Tephigrams: What you need to know

Contents

An Introduction to Tephigrams

What pilots need to know about tephigrams.

Can be as complicated as you like !

Tephigrams are a key weather forecasting tool.

Tephigrams are a meteorological forecasting tool. The tephigram is also sometimes known as the *Skew-T diagram* or, more correctly, the *Skew-T - Log P diagram*. Tephigrams can be used to forecast:

- Cloud base/cloud tops
- Convection
- Lift (Sink)
- Rain
- Thunderstorms
- Frontal activity
- & much more

Looks extremely complex, although it's simpler than most people believe. The detailed background *is* very complicated, but with some simple procedures you can determine a lot from the tephigram without a great deal of specialist knowledge.

What pilots need to know

Describes three areas key to understanding tephigrams.

1. Understand the axes of the chart
2. Understand the plots made over the axes
3. Read off likely weather phenomena

• Underlying thermodynamics is *very* complex .
• You only need to know this if you are academically inclined or are (or aspire to be) a professional meteorologist.

Some fundamentals

- "Adiabatic" means changing of temperature without energy entering or leaving the system.
- Most of what we are going to talk about is related to *potential energy* rather than kinetic energy; this is related to height above the surface, $E_p = mgh$, where g is the acceleration due to gravity at the surface = $9.8ms^{-2}$ (at the equator if you wish to be super-pedantic).

Air

Key points about air.

Air is a gas; like all gases, air is compressible.

- The pressure of the air per unit square at any given level above the Earth's surface is caused by the weight of the column of air above it.
- Air is not an "ideal" gas, and consists a mixture of various constituents: elements such as Nitrogen, N and Oxygen, O, compounds such as CO_2, and water vapour, H_2O. CO_2, and H_2O are called "greenhouse gases" because they inhibit the radiation back from the Earth's surface. There are also smaller proportions of other greenhouse gases, notably methane, CH_4, as well as traces of elemental gases such as Argon, Ar which is essentially inert (i.e. it does react easily with other substances).
- Air is a poor conductor of heat; if it wasn't, double glazing wouldn't work.
- Air does not mix easily:
  - If air is heated, so that it is warmer than the surrounding air, it will rise relative to the cooler air rather than mixing to equalise the temperature.
  - If this wasn't the case, then we wouldn't have any thermals.

Why does the air cool as it rises?

Brief description of the Gas Laws

This is due to the operation of the *Glossary* on page 31 - Boyle's Law and Charles' Law. Combined, they state that in an idealised gas,

PV = RT where P = Pressure; V = Volume; T = Temperature, R is a constant known as the *Gas Constant* .

Example: If air at ISA (1013 hPa; 15ºC) is raised adiabatically to the 980 hPa pressure level, what will it's new temperature be?

$P := 1013\ hPa \qquad V := 1 \qquad T := 288K$

$$R := \frac{PV}{T}$$

$P1 := 1013 \quad P2 := 980\ hPa \qquad T1 := 288K$

$$T2 := T1\frac{P2}{P1} \rightarrow \frac{282240K}{1013} = 278.618K$$

$$T2 = 278.618 - 273 \rightarrow 5.618 = 5.618\,°C$$

Water vapour

Water vapour (H_20) and it's importance.

- Air can hold up to a certain amount of water vapour at any given pressure.
- If the air is cooled at a constant pressure, at a temperature called the *dew-point* , T_d, the fraction reaches 100%. At T_d, the water vapour condenses out into liquid droplets, causing the formation of what we call "Cloud".
- Conventionally, in a tephigram, the *actual* air temperature at a given pressure level is referred to by the symbol T, and the dew-point temperature by T_d
- H_2O is one of the compounds that can exist in all three phases (i.e. solid, liquid, and gas) at the same temperature - the so-called "triple point". (Another such substance is Methane, CH_4, but it's triple point is very much lower; in Earth's atmosphere it exists only as a gas).

The Skew-T / Log-P axes

Understanding tephigram axes.

The first key step is to understand the chart axes. They appear strange because one axis is plotted at an angle of 45° rather than at 90° to the other.

• Lines of equal pressure; plotted on a natural logarithm scale.
• Lines of equal temperature; plotted on a linear scale, but inclined to the Log-P scale at 45° rather than at 90°.

Key point to remember is:

• These lines are *calibration lines* - you don't read off them, you use them to interpolate values of the plot lines.

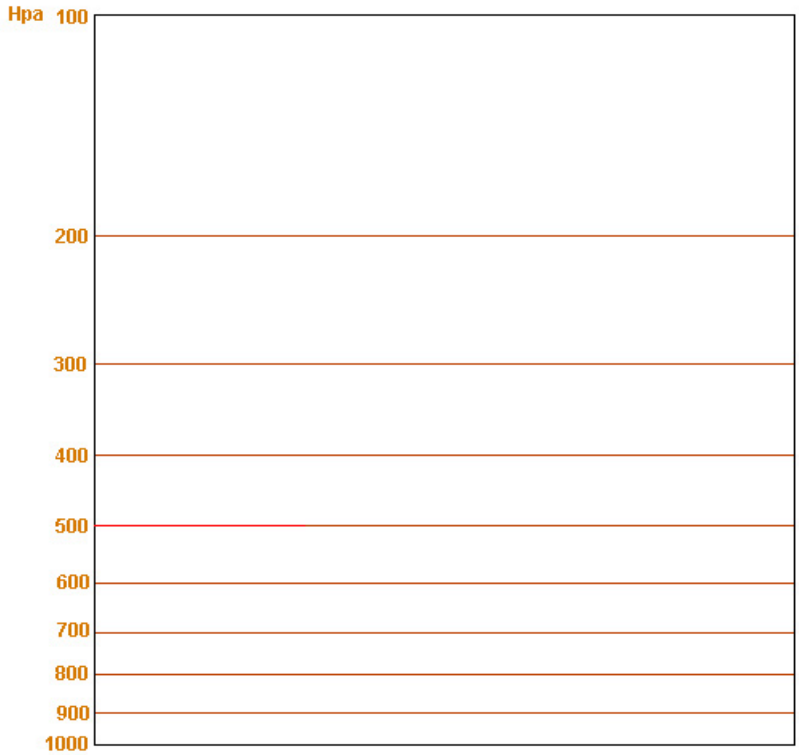
Isobars

Lines of equal pressure - the "Log-P" part.

This is the "Log-P" part. The term "Isobar" means a line of equal pressure (i.e. as on a synoptic chart), conventionally in *hecto-Pascals* (Hpa) . This is the MKS and SI unit; one Hpa = one mBar.

Note that a logarithmic scale is used, enabling us to show pressure levels from 100 Hpa down to the surface (hence "Log-P").

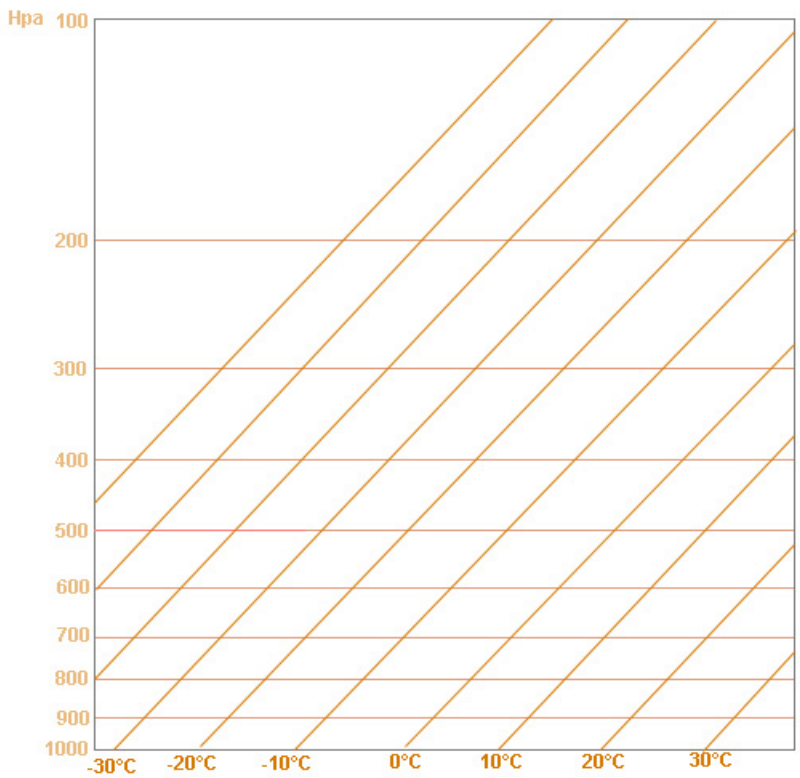
Note also that the vertical scale is *pressure levels* rather than height, although in most instances tephigrams will be shown with the equivalent height AMSL for the pressure on the day.



