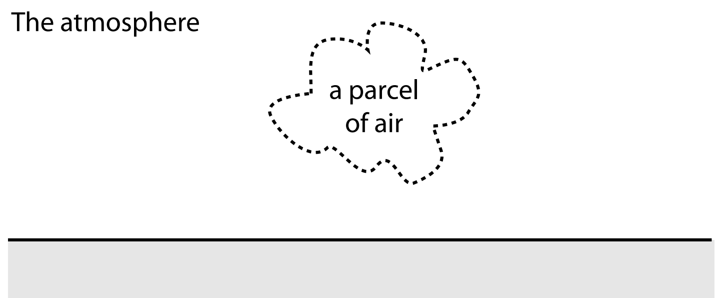
ATMOS 5130

Lecture 13

- Atmospheric Stability
  - Parcel Method
  - Local Stability
  - Brunt-Vaisaila frequency
  - Conditional Instability
  - Potential Instability

What is Atmospheric Thermodynamics?

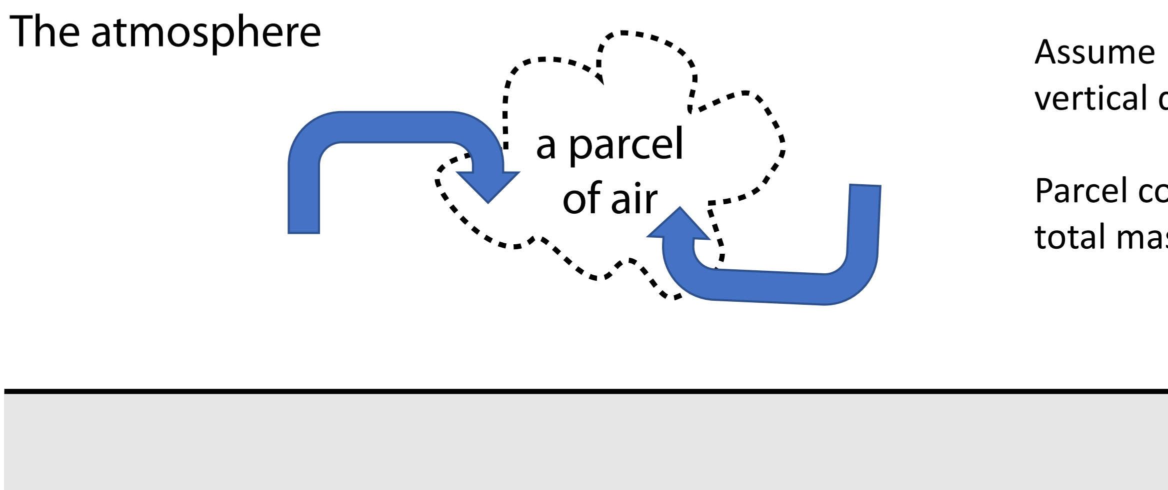
Describes the physical behavior of air on local scale



Review from Lecture 1

How does an isolated “parcel” of air respond to changes in <u>temperature</u> and <u>pressure</u>?

Add More Reality



Assume parcel is large compared to vertical distance traveled

Parcel constitutes a small fraction of the total mass of the layer

Non-ideal processes in the real atmosphere serve to **reduce** the effects of instability and **dilute** the properties of a moving parcel of air.

Thus, parcel method yields a theoretical **upper limit** on energy

Stability

- Local Stability
  - Respect to small vertical displacements within a layer

- Potential instability
  - Phenomenon in which a previously stable layer becomes unstable as a result of large scale forced lifting of entire layer – precursor to convection

- Parcel stability
  - Stability of the troposphere with respect to large vertical displacement of air parcels (often near surface); occurrence of convective clouds

