Impact of Wind Shear on The Top of Stratocumulus CLOUD

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Introduction

Analysing data from Physics of Stratocumulus Top (POST) campaign [1] two different types of stratocumulus were revealed:

- "classical", under strong temperature inversion, dry air above the cloud top and thin wind shear layer in the cloud top region;
- "non-classical" under weak temperature inversion, humid air aboveand deep shear layer.

In "non-classical" cases conditions prohibit Cloud Top Entrainment Instability.
One of "non-classical" cases (TO13) was used to set up a series of LES simulations (gridbox 20x20x2.5m) with EULAG model. In the first simulation we modeled cloud without both: wind shear and radiative cooling. In the second simulation the wind shear was switched on while radiative cooling was off. In the third simulation the wind shear was off but the radiative cooling on. The last one was the most realistic, accounting for both: wind shear and radiative cooling.

Initial profiles

Based on the data from POST TO13 flight idealized profiles of potential temperature (left panel in figure 1), wind components (middle panel) and water vapour mixing ratio (right panel) were prepared. Red lines mark initial conditions and black lines mark domain averaged profiles after 200 minutes of simulation. Dashed blue line in central panel of figure 1, marks initial wind profile for no shear cases. Grey boxes indicate region with cloud water. Initial profiles of liquid water mixing ratio is shown in figure 2.

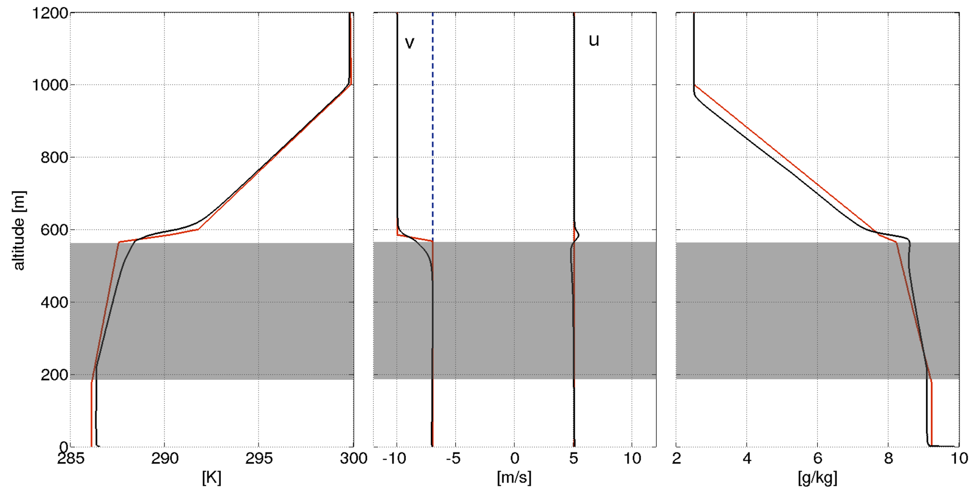
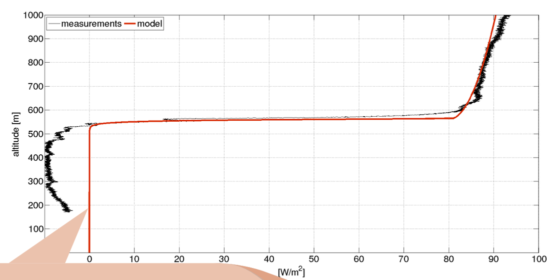


Fig. 1: Initial profiles

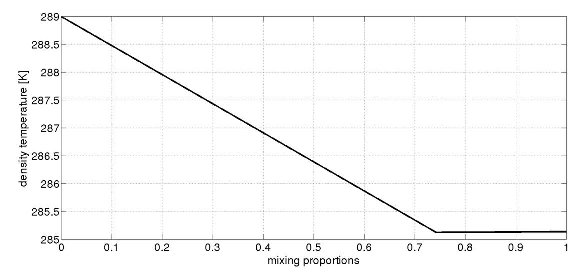
Radiative cooling

In two simulations radiative cooling was turned on after 1.5 h.
Figure on the right presents the profile of longwave radiation measured during TO13 flight (black line) and the idealized profile used in simulations, calculated with the equation below.



$$F_{rad} = \begin{cases} F_0 \exp(-\int_z^\infty k q_c dz) \\ F_0 \exp(-\int_z^\infty k q_c dz) + C(z - z_i)^{1/2} \end{cases}$$

Mixing diagram



Mixing diagram shows that mixing of cloud with the air from above the capping inversion does not result in buoyancy reversal.

