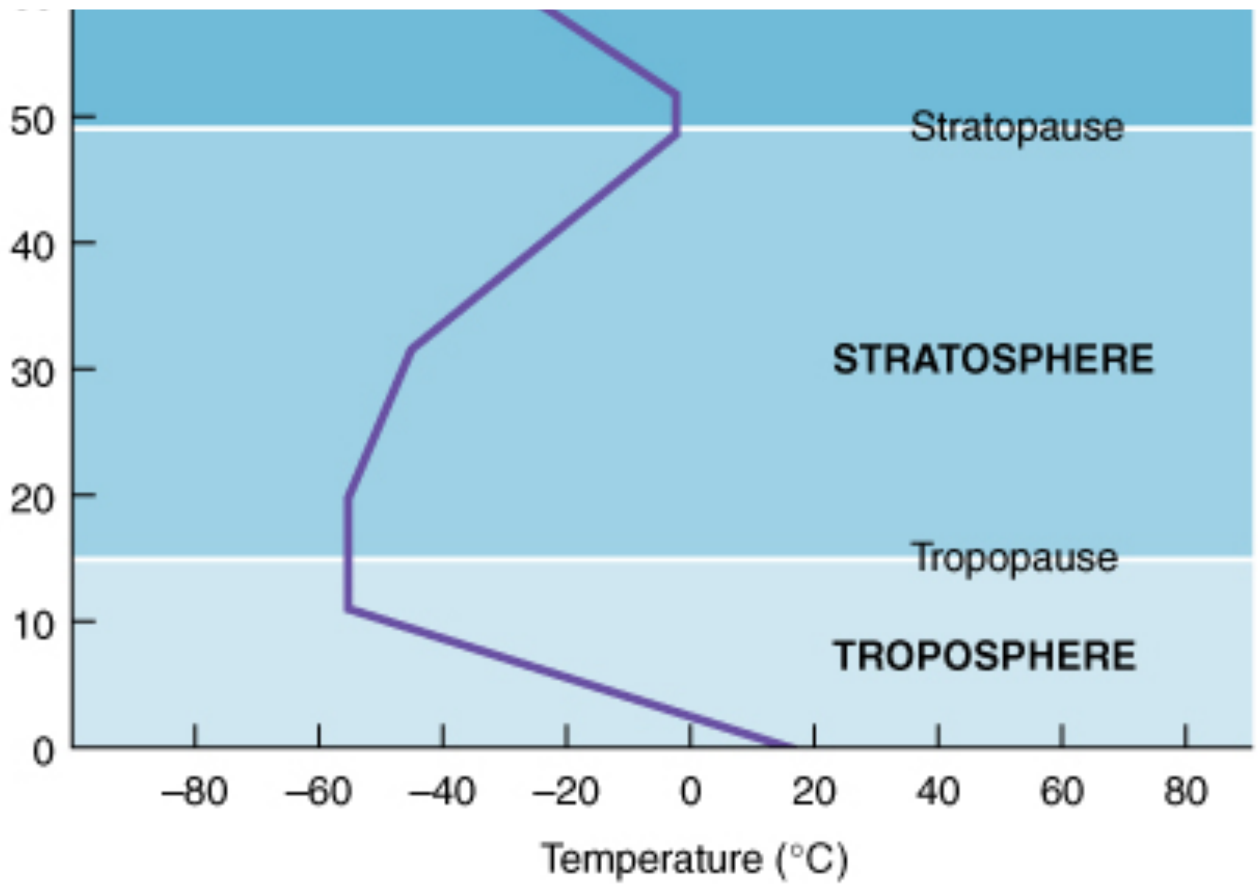
PHY392S
Physics of Climate

Lectures 3 and 4

Supplementary slides

The Vertical Structure of the Atmosphere



Weak vertical motions in the stratosphere

