Atmospheric Physics

Lecture 10

J. Sahraei

Physics Department,

Razi University

https://sci.razi.ac.ir/~sahraei

Equivalent potential temperature

Under a certain approximation, the saturated adiabatic can be calculated explicitly,

First, note that, for reversible processes, $T\,dS = dQ$,

so equation

$$\delta S = c_p \frac{\delta T}{T} - R_a \frac{\delta p}{p} = c_p \delta(\ln T) - R_a \delta(\ln p)$$

can be written

$$c_p \delta(\ln T) - R_a \delta(\ln p) = \frac{\delta Q}{T} = -\frac{L \delta \mu_s}{T}$$

Provided that the expression on the extreme right-hand side of this equation can be approximated by

$$-\delta\left(\frac{L\mu_s}{T}\right) \qquad \delta\left(c_p \ln T - R_a \ln p + \frac{L\mu_s}{T}\right) = 0$$

On integrating, dividing by c_p ,using $\kappa = R_a/c_p$

and taking exponentials, we get

$$\theta_e(T,p) \equiv T(\frac{p}{p_0})^{-k} \exp(\frac{L\mu_s}{c_p T}) = constant$$

The quantity θ_e is called the equivalent potential temperature.

equation $\theta = T(\frac{p_0}{p})^k$ and above equation we see that

$$\theta_e(T,p) \equiv \theta(T,p)\exp\left(\frac{L\mu_s(T,p)}{c_p T}\right)$$

Under the given approximation, we have therefore integrated equation

$$\frac{dT}{dp} = \frac{\Gamma_s R_a T}{gp} = \Gamma_s'(T,p)$$ explicitly,

so the curves of constant θ_e closely approximate the saturated adiabatics.

It may be shown that, as we follow a saturated adiabatic

$$\theta_e = \theta_0$$

say, to low pressure (and low temperature), it approaches the dry adiabatic

$$\theta = \theta_0$$

The relationship between the three types of potential temperature can be described as follows

$\mu = \mu_s$ (saturated environment): $\theta_e = \theta_{es}$,

$\mu = 0$ (dry environment): $\theta_e = \theta$,

$0 < \mu < \mu_{sat}$ (unsaturated moist parcel): $\theta < \theta_e < \theta_{es}$.

Saturated Adiabatic Transitions

Expansion ⇒ cooling ⇒ condensation

i.e., water vapor decreases, liquid water increases

Condensational heating partially offsets cooling due to expansion

Result: Cooling rate less than dry adiabatic rate

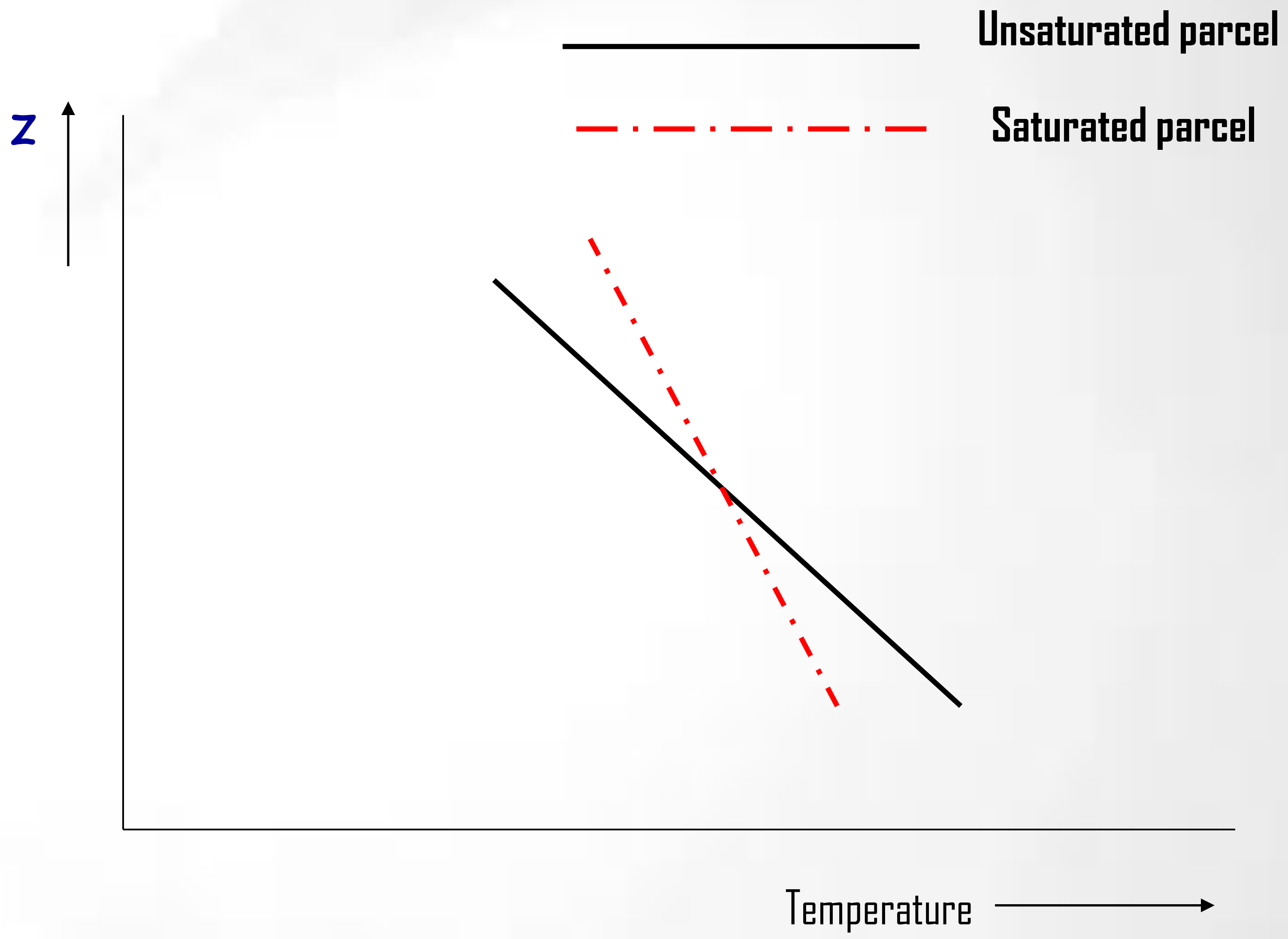
Compression ⇒ warming ⇒ evaporation

i.e., water vapor increases, liquid water decreases

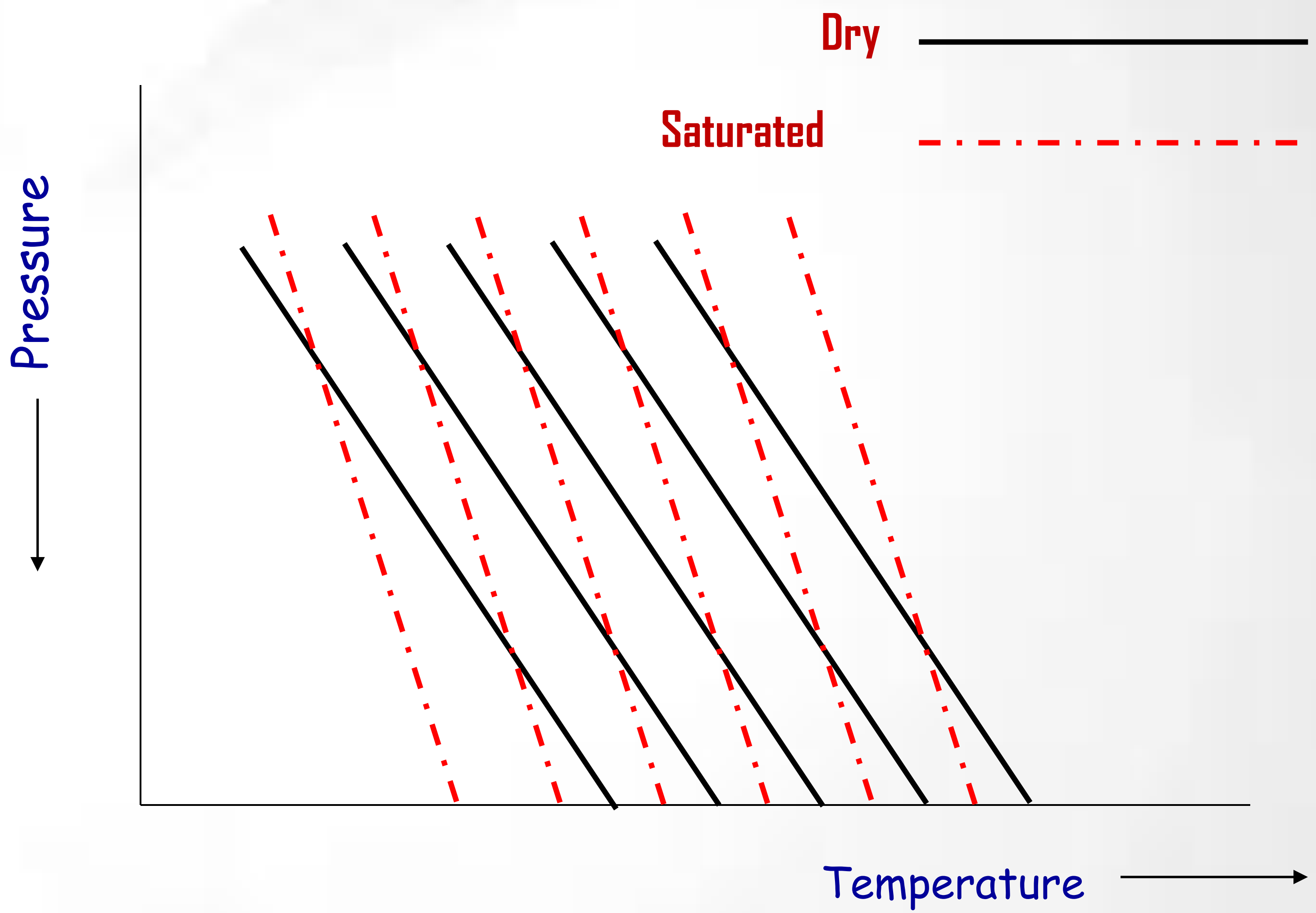
Evaporative cooling partially offsets heating due to compression

