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Conceptual models of precipitation systems

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Summary

Imagery from radars and satellites is one of the main ingredients of nowcasting. When used to provide very detailed forecasts of precipitation for a few hours ahead, the imagery needs to be interpreted carefully in terms of synoptic and mesoscale phenomena and their mechanisms. This paper gives an overview of some conceptual models that are useful for this purpose. The models represent a variety of systems associated with mid-latitude cyclones and also mesoscale convective systems in the tropics and mid-latitudes. Specific phenomena discussed are:

(i) warm conveyor belts, including those with rearward and forward sloping ascent in ana and kata cold frontal situations respectively;
(ii) cold conveyor belts ahead of warm fronts;
(iii) narrow rainbands associated with line convection at the boundary of a pre-cold frontal low-level jet;
(iv) wide mesoscale rainbands associated with mid-tropospheric convection;
(v) squall lines in the tropics and mid-latitudes;
(vi) non-squall mesoscale convective systems in the tropics and mid-latitudes;
(vii) sub-synoptic-scale comma clouds associated with cold air vortices; and
(vii) polar trough conveyor belts and instant occlusions.

1. Introduction

Nowcasting, i.e. the generation of detailed site-specific forecasts for a few hours ahead, is a particularly challenging task in the presence of precipitation-producing weather systems. This is partly because of the difficulty in observing these systems adequately owing to the large amount of mesoscale and convective sub-structure they contain. It is also because of the difficulty in predicting how these complex patterns will evolve even in the very short term.

Direct, *in situ* measurements by themselves do not offer an adequate means of observing on the mesoscale. Satellite-based measurements and ground-based radar observations, on the other hand, do provide a good opportunity for describing many of the fine-scale features, especially the cloud and precipitation patterns. Mesoscale temperature information is not so easily obtained because, for example, of the problem of retrieving satellite soundings when the field of view is contaminated by cloud and precipitation. It is, however, possible to make useful inferences about the fields of airflow (and to a limited extent the location of temperature gradients) from the form and movement of these same cloud and precipitation patterns although this calls for some subjective interpretation of the patterns.

Subjective interpretation is even more necessary in the generation of very-short-range forecasts. It is well known that simple objective extrapolation by itself is of only limited value for forecasting precipitation and that, in order to obtain an indication of probable areas of development and decay, it is necessary to be able to infer where the areas of potential instability and slantwise ascent are likely to be. Numerical models can provide guidance about the broader-scale features but subjective interpretation is still needed to unravel the complexity of the mesoscale.

Until recently a major factor impairing the forecasters' ability to exploit satellite and radar imagery has been the inadequacy of the systems for displaying and manipulating the data. Forecasters are, however, beginning to be provided with modern display systems — sometimes with facilities for action replay, image reprojection and enhancement and, in a few cases, superimposed model products. The primary impediment to using these data effectively is now the forecaster's limited ability to make sense of the cloud and precipitation patterns in terms of the dynamical factors that are producing them. There is thus a clear need for more training of forecasters in the meteorological interpretation of the imagery. As part of this training the forecaster needs to be provided with a better conceptual framework within which to interpret the imagery. In short, he needs a set of conceptual models of precipitation systems. These same conceptual models can be expected to be helpful in interpreting not only the imagery but also numerical model guidance in terms of surface weather, especially where the forecaster is able to display sequences of satellite and radar imagery superimposed on the model predictions for corresponding times.

The purpose of this article is to present some examples of conceptual models that are thought to be helpful in the interpretation of imagery. The scope of the article is limited to mesoscale precipitation systems and their larger-scale context. Both frontal systems and convective systems are discussed. The emphasis is mainly, but not entirely, on mid-latitude systems. Individual thunderstorms are not considered. Terrain effects, though important, are also excluded.

2. Conveyor belt models applicable to mid-latitude frontal systems

The frontal models of the Norwegian school have dominated our ideas of frontal structure for over half a century. Forecasters still struggle to interpret mesoscale details of mid-latitude precipitation systems within the context of the simple archetypes of the warm, cold and occluded front. These models are at best inadequate and at worst misleading and an overdependence on them has tended to bring frontal analysis into disrepute. But the task of improving on the existing models is not an easy one. Thus in this paper we can present only a few faltering steps towards a new conceptual approach in frontal analysis.

The first requirement for analysing the mesoscale features of cloud and precipitation in frontal systems is to have a synoptic-scale framework that is able to reconcile the observations in a natural (i.e. system-centred) way. A concept that has been found useful is based on the idea of the 'conveyor belt', the essence of which is that it identifies the major cloud and precipitation-producing flows in a system-relative frame of reference.

