



## Layer Cloud Forecasting Contents

- 1 Introduction
- 2 Mass Ascent
  - 2.1 *Frontal Cloud*
  - 2.2 *Cloud Formed in Precipitation*
  - 2.3 *Non-frontal Medium and High Cloud*
- 3 Orographic Uplift
  - 3.1 *Upslope Stratus*
  - 3.2 *Orographic Cloud*
- 4 Turbulent Mixing
  - 4.1 *General Principles*
  - 4.2 *Air Mass Stratus*
  - 4.3 *Forecasting Techniques*
  - 4.4 *Non-frontal Stratocumulus*
- 5 Suggestions for Further Reading

© Crown Copyright. Permission to quote from this document must be obtained from The Principal, Met Office College.



# 1 Introduction

Cloud is formed when air is cooled below its dew point, and if the air is stable the cloud will be stratiform (i.e. layered). The cooling is usually brought about by uplift - rising air expands as the pressure decreases, and adiabatic expansion lowers the temperature. In the case of layer cloud, there are three main ways in which air may be lifted to form cloud:

- Mass ascent
- Orographic uplift
- Turbulent mixing

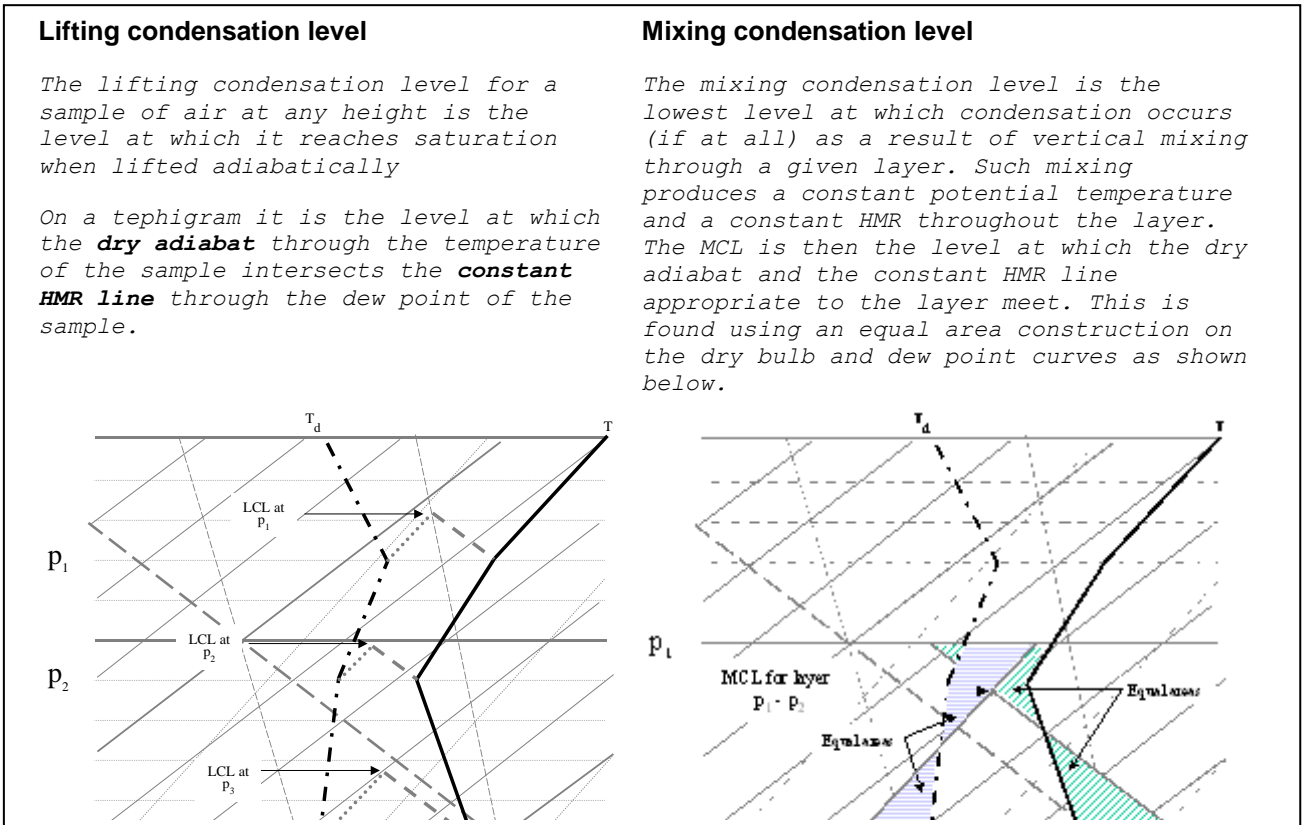
The most significant layer clouds are those which form in the boundary layer - stratus and stratocumulus. These often form quickly with full coverage of the sky and a very low cloud base, and thus their accurate forecasting is of great importance, especially to aviation.

Also to be considered are the medium and high layer clouds - altocumulus, altostratus, nimbostratus, cirrus, cirrocumulus and cirrostratus.

Reference is made in these notes to two condensation levels;

1. The lifting condensation level
2. The mixing condensation level

It is important to understand the definition of these two features and the constructions on the tephigram required to determine them.



See the box below.

## 2 Mass Ascent

### 2.1 Frontal Cloud

Fronts and depressions give rise to gentle ascent over large areas, often producing layer clouds throughout an extensive depth of the troposphere. The cloud system may not be continuous in the vertical, but may consist of layers separated by one or more layers of clear air. The main features of such ascent are its prolonged nature and small vertical velocities - of the order of a few

#### Frontal cloud structure from a tephigram

*The following guidelines should give a reasonable assessment of the likely frontal cloud structure from dew point depressions on a representative tephigram:-*

Dry bulb  $\geq 0^{\circ}$  C

$(T-T_d) \leq 1^{\circ}$ C	$8/8$ layer	OVC
$(T-T_d)$ 1 to $5^{\circ}$ C	Thin layers	SCT-BKN
$(T-T_d) > 5^{\circ}$ C	No cloud	NIL or FEW

Dry bulb  $< 0^{\circ}$  C

$(T-T_d) < 3^{\circ}$ C	$8/8$ layer	OVC
$(T-T_d)$ 3 to $5^{\circ}$ C	Thick layers	BKN
$(T-T_d)$ 6 to $10^{\circ}$ C	Thin layers	FEW-SCT
$(T-T_d) > 10^{\circ}$ C	No cloud	

If the cloud layer is:-

0 - 1500 ft	probably stratus
1500 - 8000 ft	probably stratocumulus
8000 - 20 000 ft	probably altostratus
2000 - 30000 ft	thick layers nimbostratus
$\geq 20\ 000$ ft	probably cirrus or

centimetres per second.

