AOS 630: Introduction to Atmospheric and Oceanic Physics

Lecture 19 Fall 2021

Buoyancy and stability

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Announcements

There's a Skew-T a week from this week. Due next Tuesday.

HW4 is due next week on Thursday.

Changes were made to Nov 30 schedule. Any questions about this?

Final presentations

Presentation. Organization

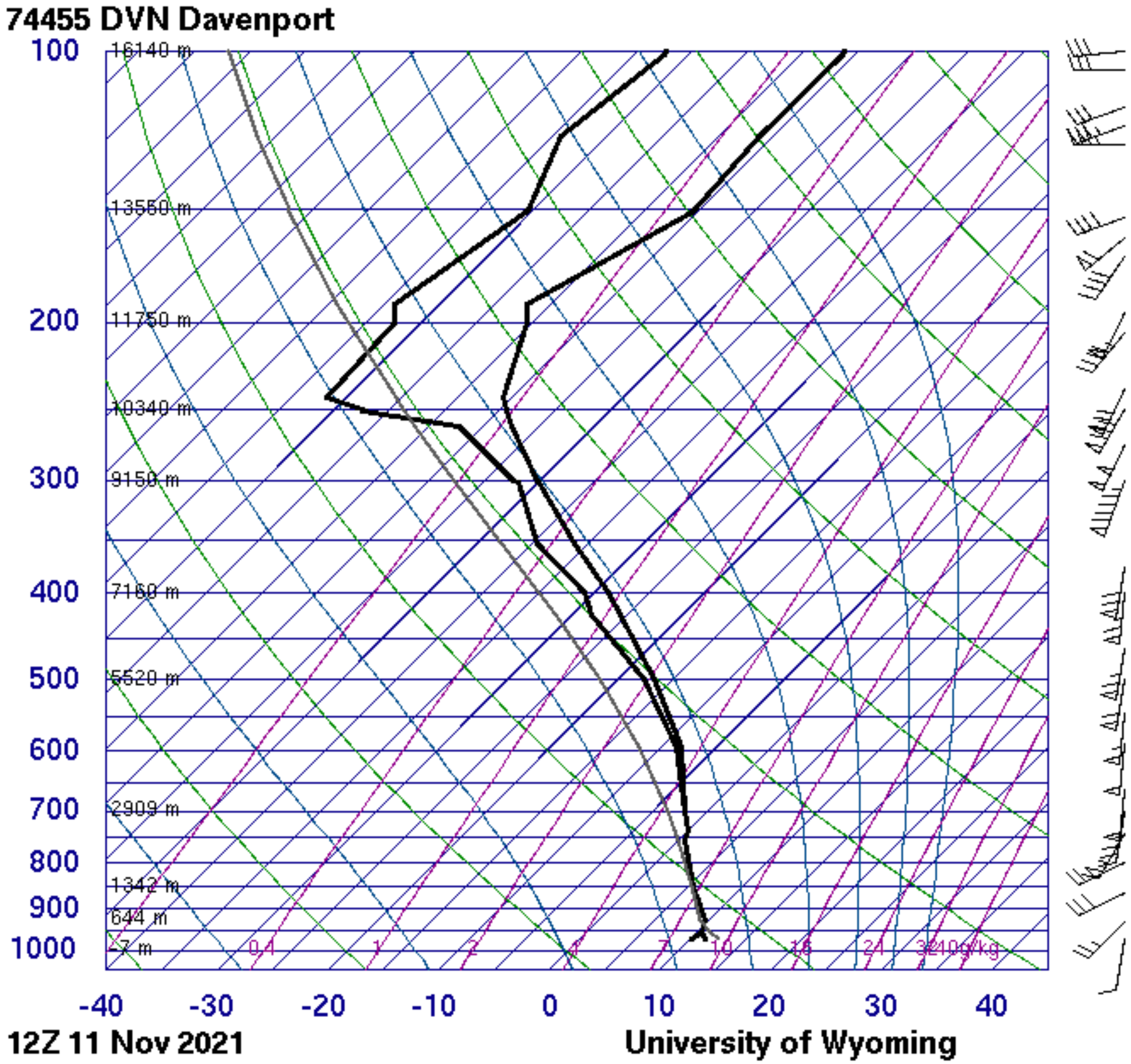
Project Design

Description of Methods and Results

Use of Time

Handling of Questions

Daily dose of thermo

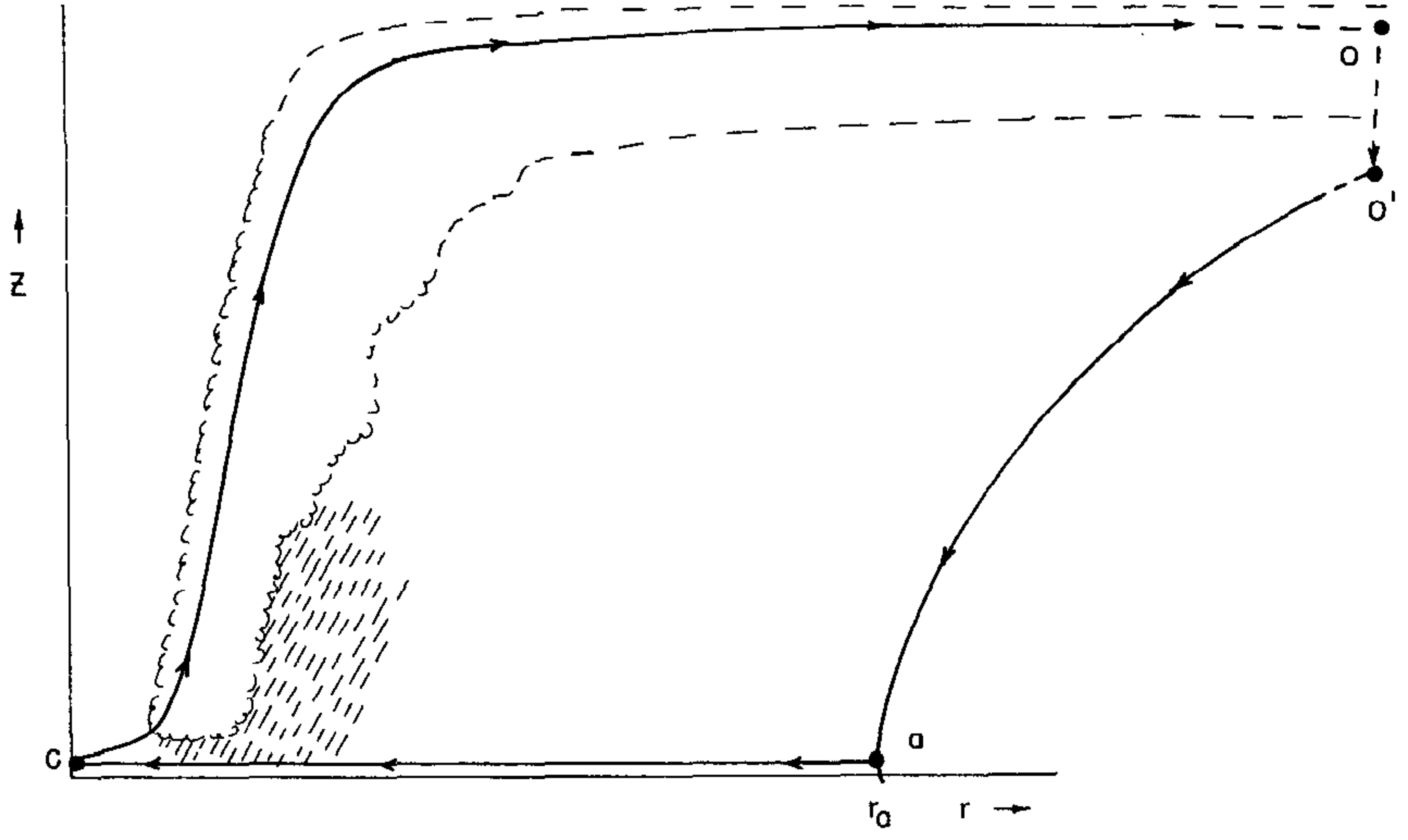


SLAT	41.61
SLON	-90.58
SELV	229.0
SHOW	4.68
LIFT	4.89
LFTV	4.98
SWET	180.2
KINX	27.90
CTOT	22.30
VTOT	22.30
TOTL	44.60
CAPE	0.00
CAPV	0.00
CINS	0.00
CINV	0.00
EQLV	-9999
EQTV	-9999
LFCT	-9999
LFCV	-9999
BRCH	0.00
BRCV	0.00
LCLT	283.0
LCLP	941.1
LCLE	311.2
MLTH	288.0
MLMR	8.21
THCK	5527.
PWAT	26.98

Class exercise

