Atmospheric Temperature and Pressure

SEA2004F

Week 4 Lecture 2

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What will you learn today?

- Explain the vertical profile of pressure in the atmosphere
- Explain how the sea-breeze circulation is an illustration of the barometric law

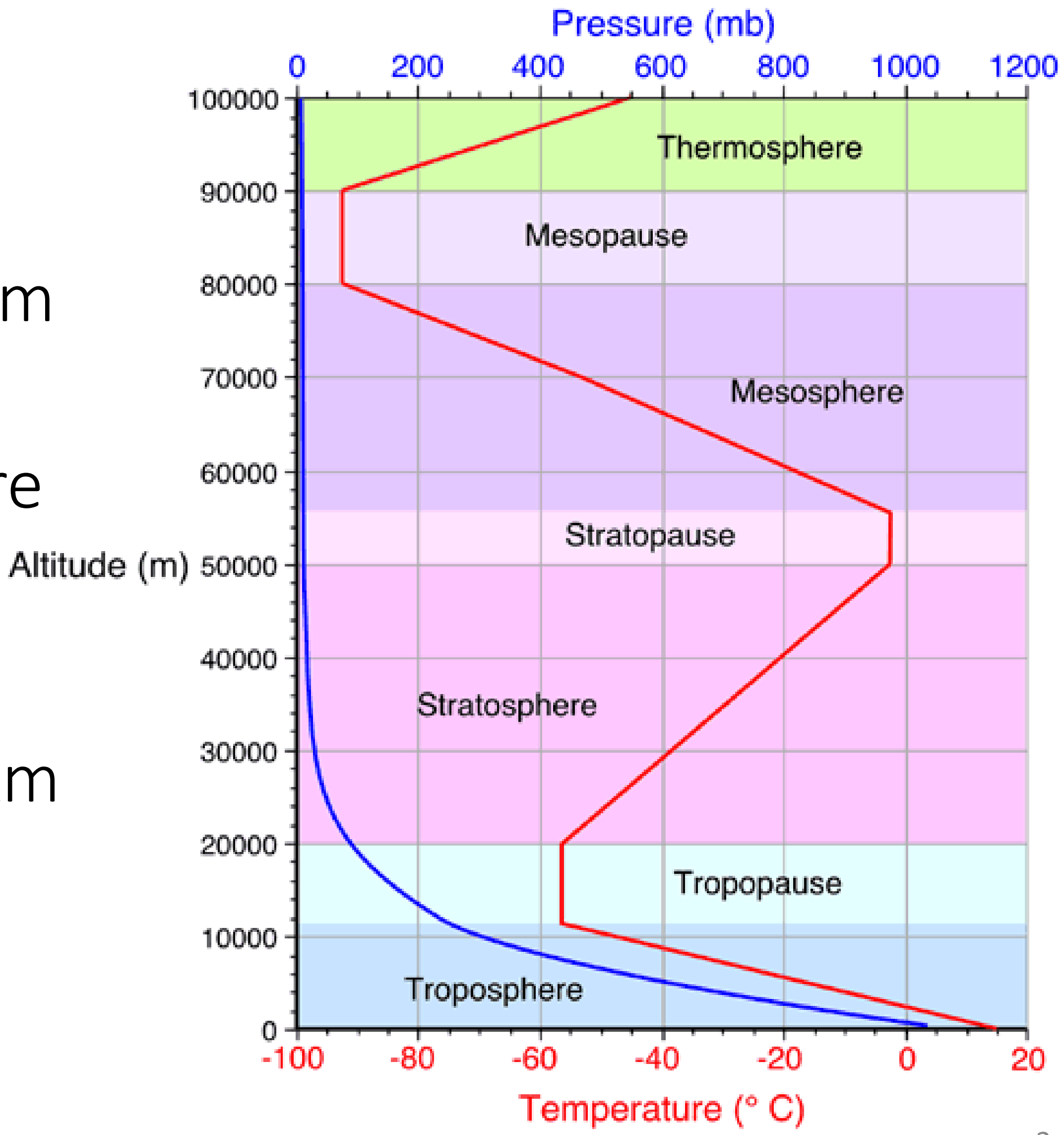
Recap: Layers of the atmosphere

<u>Troposphere</u>

- Lowest layer of the atmosphere
- Height of tropopause typically 10 – 15 km depending on latitude and time of year
- Characterized by decreasing temperature with height
- Rapid vertical mixing

