One-dimensional turbulence simulation of a laboratory analog of radiatively induced cloud-top entrainment

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Motivations

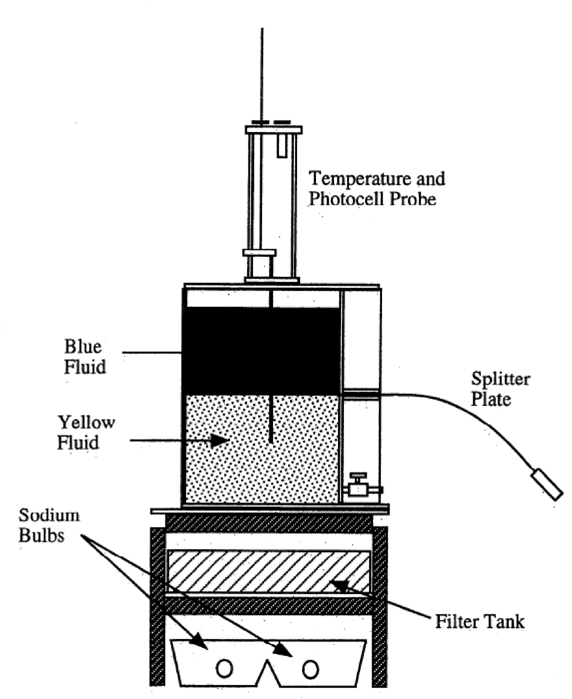
- Low clouds are increasingly recognized as main source of divergence in model based estimates of climate change [1].
- Entrainment rate in stratocumulus-topped mixed layer needs, in particular, better model [9, 10].
- Therefore, the experiment by Sayler and Breidenthal [7] is particularly interesting, both because it is a step toward an accurate parameterization of cloud top entrainment and it provides valuable data for the validation of the numerical models.
- The **One Dimensional Turbulence (ODT)** model [3] is a good candidate for the numerical simulation of fine scale interactions at the top of stratiform clouds because it **allows sufficient resolution to resolve fine scale processes while keeping acceptable run times**.
- It's then interesting to compare the results of the ODT model with the experimental results as a validation of the modeling strategy.
- Then, a future goal will be to check numerically if the laboratory results about the influence of Richardson number and molecular transport can be extrapolated to a larger-scale flow.

Questions

- Does ODT reproduce measured parameter dependences?
- Does it see any additional parameter dependences?
- (Future) do these results change as the flow scale is increased toward cloud scales?

The "Smoke Cloud" experiment by Sayler and Breidenthal

The experiment [7] reproduces an analog of the entrainment process induced by radiative heating at the top of stratiform clouds.



- The tank is filled with a blue and opaque aqueous fluid above and a yellow and translucent one below.
- A stable density stratification is achieved between the two layers, whose intensity varies for each trial. For one part of the trials the stratification is achieved by a heat difference between the layers and for the rest it's achieved by different dextrose concentrations.
- The tank is lit from below with two sodium lights to provoke radiative heating at the interface.
- The temperature and light flux are measured periodically in the tank.
- A non-dimensional entrainment E has been calculated based on these measurements. It is a **normalized displacement velocity of the interface**
- This entrainment E was found being **proportional to** Ri^{-1}

One Dimensional Turbulence

The key idea of the model:

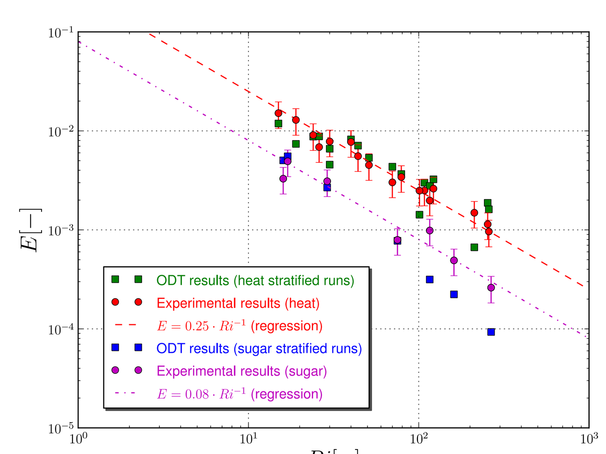
- ODT is a 1D DNS with a stochastic model for turbulent advection (implemented via maps). Time, location, and length of those are sampled from a probability distribution based on the local energetic of the turbulent field.
- Resolves all the fine scale processes while keeping acceptable run times.

