COURSE CODE: WMA 415

COURSE TITLE: Weather Analysis and Prediction

NUMBER OF UNITS: 3 Units

COURSE DURATION:

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## COURSE DETAILS:

**Course Coordinator:** Dr G. C. Ufoegbune

**Email:** gidufoes2000@yahoo.co.uk

**Office Location:** Room B205, COLERM

**Other Lecturers:** Prof NJ Bello

## COURSE CONTENT:

Principles of objective analysis and numerical weather prediction; observational statistic, prediction of individual weather elements. Short range forecasting by various methods. Meso-scale analysis, convection systems, local winds and other weather phenomena. Barotropic and baroclinic forecast; surface analysis, analysis of constant pressure surfaces and other surfaces; cross-section analysis, numerical computation of map factors and of geostropic winds; static stability computation; satellite data and other modern techniques.

Formulation of basic equations of motion: vector from Cartesian coordinate, continuity equation hydrodynamic equation, equation of state. General circulation of the atmosphere: vorticity, divergence and deformation, static stability, circular vortex, and dynamics of mesoscace phenomena, atmospheric turbulence, and waves small-scale turbulence convection treatment of Barotropic and baroclinic waves.

## COURSE REQUIREMENTS:

There is no formal pre-requisite for this course but it is necessary that students would have done WMA 308. It is an elective course.

## READING LIST:

**Basic theory of Atmospheric Dynamics**

Holton, J R, 1992: An Introduction to Dynamic Meteorology. Third Edition, Academic Press, 511 pp.

**Numerical Weather Prediction Methods**

Kalnay, Eugenia, 2002: Atmospheric Modeling, Data Assimilation and Predictability. Cambridge University Press, 364pp.

Pedlosky, J, 1987: Geophysical Fluid Dynamics. Second Edition, Springer-Verlag, 710pp.

Haltiner, G J and T Williams, 1980: Numerical Prediction and Dynamic Meteorology. Second Edition, John Wiley and Sons, 477pp.

Synoptic-Dynamic Meteorology in Midlatitudes, Vol. II: Observations and Theory of Weather Systems, by Howard B. Bluestein, Oxford University Press, New York, 1993.

Weather Analysis, by Dusan Djuric, Prentice Hall, 1994.

Weather Forecasting Handbook (5th ed.), by Tim Vasquez, Weather Graphics Technologies, Garland, TX, 2001.

Weather Analysis and Forecasting : Applying Satellite Water Vapor Imagery and Potential Vorticity Analysis, by Patrick Santurette and Christo G. Georgiev, Elsevier (Academic Press), 2005.

## LECTURE NOTES

**LECTURE NOTES**

Weather forecasting using computer models is known as numerical weather prediction (NWP). It sits at the intersection of three areas of interest -- first, the prediction of events that seem largely unpredictable, in this case, the weather; following from that, non-linear systems and chaos theory; and third, computer modeling on very big, very fast machines.

Air is a heat-conducting fluid and obeys the fundamental physical laws that constitute the primitive equations. These are the ones that we learned in school -- the laws of conservation of energy and mass, conservation of momentum, the laws of thermodynamics, the hydrostatic equation, and the ideal gas law.

We can construct a three-dimensional grid of the atmosphere and use these equations to create a mathematical model. If we plug data that we've gathered on its current state into our grid, we can then solve the equations to predict a future state -- numerical weather prediction. But of course it's not nearly that simple.

In our atmospheric model, many of the equations must be expressed as nonlinear partial differential equations. Their solutions are not usually possible by precise mathematical methods, but are achieved by approximation using numerical analysis. Therefore, a model with thousands of data-points forecasting over any significant period of time requires a huge amount of computation.

Further, because of the nonlinear nature of the equations, tiny differences in the data that are plugged in to these equations -- that define the initial state of the system -- will yield huge differences in the results. This "sensitive dependence on initial conditions" is the hallmark of any chaotic system. We'll come back to that idea again.

the process goes something like this:

1. First, settle on the area to be looked at and define a three-dimensional grid with an appropriate resolution (20 to 200 kilometers on a side, say, and going maybe 10 kilometers up).

2. Then, gather weather readings (temperature, humidity, barometric pressure, wind speed and direction, precipitation, etc.) for each grid point.

3. Run your assimilation scheme so the data you've gathered actually fits the model you've designed.

4. Now, run your model by stepping it forward in time -- a few minutes, say.

5. Go back and repeat step 2 through step 4 again.

6. When you've finally stepped the model forward as far as your forecast outlook (from a day to maybe a week), publish your prediction to the world.