Isotherms

Lines of constant potential temperature; the "Skew-T" part.

This is the "Skew-T" part. *Isotherms* are lines of constant potential temperature. In this context, the word "skew" means exactly what it says; instead of being plotted vertically, the isotherm axis is skewed through 45º. this enables more information related to other parameters to be included on the chart.



Ideal scales

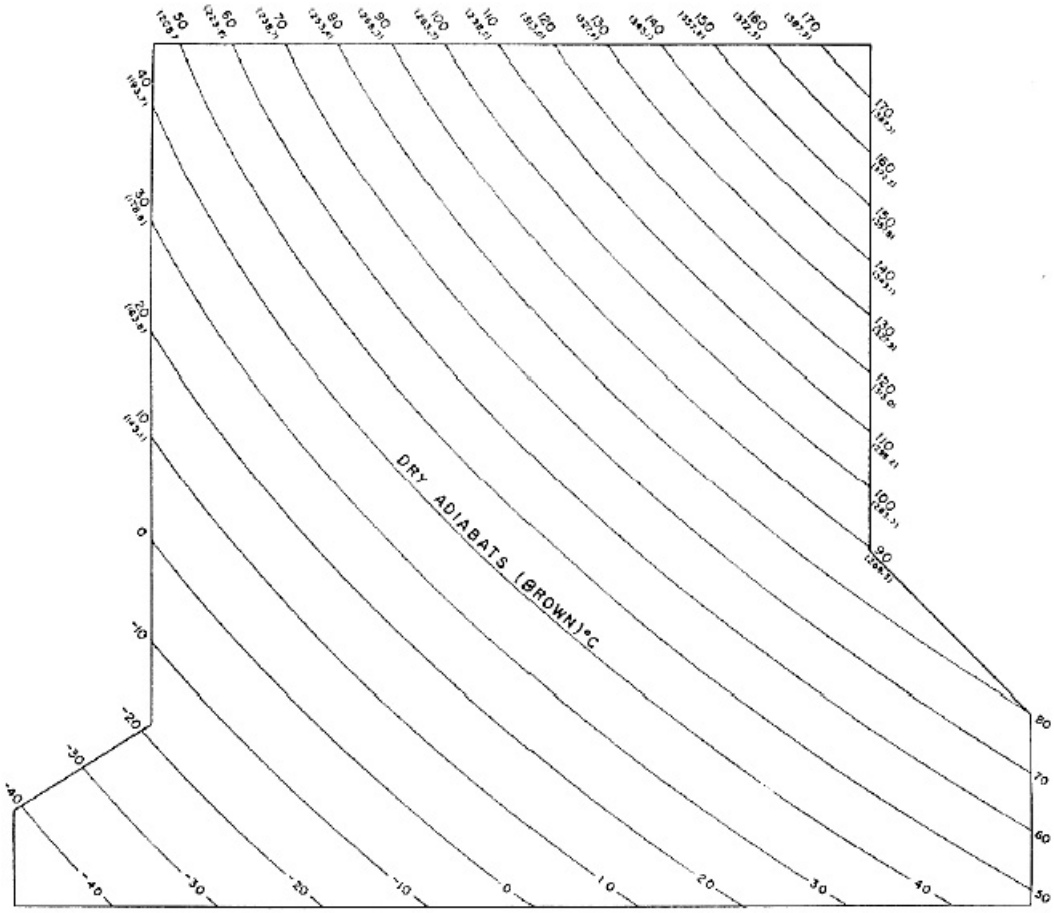
Idealised scales on the chart.

We call these scale lines "ideal" because they don't occur in the real world. For example, the "dry adiabat" lines represent "dry" air, whereas air will always contain a fraction of water vapour, however low that fraction may be (e.g. in the middle of the Sahara desert or the Antarctic). Also, the processes taking place will never be truly adiabatic - in practice, some heat will transfer to or from an air parcel.

Dry adiabats

Dry adiabatic scale.

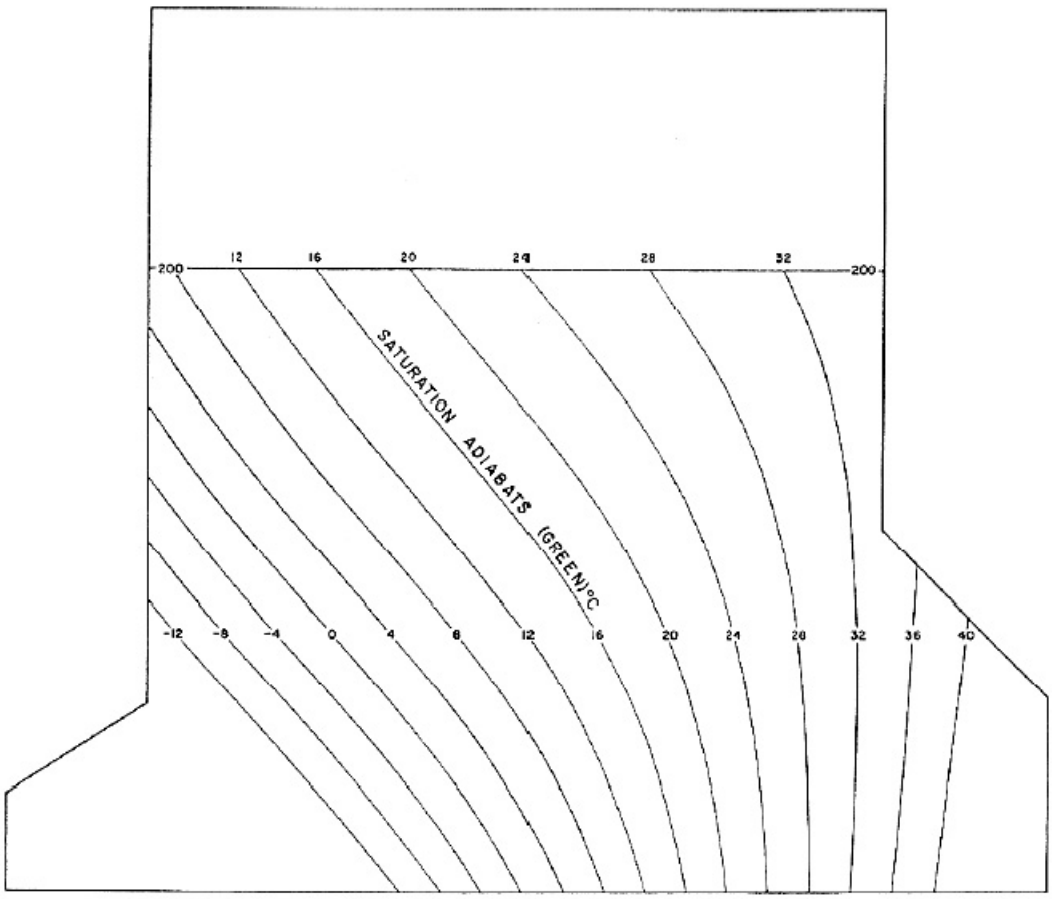
Dry adiabats indicate the rate of temperature change in a parcel of **dry air** which is rising or descending **adiabatically** i.e. with no loss or gain of heat by the parcel. There is **no change of state** occurring in the water constituent of the air - for example no H_2O is changing phase from vapour to liquid or solid, or solid to liquid to vapour.



