Some uses of Temperature/Height Diagrams in Teaching Meteorology and Climatology

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Examinations in geography, especially at Advanced level, have required increasingly more detailed and technical knowledge of the vertical aspects of meteorology. This is in recognition of the fact that weather is a three-dimensional phenomenon and requires more than the two-dimensional approach of a few years ago. More recently, questions involving the interpretation of weather maps have sought an ability to analyse temperature/height diagrams. The professionals' Tephigram with its greater detail and inclined axes can be confusing to pupils, consequently there must be a case for the wider use of simple temperature/height diagrams.

Having reached the upper school, most pupils are familiar to some extent with graphs, and it is relatively easy to introduce them to a graph where temperature (x axis) is plotted against height (y axis). This may be done initially when investigating the vertical temperature structure of the atmosphere, (Figure 1), the environmental curve, to show the infinite variety of lapse rates that can occur. There is no real need to plot absolute values, as it is the curves and lines on the graph which give most information.

Temperature/height diagrams are in common use in advanced texts, but too often they are used only to illustrate a topic further, or as an apparent afterthought. I would advocate the temperature/height diagram as a much more useful tool, since it may be used as a method of approaching and investigating a topic. The following topics are best covered

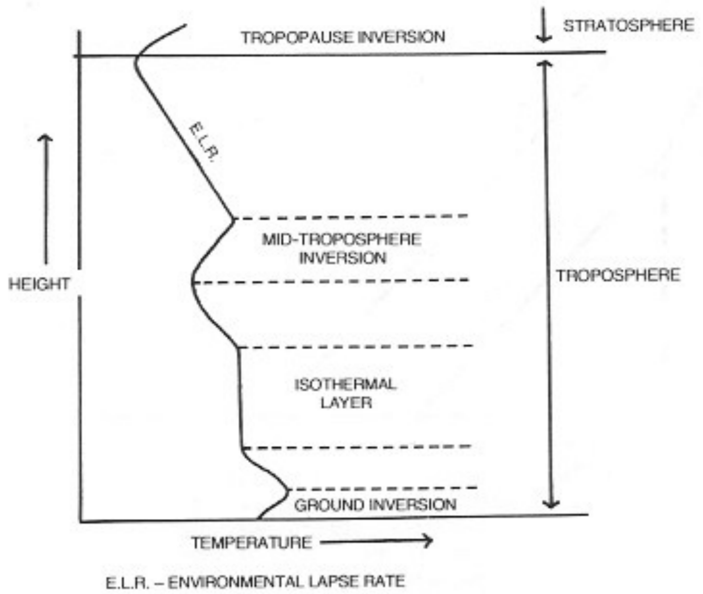


Figure 1. Vertical temperature structure of the atmosphere.

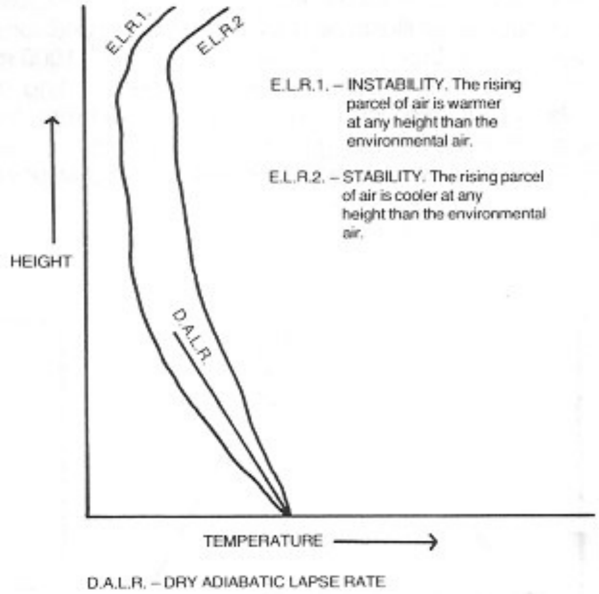


Figure 2. Stability on the temperature/height diagram.