Planetary boundary layer → surface to 1km

Free troposphere → 1 km to tropopause

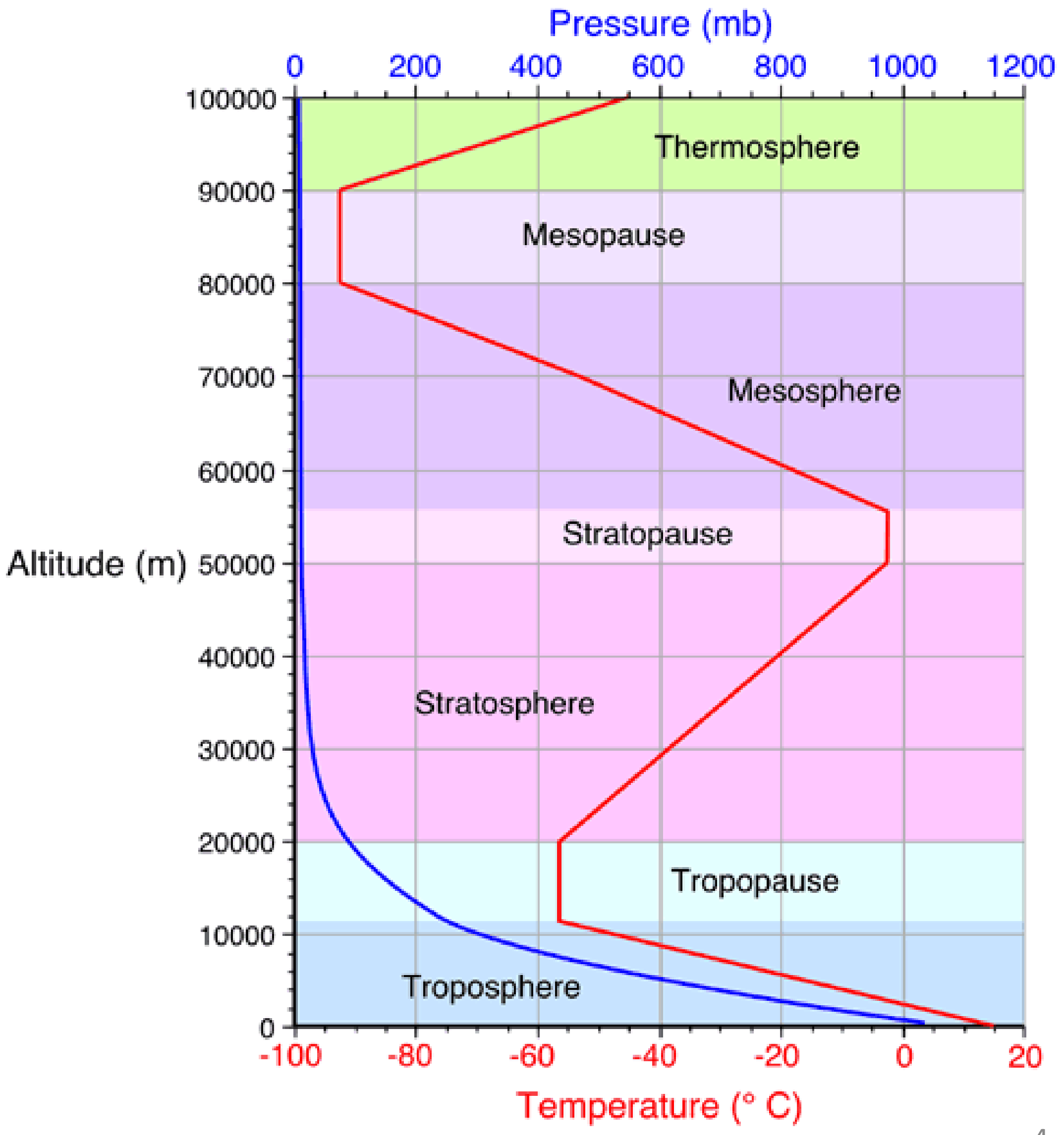


Recap: Layers of the atmosphere

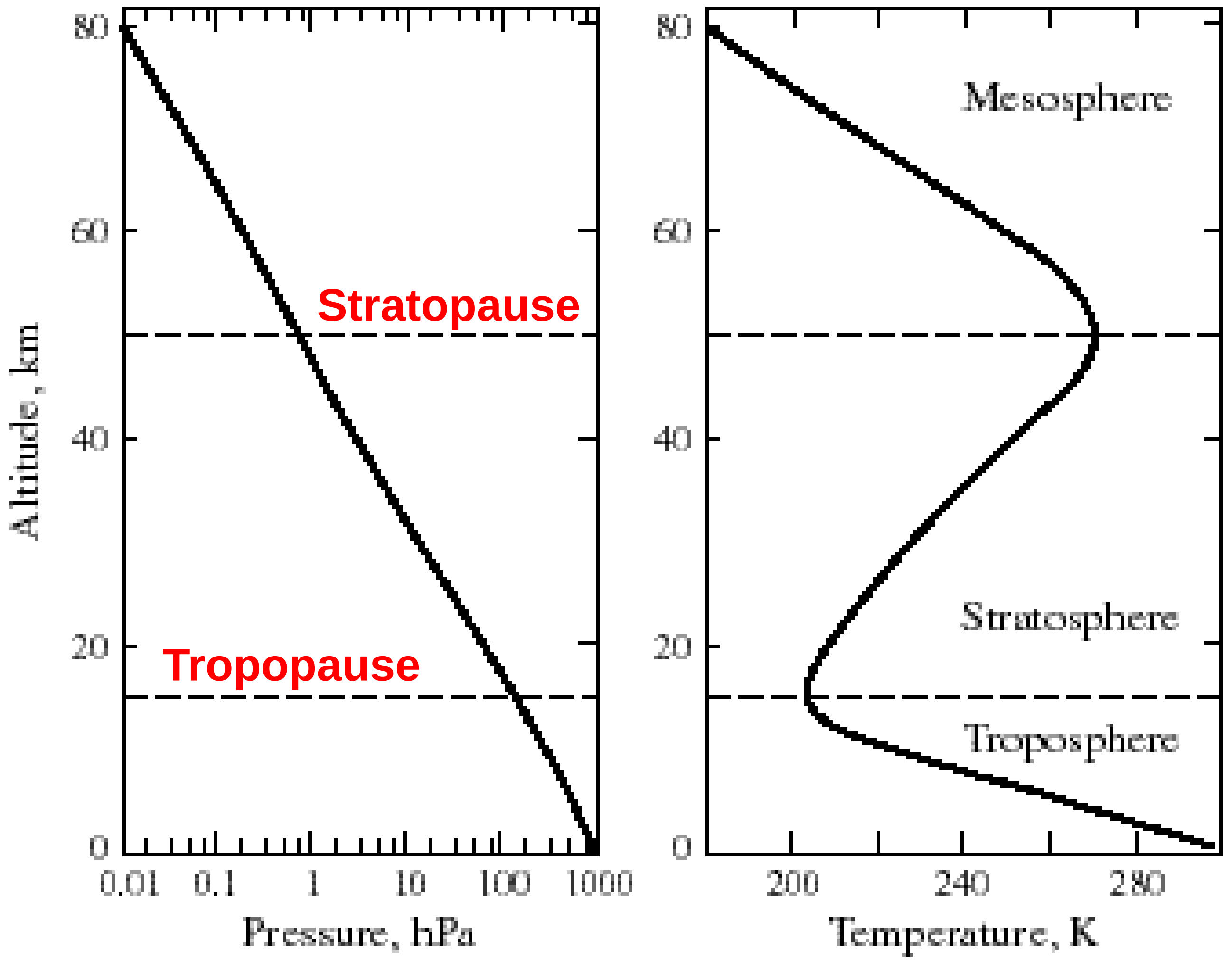
<u>Stratosphere</u>

- From tropopause to stratopause
- Stratopause is at 45 to 55 km
- Temperature increases with altitude
- Slow vertical mixing
- 90% of atmospheric ozone is in the stratosphere

Stratospheric ozone = Good
Tropospheric ozone = Bad



Recap: Vertical profiles of pressure and temperature



Units and Conversions

SI unit of pressure → *pascal* (Pa)

Other units = *atmosphere* (atm), *bar* (b), *millibar* (mb), *hectopascals* (hPa)