Comparison of liquid water mixing ratio profiles

Comparison of liquid water mixing ratio profiles for four simulations.

The left panel shows averaged profiles (blue lines – simulations without wind shear, red lines – with shear, dashed lines – radiative cooling off, solid lines – radiative cooling on). In the other panels dark gray shading spans the range between the maximum and the minimum value at any given altitude. The light shading spans between the mean value plus/minus one standard deviation. Black line marks the model domain averaged profile and dashed red line marks the initial profile.

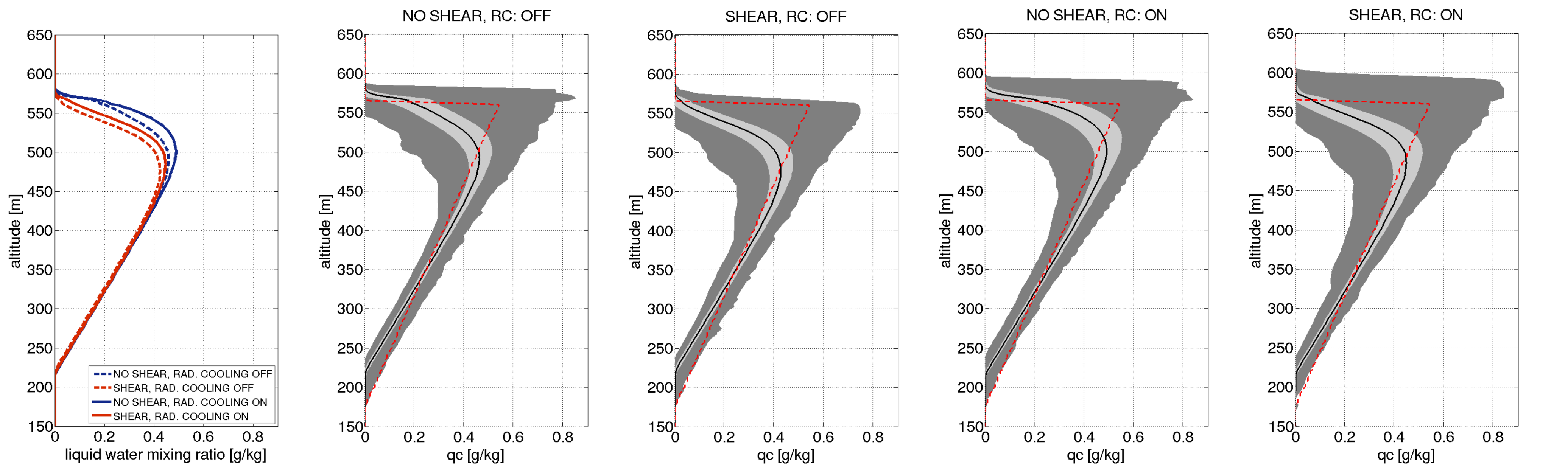


Fig. 2: Statistics of q_c profiles. RC abbreviation from Radiative Cooling.

