Radiative equilibrium and vertical temperature profile

Recap: Idealized atmosphere that is transparent to shortwave radiation but absorbing of longwave radiation ⇒ Temperature increases downward; surface is the warmest

In this case, the atmosphere is always colder than the concrete surface because the atmosphere is handicapped by its inability to absorb solar radiation; it relies exclusively on the "second-hand" re-emission of IR radiation from Earth's surface to keep itself warm. Since Earth's surface acts as the "heat source" for the atmosphere, the air layers that are closer to the heat source would end up being warmer than the layers that are away from the surface, so temperature decreases with height.

In a cold winter night, when we turn on a furnace the air in the house will warm up, but air temperature will not exceed the temperature at the surface of the furnace. Also, at equilibrium, temperature in the room would decrease away from the furnace. This holds true regardless of the detail of heat transfer processes.

One can possibly reverse the "monotonic decrease of temperature with height" only when the atmosphere also absorbs solar radiation

In reality, we do have **ozone** absorption of UV light at the upper atmosphere which causes a local warming there

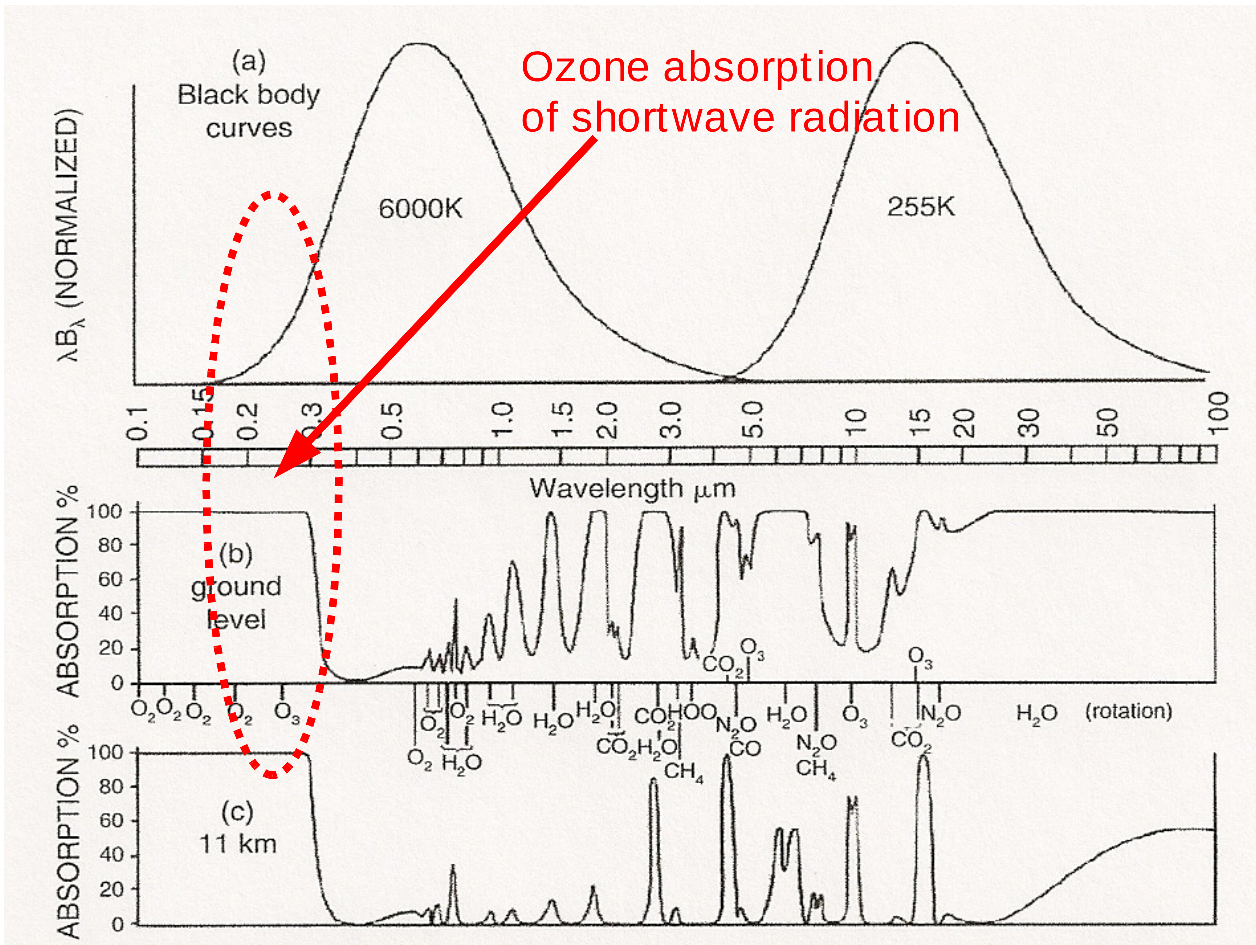
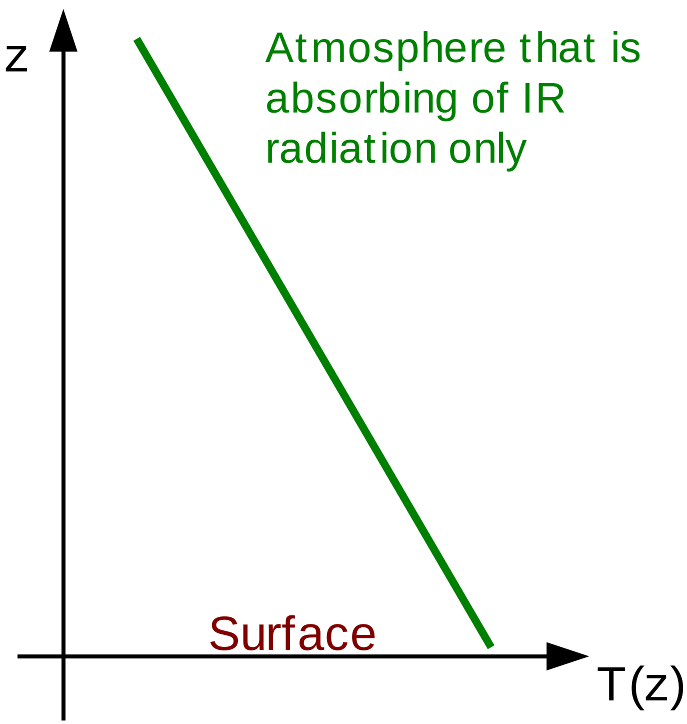