Break into groups and answer the following questions

1. What is the heat source Q of mature hurricanes?
2. What is the hurricane doing work against?
3. What happens from point a to c?
4. What about c to o?
5. What about o to o'?
6. What about o' to a?
7. What is the net result of the cycle? Where is the energy going to?
8. Discuss each step of the Carnot Cycle within the context of the piston schematic.
   A. Write the variables that go into the plot in the middle and put the locations as well (a,c,o and o').
   B. Write what Q_{in} and Q_{out} are in terms of the TC cycle.
   C. Identify the cold reservoir, the hot reservoir, and the piston in every step.



We will now begin discussing the last topic of the course:

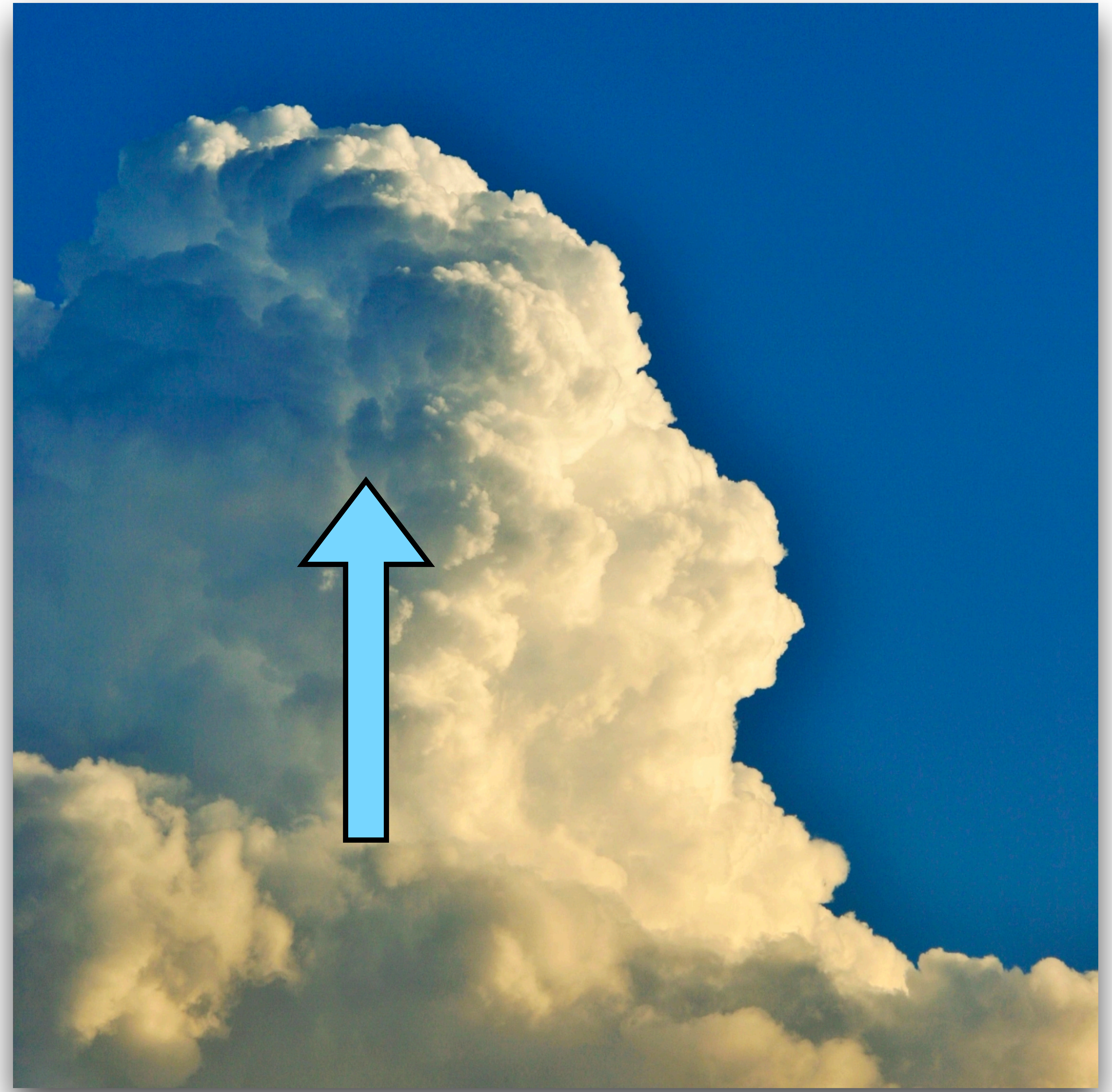
buoyancy and convection

Vertical Acceleration

Newton's second law dictates that acceleration must result from a net sum of forces.

