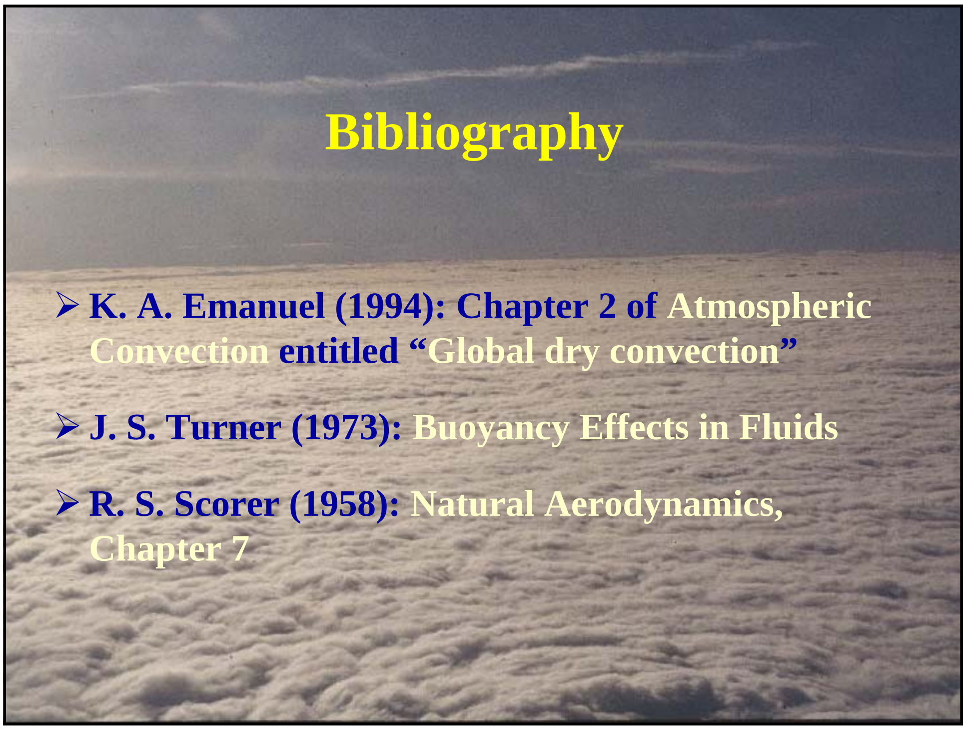
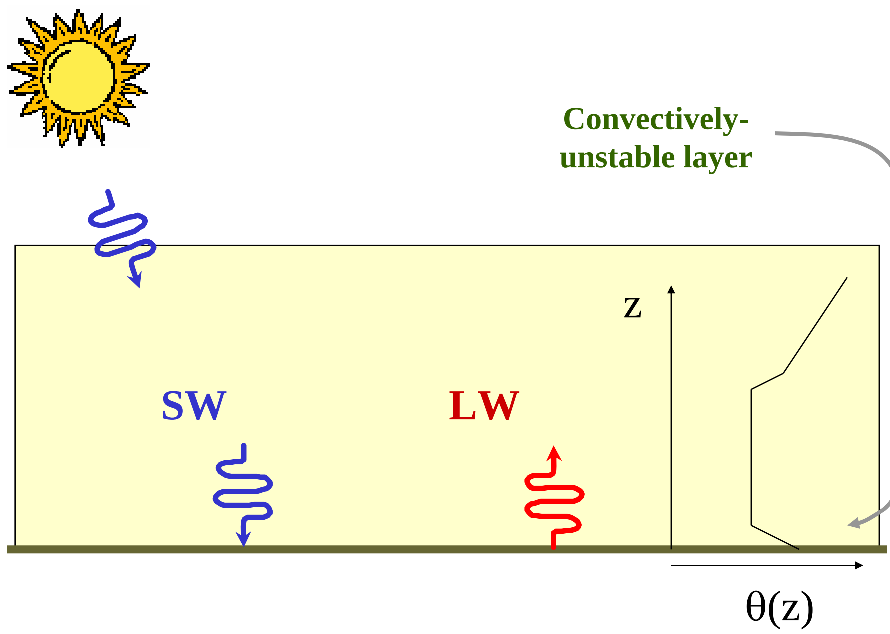
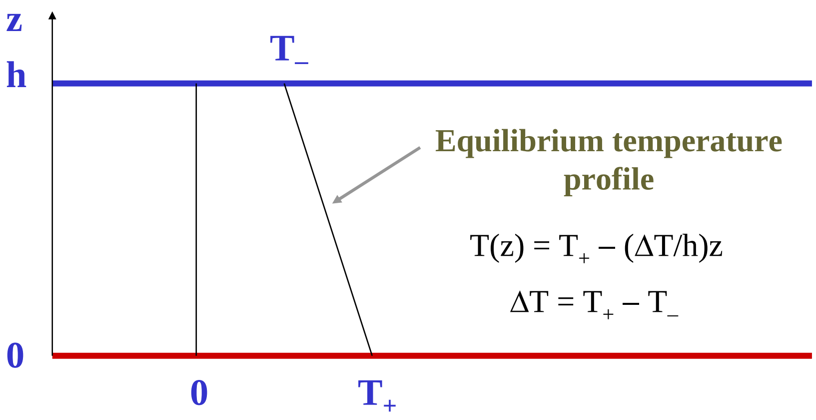