Comparison of cloud top altitudes

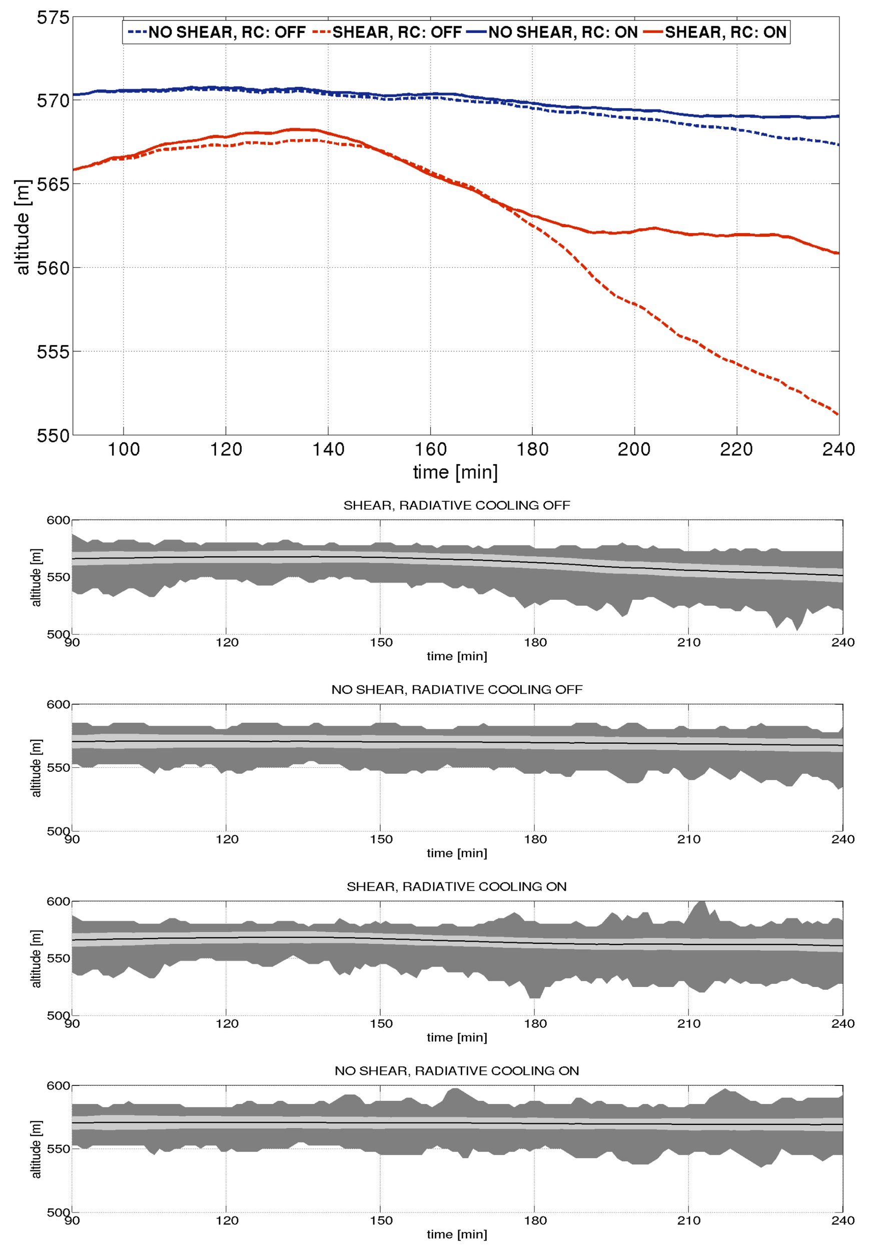


Fig. 3: Color code as in figure 2.