Apply this to vertical motion

$$\frac{Dw}{Dt} = \frac{1}{m}\Sigma_i F_z$$



Vertical Acceleration

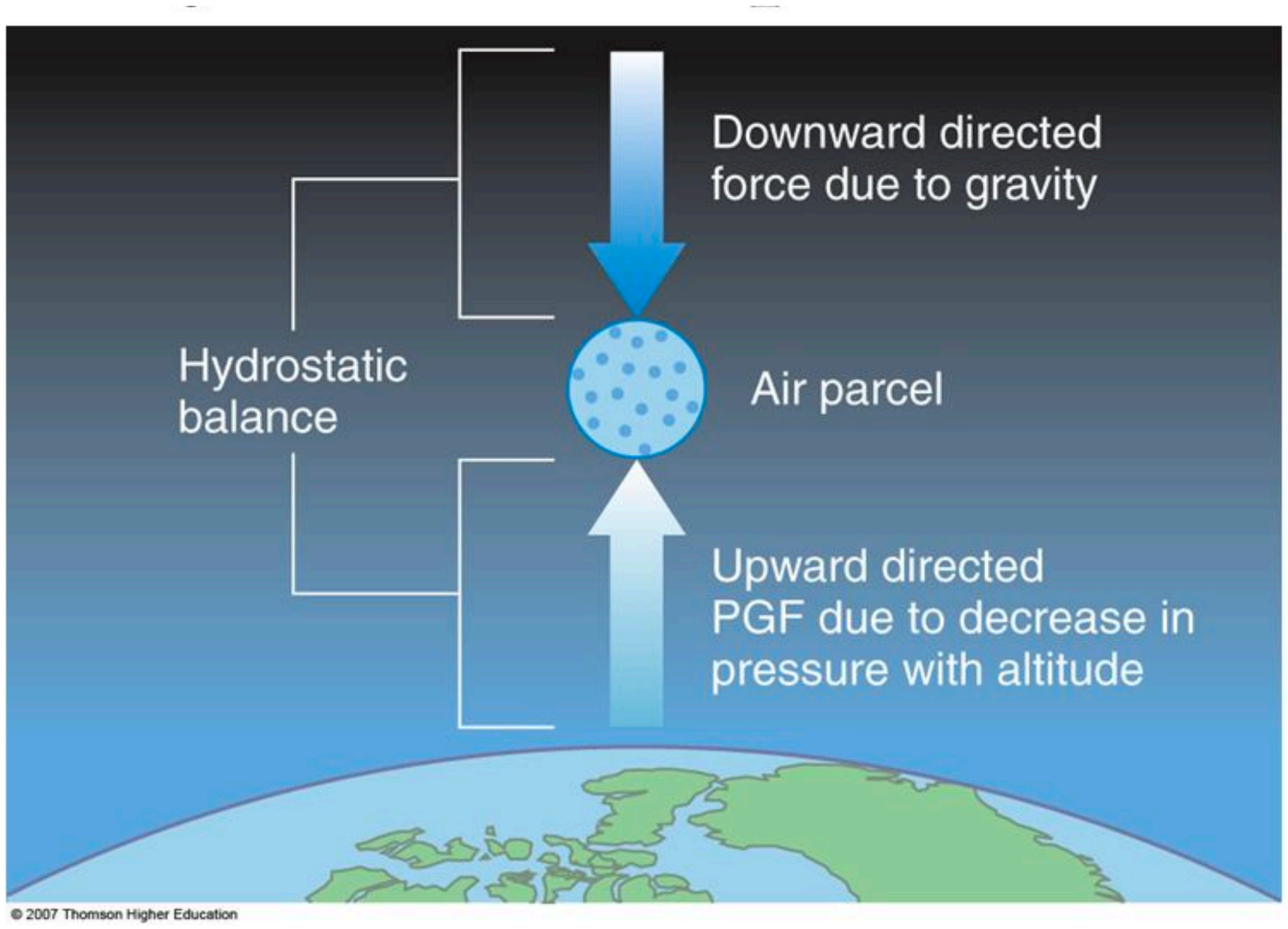
Ignoring the effects of planetary rotation and friction, the two main forces that cause vertical acceleration are gravity and the pressure gradient force.

$$\frac{Dw}{Dt} = -\alpha\frac{\partial p}{\partial z} - g$$

Acceleration

Pressure gradient force

Gravity



For quiescent atmospheric conditions, the atmosphere is maintained in place by a balance between the **downward gravitational force** and the **upward pressure gradient force.**