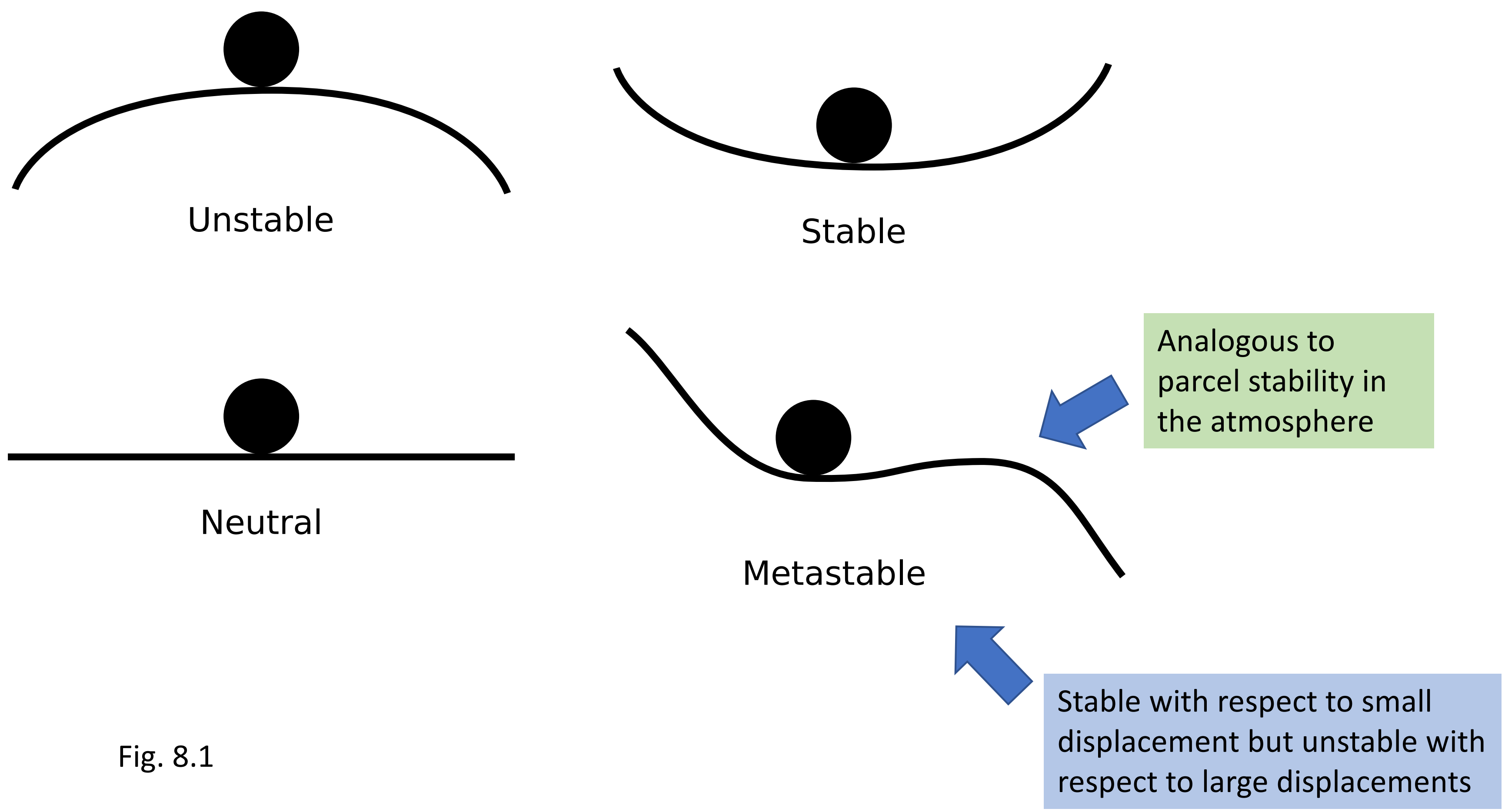

Unstable
Stable
Neutral
Metastable
Analogous to parcel stability in the atmosphere
Stable with respect to small displacement but unstable with respect to large displacements

Fig. 8.1

Buoyancy of Air parcel

Where the prime denotes the ambient/environment condition

$$F_B = (\rho' - \rho)Vg$$

$$f_B = \frac{F}{M} = \frac{(\rho' - \rho)Vg}{\rho V} = \left[\frac{\rho' - \rho}{\rho}\right] g$$

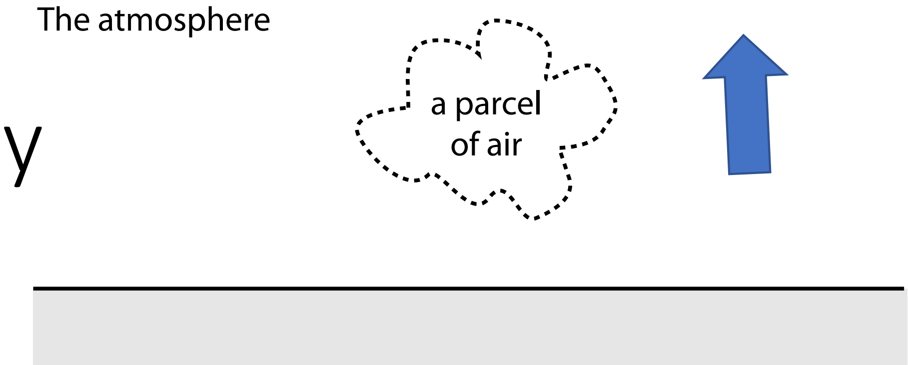
From Chapter 3

Substitute in:

