Hybrid front tracking for Stratocumulus clouds considering unsteady entrainment

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Motivation

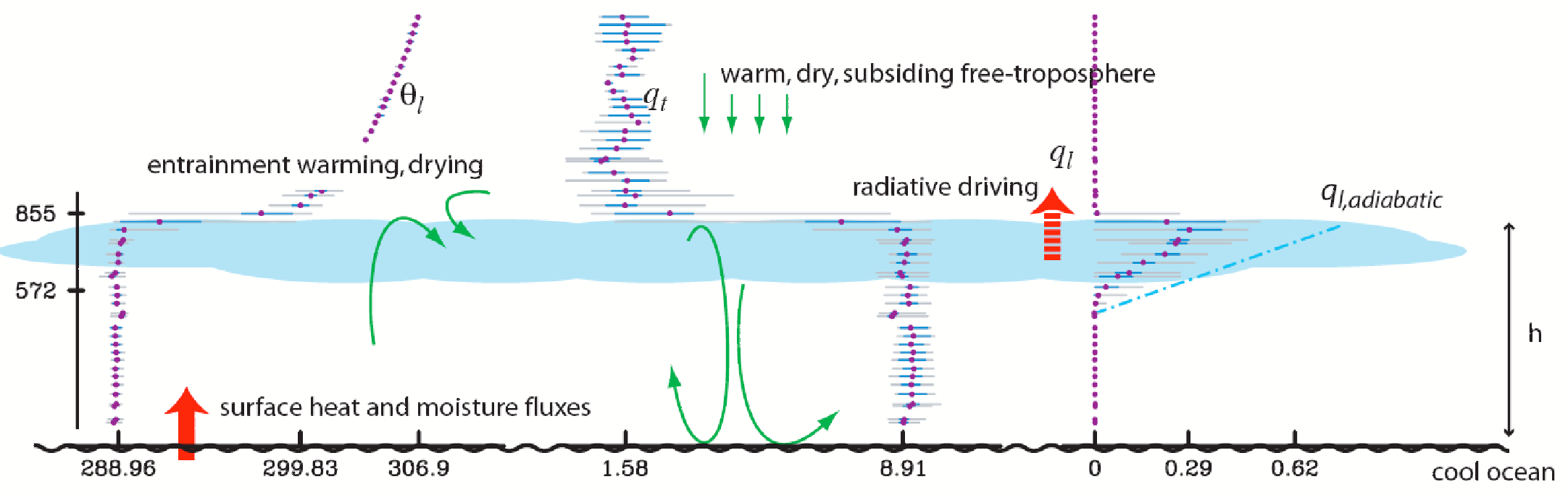
- Low clouds are increasingly recognized as the main source of divergence in model based estimates of climate change [2]
- Model based aerosol/cloud interactions require accurate representation of clouds [1]
- Our best tool for understanding clouds and microphysical interactions is LES, but fundamental issues emerge in precisely those quantities of interest (e.g. Albedo)
- Culmination of more than 10 years of work shows limitations of LES [13] to be fundamental!

Problem

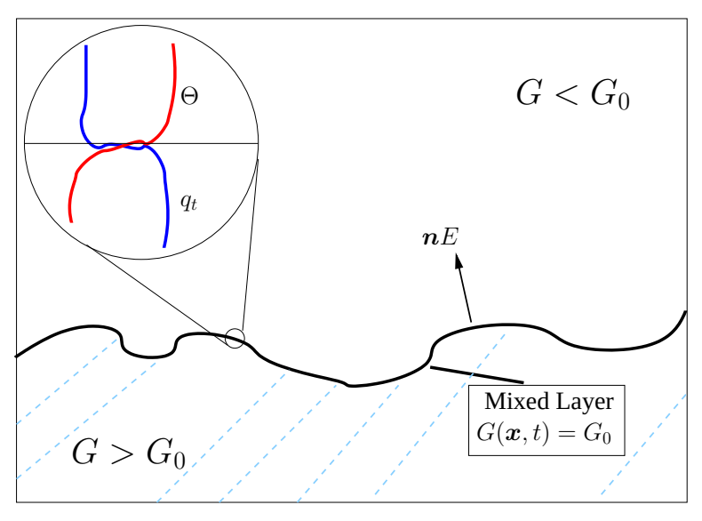
1. **Numerical vs. Physical**
   - Current LES cannot resolve the interface physics due to insufficient resolution
   - Elaborate physically based subgrid models are numerically smeared out (fed wrong)
   - Distinction between numerical and physical effects is impossible
2. **Small vs. Large Scale**
   - Interface motion is driven by large scales.
   - But mixing across the interface is a small scale phenomenon.
   - The coupling between both is not trivial.

