National Aeronautics and Space Administration

# Large-eddy simulation of a stratocumulus cloud

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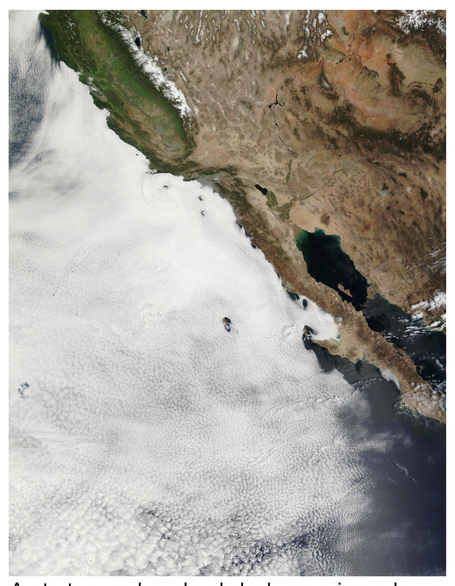


A stratocumulus cloud deck covering a large area of the East Pacific Ocean off the West coast of North America. Image from the Moderate Resolution Imaging Spectroradiometer (MODIS).

Stratocumulus (Sc) clouds form near the surface, covering 20% the Earth's surface, and typically appear as a lumpy cloud layer. Sc 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 Sc area coverage can produce energy-balance changes comparable to those due to greenhouse gases.

Large-eddy simulations (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 (Stevens et al. 2005). The computational domain is $5.1^2 \times 1.5$ km in the horizontal and vertical directions, 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 (Chung & Matheou 2014). The LES model and the case details are described in Matheou & Chung (2014).

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 the vertically-integrated amount of cloud liquid water (top right, gray scale) and cross sections of total water mixing ratio ($q_t$ = mass of water vapor + liquid / 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 sub-cloud layer turbulence transitions to the cellular-like structure that is characteristic of buoyant convection. The distinctive lumpy/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).

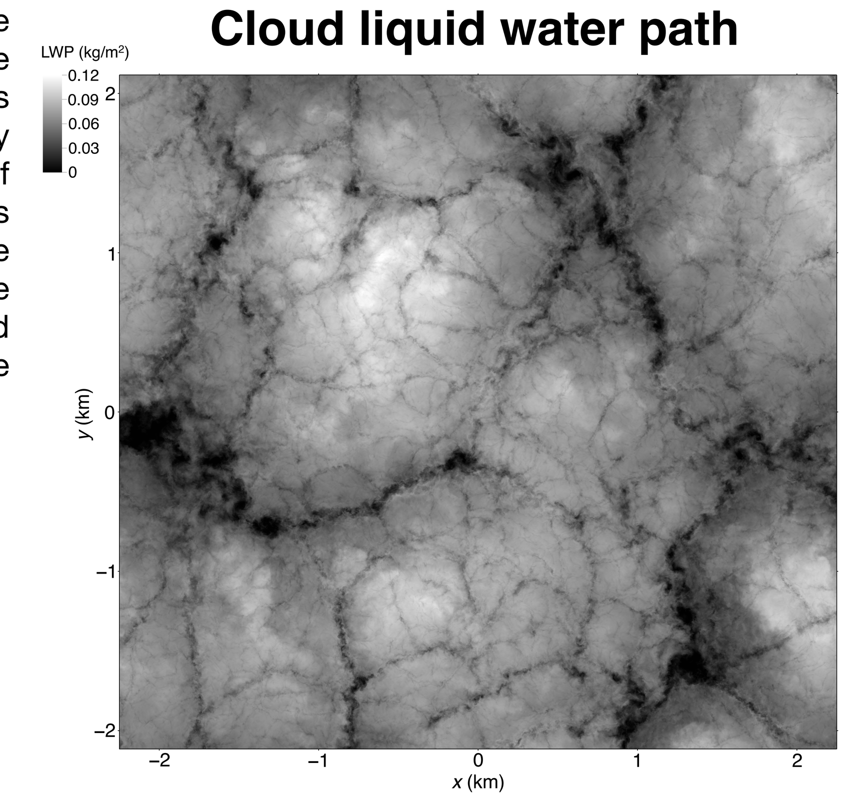
**References**

Chung, D. and G. Matheou, 2014: Large-eddy simulation of stratified turbulence. Part I: A vortex-based subgrid-scale model, *J. Atmos. Sci.*, 71, 1863–1879.