$$\rho = \frac{p}{R_d T_v} \qquad \rho' = \frac{p}{R_d T_v'}$$

$$f_B = \left[\frac{T_v - T_v'}{T_v'}\right] g$$

Local Atmospheric Stability



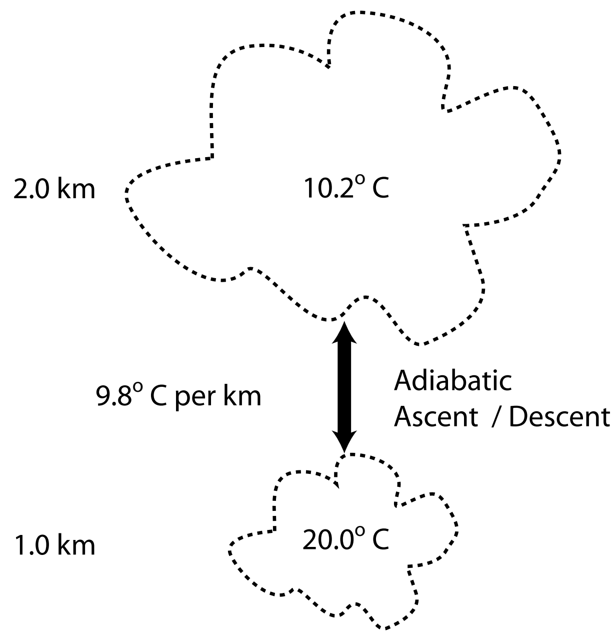
Parcel moving upward, adiabatically expands -> temperature falls

<u>Scenarios</u>

1. Stable = Parcel becomes denser than environment and buoyant forces send it back to starting point.
2. Unstable = Less dense than environment, accelerates upward.
3. Neutral = No difference in temperature continues upward until friction brings it to rest at new level.

Dry Adiabatic Lapse Rate

Review from Lecture 8



Dry Adiabatic Lapse Rate

Review from Lecture 8

$$c_p\, dT = \alpha\, dp = \frac{R_d T}{p} dp$$

$$\frac{dT}{dz} = \frac{dT}{dp}\frac{dp}{dz} = \frac{R_d T}{c_p p}\frac{dp}{dz}$$