Saturation adiabats

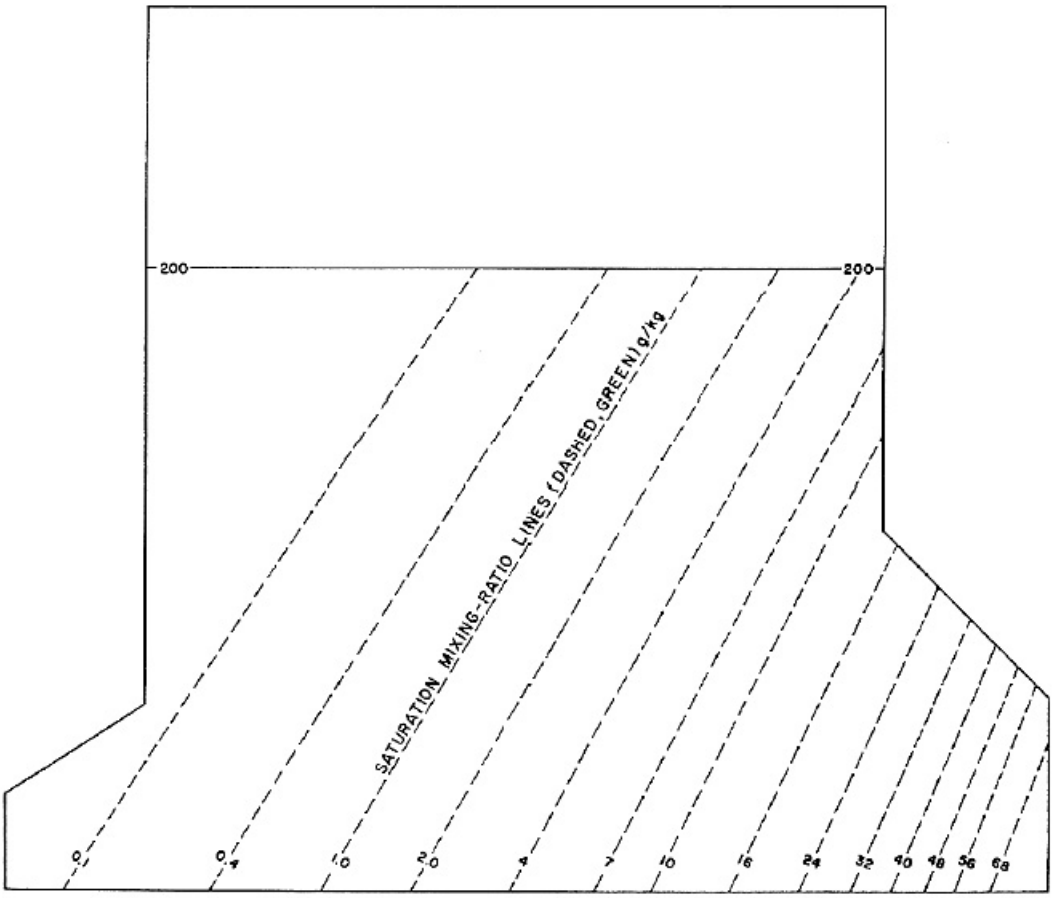
Lines of saturated vapour pressure.

Indicate the temperature change experienced by a saturated parcel of air rising pseudo-adiabatically through the atmosphere. Also known as "wet adiabats".



Saturation mixing ratio

Saturation mixing-ratio lines are labelled in parts of water vapour per 1000 parts of dry air (g Kg^{-1})


200
200
SATURATION MIXING-RATIO LINES (DASHED, GREEN) g/kg
0.1
0.4
1.0
2.0
4
7
10
16
24
32
40
48
56
68

Adding today's data

The two traces you see added are

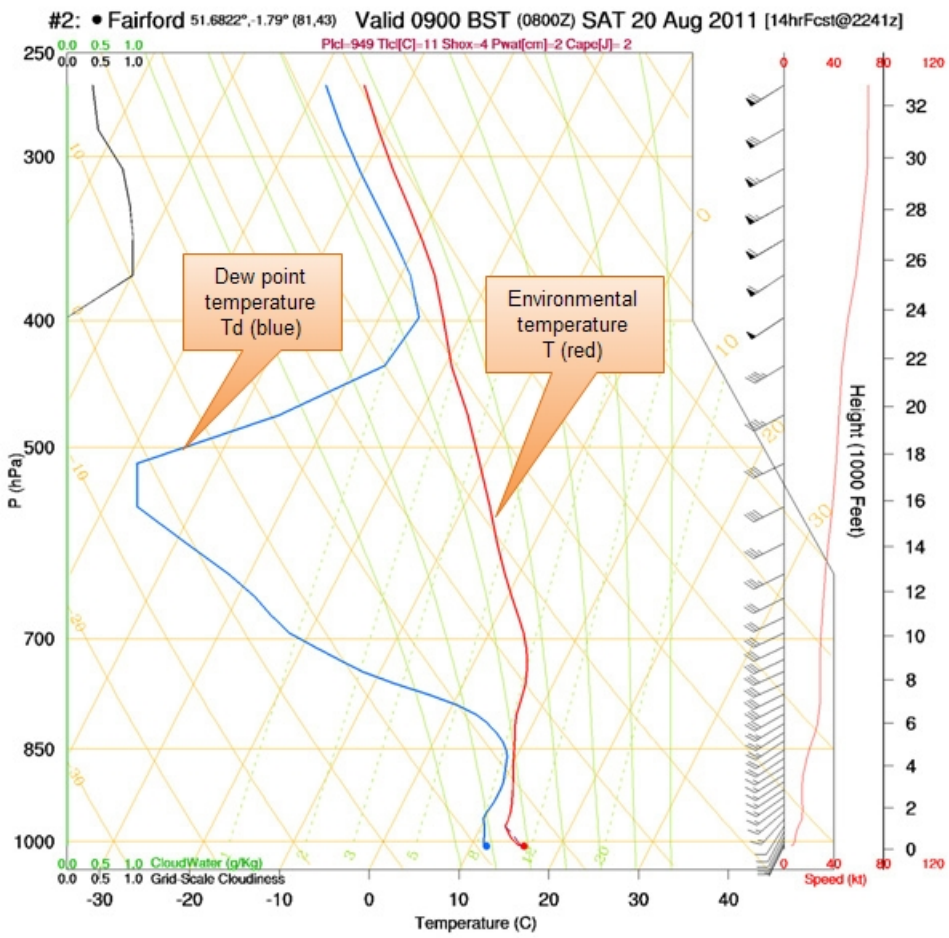
- The *environmental temperature*, T, normally plotted as a red trace;
- The *dew-point temperature*, T_d , normally plotted as a blue trace.

These are plotted from observations/forecasts at each pressure level.

A point is made on each isobar corresponding to the temperature measured or forecast. Usually it will be necessary to interpolate temperatures between the 10º isotherms.

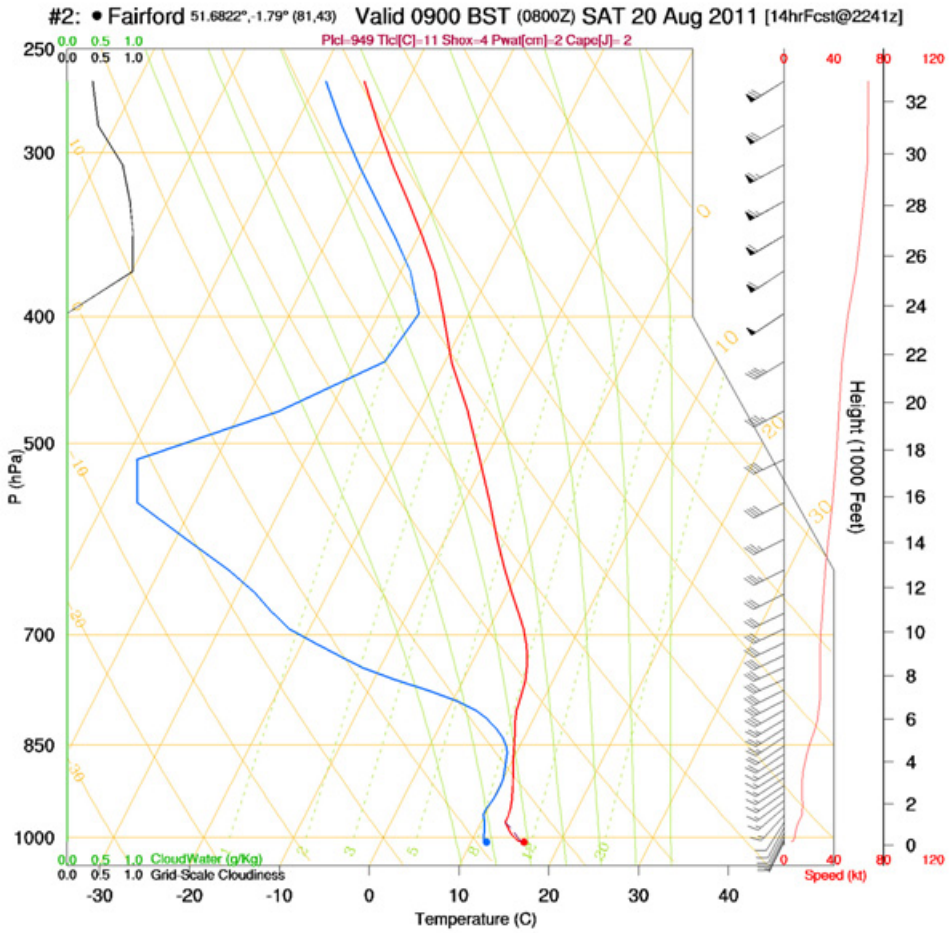
Environmental temperature and dew-point temperature

The values of the environmental temperature, T and the dew-point temperature, T_d are added as shown here:

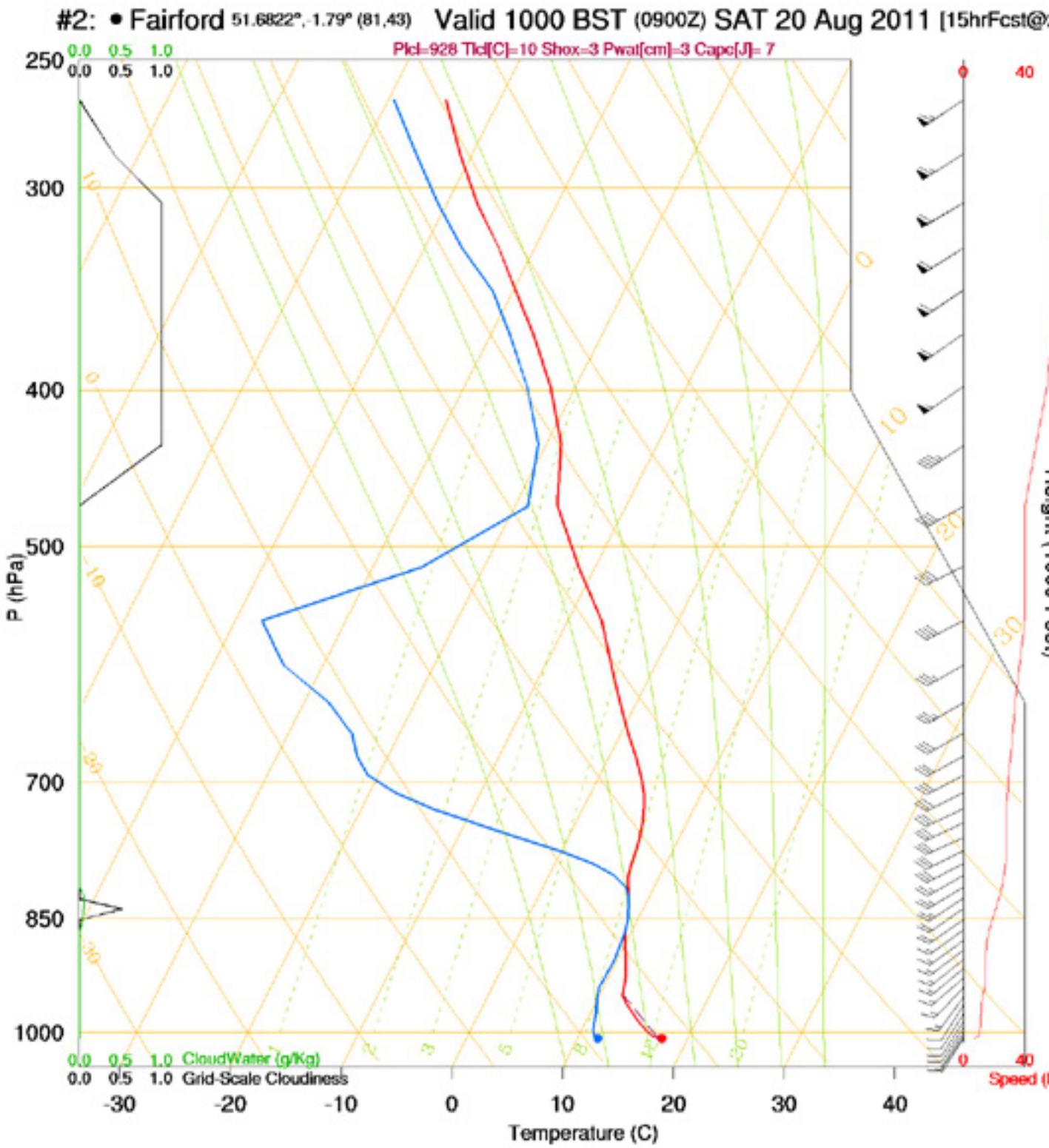


Progression of a day

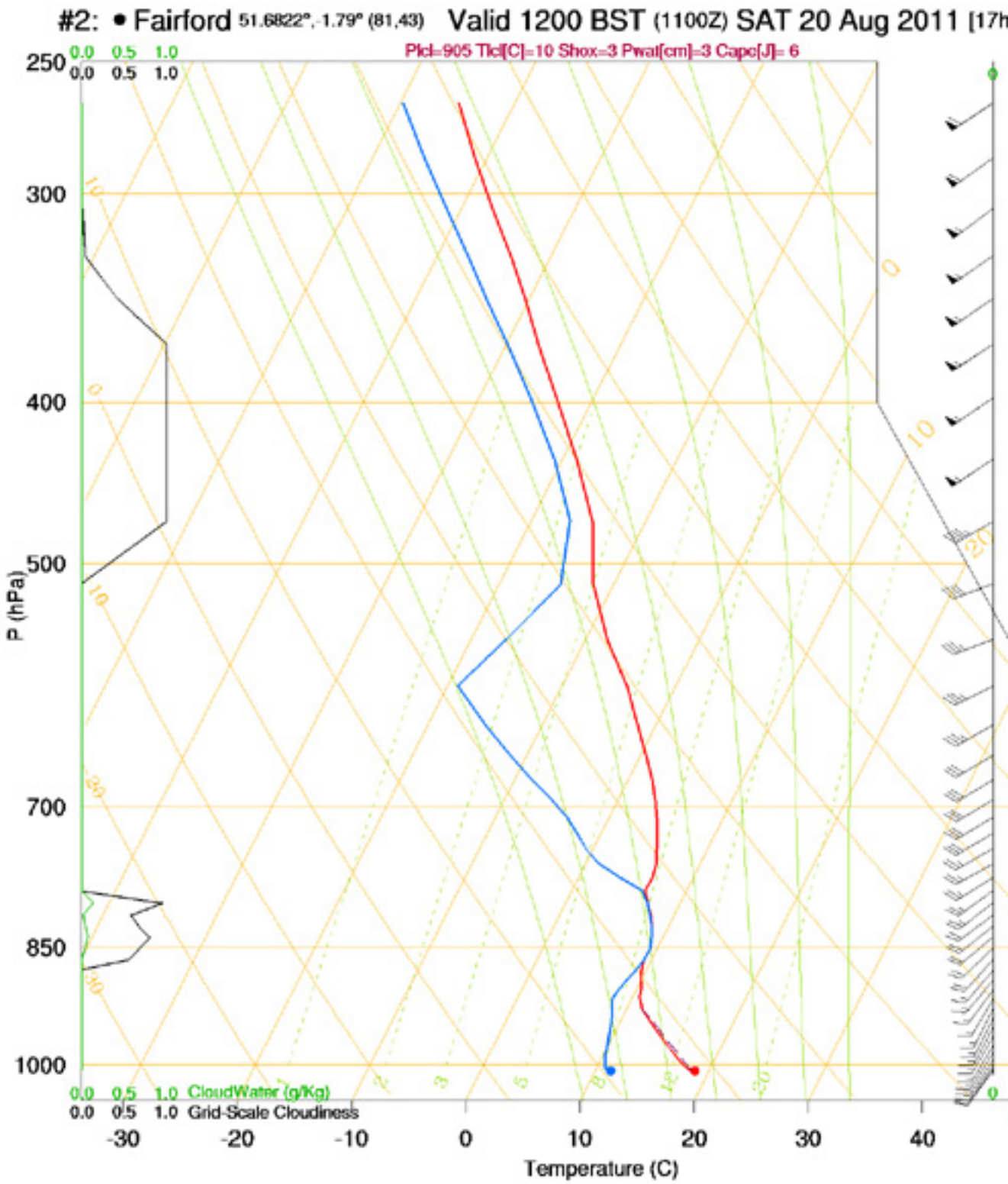
0900_hrs



1000_hrs


#2: • Fairford 51.6822°,-1.79° (81,43) Valid 1000 BST (0900Z) SAT 20 Aug 2011 [15hrFcst@
Plcl=928 Tlcl[C]=10 Shox=3 Pwat[cm]=3 Capc[J]= 7
P (hPa)
250
300
400
500
700
850
1000
0.0 0.5 1.0 CloudWater (g/Kg)
0.0 0.5 1.0 Grid-Scale Cloudiness
-30 -20 -10 0 10 20 30 40
Temperature (C)
0 40
Speed (

1200_hrs


#2: • Fairford 51.6822°, -1.79° (81,43) Valid 1200 BST (1100Z) SAT 20 Aug 2011 [17h
Plcl=905 Tlcl[C]=10 Shox=3 Pwat[cm]=3 Capc[J]= 6
P (hPa)
250
300
400
500
700
850
1000
0.0 0.5 1.0 CloudWater (g/Kg)
0.0 0.5 1.0 Grid-Scale Cloudiness
-30
-20
-10
0
10
20
30
40
Temperature (C)

Simple observations from the Skew-T

If $T = T_d$, then the air is saturated; cloud will form.