7. And finally, analyze and verify how accurately your model predicted the actual weather. Revise it accordingly.

# THERMODYNAMIC DIAGRAMS

The ***thermodynamic diagram*** is a tool frequently used by meteorologists to solve atmospheric temperature and humidity problems using simple graphical techniques. Lengthy calculations are avoided since the mathematical relationships have been accounted for in the arrangement of this diagram. Meteorologists use the thermodynamic diagram daily to forecast cloud height and atmospheric stability, the latter of which is an indicator of the probability of severe weather. They base their analyses upon the plots of the vertical profiles of air temperature, humidity and wind that are observed by a radiosonde (a balloon-borne instrument package with radio transmitter) at individual upper air stations

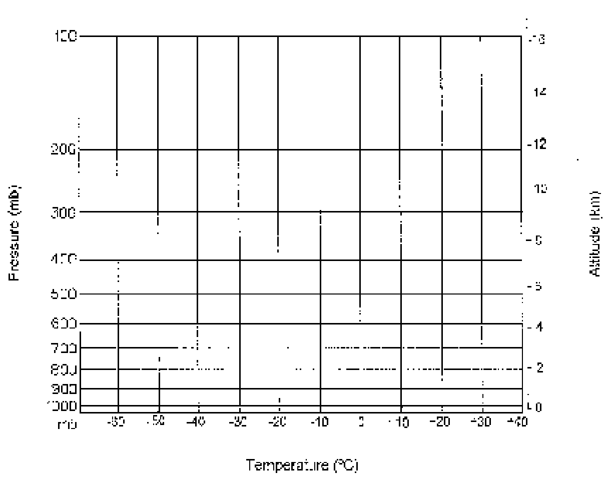
The complete thermodynamic diagram contains five sets of lines or curves:

1. pressure
2. temperature
3. dry adiabatic lapse rate
4. saturation (or "moist") adiabatic lapse rates
5. Saturation mixing ratios.

## 1) Isobars and 2) Isotherms

The pressure and temperature uniquely define the thermodynamic state of an air parcel (an imaginary balloon) of unit mass at any time. Horizontal and vertical lines for pressure and temperature are the same as in the simplified chart described; The horizontal lines represent ***isobars*** and the vertical lines describe ***isotherms***. These two quantities serve as the primary coordinates of the thermodynamic diagram because they uniquely define the thermodynamic state of an air parcel (an imaginary balloon) of unit mass at any time. The altitude of the parcel is of secondary consideration, because its pressure, and any subsequent changes in pressure, is more important for determining the changes in the state of the parcel.

Vertical Atmospheric Chart (Stüve)