2.1 *The warm conveyor belt*

The dominant mechanism in frontal systems is baroclinic slantwise ascent and Fig. 1, from Green *et al.* (1966), shows a simplified depiction of the corresponding large-scale pattern of flow in a major trough–ridge system. The key feature is the elongated band of cloud that forms along the boundary of a major confluence zone at the leading edge of the trough. In a frame of reference moving with the

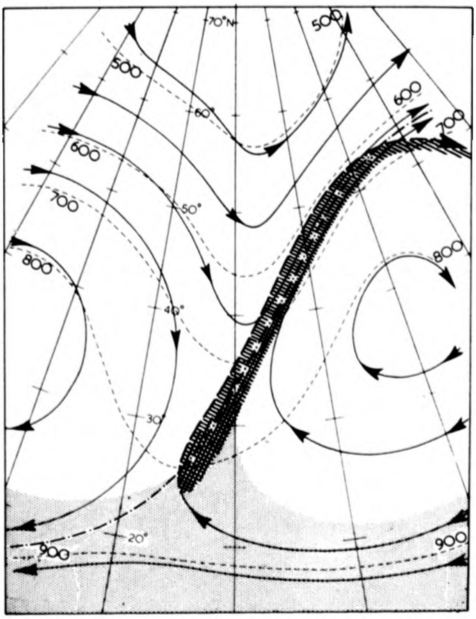
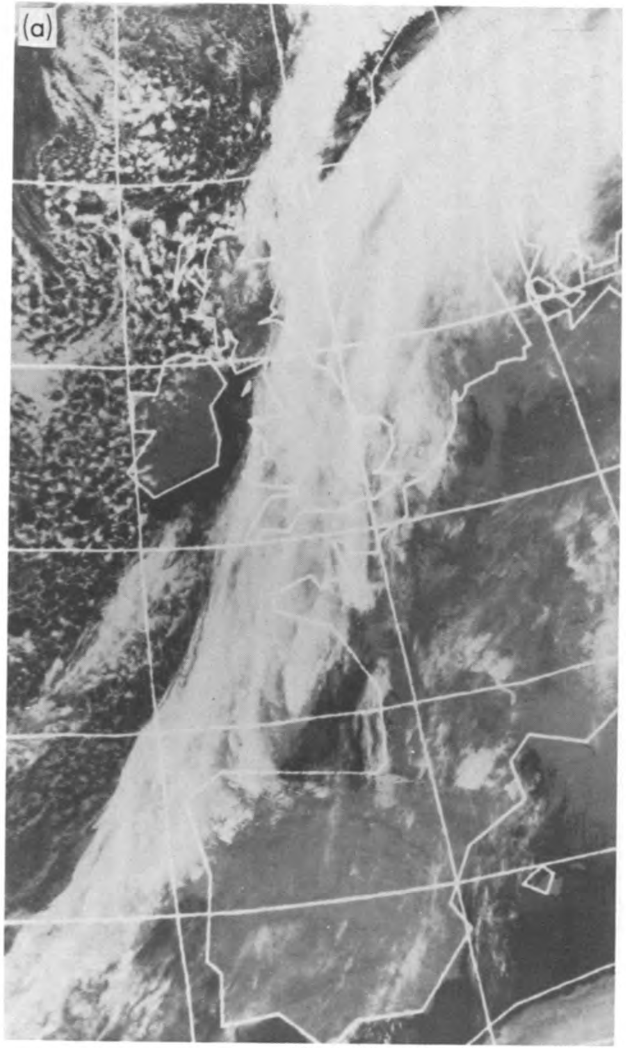


Figure 1. Schematic representation of relative flow in a major trough of large-scale slantwise convection over an ocean on a surface of constant potential temperature, θ, (about 30 °C). The isobars (mb) on the surface are shown by dashed lines. The cold frontal zone, in which the narrowing of the separation between two isobars indicates a steepening of the isentropic surface, contains a (dot-dashed) line of confluence between two principal airstreams. The stippled zone in the south shows where trajectories of the mean flow lie within the layer of small-scale convection in the boundary layer in which θ, and even more so wet-bulb potential temperature, θ_w, increases along the flow. The air is unsaturated in most areas except for the hatched area which marks a band of clouds rising above the isentropic surface. This is the region of strong south to south-westerly flow which we refer to as the warm conveyor belt. The clouds in the warm conveyor belt first form in low latitudes, where they are liable to develop into more or less deep convective clouds (in the region shown by cross-hatching); they appear subsequently as middle-level layer clouds, and eventually as ice clouds (baroclinic cirrus) in the high troposphere of middle latitudes (where they lie near and to the right of the axis of the upper-tropospheric jet stream). These clouds evaporate after the flow at their level has turned to become north-westerly and the airstream begins to subside (from Green *et al.* 1966).

trough–ridge system, warm air is seen to be drawn into the cloud belt from the convective boundary layer in low latitudes; it rises into the middle troposphere as it travels within the cloud belt and eventually produces a deck of upper tropospheric cirrus which decays ahead of the frontal system. Following Harrold (1973) we refer to the narrow airstream as the warm conveyor belt because of its role in conveying large quantities of heat (and also moisture and westerly momentum) polewards and upwards. The region of cirrus cloud associated with it is referred to by Weldon (1979) as baroclinic zone cirrus.