Note that the air doesn't need to be completely saturated for this to happen (i.e. relative humidity does not have to reach 100%). Clouds can start forming any time $T\text{-}T_d$ <6°C

Freezing level

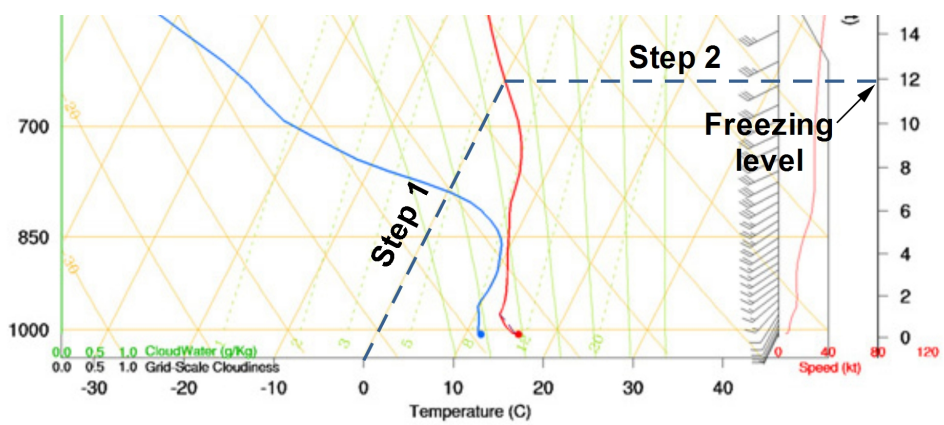
Why this is important: the freezing level is the level at which the environmental temperature, T, is 0ºC, so ice will form on flying surfaces.

Determining the freezing level

Use the following procedure to determine the freezing level.

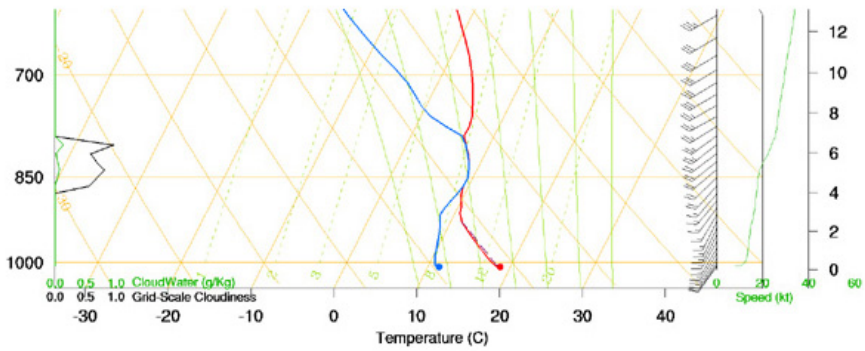
1. Step 1: trace the 0°C isotherm upwards.
   Locate the point where the 0°C isotherm intersects the environmental temperature (T) line
2. Step 2: draw a horizontal line from this point to the right.
   Read off the height where the horizontal line intersects the height axis; this value is the freezing level

Procedure for determining the freezing level



Will cloud form_

Generally, if the trace of the environmental temperature, T and the dew-point temperature, T_d overlap, cloud will form.



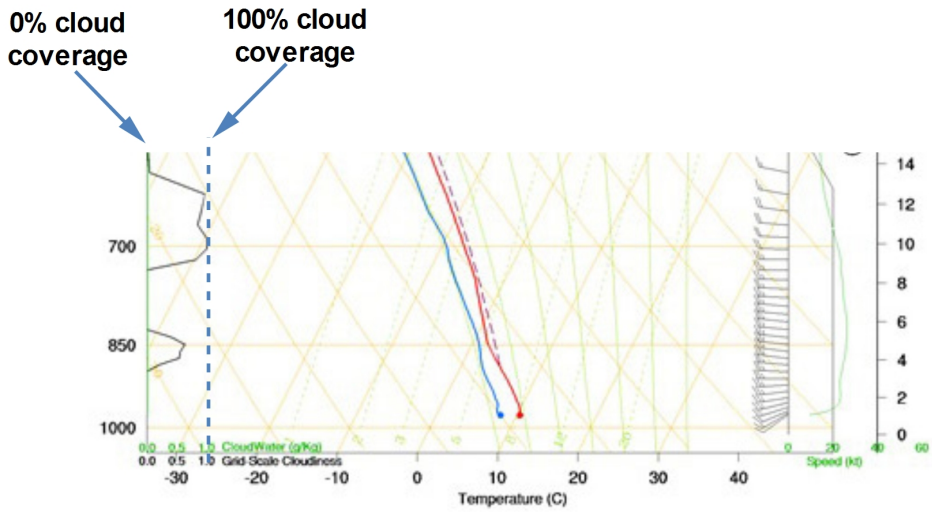
Cloud forming 5000 - 8000 ft

N.B. the traces don't have to overlap: if $T-T_d < 3°C$, cloud may form

Cloud coverage

An approximation of the cloud coverage to be expected.

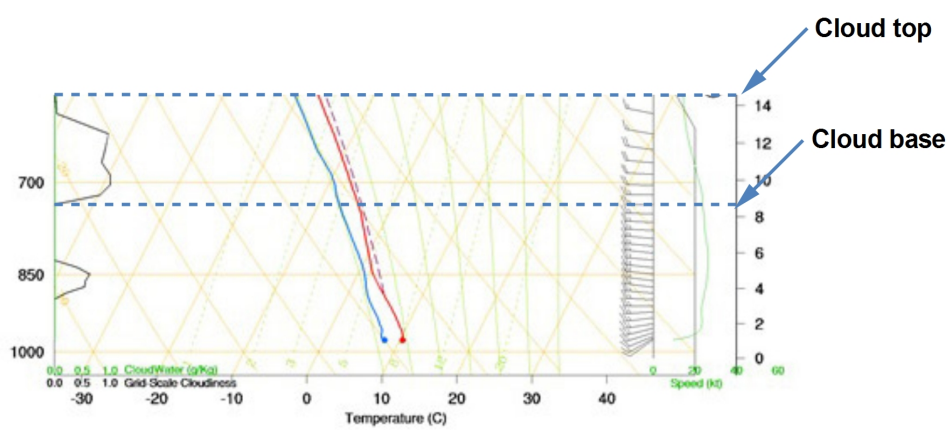
Cloud coverage is depicted on the left of the diagram.



Interpreting the cloud coverage

The example shown features two distinct cloud formations at different pressure levels:

1. For the upper cloud level, draw a horizontal line from the top of the coverage plot (where coverage = 0%) to the right hand y-axis and read of the cloud top height.

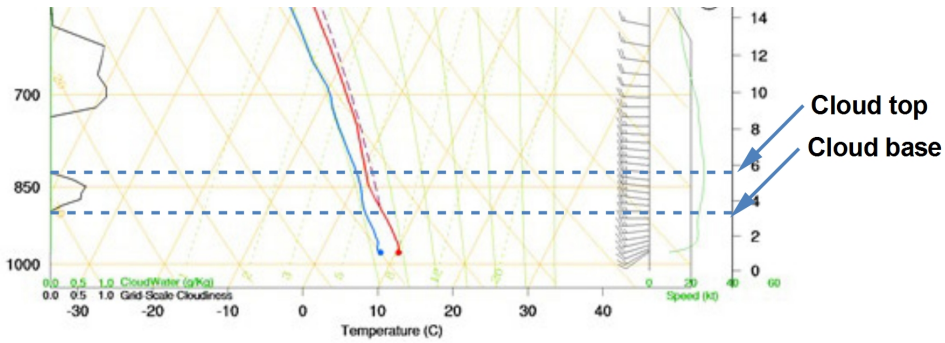


   The cloud top is at approximately 15,000ft. The cloud coverage increasing from clear air at 15,000ft down to approximately 90% coverage at 13,000ft. coverage remains at this level until approximately 9,000ft.

2. Use the same technique to determine the cloud base; draw a horizontal line from the bottom of the coverage plot (where coverage = 0%) to the right hand-axis and read of the cloud base height.

In the upper cloud layer, cloud base is just below 9,000ft.

3. For the lower cloud level, use the same technique: draw a horizontal line from the top of the coverage plot (where coverage = 0%) to the right hand y-axis and read of the cloud top height.



The lower level cloud top is at approximately 5,500ft.