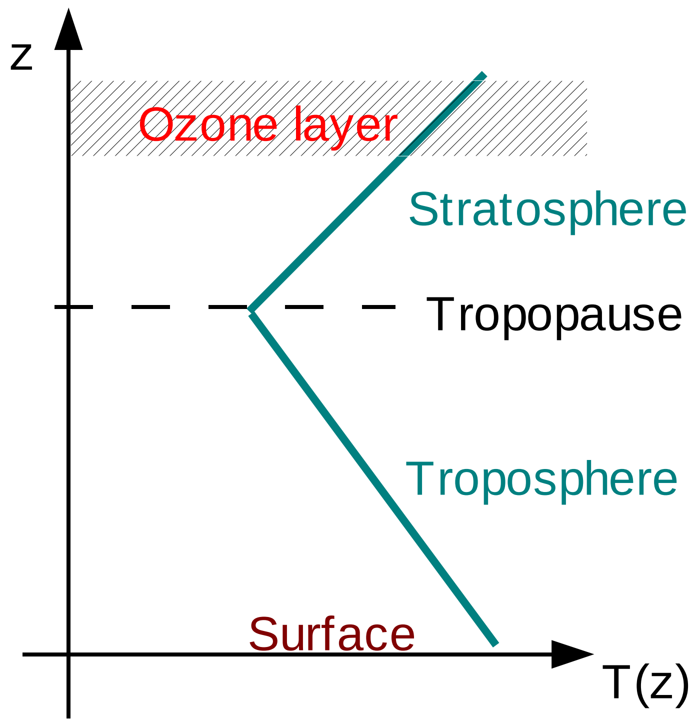
Fig. 2.6 in M&P

Two "heat sources" for the atmosphere: **Ozone layer** in the "stratosphere", and the **surface**. (Of course, the Sun is the ultimate energy source for both.)

⇒ These two places are the two "furnaces" for the atmosphere. Temperature is the highest there.