$$\rho g \simeq -\frac{\partial p}{\partial z}$$

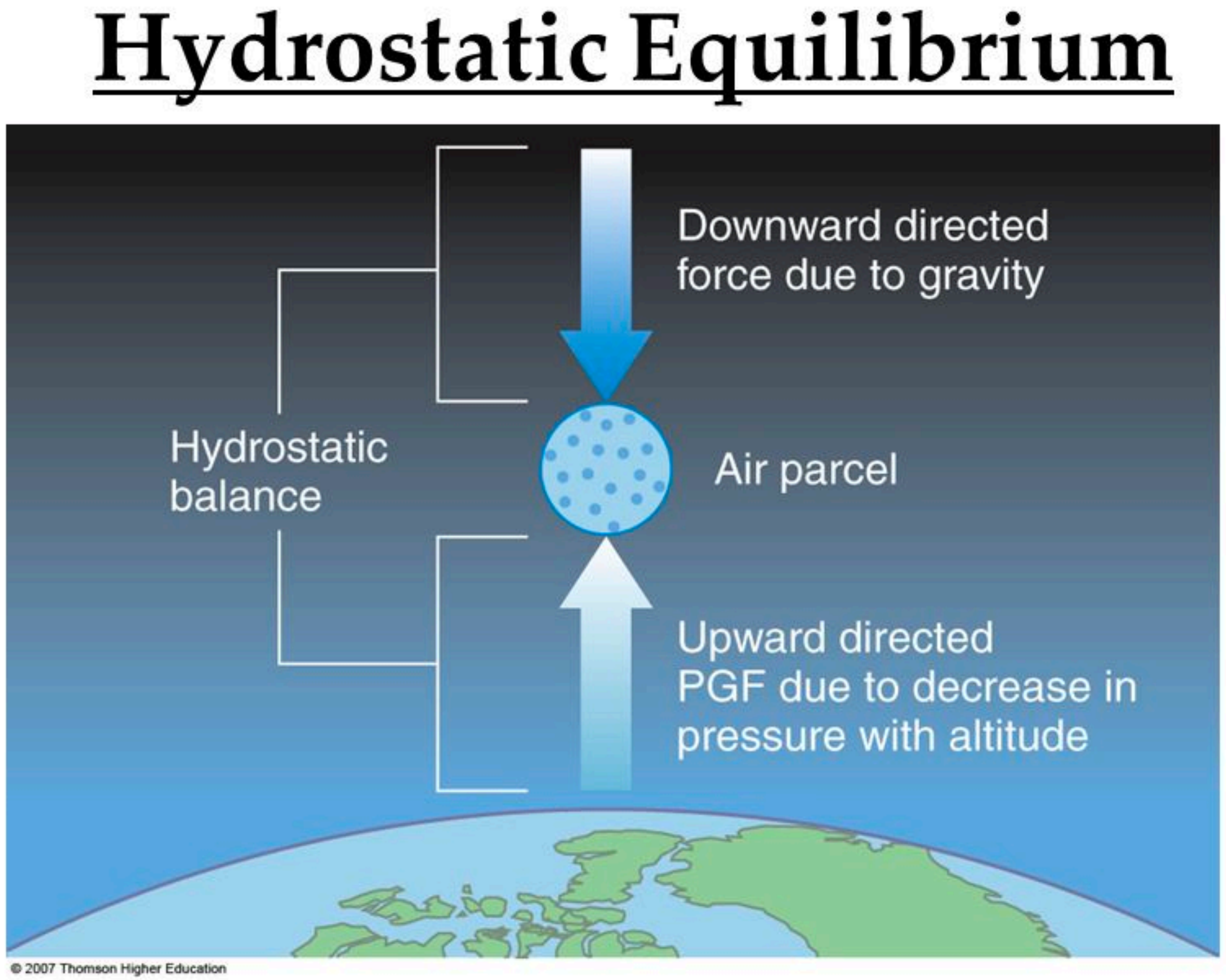


Fig. 6-13, p. 171

Defining buoyancy

We want to know how a parcel can accelerate upward. **If we assume a hydrostatic atmosphere** as the atmosphere's mean state, then

