.2016.GFM.P0012>

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- [1] R. Wood, Stratocumulus clouds, [Mon. Weather Rev.](#) **140**, 2373 (2012).
- [2] B. Stevens, C.-H. Moeng, A. S. Ackerman, C. S. Bretherton, A. Chlond, S. De Roode, J. Edwards, J.-C. Golaz, H. L. Jiang, M. Khairoutdinov, M. P. Kirkpatrick, D. C. Lewellen, A. Lock, F. Muller, D. E. Stevens, E. Whelan, and P. Zhu, Evaluation of large-eddy simulations via observations of nocturnal marine stratocumulus, [Mon. Weather Rev.](#) **133**, 1443 (2005).
- [3] D. Chung and G. Matheou, Large-eddy simulation of stratified turbulence. Part I: A vortex-based subgrid-scale model, [J. Atmos. Sci.](#) **71**, 1863 (2014).
- [4] G. Matheou and D. Chung, Large-eddy simulation of stratified turbulence. Part II: Application of the stretched-vortex model to the atmospheric boundary layer, [J. Atmos. Sci.](#) **71**, 4439 (2014).