Result: Heating rate less than dry adiabatic rate

Comparison

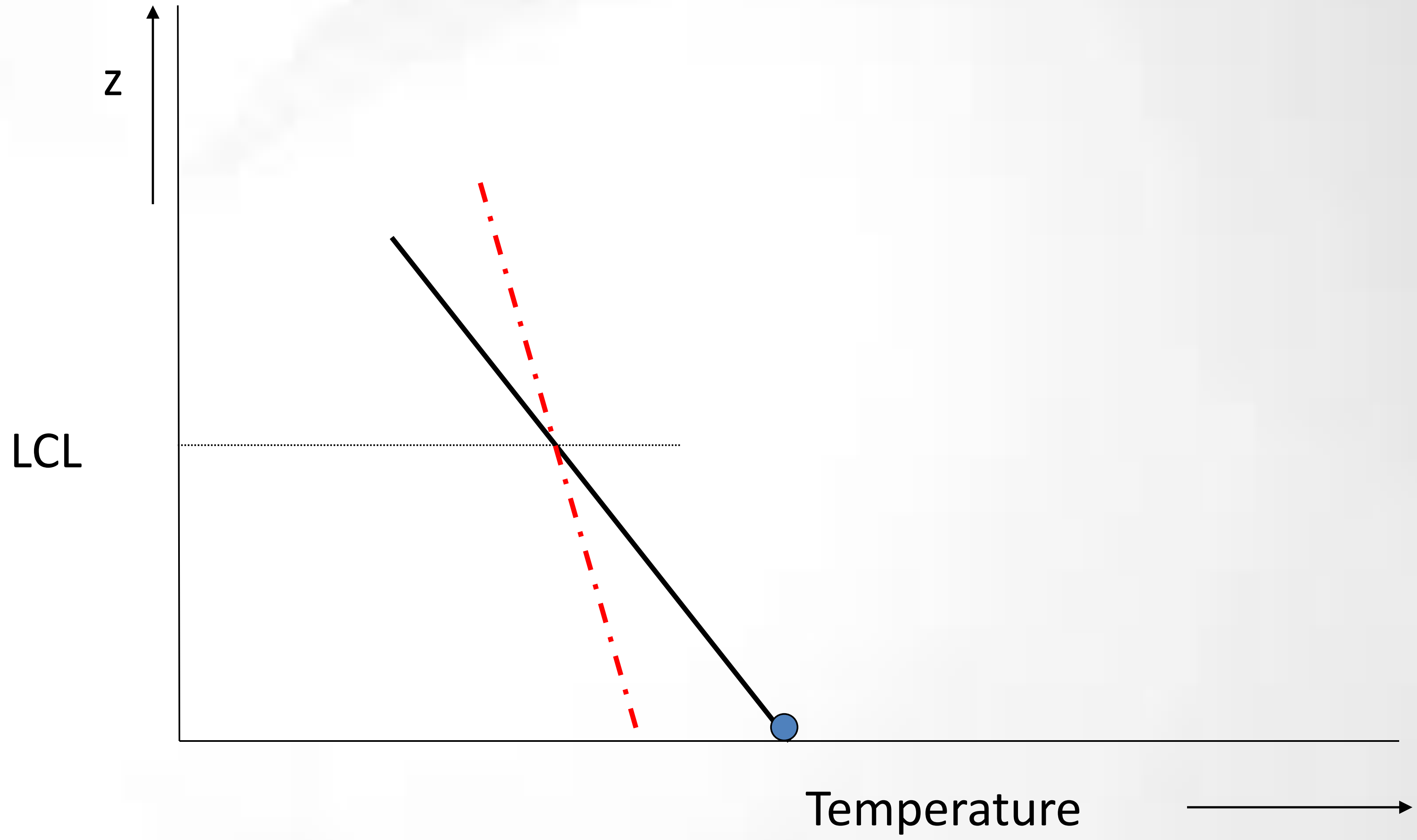


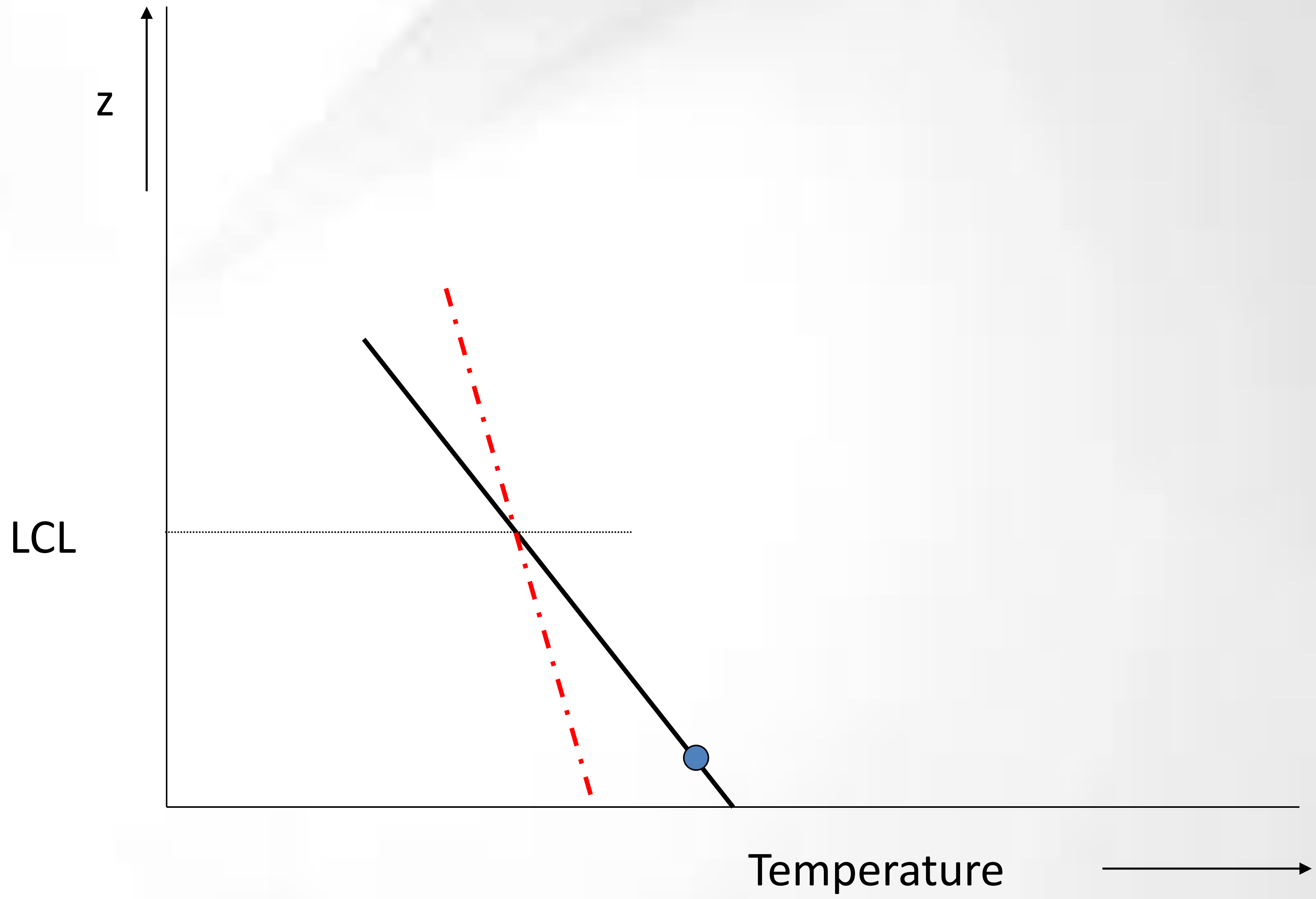
Dry and Saturated Adiabats

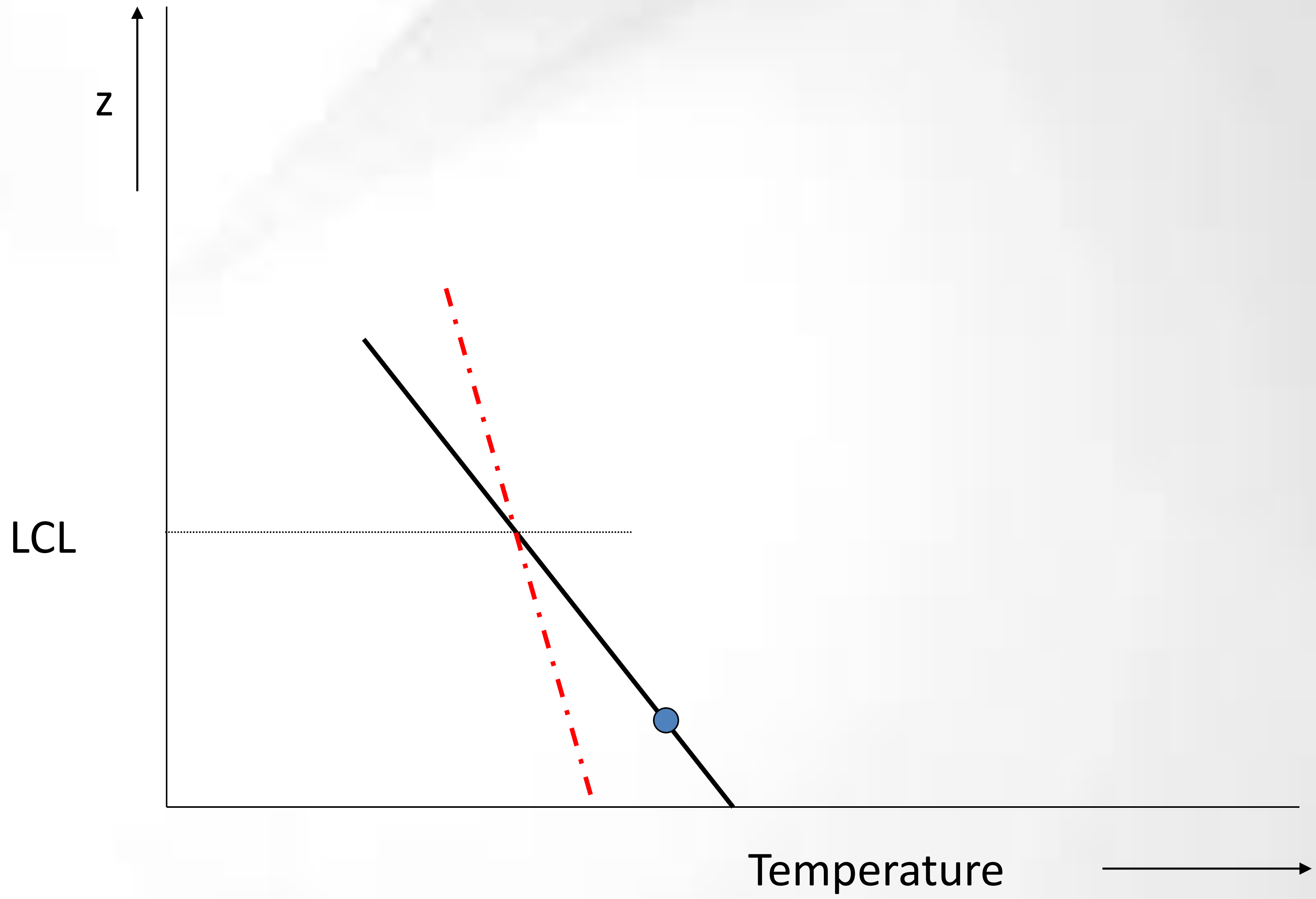


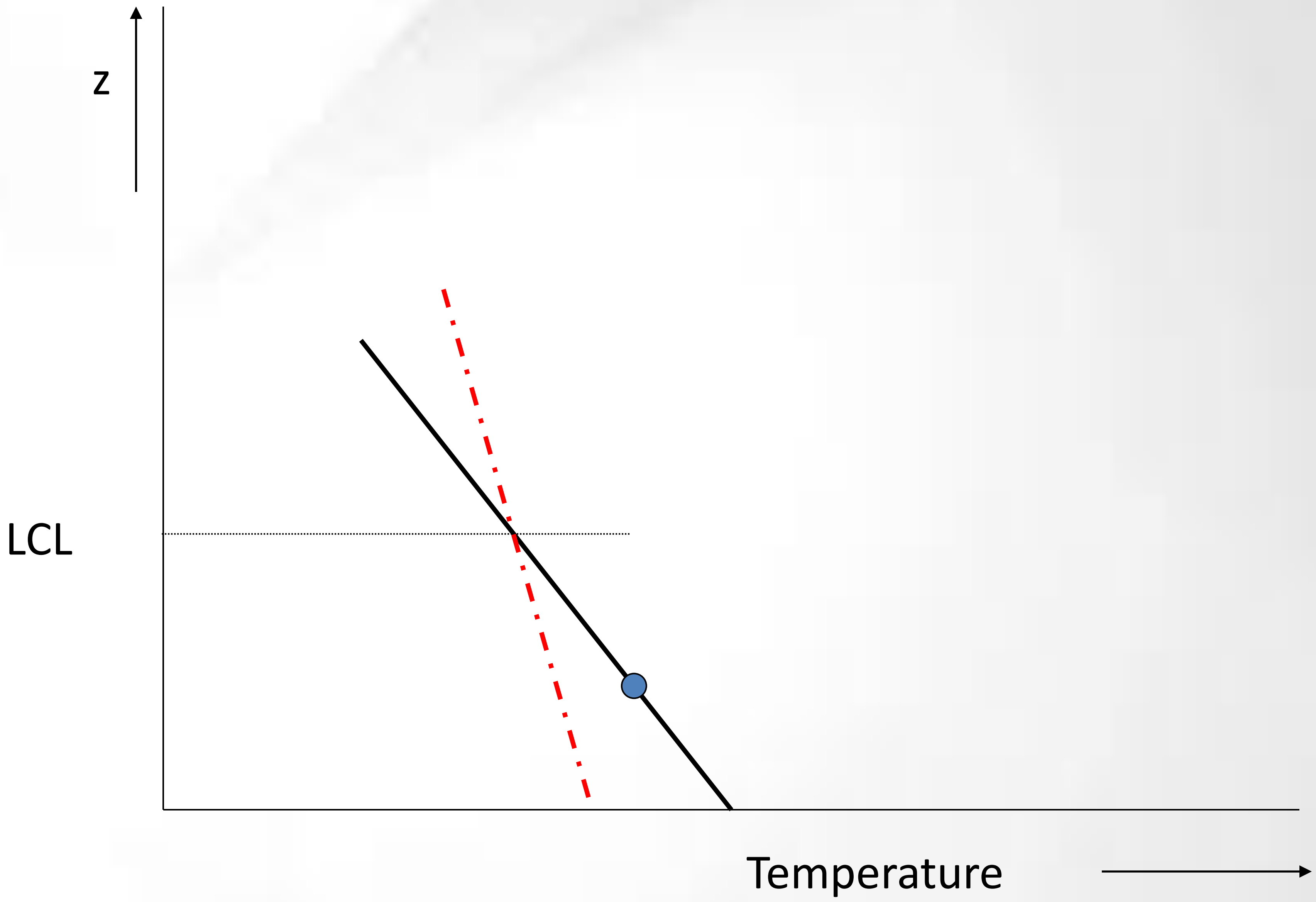
Temperature of Lifted Parcel

