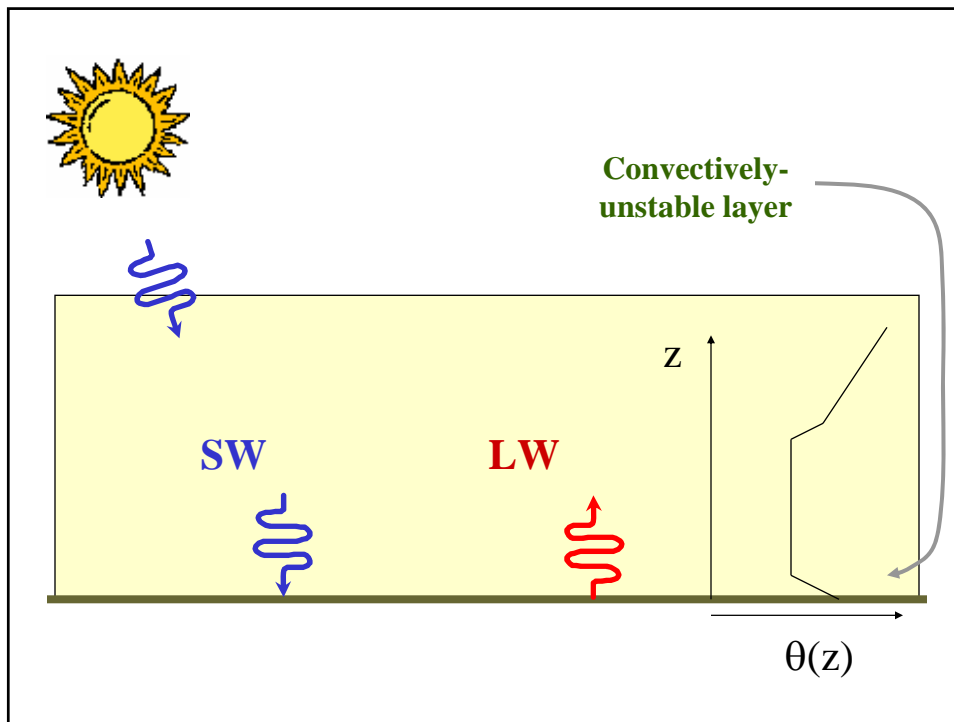
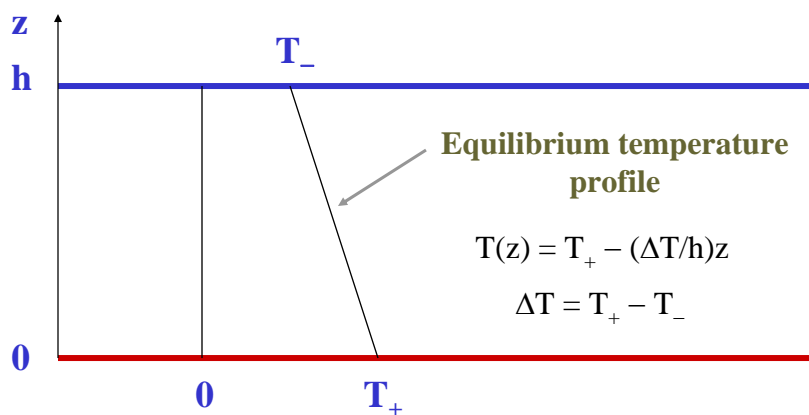


- **K. A. Emanuel (1994): Chapter 2 of Atmospheric Convection entitled "Global dry convection"**
- **J. S. Turner (1973): Buoyancy Effects in Fluids**
- **R. S. Scorer (1958): Natural Aerodynamics, Chapter 7**



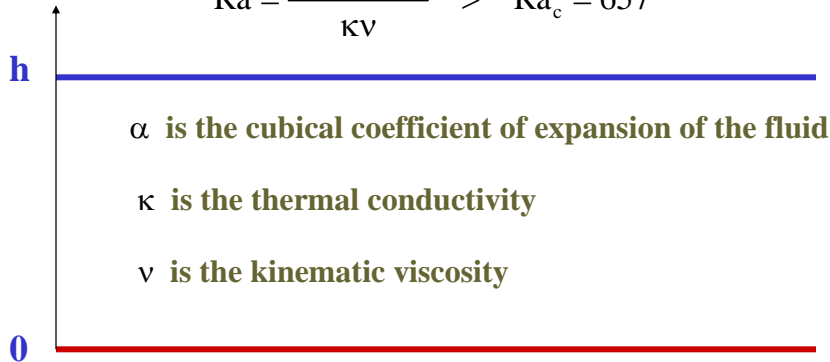
The classical fluid dynamical problem of convective instability between two horizontal plates



Convectively instability occurs if the **Rayleigh number**, Ra , exceeds a threshold value, Ra_c .

