The Course of Atmospheric Thermodynamics

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COLLEGE OF SCIENCES
ATMOSPHERIC SCIENCES DEPARTMENT
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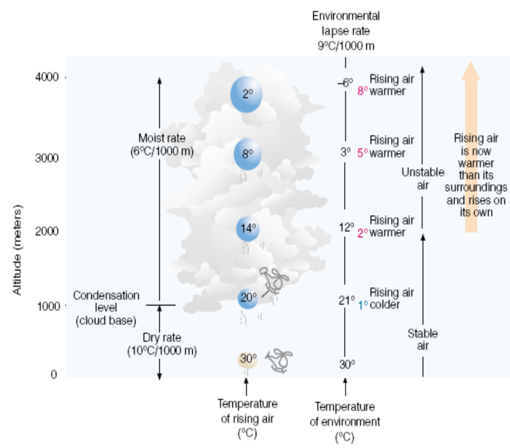
SECOND STAGE
LECTURE 5

THIS LECTURE INCLUDING THE FOLLOWING ITEMS

- CONDENSATION LEVEL.
- FREE CONVECTION LEVEL.
- Some Topics about Thermodynamic Diagrams.

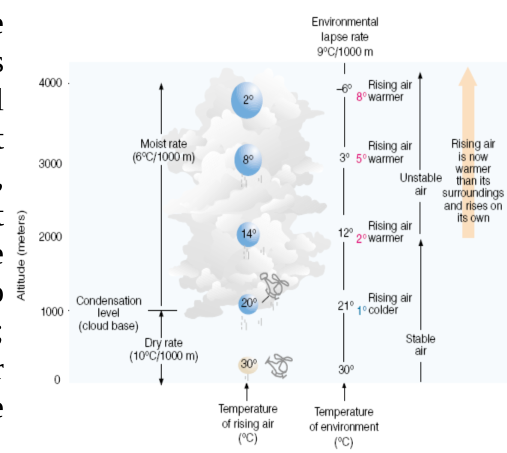
CONDENSATION LEVEL

Suppose an unsaturated (but humid) air parcel is somehow forced to rise from the surface, as the parcel rises, it expands, and cools at the dry adiabatic rate until its air temperature cools to its dew point. At this level, the air is saturated; the relative humidity is 100 percent, and furthers lifting results in condensation and the formation of a cloud.



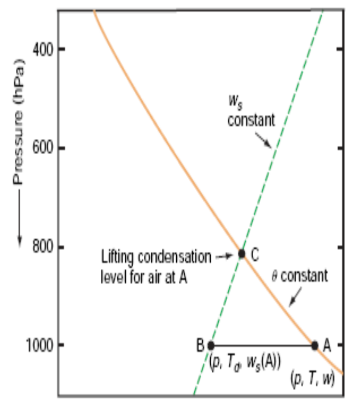
CONDENSATION LEVEL

The elevation above the surface where the cloud first forms is called the condensation level (for example 1 km) , notice that above the condensation level, the rising saturated air cools at the moist adiabatic rate. Notice also that from the surface up to a level near 2 km, the rising; lifted air is colder than the air surrounding it. The atmosphere up to this level is stable.



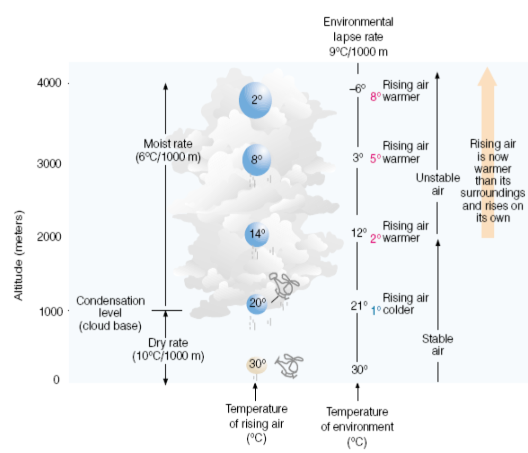
CONDENSATION LEVEL

During lifting the mixing ratio *w* and potential temperature of the air parcel remain constant, but the saturation mixing ratio w_s decreases until it becomes equal to *w* at the LCL. Therefore, the LCL is located at the intersection of the potential temperature line passing through the temperature *T* and pressure *p* of the air parcel, and the w_s line that passes through the pressure *p* and dew point T_d of the parcel



FREE CONVECTION LEVEL

Due to the release of latent heat, the rising air near 2 km has actually become warmer than the air around it. Since the lifted air can rise on its own accord, the atmosphere is now unstable. The level in the atmosphere where the air parcel, after being lifted, becomes warmer than the air surrounding it, is called the level of free convection.



Why We Use Thermodynamic Diagrams?

- They are used to graphically display the relation between two of the thermodynamic variables T, V, and p, Process lines represent on the diagram. This is done through processes lines which represent specific thermodynamic processes, and each chart contains five sets of lines including: Isotherms , Isobars , Adiabats, Pseudoadiabats(moist adabats), Saturation moisture lines.
- We used them for basic calculation such as condensation level, temperature of free convection.

Why We Use Thermodynamic Diagrams?