Consider a parcel that is initially unsaturated Parcel is lifted to LCL and beyond




z
LCL
Temperature


z
LCL
Temperature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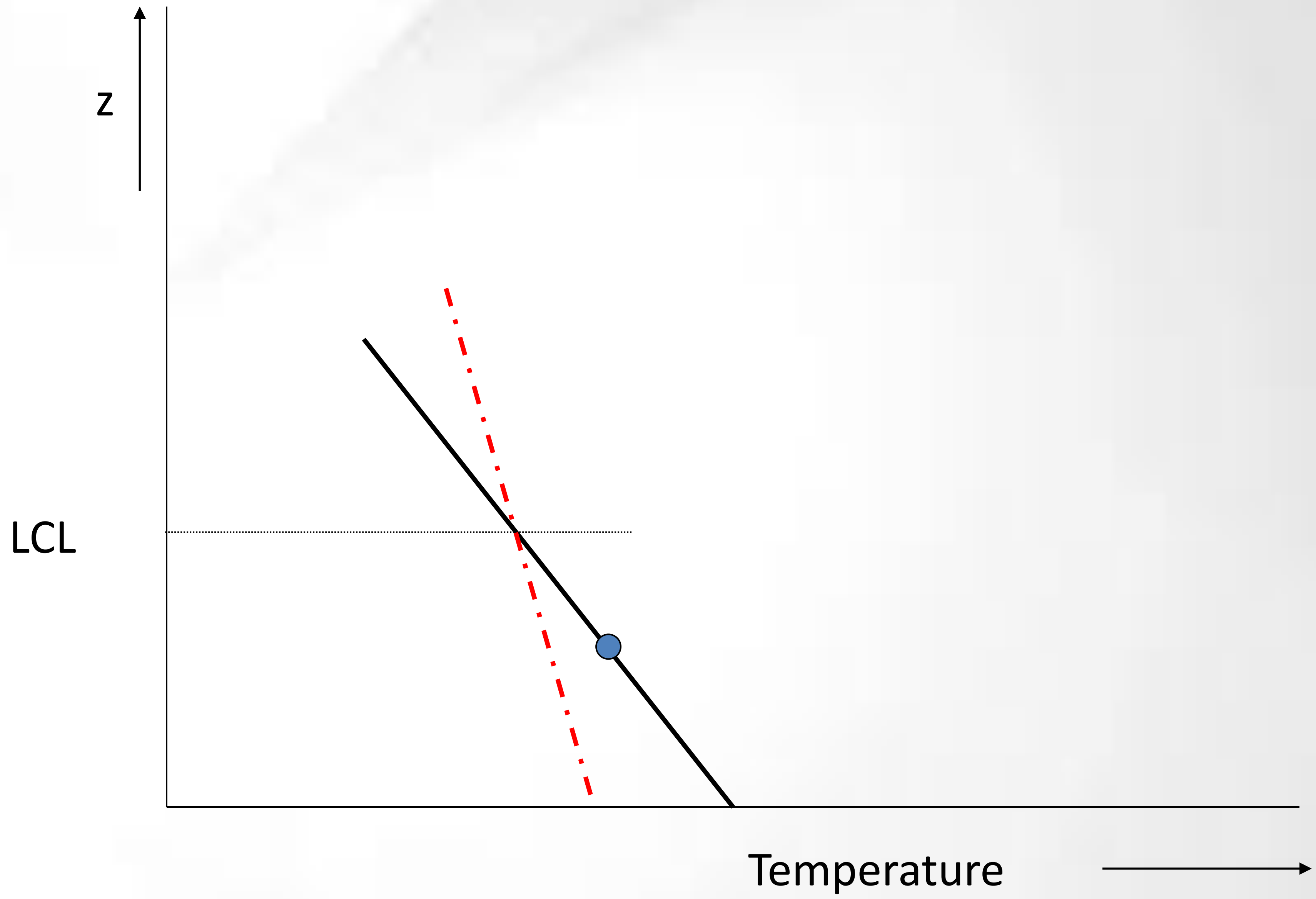
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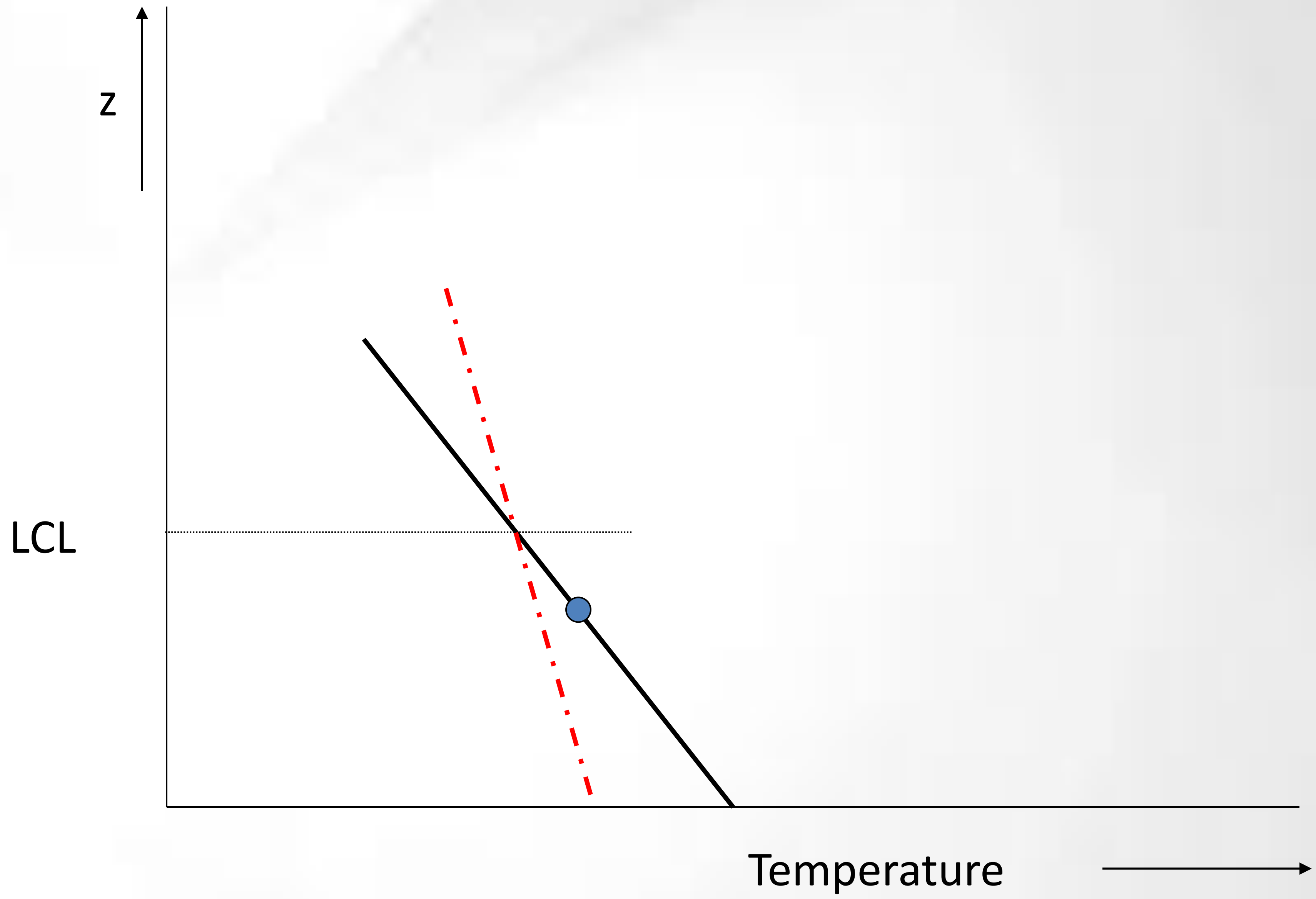
Temperature