The change in pressure in environment is same as parcel with height

$$\frac{dp}{dz} = \rho' g = \frac{p'}{R_d T'} g$$

Where the prime denotes the ambient/environment condition

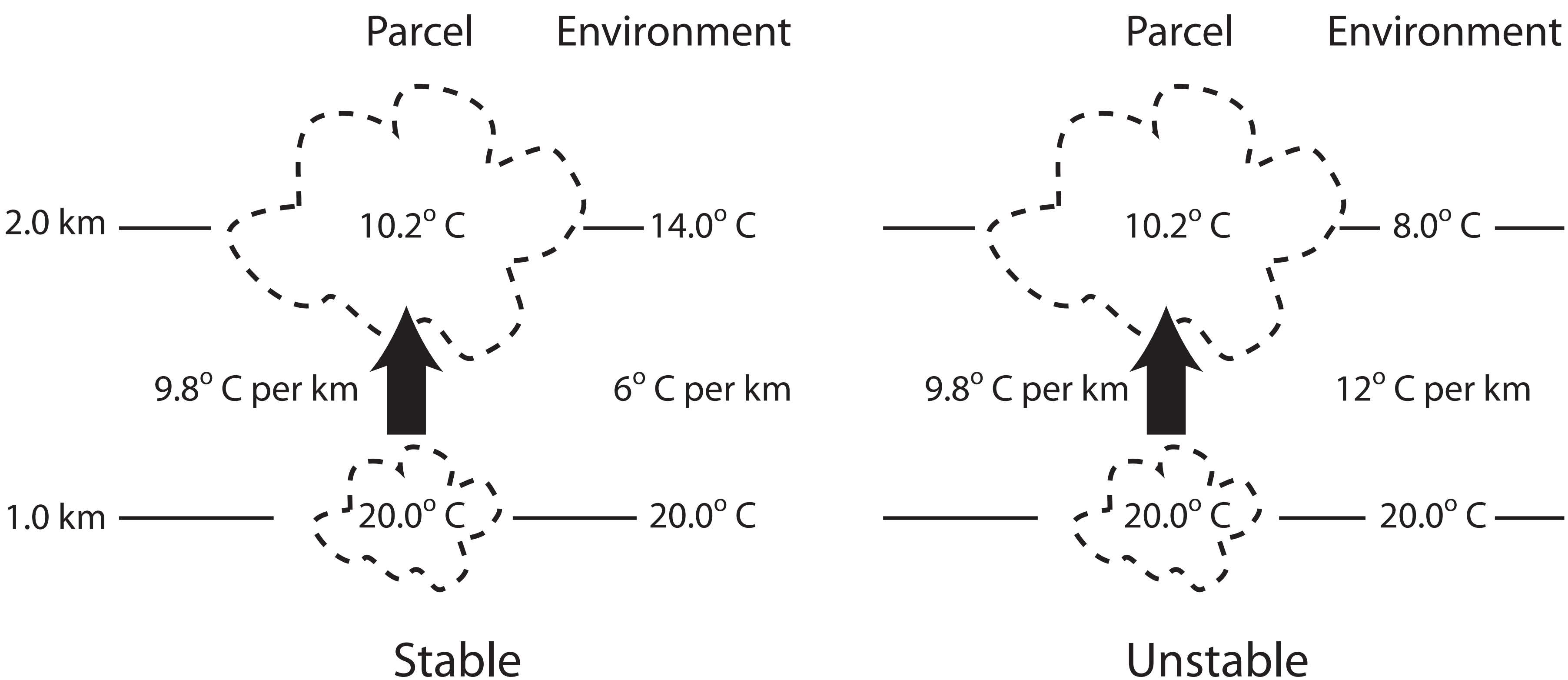
$$\frac{dT}{dz} = \frac{R_d T}{c_p p}\frac{p\prime}{R_d T\prime} g$$

$$\frac{dT}{dz} = \frac{g}{c_p}$$

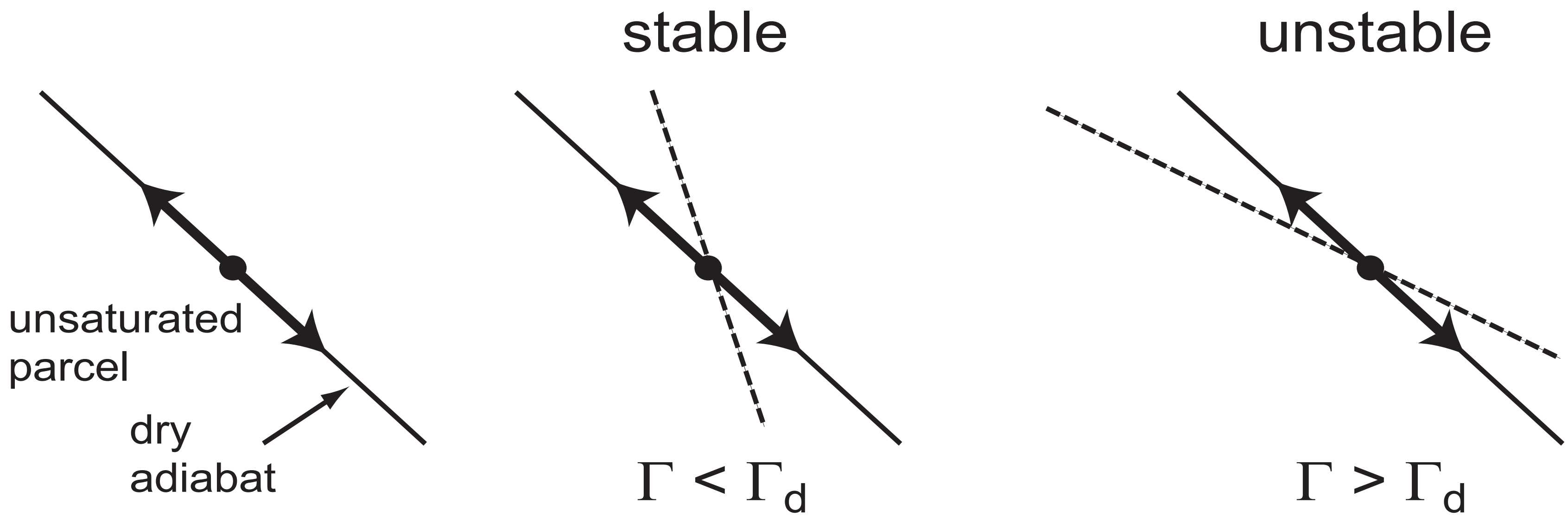
Approximation…
Poisson's equation better, if you know the pressure at each level.