$$\rho_0 g \equiv -\frac{\partial p_0}{\partial z}$$

$$\rho = \rho_0 + \rho'$$

$$p = p_0 + p'$$

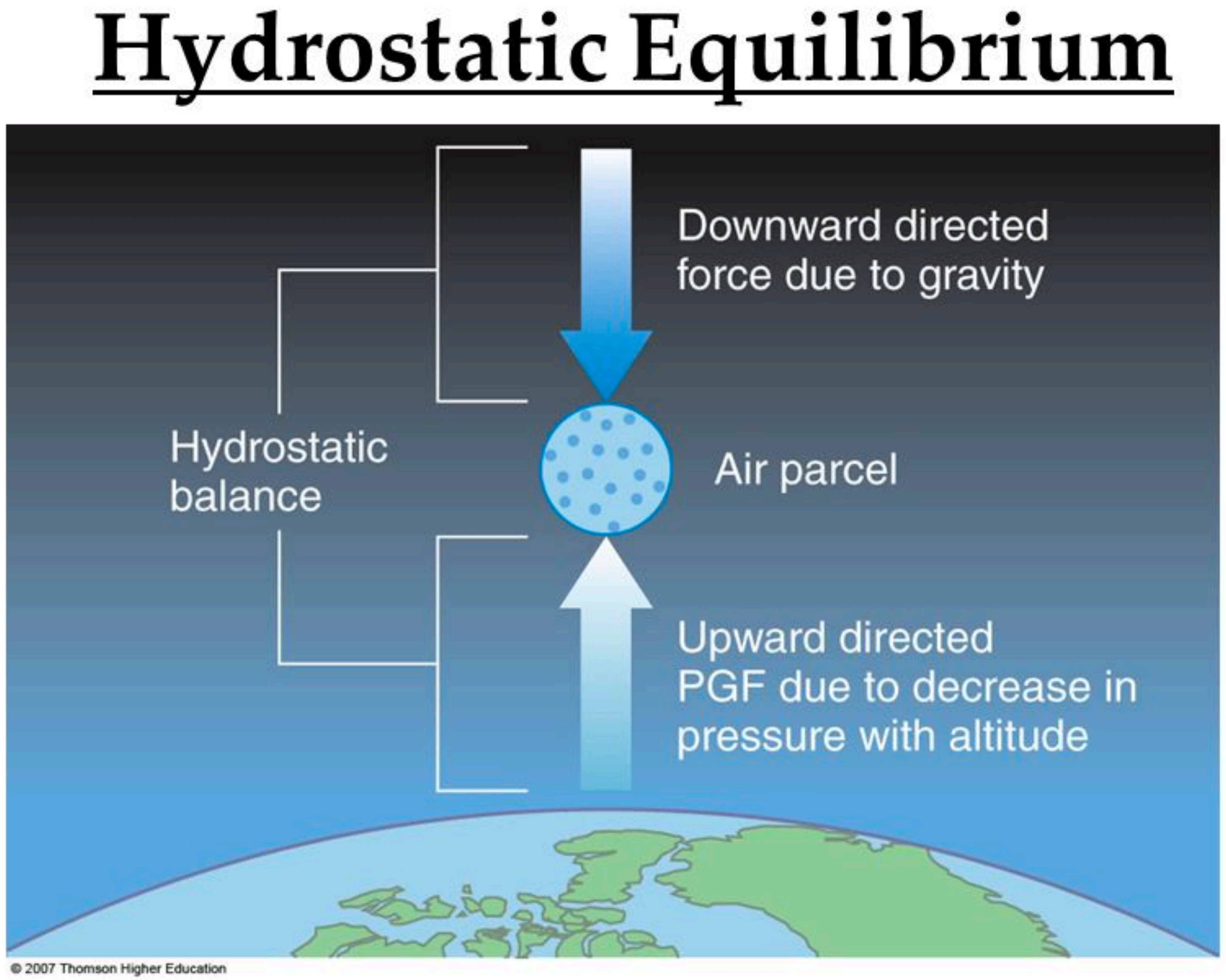


Fig. 6-13, p. 171

Defining buoyancy

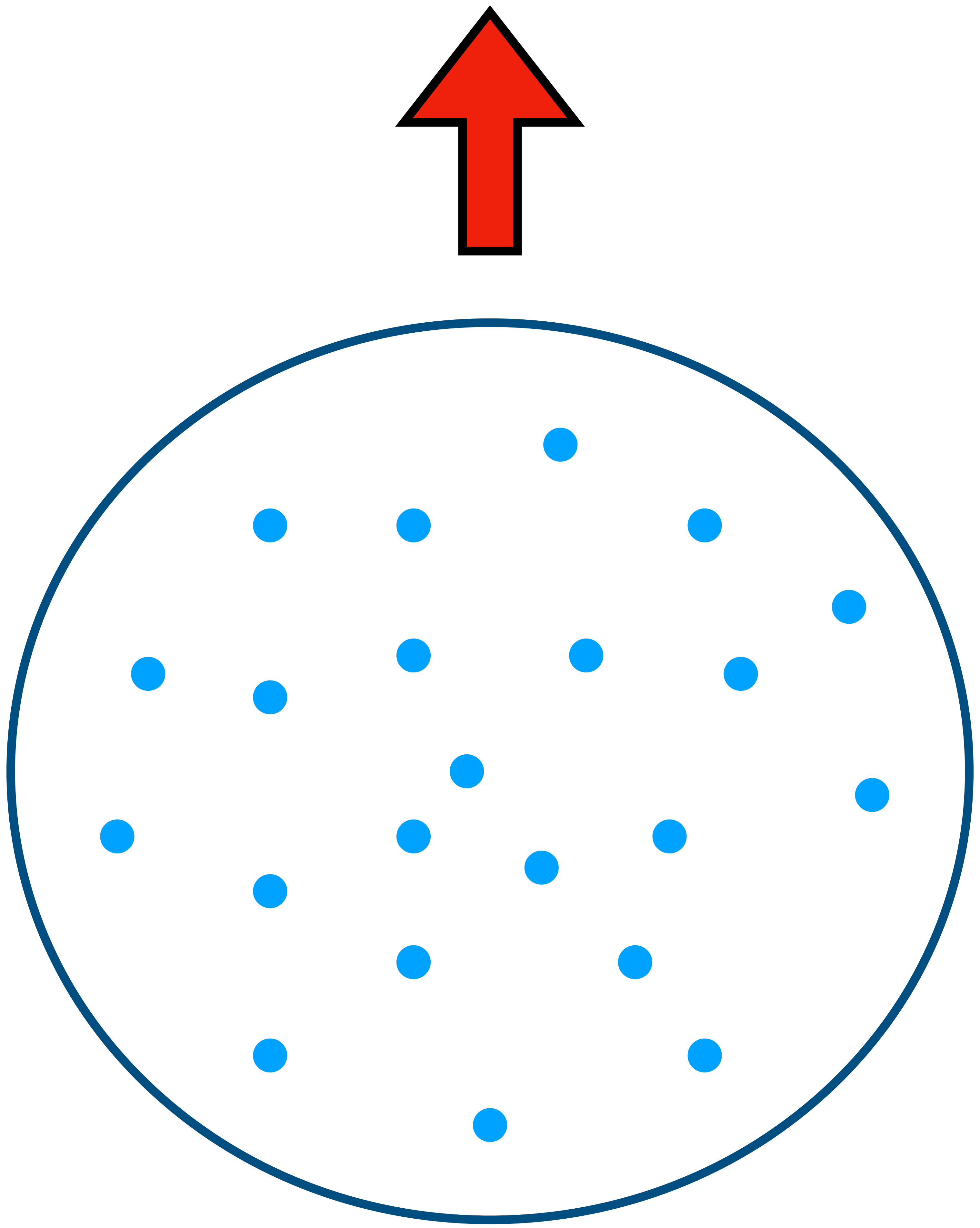
$$\frac{Dw}{Dt} = -\frac{1}{\rho_0}\frac{\partial p'}{\partial z} + B$$

Perturbation Pressure gradient force

Buoyancy

$$B \equiv -g\frac{\rho - \rho_0}{\rho_0}$$

How can a parcel accelerate upward?

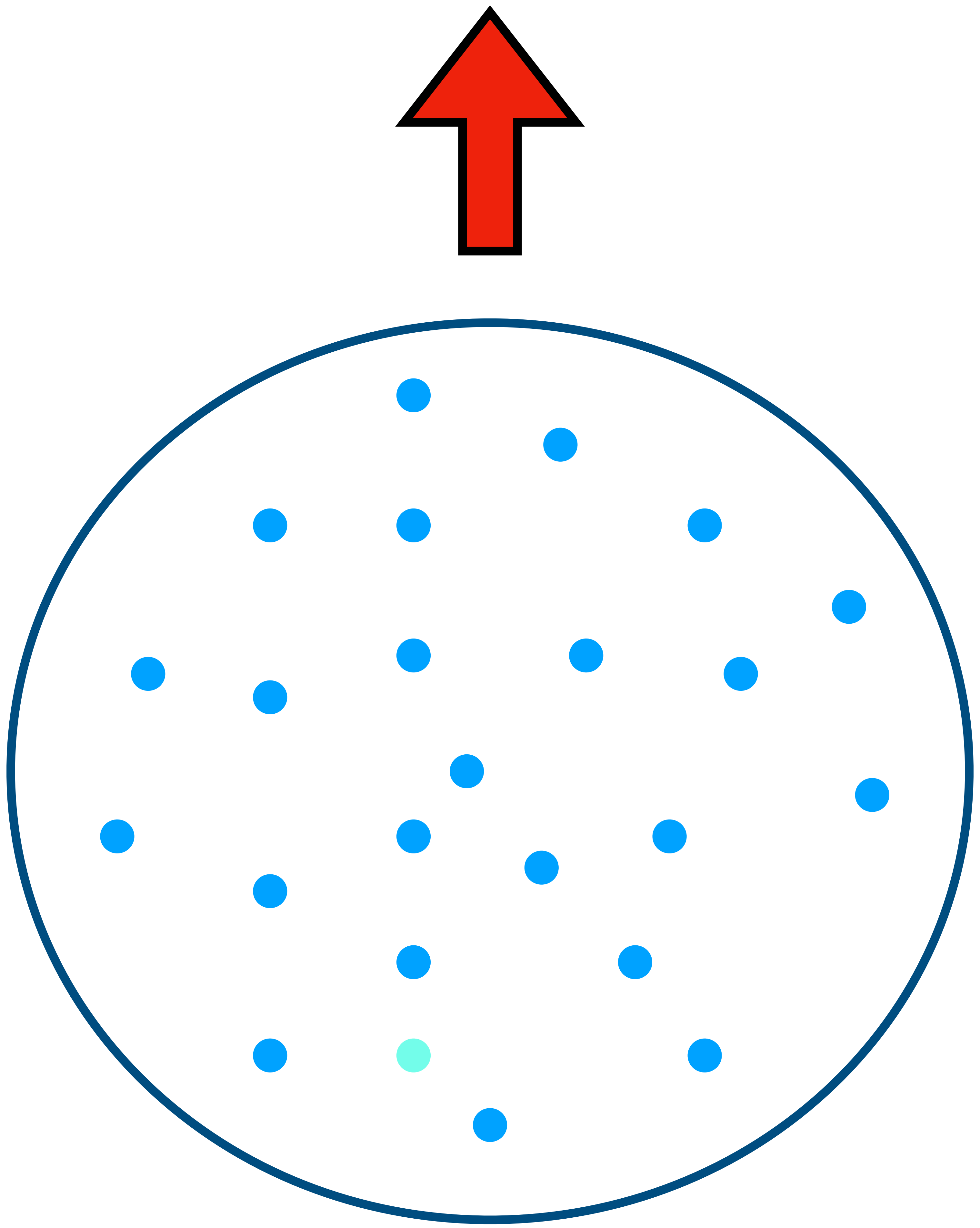


Note: The book uses F_B for buoyancy

For moist unsaturated air

Can express the buoyancy as the difference in virtual temperature between the parcel and its surroundings.