Matheou, G. and D. Chung, 2014: Large-eddy simulation of stratified turbulence. Part II: Application of the stretched-vortex model to the atmospheric boundary layer, *J. Atmos. Sci*., 71, 4439–4460.

Stevens, B., et al., 2005: Evaluation of large-eddy simulations via observations of nocturnal marine stratocumulus. *Mon. Wea. Rev*., 133, 1443–1462.

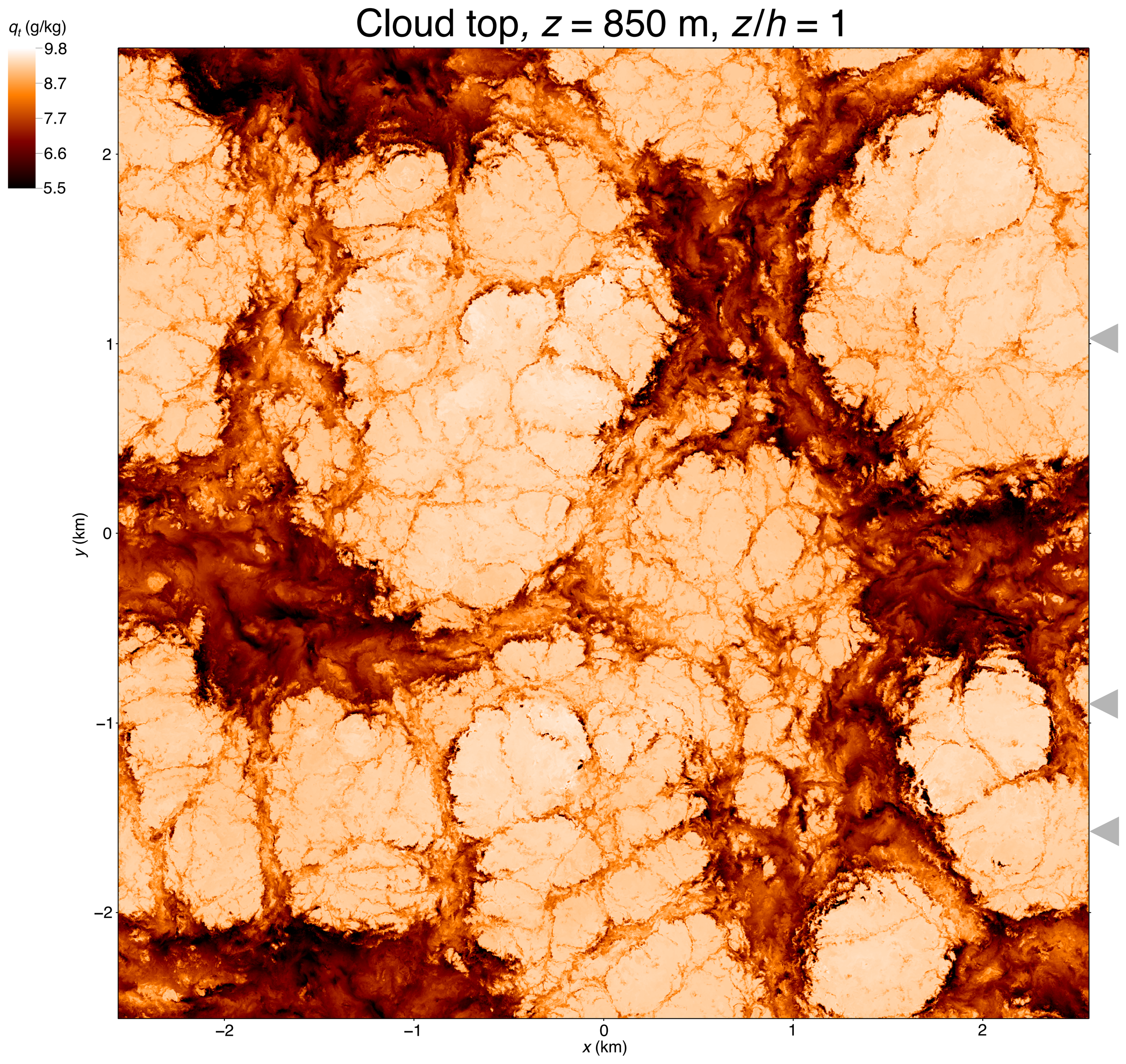
## Cloud liquid water path



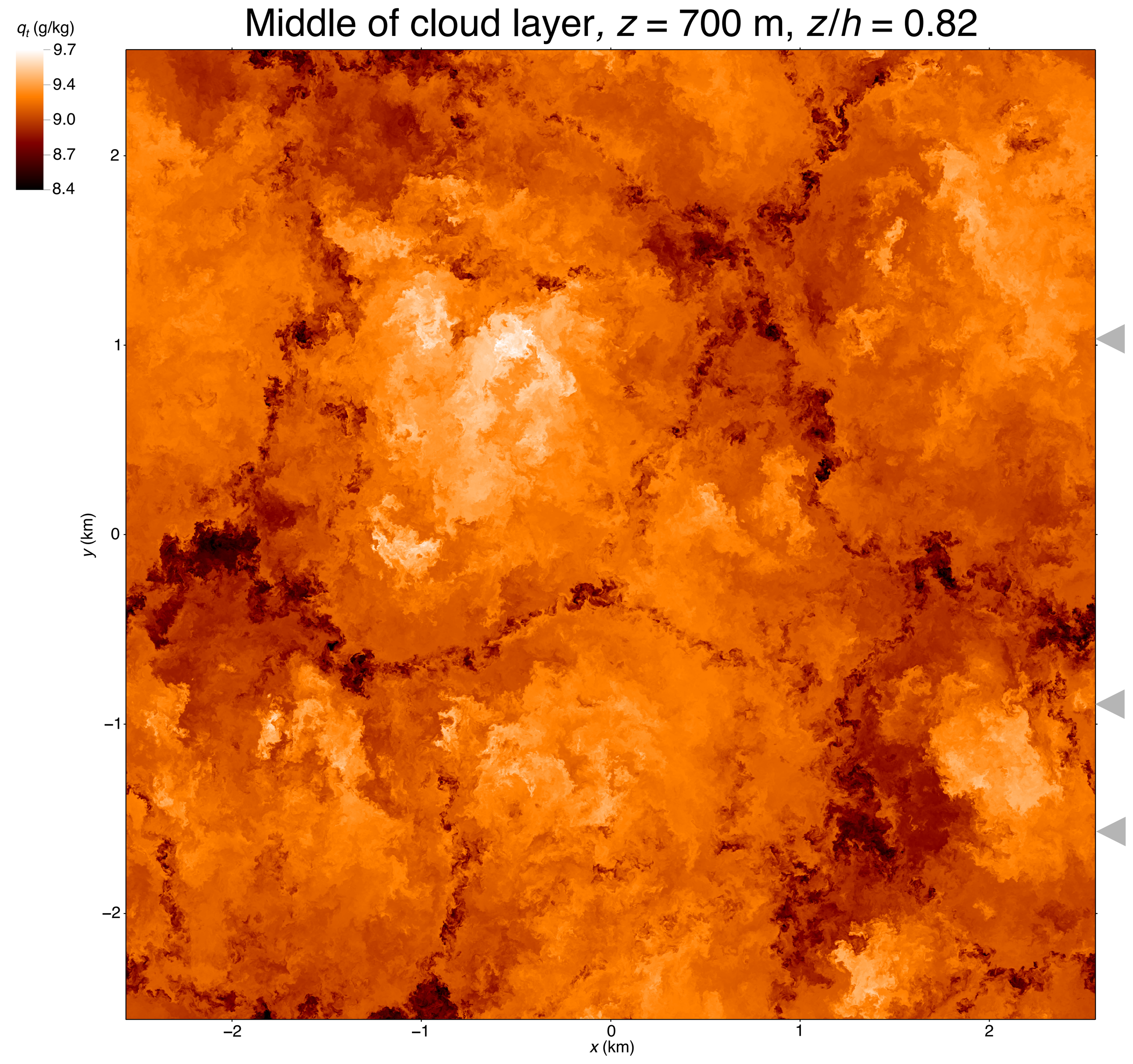

## Horizontal planes

*h* corresponds to the height of the boundary layer (i.e., the cloud top).
Triangles denote the locations of the x–z vertical cross-sections.