#### 2.1.1 Forecasting Technique

The forecasting of frontal layer cloud involves the following three principal considerations:-

- ANALYSIS
- ADVECTION

#### DEVELOPMENT

Looking at the forecasting task in more detail, both in the short term and the longer term, these three considerations may be applied as follows:-

##### Short-term forecasting (up to about 12 hours)

ANALYSIS of the current situation in detail:

- Surface observations (upper cloud may be obscured)
- Upper air observations and ascents (see box)
- Satellite imagery (high cloud may obscure low)

ADVECTION of the current state with wind field:

- Component of gradient wind normal to front
- Actual or forecast winds at cloud level

DEVELOPMENT of the current state with time:

- Pressure tendencies
- Wave development on front?
- Development areas on upper air charts?
- Model output verify early frames against observations
- Local effects coastal, orographic etc.

##### Longer term forecasting (beyond 12 hours)

The above guidelines continue to apply, but become less reliable with time. In addition:-

- Use model output to position fronts/lows/rain-bands and assess the likely activity of the system.
- Apply classical frontal theory (bearing in mind its shortcomings) and local knowledge to produce a best estimate of the likely cloud structure.

## 2.2 Cloud Formed in Precipitation

When precipitation falls from cloud into a cloud-free layer, evaporation takes place. This cools the air and increases its dew point, and may give rise to condensation and cloud.

### 2.2.1 In Rain

Stratus *pannus* forms beneath thick rain cloud during prolonged rain. It is ragged in appearance and generally patchy - seldom approaching 8/8 and needing very prolonged rain to do so. A rough guide to forecasting the base of stratus *pannus* is:-

2 hrs continuous mod/hvy rain - stratus base 800 ft  
 3 hrs continuous mod/hvy rain - stratus base 400 ft

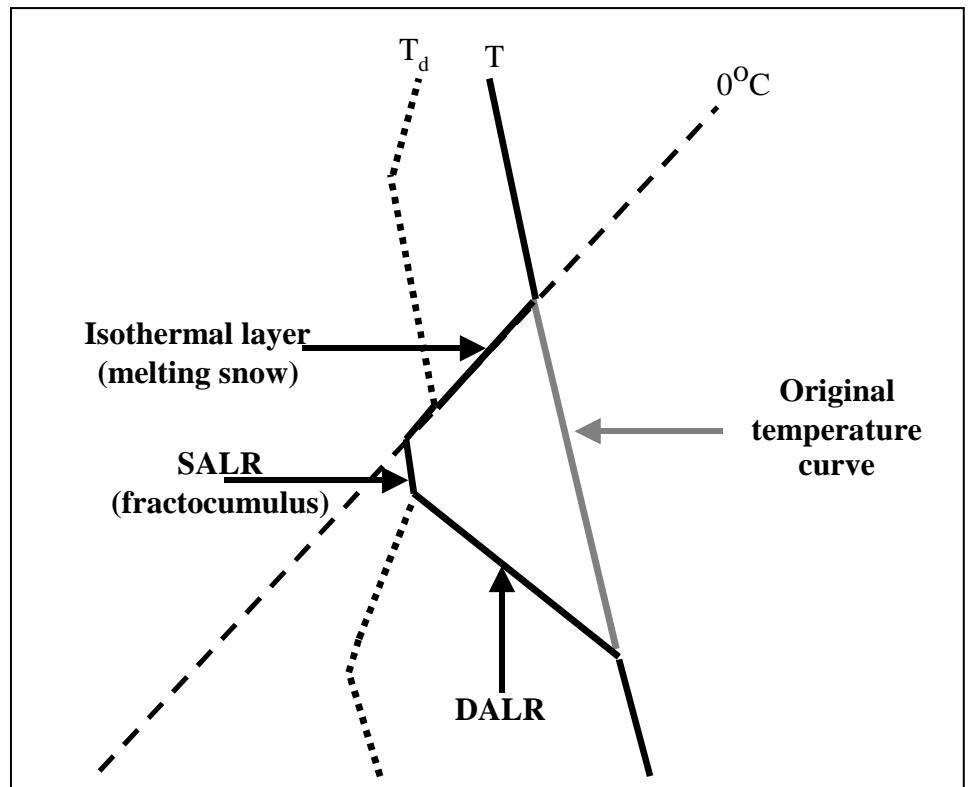
but note that this does not allow for upslope or advective effects. Upwind observation may also be helpful in assessing the likelihood and height of stratus pannus at your station.

### 2.2.2 In Snow

If precipitation is falling from sub-freezing cloud in the form of snow into cloud-free air with a temperature above freezing, it will begin to melt. The melting of snow requires latent heat, and this has the effect of cooling the air to produce an isothermal layer. It has been calculated that:-

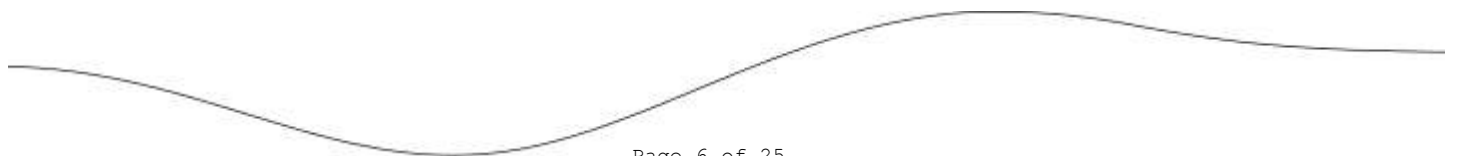
1 hour of snow will produce an isothermal layer 600 ft deep, increasing to a maximum of 1200 ft deep after 4 hours

The extension downwards of the 0°C isothermal layer into the underlying warmer air causes a DALR to form between the cooled and the unmodified ambient air. If saturation is reached, instability causes a layer of ragged *fractocumulus* a few hundred feet thick to form near the 0°C isotherm and below the precipitating cloud base. Figure 1 illustrates



the modified temperature profile produced.

Figure 1. *Schematic temperature profile produced by melting snow*



If there is sufficient cooling for the snow to reach the ground without melting, an isothermal layer with temperature near 0°C is usually established near the ground with stratus *pannus* forming at, or very near, the surface.

### 2.3 Non-frontal Medium and High Cloud

Most medium and high cloud occurs in association with mass ascent and can be forecast using the techniques described in section 2.1. Non-frontal cloud is harder to predict, particularly when it occurs in thin layers difficult to discern on upper air sounding and not significant enough to be represented in numerical model products. Such cloud is often associated with areas of medium or upper-level instability, or with wind shear, and the following may be helpful in forecasting its occurrence.

