ENTRAINING STRUCTURES IN LABORATORY ANALOG OF CLOUDS: TEMPERATURE INVERSION AND OVERSHOOTING UPDRAFTS

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Abstract We simulate mixing at the top of a cloud in a laboratory chamber and observe entraining structures by means of Particle Image Velocimetry (PIV) technique. Two different cases corresponding to different atmospheric situations: an overshooting cumulus cloud penetrating through a temperature inversion (layer of high static stability) and a weak convective updraft in a stratocumulus diverging below a temperature inversion, are studied. We show that entraining eddies in these cases are characterized by the opposite circulations.

THE EXPERIMENT

The experiment follows the earlier studies of [1, 2, 3]. Cloud, generated by ultrasonic humidifiers is observed in a laboratory chamber. Conditions in the chamber are set to mimic some aspects of the real atmosphere. Cloud droplets, visualized with a sheet of light serve as markers. PIV allows to determine flow in a vertical cut through the cloud. The present study is aimed at observations of entraining eddies at the cloud clear air interface.

Before each experimental series the chamber is cleaned and filled with the air of temperature $\sim$22°C and relative humidity of $\sim 35\%$. Then a cloudy layer of depth of ~ 50 cm is created by gentle filling of the bottom part of the chamber with saturated air of the same temperature. Mixing at the top of this layer and following evaporative cooling triggers convection which effectively reduces temperature across the layer depth. In effect, stratification in the chamber corresponds to that observed often in the atmosphere: convective boundary layer (here cloudy, resembling stratocumulus) capped by a very stable inversion and slightly stable layer above (Fig. 1). Then, trough the tube of ~ 10 cm diameter a negatively buoyant updraft is forced. A strong updraft, penetrating the inversion, mimics kinematics of overshooting cumulus turret. A weak updraft, diverging below the inversion, mimics an ascending branch of convective cell in a weakly convective boundary layer. Using high speed camera of resolution 1280×1024 pixels we collect series of images of developing entraining eddies. PIV on the successive pairs of images allow to reconstruct two components of velocity in cloudy filaments in the vertical plane.

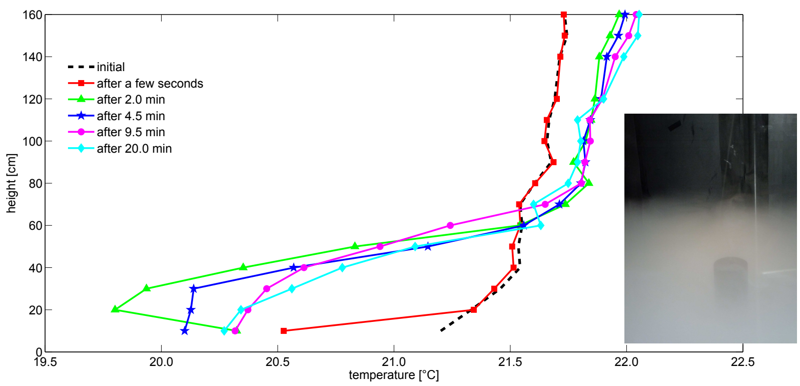

Figure 1. Temperature profiles in the cloud chamber in the course of preparation stage of the experiment. After 4.5 min the sim30 cm layer in the chamber is well mixed and capped with the inversion reaching sim60 cm height. In the right hand side a photo showing the cloud layer is presented.

ENTRAINING STRUCTURES AT THE TOP OF AN OVERSHOOTING CUMULUS

A typical still image from such a case is shown in Fig. 2. Penetration through a stable inversion enhances the formation of a regular vortex ring around the updraft core. Unmixed air from the cloud core gets to the cloud top, diverges into the vortex ring and circulates inside, forming a spiral structure of cloud-clear air filaments. The environmental air is entrained into the vortex ring from below. Such vortex ring is consistent with a generic conceptual model of cumulus cloud based on airborne observations (see e.g. [4]). Environmental air is entrained into the cloud top in the wake of the ring.