Global dry convection


Bibliography
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

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

h

$\alpha$ **is the cubical coefficient of expansion of the fluid**

$\kappa$ **is the thermal conductivity**

$\nu$ **is the kinematic viscosity**

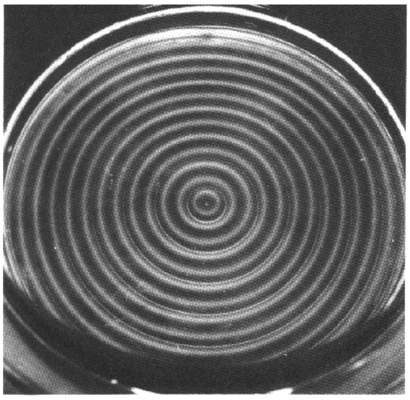
0

**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

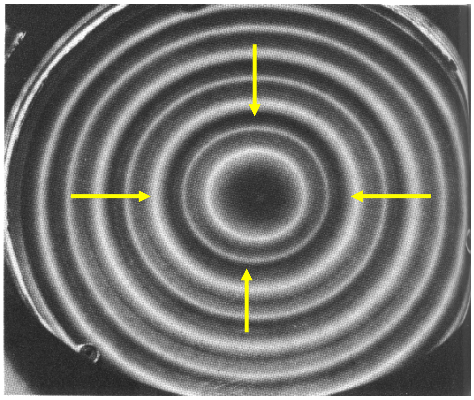
- **For Ra < $Ra_c$ = 657, the equilibrium temperature gradient is stable (Lord Rayleigh, 1916).**
- **For** Ra > $Ra_c$**, small perturbations to the equilibrium are unstable and overturning motions occur.**
- **If** Ra **is only slightly larger than** $Ra_c$**, the motion is organized in regular cells, 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