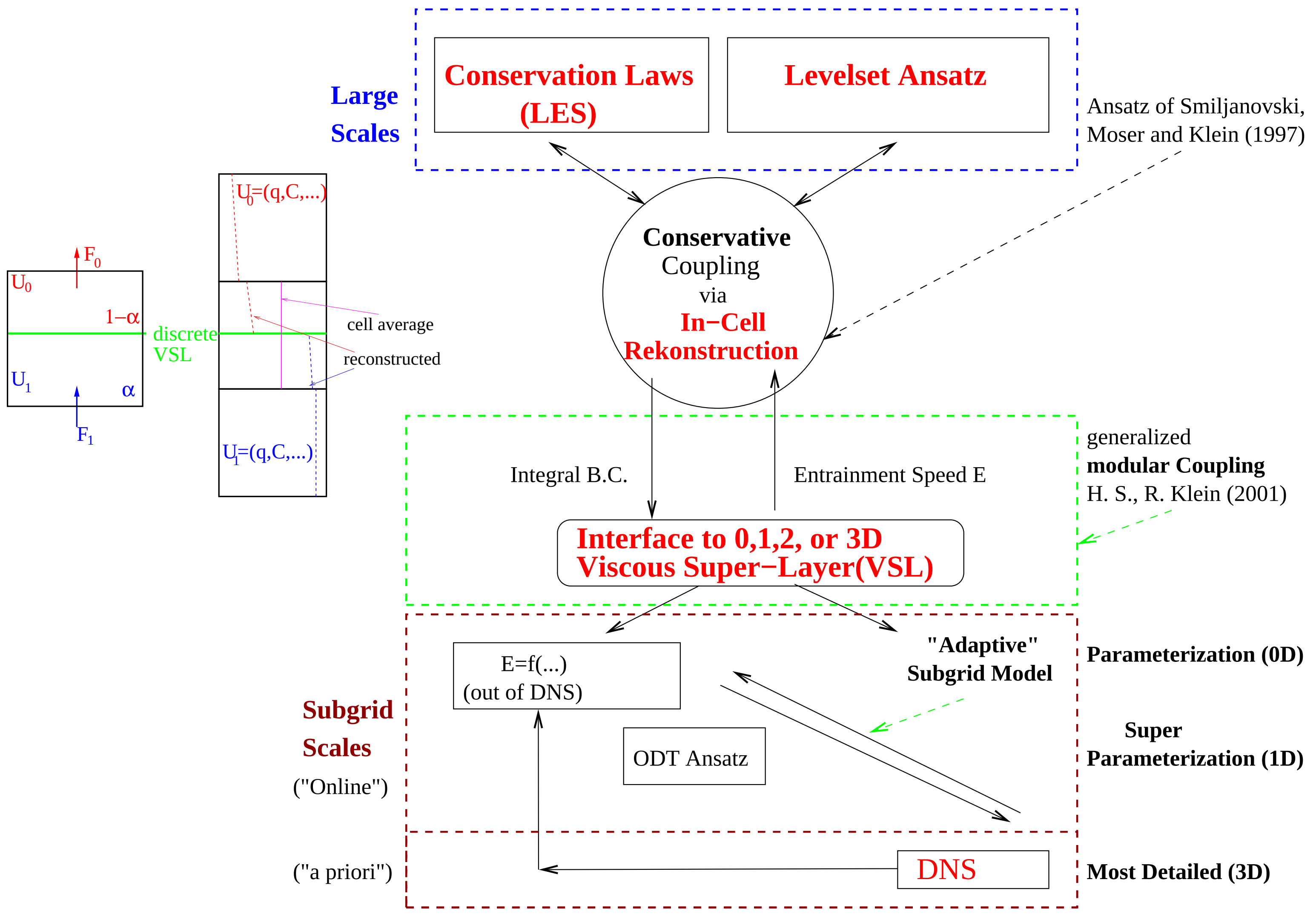
Key Ideas

1. **Separation of Numerical and Physical Issues**
   - Interface method to avoid numerical smearing, [9, 11]
   - Consistent embedding of entrainment physics [5]
2. **Separate Treatment of Small and Large Scales**
   - VLES + front tracking for large scales
   - DNS, one dimensional turbulence (ODT), and lower order models for small scale
   - Modular coupling procedure [9], which has been developed for combustion and two phase flow problems, helps to combine both scales in a consistent manner.



Sketch of the Ansatz





Large Scales

Conservation Laws (LES)

Levelset Ansatz

Ansatz of Smiljanovski, Moser and Klein (1997)

Conservative Coupling via **In−Cell Rekonstruction**

Integral B.C.

Entrainment Speed E

generalized **modular Coupling** H. S., R. Klein (2001)