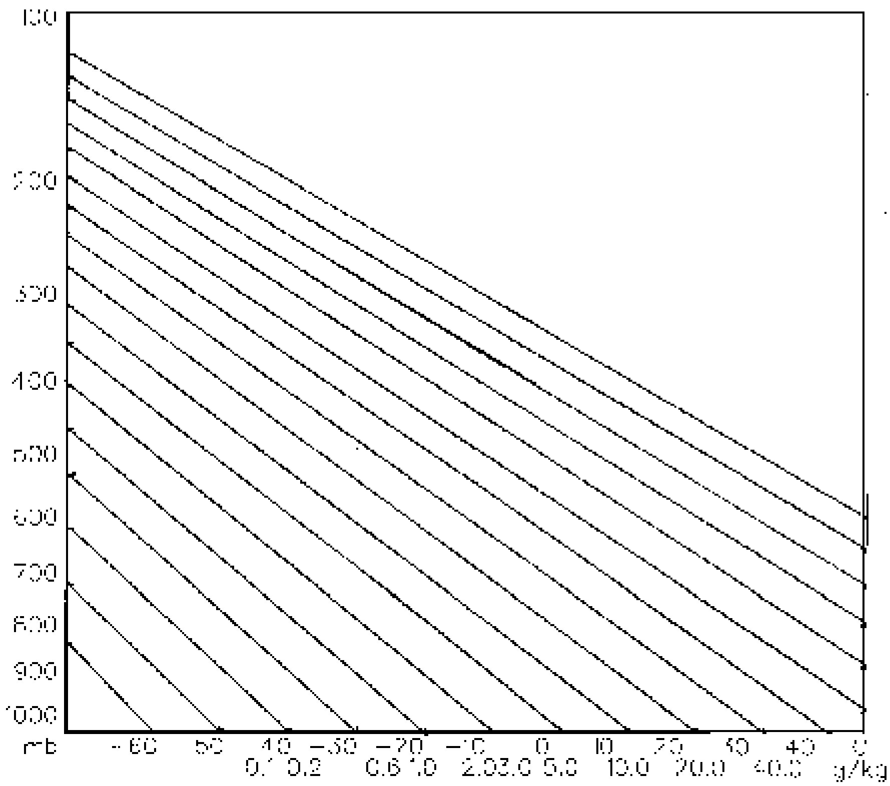



An additional scale is provided along the side to approximate the geometric altitude of various pressure levels, using a typical, reference atmosphere.

You can locate a parcel's position on the chart with respect to the temperature and pressure lines. For example, we can locate a parcel that has a temperature of 20°C and a pressure of 900 mb. A point (P, T) on the chart does not necessarily have to fall on these reference lines. You can always interpolate, or draw in all these lines through that point as long as you keep them parallel to the reference lines! You should note that the values of pressure decrease from bottom to top and that the non-uniform spacing reflects the manner in which the pressure changes with height in the real atmosphere. For completeness, the dewpoint temperature of the parcel (Td) can be plotted upon the diagram at the same pressure level.

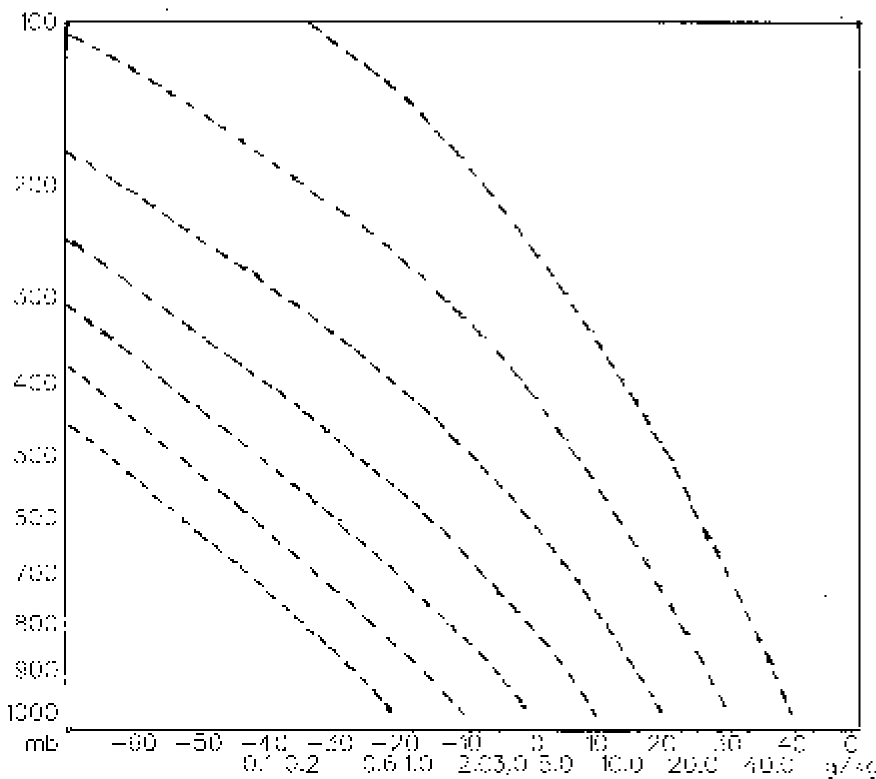
### 3) Dry adiabats

The straight, solid, lines sloping upward to the left on the diagram are called "dry adiabats" or **potential temperature,** θ, or *isentropes*. These lines represent the change in temperature that an unsaturated air parcel would undergo if moved up and down in the atmosphere and allowed to expand or become compressed (in a dry adiabatic process) because of the air pressure change in the vertical. If you would lift an air parcel from a known initial point to a final point, you would trace the amount of cooling on the nearest dry adiabat.