Results and work in progress:

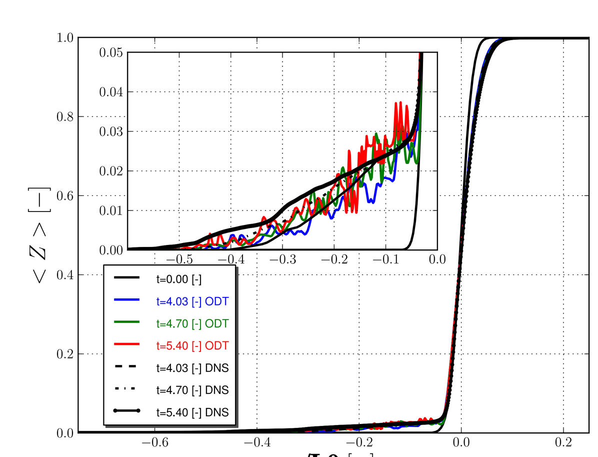
- ODT reproduces experimentally observed molecular effects on entrainment in radiatively forced convection experiments (see figure).
- Comparisons with DNS on buoyancy reversal results as a validation of the modeling strategy (see figure).

Future work:

- Does it see any additional parameter dependences (e.g. Pr effects)?
- Do these results change when we extend the scales beyond DNS limits (future work)?
- Following the future DNS setups (finite rate effects)



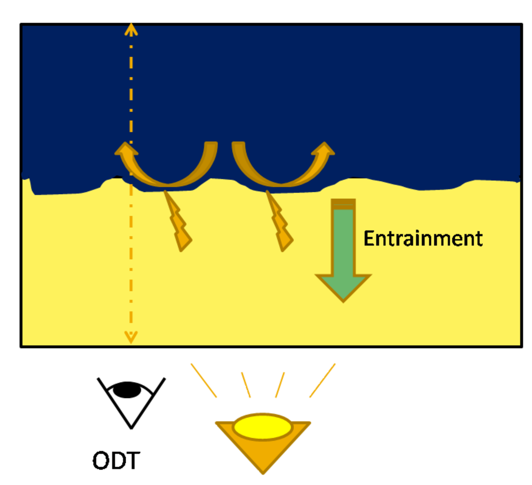
Radiatively forced entrainment: ODT vs. experimental results



Buoyancy reversal study: ODT vs. DNS results

The ODT setup

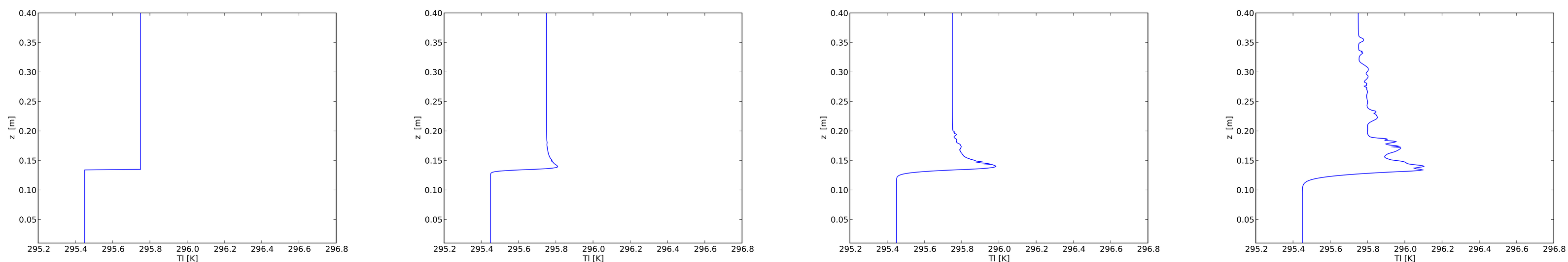
Here the 1D domain corresponds to a vertical (normal to the interface) line of sight through the tank. The two fluids system is represented by the 1D profiles of temperature and the three velocity components and for some runs the dextrose concentration.



The absorption of the light flux is quantified by a length σ such that the ratio of transmitted to incident radiation in a layer of pure blue fluid of thickness D is $\exp(-D/\sigma)$.

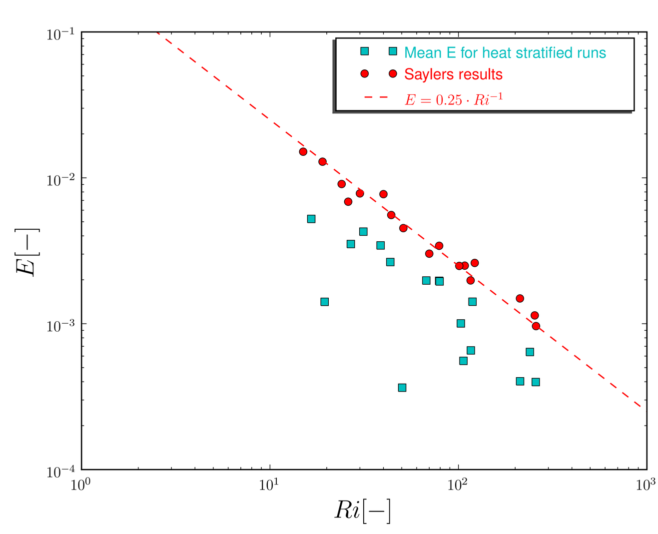
For simulation purposes, a mixture fraction Z is used to represent the volume fraction of initially pure acidic fluid in a mixture. In our idealized model it is assumed that σ has the value for pure acidic fluid ($Z = 1$) if $Z > Z_s$, otherwise $\sigma = \infty$ (i.e., no absorption). Z_s is the value of Z at which the mixture crosses between the transparent and absorbing states. Its value is related to the equivalence ratio τ of the reaction between the acidic and the basic species.

