LARGE EDDY SIMULATIONS OF WEAKLY HEATED STRATOCUMULUS TOP BOUDARY LAYER

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Abstract Performing Large Eddy Simulations (LES) of marine stratocumulus in the weakly heated boundary layer is an opportunity to evaluate the relative importance of radiative cooling and of a wind shear in cloud top region on cloud structure. It is shown that cooling due to longwave radiation influences the convective circulation in the atmospheric boundary layer and counteracts dilution caused by the wind shear.

INTRODUCTION

Analysing data from Physics of Stratocumulus Top (POST) campaign (1) two different types of stratocumulus (Sc) were revealed (2): ”classical” - capped by a strong, thin temperature inversion with wind shear and dry air above and ”non-classical” capped by a weak temperature inversion, humid air above and a shear layer penetrating the cloud top. The key physical difference is that entrainment in "classical" stratocumulus may result in negative buoyancy of mixed parcels due to sufficiently effective evaporative cooling, while entrainment in "non-classical" cloud may not. Since most LES of stratocumulus clouds described in the literature are based on ”classical” cases (see e.g. 5, and references therein), one of ”non-classical” cases (research flight TO13) was used to set up a series of LES numerical experiments.

To effectively perform the simulations we used EULAG model (4, 3) in a new version paralellized in all three dimensions (3). The measurements indicate presence of multiple thin sub-layers in a proximity of cloud top, thus anisotropic grid of resolution of 20 x 20 x 2.5 m was used, spanned over the computational domain of 4 x 4 x 1.2 km and with horizontally periodic boundary conditions. In such a setup we were able to conduct a series of 4 h long simulations with a time step of 0.3 s.

In order to investigate different mechanisms responsible for entrainment and mixing a set of 4 simulations was performed: 1) ”ref”- reference simulation, no wind shear and no radiative cooling at the cloud top 2) ”sh”- shear simulation, no radiative cooling 3) ”rc” - radiative cooling simulation, no shear 4) ”shrc” - shear and radiative cooling simulation. In simulations ”rc” and ”shrc” parametrisation of radiative cooling was turned on after the spin-up period of 1.5 h. The simulations were continued up to 4 h of model time.

RESULTS

The left panel in Figure 1 presents profiles of liquid water mixing ratio at the end of simulations in the uppermost 120 m of the cloud. Not surprisingly, shear dilutes the cloud top due to entrainment and mixing of cloudy air with subsaturated air from above, while radiative cooling increases q_c in cloud top region. In wind shear cases (red lines) the maximum of q_c has smaller value and is located on lower altitude than in simulations without shear (blue lines).

The domain averaged cloud top altitude acts to change in radiative cooling with a 1.5 hour delay (top right panel in Figure 1), witch is comparable to the spin-off time of the model. This suggests that the average cloud top altitude is to a large extent governed by convective eddies spanning the boundary layer (BL) depth. Since heat fluxes due to radiative cooling are significantly greater than fluxes from the surface, response of cloud top to radiative cooling is due to its effect on convective circulations. Differences between the simulations, except the ”sh” case, are not significant.

Contrary to the cloud top altitude, the mean LWP reacts immediately to radiative cooling (bottom right panel in Figure 1). In ”ref” simulation the mean LWP is almost constant during the whole simulation. Turning on the radiative cooling (”rc” simulation) leads to LWP growth. In ’sh” simulation LWP tends to decrease after $\sim$3 hours from the beginning of the simulation. In a case of radiative cooling switched on and wind shear present ("shrc") we can observe that mean LWP stabilizes after initial growth.

LWP field at the end of the simulations is shown in the middle panels of Figure 2, while histograms of LWP in domain columns are presented in the edge panels. It can be seen, that presence of shear moves the LWP distribution to the left (lower values) preserving the shape. Cloud top region is diluted due to shear and LWP is more spatially variable. On the other hand radiative cooling affect the right half of the distribution increasing the maximum values of LWP. These maximum values appear at the top of the updrafts, leading to more inhomogeneous structure of the cloud top than in the case without radiation.