The warm conveyor belt has been found to be a useful concept for accounting for frontal systems not only in north-west Europe where the idea was first evolved but also in the USA (Carlson 1980) and Australia (Ryan and Wilson 1985). Cahir *et al.* (1985) have carried out a composite analysis of a large number of warm conveyor belts and show that, in these high-speed flows of warm moist air, the relative wind jet stream is situated within and closely parallel to the typically sharp left-hand cloud edge. An example of a well-defined cloud belt associated with a long warm conveyor belt is given in Fig. 2. Warm conveyor belts vary greatly in length and certainly are not always as long as in Figs 1 and 2.

Air in the warm conveyor belt flows along the length of the cold front, part of it often being in the form of a low-level jet within the boundary layer just ahead of the surface cold front (Browning and Pardoe 1973). The warmest air of all, having originated farthest south, is usually to be found immediately ahead



Photograph by courtesy of University of Dundee

Figure 2(a). Infra-red photograph from a NOAA satellite at 0317 GMT on 13 January 1983 showing an elongated belt of cloud associated with a major warm conveyor belt.

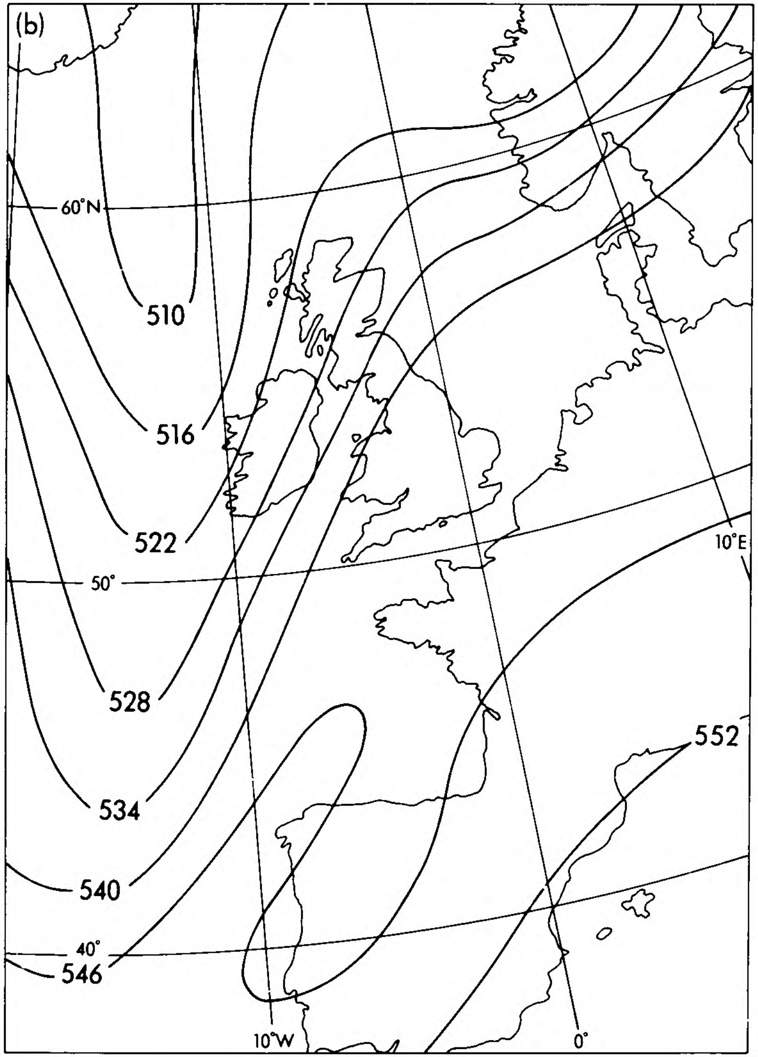


Figure 2(b). 1000–500 mb thickness (dagpm) analysis for 0000 GMT on 13 January 1983 showing the major trough–ridge system with which the warm conveyor belt was associated.

of the surface cold front. The associated negative horizontal temperature gradient ahead of the cold front in the warm conveyor belt accounts, through the thermal wind relationship, for the decrease in wind speed above the low-level jet.

Although the main component of motion within the warm conveyor belt is parallel to the cold front, the relatively small and mainly ageostrophic component perpendicular to the front has an important bearing on the frontal structure. It is useful to distinguish two contrasting situations:

(i) A 'rearward sloping ascent' configuration in which the air in the warm conveyor belt has a component of motion rearwards relative to the movement of the cold front and in which the slantwise ascent occurs in the vicinity of and above the cold frontal zone (Fig. 3).