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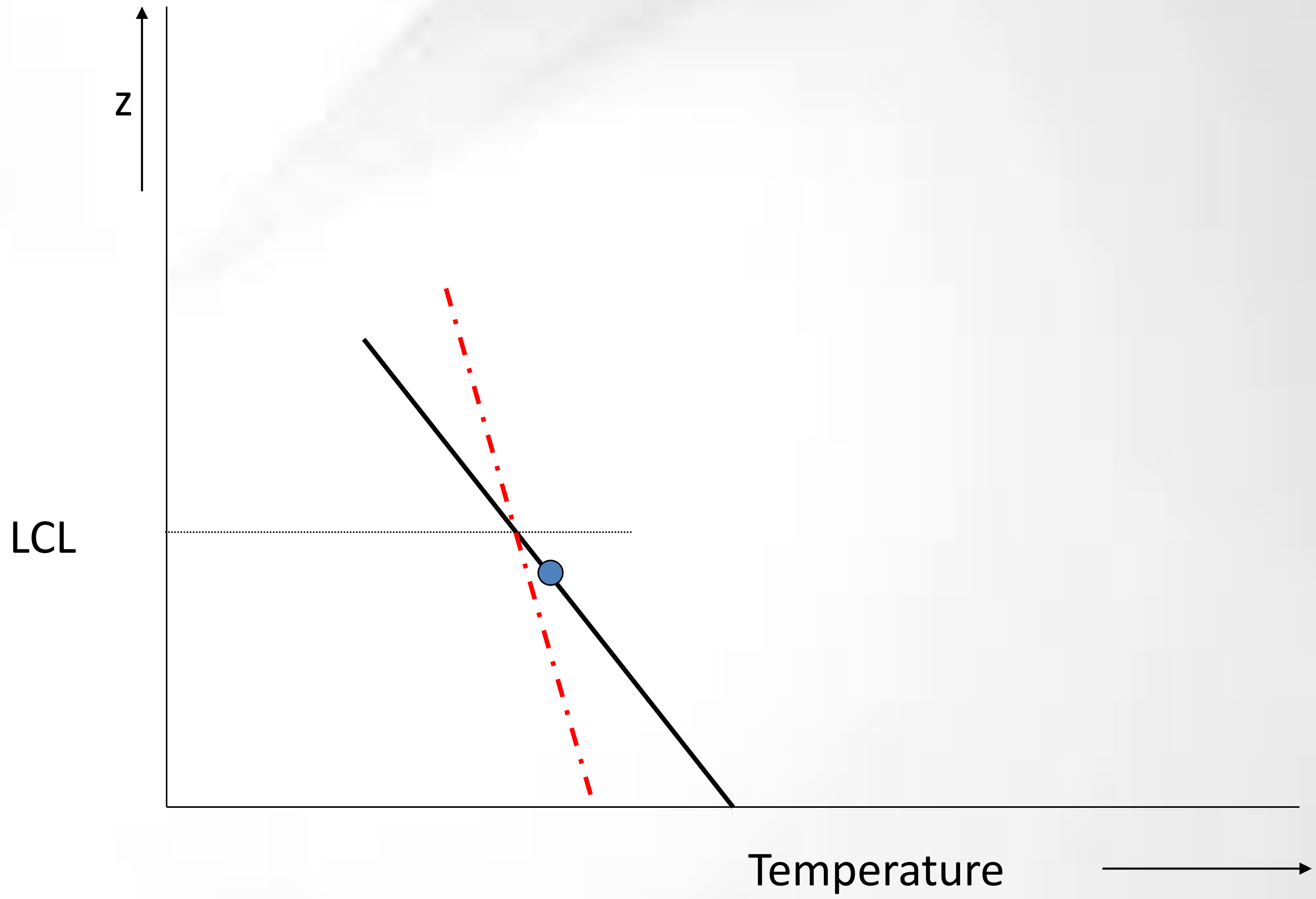