- i) Use satellite imagery - especially infrared
- ii) Use actual or forecast ascents:
  - $(T - T_d) < 10^\circ\text{C}$
  - strong vertical wind shear (wind *increasing* with height)
  - conditional or potential instability at medium/height levels
- iii) Use model cloud or relative humidity fields
- iv) Areas favourable for medium and high cloud are:
  - Cold pools or sharp thickness troughs
  - On warm side of jet (within 300 miles of jet axis)
  - On, or just to rear of, a sharp 300mb ridge
- v) Relate cirrus tops to the tropopause:
  - Low trop (below 30000ft) - cirrus often extends to trop
  - High trop (above 35000ft) - tops a few thousand feet below

The Handbook of Weather Forecasting includes a detailed discussion of cirrus forecasting techniques. For further information see chapter 19, pp. 78-83.

### 3 Orographic Uplift

#### 3.1 Upslope Stratus

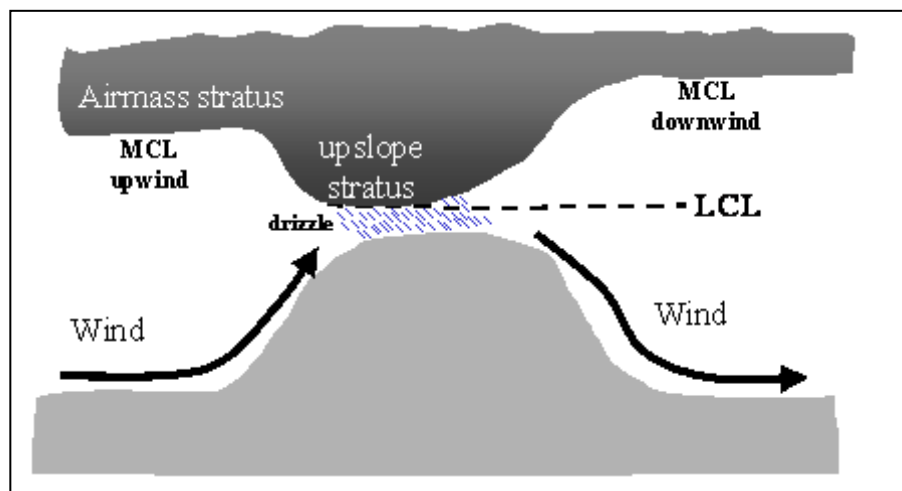
When stable air is forced by high ground to ascend above its lifting condensation level (LCL) , stratus cloud forms. If the air is very moist, the LCL will be low and fog may form even on quite small hills.

The formation of upslope stratus is depended upon suitable, sloping topography, and the precise wind direction may be crucial in determining whether or not it will form over a particular station. Hence a detailed knowledge of the characteristics of the local area is vital if its formation is to be successfully forecast. Table 1 summarises the factors which are generally favourable for the formation of upslope stratus.

- Stable atmosphere
- Air near to saturation at lowest levels
- Sloping terrain
- Suitable (upslope) wind direction
- Moderate breeze

Table 1. *Factors favourable for the development of upslope stratus.*

Note that in synoptic situation where turbulent mixing maintains extensive low stratus over low-lying terrain (its base given the by the mixing condensation level, or MCL), the base of the stratus cloud on windward slopes of hills (LCL) is usually lower. Also if precipitation occurs, a Fohn effect may give a higher base, or smaller cloud





amounts on the lee side of the high ground, see figure 2.

Figure 2. *The variation of stratus base in response to upslope motion and the Fohn effect.*

To determine the stratus base (see figure 3):-

- i) Select a suitable representative upper air sounding
- ii) Modify the temperature and moisture profiles near the ground to fit the local temperature and dew point.
- iii) Find the LCL from a series of levels near the surface.
- iv) Upslope stratus base is given by the lowest LCL (this will normally be the LCL from the surface, unless the air has a marked negative hydrolapse).

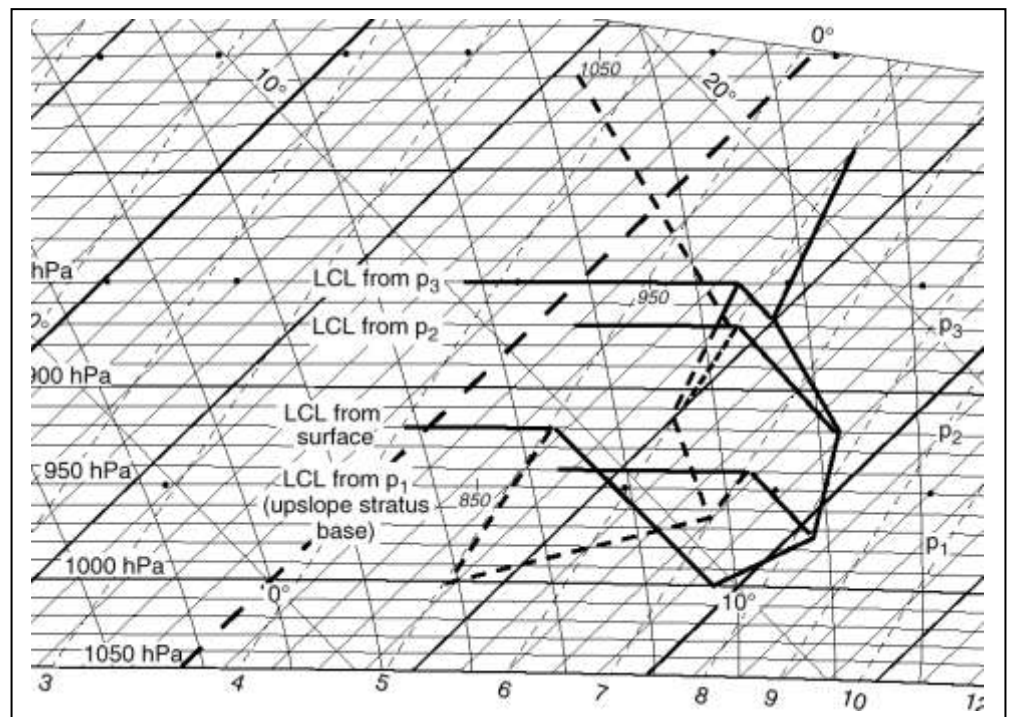


Figure 3. *Determining the base of upslope stratus (given by the lowest LCL in the lifted layer).*

### 3.2 Orographic Cloud

The vertical motions induced in an air stream crossing high ground often give rise to orographic clouds with distinctive features. The actual cloud formation will depend on the wind and temperature profile and the nature of the topography, and a detailed discussion of orographic cloud is beyond the scope of these notes, but some of the

main cloud types are listed below, and illustrated in figure 4.

- Cap cloud: Low cloud with its base near, or below the mountain top level, and a relatively smooth top roughly the same shape as the mountain.
- Lenticular cloud: Stationary or quasi-stationary, smooth, lens-shaped clouds which form in bands parallel to and downwind of the mountain. These occur when the atmosphere is conducive to lee-wave motions.
- Rotor cloud: A line of stratus or stratocumulus parallel to the ridge, formed by turbulent rotor motion to the lee of the mountain.
- Banner cloud: A stationary, banner-shaped cloud formed to the lee of isolated, cone-shaped mountains in strong winds.