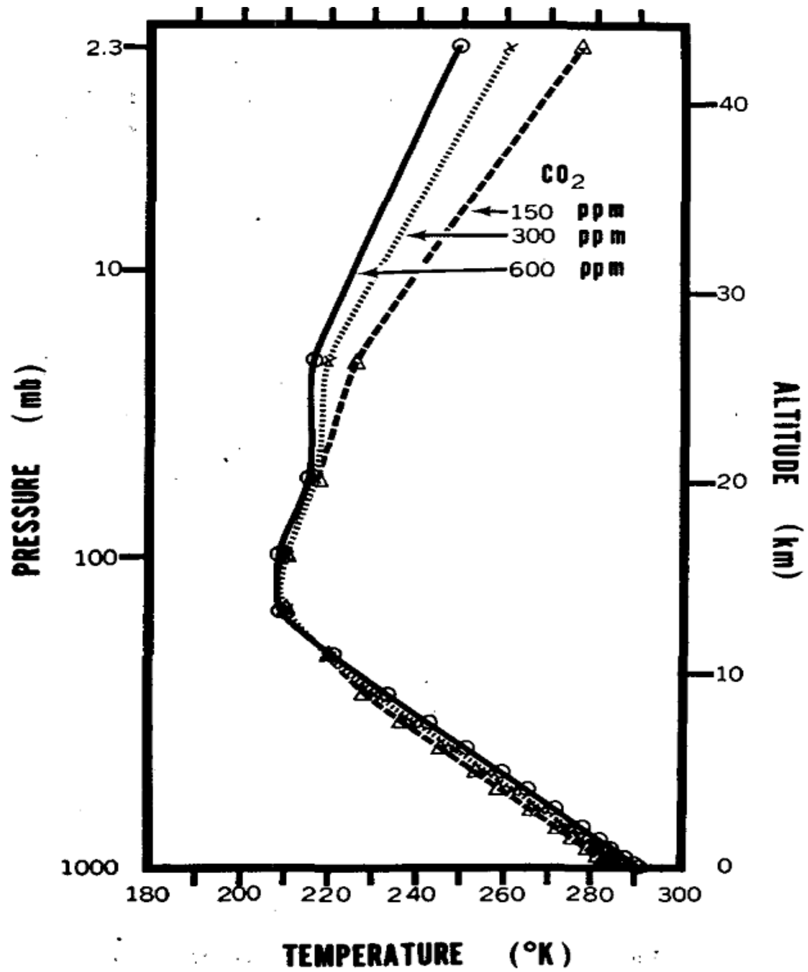
The coldest place, the "**tropopause**", is somewhere midway between the two "furnaces" and farthest away from the influences of both.



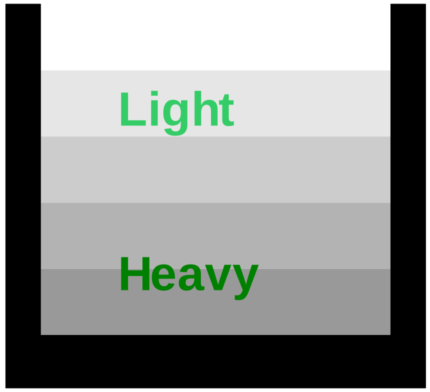


Recall from previous slide set ...

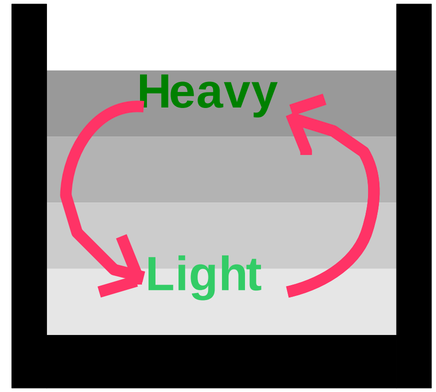
A "radiative-convective equilibrium" calculation, Manabe and Wetherald (1967)



Stable vs. unstable stratification (will be revisited)



Stable
(density decreases
with height)



Unstable
(Density increases
with height)

Density is fundamental here.

For the atmosphere (close to an ideal gas), density depends strongly on both temperature and pressure, $\rho = p/RT$; "Warmer" does not necessarily imply "lighter".