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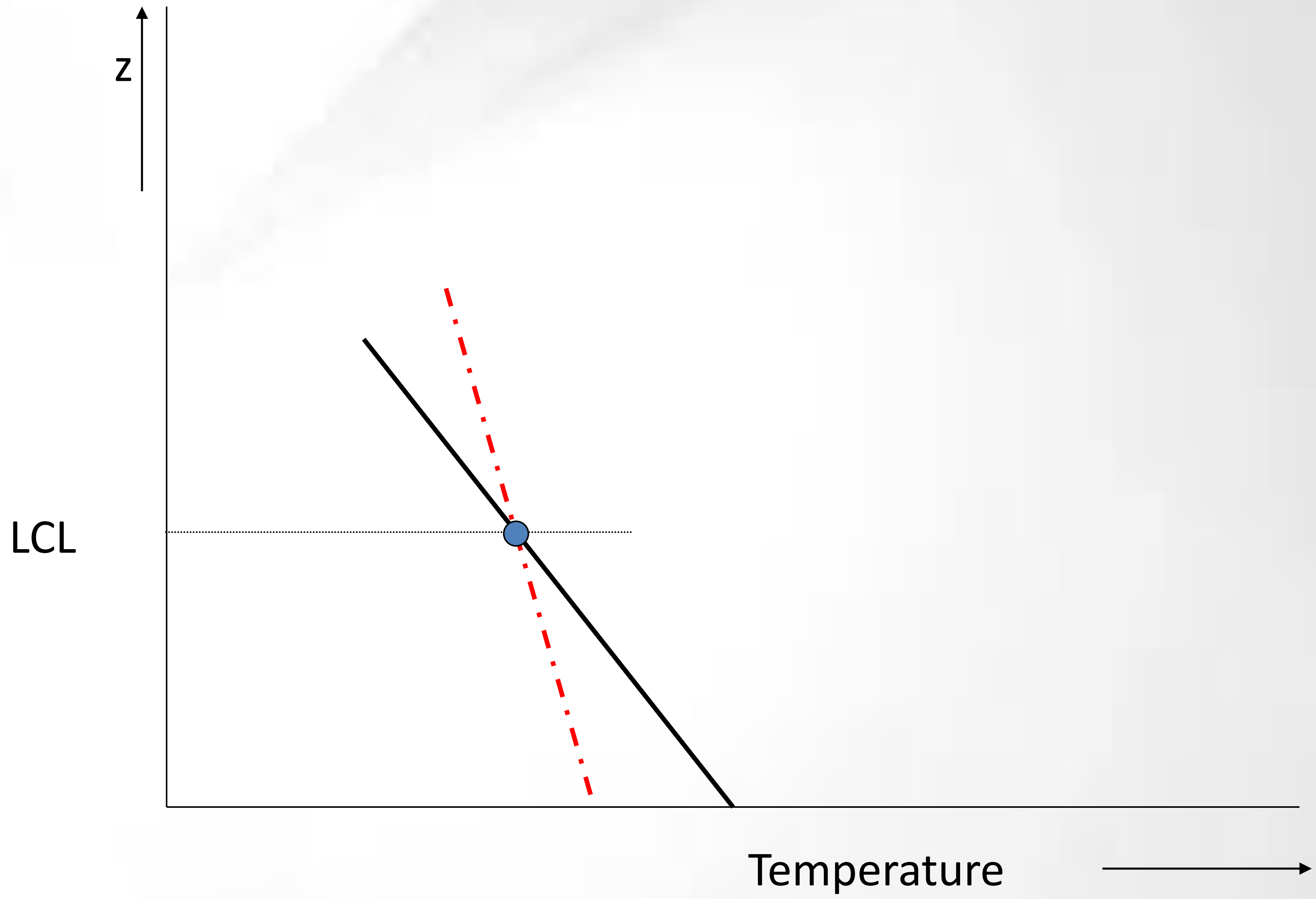
Temperature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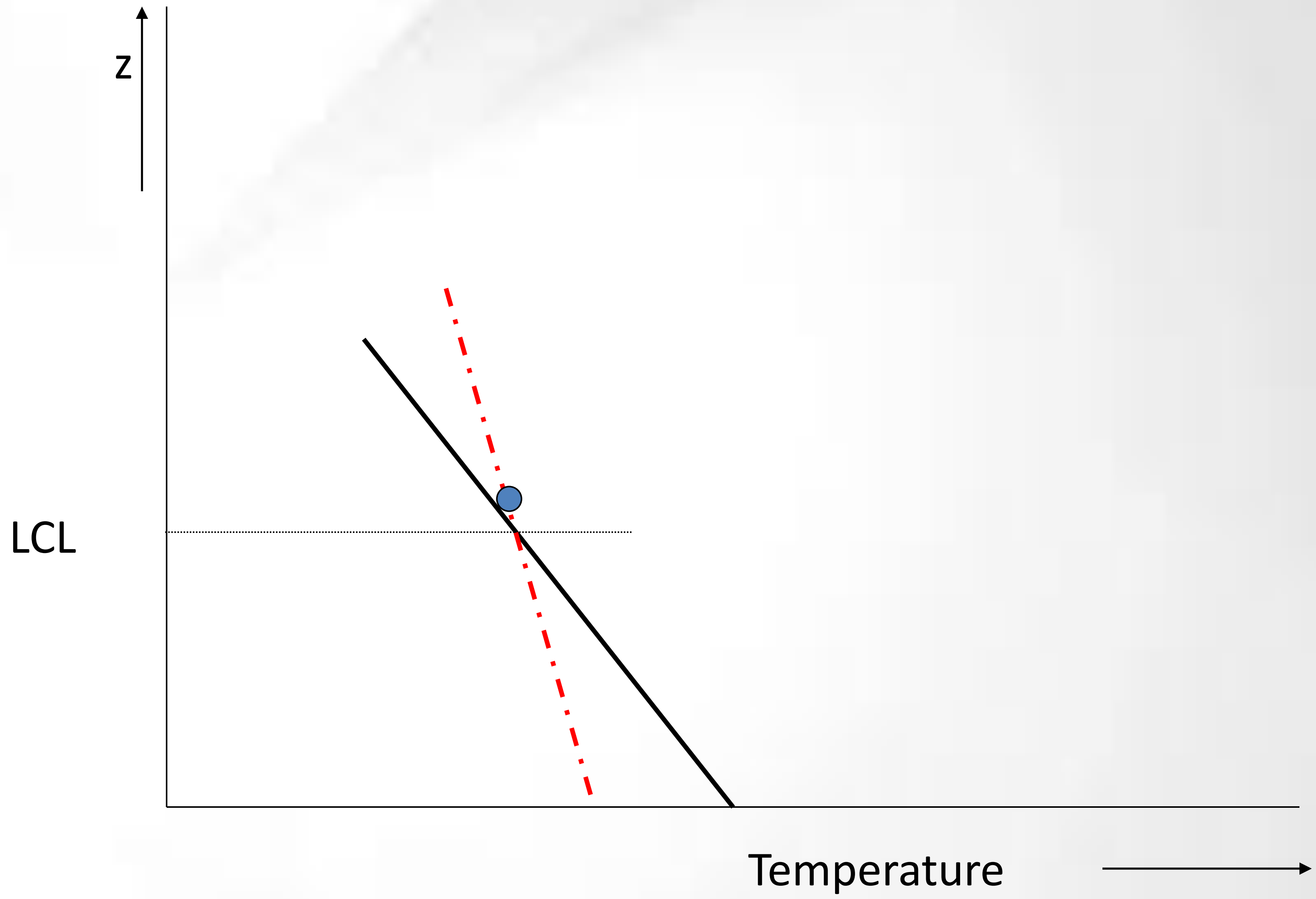
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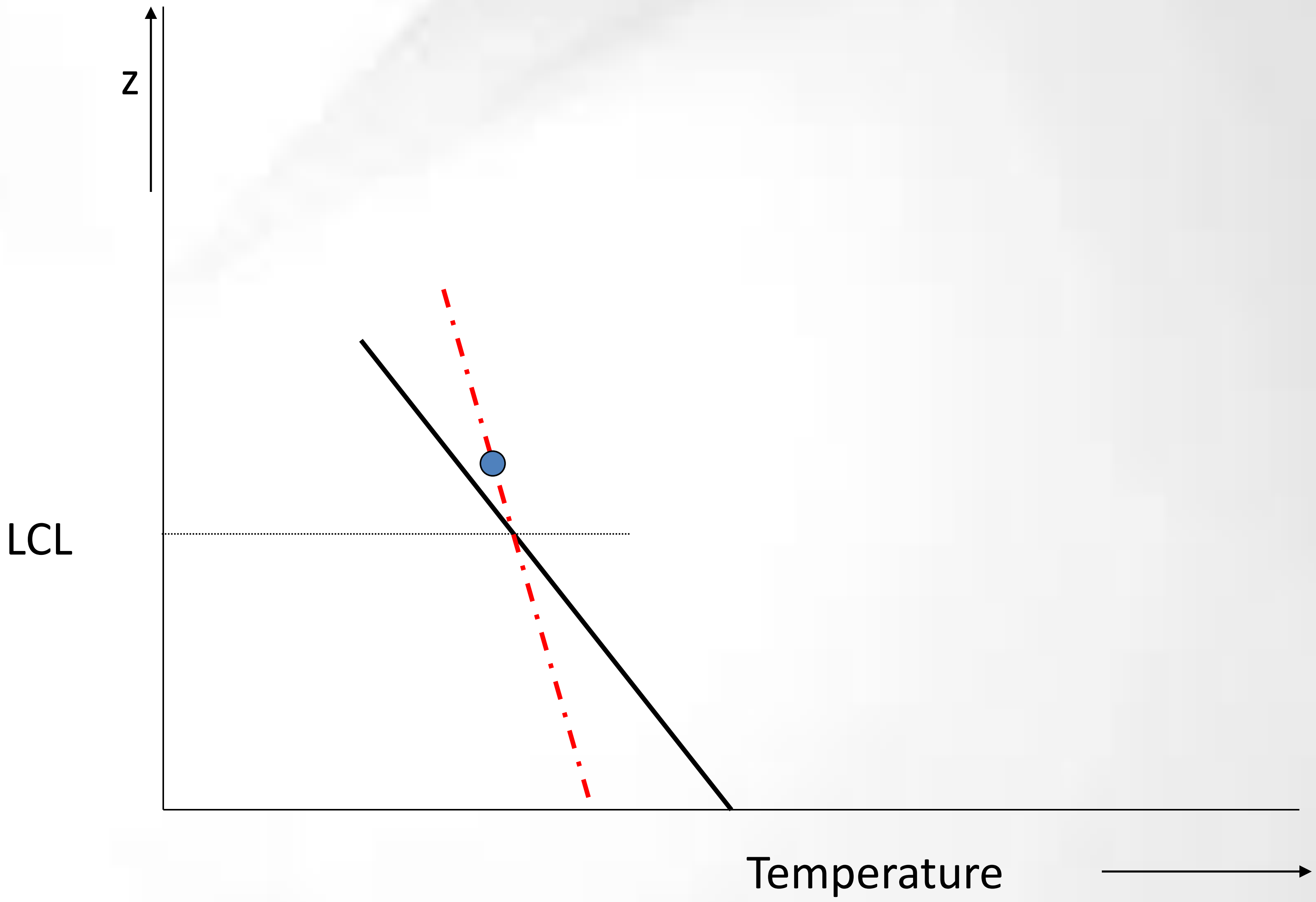
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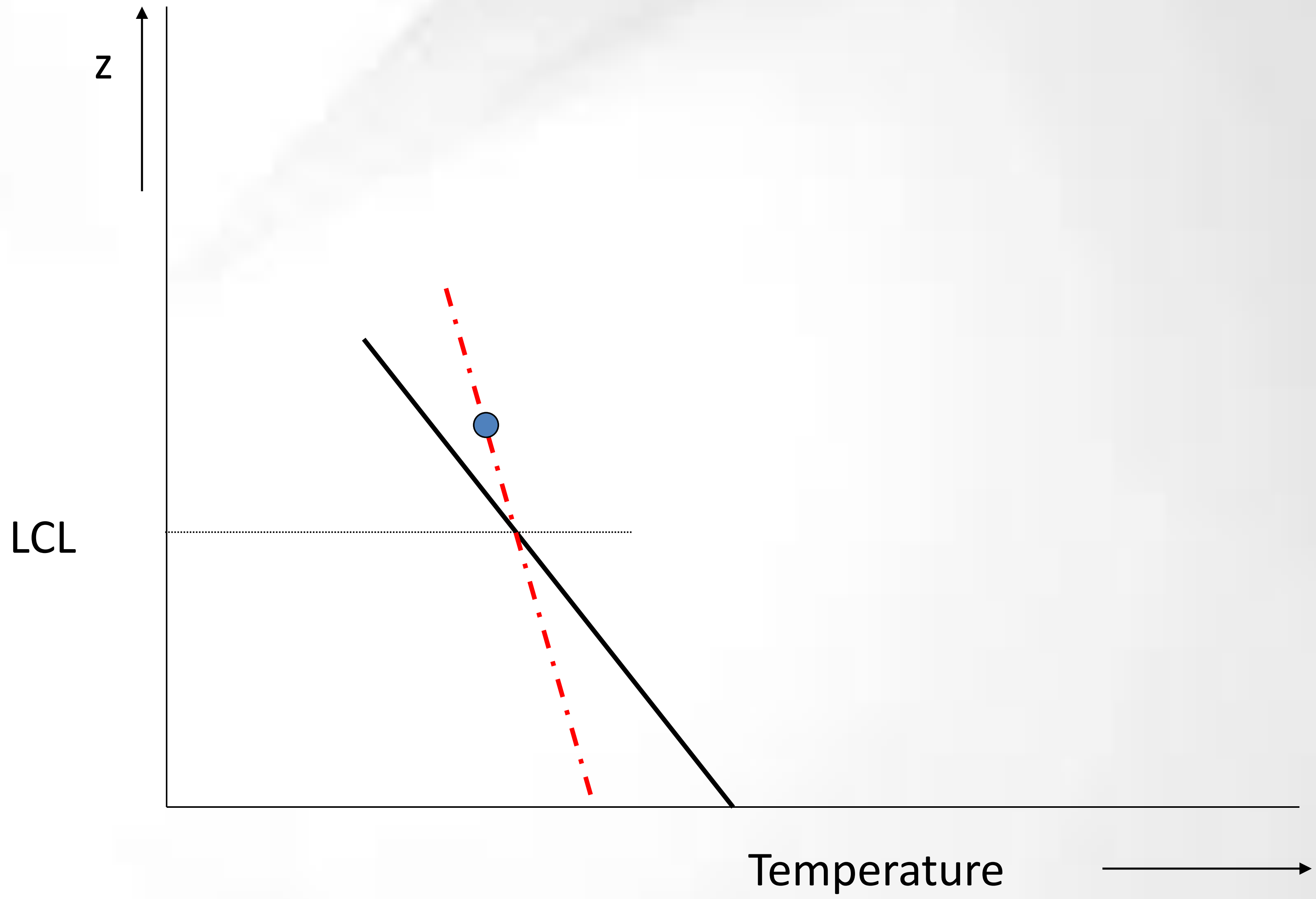