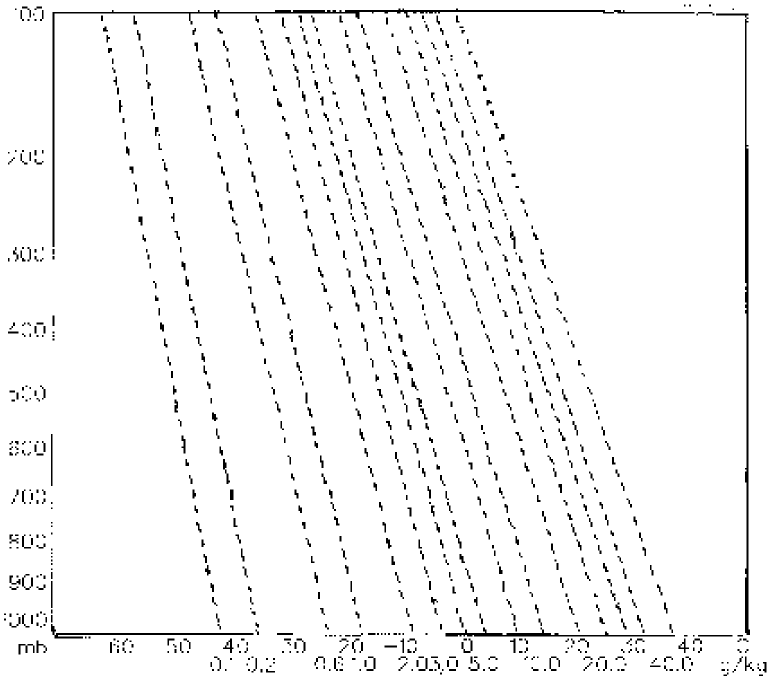

### 4) Saturation adiabats

The set of dashed curves are "saturation adiabats", also known as lines of **equivalent potential temperature,** $\theta_e$. These 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. These curves portray the temperature changes that occur upon a saturated air parcel when lifted.




## 5) Isohumes

A set of Sloping Solid Lines at a Small Angle from the vertical appearing on the thermodynamic diagram is needed to assess the moisture characteristics of an air parcel. These lines (also called saturation mixing ratio lines $w_s$) 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. Recall that the mixing ratio is defined as the mass of water vapor per mass of dry air, expressed as grams of vapor per kilogram of dry air. These lines can be used to determine whether the parcel was saturated or not. If the temperature and the pressure of an air parcel are known, the parcel's saturation mixing ratio can be read directly from the chart using the set of saturation mixing ratio lines.




We can also determine the actual mixing ratio of the air parcel from this same set of lines if the dewpoint temperature were known also. If we know the pressure and both the air and dewpoint temperatures, we can determine the saturation mixing ratio and w, respectively. Thus, from the above example of an air parcel with T = 26°C and P = 1000 mb, and a dewpoint, Td equal to 15°C, then the saturation mixing ratio is 20 g/kg and actual mixing ratio = 10 g/kg.