$Ra = 2.9Ra_c$

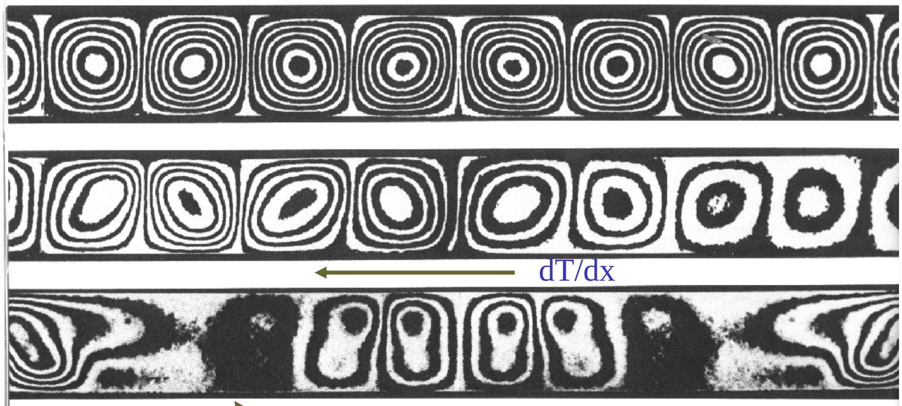
**Uniformly-heated base plate**



**Base plate is hotter at the rim than at the centre**

## Buoyancy-driven convection rolls

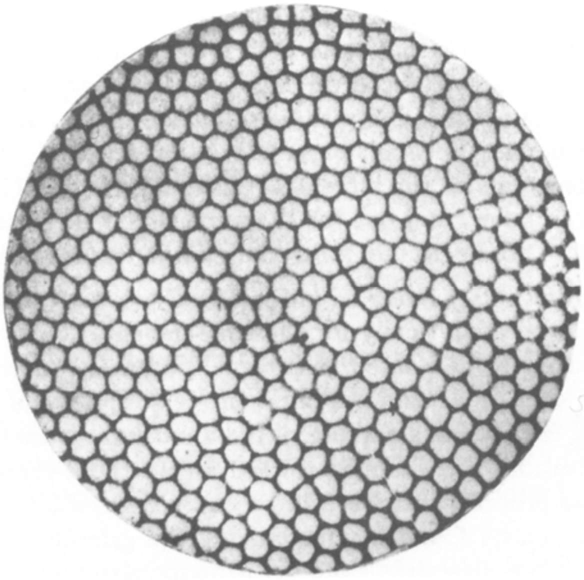
**Rayleigh-Bénard**



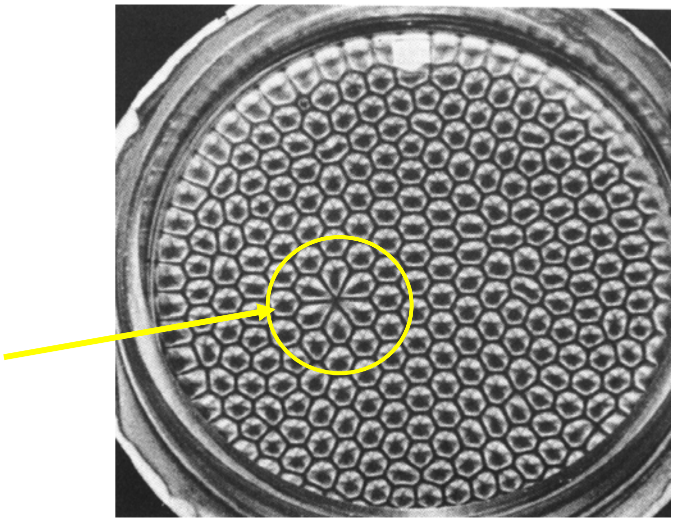

Rotation about a vertical axis

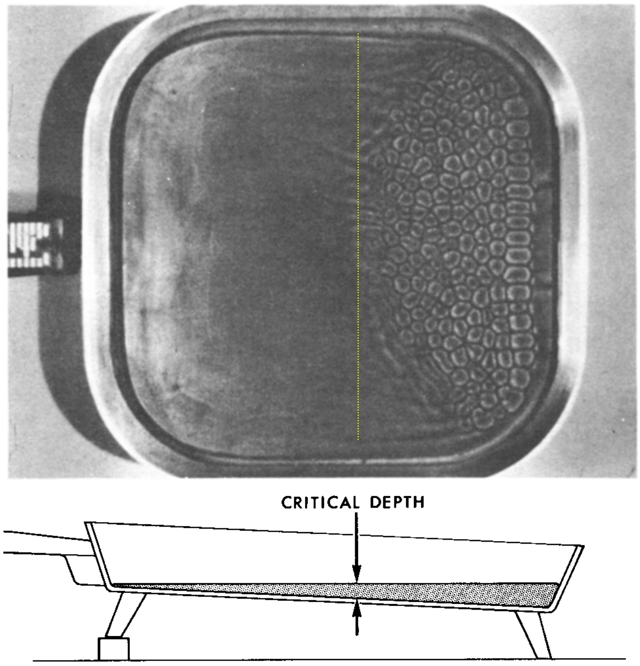
**Differential interferograms show side views of convective instability of silicone oil in a rectangular box of relative dimensions 10:4:1 heated from below.**