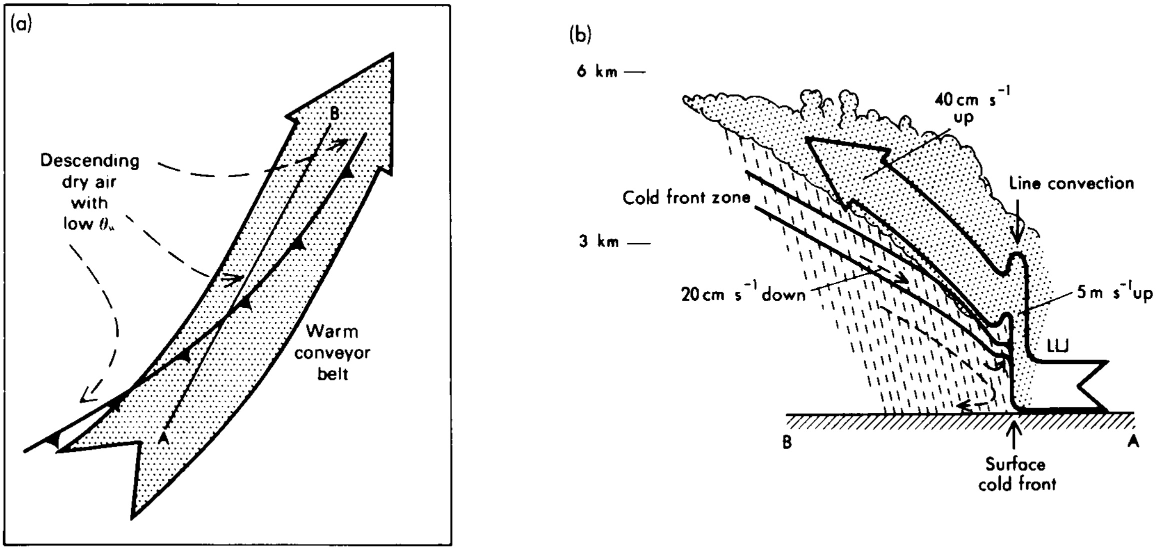


Figure 3. Schematic portrayal of airflow at a classical ana cold front showing the warm conveyor belt (bold arrow) undergoing rearward sloping ascent above the cold frontal zone with the cold air (dashed lines) descending beneath it: (a) plan view, (b) vertical section along AB in (a) (LLJ marks axis of low-level jet). Flows are shown relative to the moving frontal system.

(ii) A 'forward sloping ascent' configuration in which the air in and above the warm conveyor belt has a component of motion forwards relative to the movement of the cold front, with its main region of slantwise ascent occurring farther downwind in regions of warm frontal baroclinicity (Fig. 4).

Transitions between rearward and forward sloping ascent can occur; the transition may occur both in time and in space (along the length of a cold front).

2.2 *The warm conveyor belt with rearward sloping ascent*

The rearward sloping ascent configuration (Fig. 3), in which some or all of the warm conveyor belt air rises with a component rearwards above an advancing wedge of cold air, corresponds to the classical ana cold frontal situation (Sansom 1951). In the United Kingdom this configuration is not as common as the situation of forward sloping ascent described in section 2.3. In contrast to situations of forward sloping ascent, the surface cold front in cases of rearward sloping ascent tends to be sharp. The warm air in the boundary layer ahead of the surface cold front is lifted abruptly at up to several metres per second within a narrow strip adjacent to the surface cold front. This is a region of intense cyclonic shear (10^{-2} s^{-1}) on the western boundary of the pre-cold frontal low-level jet and the vertical air velocity is consistent with the expected Ekman layer convergence. Release of latent heat in the presence of friction has been shown to be an important factor contributing to the strength of both the low-level jet and the cyclonic shear (Hsie *et al.* 1984).

The air rises only 2–3 km during its abrupt ascent at the surface cold front. It undergoes further ascent in slantwise fashion, at a few tens of centimetres per second, above the wedge of cold air (Browning and Harrold 1970). These two regions of ascent produce two distinct patterns of precipitation:

(i) A narrow band of very heavy rain at the surface cold front.

(ii) A broad belt of light-to-moderate rain extending behind and often to some extent ahead of the surface cold front.

These features are discussed further in section 3.