Interface to 0,1,2, or 3D Viscous Super−Layer(VSL)

Subgrid Scales ("Online")

E=f(...) (out of DNS)

"Adaptive" Subgrid Model

Parameterization (0D)

ODT Ansatz

Super Parameterization (1D)

("a priori")

DNS

Most Detailed (3D)

Large Scales and Modular Multi Scale Coupling (ZIB)

Characteristic Scales

Large Scales:
Fluctuation of key values over a large scale eddy ($l \approx 800$m): $\Theta' \approx 0.08$K, $q_t' \approx 4 \cdot 10^{-5}$g/kg, and $\tau_l = 600$s. Large scale turbulence is driven by radiation on top of the cloud, since cloud is opaque.

Small Scales:
Changes across the viscous super layer $\leq 10m$:
$\Delta\Theta \approx 10K$ and $\Delta q_t \approx 8$g/kg

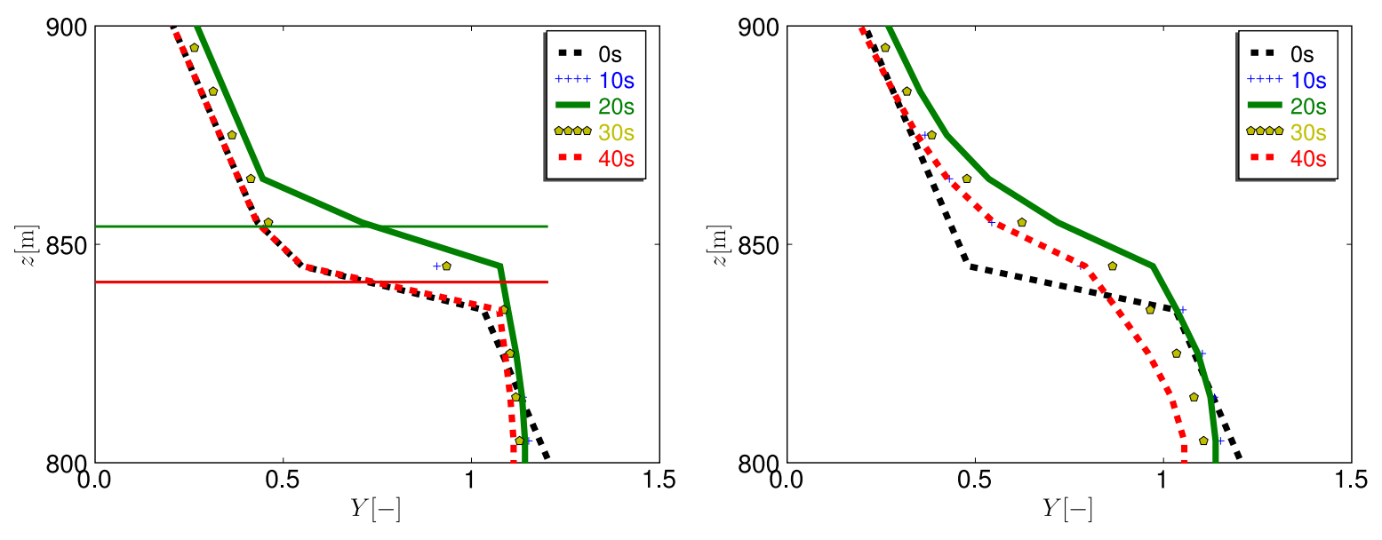
Scale Relation:

$\frac{\Delta q_t}{q'} \gg 1$ and $\frac{\Delta\Theta}{\Theta'} \geq 100$ ⇒ Looks like an interface!