## Bénard convection – hexagonal cells

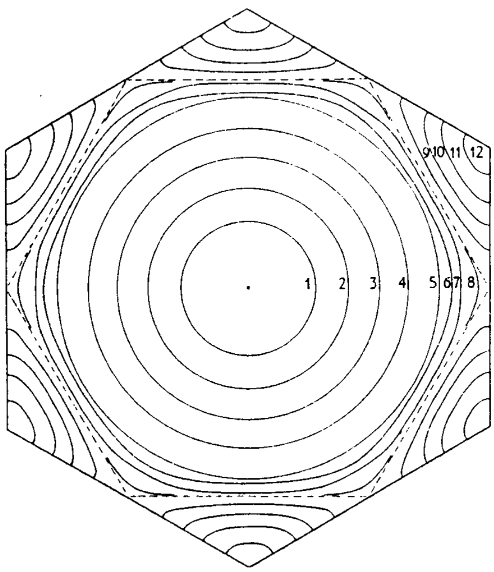


## Imperfections in a hexagonal Bénard convection pattern

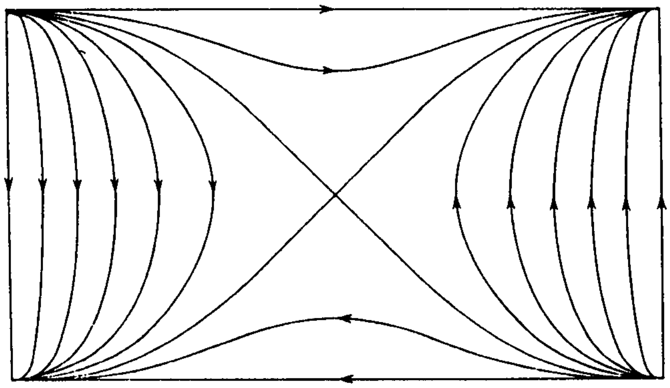


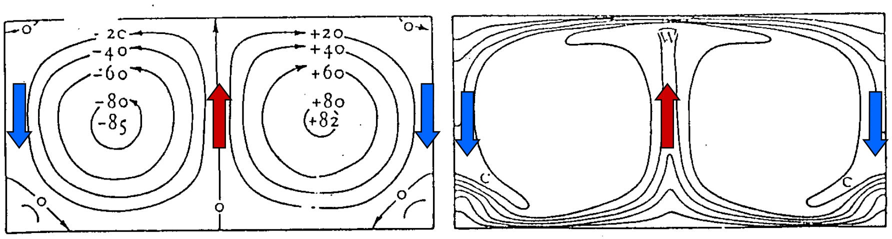



**Contours of constant w in a hexagonal cell**

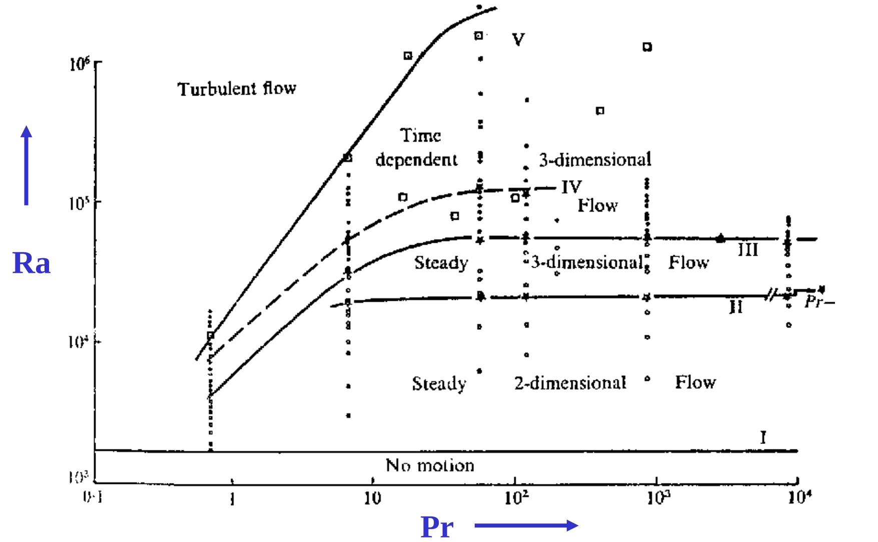