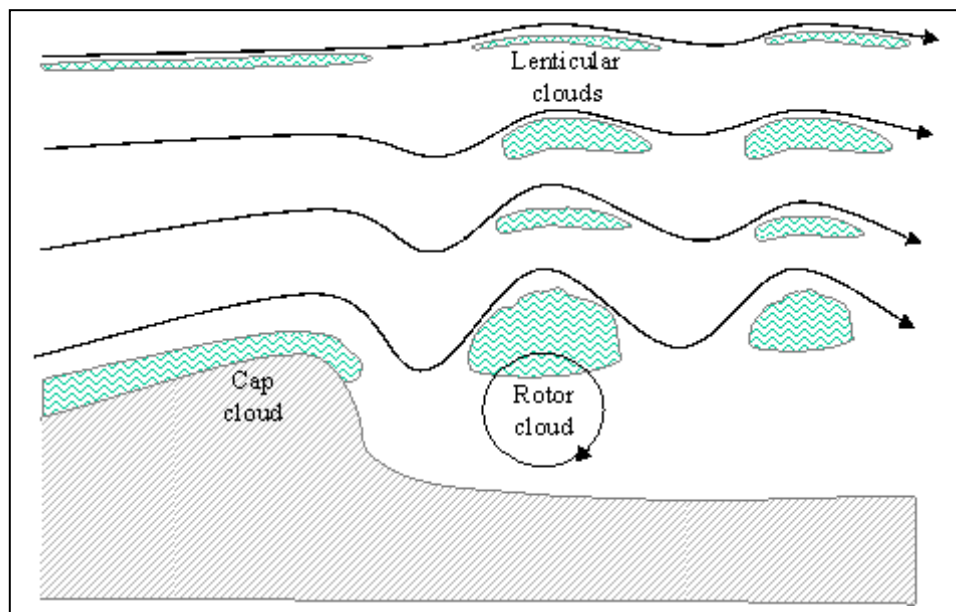


Figure 4. Cloud features typical of well-developed mountain wave activity.

## 4 Turbulent Mixing

### 4.1 General Principles

Turbulent mixing within a layer is brought about by wind shear. Although this can happen at any height, the most important to forecasters is that of the boundary layer, where surface friction creates marked wind shear in the

lowest few thousand feet of the earth's atmosphere. This section concentrates on turbulent cloud in the boundary layer (or *mixing layer*). See section 2.3 for guidelines on forecasting non-frontal medium and high cloud.

Turbulence tends to establish a DALR temperature profile in the mixing layer, with the humidity profile developing a constant HMR value. Consequently the relative humidity increase with height and, if saturation is reached, cloud forms the base given by the mixing condensation level (MCL) of the layer. Turbulence clouds are often surmounted by an inversion, with a sharp increase in temperature and decrease in dew point above the cloud top, while the temperature profile within the cloud layer approaches an SALR (see figure 5).

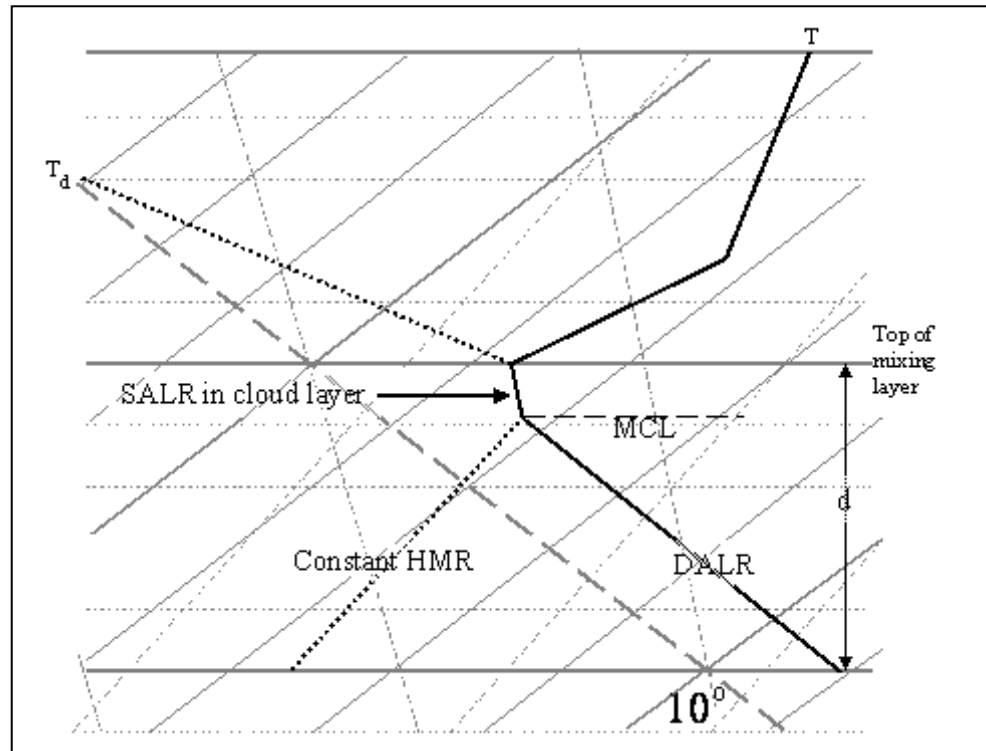


Figure 5. Schematic temperature and dew point profiles throughout a well-mixed boundary layer, depth  $d$ .

Use of the MCL to determine the cloud base requires a knowledge of the depth of the mixing layer,  $d$ . This is easy to assess if the top is marked by a sharp temperature inversion, but if this is not the case an estimate must be made using one of several empirical techniques available. For example:-

For surface winds  $\leq 16$  kts:

$$d \approx 200V_s$$

(were  $V_s$  is the surface wind speed in kts)

For surface winds  $> 16$  kts:

$$d \approx 3300 \text{ to } 3600 \text{ ft during the night}$$

$$d \approx 4000 \text{ ft during the day}$$

The difficulty in obtaining an accurate estimate of  $d$  limits the usefulness of the MCL construction, and locally derived empirical methods for forecasting the cloud base often give more reliable results.

## 4.2 Air Mass Stratus

Air mass stratus is formed when moist air in a turbulent boundary layer is cooled below its dew point by contact with a cold surface, as illustrated in figure 6.