$1 \text{ Pa} = 1 \text{ N m}^{-2} = 1 \text{ kg m}^{-1} \text{ s}^{-2}$

$1 \text{ atm} = 1.01325 \times 10^5 \text{ Pa}$

$1 \text{ b} = 10^5 \text{ Pa}$

$1 \text{ mb} = 100 \text{ Pa} = 1 \text{ hPa}$

$1 \text{ torr} = 1 \text{ mm Hg} = 134 \text{ Pa}$

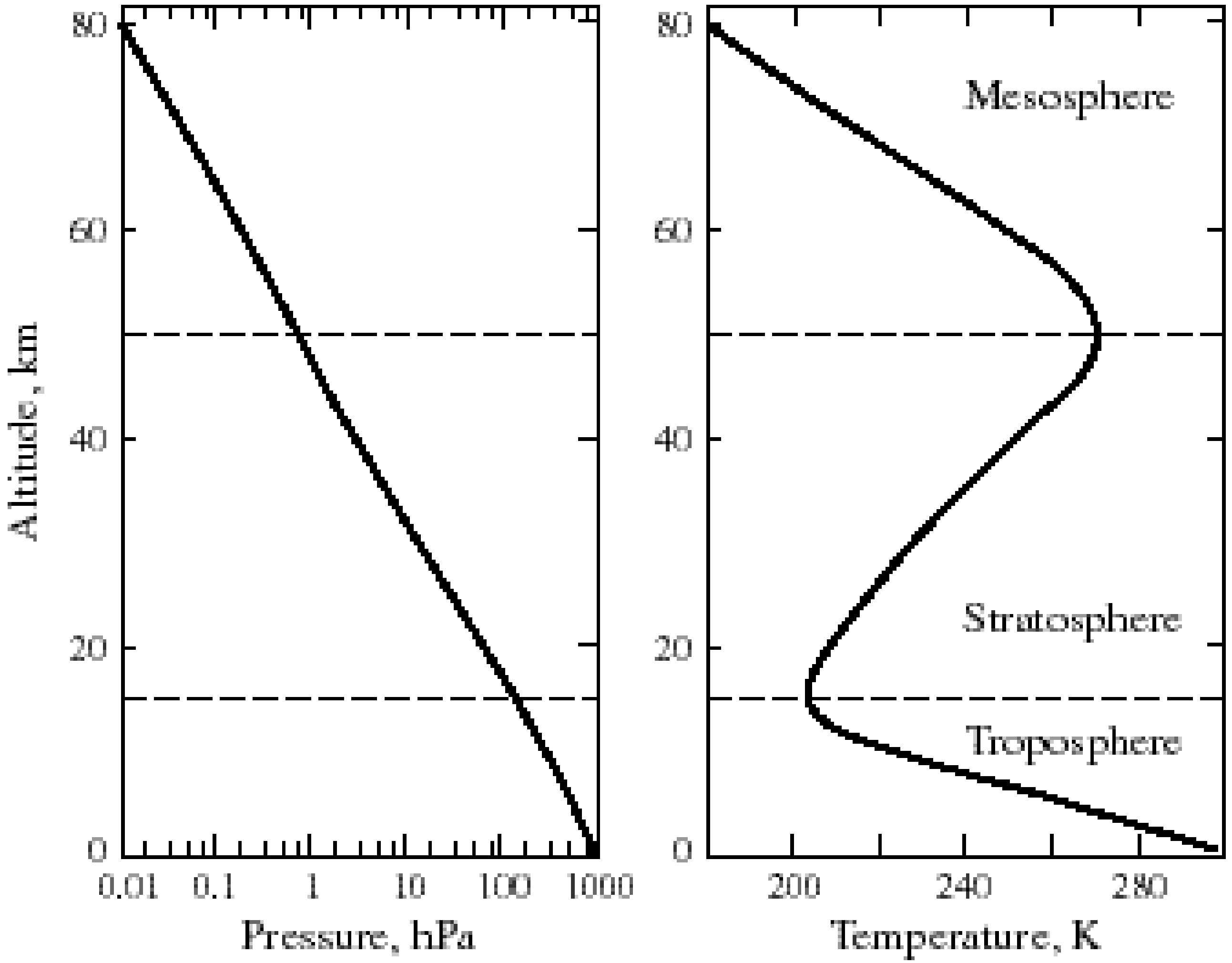
Mean atmospheric pressure at sea level is
$1.01325 \times 10^5 \text{ Pa} = 1013.25 \text{ hPa} = 1013.25 \text{ mb} = 1 \text{ atm} = 760 \text{ torr}$

Part I: Atmospheric Pressure

Temperature and Pressure

- Temperature varies by less than a factor of 2
- Pressure changes by six orders of magnitude

For some pressure related calculations, we can assume T is constant



Atmospheric Pressure

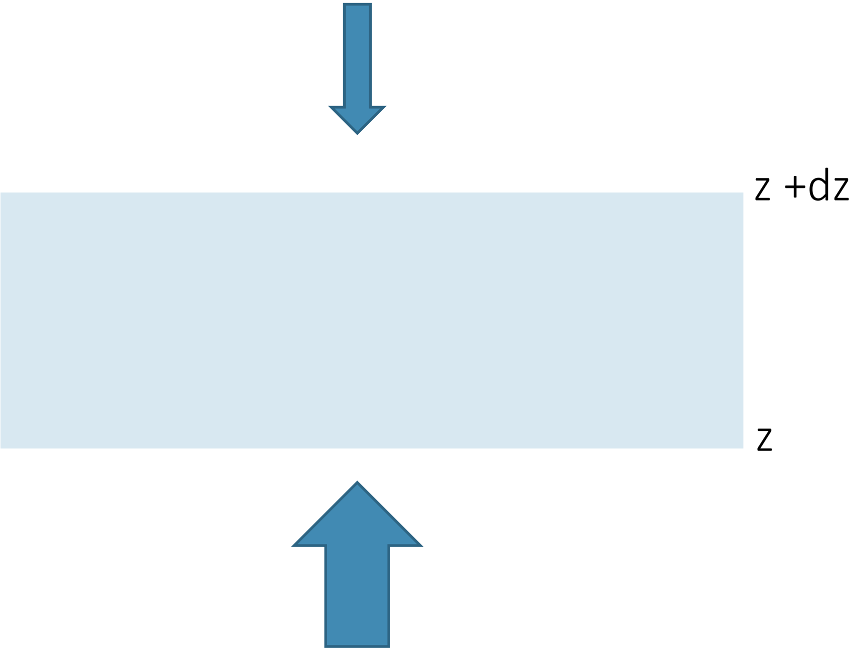
P at any height in the atmosphere is due to the force per unit area exerted by the weight of all of the air lying above that height