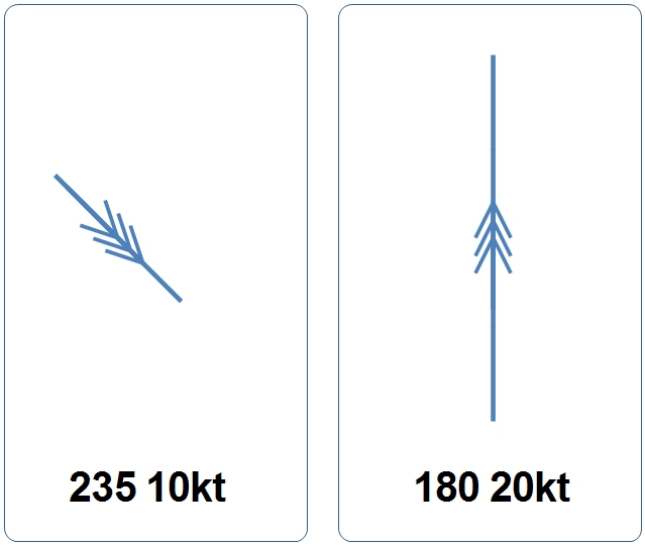
4. Similarly, to determine the cloud base; draw a horizontal line from the bottom of the coverage plot (where coverage = 0%) to the right hand-axis and read of the cloud base height.
The lower level cloud base is at approximately 3,500ft.

Wind plots

Wind plots show wind strength and direction at each pressure level.

Wind is a *vector* quantity - that is to say it has two vector components, its *strength* and its *direction*.

Wind vectors are shown here:



Note that conventionally, wind vectors express direction as the direction *from which the wind comes*. In the example on the left, the wind is coming from the north west (i.e. 235° true) and has a strength of 10kt. In the example on the right, the wind is coming from the south; the vector has direction 180° true) and a strength of 20kt.

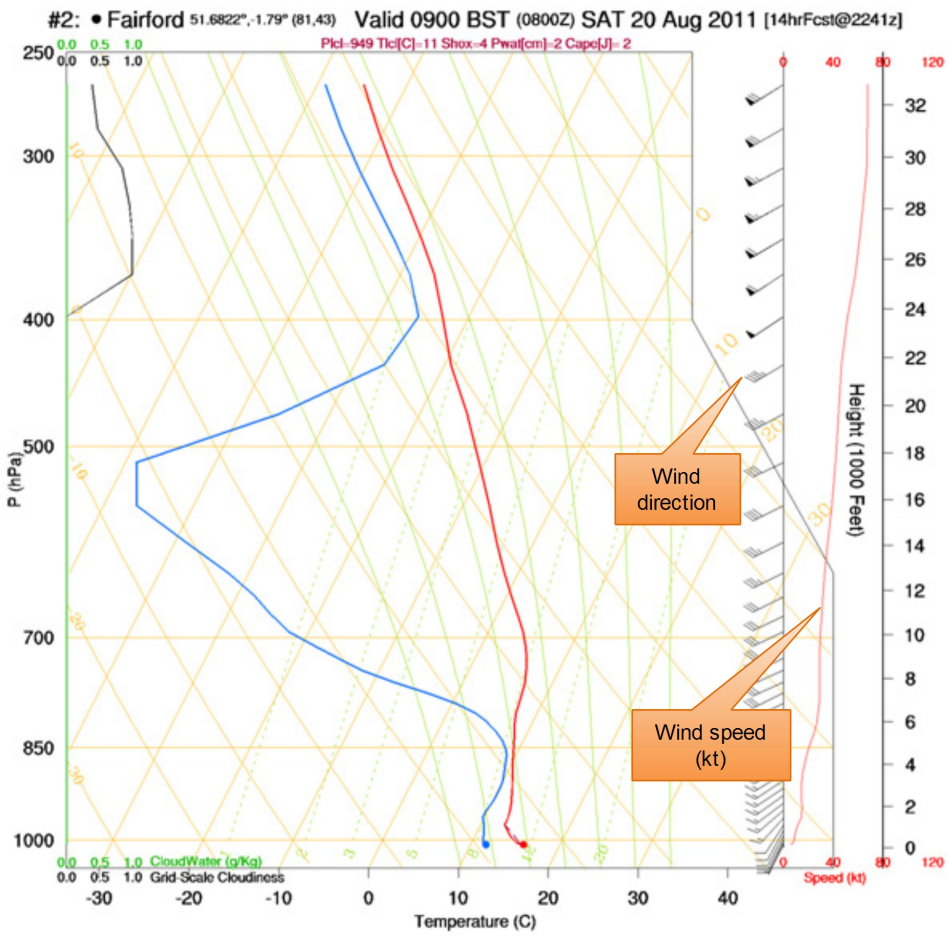
Vector quantities are unlike *scalar* quantities, such as temperature, which has a value but no other parameter.

Winds vector example

How to read wind parameters.

On the right of the chart, we see plots depicting wind paramaters:

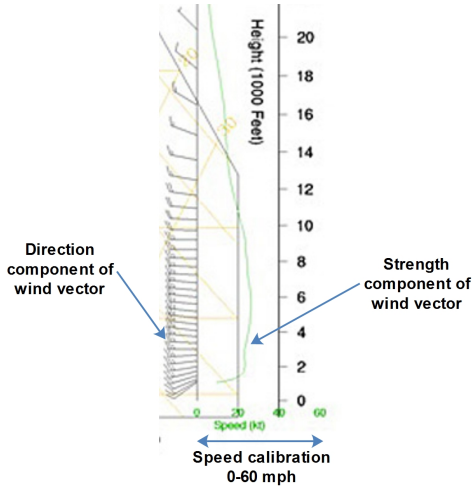
- The red trace shows wind speed vs. height. In this example, wind at the surface is very light (~5mph), whereas at 32,000 feet is it much stronger (~75mph).
- Wind direction is shown by the black barbs. The number of barbs give a rough indication of wind strength.



Interpreting the wind plots

The wind plots can be used to determine wind strengths at various heights; you can also compare these to the wind strengths given on the Met. Office Form 214. Also, by using the procedure below you can build a picture of the *wave profile* and assess whether wave flying opportunities are likely.

1. Determine the wind strength at various heights can be determined from the tephigram using the wind traces on the right of the diagram.



In this example, at 3,000ft, the vector is: direction ~ 270° true; strength: ~ 27kt

2. Examine the direction components at increasing heights.
   At low levels, the wind veers from ~ 230° true to ~ 270° true. between 2,000ft and about 11,000ft, the wind direction is constant ~ 270° true; could be a good sign of mountain lee wave (MLW on Form 215).
3. Examine the wind strength at increasing heights.
   Light (~10kt) at 1,000ft; strengthens very rapidly at about 1,500ft; remains about the same until about 7,000ft and then decreases. Not such a good wave profile

A really strong wave profile would be where the wind direction was consistently the same with increasing height, and where the strength is gradually increasing with height. This example seems good with respect to the direction components but not so good for the strength components. Wave is quite likely, but will not extend above about 8,000ft, as the wind strength starts decreasing above this height.

More complicated Skew-T observations

The tephigram can be used to determine two important condensation levels:

- Lifting Condensation level (LCL)
- Convective Condensation Level (CCL)

Convective condensation level (CCL)

Why this is important: the CCL determines cloudbase when air is heated from the ground.

The Convection Condensation Level is the height at which a parcel of air, when *heated from below*, will rise dry adiabatically until it is just saturated.

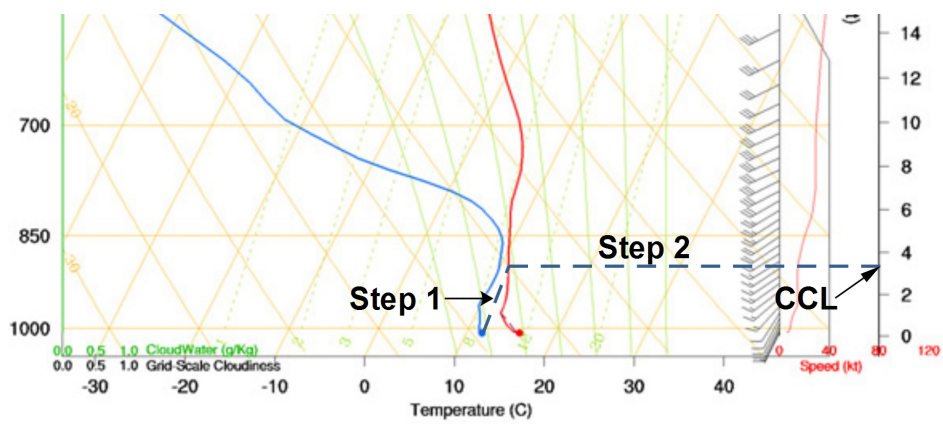
This is the height of the base of cumiliform clouds which are produced by thermal convection from heating of the Earth's surface by incoming solar radiation - the classic "thermal" in fact.

