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# Turbulent mixing of cloud with the environment: small scales of two-phase evaporating flow seen by particle imaging velocimetry

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**Abstract.**

*Cloud-clear air mixing is investigated in the laboratory experiment by means of Particle Imaging Velocimetry (PIV). It occurs that turbulent velocities depend on thermodynamic contrasts between the cloud and its environment. Evaporative cooling at the edges of cloud/clear filaments and/or uneven mass loading result in buoyancy fluctuations which affect the smallest scales of turbulence. These effects are illustrated by means of second order structure functions of velocity field.*

Keywords*:* turbulent mixing, anisotropy, clouds.

Experimental evidence of the small-scale turbulence in clouds is very limited. By small-scale we understand here turbulence close to dissipation range, i.e. for the range of scales from 10cm down to a fraction of 1 mm. Since it is hard to observe it in natural conditions [1], [2], laboratory simulations mimicking some aspects of cloud-clear air turbulent mixing is prformed. The setup of these experiments closely follows earlier studies by [3],[4],[5].

In brief, cloud-clear air mixing is investigated by observation of motion of cloud droplets in a glass walled chamber. A box placed on the top contains saturated air with suspended water droplets of diameters in range from 7 to 25 $\mu$m, similar to those in real clouds. After opening the hole between the chambers air from the box descends, forming a negatively buoyant, turbulent plume undergoing mixing with the unsaturated air in the main chamber. The plume is illuminated with a narrow sheet of laser light in a vertical cross-section through the central part of the chamber. Light scattered on cloud droplets is imaged with a high-resolution CCD camera. PIV technique is used to study the flow (Fig.1).

Similar mixing process was studied in a series of idealized numerical simulations of cloud-clear air mixing [6], [7], [5], [8]. Key findings from numerical simulations and experiments can be summarized in the follwing way. Large scale velocity fluctuation lead to filamentation of the cloud. At the cloud-clear interface droplets evaporate. Evaporative cooling and uneven mass loading

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effect in small scale buoyancy fluctuations. These fluctuations result in production of additional, small scale turbulence. Since priduction of turbulence in small scale is anisotropic, small-scale velocity fluctuations are anisotropic with preferred vertical direction. Deatils of mixing process depend on thermodynamical properties of cloud and environment, mass fraction of the cloudy air in the mixing event, cloud droplet size spectrum and turbulent kinetic energy flux cascading down from large scales.

In the present study new laboratory results, focusing on the effect of evaporative cooling on the properties of small-scale turbulence are presented. A range of thermodynamic conditions and possible effects of mixing on buoyancy are illustrated by mixing diagram (Fig.2) showing dependence of a buoyancy temperature $T_b$ ( [9], eq. 4.3.6 ) on mixing proportion:

$$T_b = T\left[1+\left(\frac{R_v}{R_d}-1\right)q-x\right]. \qquad (1)$$

Here $T$ is the air temperature, $R_v$ and $R_d$ are gas constants for water vapor and dry air, $q$ and $x$ are the water vapor and cloud water contents. It can be seen, that conditions cover a range of buoyancy effects, allowing for more detailed investigation of the influence of evaporative cooling on small-scale turbulence.

An example result is presented in Fig.3. It shows second order structure functions of velocity drived from PIV of cloud droplets at various relative humidities in the environment. It can be seen that decrease of the environmental hymidity results in increase of squared velocity differences. It can be interpreted in a following way: at given temperature and constant conditions in cloud (Fig.2) a possible buoyancy production due to evaporative cooling depends on the relative humidity of the environment. Buoyancy effects produce turbulent kinetyc energy in small scales, which is reflected by the increase of squared velocity differences.

More detailed analyses will be presented at the ETC512 meeting.

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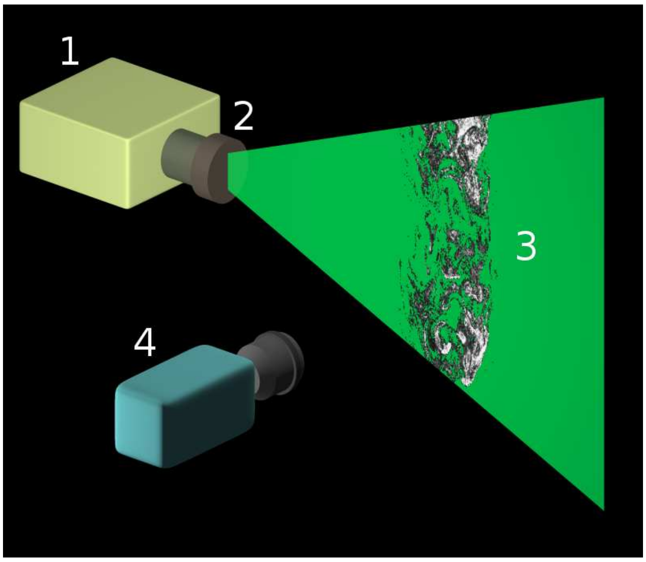


Figure 1: A sketch of the experimental setup. 1 - laser, 2- beam-shaping optical system, 3 - light sheet at the vertical cross-section through the cloudy plume undergoing mixing with the environment in the chamber, 4 - camera.

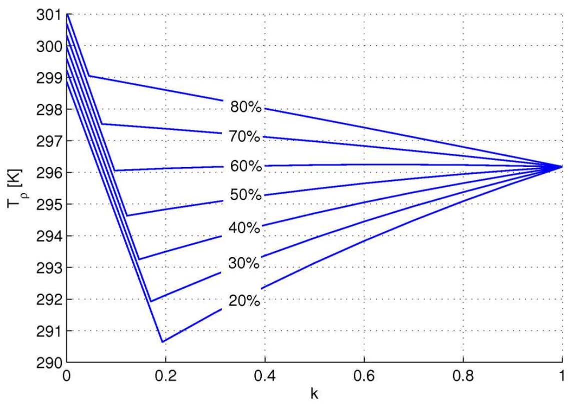


Figure 2: Mixing diagram illustraties a range of buoyancy fluctuations inside the cloud chamber at various specific humidities of the environmental air at given temperature and liquid water content of cloud. Horizontal axis depicts mixing proportion k. k=0 indicates environment, k=1 indicates cloud, intermediate values correspond to proportion of both spieces in the mixing event. Vertical axis - buoyavcy temperature of the homogeneized mixture. High buouancy temperature corresponds to low deisity of air (cloud). Successive ”v shape” lines show dependence of densiity temperature of mixture on the relative humidity of the environment. At low humidities potential for evaporative cooling is high, as indicate absolute minima of the density temperature. At relative humidities higher than 0.6 the maximum density temperature of the mixture is lower than that of the cloud.

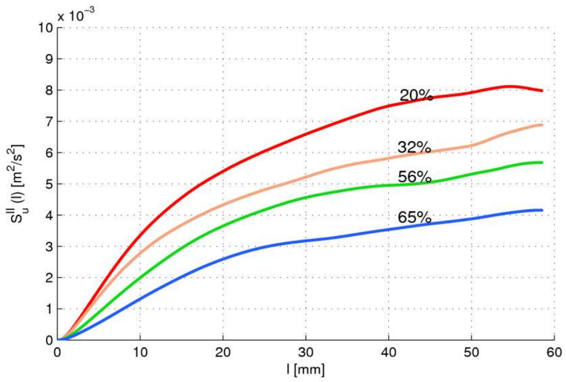


Figure 3: Second order longitudinal structure functions of horizontal velocity component for various relative humidities of the environmental air.