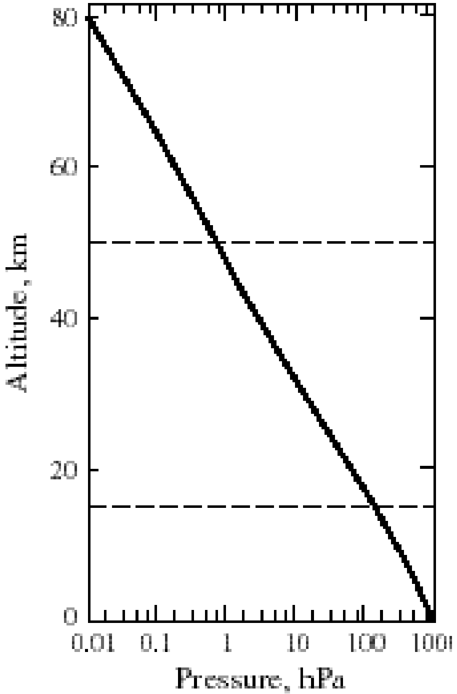
Therefore, atmospheric pressure decreases with increasing height above the ground

Pressure-gradient force

Downward pressure force on the top of the slab

Slab of atmosphere at altitude z





Upward pressure force on the bottom of the slab

+ = pressure-gradient force – which is directed upward

P-G force → Barometric law

If the net upward force on the slab is equal to the net downward force on the slab, the atmosphere is in hydrostatic balance

- What would that mean?

P-G force → Barometric law

If the net upward force on the slab is equal to the net downward force on the slab, the atmosphere is in hydrostatic balance

Mass of air in slab = ρdz where ρ is the density of the air at height z

Downward force acting on the slab = $g\rho dz$ where g is the acceleration due to gravity at height z

Change in pressure from height z to height z + dz must be negative, $-dp$

z +dz

Slab of atmosphere at altitude z

Mass = ρdz

z

P-G force → Barometric law

If the net upward force on the slab is equal to the net downward force on the slab, the atmosphere is in hydrostatic balance

Mass of air in slab = ρdz where ρ is the density of the air at height z

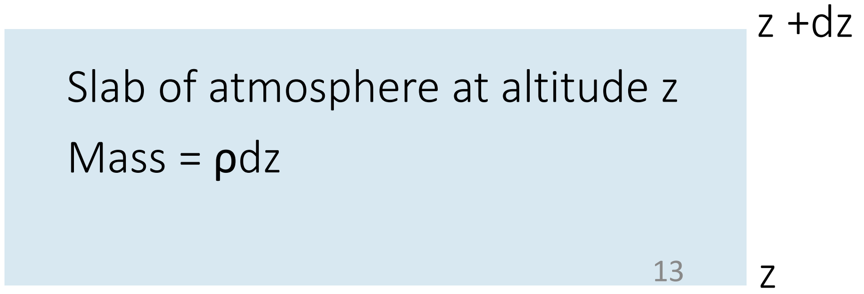
Downward force acting on the slab = gρdz where g is the acceleration due to gravity at height z

Change in pressure from height z to height z + dz must be negative, –dp

If hydrostatic balance is reached, then:

$-dp = g\rho dz$ rearrange to →

$\frac{dp}{dz} = -g\rho$ = The Hydrostatic Equation



Barometric Law

The hydrostatic equation and the ideal gas law are used to derive the Barometric Law:

$$P(z) = P(0)e^{-z/H}$$

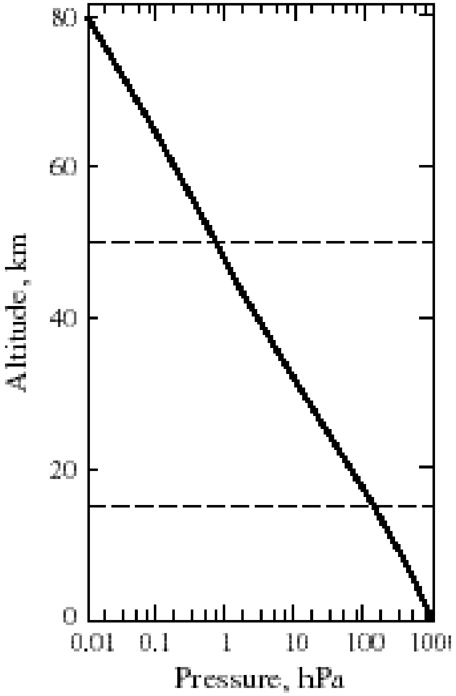
Where H = scale height

$$H = \frac{RT}{M_a g}$$

R and T come from ideal gas law PV=nRT

g is still the acceleration of gravity

M_a is the average molecular weight of air



Barometric Law explains the observed exponential dependence of P on z

Scale Height of Atmospheres

Scale Height (H) is the vertical distance over which the density and pressure fall by a factor of 1/e. These values fall by an additional factor of 1/e for each additional Scale Height. Thus, it describes the degree to which the atmosphere "hugs" the planet.

We can think of the atmosphere as having constant density (at the ground level value) out to an elevation of H – a slab of constant density.

Elevation	Density
0	ρ_0
H	$(1/e)\ \rho_0=0.368\rho_0$
2H	$(1/e^2)\ \rho_0=0.135\rho_0$
3H	$(1/e^3)\ \rho_0=0.050\rho_0$

e = 2.718
It's the base of the natural logarithm

Scale Height

At mean atmospheric temperature of 250 K, what is scale height?

$$H = \frac{RT}{M_a g}$$

H= 7.4 km

This means:

For every H rise in altitude, the pressure and density of air drop by a factor of e

or

For every 7.4 km rise in altitude, the pressure and density of air drop by a factor of 2.7

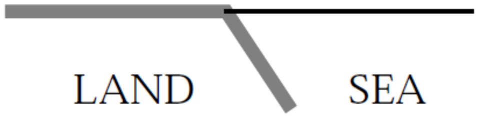
Part II: The Sea Breeze Circulation

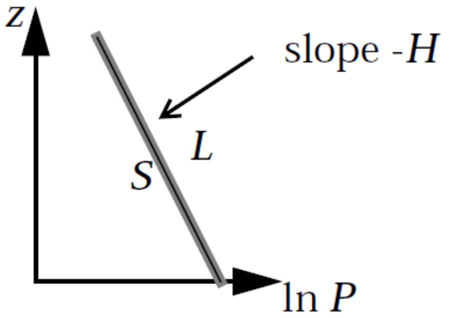
Sea-Breeze Circulation

Initial conditions:

Equal temperatures and equal pressures over land and sea, no wind

$T_L=T_S$ and $P_L=P_S$ and the total air columns over each region remain the same so at the surface $P_{(0)L}=P_{(0)S}$





It's a hot summer day – the land is warmed more than the sea

- The sea has a larger heat capacity than the land

$T_L > T_S$

Remember – Scale Height (H) is temperature dependent!

Sea-Breeze Circulation

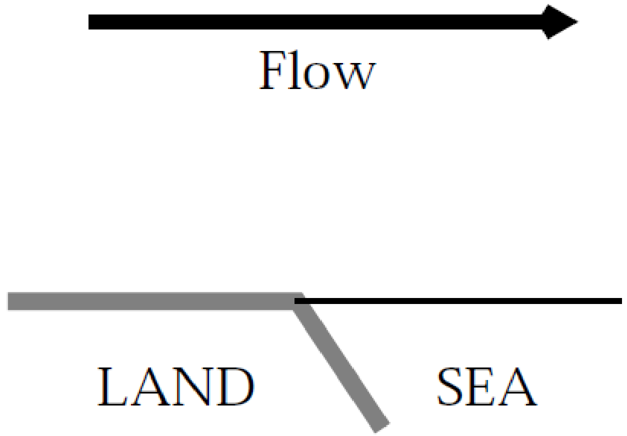
$$H = \frac{RT}{M_a g}$$

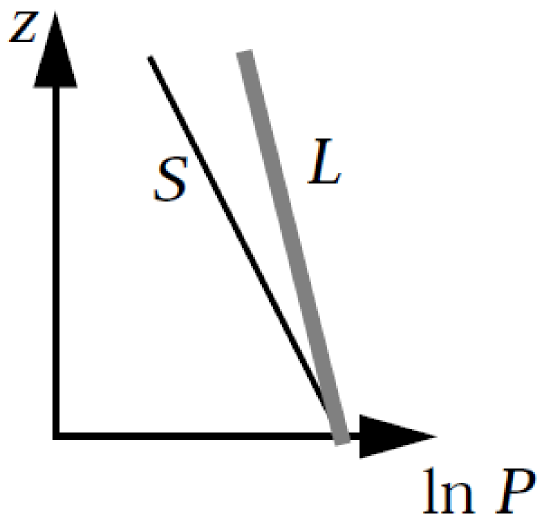
Direct, linear, and positive relationship between T and H