The velocities are initialized with small values, the temperature is initially constant in each layer but different in order to achieve the sharp density stratification. For the trials with dextrose stratification, the temperature is initially constant in the whole domain and the dextrose concentration is zero in the upper layer and constant in the lower one.

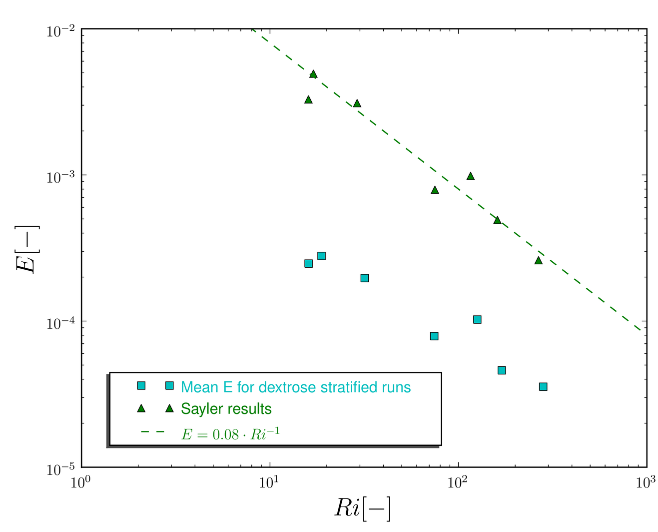


Growing of the turbulence in the upper layer, simulated by the ODT model

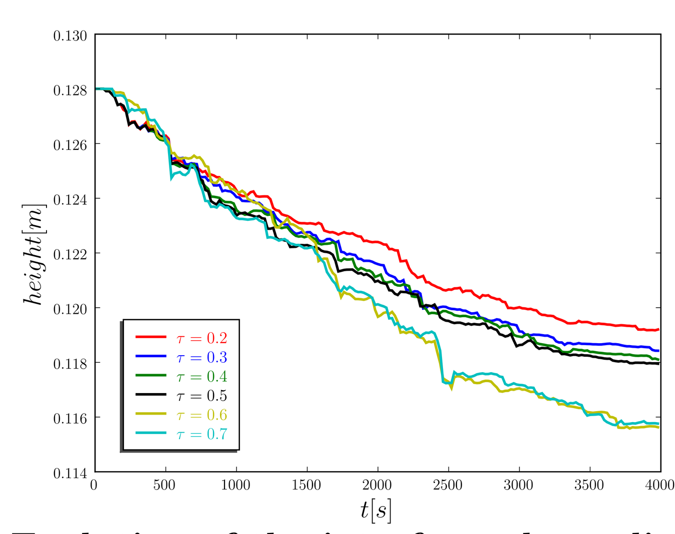
Results



Comparison of entrainment rates versus Richardson numbers : ODT (light blue) and experimental results (Red)



Comparison of entrainment rates for the dextrose stratified cases



Evolution of the interfaces depending on the τ parameter

- The scaling with the Richardson number is quite well reproduced by the ODT model for both heat stratified and dextrose stratified trials.
- The influence of the molecular processes has been reproduced too. Indeed, the rates of the dextrose stratified runs are much lower than those of the heat stratified runs.
- The τ parameter is related to the acid-base chemical reaction and to the transition point between the translucent and the opaque layer. It has a significant influence on the displacement velocity of the interface (see figure above). This hints at sensitivity to details of radiative absorption.

Work in progress

- Parasitic turbulence seems to have taken place in the lower layer during the experiment and the influence of this on the results is investigated.
- A more accurate definition of the radiative absorption is needed.
- The influence of the optical depth on the results seems quite important and the calibration of this parameter during the experiment is not accurately known. Simulations will indicate how much it impacts the results.
- Resolution studies for the dextrose cases
- A comparison to a the results of a Direct Numerical Simulation strategy [5,6]
- Using ODT in a Superparametrization [2,8]

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