2.3 *The warm conveyor belt with forward sloping ascent*

The forward sloping ascent configuration, shown in Fig. 4, corresponds to a kata cold front situation for which the main ascent occurs ahead of the surface cold front and recently descended air with low wet-bulb potential temperature (θ_w) overruns the warm conveyor belt in the middle troposphere (Miles 1962). This leads to the generation of potential instability which is realized as convection once the general flow has been lifted sufficiently. This convection sometimes occurs as deep convection from the surface (section 4.1) but more usually in the United Kingdom it occurs as shallow middle-level convection. Eventually the cloudy warm conveyor belt flow turns anticyclonically (i.e. to the right) as it overtakes and ascends over the cold air ahead of the surface warm front. The convex-poleward

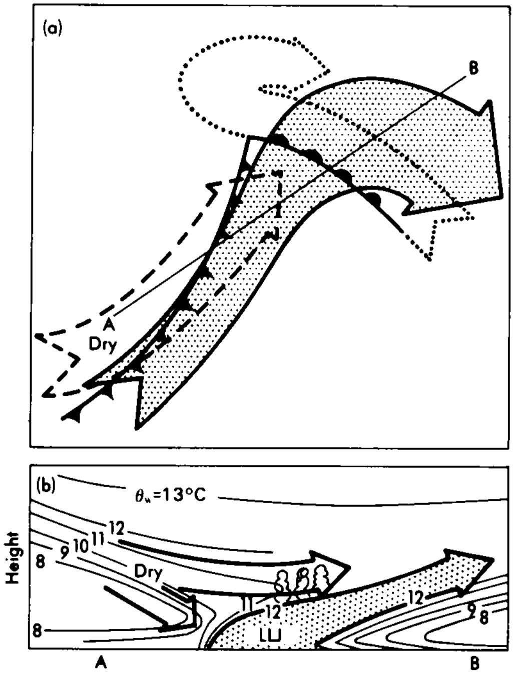


Figure 4. Schematic portrayal of airflow in a mid-latitude cyclone in which the warm conveyor belt (bold arrow with stippled shading) is undergoing forward sloping ascent ahead of a kata cold front before rising above a flow of cold air ahead of the warm front (dotted arrow, referred to in section 2.4 as the cold conveyor belt). Cold middle-tropospheric air with low θ_w (dashed arrow) is shown overrunning the cold front and generating potential instability in the upper portion of the warm conveyor belt: (a) plan view, (b) vertical section along AB in (a) (LLJ marks axis of low-level jet). Flows are shown relative to the moving frontal system.

boundary to this flow where it ascends and turns to the right is often clearly detectable in satellite visible imagery from the shadow the upper cloud casts on the lower cloud layer.

The leading edge of the overrunning dry, low θ_w air advancing ahead of the surface cold front often appears as a well-defined upper cold front (UU in Fig. 5). Ahead of the upper cold front the depth of the warm moist air increases abruptly in association with an organized band of convection. This gives a wide band of moderate-to-heavy rain, often at the trailing edge of a region of rather lighter warm frontal precipitation much of which may evaporate before reaching the ground. The passage of the upper cold front is followed by a shallow moist zone with scattered outbreaks of weakly convective rain and drizzle perhaps with some outbreaks of deeper convection close to the cyclone centre. Because of the separate existence of the upper cold front ahead of the surface cold front, this is referred to as a split front model (Browning and Monk 1982). Split cold fronts are very common in the United Kingdom. There is much