If $T_L > T_S$, then $H_L > H_S$

$$P(z) = P(0)e^{-z/H}$$

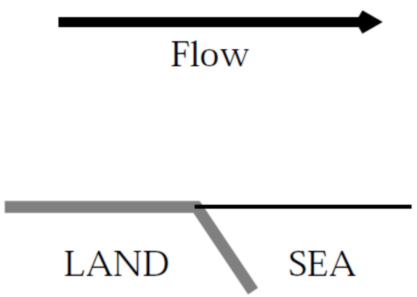
If $H_L > H_S$, then $P_{(z)L} > P_{(z)S}$ when z=z





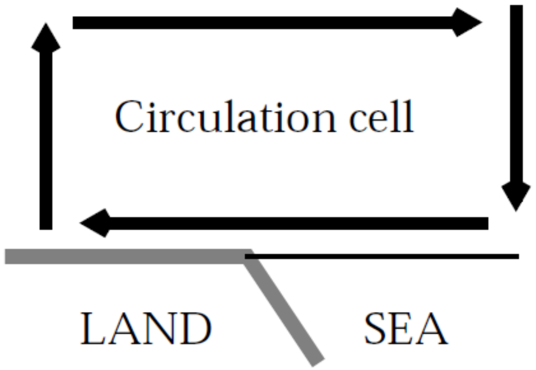
Sea-Breeze Circulation

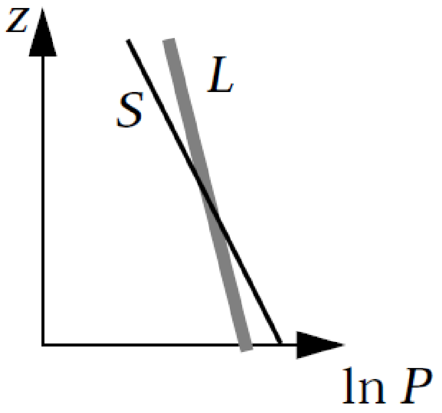
Above the surface, the pressure difference causes the air to flow from land to sea.



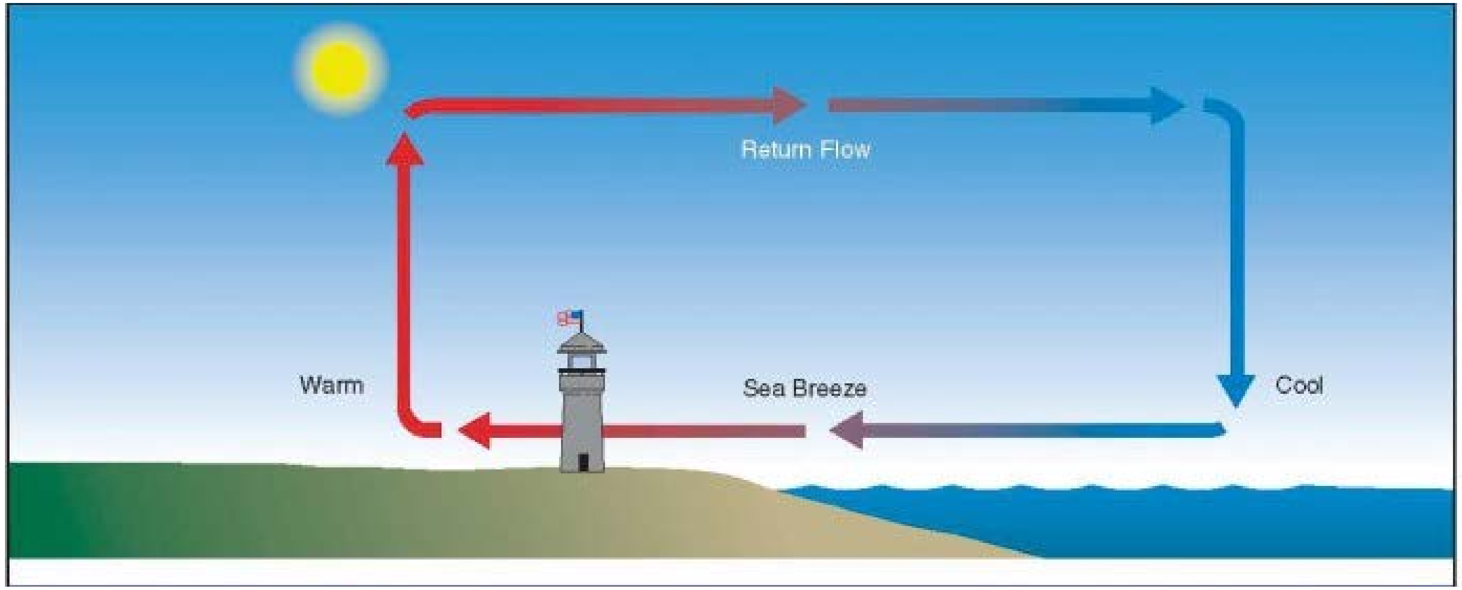
This decreases the mass of the air column over land such that $P_{(0)L} < P_{(0)S}$

At the surface, the flow is thus from sea to land.