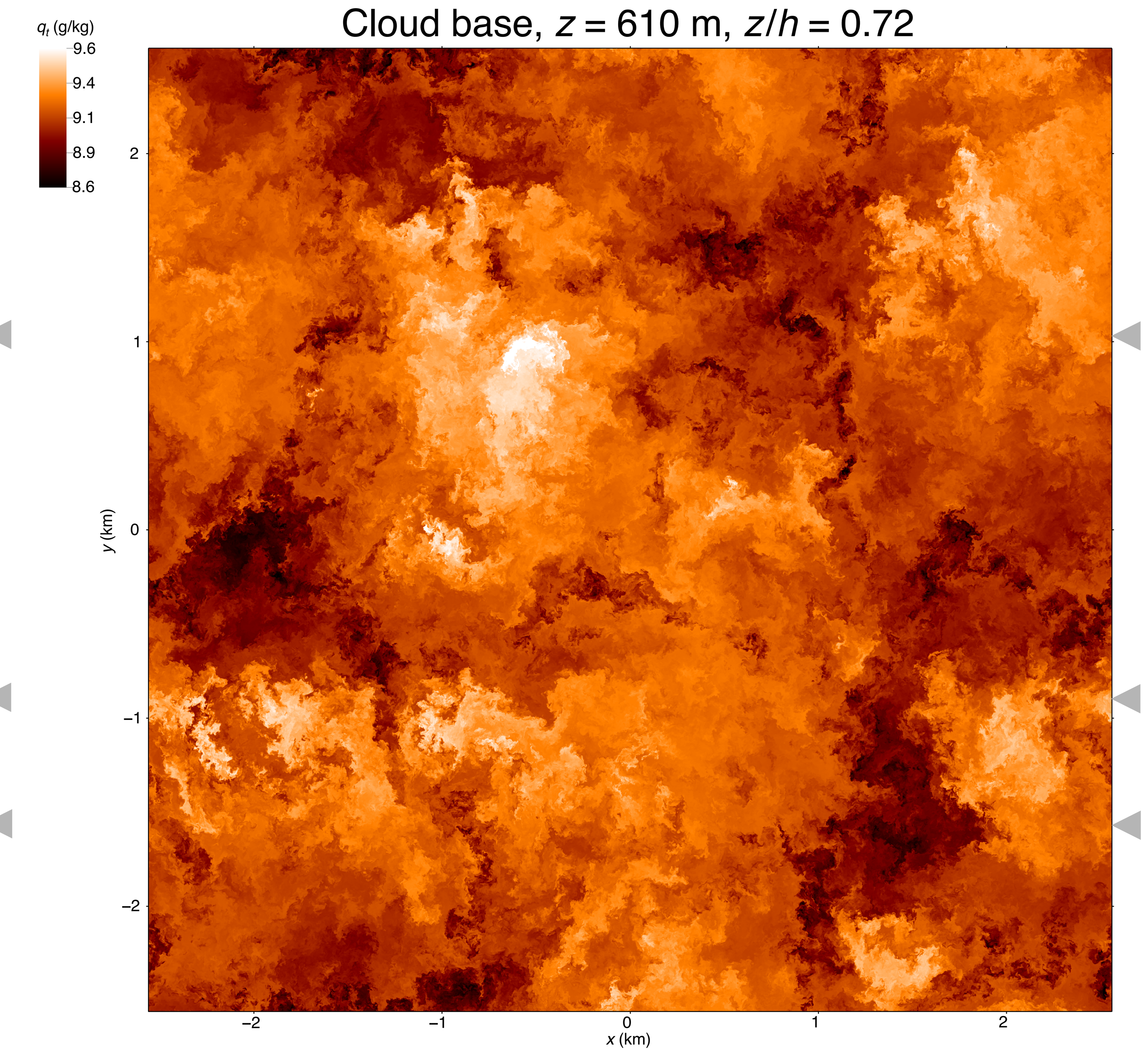
Cloud top, $z = 850$ m, $z/h = 1$



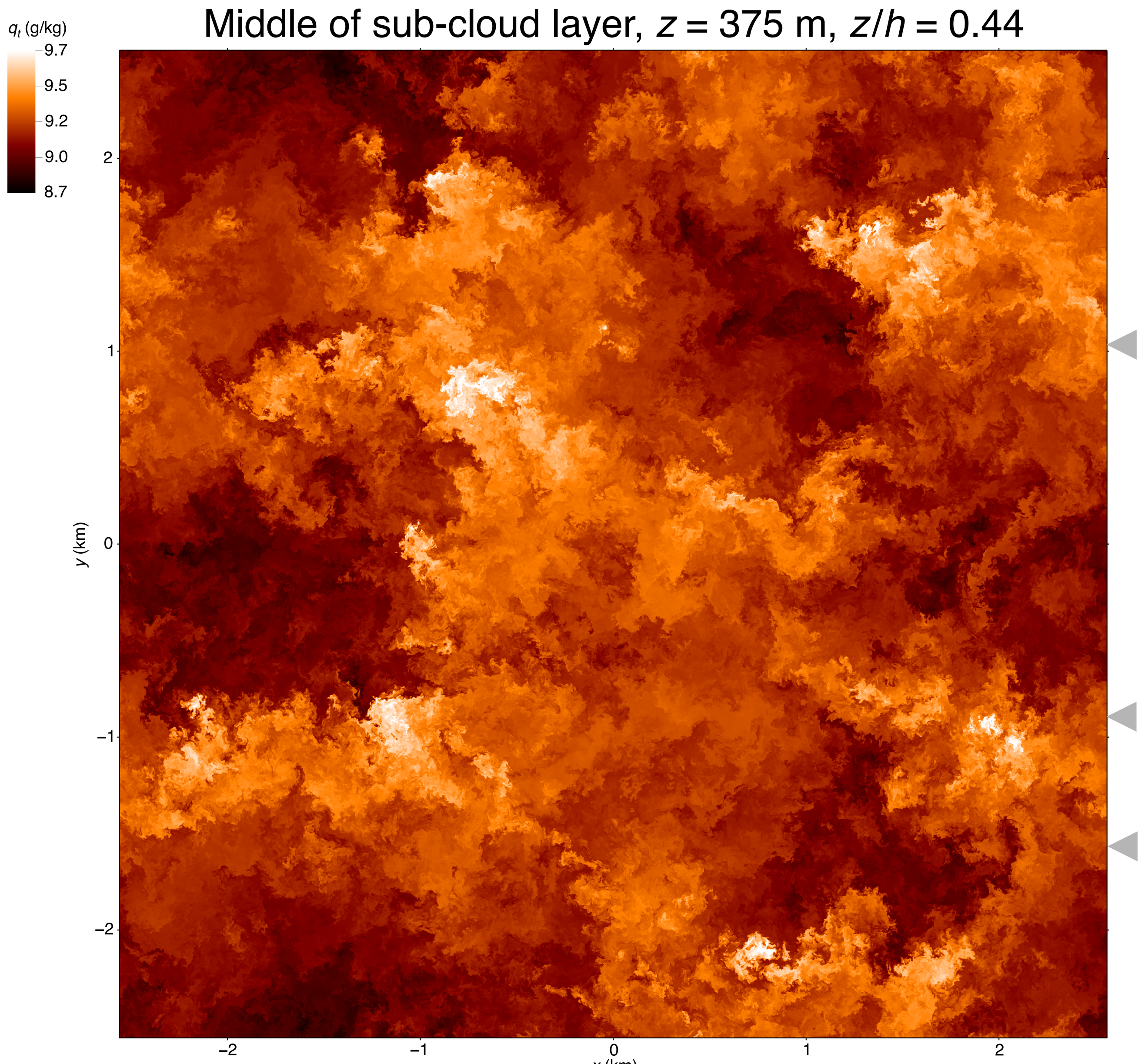

Middle of cloud layer, $z = 700$ m, $z/h = 0.82$