$$B \simeq g \frac{T_v - T_{v0}}{T_{v0}}$$



Atmospheric Stability

Ignoring perturbations in the pressure gradient force, our acceleration becomes

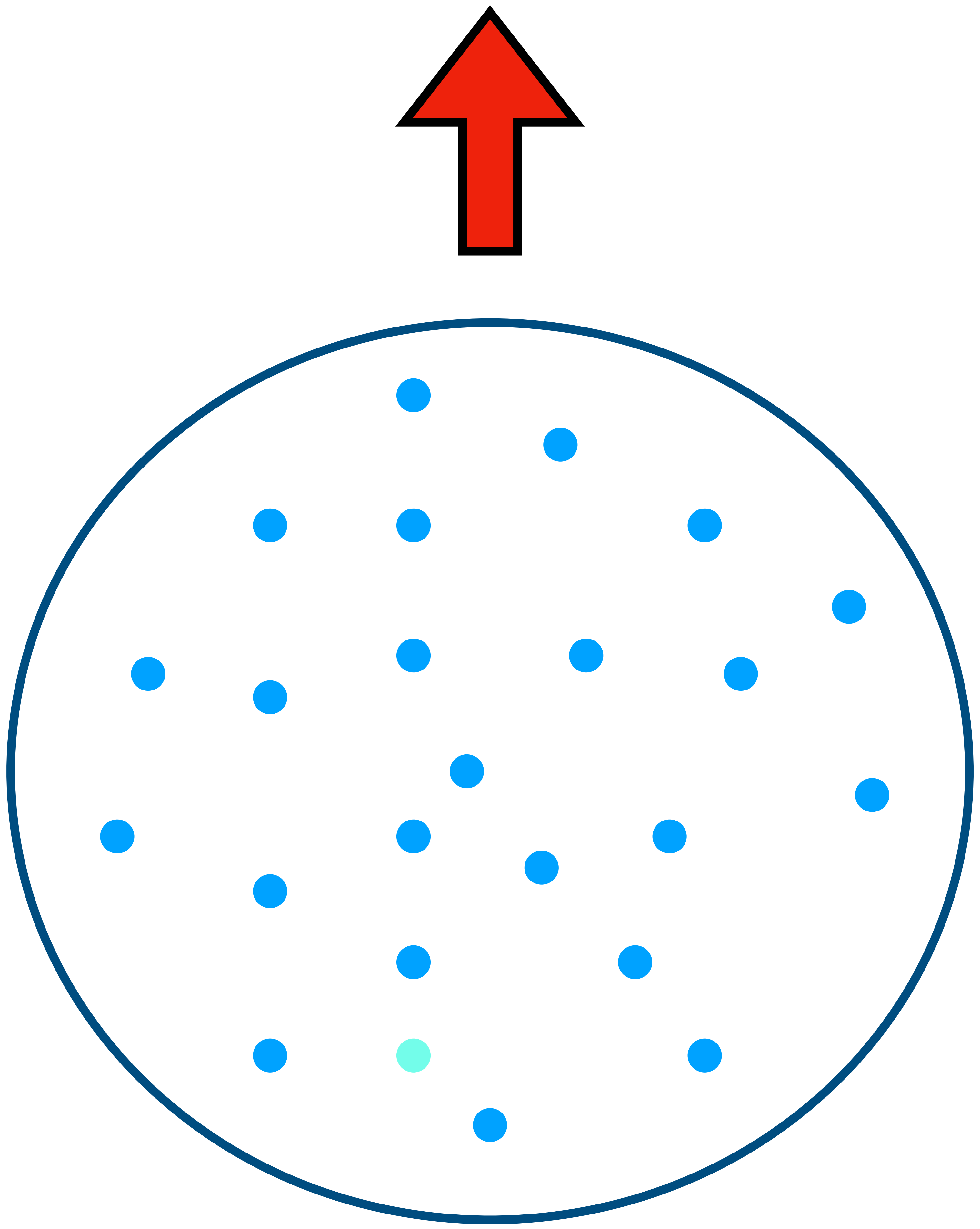
$$\frac{Dw}{Dt} = g\frac{T_v - T_{v0}}{T_{v0}}$$

Recognizing that the vertical velocity is just the change of height wit time

$$w = \frac{Dz}{Dt}$$

We get

$$\frac{D^2z}{Dt^2} = g\frac{T_v - T_{v0}}{T_{v0}}$$



Atmospheric Stability

For a dry atmosphere

$$\frac{D^2 z}{Dt^2} = g\frac{T - T_0}{T_0}$$

For our planet's troposphere, temperatures change linearly with height

$$T(z) = T_s - \Gamma_d z$$

$$T_0(z) = T_s - \Gamma z$$

Dry adiabatic lapse rate

$$\Gamma_d = \frac{g}{c_p}$$

Environmental Lapse rate

$$\Gamma = -\frac{\partial T}{\partial z}$$

For a dry atmosphere

$$\frac{D^2 z}{Dt^2} = g\frac{(\Gamma - \Gamma_d)z}{T_0}$$

We can further simplify by using the potential temperature definition

$$\frac{1}{\theta}\frac{\partial \theta}{\partial z} = \frac{1}{T}\left(\Gamma_d - \Gamma\right)$$

$$\frac{D^2 z}{Dt^2} = -N^2 z \qquad N^2 = \frac{g}{\theta}\frac{\partial \theta}{\partial z}$$

Atmospheric Stability: Solutions

$$\frac{D^2 z}{Dt^2} = -N^2 z \qquad N^2 = \frac{g}{\theta}\frac{\partial \theta}{\partial z}$$

BV freq.	Stratification	Stability	ODE Solution (N constant)
$N^2 > 0$	$\frac{\partial \theta}{\partial z} > 0$	*Stable*	$z(t) = c_1 \cos(Nt) + c2 \sin(Nt)$
$N^2 < 0$	$\frac{\partial \theta}{\partial z} < 0$	*Unstable*	$z(t) = c_1 \exp(Nt) + c2 \exp(-Nt)$
$N^2 = 0$	$\frac{\partial \theta}{\partial z} = 0$	*Neutral*	$z(t) = c_2 t + c_1$