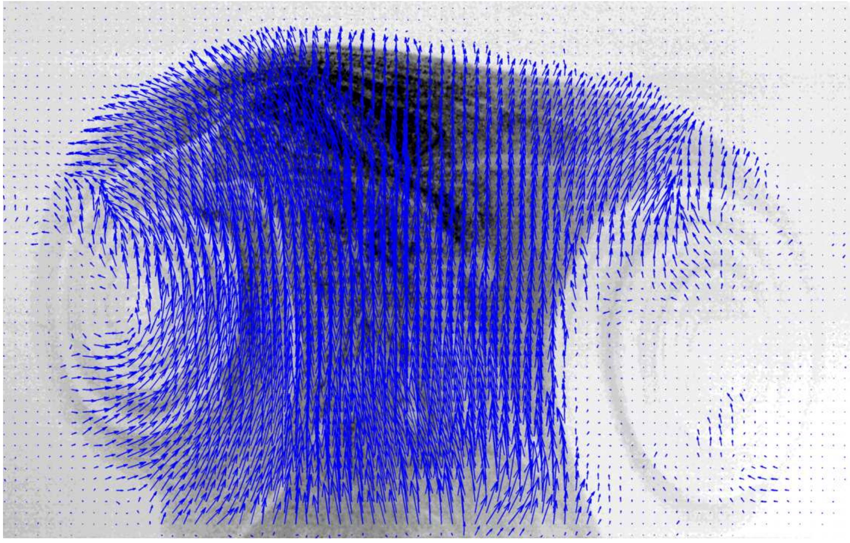

Figure 2. Example cross-section through the vortex ring at the top of an updraft penetrating the inversion layer. Multiple filaments of cloud and clear air spinning around the vortex core are clearly seen.

ENTRAINING STRUCTURES ON THE STRATOCUMULUS TOP

In the case of small updraft velocity its kinetic energy is insufficient to penetrate through the capping inversion (Fig. 3). The updrafting air impinges upon inversion. The flow diverges and air spreads horizontally. Similar behavior of updrafts was reported by [5] on a basis of realistic large eddy simulations of stratocumulus topped atmospheric boundary layer. Diverging flow triggers Kelvin-Helmholtz instability at the cloud-clear air interface and produces vortices of rotation opposite to that in the vortex rings of overshooting cumulus.

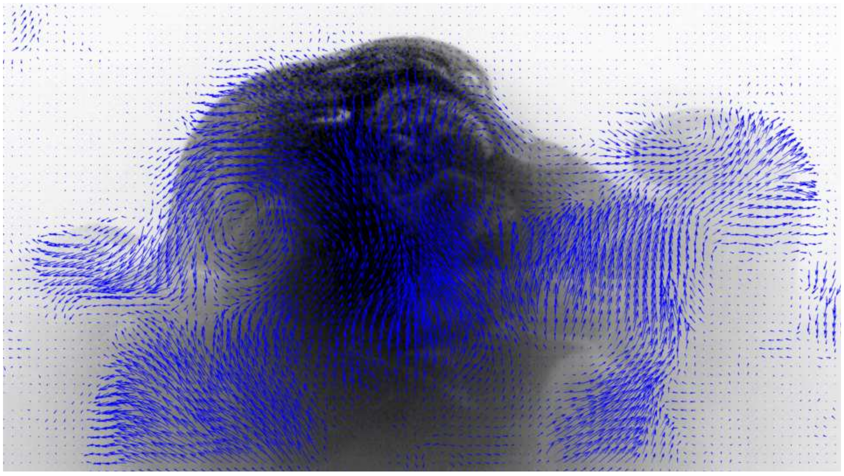

Figure 3. Example cross-section through an updraft impinging upon inversion. Notice direction of circulations at the cloud–clear air interface.

References

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