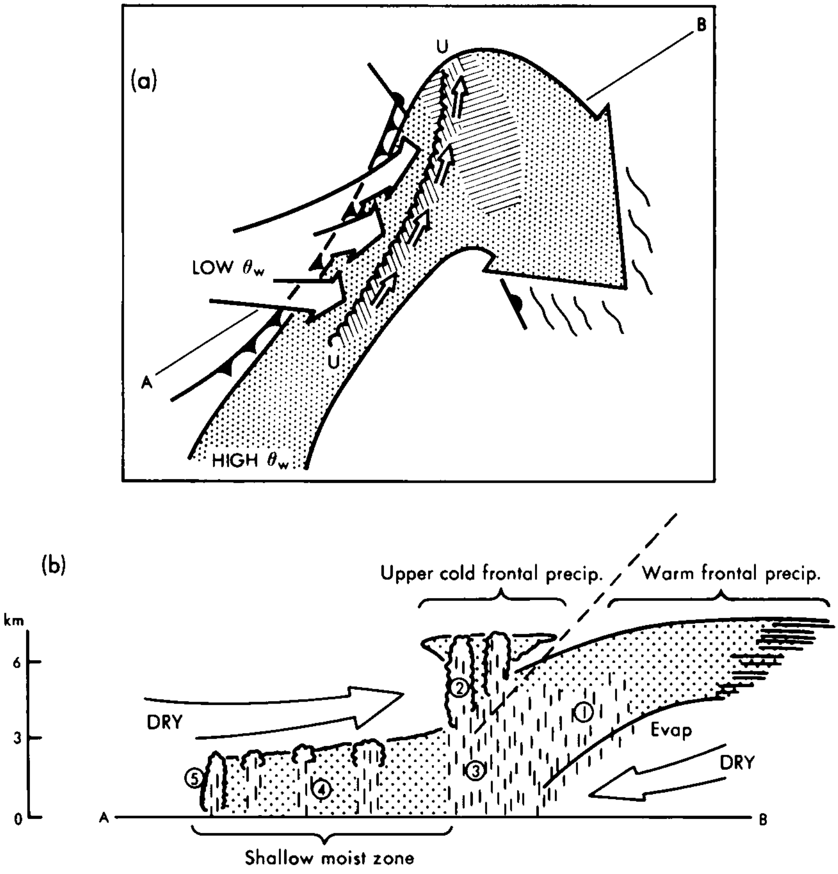


Figure 5. Schematic portrayal of the same situation as in Fig. 4, i.e. with the warm conveyor belt undergoing forward sloping ascent, but drawing attention to the split front characteristic and the overall precipitation distribution: (a) plan view, (b) vertical section along AB in (a). In (a) UU represents the upper cold front. The hatched shading along UU and ahead of the warm front represents precipitation associated with the upper cold front and warm front respectively. Numbers in (b) represent precipitation type as follows: 1, warm frontal precipitation; 2, convective precipitation-generating cells associated with the upper cold front; 3, precipitation from the upper cold frontal convection descending through an area of warm advection; 4, shallow moist zone between the upper and surface cold fronts characterized by warm advection and scattered outbreaks of mainly light rain and drizzle; 5, shallow precipitation at the surface cold front itself (after Browning and Monk 1982).

confusion in their analysis when forecasters attempt to apply the simple classical frontal model. To avoid this confusion the traditional cold frontal symbolism should be reserved for the surface cold front and the upper cold front should be identified differently, perhaps by a scalloped line as in Fig. 5(a). More often than not the two fronts are better defined in the humidity (and θ_w) fields than in the temperature field, in which case they are better regarded as 'humidity fronts'.

2.4 *The cold conveyor belt*

The warm conveyor belt has been identified as the dominant cloud- and precipitation-producing flow in mid-latitude systems. A secondary cloud-producing flow is the cold conveyor belt (dotted arrow in Fig. 4) which originates in the anticyclonic low-level flow to the north-east of a cyclone (Carlson 1980, Ludlam 1980). Relative to the advancing cyclone, air in the cold conveyor belt travels westwards just ahead of the surface warm front beneath the warm conveyor belt. At first this air subsides and is very dry. Precipitation from the warm conveyor belt evaporates on falling into it. As it travels westwards towards the cyclone centre this air begins to ascend, reaching into the middle troposphere near the apex of the warm sector. Air on the cyclonically sheared edge of the cold conveyor belt, near the surface warm front, experiences enhanced ascent due to frictional convergence. If and when the cold conveyor belt emerges beneath the western edge of the warm conveyor belt, it may ascend anticyclonically and merge with the warm conveyor belt as sketched in Fig. 4; alternatively it may descend cyclonically around the cyclone centre. The area of cloud associated with the emerging cold conveyor belt constitutes the head of a large-scale comma cloud system.

3. Classification of mesoscale rainbands in mid-latitude frontal systems

The main cloud and precipitation-producing airstreams have been described in section 2 in terms of system-relative flows called conveyor belts. To a first approximation the rain areas are aligned along these flows. Often the flows are parallel to surface fronts and the belts of precipitation take on a similar orientation. At other times a conveyor belt may be oriented across a surface front. This happens, for example, in association with an upper cold front where it overruns the surface warm front. In such a case the belt of precipitation will be oriented parallel to the upper cold front instead of the underlying warm front.

Precipitation is seldom uniform across a conveyor belt. Convective and mesoscale circulations develop which modify the distribution of precipitation and lead to quite complex patterns even in the absence of terrain-induced effects. The convection leads to a tendency for the precipitation to concentrate in small-scale cells. The mesoscale circulations are of two kinds. One of them leads to groups of convective cells forming in clusters, giving rise to so-called mesoscale precipitation areas tens of kilometres across. The other, discussed more fully below, leads to banded precipitation features. Sometimes the rainbands are rather uniform along their length; more often they consist of aligned mesoscale precipitation areas. Some rainbands are perhaps no more than mesoscale precipitation areas roughly and perhaps fortuitously aligned along the axis of a conveyor belt. Other rainbands are clearly the result of more nearly two-dimensional mesoscale circulations. Considerable attention has been paid to the nature of mesoscale rainbands and many categories have been identified. Broadly speaking, however, there are two principal categories: narrow rainbands and wide rainbands. Examples of these two types are shown in Figs 6 and 7.