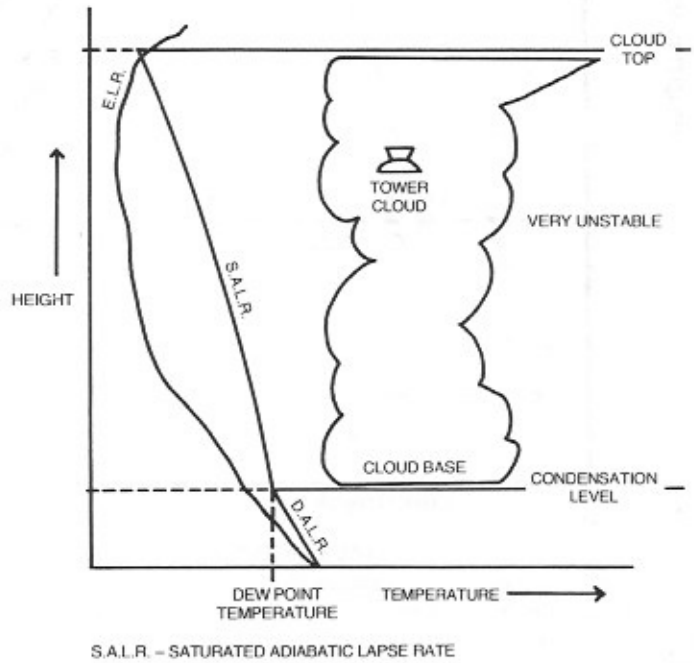


Figure 3. Instability and cloud development.

using temperature/height diagrams as the main method of teaching the fundamentals of each topic.

Stability/instability – showing adiabatic lapse rates.
Forced ascent – air rising orographically in stable conditions.
Anticyclones – limitations on cloud development, the formation of fog, frost, etc.
Air masses – at source, modifications, and to aid an understanding of the weather associated with them.
The Trade Wind Belt – cloud development.

Stability and instability

The use of the temperature/height diagram in the teaching of stability makes obsolete the diagram showing, in figures, the temperature of rising parcels of air at differing heights. Since the D.A.L.R. is a set rate it may be shown on the graph as a straight line, and its position on the graph in relation to possible E.L.R. curves will illustrate stable or unstable conditions (Figure 2). The fact that the D.A.L.R. is about 10°C/1000 m becomes a mere frill around a deeper understanding of why stable or unstable conditions occur. On the graph for unstable conditions, the rising parcel of air will cool at the D.A.L.R. (Figure 3). When the air has cooled to its dew point

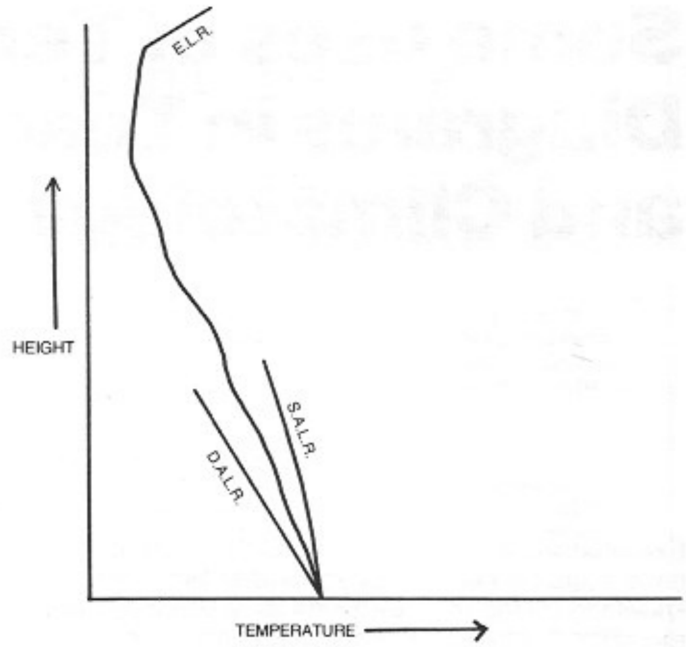


Figure 4. Conditional instability.