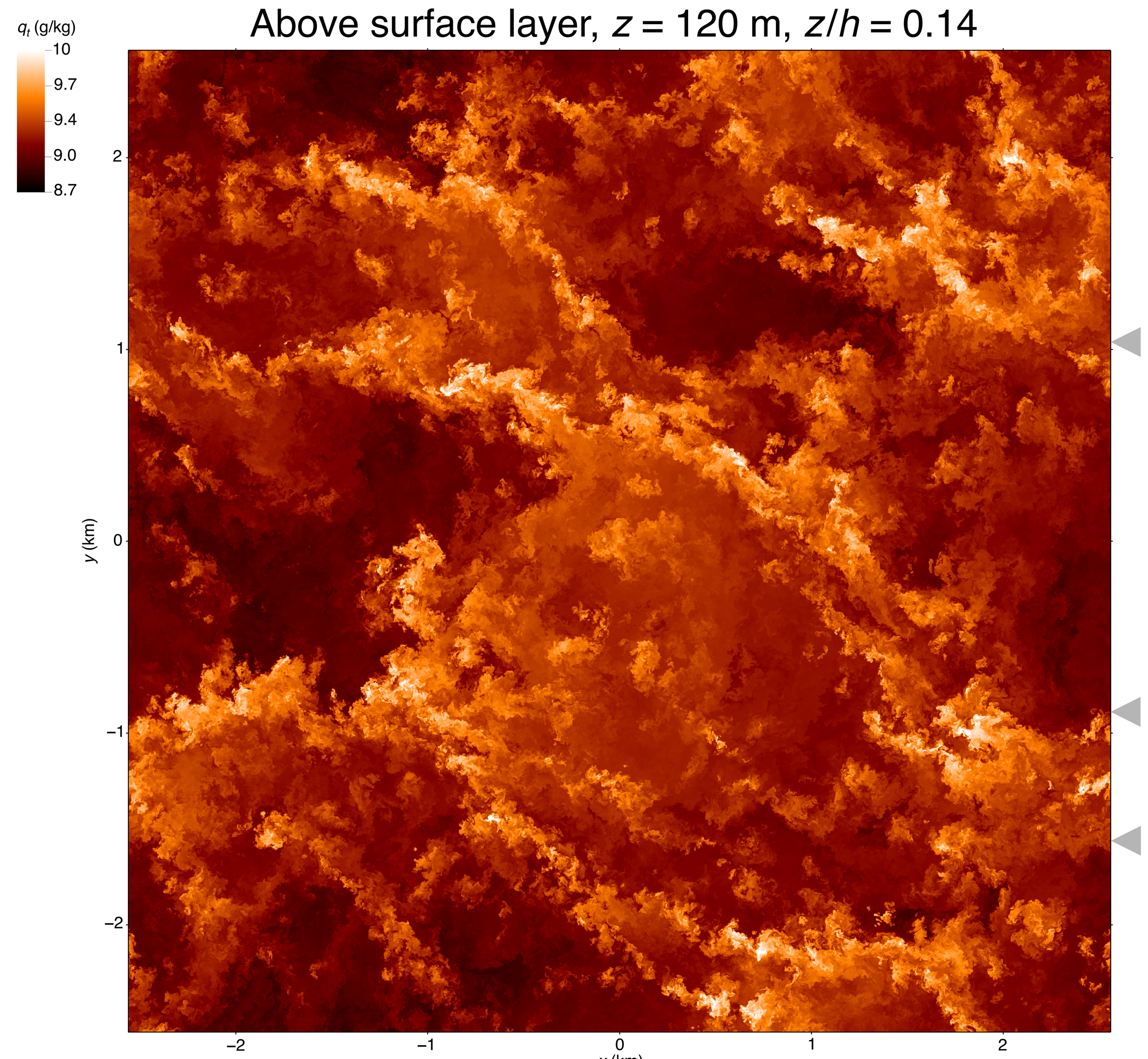

Cloud base, $z = 610$ m, $z/h = 0.72$



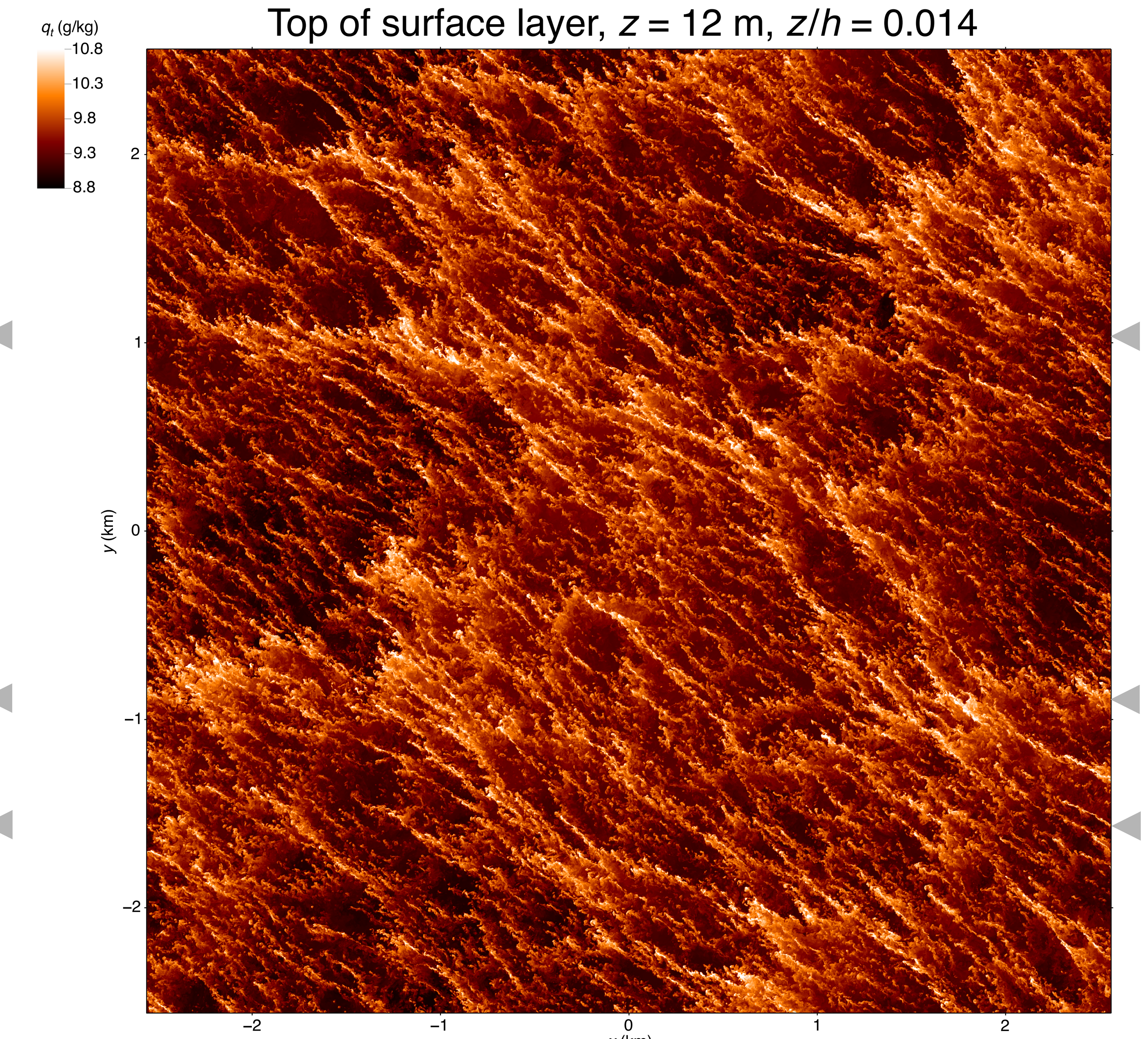

Middle of sub-cloud layer, $z = 375$ m, $z/h = 0.44$




Above surface layer, $z = 120$ m, $z/h = 0.14$



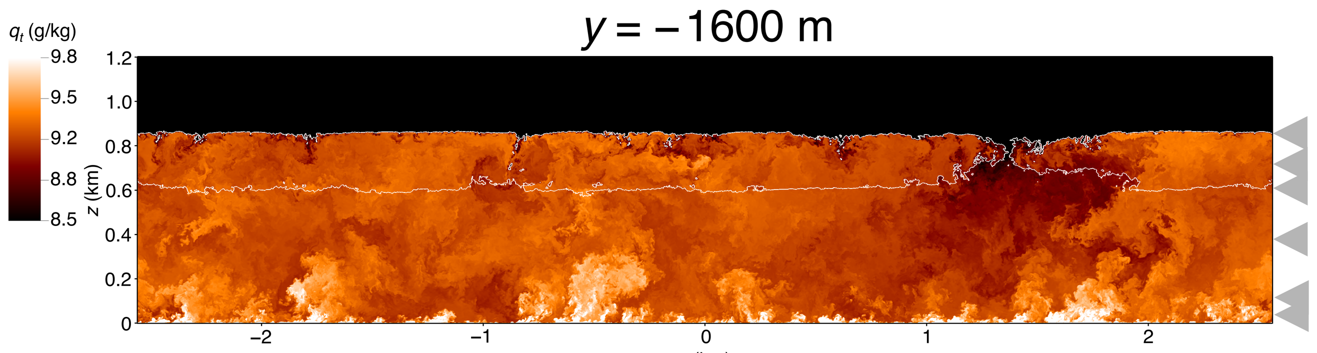

Top of surface layer, $z = 12$ m, $z/h = 0.014$