Temperature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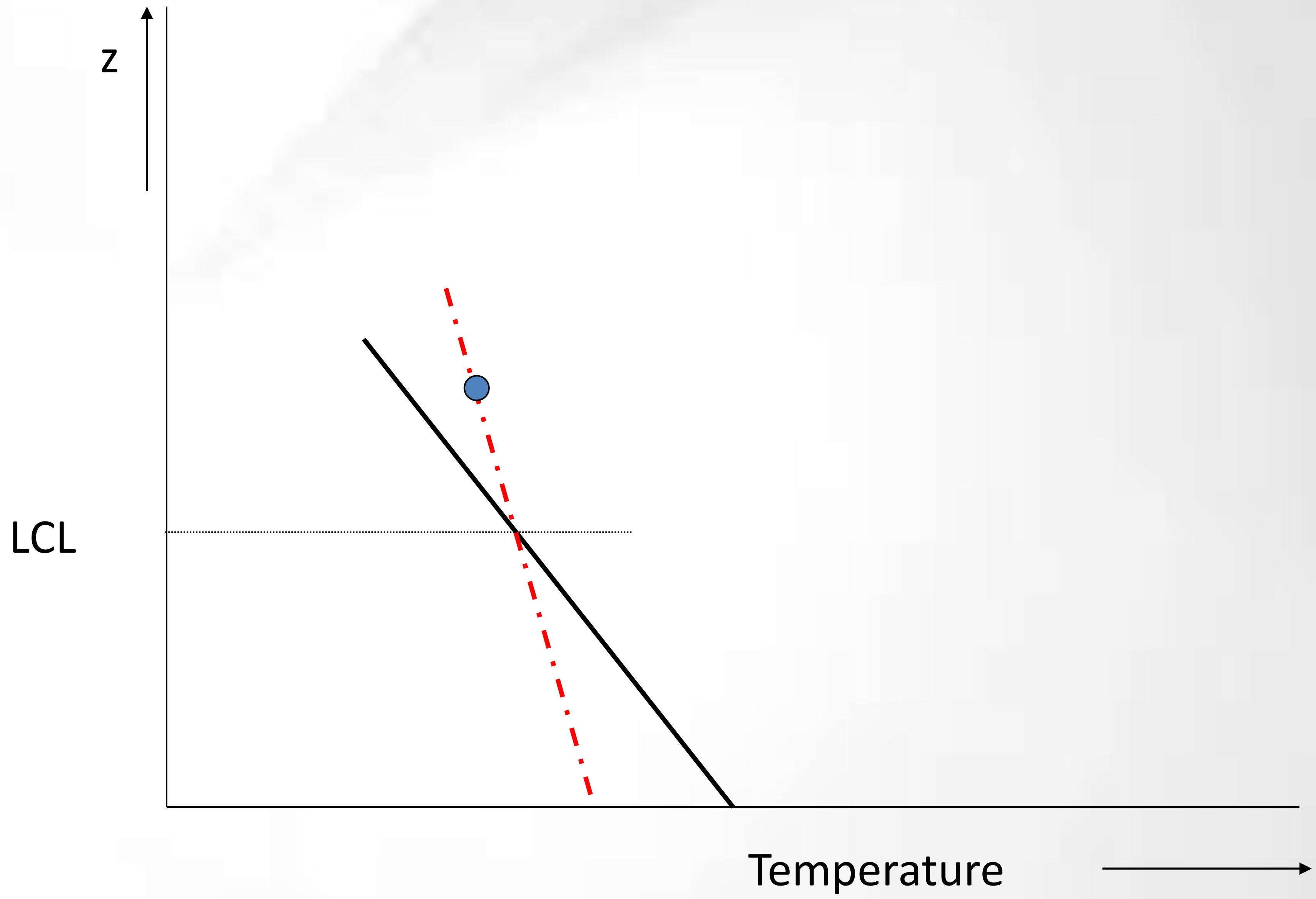
Temperature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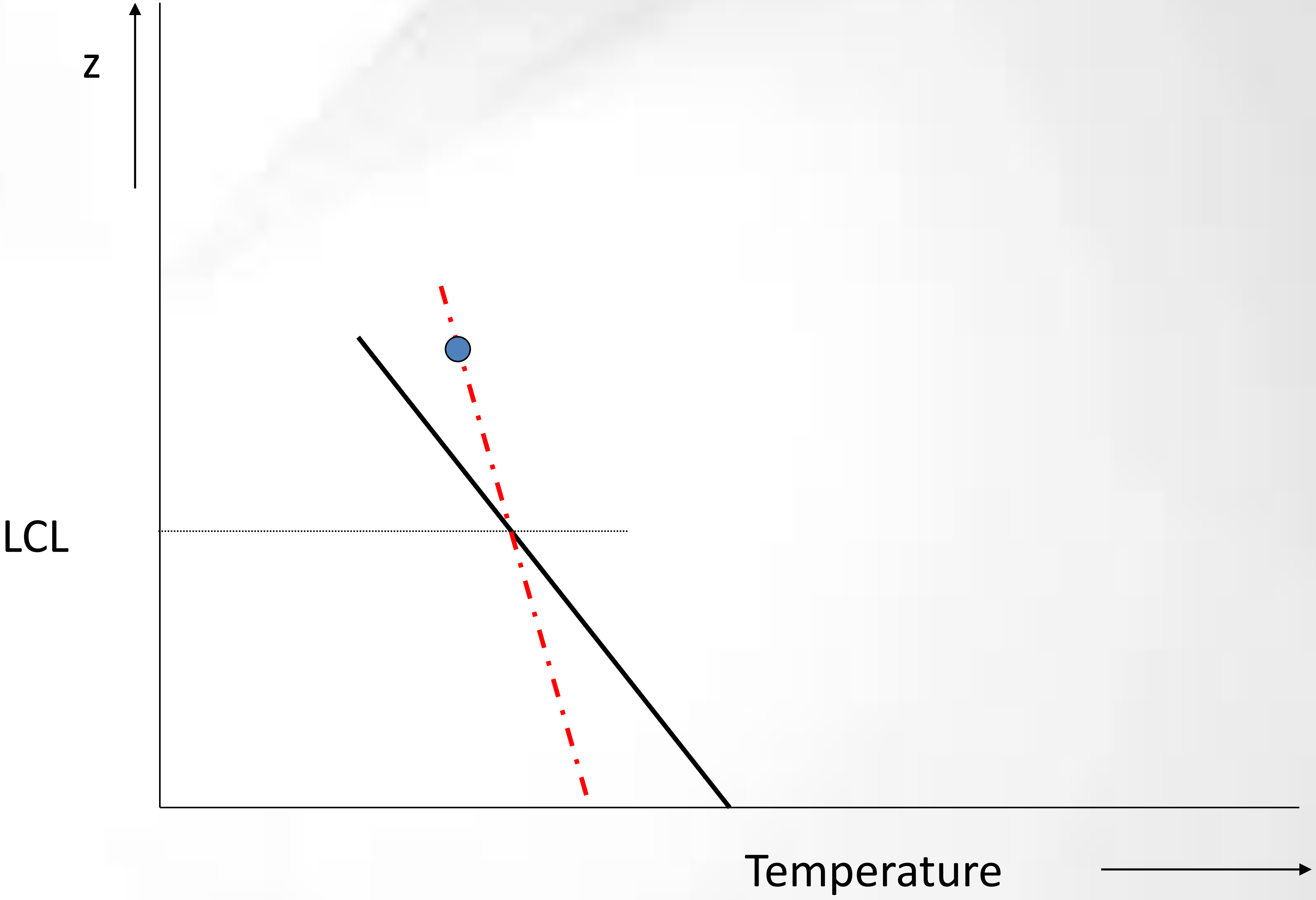
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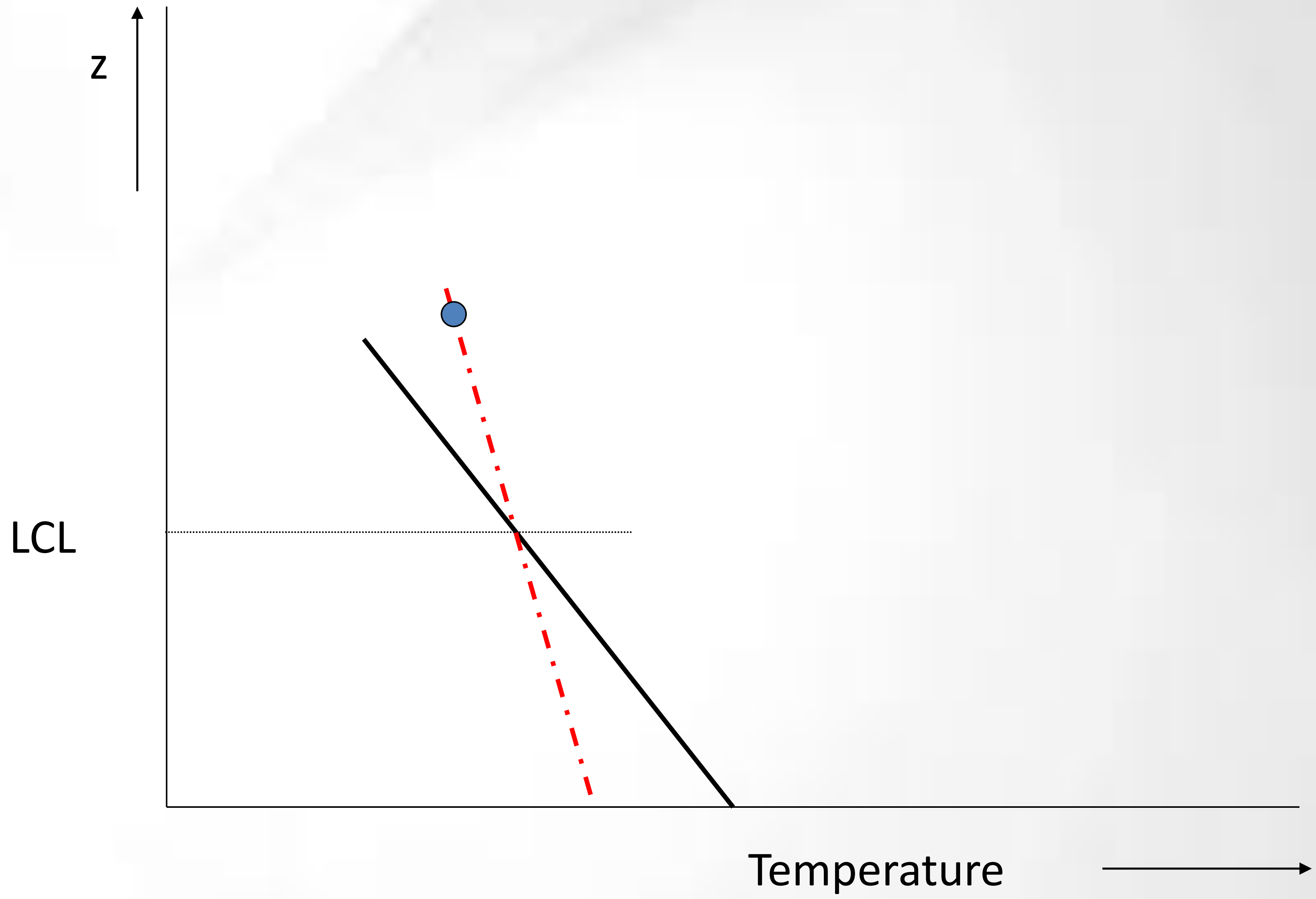
Temperature