Dry Static Stability

$\Gamma < \Gamma_d$	STABLE
$\Gamma \approx \Gamma_d$	NEUTRAL
$\Gamma > \Gamma_d$	UNSTABLE



Parcel
Environment
2.0 km
10.2° C
14.0° C
9.8° C per km
6° C per km
1.0 km
20.0° C
20.0° C
Stable
Parcel
Environment
10.2° C
8.0° C
9.8° C per km
12° C per km
20.0° C
20.0° C
Unstable


stable
unstable
unsaturated
parcel
dry
adiabat
Γ < Γd
Γ > Γd

$$\Gamma_d = \Gamma$$
$$\frac{\partial\theta}{\partial z} = 0$$

Dry Adiabats

$$\Gamma_d = \frac{\partial T}{\partial z} = \frac{g}{c_p} = 9.8 \text{ K/km}$$

Potential Temperature

Review from Lecture 8

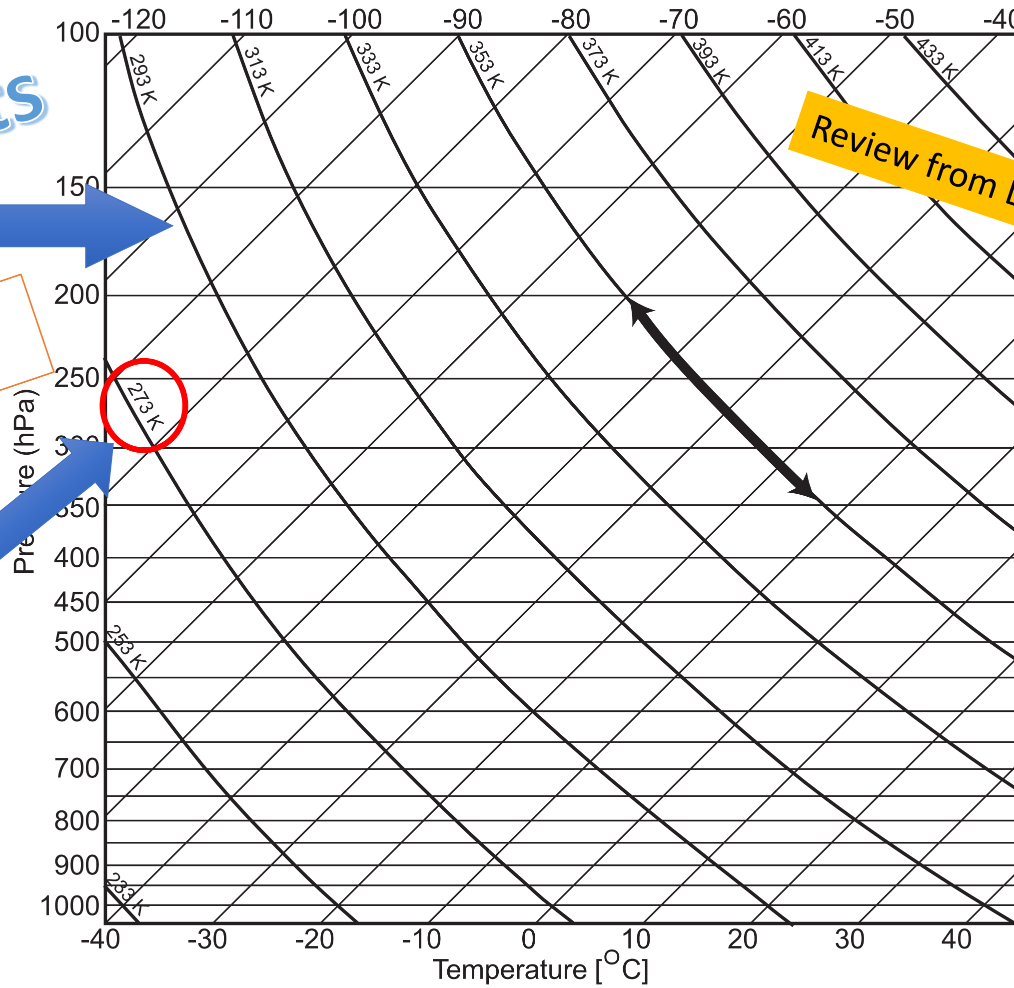


Fig. 5.3

Dry Static Stability

$$\frac{\partial \theta}{\partial z} > 0$$ STABLE

$$\frac{\partial \theta}{\partial z} = 0$$ NEUTRAL

$$\frac{\partial \theta}{\partial z} < 0$$ UNSTABLE

Dry Static Stability

$\Gamma < \Gamma_d$ STABLE

$\Gamma \approx \Gamma_d$ NEUTRAL