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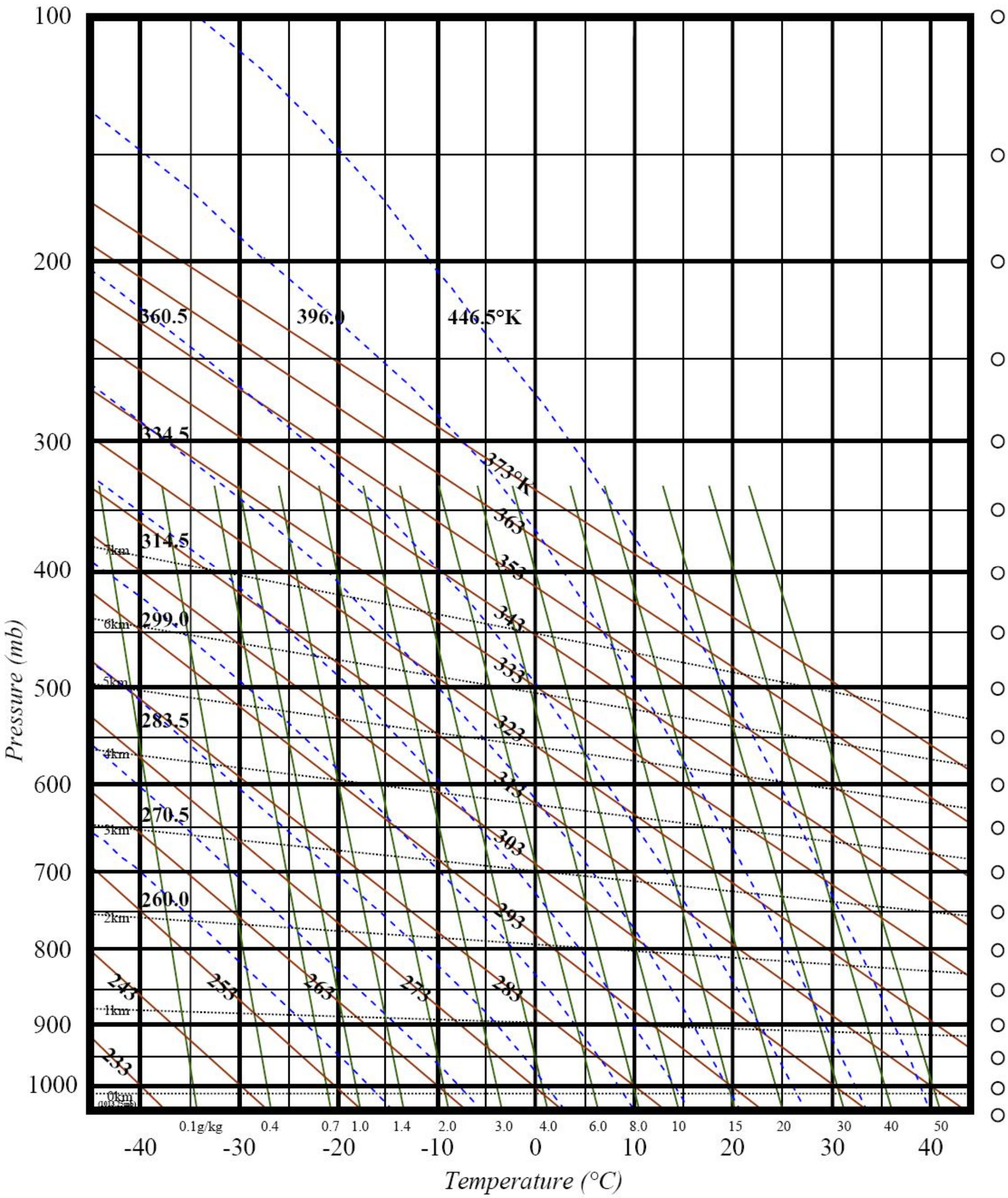

100
200
300
400
500
600
700
800
900
1000
Pressure (mb)
360.5
396.0
446.5°K
334.5
314.5
299.0
283.5
270.5
260.0
373°K
363
353
343
333
323
313
303
293
283
273
263
253
243
233
7km
6km
5km
4km
3km
2km
1km
0km
0.1g/kg
0.4
0.7
1.0
1.4
2.0
3.0
4.0
6.0
8.0
10
15
20
30
40
50
-40
-30
-20
-10
0
10
20
30
40
Temperature (°C)

To find the temperature of a parcel: To find the temperature of a parcel lifted dry adiabatically, find the initial point (given temperature and pressure) and travel upwards parallel to the nearest dry adiabat. Since the wet adiabats diverge with decreasing pressure, when lifting a parcel wet adiabatically it is important to stay equidistant between two wet adiabats. *Do not go parallel to just one!*

**1. WHAT IS THE TEMPERATURE OF A PARCEL LIFTED DRY ADIABATICALLY**

*a) from 30°C @1000mb to 700mb?* $T_p$=

*b) from 15°C @1000mb to 600mb?* $T_p$=

*c) from -10°C @900mb to 650mb?* $T_p$=

**2.WHAT IS THE TEMPERATURE OF A PARCEL LIFTED WET ADIABATICALLY**

*a) from 30°C @1000mb to 700mb?* $T_p$=

*b) from 15°C @1000mb to 600mb?* $T_p$=

*c) from -10°C @900mb to 650mb?* $T_p$=

**3. WHAT IS THE TEMPERATURE OF A PARCEL STARTING FROM 32°C@1000**

*a) lifted dry adiabatically to 850 mb and wet adiabatically to 400mb?* $T_p$=

*b) lifted dry adiabatically to 650 mb and wet adiabatically to 300mb?* $T_p$=

**Potential temperature (θ)** is defined as the temperature air would be if brought dry adiabatically to 1000 mb. It allows one to determine the amount of internal energy air has.

**5. WHAT IS THE POTENTIAL TEMPERATURE OF AIR**

*a) At 500 mb with a temperature of -11°C?*

*b) At 850 mb with a temperature of 2°C?*

*c) Which is potentially warmer? T=8°C @ 500mb or T=21°C @ 1000mb?*

**To find the LCL:** The **LCL**, or **Lifting Condensation Level**, is the level at which dynamically lifted air reaches saturation. To find the LCL, locate the intersection of the constant mixing ratio line through the surface dew point with the dry adiabats through the surface temperature.