Accurate large scale control of the progress variable is important! This is a necessary condition for embedding a subgrid scale model that is driven by the large scales and has significant feedback on them at the same time. There are analogies to combustion and two phase flow modelling, but poorely explored!

Simple 1D test problems

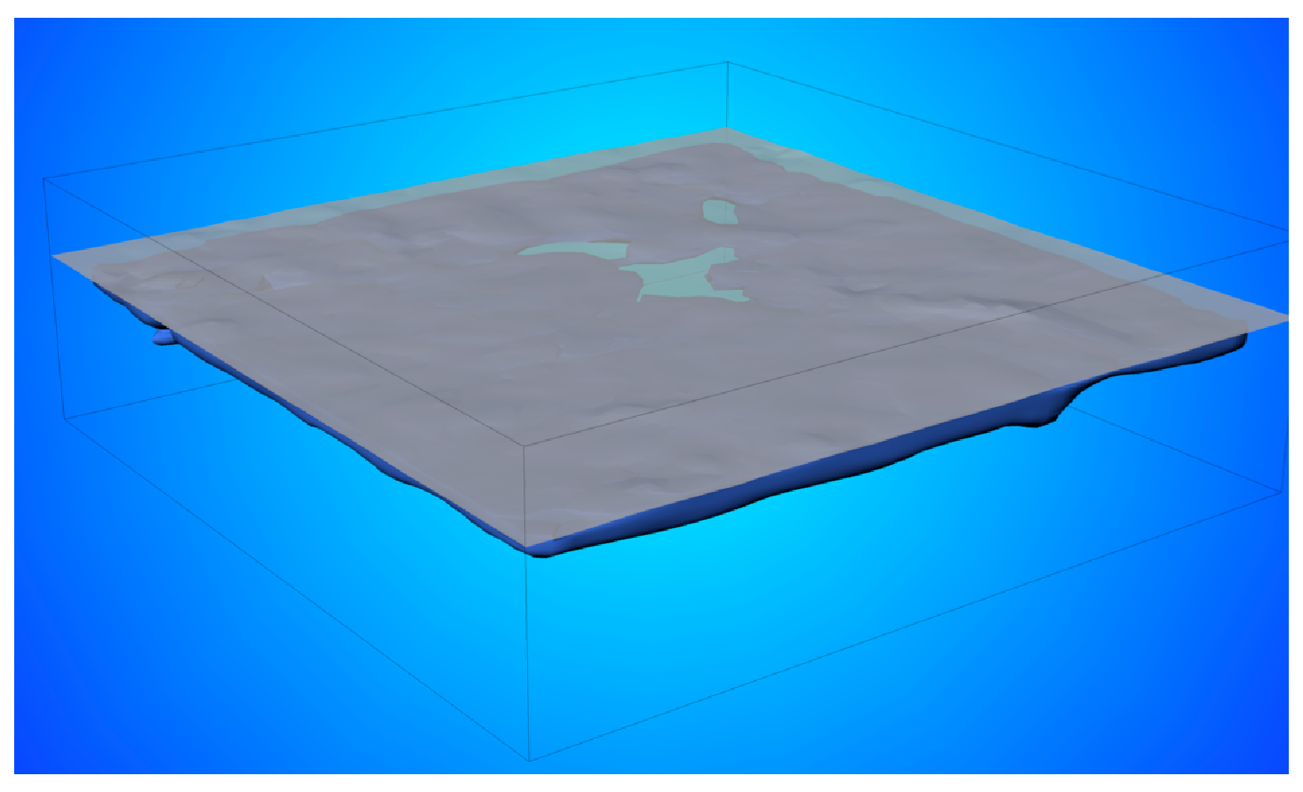
- Evolution of the Interface:
  $$\frac{\partial}{\partial t}\Phi + (\boldsymbol{v} + E\boldsymbol{n}) \cdot \nabla\Phi = \text{sign}(\Phi)\,(1 - |\nabla\Phi|)\frac{|\Phi|}{\zeta}$$
- One-sided diffusion in oscillating velocity fields
- No *artificial* diffusion when the levelset and conservation principles over the interface are used [10]



One-sided diffusion of a tracer with superimposed oscillation with an amplitude of 1m/s. A mesh size of $dz = 10$m is used. The results after one oscillation for a levelset/FVM approach (left) and a standard FVM (right) are plotted.