Comparison of liquid water path

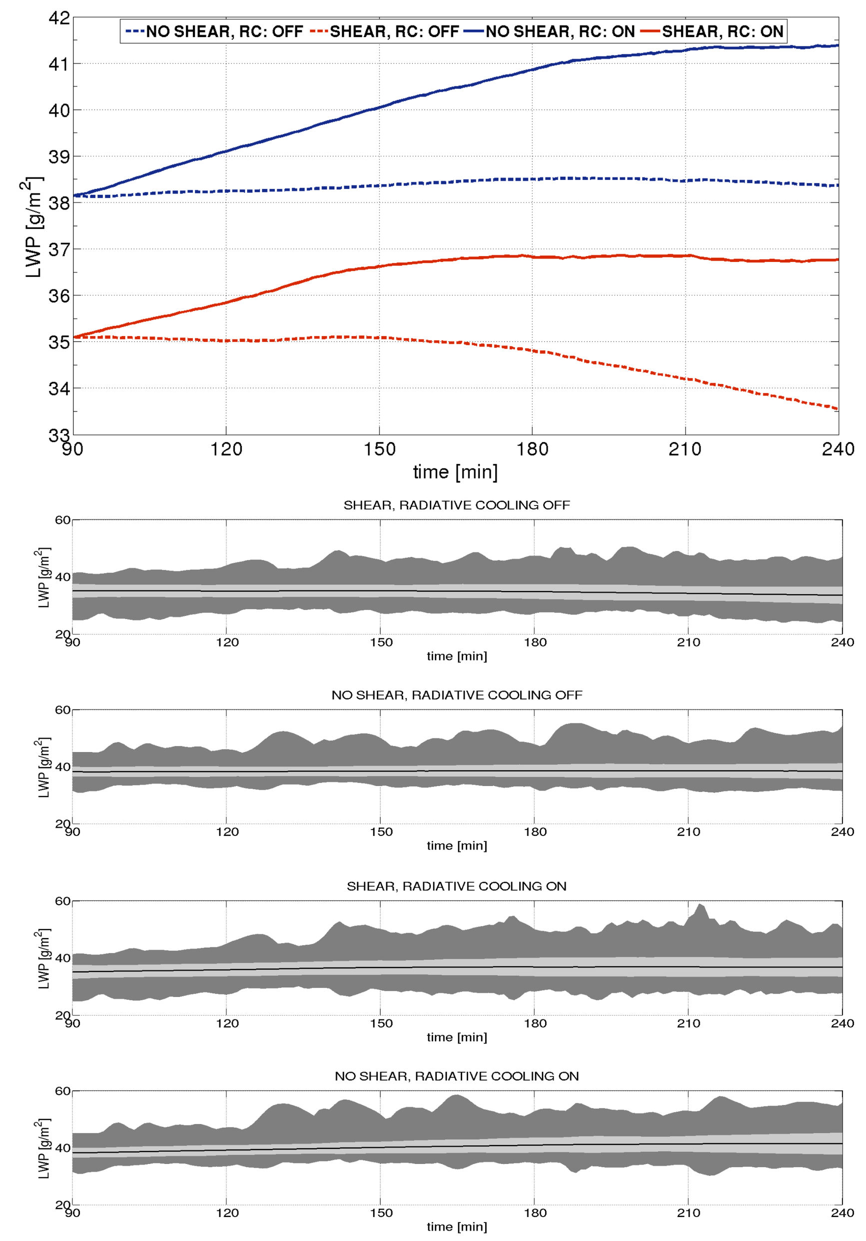


Fig. 4: Color code as in figure 2.

In figure 3 timeseries of cloud top altitudes are presented.

Figure 4 displays timeseries of liquid water path.

Upper panels of both figures show domain averaged values for four simulations. Blue lines mark data from the simulations without wind shear and red lines mark data from simulation with the shear. Dashed lines are for simulations without radiative cooling, solid lines mark data from simulations with radiative cooling swithed on. Shading of lower panels has the same meaning as in figure 2.

Virtual aircraft

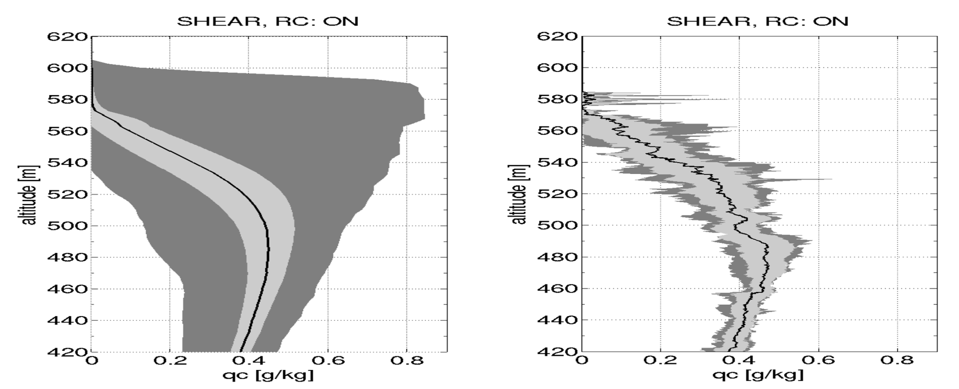


Fig. 5: Comparison of virtual aircraft data statistics (right panel) with statistics from the whole domain of the model.

Virtual aircraft is a method to sample computational domain. The main goal of this method is to collect data in the virtual reality of the model in the same way as research aircraft performs measurements in a real cloud: along a prescribed trajetory and in the course of cloud evolution. A series of trajectories was prepared based on real flight trajectories from TO13 flight.

The left panel of figure 5 presents liquid water mixing ratio of the top of stratocumulus cloud from the most realistic simulation (with radiative cooling swithed on and with the wind shear, enlarged fragment of rightmost panel of figure 2). The right panel shows liqud water mixing ratio from the virtual aircraft. Shading of both panels is as in figure 2.
In figure 6 data collected by the virtual aircraft in the course of the simulation and by the real cloud in the course of the research flight are compared. The consecutive panels in left column present profiles from the porpoises of the virtual aircraft, corresponding panel in the right column presents data frata TO13 flight. Spatial resolution of the data is similar in both cases.