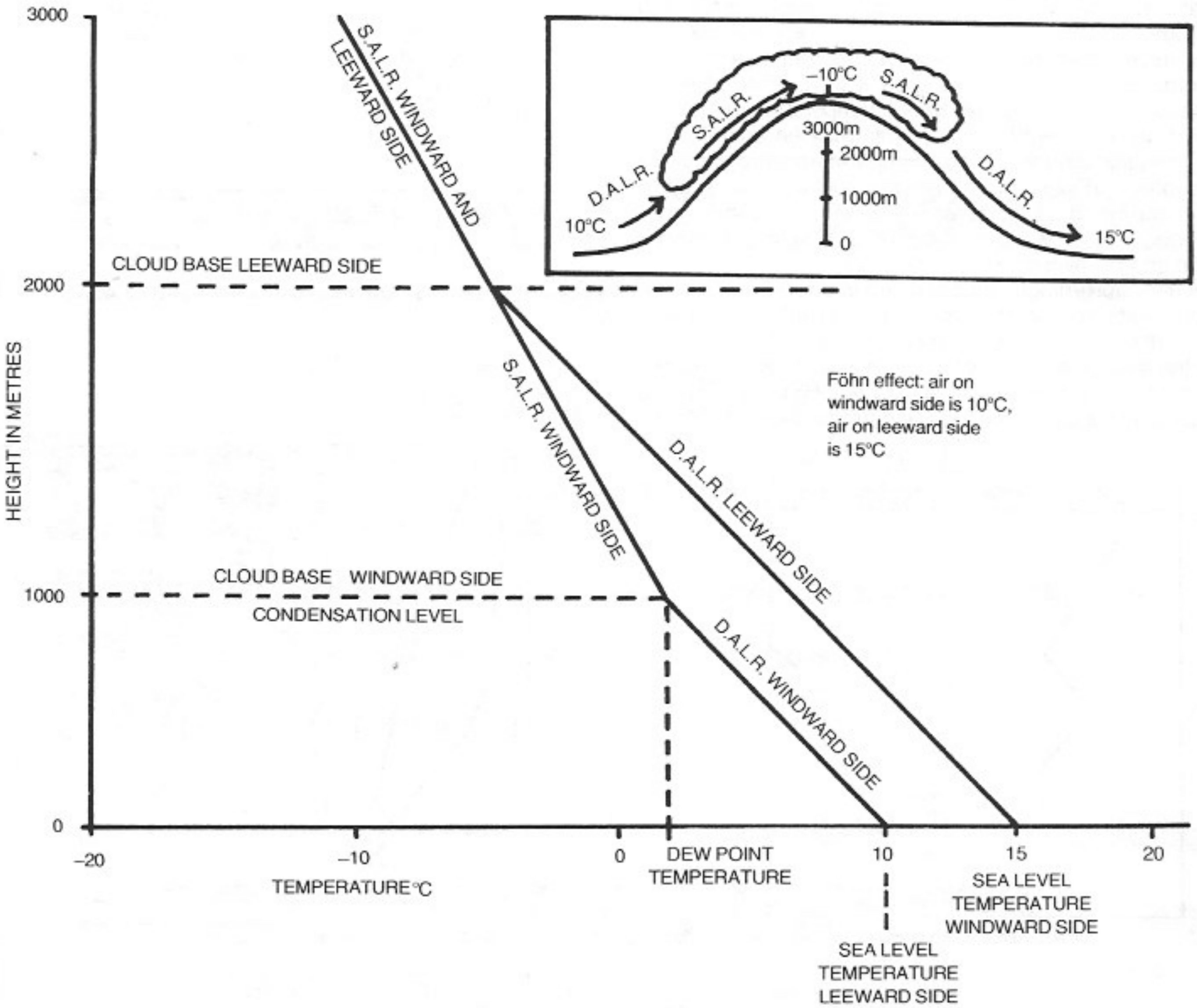


Figure 5. Forced ascent – the Föhn or Chinook effect.