Large Eddy Simulation

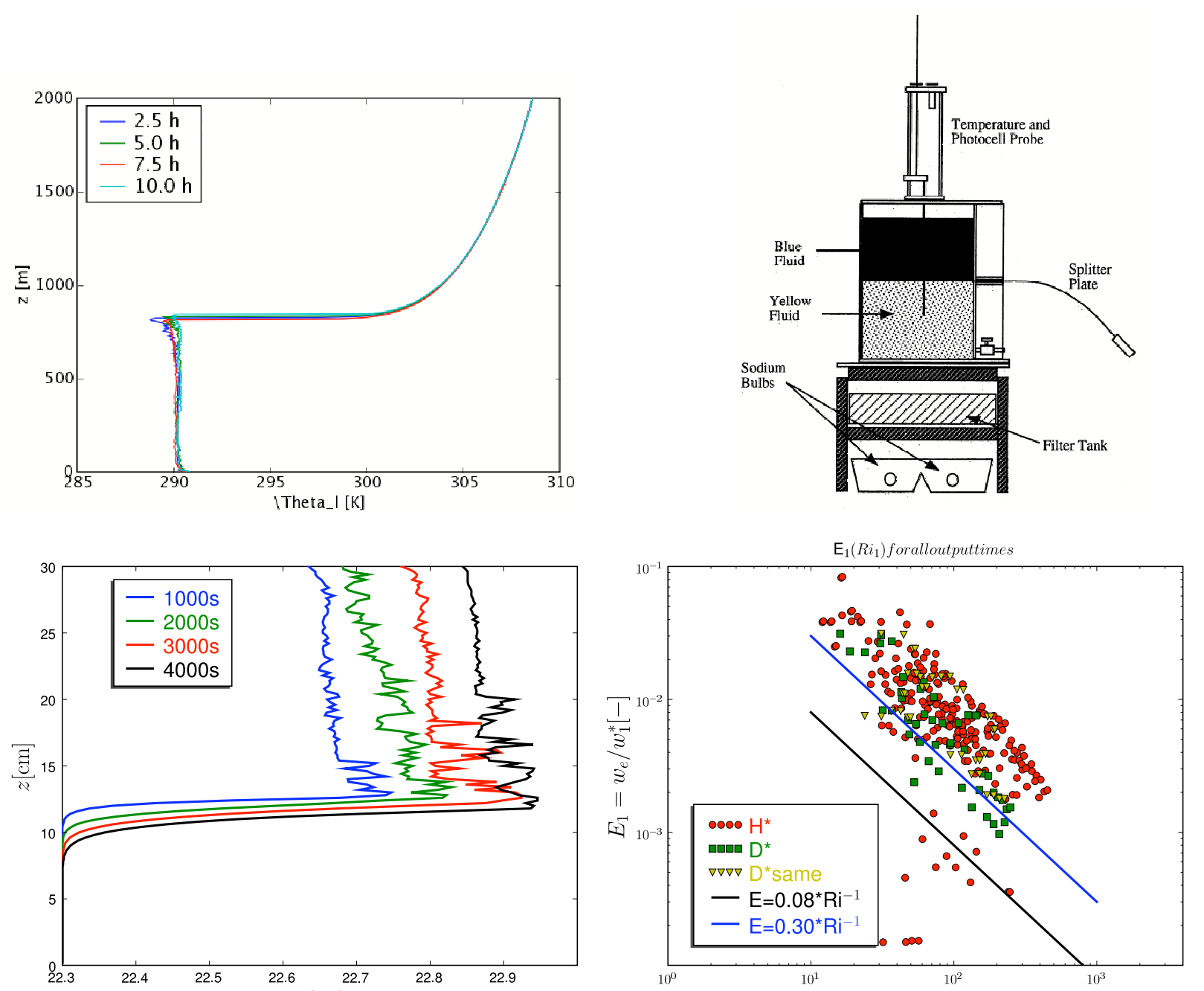
We are implementing the Heterogeneous Multiscale Model from [9] into the anelastic UCLA-LES solver [13]. Comparison with DYCOMSII [12] is far goal.