- When an air parcel undergoes a reversible process, the succession of states is represented on the thermodynamic diagram by a curve.
- A cyclic process is represented by a closed curve.
- On some charts the area so enclosed is directly proportional to the work done in the process.

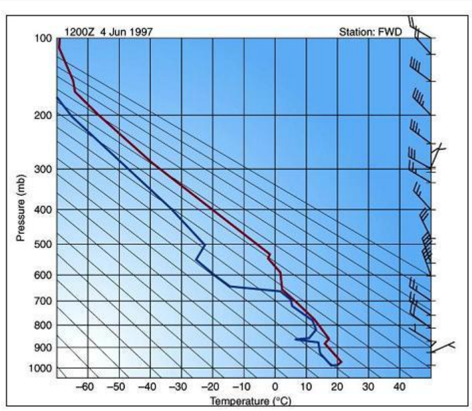
FYI: Thermodynamic Diagrams Info.

Common Thermodynamic Diagrams and Some of Their Properties

Chart	X (x-axis)	Y (y-axis)	Equation for T = const	Equation for θ = const	Thermodynamic work by system	Remarks
Aerogram or **Refsdal diagram**	$\ln T$	$-T \ln p$	$X = \ln T$	$Y = \frac{c_p}{R}(\ln\theta - X) + \text{const}$	$-R\int Y dX$	Only isotherms are straight lines.
Clapeyron (α, $-p$)	α	$-p$	$Y = -\frac{RT}{X}$	$Y = \text{const}\left(\frac{\theta}{X}\right)^{c_p/c_v}$	$-\int Y dX$	Classic physics diagram; isentropes curved and nearly parallel to isotherms.
Emagram or **Neuhoff diagram**	T	$-\ln p$	$X = T$	$Y = \text{const} - \frac{c_p}{R}\ln\left(\frac{X}{\theta}\right)$	$-R\int Y dX$	Isentropes slightly curved.
Pastagram	T_0	$T_0\left[1 - \left(\frac{p}{p_0}\right)^{R\gamma/g}\right]$	$Y = X - T$	$Y = X\left[1 - \left(\frac{\theta}{X}\right)^{1/(1 - g/c_p\gamma)}\right]$	Not relevant	T_0, p_0 are surface values, γ = 6.5 K km^{-1}; used mainly for hydrostatic calculations.
Stüve or Pseudo-adiabatic	T	$-p^{R/c_p}$	$X = T$	$Y = \text{const}(X/\theta)$	$c_p\int \ln(-Y) dX$	Isentropes are straight, inclined lines; proportionality of area and work sacrificed.
Skew T–log p or Skewed emagram	$T - c \ln p$	$-\ln p$	$Y = \frac{X - T}{c}$	$\frac{R}{c_p}Y + \ln(X - cY) = \ln\theta + \text{const}$	$-R\int Y dX$	Isotherms straight, but tilted according to $T = X - cY$; isentropes curved.
Tephigram	T	$\ln\theta$	$X = T$	$Y = \ln\theta + \text{const}$	$-c_p\int Y dX$	Isobars are curved, inclined lines.
Thetagram	T	$-p$	$X = T$	$Y = X\ln(-Y) + \text{const}$	$-R\int (X/Y) dY$	Isentropes curved; area not proportional to work.

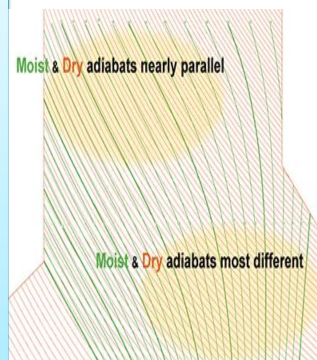
Isobars and Isotherms in a Thermodynamic Diagrams

The pressure and temperature uniquely define the thermodynamic state of a dry air parcel of unit mass at any time. The horizontal lines represent isobars and the vertical lines describe isotherms.



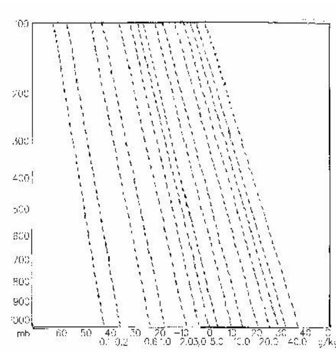
Dry Adiabats and Moist or Pseudo Adiabats

Dry Adiabats lines represent the change in temperature that an unsaturated air parcel would undergo if moved up and down in the atmosphere.
Pseudo or moist Adiabatic Lines usually curves portray the temperature changes that occur upon a saturated air parcel when vertically displaced. Saturation adiabats appear on the thermodynamic diagram as a set of curves with slopes ranging from 0.2C°/100 m in warm air near the surface to that approaching the dry adiabats (1C°/100 m) in cold air aloft, why?



Isohume – Mixing Ratio Lines

These lines (also called saturation mixing ratio lines or isopleths) uniquely define the maximum amount of water vapor that could be held in the atmosphere (saturation mixing ratio) for each combination of temperature and pressure. These lines can be used to determine whether the parcel were saturated or not.