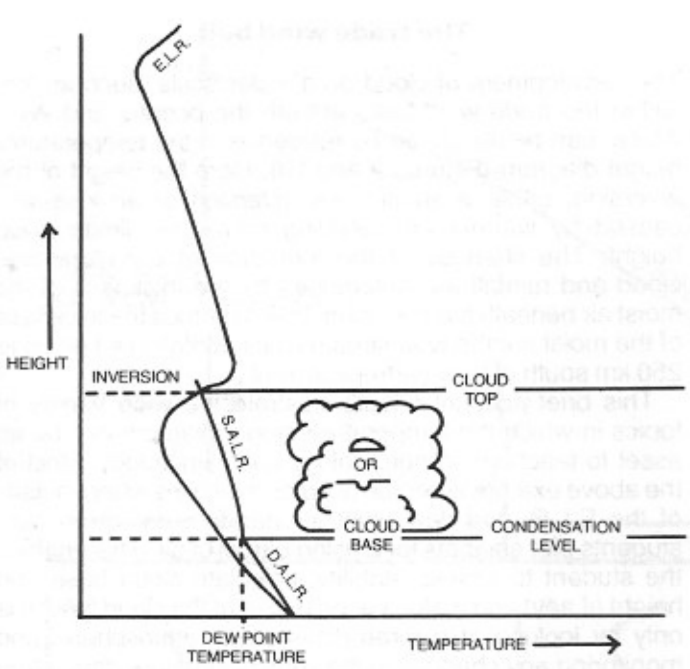


Figure 6. A mid-tropospheric subsidence inversion.

temperature it will continue to cool at the S.A.L.R., a changing rate, dependent upon the temperature of the air. The S.A.L.R. is shown as a curve on the graph. When the S.A.L.R. crosses the E.L.R., the rising parcel of air is no longer warmer than its surroundings and it will not continue to rise. The cloud base, cloud top and the probable cloud type can be estimated from the graph. It is, of course, possible to plot actual ascents and work out the possibilities of convection and cloud formation.

Conditional instability can be shown by a graph where the E.L.R. is between the D.A.L.R. and S.A.L.R., and instability is conditional upon the rising parcel of air being saturated and cooling less quickly with height (Figure 4).

Forced ascent

This is where stable air is compelled to rise, as at a frontal boundary, where warm air rises over cold air, or over hills to form orographic cloud. The temperature/height diagram can be used to find the condensation level and illustrate the Föhn or Chinook effect, in which air on the leeward side of mountains is considerably warmer than that on the windward side at a given altitude. The following example can be used as an exercise where pupils plot the lapse rates on graph paper. The S.A.L.R. is taken as a set rate of 6°C/1000 m.

If a parcel of air with a sea level temperature of 10°C and a dew point temperature of 2°C is forced to ascend over a mountain 3000 m high, the height of the cloud base on the windward side can be shown (Figure 5). When precipitation occurs over the mountain, the cloud base on the leeward side may be higher, say 2000 m. The temperature of the air on the leeward side, as air 'warms' at the respective adiabatic rates, is higher than that on the windward side.

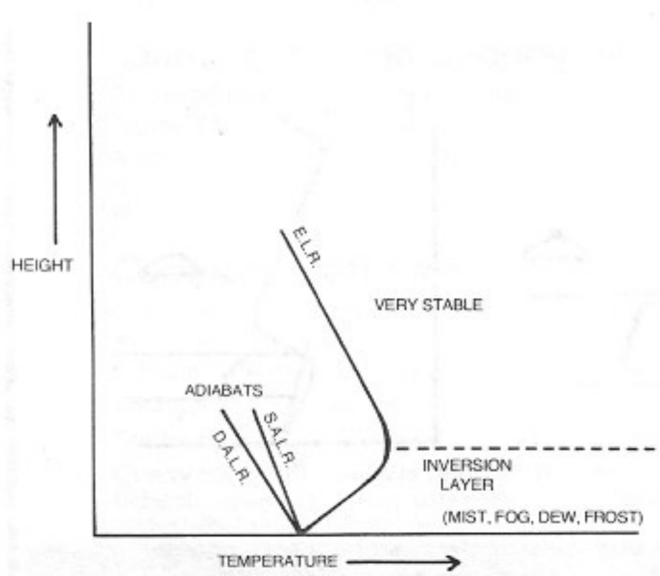


Figure 7. A ground inversion.