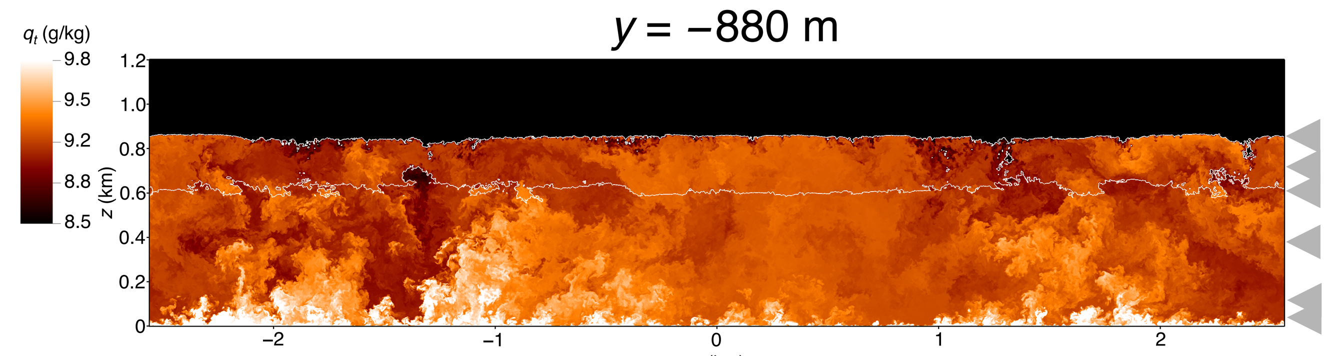

## Vertical $x$–$z$ planes

White contour denotes the cloud boundary. Triangles show the locations of the horizontal cross sections.