**7. FIND THE LCL IF THE SURFACE TEMPERATURE AND DEW POINT ARE**

*a) 25°C and 20°C, respectively.* ***LCL= mb***

*b) 18°C and -1°C, respectively.* ***LCL= mb***

*c) 25°C and 20°C, respectively @ 900mb.* ***LCL= mb***

## To find w or $w_s$

The **mixing ratio** (**w**) is determined by locating the value of the constant mixing ratio line at the given pressure and *dew point*. To find the **saturation mixing ratio ($w_s$)** (that is, what the mixing ratio would be if the parcel were saturated), locate the value of the constant mixing ratio line at the given pressure and *temperature*. For both processes, interpolate (approximate the value between to known values by the fractional distance between each one) if necessary. Mixing ratio is a function of vapor content, while saturation mixing ratio is a function of temperature,

$$\text{so } T \rightarrow w_s \text{ as } T_D \rightarrow w$$

If $RH = {}^{w}/_{w_s}\,(\%)$ **WHAT IS THE RELATIVE HUMIDITY OF A PARCEL AT THE SURFACE (*ASSUME TO BE 1000MB UNLESS OTHERWISE INDICATED*)?**

*a) T= 24°C Td= 8°C* ***w= $w_s$= RH=***

*b) T= 5°C Td=-2°C* ***w= $w_s$= RH=***

*c) T=30°C Td=10°C p=850mb* ***w= $w_s$= RH=***

## The three thermodynamic diagrams in common use in operational meteorology

| Line on diagram | units used (usually) | SKEW-T/LOG(P) | STÜVE | TEPHIGRAM |
|---|---|---|---|---|
| **ISOTHERMS** (lines of constant 'real' temperature) | **degC** | straight & parallel; angled 45deg/slope to right. Equal spacing (linear); angled circa 90deg to Dry Adiabats up to 300hPa. | straight, parallel & vertical. Equal spacing (i.e. linear). | straight & parallel; angled 45deg/slope to right. Equal spacing (linear); angled exactly 90deg to Dry Adiabats whole diagram. |
| **ISOBARS** (lines of constant atmospheric pressure) | **hPa** (or millibars in old money) | straight, parallel & horizontal; increased spacing per unit pressure change with altitude. | straight, parallel & horizontal; increased spacing per unit pressure change with altitude. | very slightly curved upwards (i.e. convex towards top of diagram). [ not really noticeable for routine use.]; quasi-horizontal; increased spacing per unit pressure change with altitude. |
| **DRY ADIABATS** (lines of constant potential temperature for a dry air sample [ i.e. an unsaturated air parcel path. ] ) | **degC** (but strictly, and sometimes found, degrees Kelvin are used) | curved: approx. 45deg to left near 1000 hPa, decreasing to within 10deg of vertical near 100 hPa. | straight - sharply angled to left - gently convergent to left. (meet at a theoretical point where P=0; T(K)=0) | straight & parallel; angled 45deg/slope to left; Equal spacing (linear); angled exactly 90deg to Isotherms whole diagram. |
| **SATURATED ADIABATS** (lines of equivalent potential temperature for a saturated [or 'wet'] air parcel path.) | **degC** (but strictly, and sometimes found, degrees Kelvin are used) | curved - but not constant; on right-hand side of diagram, curve starts right and bears left above 400 hPa; on left-hand side, curve starts left and quickly become parallel with Dry Adiabats. | slightly curved to left with height - curve minimal left-hand side of diagram; a gently increasing left turn on right hand side. | The only *notably curved* lines on this diagram: On the right-hand side, starts slightly right before curving left; on left-hand end, curve all to left. On most diagrams, not shown above about -50degC. |
| **SATURATED HUMIDITY MIXING RATIO** (lines of constant saturation mixing ratio with respect to a plane water surface.) | **g/kg** ( i.e. ratio of mass of water vapour in given volume to the mass of the dry air in that sample. ) | quasi-straight*; angled to right, at less than 45deg to the vertical; gently convergent to a point well above the top of the diagram. (* for practical work can be regarded as straight & parallel) | quasi-straight*; angled to left, at less than 20deg to the vertical; gently convergent to a point well above the top of the diagram. (* for practical work can be regarded as straight & parallel) | quasi-straight*; angled to right at less than 45deg to vertical, i.e. less slope than isotherm. (* for practical work can be regarded as straight & parallel) |