## Streamlines in a horizontal plane for a rectangular cell

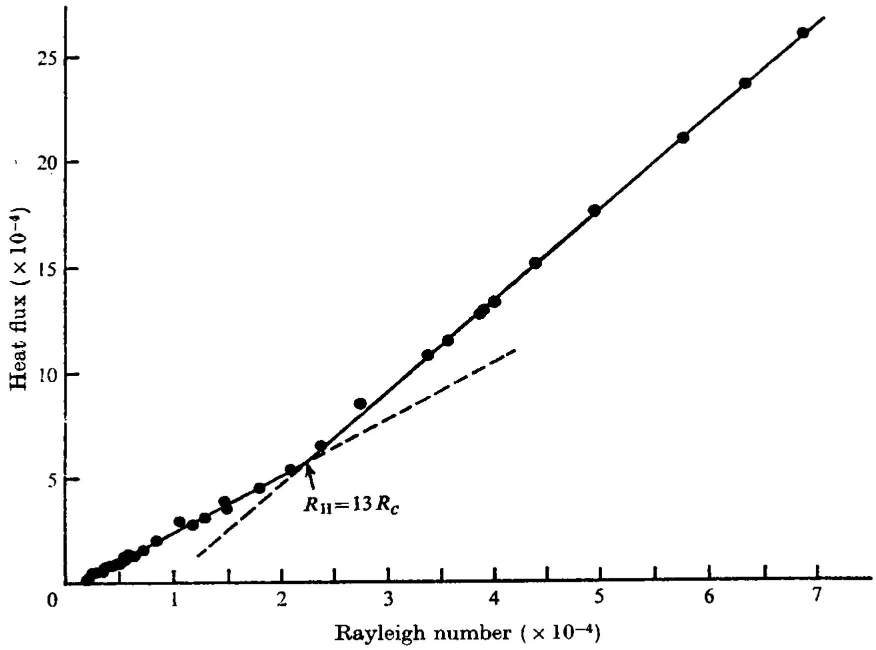




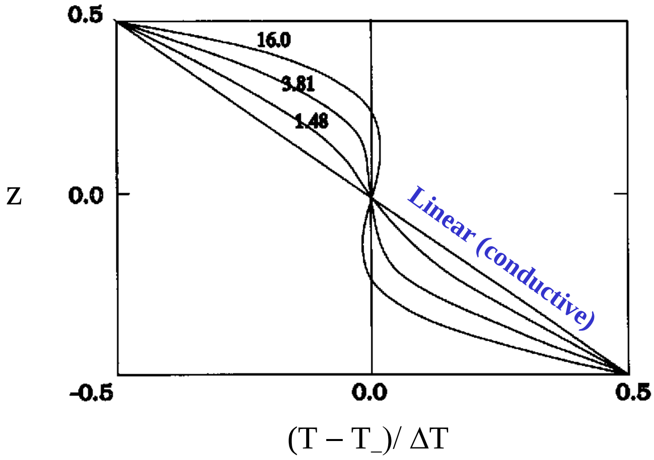
## Regime diagram for experiments on Rayleigh convection




Circles => steady flows, circular dots => time-dependet 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).