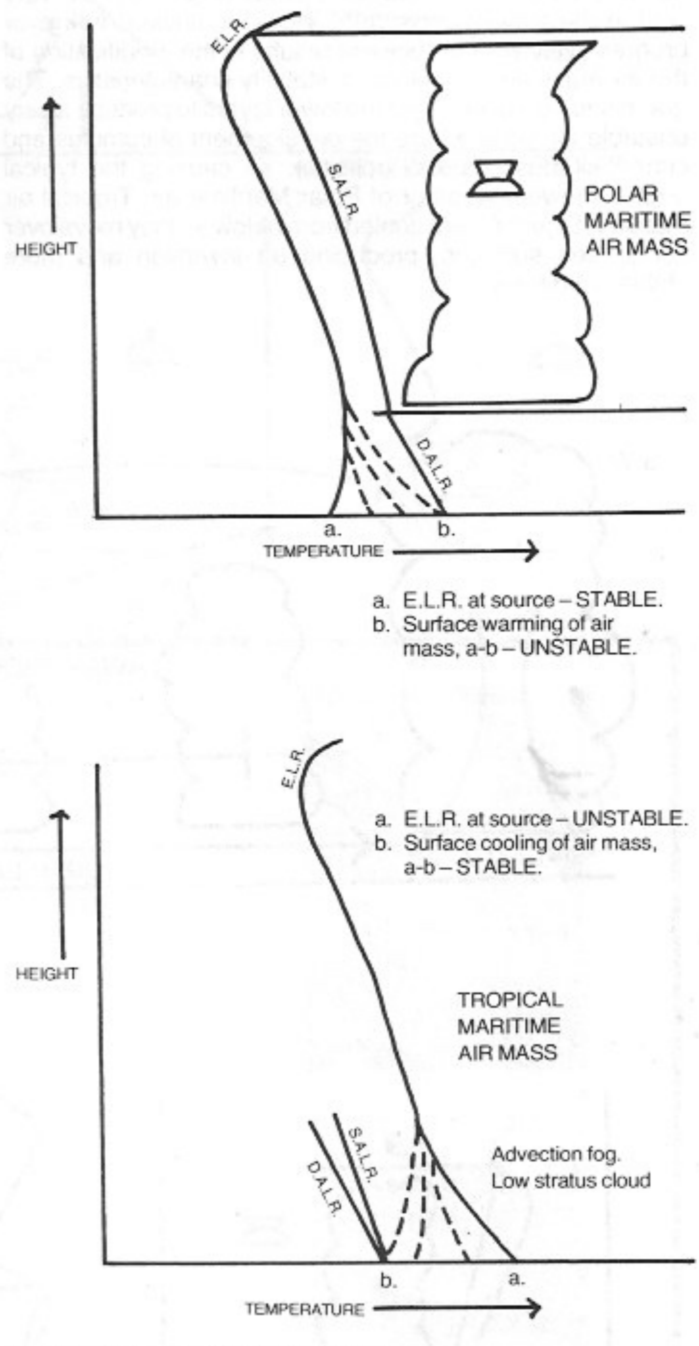


Figure 8. The stability of air masses.

Anticyclones

Fundamental to an understanding of anticyclonic weather is the fact that air is descending, warming and causing a subsidence inversion. A mid-tropospheric subsidence inversion and its effects on cloud development in anticyclonic conditions can easily be shown on the temperature/height diagram (Figure 6). Surface cooling by radiative heat loss and the formation of a ground inversion allows the introduction of the weather phenomena dependent upon near-surface cooling of air (Figure 7). The ground inversion illustrates very stable conditions, since air cooling at either the D.A.L.R. or S.A.L.R. will be cooler than the environmental air.

Air masses

The vertical temperature structure of air masses at source and after extensive modification can be drawn to illustrate the probable effect on the weather associated with air masses. At source, Polar air masses (Figure 8), are very cold in the lower troposphere, but a southward trek over progressively warmer oceans results in the modification of the air mass and a change in stability characteristics. The graph shows a warming of the lower layers to produce a very unstable air mass where the development of cumulus and cumulonimbus cloud is possible, so causing the typical bright, showery weather of Polar Maritime air. Tropical air masses (Figure 8), are cooled from below as they move over cooler sea surfaces, producing an inversion and more stable conditions.

The trade wind belt

The development of cloud on a wider scale, such as that within the trade wind belts of both the oceans and West Africa, can be illustrated by reference to the temperature/height diagram (Figures 9 and 10). Here the height of the inversion, either a subsidence inversion or an inversion caused by warmer air overlying cooler air, limits cloud height. The chances of the formation of cumulonimbus cloud and rainfall are determined by the thickness of the moist air beneath the inversion. In West Africa the thickness of the moist southerly airstream limits rainfall in a belt up to 250 km south of the intertropical front.