z
LCL
Temperature

THERMODYNAMIC DIAGRAMS

which helps us represent atmospheric states and processes on a chart

Purpose:

A thermodynamic diagram is to provide a graphic display of the lines representing major processes to which air may be subject, namely
isobaric, isothermal, dry adiabatic, and pseudoadiabatic processes

Thermodynamic diagrams are particularly useful for examining the effects of moisture, for which there are no simple formula allowing easy analytical calculations.

Fundamental lines:

a) isobars,

b) isotherms,

c) dry adiabats,

d) pseudoadiabats,

e) saturation mixing ratio

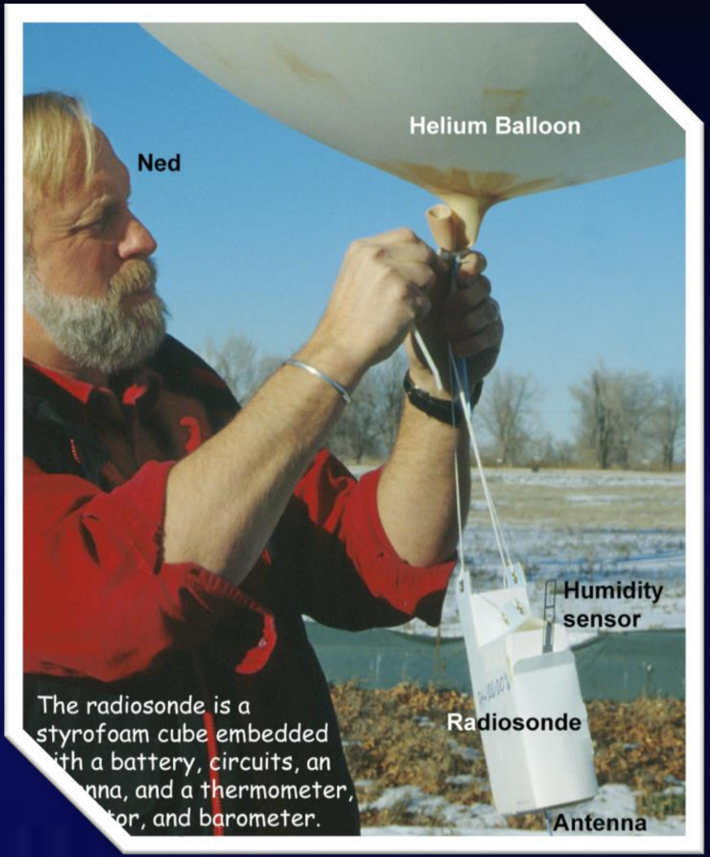
Data to be represented:

the data to be represented are obtained from soundings and consist of temperature, pressure, and humidity

Radiosondes

An instrument package lifted by a balloon with sensors for

pressure, temperature, humidity



There are four such diagrams called :

1) The Emagram

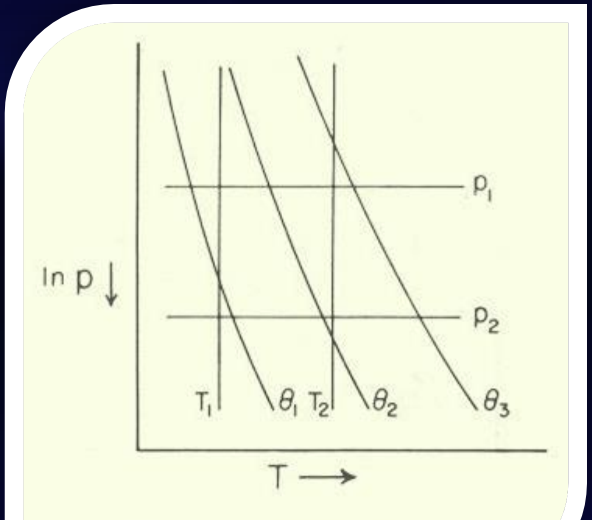


FIG. 1.5. Schematic emagram.

2) The Tephigram

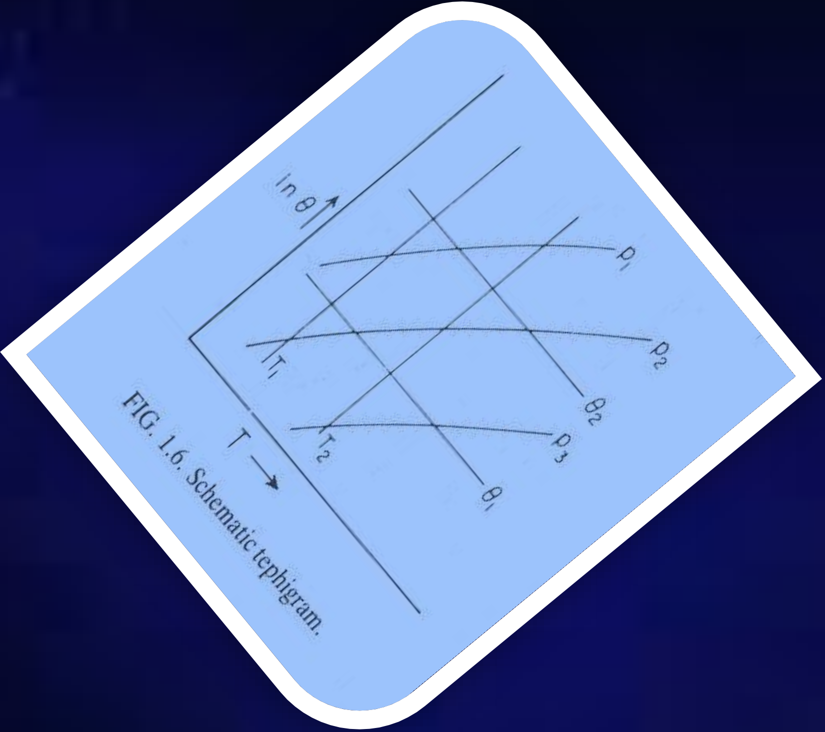


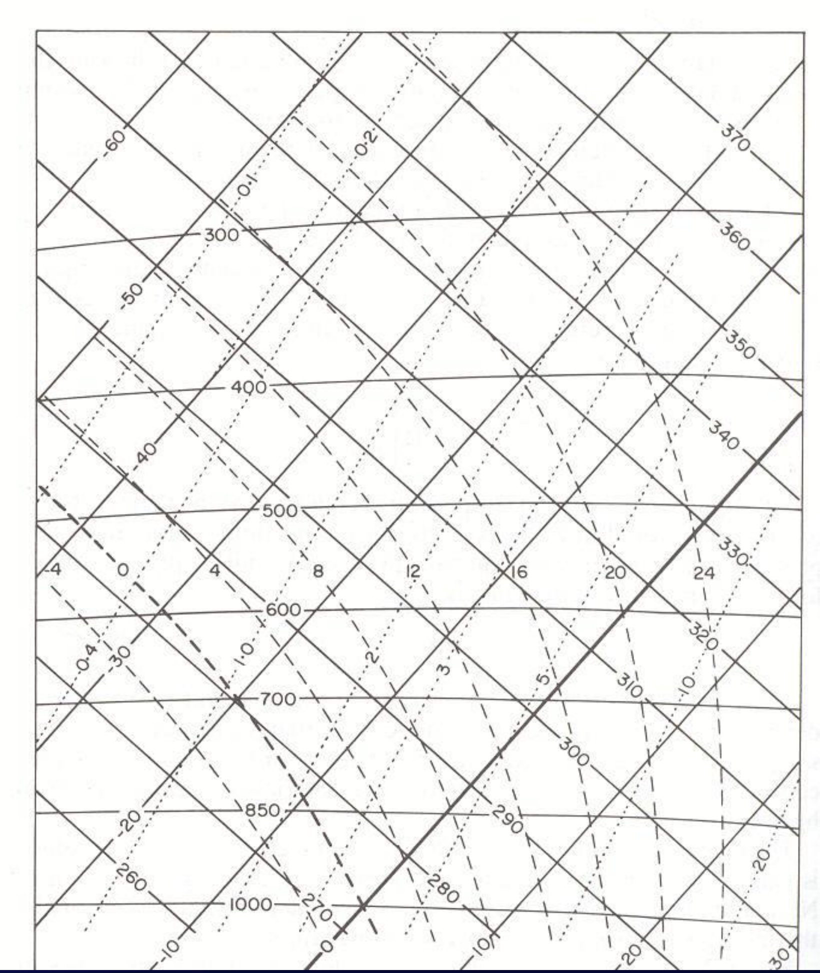
FIG. 1.6. Schematic tephigram.

The tephigram

The Tephigram takes its name from the rectangular Cartesian coordinates : temperature and entropy.

The Greek letter 'phi' was used for entropy, hence Te-phi-gram (or T-Φ-gram)

Meteorologists find it convenient to represent the vertical profiles of atmospheric temperature and moisture on thermodynamic diagrams.



The tephigram

Allows a radiosonde profile to be analysed for stability

Allows calculations involving moisture content (e.g. saturated adiabatic lapse rate) to be performed graphically

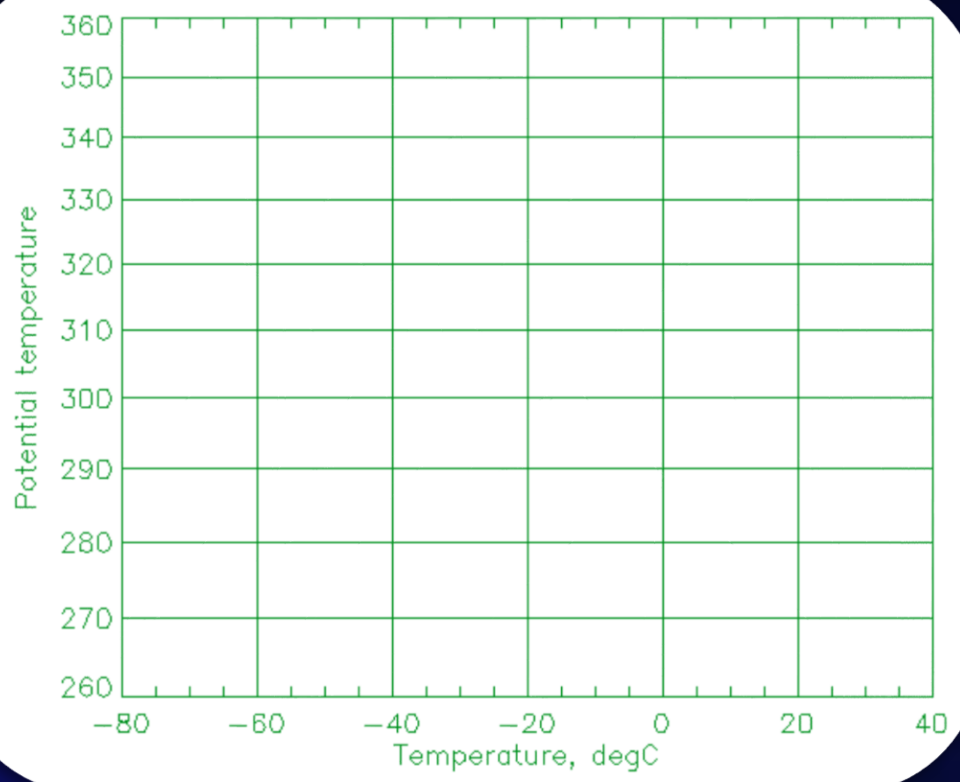
Is very confusing at first sight!