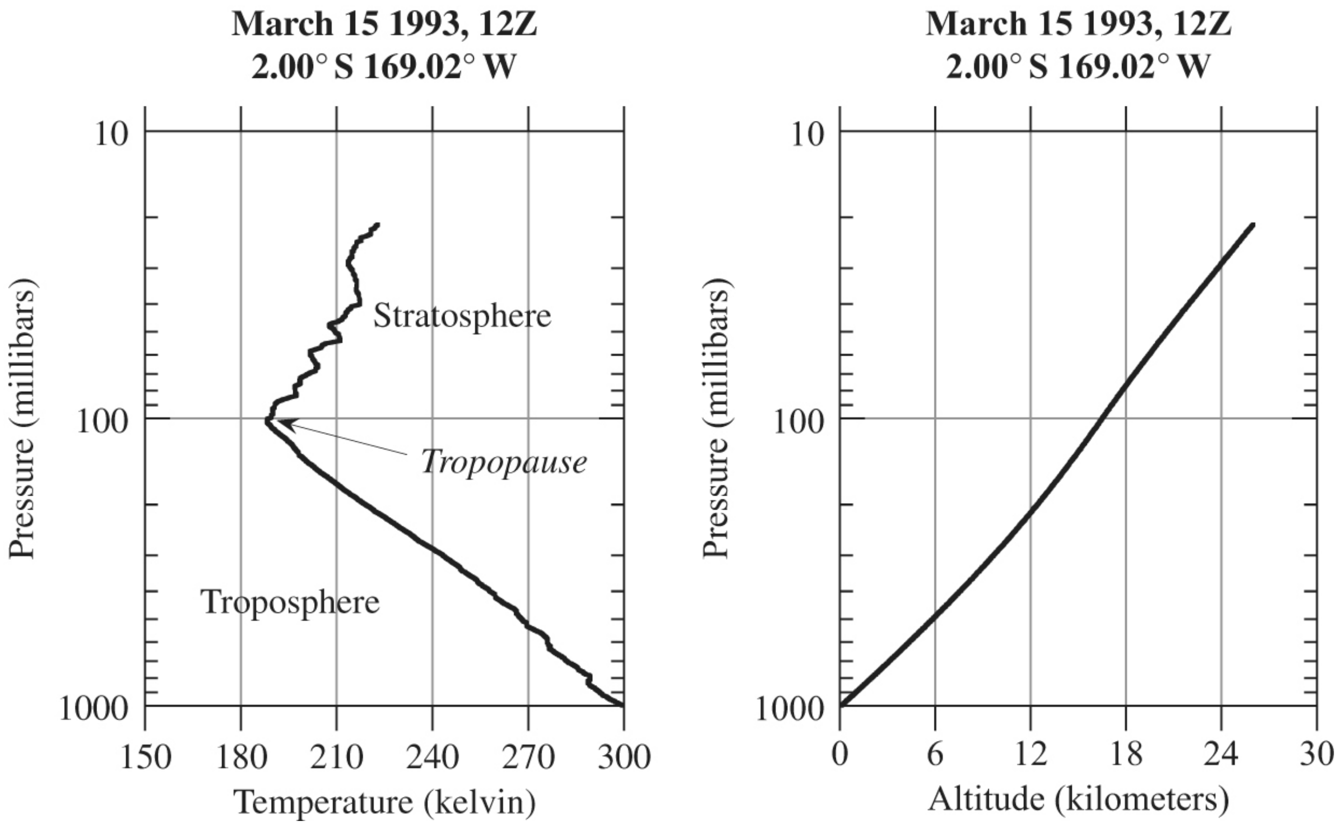
strong overturning motion (convection) in the troposphere

The layers of the atmosphere are defined by the variation of temperature with altitude:

Troposphere: temperature decreases with altitude

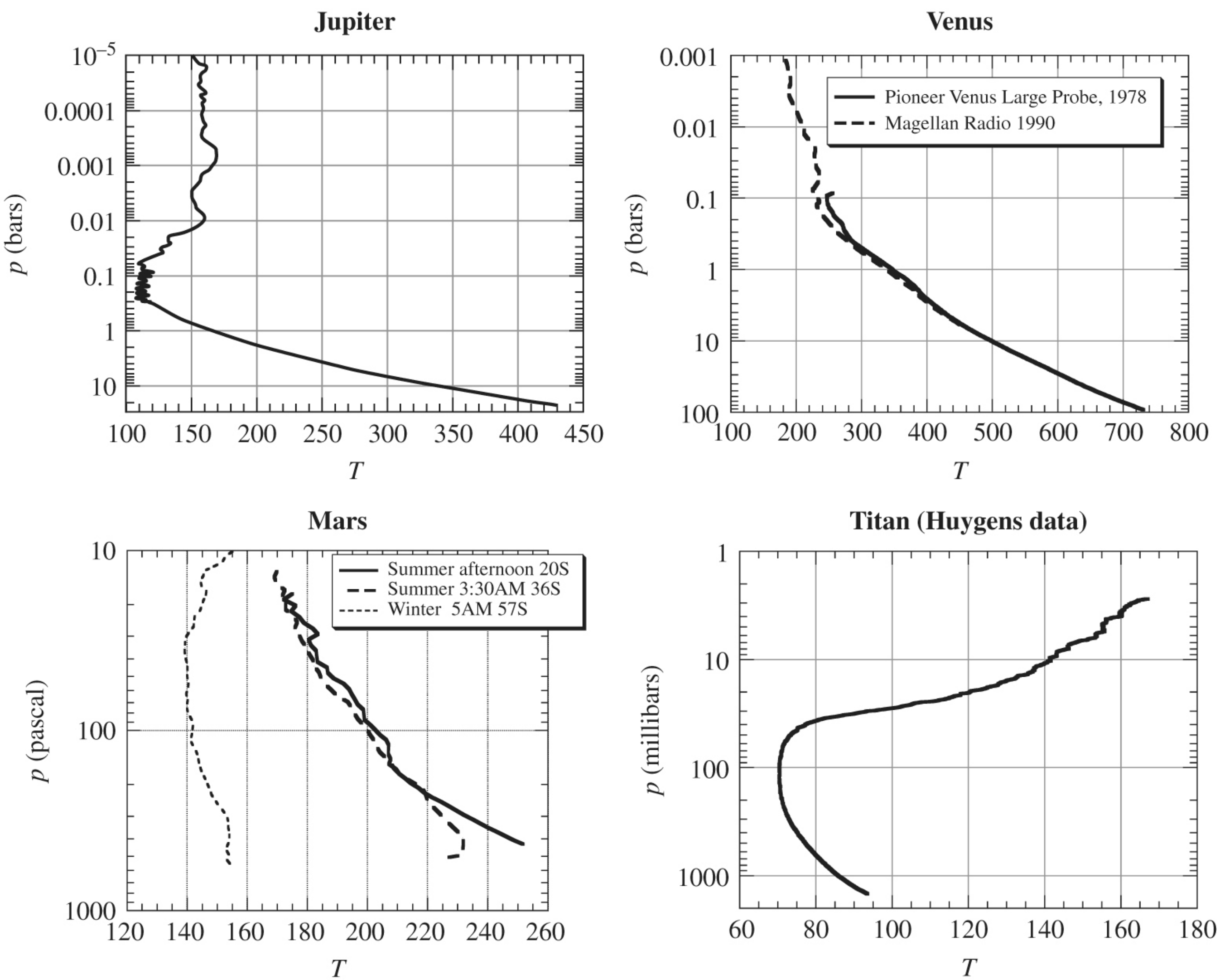
Stratosphere: temperature increases with altitude

Temperature and Pressure Profile



[From Pierrehumbert, 2010]