Step towards a Sc simulation (UCLA-LES) including a tracked viscous super-layer: Isosurface of liquid water (blue) and zero levelset (gray)

Subgrid Scale Entrainment Modeling

- One Dimensional Turbulence Model [6] for Sc [7]
- Code is currently tested against experiments

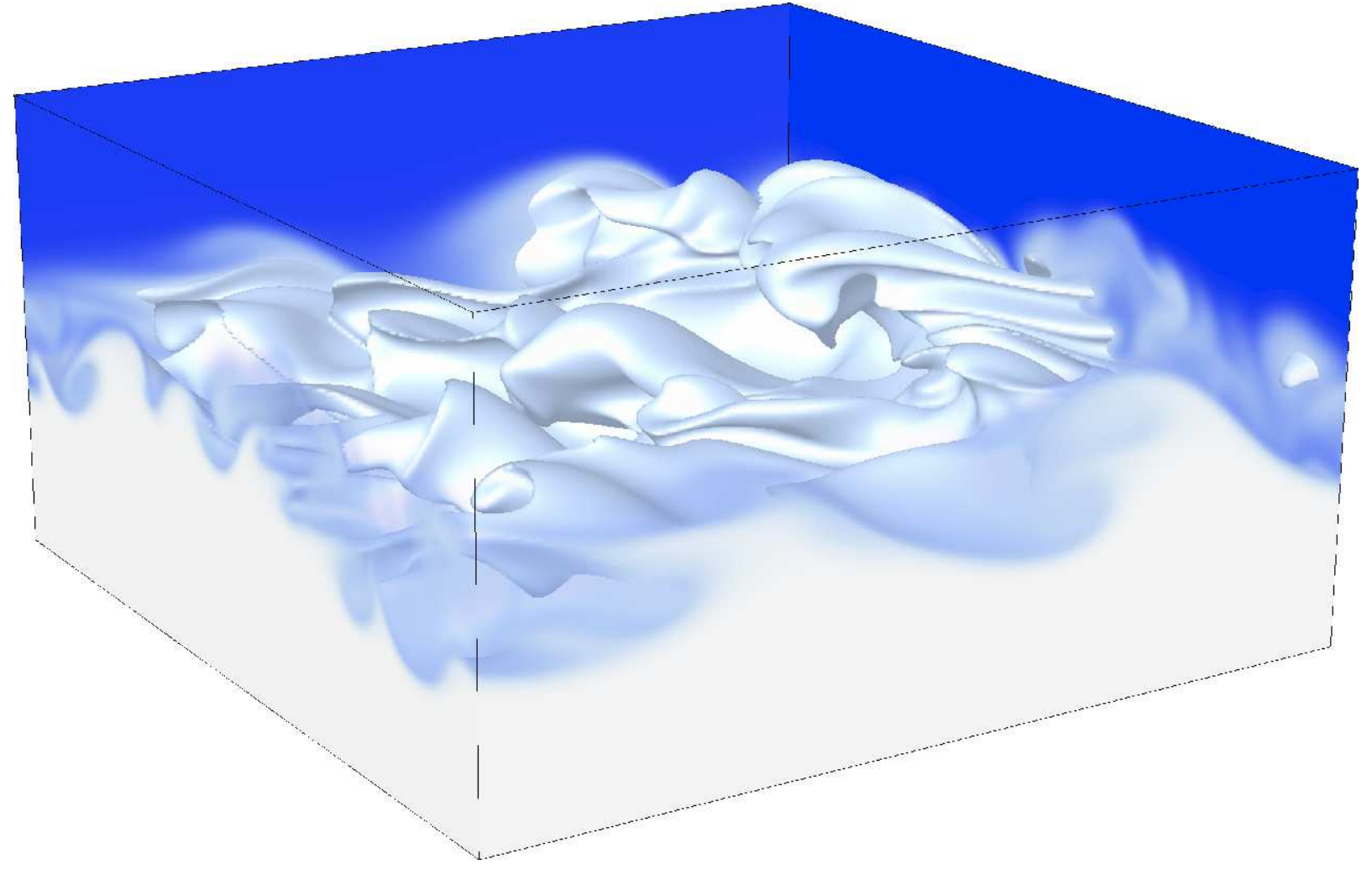


ODT simulation of SC topped boundary layer (left top), experimental set up (Sayler & Breidenthal[8], top right), ODT temperature profiles (bottom left), and preliminary ODT results (bottom right) for the entrainment as a function of the Richardson number. What is the role of molecular effects?

DNS and Entrainment Modeling (ITV)

Stratified Mixing Layer