Basic idea

Plot temperature as x-axis and entropy as y

$$S = c_p \ln\theta$$

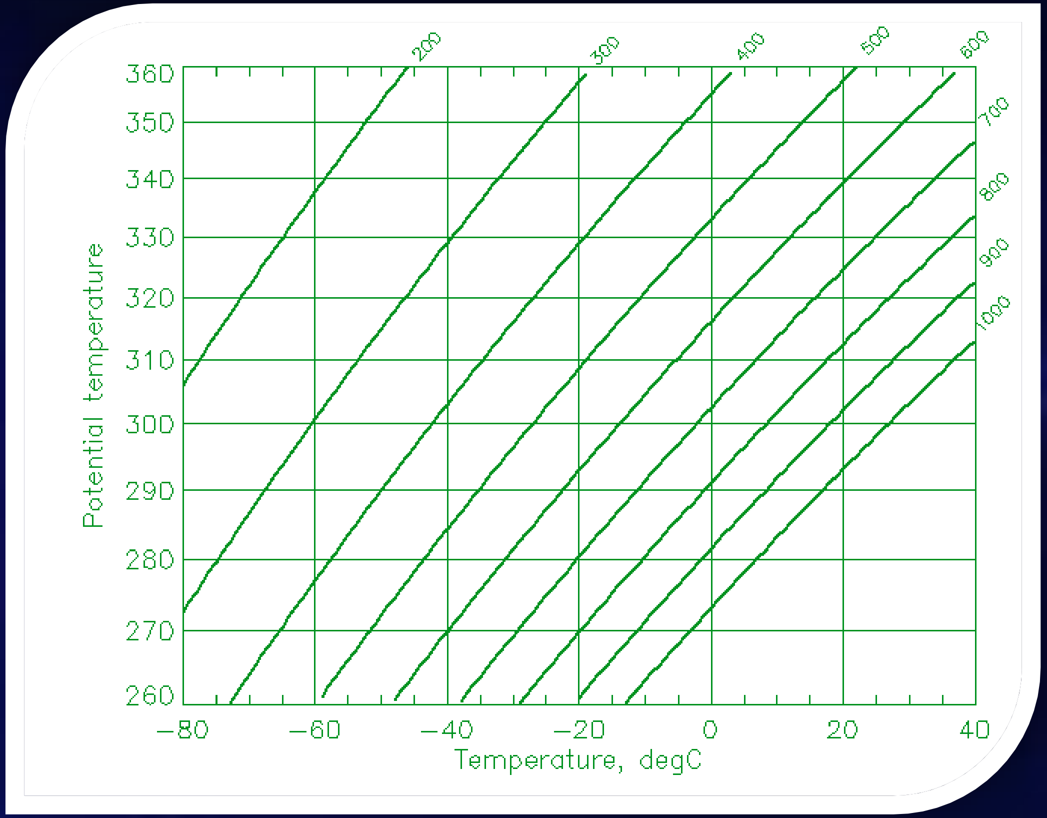
so we plot temperature versus lnθ



Adding pressure

Our measurements are of temperature and pressure, so we want to represent pressure on the plot

The curved lines are isopleths of constant pressure, in mb



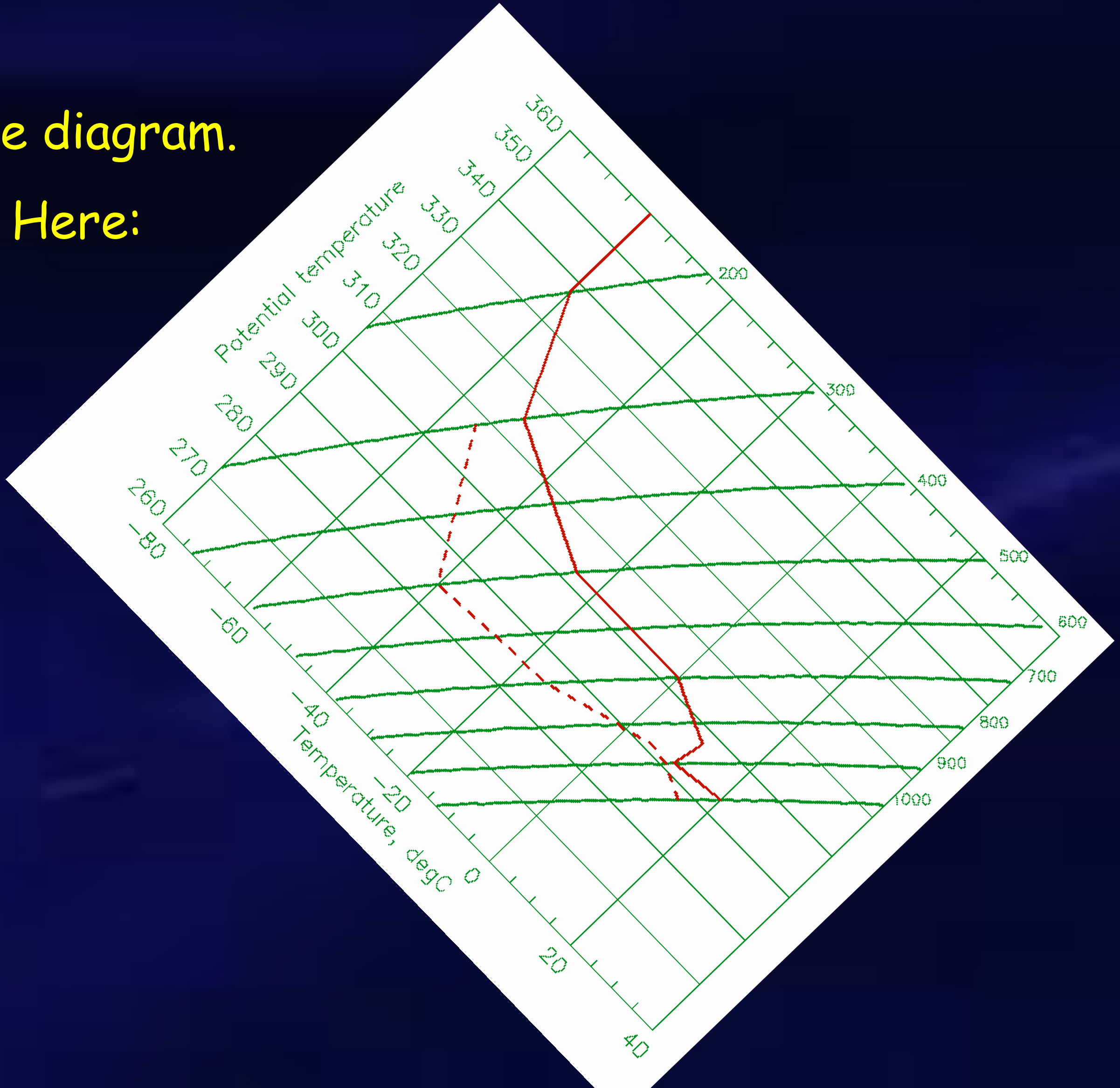
Rotating plot and plotting profile

The diagram is rotated through 45° so that the pressure lines are quasi-horizontal

Temperature and Dew point are plotted on the diagram.

Dew point is simply plotted as a temperature. Here:

Pressure,, mb	Temp., °C	Dew point, °C
1000	20	15
900	10	9
850	11	5
700	0	-15
500	-25	-40
300	-50	-55
200	-60	
100	-60	

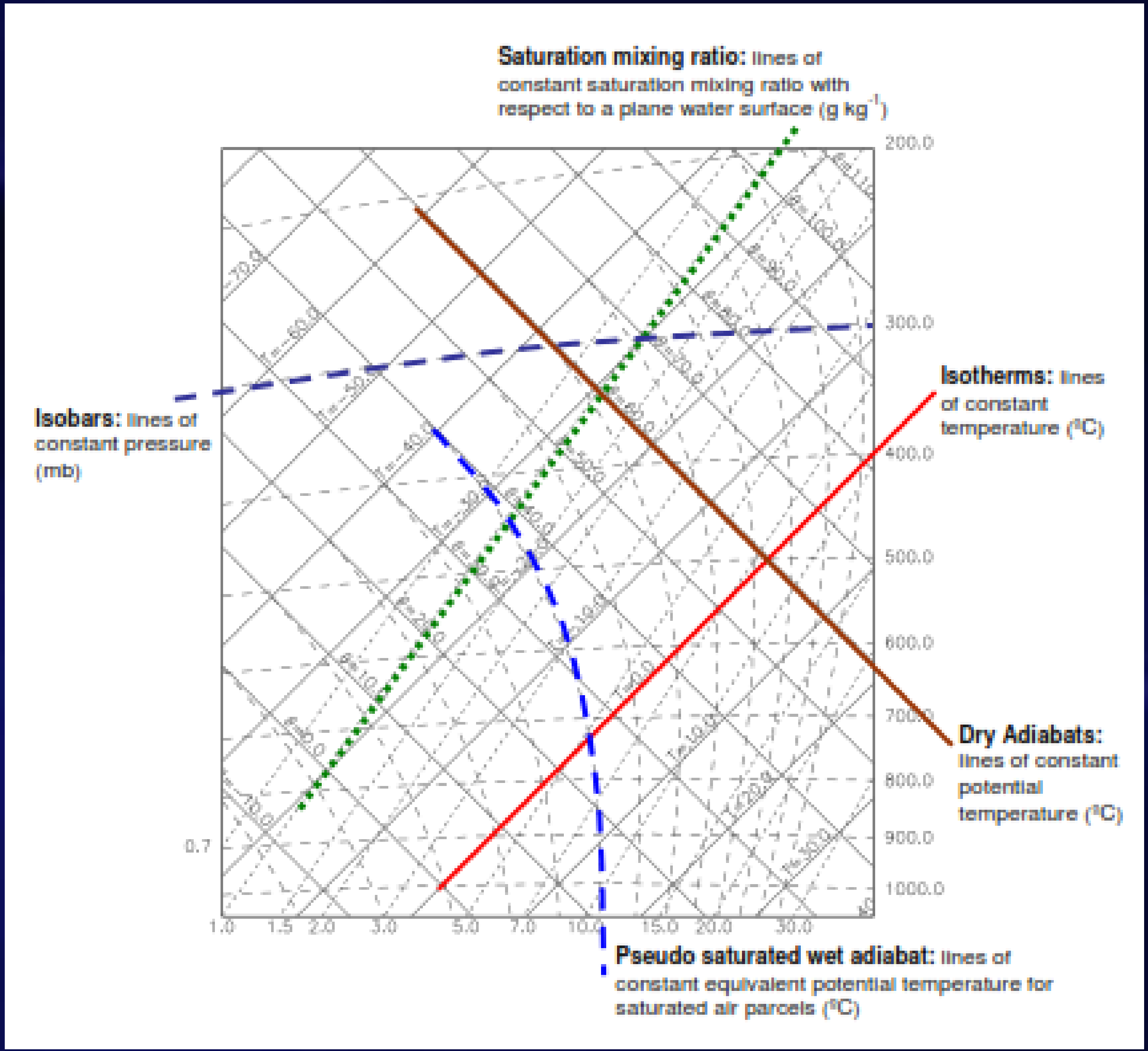


Adding Moisture information

Dew point is a measure of moisture content. The tephigram can be used to convert (T_D, T) to mixing ratio

Mass mixing ratio isopleths are light dashed lines. Units are g kg^{-1}

Curved lines are saturated adiabats – the path a saturated parcel of air follows on adiabatic ascent


Saturation mixing ratio: lines of constant saturation mixing ratio with respect to a plane water surface (g kg-1)
Isobars: lines of constant pressure (mb)
Isotherms: lines of constant temperature (°C)
Dry Adiabats: lines of constant potential temperature (°C)
Pseudo saturated wet adiabat: lines of constant equivalent potential temperature for saturated air parcels (°C)
200.0
300.0
400.0
500.0
600.0
700.0
800.0
900.0
1000.0
0.7
1.0
1.5
2.0
3.0
5.0
7.0
10.0
15.0
20.0
30.0