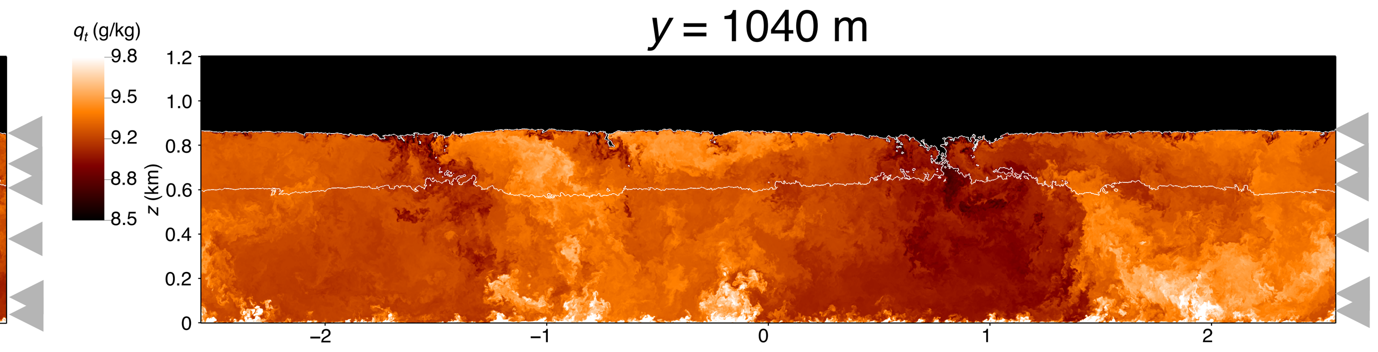
$y = -1600$ m




$y = -880$ m




$y = 1040$ m

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