ENTRAINMENT AND DETRAINMENT RATES FROM THE PIV MEASUREMENTS AT THE TOP OF LABORATORY ANALOGS OF STRATOCUMULUS AND CUMULUS CLOUDS

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Abstract We analyze mixing at the top of laboratory analogs of convective clouds: stratocumulus and cumulus to investigate entrainment of environmental air into the cloud. We retrieve two components of air velocity using Particle Image Velocimetry technique. Suitable image processing allows to determine cloud–clear air interface. Using velocity differences between cloudy and clear sides of the interface we calculate entrainment / detrainment rates.

THE EXPERIMENT

We simulate mixing at tops of cumulus and stratocumulus clouds in a laboratory cloud chamber of dimensions $1.0\times1.0\times$ 1.8 m. We monitor temperature stratification in the chamber with a vertical chain of 15 thermocouples located every 10 cm. 4 capacitive sensors deployed every 20 cm give information on humidity profile. We use ultrasonic humidifiers (producing droplets diameters of 3–10 μm, [2] to generate cloud. In order to obtain stratification profile similar to the atmospheric boundary layer capped with inversion and free troposphere we fill a bottom $\sim$ 60 cm of the chamber with a layer of saturated moist air ($T \sim$ 22 °C) containing droplets. Mixing at the top of this layer ($T \sim$ 22 °C, $RH \sim$ 35 %) results in evaporative cooling, which triggers downward convection and leads to a formation of a well mixed layer capped with temperature inversion of $T \sim 2$ °C temperature jump across $\sim$ 30 cm depth. Then, in a center of the chamber, we force cloudy updrafts through the mixed layer. Updrafts strong enough to penetrate the whole inversion layer simulate overshooting cumulus cloud tops. Weaker updrafts, divergeing within the inversion layer simulate convective currents at the stratocumulus top. With cloud droplets as tracers for the Particle Image Velocimetry, using upgraded mutiscale PIV algorithm based on [1] we retrieve 2D velocity fields in a vertical plane cut through the cloud layer.

ENTRAINMENT / DETRAINMENT

Using image processing we detect an interface between a cloud and an environment. Knowing location of the interface we select neighbouring velocity vectors on cloudy and clear air sides. Knowing thermodynamic parameters of the cloud and the environment we calculate entrainment and detrainment rates from the following formula:

$$
\begin{aligned}
E &= -\rho_a(\mathbf{u}_a - \mathbf{u}_i), \\
D &= \rho_a(\mathbf{u}_a - \mathbf{u}_i),
\end{aligned}
\tag{1}
$$

where:
ρ_a – density,
$\mathbf{u}_a$ – air velocity,
$\mathbf{u}_i$ – interface velocity.
Examples of local entrainment / detrainment rates are presented in Fig. 1 (analogue of stratocumulus) and Fig. 2 (analogue of cumulus). In analogues of cumulus we measure systematically higher entrainment / detrainment rates than in analogues of stratocumulus. Statistics of entrainment / detrainment rates and patterns will be presented at the conference.

References

[1] P. Korczyk, S. P. Malinowski, and T. A. Kowalewski. Mixing of cloud and clear air in centimeter scales observed in laboratory by means of Particle Image Velocimetry. *Atmos. Res.*, **82**:173–182, 2006.
[2] P. M. Korczyk, T. A. Kowalewski, and S. P. Malinowski. Turbulent mixing of clouds with the environment: Small scale two phase evaporating flow investigated in a laboratory by particle image velocimetry. *PhysicaD*, **241**:288–296, 2012.

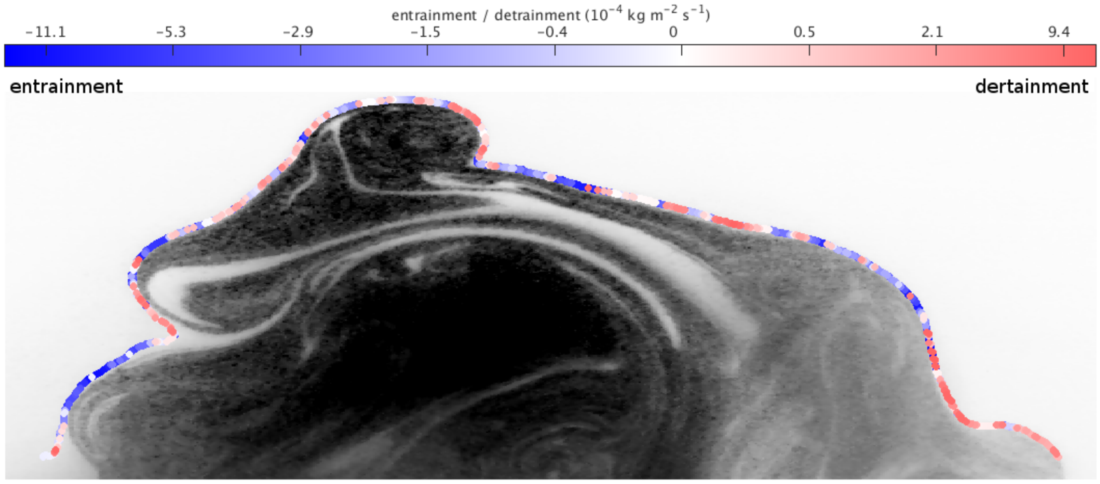

Figure 1. Entrainment / detrainment rates at the top of stratocumulus cloud at the cloud–clear air interface. Mean entrainment rate for this case is $1.2452 \cdot 10^{-4}$ kg m^{-2} s^{-1}.

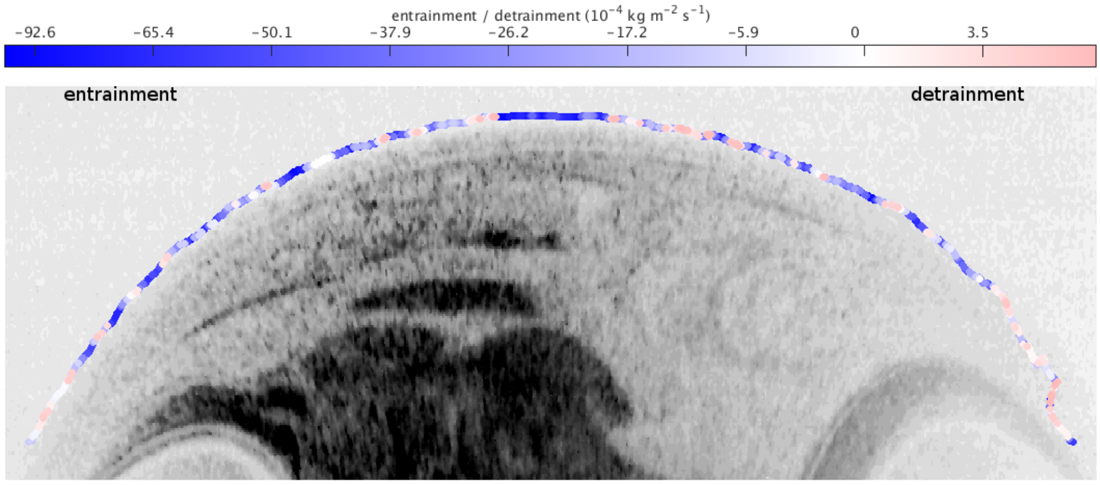

Figure 2. Entrainment / detrainment rates at the top of cumulus cloud at the cloud–clear air interface. Mean entrainment rate for this case is $28.1341 \cdot 10^{-4}$ kg m^{-2} s^{-1}.