Entrainment in Laboratory Analogs of Cumulus and Stratocumulus Clouds Tops

A. Górska[1*,3], S. P. Malinowski[1,3], S. Błoński[2], J. Fugal[3,4], T. A. Kowalewski[2], P. Korczyk[2], W. Kumala[1]

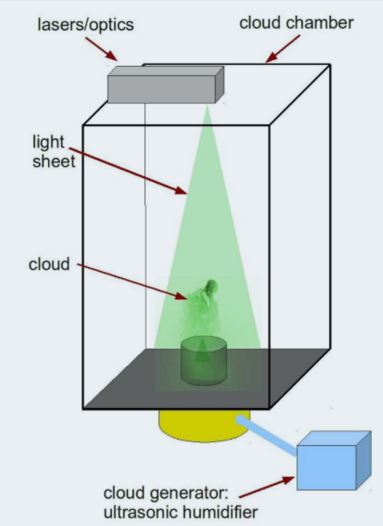
[1] Institute of Geophysics, University of Warsaw, Warsaw, Poland
[2] Institute of Fundamental Technological Research, Polish Academy of Sciences, Warsaw, Poland
[3] Institute of Atmospheric Physics, Johannes Gutenberg University, Mainz, Germany
[4] Max Planck Institute for Chemistry, Mainz, Germany

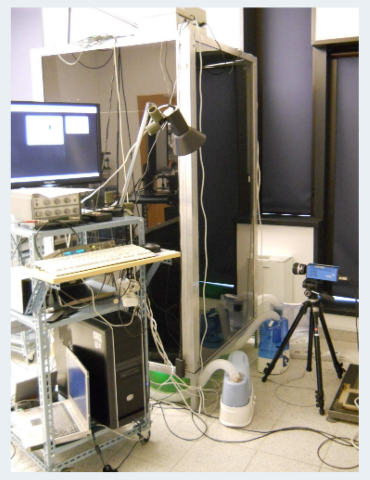
Introduction

Understanding entrainment of non–turbulent environmental air into turbulent convective clouds is still challenging (e.g. de Rooy et al., 2013; Wood, 2012). The aim of our experiment is to create laboratory analogs of cumulus and stratocumulus clouds tops in a cloud chamber in order to study details of entraining structures by means of Particle Imaging Velocimetry (PIV).

Experimental setup

We modify an experimental setup used previously by Korczyk et al. (2012). Cloud analogs created in the laboratory chamber consist of real saturated air and real water droplets. Vertical profiles of temperature and humidity in the chamber are monitored by vertical arrays of thermometers and hygrometers. We record series of ∼700 of cloud cross–sections images (1280×1024 px, 13×10 cm) spaced 10 ms apart.



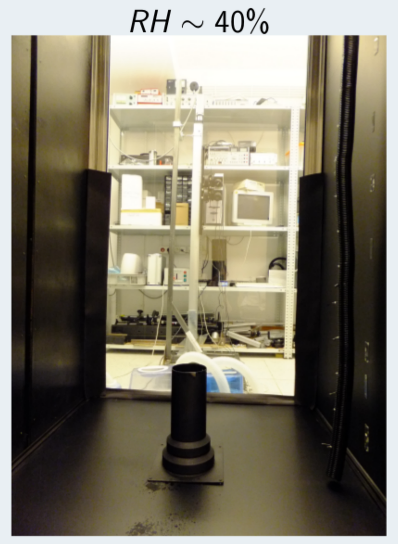


Data processing

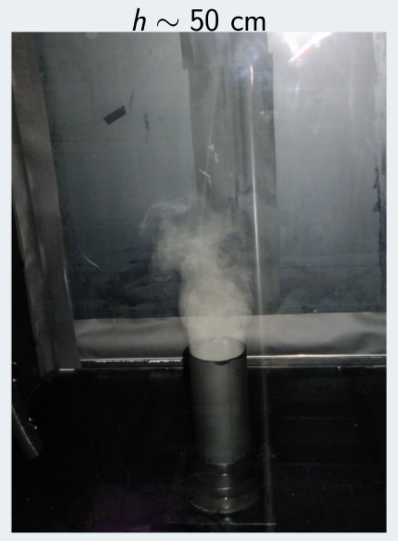
In order to retrieve 2-component velocities we use a substantially modified and improved PIVKor algorithm (Korczyk et al., 2012). The algorithm is significantly accelerated which allows us to calculate velocities in long series of image pairs to study the evolution of entraining structures. The algorithm was tested and calibrated on reference images (Okamoto et al., 2000). The mean relative error of reference velocity fields is ∼3.2%.