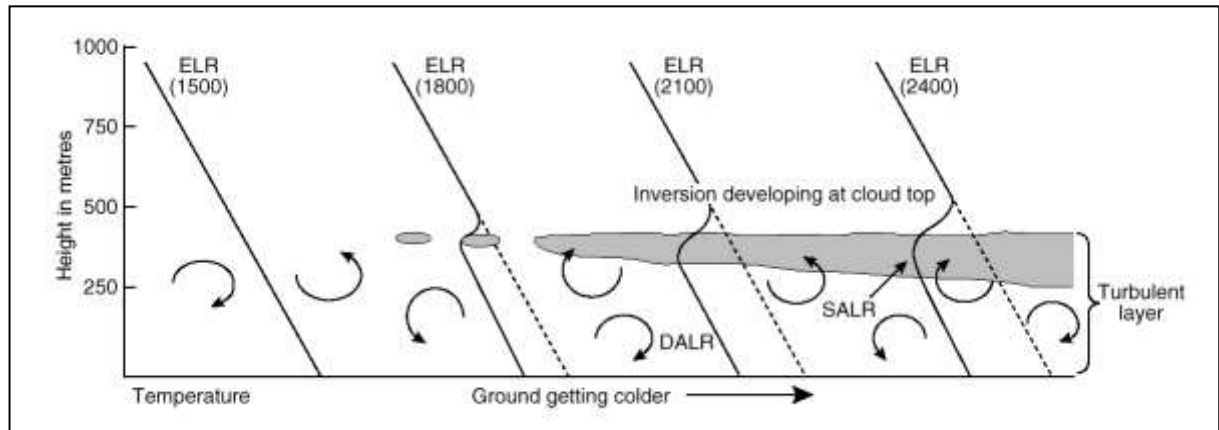


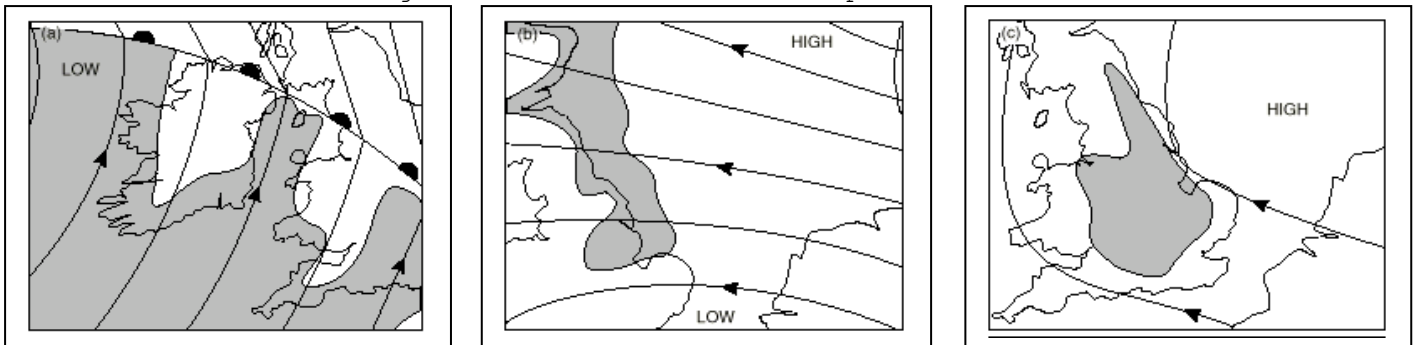
Figure 6. *The formation of stratus by nocturnal cooling. Temperature profiles are shown every three hours as surface cooling and turbulent mixing act to lower the temperature of the boundary layer, with stratus forming beneath the inversion.*

Mansfield (1988) identified three principle regimes for stratus formation in the UK:-

- **Moist south-westerly:** When moist, stable tropical maritime air spreads north-eastwards across the Atlantic towards the British Isles it is cooled from below by contact with a progressively colder sea surface, giving widespread stratus around southern and western coasts and sometimes sea fog (stratus is more likely with surface winds above about 15 kt). Penetration of the stratus inland varies greatly with the season - in the warmer months it is readily *burnt off* but in the autumn and winter it can be widespread and persistent over Southern England.
- **Cold easterly:** In spring and summer warm air advected from the east across the relatively cold North Sea may be cooled and moistened sufficiently to form stratus on the east coasts of England and Scotland. The spread inland of North Sea stratus is a frequent problem for airfields in eastern districts.
- **Winter south-easterly:** South-easterly winds from the continent may cause the development of low stratus over parts of south-east Britain. This is due to the cooling of air by contact with a cold surface and is most likely to form overnight, or when there is snow lying. Airfields situated on ground sloping down towards the

south-east are particularly prone to stratus in these situations (see section 3.1 for more information on upslope stratus).

Figure 7 shows the areas most prone to stratus in each of



these three regimes.

Figure 7. Areas of the British Isles prone to stratus (shaded) in the three principal regimes: a) moist south-westerly, b) cold easterly, c) winter south-easterly.

Another common scenario, not shown above, occurs when tropical air is drawn around an anticyclone centred to the west of the UK. This can often lead to stratus affecting northeastern facing coasts, particularly in spring when sea surface temperatures are at their coldest. Such stratus is commonly referred as North Sea stratus, "Haar" or "Sea Fret". (See also course notes on Fog, section 3.)

The extent to which marine stratus will both move inland, or indeed recede back to the coast, depends on the degree of differential heating between land and sea and the strength of the onshore wind. The edge of the stratus sheet denotes the equilibrium point between two opposing processes; net condensation caused by cooling over the sea and net evaporation caused by heating (and the presence of drier air) over the land. Daytime heating leads to an increase in evaporation rates which during the summer is usually enough to offset the onshore feed of stratus and "burn" the stratus back to the coast. However, an increase in onshore wind, caused by a sea breeze for example, can bring the cloud edge back on to the coast. During the evening, the cloud edge moves inland as land temperatures, and hence evaporation rates, fall. This diurnal cycle will persist for as long as the synoptic situation remains unchanged, but subtle variations in humidity and wind speed make accurate prediction a forecasting challenge.

Many coastal sites have developed their own local techniques for forecasting the advection of coastal stratus

and these should be studied closely on arrival at a new station. As a general guide coastal stratus will start to spread inland when the temperature on the coast has fallen a degree or two below the morning stratus clearance temperature. (If the coastal temperature is not known, use the sea temperature).

## 4.3 Forecasting Techniques

If stratus is expected to form, the following will have to be predicted:-

- Stratus base
- Stratus tops
- Temperature of formation and clearance
- Time of formation and clearance

Numerous different formulae, theoretical and empirical, have been developed to aid in the prediction of stratus formation. Success with these is, however, dependent upon location and they will not be discussed here. There is no substitute for experience and local knowledge. Find out which methods work best in your area and look at local studies and airfield weather diagrams.

### 4.3.1 Forecasting the stratus base

The height of the base is determined principally by the:-

- Strength of the wind
- Relative humidity of the air

The strength of the wind affects the efficiency of the turbulent mixing and the dept of the mixing layer. As a general rule,

*the stronger the wind, the higher the base*

One commonly used "rule of thumb" is that the height of the base,  $h$  (ft)m is given by:

$$h \approx 75 V_s$$

where  $V_s$  is the forecast surface wind speed (kts).