What are the properties of a Useful Thermodynamic Diagrams?

The diagrams are such that equal area represents equal energy on any point on the diagram.
A useful thermodynamic diagram should have the following general properties

- The **area enclosed by a cyclic process** should be **proportional to the work done** during the process.
- As many of the **process lines** as possible should be **straight**.
- The **angle** between the isotherms and adiabats should be as **close to 90** as possible.

FYI: How to create a diagram?

We can create a diagram **with area proportional to work** using the p-α diagram.
Since work per unit mass is defined as $dw = - p\, d\alpha$, the area on a p- α diagram is proportional to work.

But this diagram is not very useful for meteorologists because

- The angle between isotherms and adiabats is very small
- Process lines aren't very straight
- Volume is not a convenient thermodynamic variable for meteorology.

How to create a Useful diagram for Meteorologist?

By using (T and p) as the thermodynamic variables, but we have to find a way of setting up the axes of our diagram so that area will be proportional to work.

What are the True thermodynamic diagram?

Because equal area represents equal energy on any point on the diagram, a true thermodynamic diagram has an Area and Energy

FYI: How to create a Useful diagram for Meteorologist?

- Let the variables for the axes be X and Y, and let X and Y be functions of the thermodynamic variables.
- For area to equal work in a cyclic process we need

$$-\oint p\,d\alpha = \oint Y\,dX \,,$$

or

$$\oint (p\,d\alpha + Y\,dX) = 0 \,.$$

- The quantity $p\,d\alpha + Y\,dX$ is an exact differential. Therefore, from the Euler reciprocity relation

$$\left(\frac{\partial p}{\partial X}\right)_\alpha = \left(\frac{\partial Y}{\partial \alpha}\right)_X \,.$$

Equation A

- We are free to choose any X and Y and as long as they meet the above restriction then area will be proportional to work on our diagram.

What are the Types of Diagrams?

Some of the types of the Thermodynamic Diagrams are:

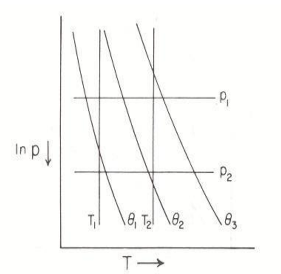
- Emagram
- Tephigram
- SkewT/Log P diagram (modified emagram)
- Psuedoadiabatic (or Stüve) diagram

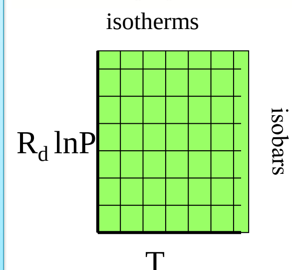
What is The EMAGRAM? What are the Properties of its Lines?

The emagram (energy-per-unit-mass diagram) is created by letting X = T, and by using the equation of state for dry air with some mathematical processes we get the diagram axes: $X=T$, $Y= - R_d \ln P$

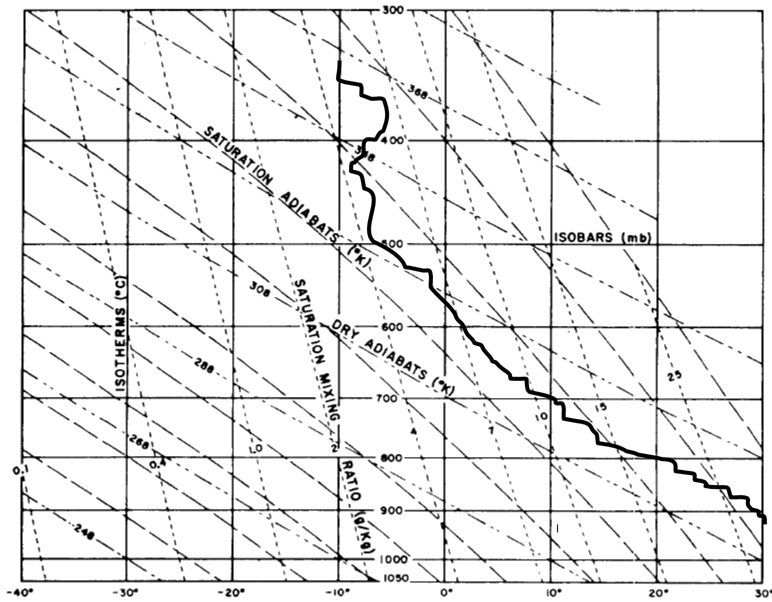
The properties of the lines in Emagram are:

- Dry Adiabats are slightly curved, concave upward, Pseudoadiabats are curved convex upward, Isotherm – adiabat angle varies with axis scale, but is usually about 45°.
- Area denotes total work done in a cyclic process $\oint w = -R_d \oint T \, d\ln P$, and this it represent a true thermodynamic diagram.





EMAGRAM


SATURATION ADIABATS (°K)
DRY ADIABATS (°K)
SATURATION MIXING RATIO (g/kg)
ISOTHERMS (°C)
ISOBARS (mb)
300
400
500
600
700
800
900
1000
1050
-40°
-30°
-20°
-10°
0°
10°
20°
30°