Sea-Breeze Circulation



This cell typically extends ~10 km horizontally across the coastline and ~1 km vertically

What happens at night?

Sea-Breeze Circulation

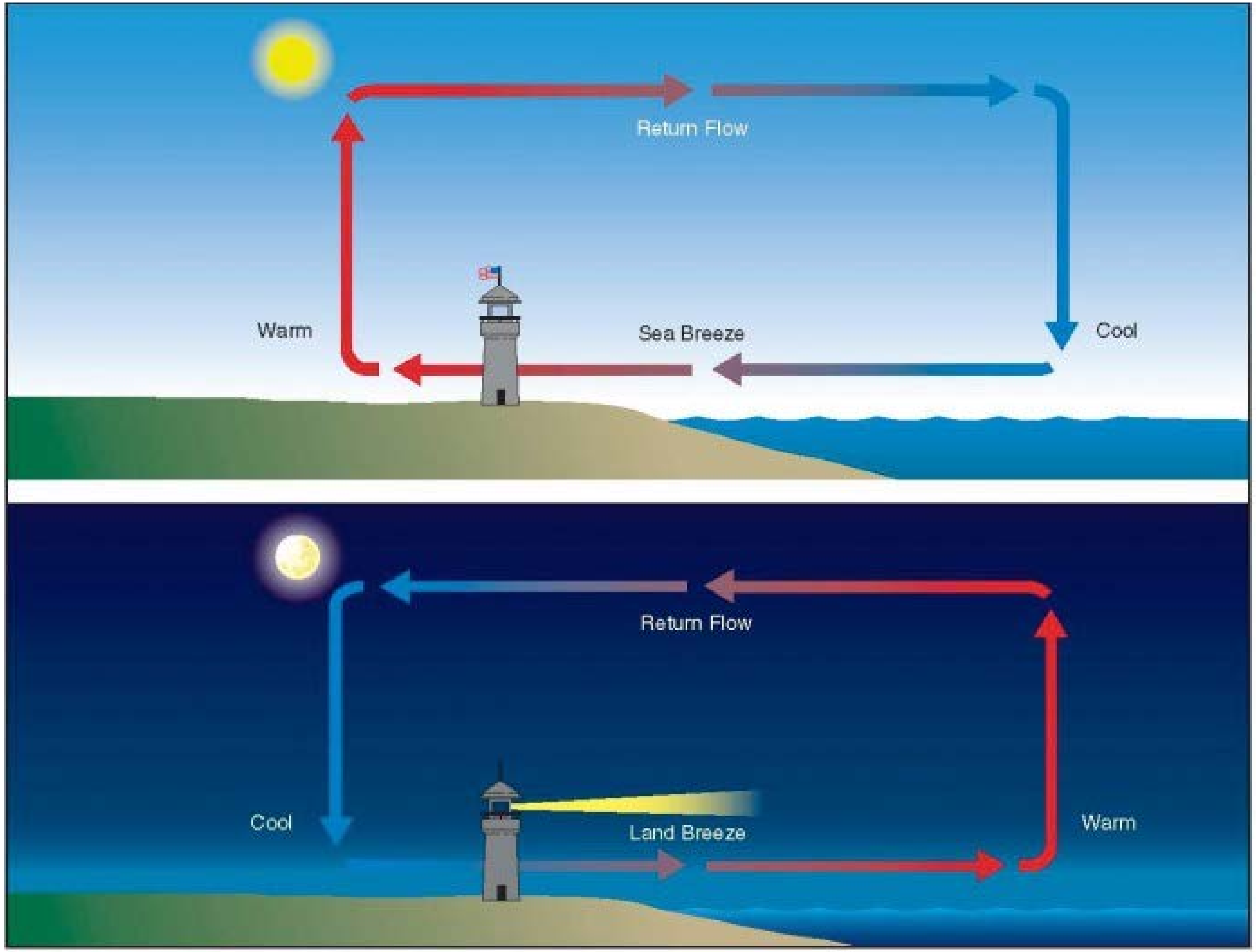


Figure 10-13. Sea breeze and land breeze wind circulation patterns.

Take Home Messages

- Atmospheric pressure decreases with increasing height above the ground.
- The atmosphere has constant density out to an elevation of H, the Scale Height
- Sea-breeze circulation is an illustration of the Barometric Law.