The relative humidity of the air determines the height of the MCL. The difference between the surface temperature and dew point ( $T-T_d$ ) may be used to estimate the stratus base using the empirical formula:

$$h \approx 420 (T-T_d)$$

It must be borne in mind, however, that the surface dew point depression may not be representative of the mixing layer as a whole; when the ground is cooling, the height of the stratus base is likely to be under-estimated, and when the ground is warming, the height of the base may be over-estimated.

These techniques will not always give reliable results, and may have to be adjusted according to local characteristics.



If stratus has already formed upwind, the observed base may be a more useful guide, though this may need to be adjusted to allow for cooling and local effects.

### 4.3.2 *Forecasting the stratus top*

The stratus top will occur at the top of the mixing layer (see section 4.1). In cases where the depth of the mixing layer is uncertain, remember that in most situations stratus is likely to be no more than a few hundred feet thick.

### 4.3.3 *Forecasting the temperature of stratus formation*

The stratus formation temperature,  $T_{st}$ , may be found from a number of sources, the choice of which to use depending on the location and synoptic situation.

Stratus may form at:-

- The temperature which stratus is already present on the chart.
- The stratus clearance temperature earlier in the day (minus 1 or 2°C).
- The sea temperature if stratus is expected to be advected in from the sea
- The stratus formation temperature determined from a representative ascent (see figure 8).

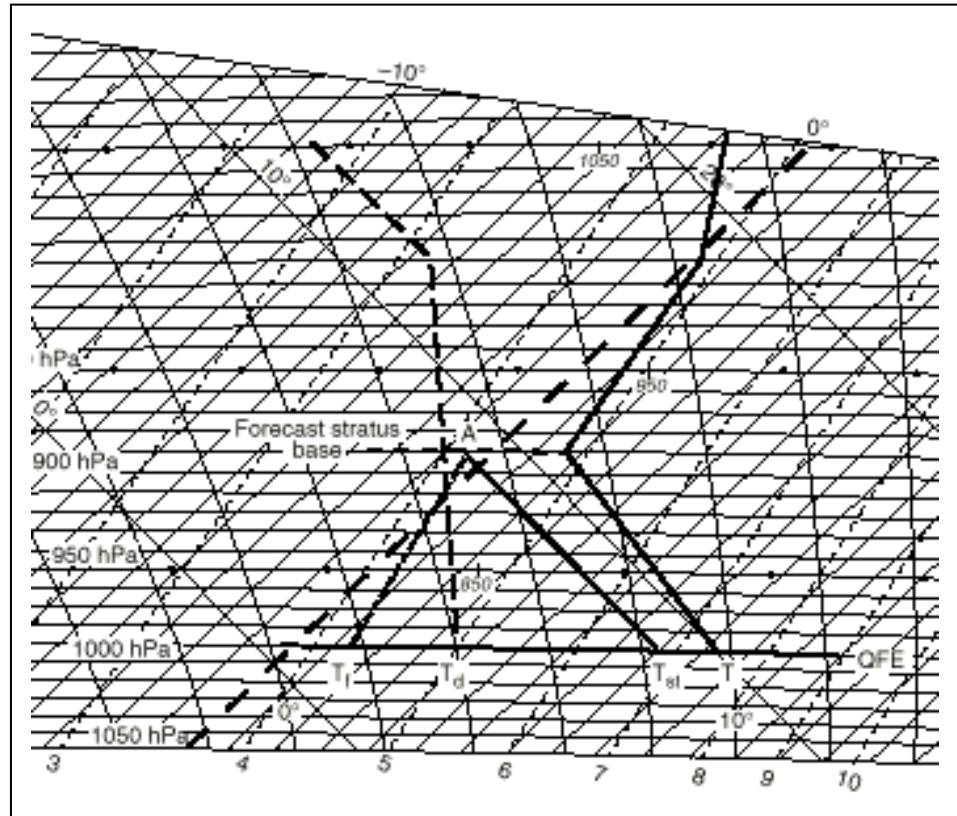


Figure 8. Determination of the stratus formation temperature ( $T_{st}$ ) from a representative ascent:

- i) Use Saunders technique to find the fog point,  $T_f$
- ii) From  $T_f$  draw a constant HMR line to the pressure level at which you expect the stratus to form (point A).
- iii) From A, follow a dry adiabat to the surface pressure (QFE). The temperature at this point is  $T_{st}$ .

#### 4.3.4 Forecasting the time of stratus formation

The usual method is to construct a cooling curve assuming clear sky conditions. The time at which the temperature falls to  $T_{st}$  is the time at which stratus may be expected to form.

#### 4.3.5 Forecasting the clearance of stratus

There are three main mechanisms by which stratus may be cleared:-

- Insolation
- Increased wind

- Advection of drier air

#### 4.3.5.1 Stratus clearance by insolation

The temperature at which the stratus will clear may be determined from a representative ascent, as shown in figure 9.

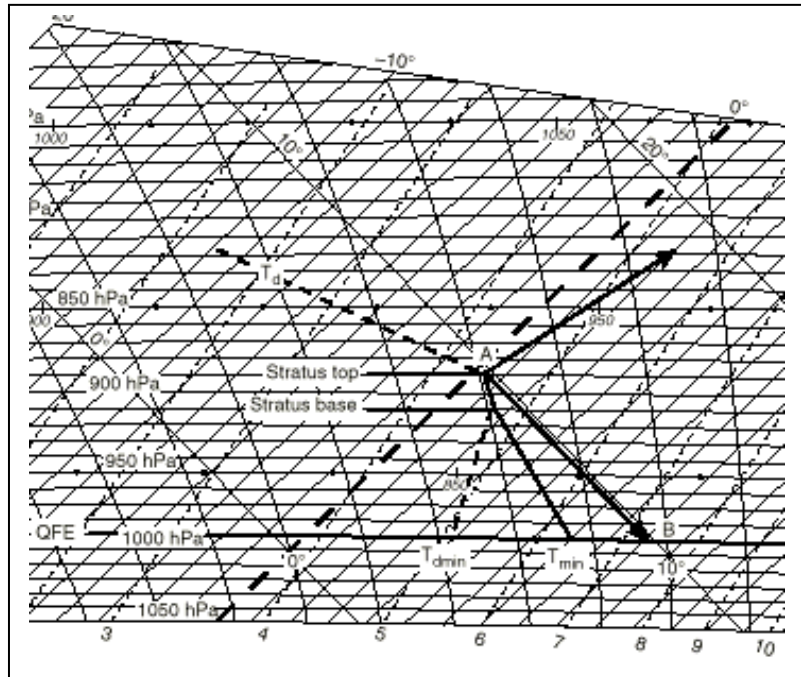


Figure 9.