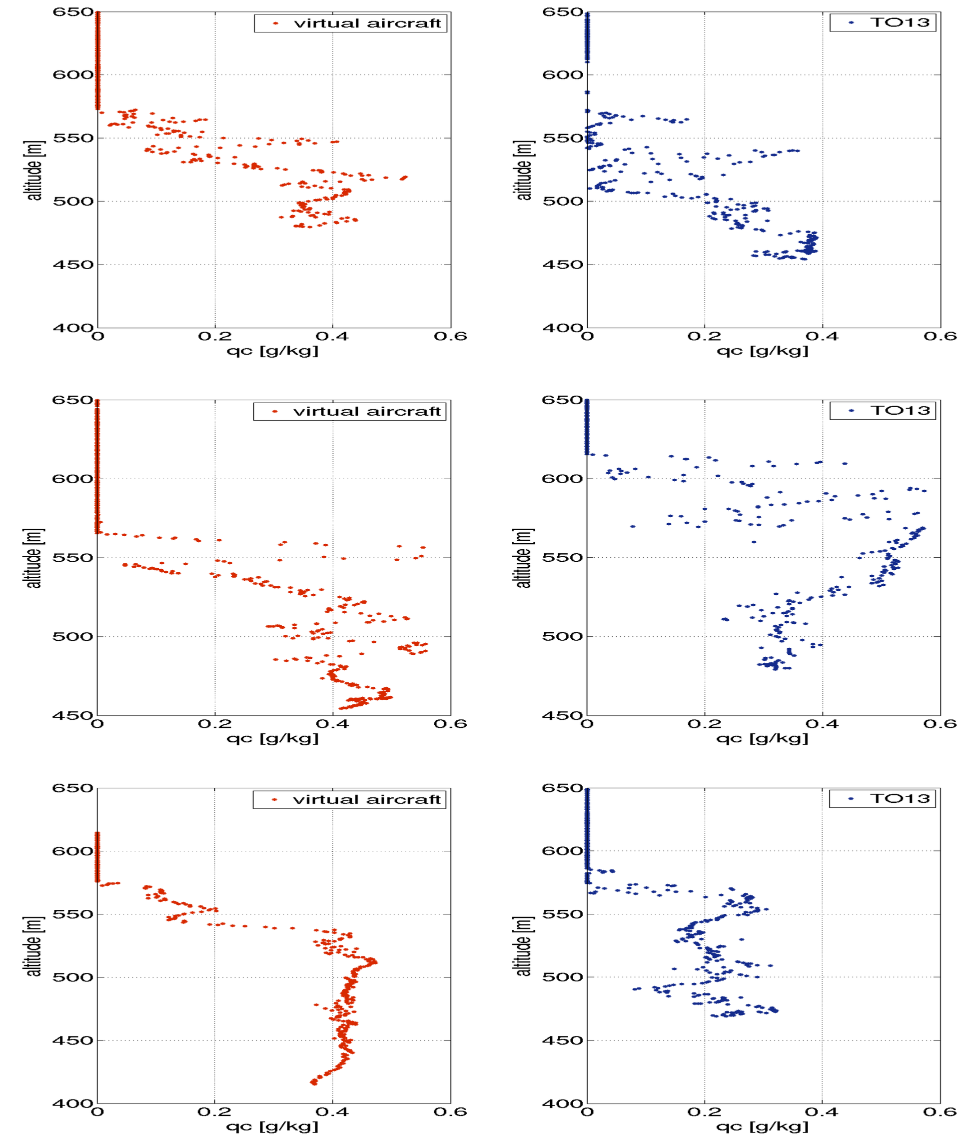


Fig. 6: Comparison of examples of virtual aircraft data with data from TO13 flight.

Conclusions

- Wind shear dilutes the cloud (lower values of liquid water path and cloud top altitudes than in no shear cases; see upper panels of firures 3 and 4).
- In wind shear cases maximum value of liquid water mixing ratio is smaller and is located on lower altitude than in simulations without shear (see left panel of figure 2)
- Radiative cooling enables groving of the cloud top and counteracts dilution due to wind shear (see upper panels of firures 3 and 4).
- Virtual aircraft method produces comparable statistics as the statiscics made for the whole domain exept for the span between the maximum and tne minium values at given altitude (see figure 5).
- Profiles "collected" by virtual aicraft look alike profiles from real airborne measurements. Fluctuations in the profiles effect from the horizontal variability of the cloud.

References

[1] H. Gerber, G. Frick, S. P. Malinowski, W. Kumala, and S. Krueger. Entrainment rates and microphysics in post stratocumulus. J. Geophys. Res-Atmos., 118:12094?12109, 2013.

Acknowledgements

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