The Rayleigh number criterion

$$Ra = \frac{g \alpha \Delta T h^3}{\kappa \nu} > Ra_c = 657$$

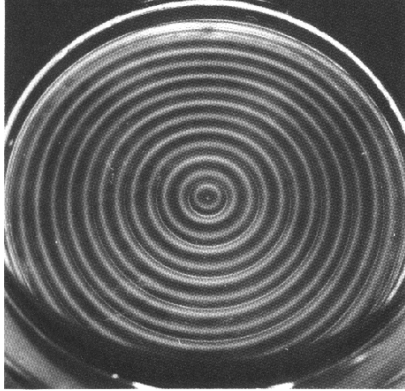


The **Rayleigh number** is ratio of the gross buoyancy force that drives the overturning motion to the two diffusive processes that retard or prevent it.

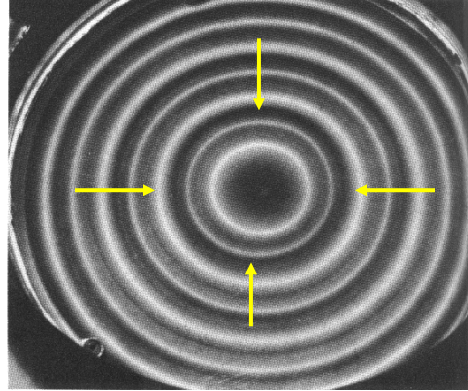
The nature of the instability

- For $Ra < Ra_c = 657$, the equilibrium temperature gradient is **stable** (Lord Rayleigh, 1916).
- For $Ra > Ra_c$, small perturbations to the equilibrium are **unstable and overturning motions occur**.
- If Ra is only slightly larger than Ra_c , the motion is organized in **regular cells**, typically in **horizontal rolls**.
- As $Ra - Ra_c$ increases, the cells first take on a **hexagonal planform** and later become more and more irregular and **finally turbulent** (Krishnamurti, 1970).
- The **turbulent convective regime is normally the case in the atmosphere**.

Circular buoyancy-driven convection cells



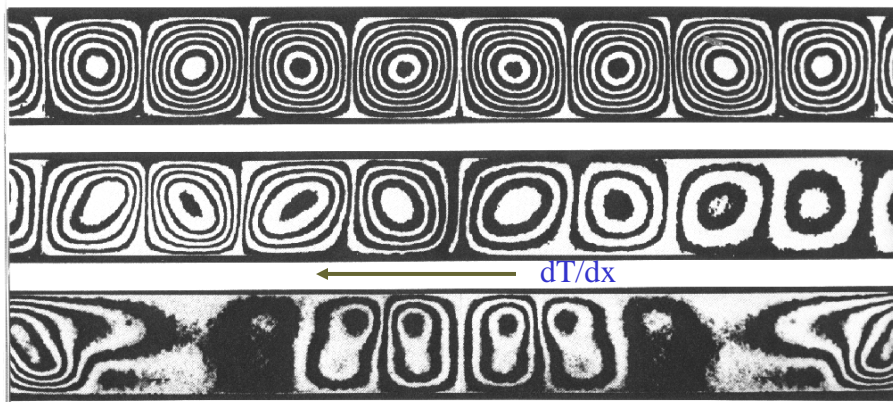
$Ra = 2.9Ra_c$
Uniformly-heated base plate