Determination of the stratus clearance temperature from a representative ascent:

- Construct a dry adiabat from the level of the stratus top on the temperature curve (point A) to the surface pressure level QFE (point B).
- The temperature at B is the stratus clearance temperature.

If a day heating curve is constructed assuming cloudy conditions, the time of clearance will then be the time at which the stratus clearance temperature is reached.

Note that in winter stratus often persists all day, or clears only briefly at the time of maximum temperature before returning in the afternoon.

### 4.3.5.2 Stratus clearance by increased wind

An increase in wind speed has the effect of deepening the mixing layer. This can mix drier air from above into the cloudy layer and may disperse the stratus, as illustrated in figure 10.

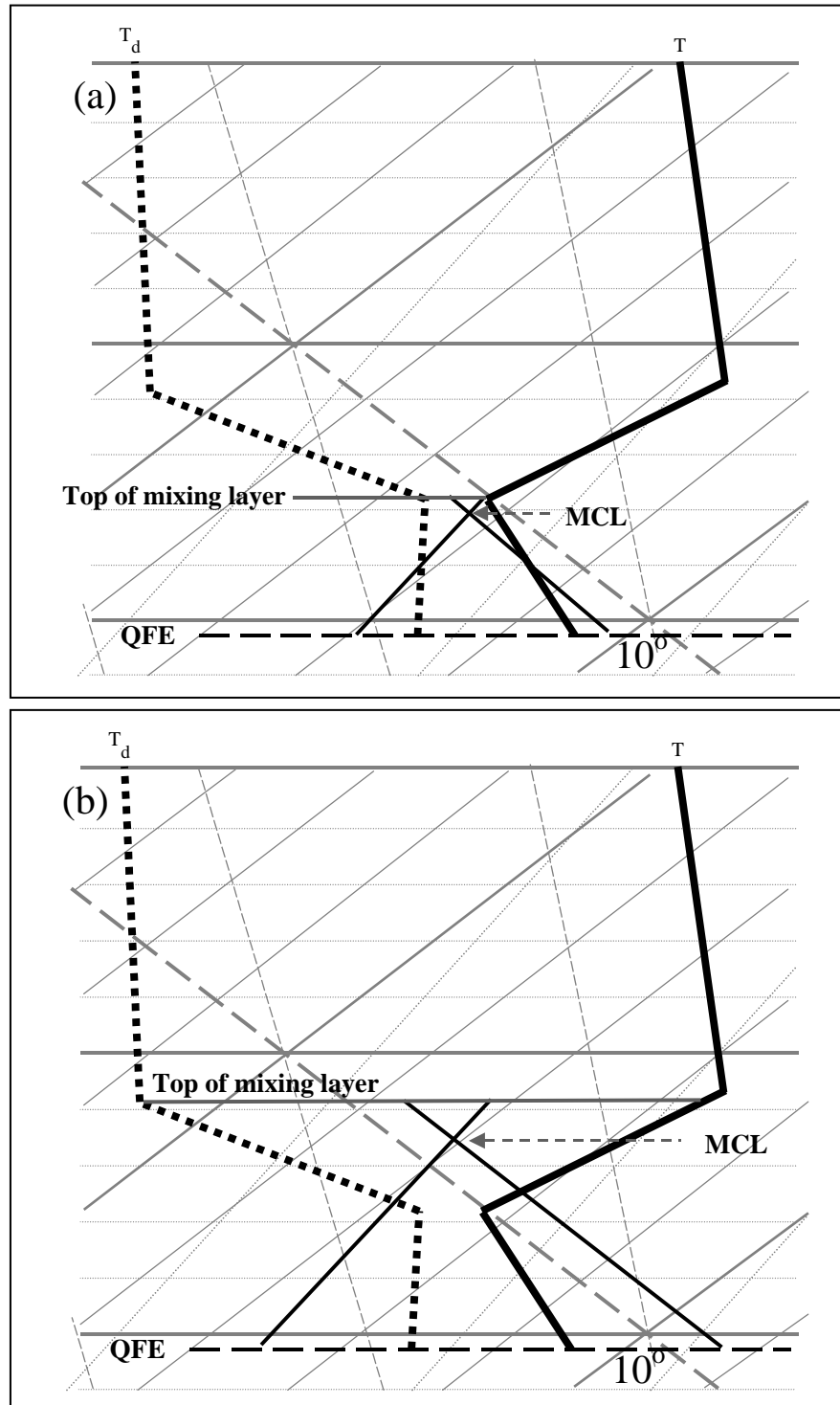


Figure 10. *Stratus clearance by increased wind: a) stratus with shallow mixing layer (light winds), b) cloud-free, deeper mixing layer (stronger winds).*

### 4.3.5.3 Stratus clearance by advection of drier air

The advection of drier air, perhaps from a somewhat different track, may result in the clearance of stratus. In such cases the rear edge may be followed on satellite pictures and/or synoptic charts.

One example commonly seen is the clearance of North Sea stratus by the backing of the wind to give a shorter sea track from the continent.

## 4.4 Non-frontal Stratocumulus

For stratus formation, the turbulence is generally purely mechanical - caused by friction at the earth's surface. In the case of stratocumulus, however, convection often plays some part, as evidenced by the cellular nature of the cloud on many occasions.

Stratocumulus may be very persistent and cover large areas, and the prediction of its formation and dispersal remain difficult problems for the forecaster. These notes are restricted to a brief discussion of the forecasting of non-frontal stratocumulus. For more detail on the physics and dynamics see Bennetts, *et al* (1986).

It is helpful to identify two main categories:-

- Stratocumulus formed by the spreading out of cumulus
- Anticyclonic stratocumulus

### 4.4.1 Stratocumulus formed by the spreading out of cumulus

When cumulus reaches a stable layer, vertical growth is inhibited and tops spread out as stratocumulus, some times becoming an almost unbroken sheet for the rest of the day (see figure 11).

This is a common occurrence in subsiding polar maritime air masses, particularly on the eastern side of anticyclones. Table 2 lists the main criteria for the development and dispersal of stratocumulus formed by the spreading out of cumulus.