Atmospheric Stability: Solutions

BV freq.	Stratification	Stability	ODE Solution (N constant)
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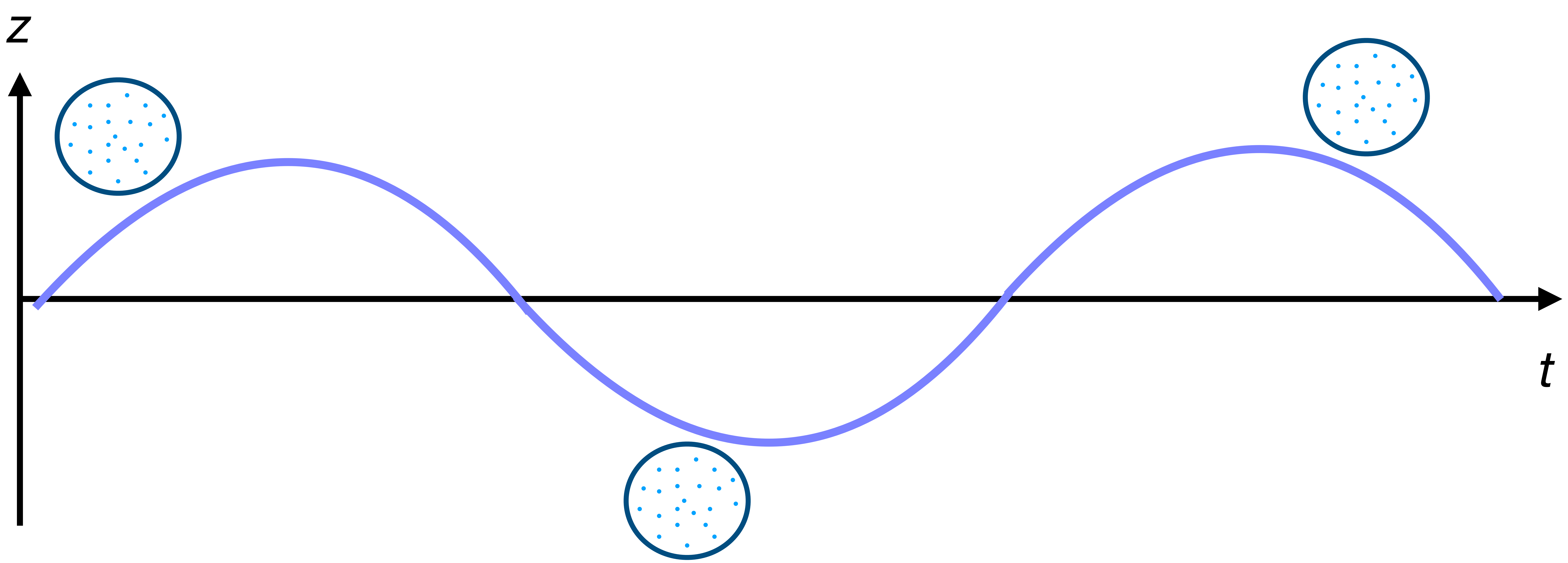

Can a stable atmosphere create clouds?

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Lifting in stable atmospheres can create clouds only if the lifting is already close to the cloud layer.

Cooling and other processes can create clouds (e.g. fog) even if the atmosphere is stable.

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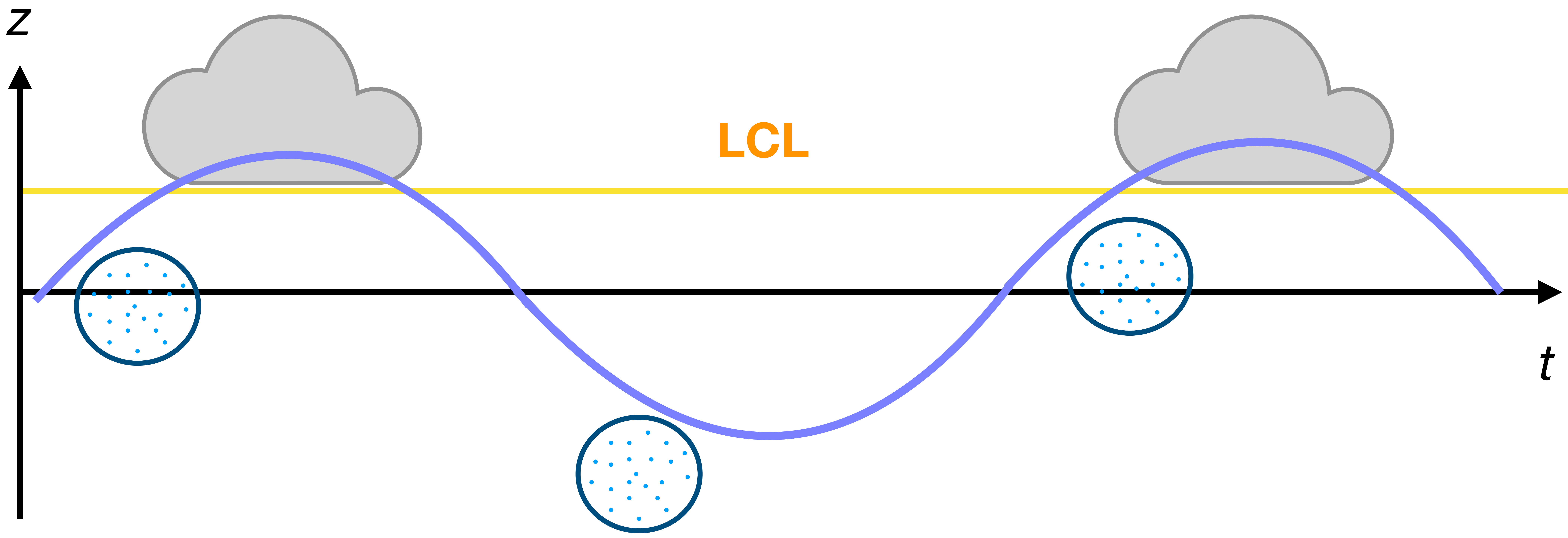

Can a stable atmosphere create clouds?

Can it create deep cumulonimbus clouds though?