Base plate is hotter at the rim
than at the centre

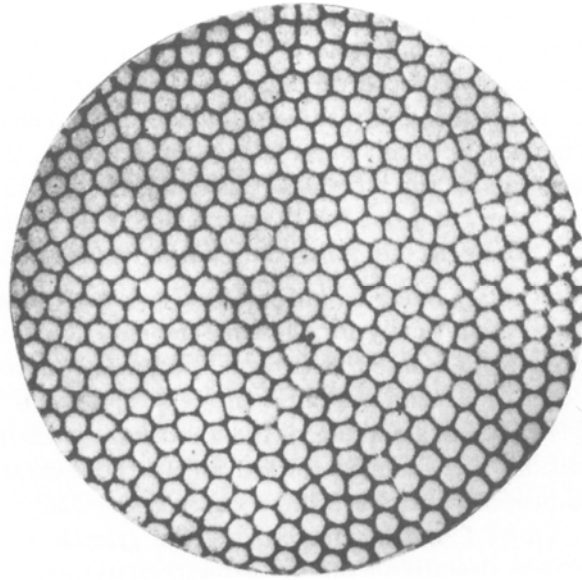
Buoyancy-driven convection rolls

Rayleigh-Bénard ↙

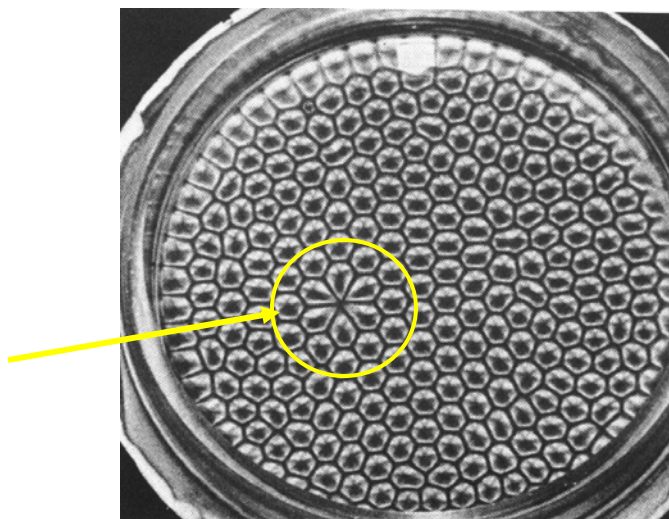


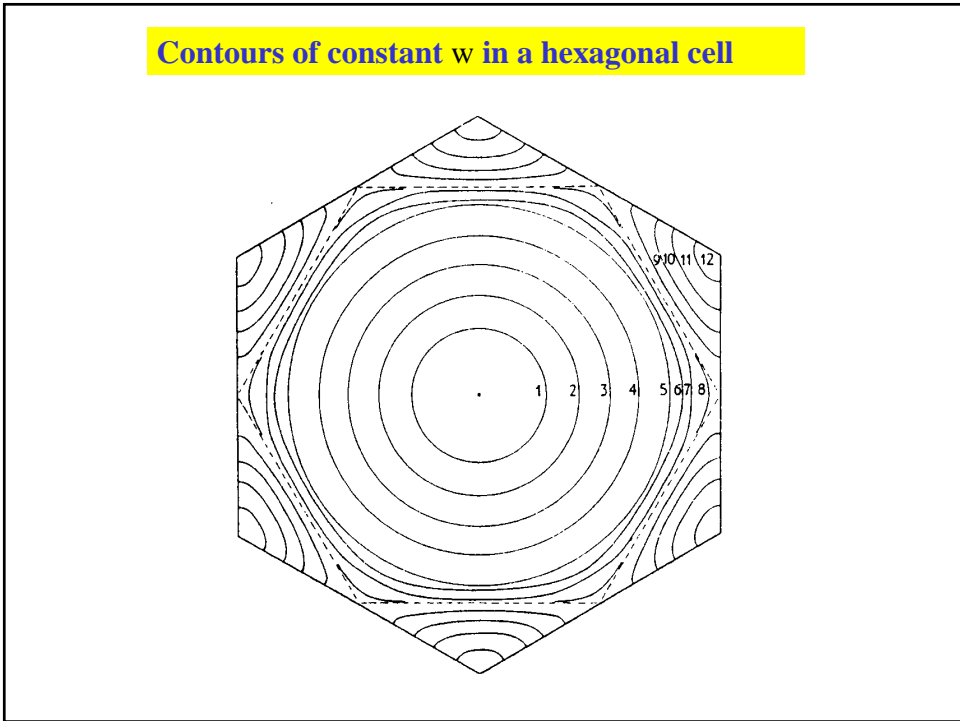
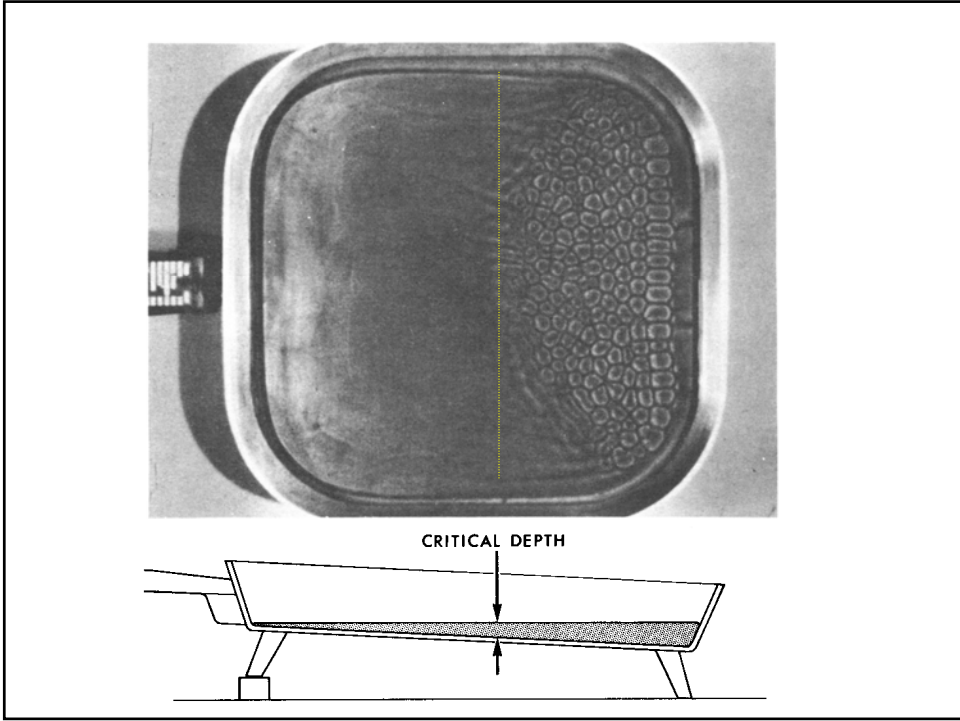
Differential interferograms show side views of convective instability of silicone oil in a rectangular box of relative dimensions 10:4:1 heated from below.