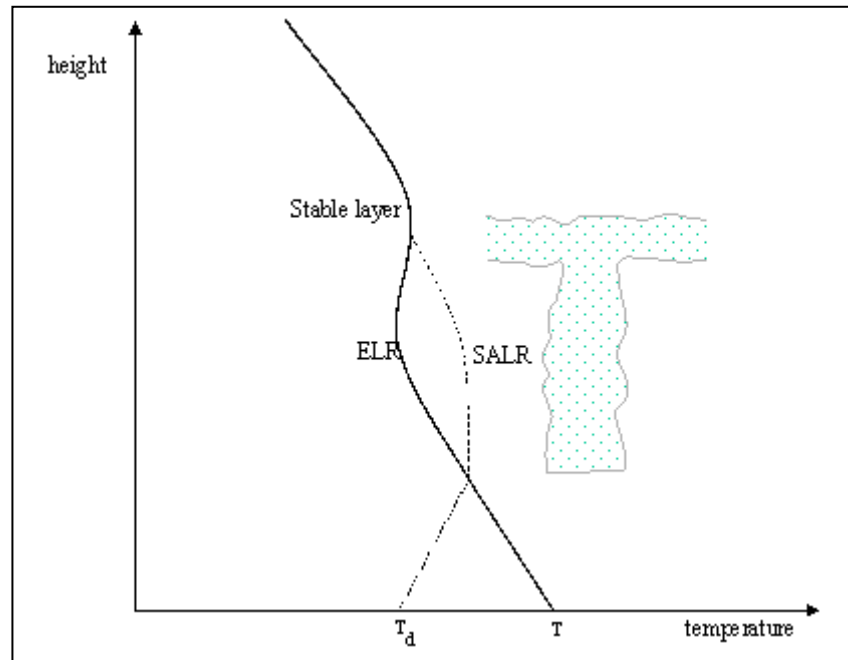


Figure 11. Formation of stratocumulus from the spreading out of cumulus beneath a stable layer.

<u>Development</u>	<u>Dispersal</u>
<ol style="list-style-type: none"> <li>1. An inversion or well-marked stable layer strong enough to halt all convective upcurrents even at the time of maximum insolation</li> <li>2. A lapse rate close to the DALR up to the base of the inversion when convection starts</li> <li>3. A LCL at least 2000 ft below the level of the inversion,</li> <li>4. A dew point depression between the LCL and the base</li> </ol>	<ol style="list-style-type: none"> <li>1. A decrease in dew point such that the LCL rises to within 30 hPa of the inversion.</li> <li>2. An increase in surface temperature such that the LCL rises to within 30 hPa of the inversion</li> <li>3. Continued subsidence such that the inversion lowers to within 30mb of the LCL</li> <li>4. A weakening of the inversion sufficient to allow cumulus tops to break through to higher levels and initiate entrainment of dry air into</li> </ol>

<p>of the inversion of 5C or less.</p>	<p>the cloud layers</p> <p>5. A cessation of convection due. to nocturnal cooling (does not apply over the sea).</p>
--	--

Table 2. The main criteria for the development and dispersal of stratocumulus formed by the spreading out of cumulus.

### 4.4.2 Anticyclonic stratocumulus

Stratocumulus frequently forms in anticyclonic conditions under the subsidence inversion, as illustrated in figure 12. The cloud sheet may extend for thousands of square miles and be very persistent.

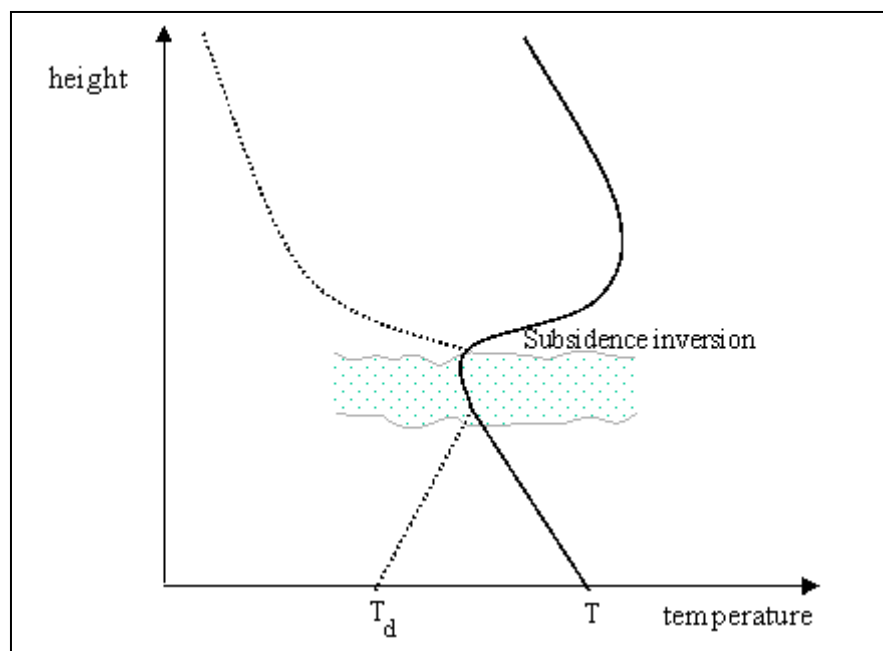


Figure 12. The formation of anticyclonic stratocumulus beneath the subsidence inversion.

#### 4.4.2.1 Formation

Formation may be brought about by mechanical turbulence in the mixing layer beneath the subsidence inversion or by

convection due to surface heating or a combination of the two. Convection is particularly important when cold air moves over a warmer sea - the inversion limits the depth of convection and a sheet of stratocumulus quickly develops.

Forecasting notes:

- i) Advect the cloud edge with the wind at cloud level
- ii) Use satellite imagery (especially the visible waveband)
- iii) It is usually best to forecast NIL or 8/8
- iv) The cloud sheet reduces insolation and inhibits night cooling
- v) Anticyclonic stratocumulus may be very persistent, especially in winter

#### 4.4.2.2 Dispersal

It is very difficult to predict the dispersal of anticyclonic stratocumulus, especially in winter, but the following notes may help:-

- i) Look for a rear edge to the cloud sheet and advect it with the wind at cloud level, or by continuity (using satellite imagery or upwind observations).
- ii) If the surface temperature rises sufficiently to give a DALR profile up to the cloud top, the cloud may start to break up, but re-form when the temperature drops (dispersal by this mechanism is unlikely in winter).
- iii) Continued subsidence may lower the inversion sufficiently to bring drier air down and disperse the cloud. This is, however, unusual.
- iv) Two objective techniques are described in the Forecasters Reference Book: James' rule and Kraus' rule. However, neither of these is a particularly reliable tool for forecasting.

## 5 Suggestions for Further Reading

1. The Forecasters Reference Book contains a section on the forecasting of layer cloud, including some useful hints and tips. See Chapter 5.
2. For a more thorough discussion of layer cloud forecasting the best reference is the Handbook of



Weather Forecasting (Met. O 875). Chapter 19 is devoted to the forecasting of clouds and precipitation.

3. Two Meteorological Magazine articles are recommended for further detail on specific topics:-

- Bennets, D.A., McCallum, E. And Nicholls, S.  
Stratocumulus: An Introductory Account, March 1986, pp. 65-76
- Mansfield, D.A.  
An investigation into stratus distribution over the United Kingdom, August 1988, pp. 236-245.