Pressure (*p*) generally decreases with height (we will quantify it in Ch. 3)

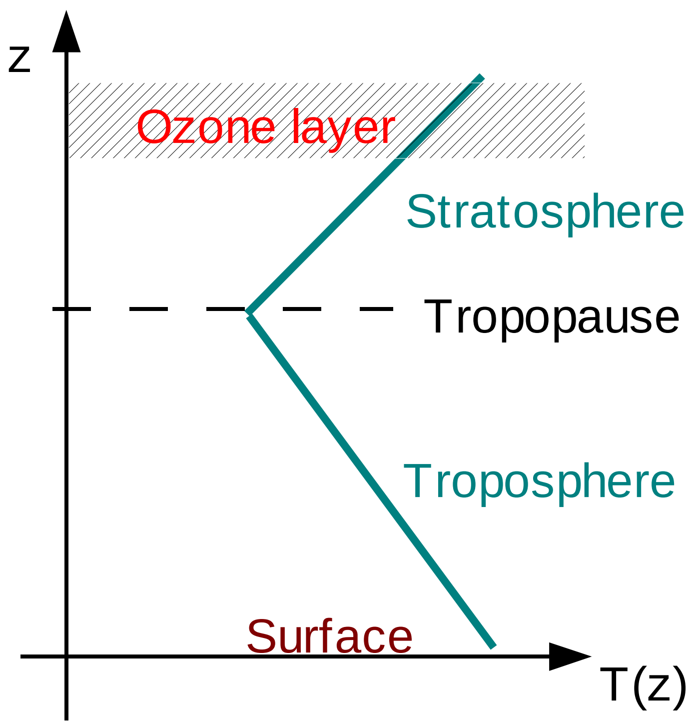
Stratosphere: *T* increases with height while *p* decreases with height

$\Rightarrow$ Density always decreases with height $\Rightarrow$ **Stable***

The stable stratification in stratosphere suppresses overturning convection;

Stratosphere puts a "cap" on the convection from troposphere

(Tropopause = the uppermost reach of thermal convection from below)



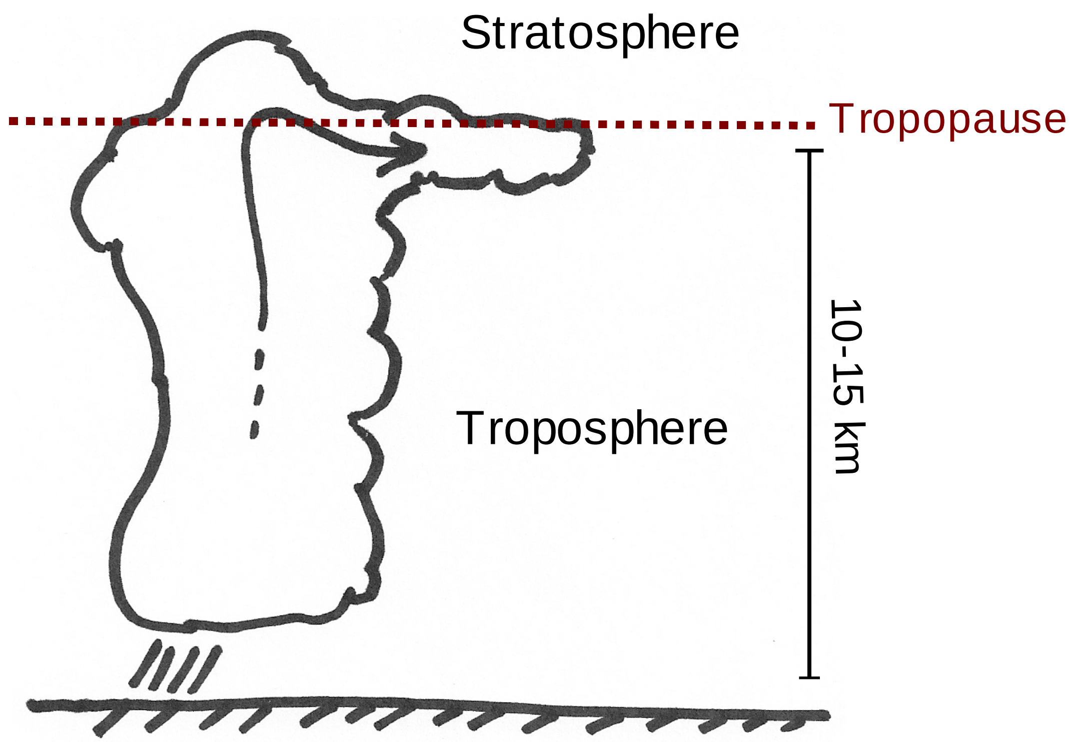
* The statement made here would require some modification when we consider the decrease of density of an "air parcel" as it is adiabatically lifted to a higher altitude (lower pressure). This effect is absent for a system of liquid fluid because in that case the dependence of density on pressure is weak. A more useful variable to consider for the atmosphere is "**potential temperature**", to be discussed later.