Determining the convective condensation level (CCL)

Use the following procedure to determine the convective condensation level (CCL) .

1. Step 1: from the surface dew-point temperature, draw a line parallel to the saturation mixing ratio line to where it intersects the environmental temperature curve.
   This is the CCL.
2. Step 2: draw a line to the right, parallel to the x-axis. Read off the CCL from the height scale.
   In this example, the CCL is around 3,200 feet.

Procedure for determining the convective condensation level (CCL)



Convection temperature

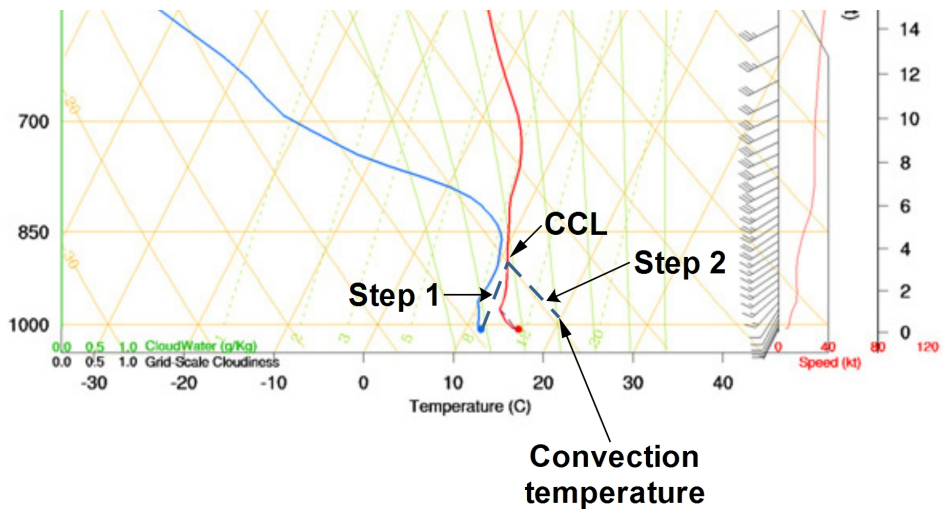
The convection temperature, Tc, is the temperature to which the surface must be heated to cause the formation of thermals. Also sometimes known as the *trigger temperature* .

Determining the convection temperature

Use the following procedure to determine the convection temperature, T_c

1. Step 1: from the surface dew-point temperature, draw a line parallel to the saturation mixing ratio line to where it intersects the environmental temperature curve.
   This is the CCL
2. Step 2: From the CCL, draw a line parallel to the dry adiabat down to the surface isobar. Interpolate the value of Tc from the isotherm scale.
   In this example, T_c is approximately 20°C.

Procedure for determining the convection temperature, T_c



Lifting Condensation Level (LCL)

Why this is important: *Lifting Condensation Level (LCL)* is the height at which a parcel of air becomes saturated with water vapour as a result of it being *mechanically lifted* - for example by orographic lifting when passing over a ridge or a mountain. If the parcel of air rises further, it will cool further, resulting in condensation and the formation of cloud.

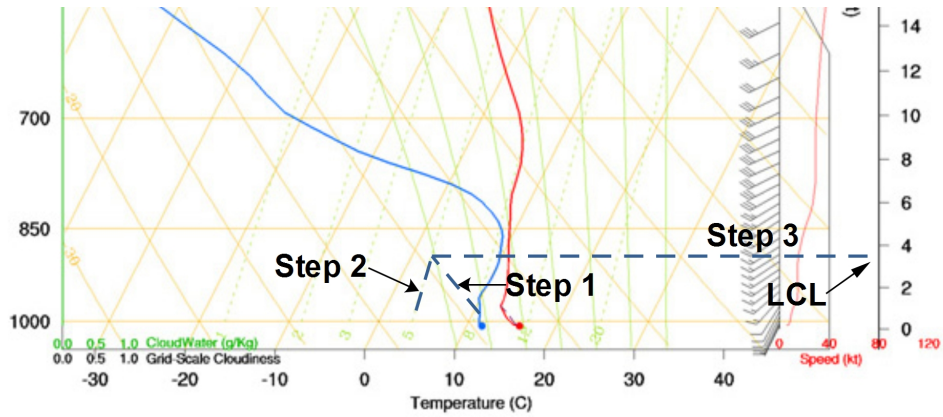
Determining the lifting condensation level (LCL)

Use the following procedure to determine the lifting condensation layer (LCL).

1. Step 1: Draw a line parallel to the dry adiabatic lapse rate starting from the temperature that is 50 mb above the surface.

2. Step 2: Draw a line parallel to the mixing ratio lines starting from the dew-point that is 50 mb above the surface.
   The intersection of these lines is the LCL
3. Step 3: Draw a line from the LCL to right parallel with the x-axis
   Read off the LCL height

Procedure for determining the lifting condensation level (LCL)



Positive and negative energy areas

Work in progress

Unstable air mass

A parcel of air that is warmer than the air around it is less dense and therefore buoyant, and the layer said to be unstable. Conventionally, this is also referred to as a *positive energy area* , i.e. an area where the air mass is rising.

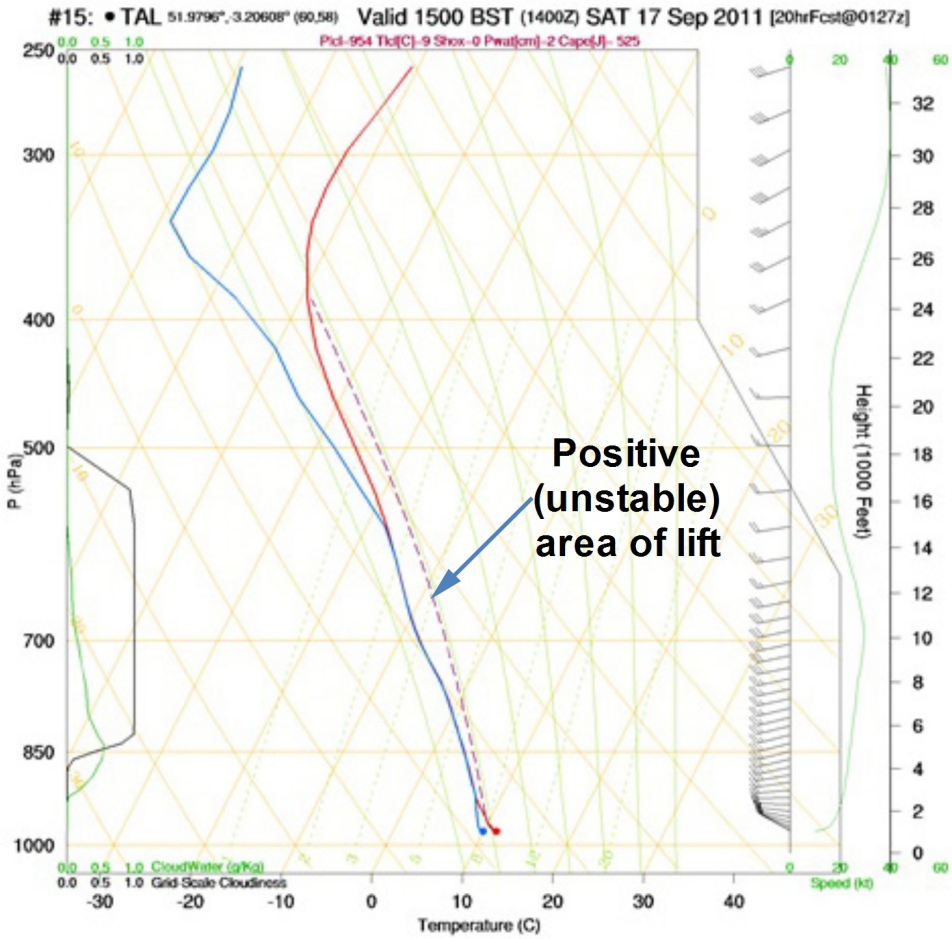
Stable air mass

Air that is cooler than the air around it is denser and therefore negatively buoyant, and the layer is said to be stable. Conventionally, this is also referred to as a *negative energy area* , i.e. an area are where the air mass is sinking.