3.1 *Narrow rainbands*

Narrow rainbands are largely boundary-layer phenomena. Although narrow bands of light rain and drizzle, probably generated by helical vortex circulations, can be generated within warm sectors, the

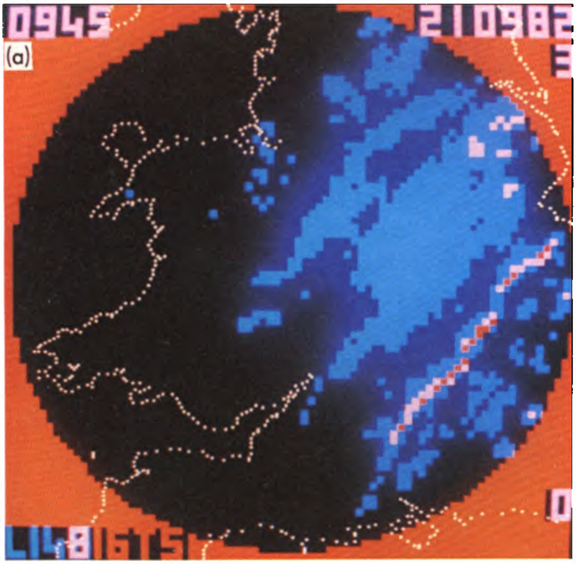


Figure 6(a). Radar display showing a narrow cold frontal rainband over England. Pink and red, heavy rain mostly associated with the narrow rainband; blue, light and moderate rain. Resolution is 5 km × 5 km.

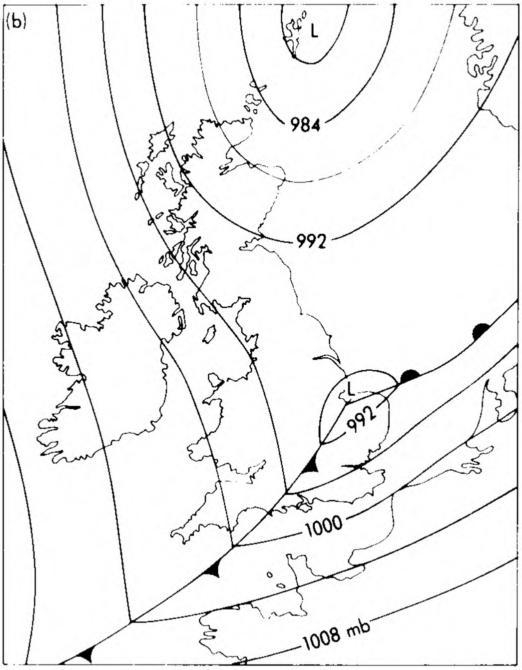


Figure 6(b). Surface analysis corresponding to Fig. 6(a).

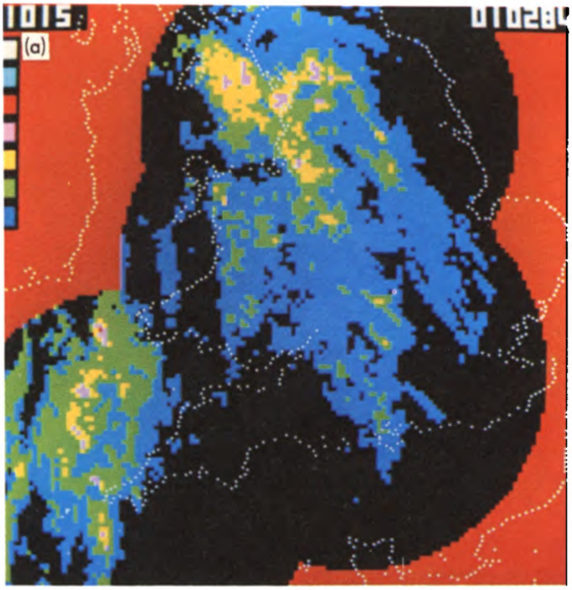


Figure 7(a). Radar network display showing wide frontal rainbands. Those over northern and central England are associated with a warm front. Those in the south-western approaches are associated with a cold front. The ill-defined ragged nature of these bands is typical of wide rainbands. Some (not all) of the complexity is due to orographic effects. Pink and yellow, heavy rain; green, moderate rain; blue, light rain.

