Geophysical Research Abstracts,
Vol. 10, EGU2008-A-03040, 2008
SRef-ID: 1607-7962/gra/EGU2008-A-03040
EGU General Assembly 2008

Investigation of penetrative convection in stratified fluids through 3D-PTV

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Penetrative convection is the motion of a vertical turbulent plume or dome into a fluid layer of stable density and temperature stratification when the plume has enough momentum to extend into that fluid layer for a significant distance from the original interface. In its initial stages, convection is organized in coherent structures persisting over time. Subsequently the flow becomes turbulent and the structures break up. The dynamics of penetrative convection in nature influences the transport and mixing features of stratified fluids, in fact the flux through the interface between the mixing layer and the stable layer plays a fundamental role in characterizing and forecasting the distribution of chemical species with implication for: - air or water quality (dispersion of pollutants, released inside the mixing layer, is confined inside it) - absorption of UV radiation (in case of ozone, a natural filter for UV in the upper atmosphere, but a harmful contaminant in the lower troposphere) - climate change (in case of greenhouse gases) - water turnover, ecosystems, algal blooms and eutrofization (in case of oxygen and nutrients in oceans and lakes) The present work contributes to this research in three ways. The combined use of thermocouples and flow visualization techniques allows the simultaneous measurement of temperature and velocity components. This then allows employing and cross-validating different methods to estimate the mixing layer growth. Furthermore, 3D-PTV is employed to detect 3D trajectories of tracer particles, obtaining a more realistic description of the velocity field than more traditional 2D techniques. Finally, when turbulent convective phenomenon occurs, dispersion is mostly due to transport by large organized structures while molecular diffusion can be neglected. A way of dealing with this fundamental dispersion issue is through

the formulation of the transilient turbulence theory. The main output of the theory is the transilient matrix that accounts for all the mixing processes resolved by the grid spacing, from smallest eddy traced by the pollen particles to the medium and large coherent structures over the entire mixed layer depth (Moroni and Cenedese, 2006). On the other hand, the spatial correlation of the velocity field, providing the plume horizontal dimension, allows the spatial extension of the mixing region to be determined. The model used for laboratory experiments is a tank with glass sidewalls of dimension 40x40x41 cmˆ3 in the two horizontal and vertical directions respectively. The working fluid is distilled water. Pollen particles with average size equal to dp= 0.080 mm is used as passive tracer. The fluid has been seeded during the test section filling up. A stable stratification, e.g. a positive vertical temperature gradient, is generated by means of two connected tanks. After being stratified, the chamber is heated from below, to simulate the solar radiation effects and to cause penetrative convection. Temperature has been detected through thermocouples placed within the test section along a vertical line (array of 26 thermocouples) to measure vertical profiles and on the lower boundary to test horizontal homogeneity. Thermocouples provide the instantaneous values of temperature. Velocity has been three-dimensionally detected through an image analysis technique (3D-PTV). Images of the well reflecting tracer particles have been recorded using a stereoscopic system of three monochrome 8-bit CCD cameras with a time resolution of 25 fps, focused on the mixing layer region. The measuring volume has been illuminated by a high power (1000 Watt) arc lamp. The goal in the experiments is to image a volume far away the boundary walls, to design the appropriate photogrammetric 3D-PTV system, to lengthen the trajectories through an accurate experimental technique and improve the statistical accuracy of the method. A combination of image and object space based information is employed to establish the spatio-temporal correspondences between particle position of consecutive time steps. The system calibration features have been examined in details. An appropriate calibration procedure for the stereoscopic system is necessary. It provides the intrinsic and extrinsic parameters of the stereoscopic system in order to be able to determine the correspondence of points in the object or world reference frame and in the image reference frame. The photogrammetric principles used by 3D Particle Tracking Velocimetry are described. First the fundamental mathematical model of the collinearity condition and its extensions are explained. Then the epipolar line intersection method built upon multicamera correspondences is discussed. Photogrammetric 3D-PTV, rather than "scanning" 3D-PTV (Moroni and Cushman, 2001), has been employed to reconstruct trajectories. The photogrammetric technique is, in fact, more accurate when the tracer particles density is high because particles may be tracked directly in the 3D space rather than through matching of 2D projections.

Moroni M., J.H. Cushman, 2001. Three-Dimensional Particle Tracking Velocimetry

Studies of the Transition from Pore Dispersion to Fickian Dispersion for Homogeneous Porous Media. Water Resour. Res. 37(4), 873-884. Moroni M., A. Cenedese, 2006. Penetrative convection in stratified fluids: velocity measurements by image analysis techniques. Nonlinear Process in Geophysics 13, 353-363.