$\Gamma > \Gamma_d$ UNSTABLE = Superadiabatic

Rarely observed, except close to the ground when strong surface heating

Brunt Vaisaila frequency

Angular frequency of oscillation of parcel in a stable layer

The more stable the layer – the more frequent the oscillation

Brunt Vaisaila frequency

$$f_B = \left[\frac{T_v - T_v{}'}{T_v'}\right] g$$

$$f_B = \left[\frac{\theta - \theta'}{\theta}\right] g$$

Ignore moisture

$$f_B = \left[\frac{\theta}{\theta'} - 1\right] g$$

Now $\theta' = \theta + \frac{\partial \theta}{\partial z} \mathrm{z}$

$$f_B = \left[\frac{\theta}{\theta + \frac{\partial \theta}{\partial z} \mathrm{z}} - 1\right] g$$

For $x \ll 1, \frac{1}{1 - x} \approx 1 + x$

$$f_B = -\left[\frac{1}{\theta} \frac{\partial \theta}{\partial z}\right] g z$$

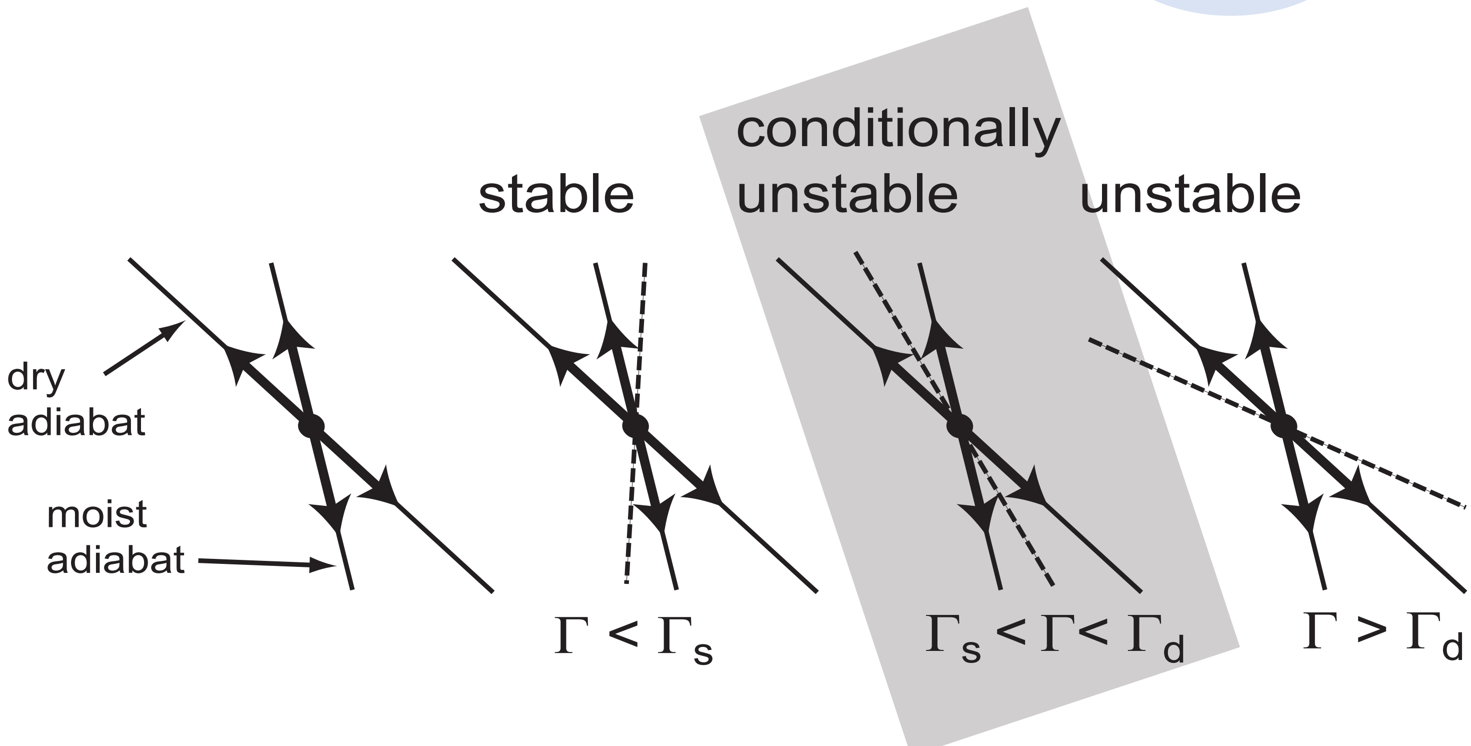
Restoring force, particle accelerates in the direction opposite to displacement