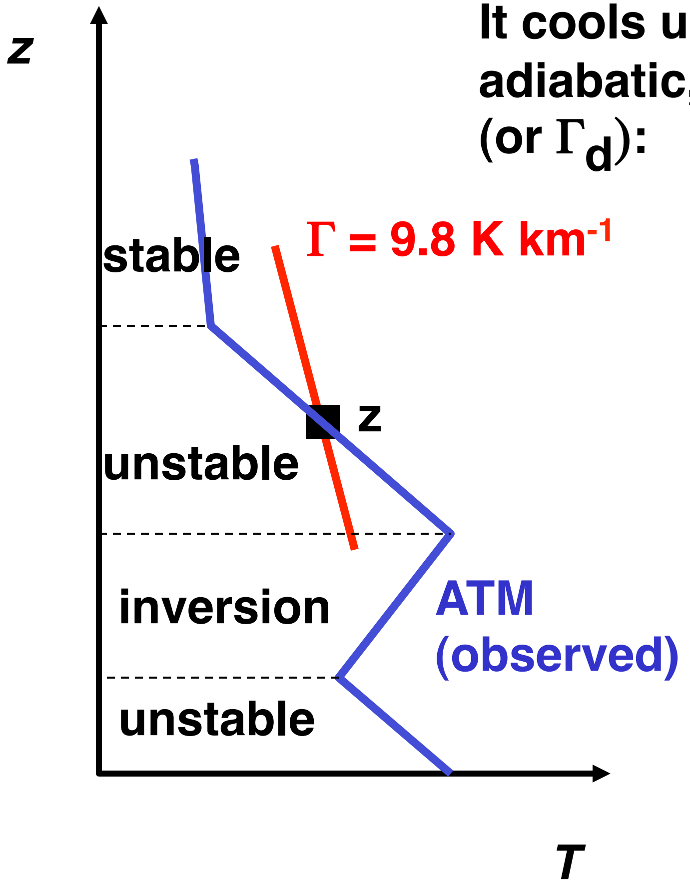
Atmospheric Temperature Profile on Other Planets



[From Pierrehumbert, 2010]

Atmospheric Lapse Rate and Stability

"Lapse rate" = -*dT/dz*



Consider an air parcel at *z* lifted to *z+dz* and released. It cools upon lifting (expansion). Assuming lifting to be adiabatic, the cooling follows the adiabatic lapse rate Γ (or Γ_d):

$$\Gamma = -dT/dz = \frac{g}{C_p} = 9.8 \text{ K km}^{-1}$$

What happens following release depends on the local lapse rate $-dT_{atm}/dz$:

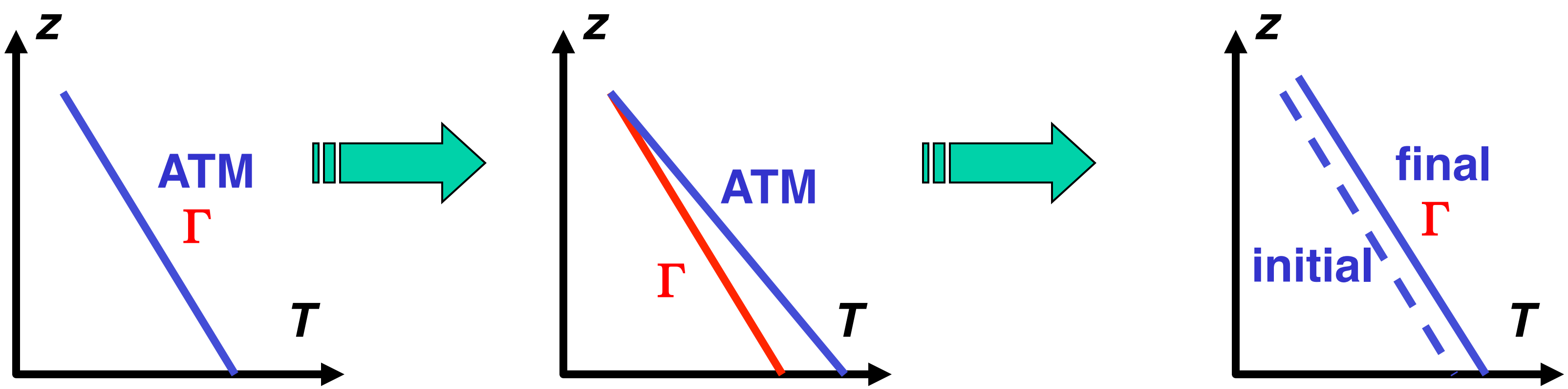
- $-dT_{atm}/dz > \Gamma$ ⇨ upward buoyancy amplifies initial perturbation: atmosphere is *unstable*
- $-dT_{atm}/dz = \Gamma$ ⇨ zero buoyancy does not alter perturbation: atmosphere is *neutral*
- $-dT_{atm}/dz < \Gamma$ ⇨ downward buoyancy relaxes initial perturbation: atmosphere is *stable*
- $dT_{atm}/dz > 0$ ("inversion"): very stable

The stability of the atmosphere against vertical mixing is solely determined by its lapse rate

[courtesy, D. Jacob]

What Determines the Lapse Rate of the Atmosphere?