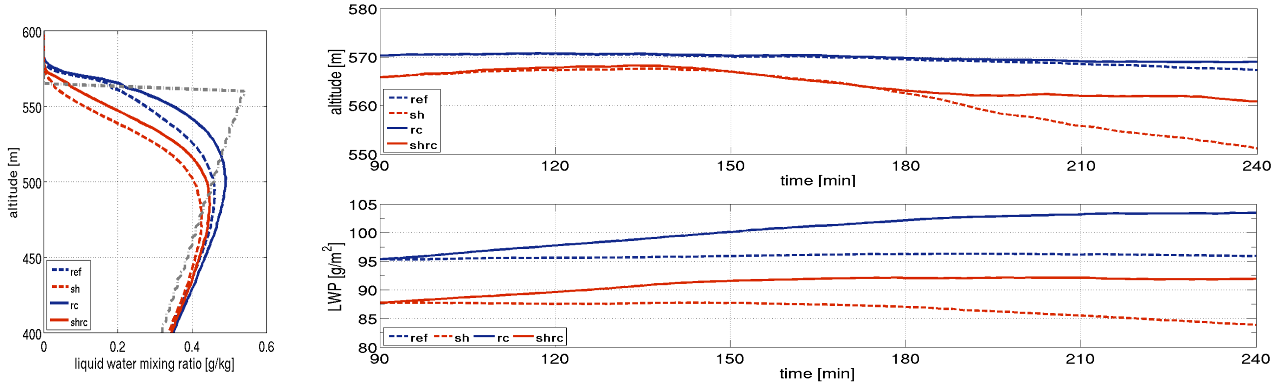

Figure 1: *Left panel*: Liquid water mixing ratio profiles from all simulations. Dashed grey line - initial profile. *Top right panel*: Timeseries of cloud top altitude. *Bottom right panel*: Tiemseries of LWP. *Color code in all panels*: blue lines - simulations without sher, red lines - with shear, dashed lines - no radiative cooling, solid lines - with radiative cooling.

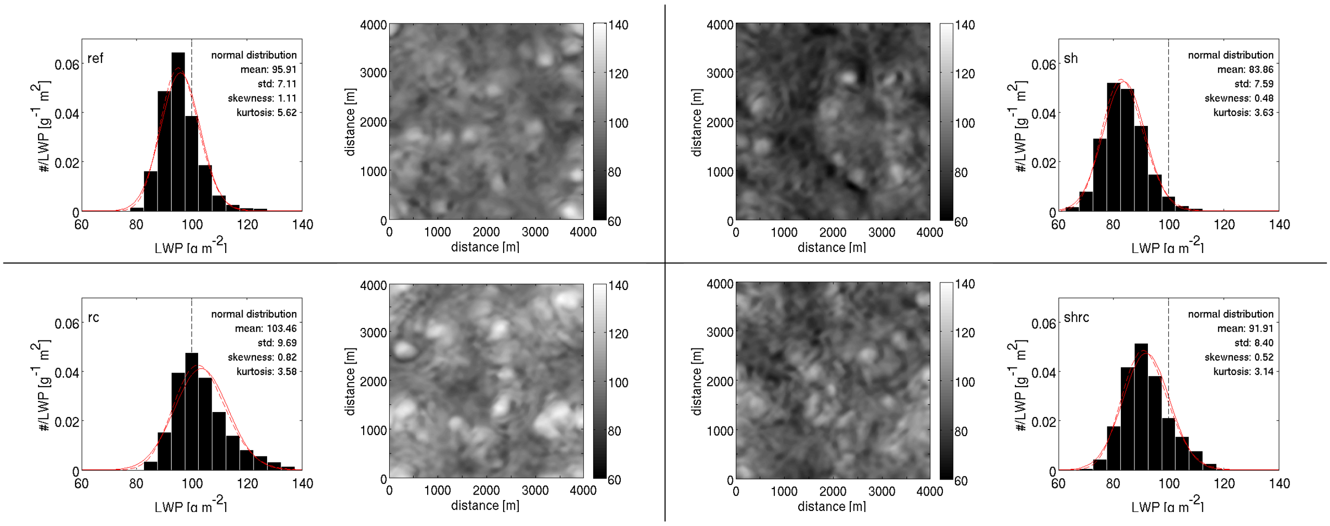

Figure 2: Visualisation of LWP (middle panels) and its histograms (edge panels) after 4h. Panels are grouped in four sections. Top left section - "ref" simulation, top right section - "sh" simulation, bottom left section - "rc" simulation, bottom right section - "shrc" simulation. Red solid lines on histograms - normal distribution. Red dashed lines - log-normal distribution. Black dashed lines marks LWP equal to 100 g/m^2.

ACKNOWLEDGEMENTS

This work was supported by Poland's National Science Center (Narodowe Centrum Nauki) [decision no. 2012/07/N/ST10/03473]

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