Troposphere: In radiative equilibrium (without taking into account adjustment by atmospheric convection), ***T* decreases with height but *p* also decreases with height**. Density could decrease or increase with height depending on the detailed temperature profile. A very sharp decrease of temperature with height may lead to an increase of density with height. Detailed radiative transfer calculations indicate that this could indeed happen; The radiative equilibrium temperature profile could be **unstable*** in the troposphere

$\Rightarrow$ **Convection happens to restore the vertical profile to stability or neutrality**

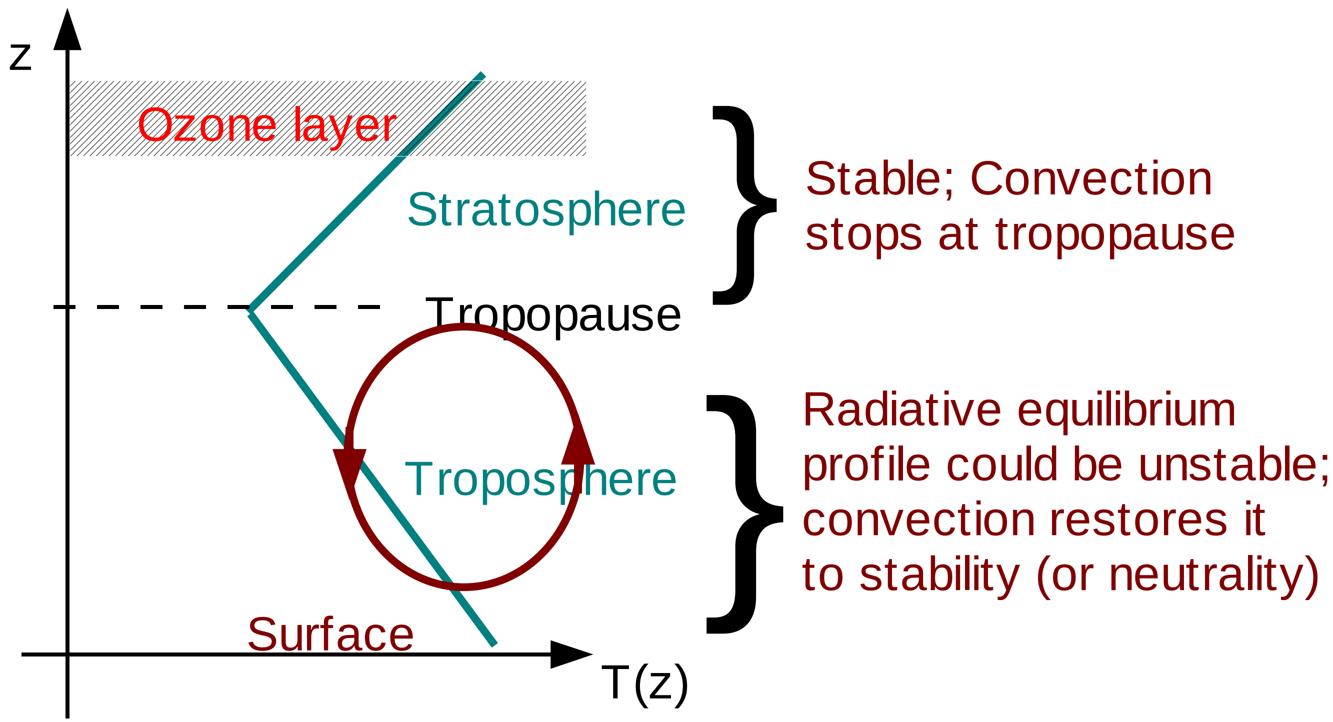
Since stratosphere is stable, convective cells coming from below will stop at tropopause (altitude ~ 15 km in the tropics, 10 km in polar regions)

* See footnote in preceding slide



Stratosphere
Tropopause
Troposphere
10-15 km

Summary



In stratosphere, the radiative equilibrium temperature profile is closer to the actual profile (cf. Fig. 3.4 in M&P)

Above the stratosphere, there is yet another temperature maximum (at the "thermosphere", ~ 100 km altitude) which is created by the absorption of solar radiation by oxygen. Since air density at that altitude is extremely small, what's happening up there is inconsequential to the major geophysical flows in the lower atmosphere. We will not dwell on this minor feature. (But see Fig. 3.1 in M&P)