Temporally-evolving shear layers are simulated. Focus is on the nonturbulent/turbulent transition region (viscous superlayer, Corrsin, 1955). Water equilibrium conditions are assumed and an Eulerian-Eulerian (two-fluid) formulation. Latent heat effects investigated by looking at the large- and small-scale phenomena (dissipation element analysis, Wang and Peters, 2006).



Vertical shear layer with total specific humidity field. Initially there is hot dry air on top of cold moist air.

Incompressible Boussinesq code developed.

Entrainment Model

Global entrainment velocity is defined as temporal change of a mixing region thickness δ_ω,

$$E = \frac{d\delta_w}{dt}. \tag{1}$$

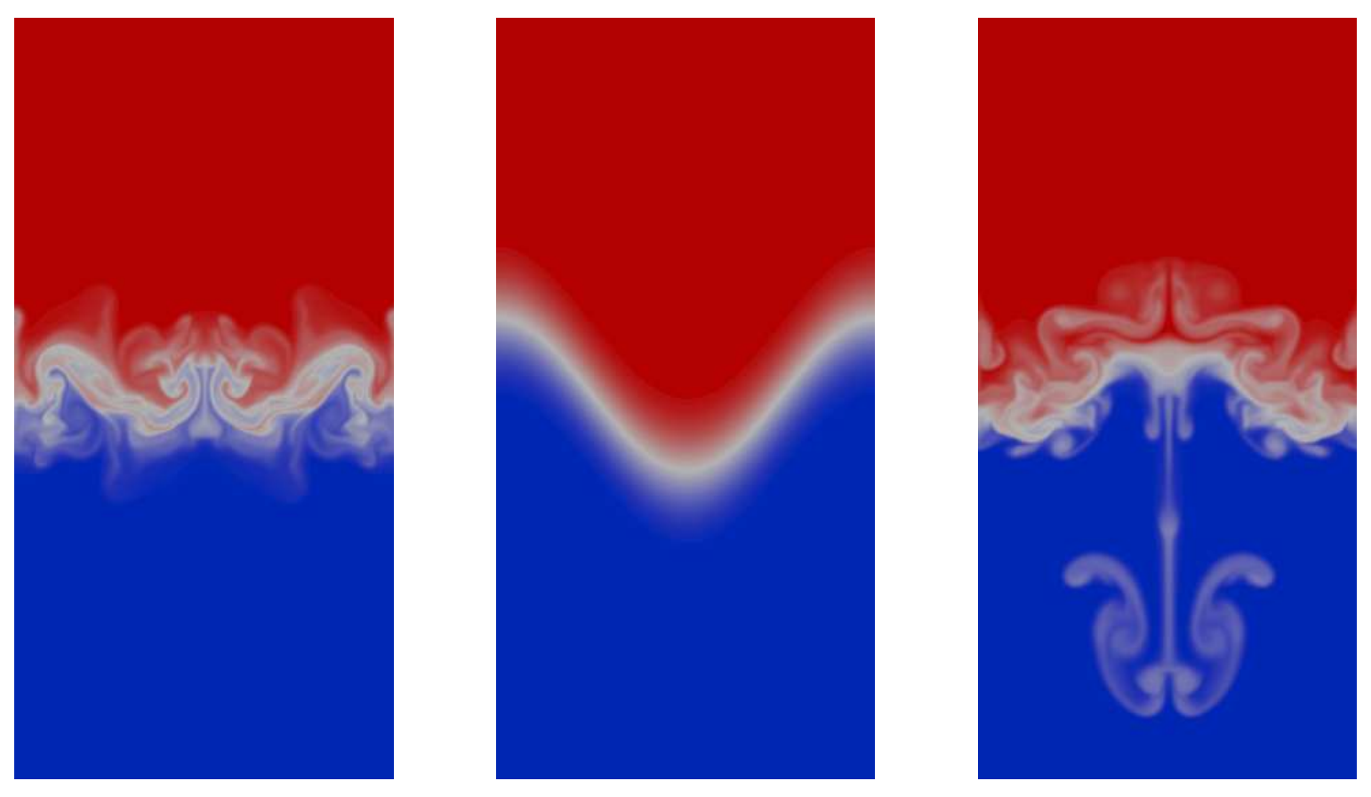
We need to know the dependence of E on the nondimensional parameters of the problem, possibly:

$$E = E(Ri, D, \chi_m) \tag{2}$$

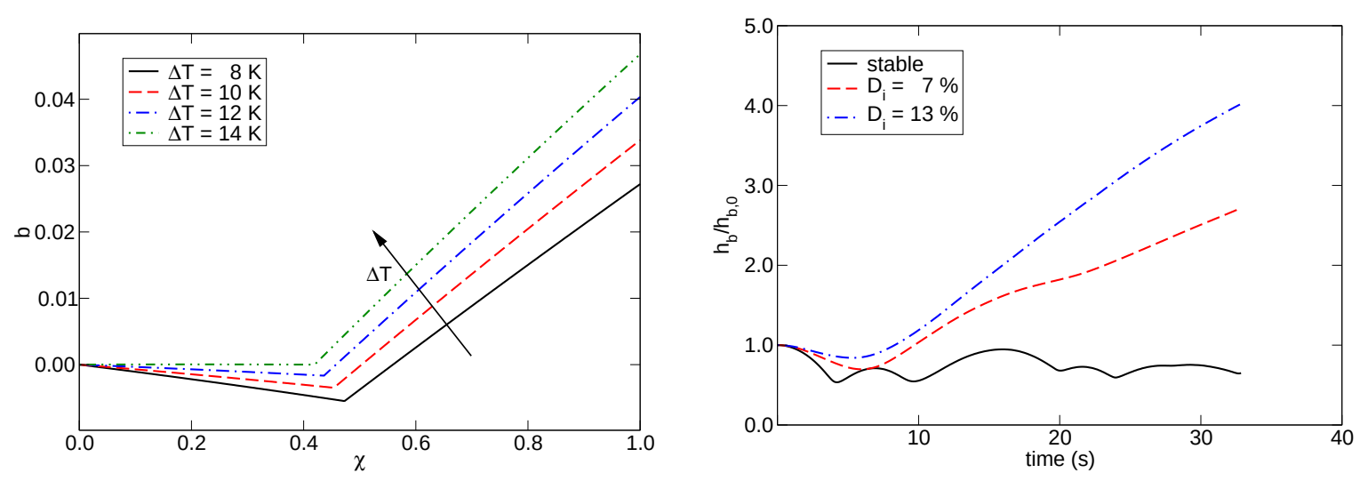
- Richardson number Ri.
- Normalized maximum density difference D at mixture fraction χ_m.

Buoyancy Reversal

The two-layer system of hot/dry air on top of cold/moist air can have buoyancy reversal instability due to evaporative cooling. Central figure below represents the perturbed initial condition: the stable mode develops a turbulent mixing region around the central position due to baroclinic production of vorticity (left); if buoyant reversal, an additional downdraft might be formed (right).



Study done in terms of buoyancy function $b(\chi)$, $\chi = 0$ lower layer, $\chi = 1$ upper layer (figure below, left). The buoyancy reversal parameter D compares the minimum of the curve $b(\chi)$ with the ordinate at $\chi = 1$.



As D is increased, the downdraft develops faster, as shown in figure above (right). The finger length h_b is measured by the distance between the falling front and the mean position of the oscillating mode. First results submitted for publication (Mellado et al., 2008)

What is the relevance of buoyancy reversal in the turbulent configuration?

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