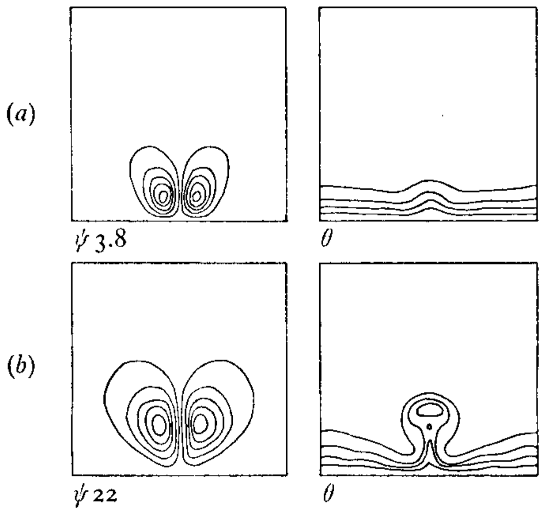


## Temperature profiles as a function of Ra




**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.**

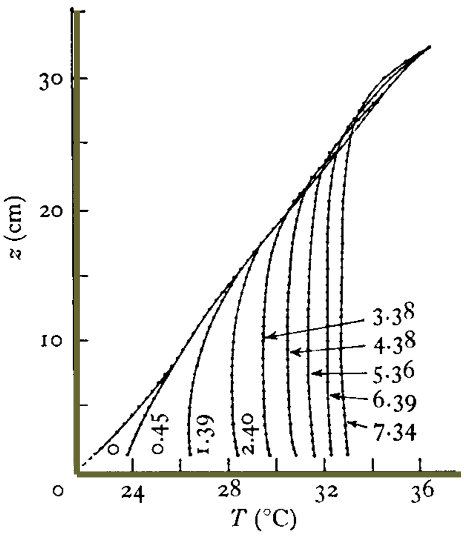
## Penetrative convection



## The formation of plumes or thermals rising from a heated surface

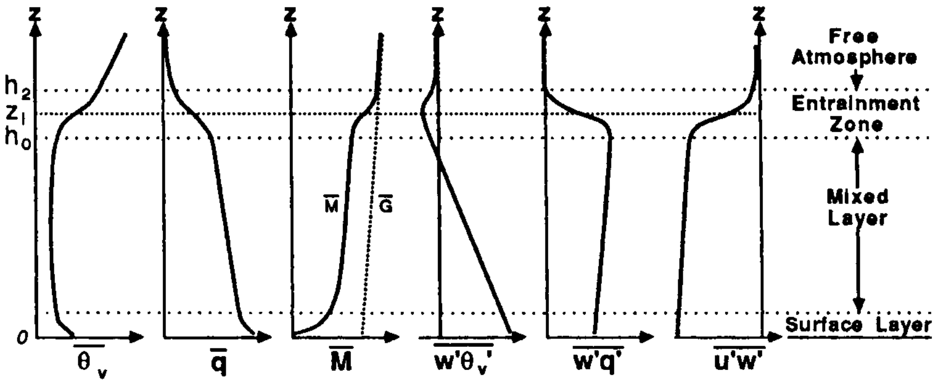
Higher heating rate

**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**

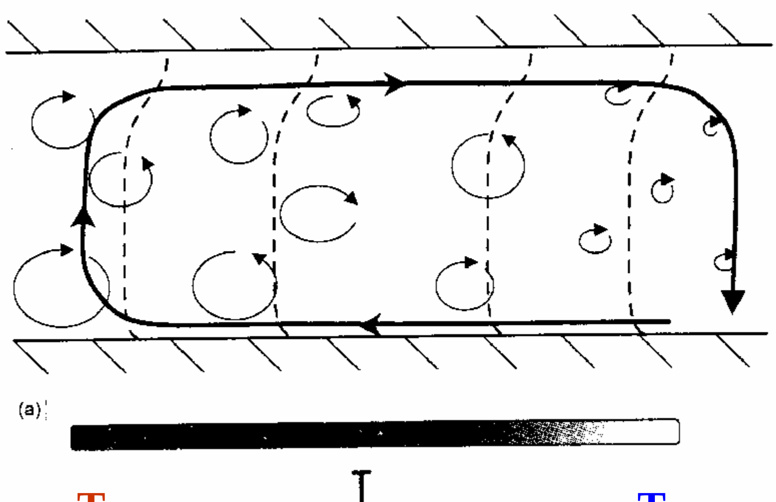



**Vertical profiles of temperature in a laboratory tank, set up initially with a linear stable temperature gradient and heated from below. the profile labels give the time in minutes. (From Deardorff, Willis and Lilly, 1969).**

## Typical profiles of quantities in a convective boundary layer




mean virtual potential temperature | mean specific humidity | mean wind speed | buoyancy flux | specific humidity flux | momentum flux




$T_+$ $T_-$

← boundary temperature gradient

From Emanuel et al., 1994


The End