Conditional Instability

$\Gamma < \Gamma_s$ ABSOLUTELY STABLE

Recall

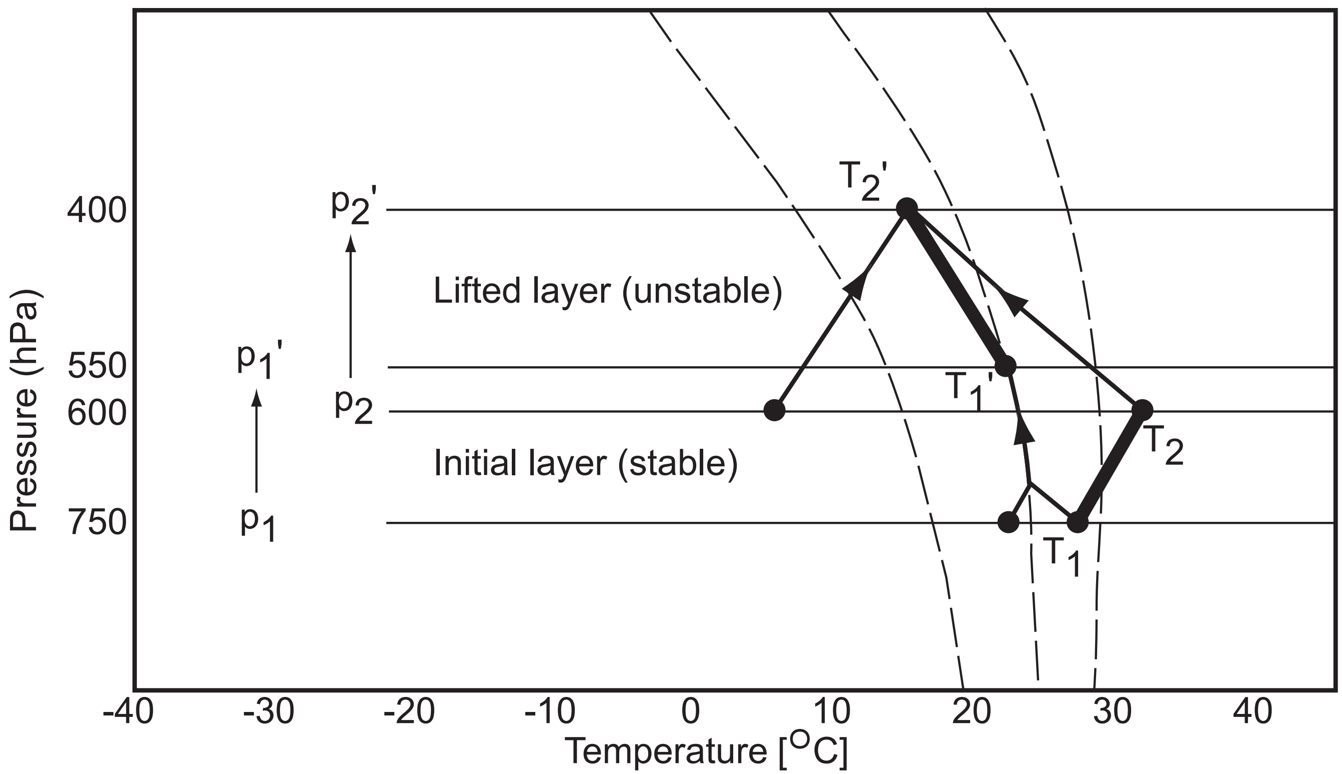
$\Gamma_d > \Gamma_s$



Static Stability

$\Gamma = \Gamma_s$	Saturated NEUTRAL
$\Gamma_s < \Gamma < \Gamma_d$	CONDITIONALLY STABLE
$\Gamma = \Gamma_d$	Dry NEUTRAL
$\Gamma > \Gamma_d$	ABSOLUTELY UNSTABLE