Bénard convection – hexagonal cells

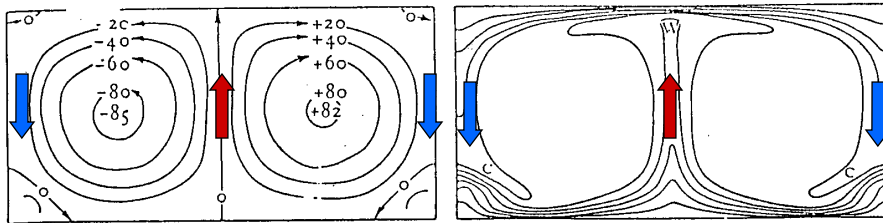
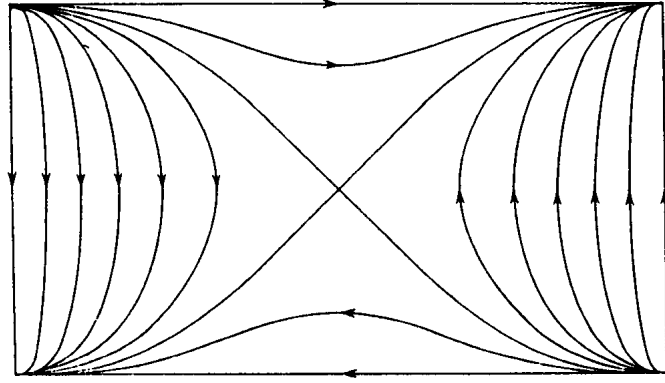