Unstable (Positive energy) areas

When a parcel of air can rise freely because it is in a layer where the saturated adiabat it follows is warmer than the environmental temperature plot, the area between the saturated adiabat and the environmental temperature curve is proportional to the Convective Available Potential Energy (CAPE), also called positive areas - in other words are area of lift. This energy is available for conversion to kinetic energy of motion of the parcel. A parcel rising in these CAPE areas is at a higher temperature than the surrounding air and so continues to rise freely. Such unstable areas and are regions where clouds of greater vertical extent can form.

See the example below:



Stable (Negative energy) areas

When a parcel or air on a sounding lies in a negative area, energy has to be supplied to it to move it either up or down. The area between the path of such a parcel moving along a saturated adiabat and the environmental temperature curve is proportional to the amount of energy that must be supplied to move the parcel. This negative area is called a region of Convective Inhibition (CIN) - otherwise known as an area of sink.

Some key forecasting parameters

Thunderstorm parameters

Thunderstom prediction techniques

Thunderstorm activity can be gauged from three parameters derived from the Skew-t/Log-P chart. These are the K index - a measure of thunderstorm coverage; the Lifted index LI; a measure of the probable severity of a storm; and the TT index; a measure of the likelihood of a storm occurring.

The K-Index is worked out from the equation:

$K = T_{850} + T_{d850} + T_{d700} - T_{700} - T_{500}$

The Lifted index is worked out from the equation:

$LI = T_{500} - T_{p850}$

T_{p850} Tp is the temperature of a parcel of air lifted to 500mb moist adiabatically from the surface lifting condensation level.

The TT Index is given by the equation

$TT = T_{850} + T_{d850} - 2T_{500}$

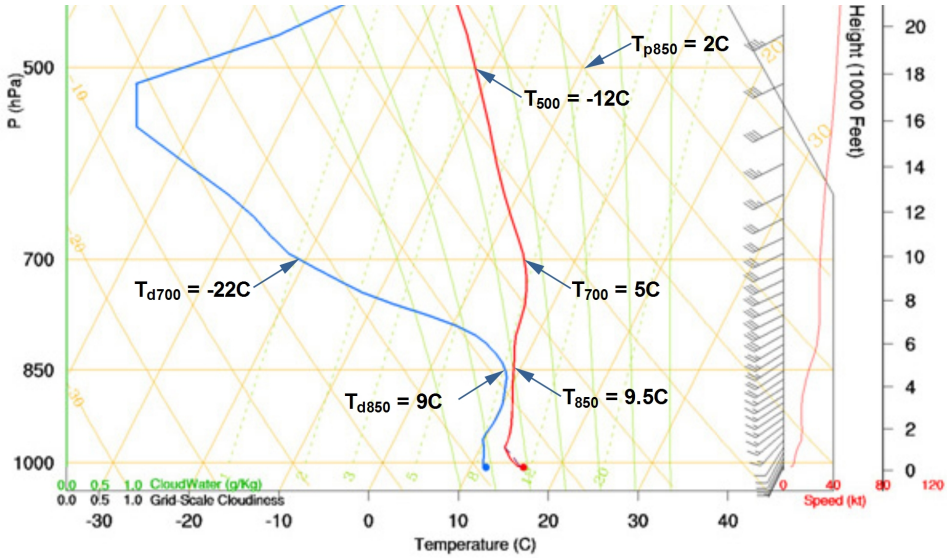
Thunderstorm parameters are then estimated from this table:

COVERAGE (K): How *widespread* will thunderstorms be?	Range		SEVERITY (LI): How *violent* will thunderstorms be?	Range		LIKELIHOOD (TT): How *likely* is it that thunderstorms will occur?	Range	
	< 20	Rare		< -2	Weak		< 44	Unlikely
	20 - 25	Isolated		-3 to -5	Strong		44 - 48	Scattered, non-severe
	26 - 30	Widely Scattered		> -5	Very strong		49 - 52	Few severe
	31 - 35	Scattered					>52	Many severe
	> 35	Numerous						

Note: in terms of 'Likelihood', mathematically this is a *probability*, p. Mathematically, $0 < p < 1$.

Determining thunderstorm parameters

First, from the chart, derive the temperature parameters required:



In this example:

T_{850} = +9.5ºC	T_{d850} = +9.0ºC	T_{d700} = -22.0ºC	T_{700} = +5ºC	T_{500} = -12ºC	T_{p850} = -10ºC

1. Step 1: $K = T_{850} + T_{d850} + T_{d700} - T_{700} – T_{500} = 9.5 + 9.0 + (-22) - 5 - (-12) = 3.5$
   Under these conditions, thunderstorms will be *Rare* occurrences (i.e. K < 20) .
2. Step 2: $LI = T_{500} - T_{p850} = -12 - 2 = -14$
   If they do happen, they may be *very strong* (i.e. LI > -5).
3. Step 3: $TT = T_{850} + T_{d850} – 2T_{500} = 9.5 + 9.0 - 2*(-12) = 42.5$
   However, the chances of any storms is *unlikely* (i.e. TT < 44)

Remember

- Tephigrams are a *forecasting* tool, not a report.
- Tephigrams are primarily a tool for *vertical* atmospheric characteristics; they don't tell us much about horizontal movement, apart form the wind scale (which, strictly speaking is not part of "Skew-T/Log-P").
- We are in the business of probabilities here;
- Having said that, the tephigram is one of the key tools available to meteorologists.

Snags with tephigrams

- There is no such thing as "dry" air - there will always be some water vapour present.
- The proportions of the constituent gases in air are not constant. Since the value of R in the equation PV=RT differs markedly in dry air as compared to saturated air, the relationship will therefore be different in different air masses. See: *Snags with tephigrams* on page 30.
- Processes in the atmosphere are not completely adiabatic. Despite the fact that air is not a good mixer, some mixing does take place, so some heat will enter and leave an air parcel.
- Tephigrams primarily give us a *vertical* picture of the atmosphere; they do not convey much horizontal information apart from wind direction. During periods of light wind strength, the vertical dynamics typically dominate the weather, i.e. turbulence; where an when clouds form, etc. Apart from this tephigrams give little information about air masses (and by implication, changes in the weather) moving into an area. It is possible to do some extrapolation - for example in a westerly air flow, looking at the tephigram say 200km west of your location may tell you what is likely to be happening at your location in a few hours but this won't necessarily be accurate. It makes no allowance for changes in elevation of the general terrain, or if the westerly station is coastal and your location is inland, the overall atmospheric water content will likely be different. Also, in period of high wind strength, tephigram derived information may be less reliable.
- Interpolation errors are quite possible when you read the chart, especially if you do so directly from a computer screen.
- QNH varies very dynamically, so the relationship between pressure levels (on the left of the tephigram) and height (on the right) will change.
- The further in the future we look, the less accurate the forecast T and T_d at a given pressure level is likely to be.

Speed conversion table

Conversions between common units of speed. (Values in bold face are exact.)

	ms^{-1}	kmh^{-1}	mh^{-1}	kt	fts^{-1}
ms^{-1}	**1**	**3.600000**	2.236936	1.933894	3.280840
kmh^{-1}	0.277778	**1**	0.621371	0.539957	0.911344
mh^{-1}	**0.447040**	**1.609344**	**1**	0.868976	1.466667
kt	0.514444	**1.852000**	1.150779	**1**	1.687810
fts^{-1}	**0.3048**	**1.097280**	0.681818	0.592484	**1**

Glossary

Adiabatic	Thermodynamic process in which the net heat transfer to or from the working fluid is zero.
Boyle's Law	A special case of the ideal gas law, which states that the pressure of a gas is inversely proportional to its volume. Mathematically is written P = Vk where P=pressure; v=Volume; k is is a constant representative of the pressure and volume of the system.
Charles' Law	States that the volume of a gas is directly proportional to its temperature
Gas constant	A constant, R, in the idealised Gas Laws governed by the equation PV=RT. The Gas constant for an ideal gas is 8.315 J K^{-1} mol^{-1}. In practice, the atmosphere is far from being an "ideal gas". For dry air, the constant R_d = 287 J K^{-1} kg^{-1}; for water vapour R_w = 462 J K^{-1} kg^{-1}
Gas Laws	A family of laws including *Boyle's Law* and *Charles Law* . Mathematically written as PV = RT where p=pressure; V=volume; T=temperature; R is the gas constant.
International standard atmosphere	Defined at T=15°C, P=1013hPa Normally abbreviated *ISA*.
Partial pressure	In a mixture of gases (such as air), each constituent gas has a partial pressure which is the pressure which that gas would have if *it alone* occupied the volume. The actual pressure of the gas mixture is the sum of partial pressures of constituent gases in the mixture.
Saturated vapour pressure	The partial pressure exerted by water vapour in a given volume of air when the vapour is saturated at the current temperature.
Isothermal	Thermodynamic change in a system, in which the temperature remains constant.

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