Potential instability = Convective instability



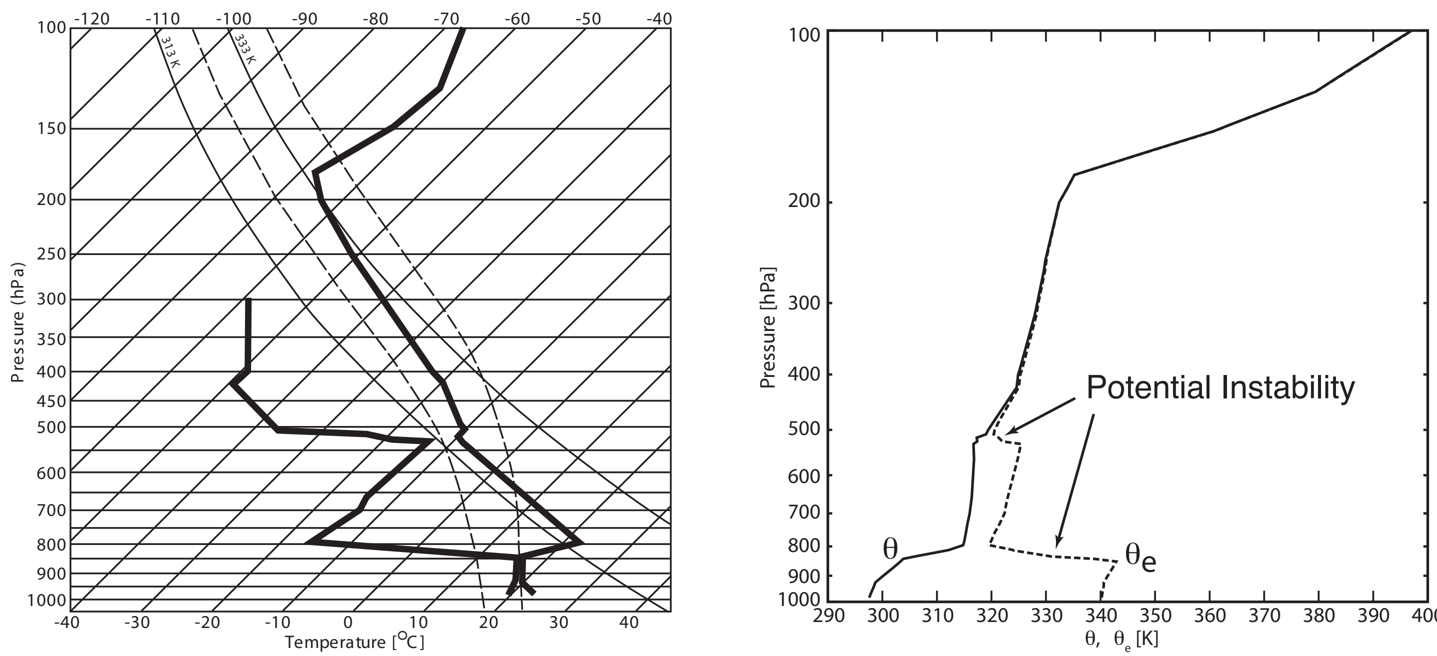
Associated with decreasing RH with height

Static Stability

$$\frac{\partial \theta_e}{\partial z} > 0$$ POTENTIALLY STABLE

$$\frac{\partial \theta_e}{\partial z} = 0$$ NEUTRAL

$$\frac{\partial \theta_e}{\partial z} < 0$$ POTENTIALLY UNSTABLE



-120
-110
-100
-90
-80
-70
-60
-50
-40
313 K
333 K
100
150
200
250
300
350
400
450
500
600
700
800
900
1000
Pressure (hPa)
-40
-30
-20
-10
0
10
20
30
40
Temperature [°C]
Potential Instability
θ
θe
Pressure [hPa]
290
300
310
320
330
340
350
360
370
380
390
400
θ, θe [K]

Fig. 8.5