Imperfections in a hexagonal Bénard convection pattern

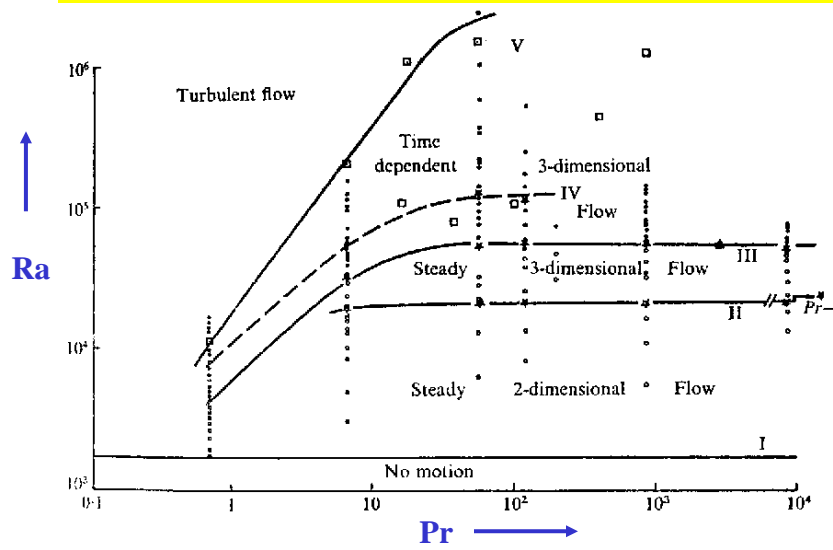




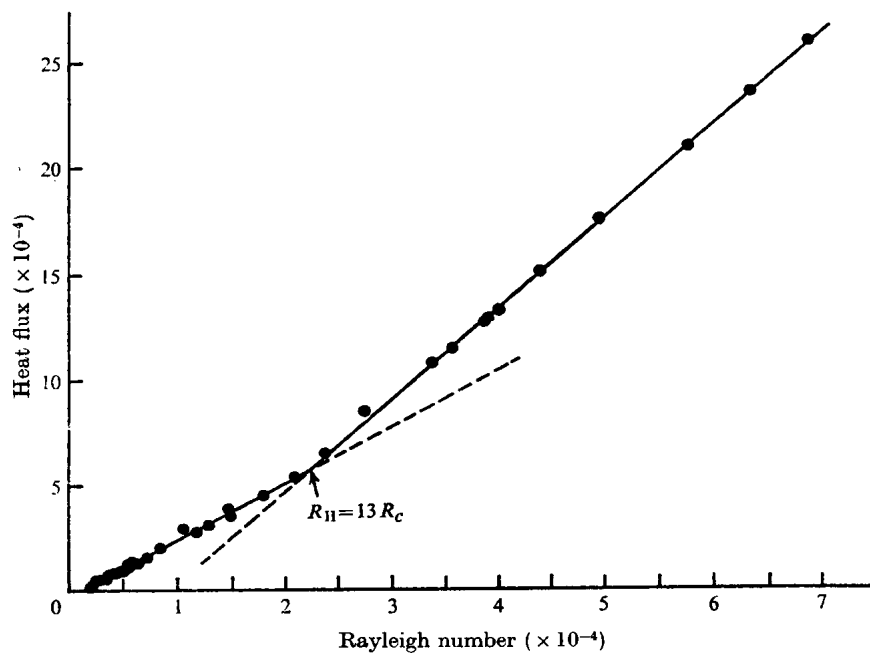
Streamlines in a horizontal plane for a rectangular cell



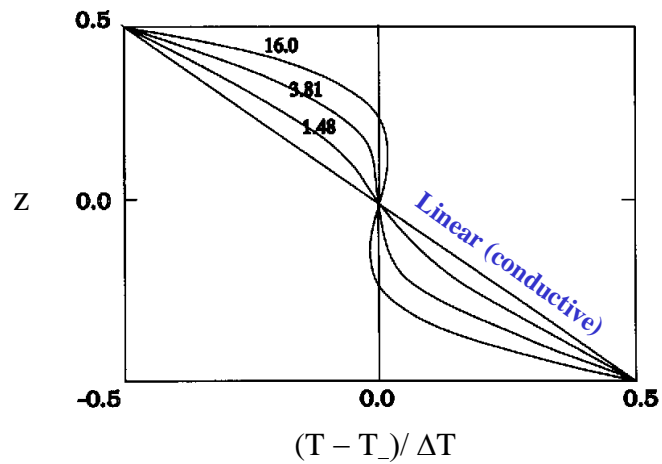
Regime diagram for experiments on Rayleigh convection



Circles => steady flows, circular dots => time-dependent convection, stars => transition points, open squares => independent laboratory observations of time-dependent flow by Rossby (1966), squares with a dot in the center => observations of turbulent flow by Willis and Deardorff (1967).

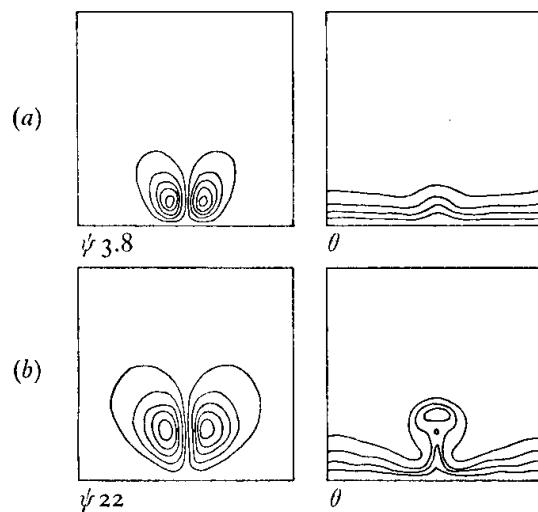


Temperature profiles as a function of Ra



As the Rayleigh number increases above Ra_c , the vertical profile of the horizontally-averaged temperature departs significantly from the linear equilibrium profile resulting from conduction only.