Initial conditions

$T \sim 22$°C
$RH \sim 40\%$



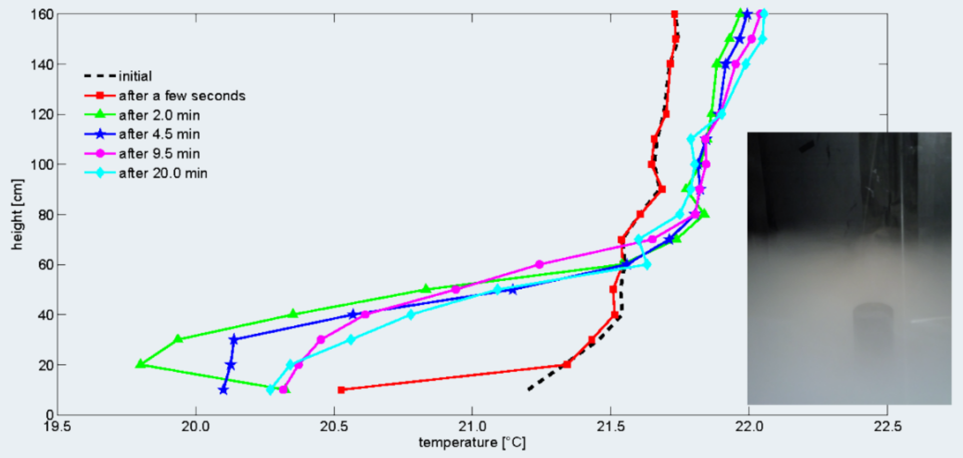
$\sim 3 - 10 \mu m$
$w \sim 15$ cm/s
$h \sim 50$ cm



$LWC \sim 10$ g/kg

$T \sim 21$°C

$\Delta h \sim 50$ cm
$\Delta T_{inv} \sim 2$°C
$\Delta h_{inv} \sim 20$ cm



Cu

Sc

Overshooting cumulus

Stratocumulus top

Conclusions

- simulated boundary layer cloud tops :
  - static stability and temperature inversion
- simulated overshooting cumulus cloud:
  - double vortex structures like in Damiani and Vali (2007)
- simulated an analog of an updraft in a stratocumulus cloud:
  - similarities to LES simulations e.g. (Kurowski et al., 2009)
  - similarities to in-situ data e.g. (Malinowski et al., 2013)
- typically, entraining eddies in Cu and Sc rotate in opposite directions

Acknowledgements

This research was supported by the Polish National Science Centre with the grant 2013/08/A/ST10/00291.

References

R. Damiani and G. Vali. Evidence for tilted toroidal circulations in cumulus. *J. Atmos. Sci.*, 64(6):2045–2060, 2007.

W. C. de Rooy, P. Bechtold, K. Frohlich, C. Hohenegger, H. Jonker, D. Mironov, A. P. Siebesma, J. Teixeira, and J.-I. Yano. Entrainment and detrainment in cumulus convection: an overview. *Q. J. R. Meteorol. Soc.*, 139:1–19, 2013.

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.

M. J. Kurowski, S. P. Malinowski, and W. W. Grabowski. A numerical investigation of entrainment and transport within a strotocumulus–topped boundary layer. *Q. J. R. Meteorol. Soc.*, 135(638):77–92, 2009.

S. P. Malinowski, H. Gerber, I. Jen-LaPlante, M. K. Kopeć, W. Kumala, K. Nurowska, P. Y. Chuang, and K. E. Haman. Physics of stratocumulus top (POST): turbulent mixing across capping inversion. *Submitted to Atmos. Chem. Phys.*, 2013.

K. Okamoto, S. Nishio, T. Saga, and T. Kobayashi. Standard images for particle-image velocimetry. *Meas. Sci. Technol.*, 11:685–691, 2000.

R. Wood. Stratocumulus Clouds. *Mon. Wea. Rev.*, 140(8):2373–2423, 2012.

*Corresponding author: Pasteura 7, 02–093 Warsaw, Poland, e-mail: anna.gorska@igf.fuw.edu.pl