Atmospheric Stability: Solutions

BV freq.	Stratification	Stability	ODE Solution (N constant)
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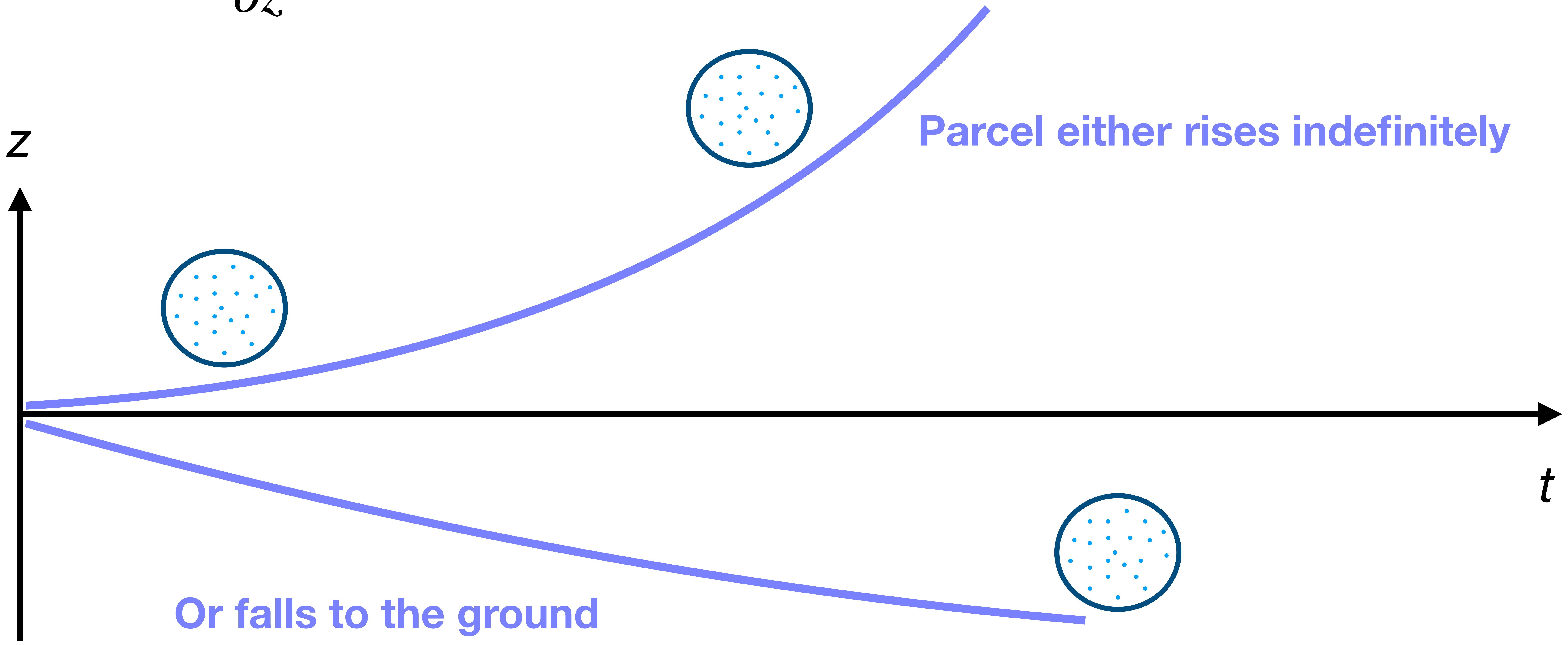
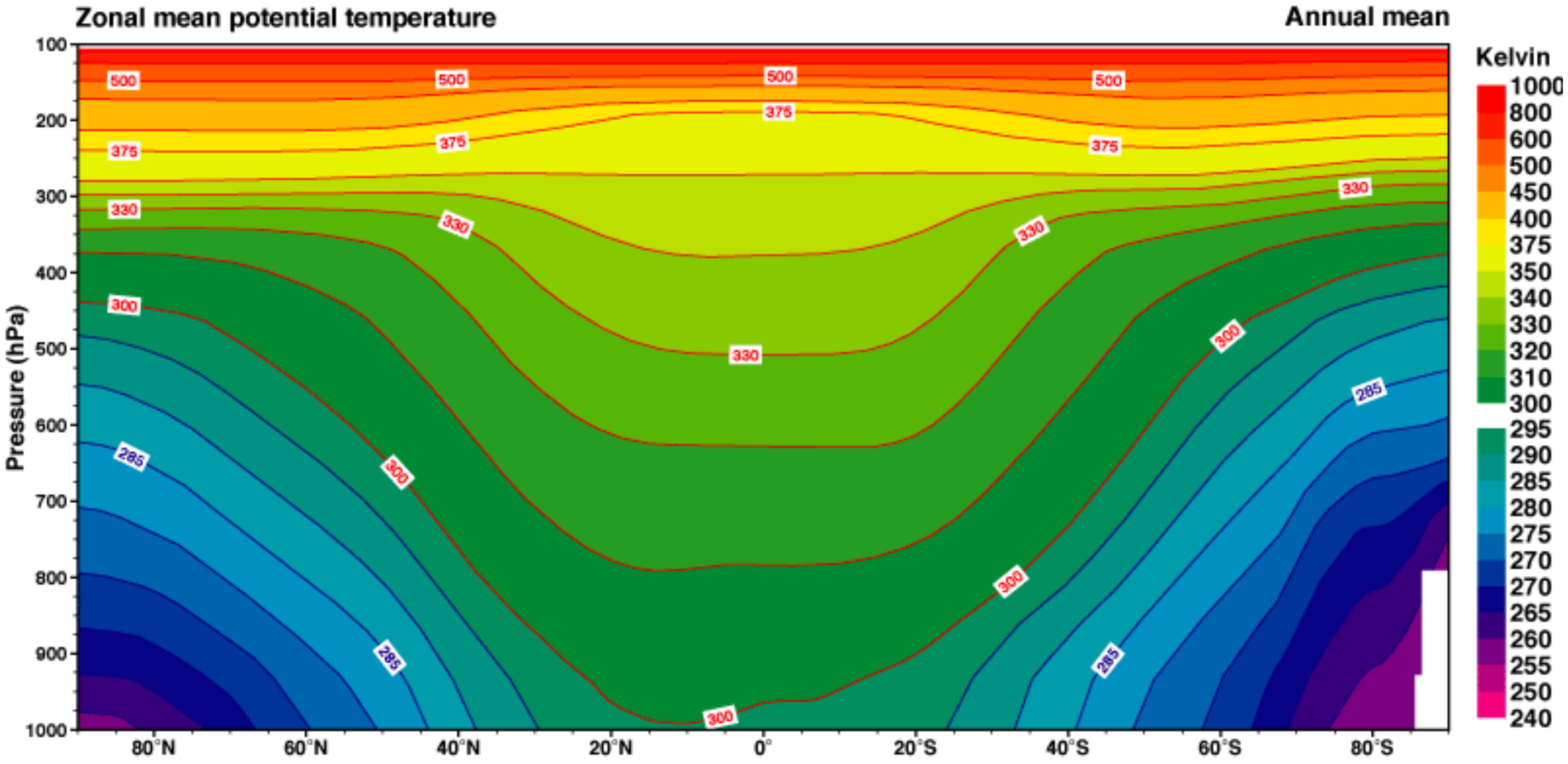


Can an unstable atmosphere create clouds?

Is the atmosphere usually stable or unstable?



Dry Stability

The atmosphere is usually statically stable.

It is only unstable under specific conditions, such as when the ground warms due to solar heating. This only happens near the surface.

Need other processes to account for the development of most deep clouds.

Next Class

Buoyancy and stability of saturated parcels

Available potential energy