Penetrative convection

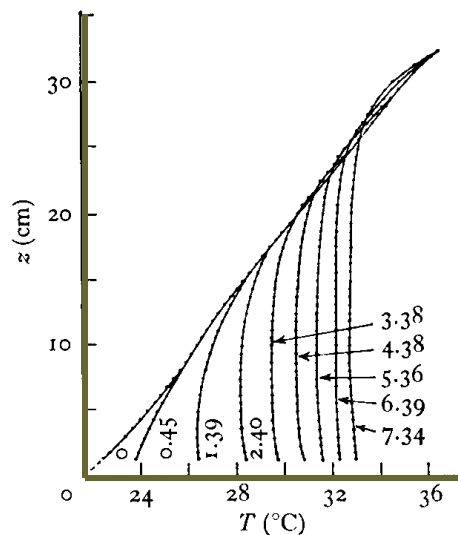


The formation of plumes or thermals rising from a heated surface



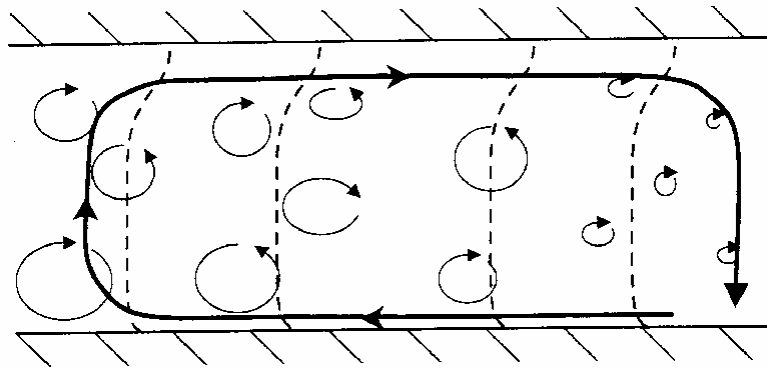
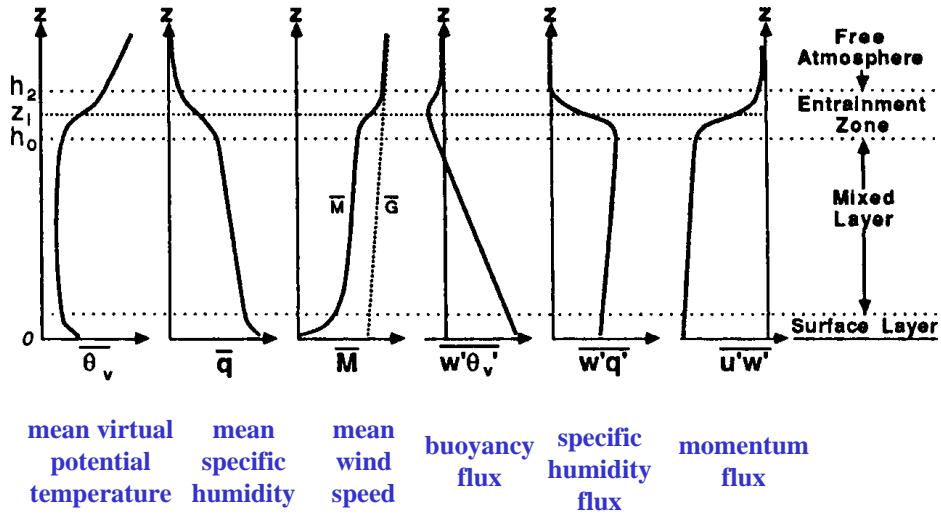
Higher heating rate

In the turbulent convection regime, the flux of heat from heated boundary is intermittent rather than steady and is accomplished by the formation of thermals



Vertical profiles of temperature in a laboratory tank, set up initially with a linear stable temperature gradient and heated from below. the profile labels give the time in minutes. (From Deardorff, Willis and Lilly, 1969).

Typical profiles of quantities in a convective boundary layer



(a)

T_+

T

T_-

← boundary temperature gradient

From Emanuel et al., 1994