This brief account should illustrate the wide variety of topics in which the temperature/height diagram can be an asset to teachers of meteorology and climatology. Most of the above examples can be used as exercises where details of the E.L.R. and dew point temperature are given, and students plot adiabats for a rising parcel of air. This enables the student to assess stability, calculate cloud base and height (if any) and make a good guess at the cloud type. It is only by looking at a three-dimensional atmosphere, and monitoring any changes in the vertical structure, that a true understanding of meteorology can be taught.

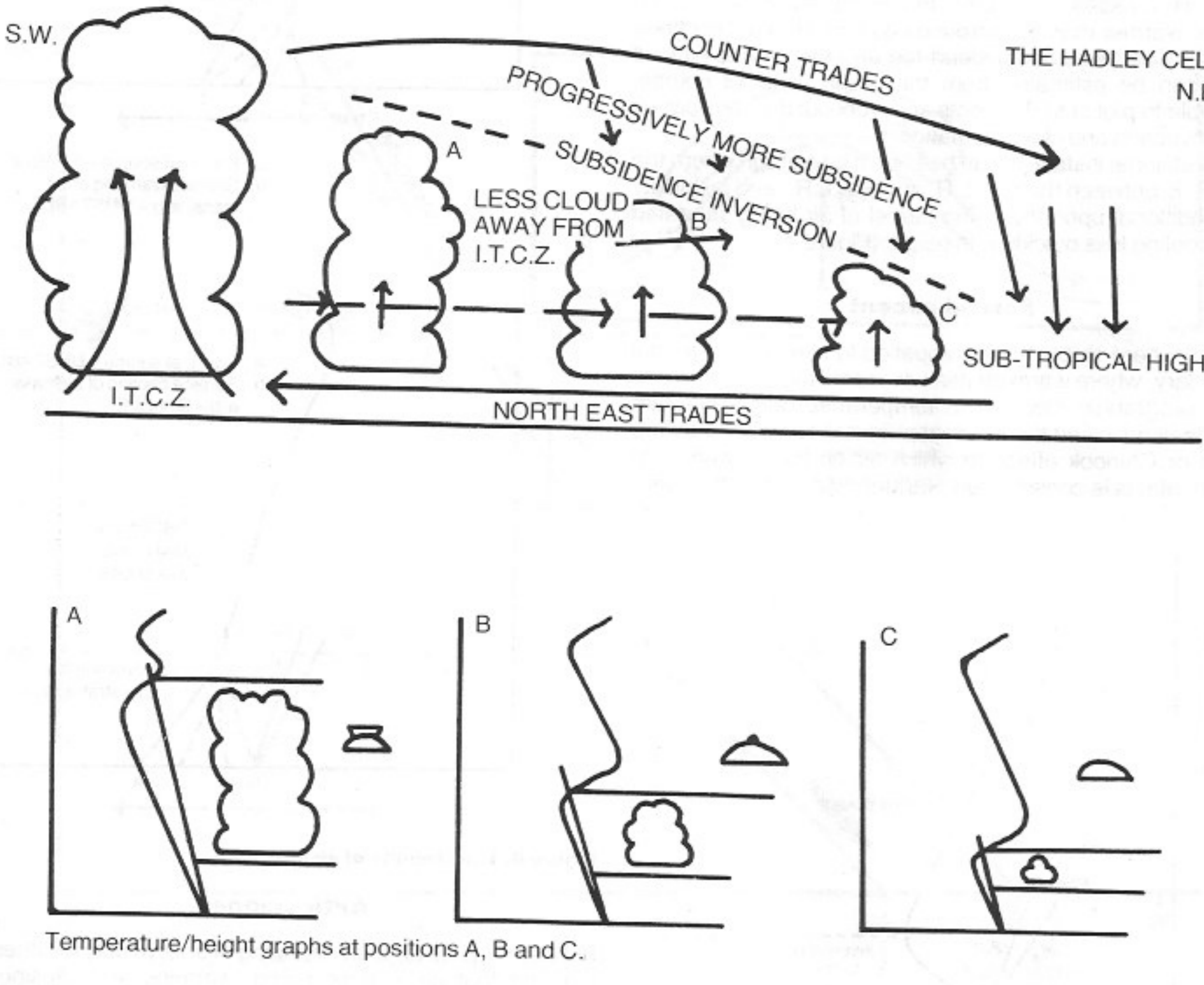
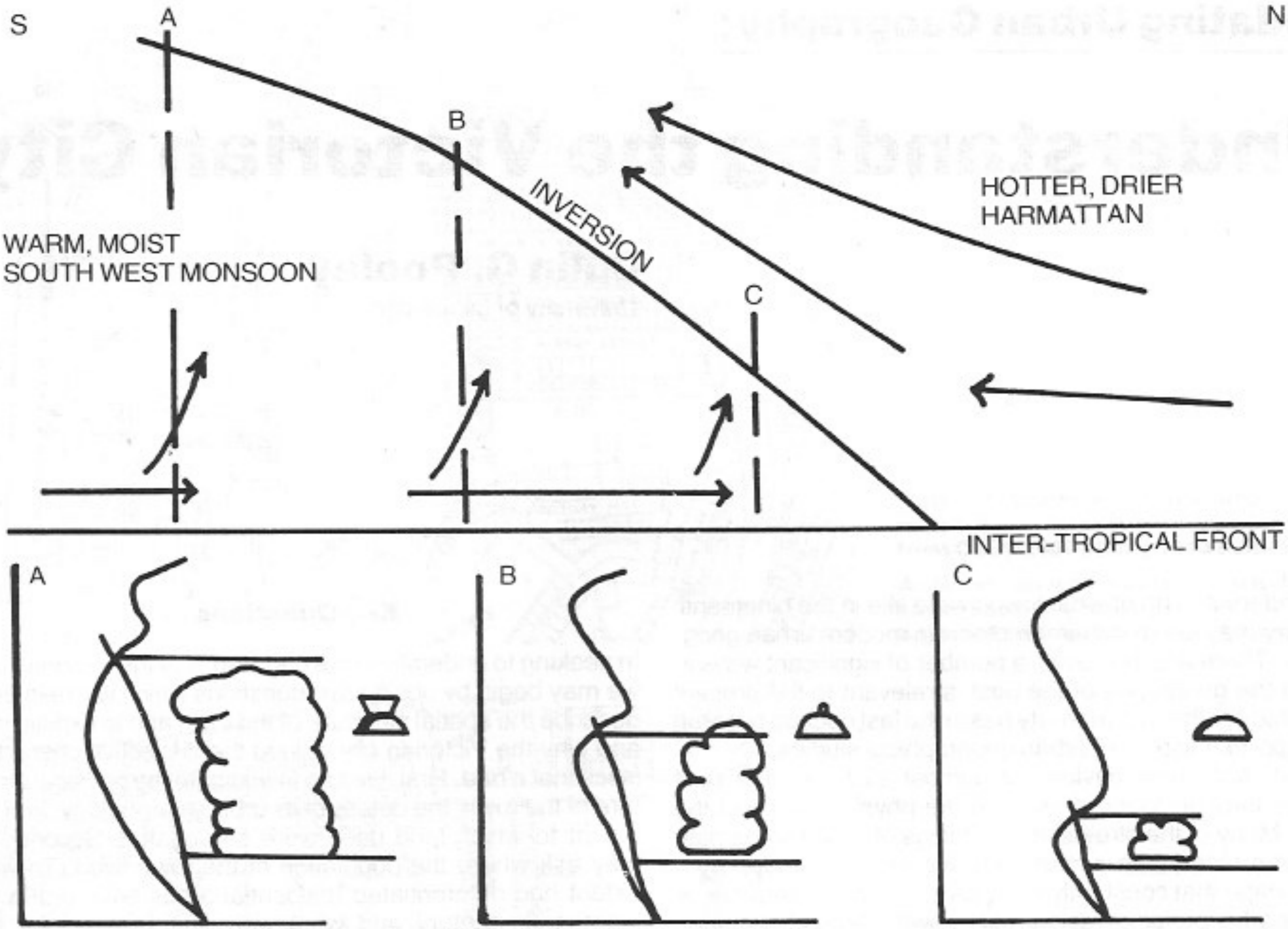


Figure 9. Cloud development in the Trade Wind belt.



Temperature/height diagrams at positions A, B and C.

Figure 10. Cloud development in the south-west monsoon, West Africa.