- An atmosphere left to evolve adiabatically from an initial state would eventually tend to *neutral* conditions ($-dT/dz = \Gamma$) at equilibrium
- Solar heating of surface disrupts that equilibrium and produces an unstable atmosphere:



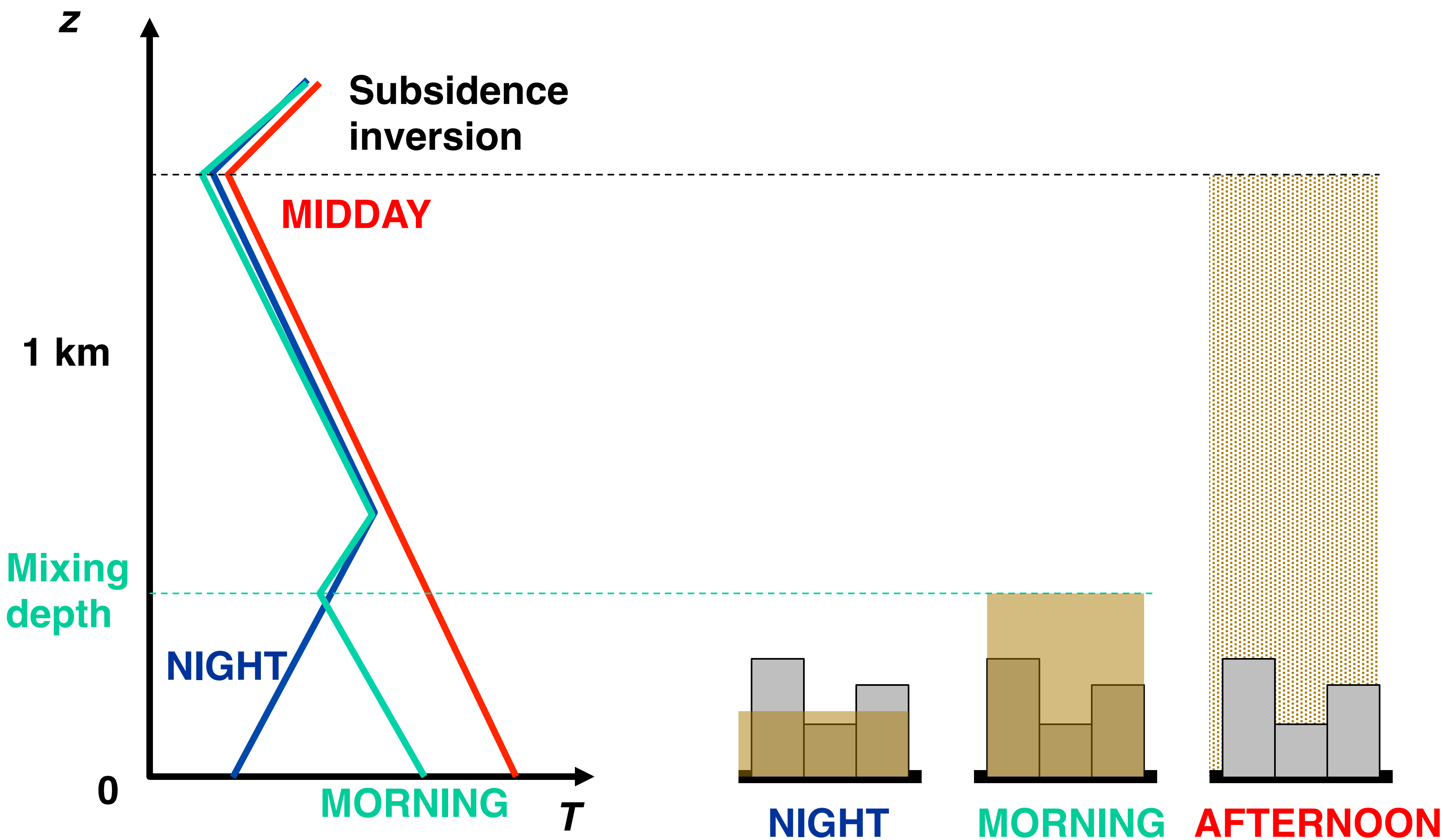
Initial equilibrium state: $-dT/dz = \Gamma$

Solar heating of surface: unstable atmosphere

buoyant motions relax unstable atmosphere to $-dT/dz = \Gamma$

- **Fast vertical mixing in an unstable atmosphere maintains the lapse rate to Γ. <u>Observation</u> of $-dT/dz = \Gamma$ is sure indicator of an unstable atmosphere.**

Diurnal Cycle Of Surface Heating/Cooling



[courtesy, D. Jacob]

Moist Convection

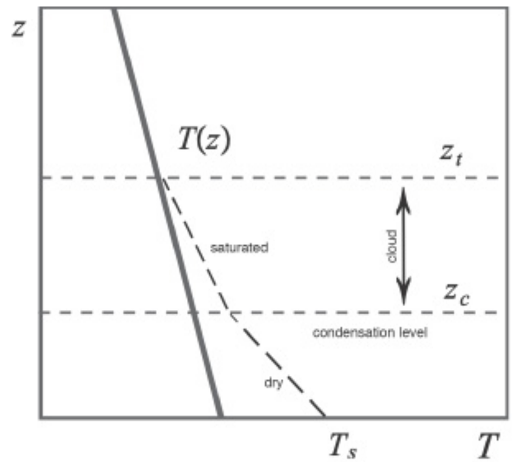


Figure 4.18: The temperature of a moist air parcel lifted in convection from the surface at temperature T_s will follow a dry adiabat until condensation occurs at the condensation level z_c. Above z_c, excess vapor will condense, releasing latent heat and warming the parcel, off setting its cooling at the dry adiabatic rate due to expansion. Thus a moist parcel cools less rapidly (following a moist adiabat) than a dry one, until neutral buoyancy is reached at z_t, the cloud top. This should be compared to the case of dry convection shown in Fig. 4.11.

Impact of Convection on the Temperature Profile

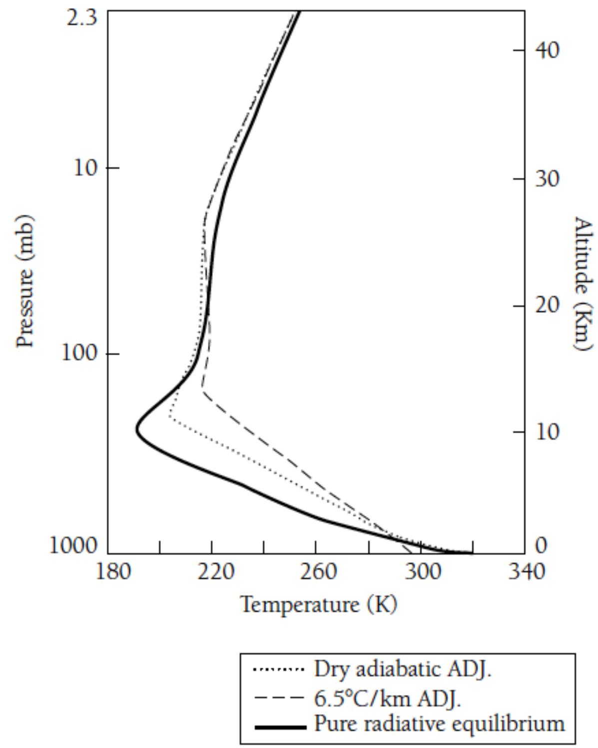


Figure 7.14 Comparison of results from a purely radiative equilibrium model of the atmosphere (solid line) with results from models in which the lapse rate of temperature was constrained not to exceed the dry adiabatic limit (dotted line) or a lapse rate of 6.5°C km^{-1} (dashed line). Source: Manabe and Strickler 1964.

[From McElroy, 2002]