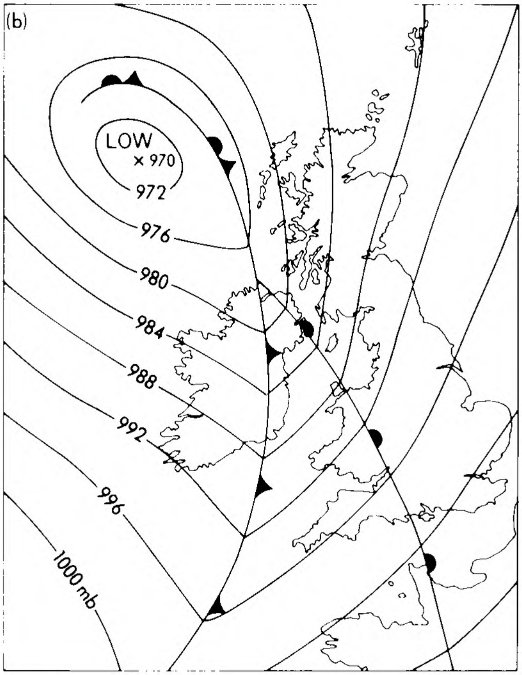


Figure 7(b). Surface analysis corresponding to Fig. 7(a).

most significant narrow bands are those that occur in the cold seasons at the sharp surface cold frontal discontinuity in the situations of rearward sloping ascent described in section 2.2. In the region immediately ahead of the front the boundary layer can be 2–3 km deep, capped by a stable layer. The narrow rainbands that occur here are aligned along the length of the surface front and, even though they are seldom more than 3 km deep and the same in width, they frequently produce a burst of very heavy rain and sometimes small hail.

The band of almost vertical convection that gives rise to a narrow cold frontal rainband is referred to as line convection (Browning and Harrold 1970). The line convection occurs immediately in advance of the cold air, the leading edge of which has the properties of a density current (Carbone 1982). Its passage is associated with a characteristic temperature drop and pressure kick. The boundary layer ahead of the front is neutrally stratified with respect to saturated ascent and the density current has the effect of generating convection which is forced rather than free. Line convection can on occasion extend as an unbroken line for 100 km but, more usually, it is broken into series of line elements each of the order of 10 km long. This is associated with a horizontal shearing instability on the strongly sheared edge of the low-level jet that occurs ahead of the front (cf. section 2.2). The resulting rainfall pattern is as shown in Fig. 8 (Hobbs and Biswas 1979, James and Browning 1979).

The narrow rainbands associated with the line convection tend to occur towards the leading edge of the belt of stratiform cloud associated with the slantwise convection. Sometimes they occur right at the leading edge, in which case they may be detectable in the satellite imagery. More often the shallow cumulonimbus associated with the line convection is embedded deep within the main mass of stratiform cloud (Fig. 8); it is then not evident in the satellite imagery (Fig. 9(a)) although it can be seen clearly by radar (Fig. 9(b)).

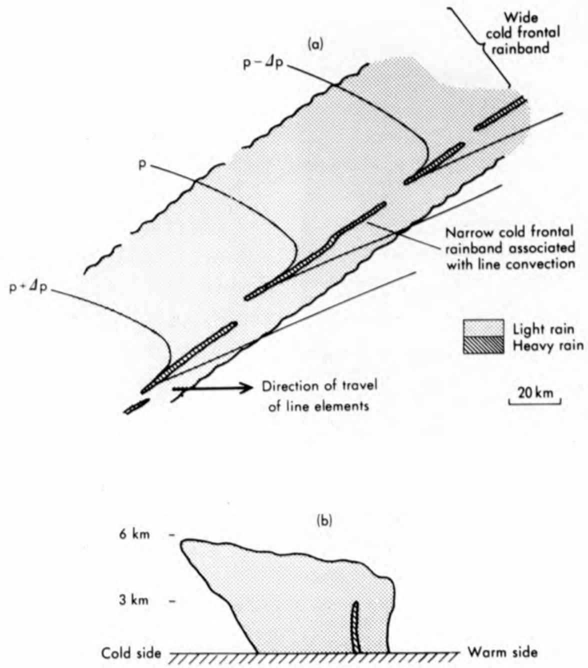
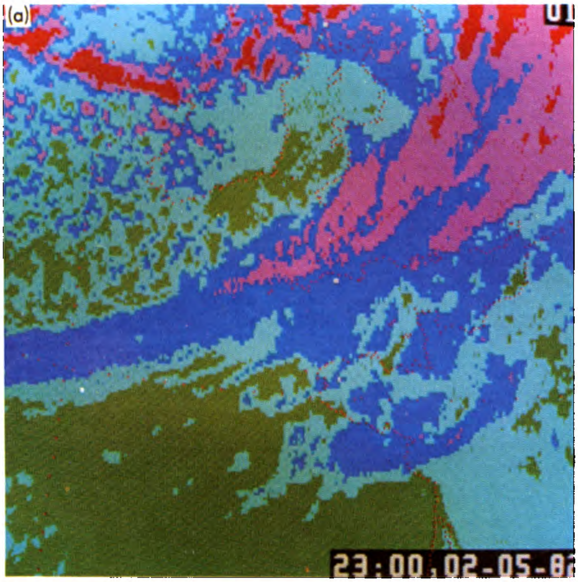


Figure 8. Schematic depiction of the pattern of precipitation and pressure (p) at a sharp cold front: (a) plan view; (b) vertical section normal to the front.



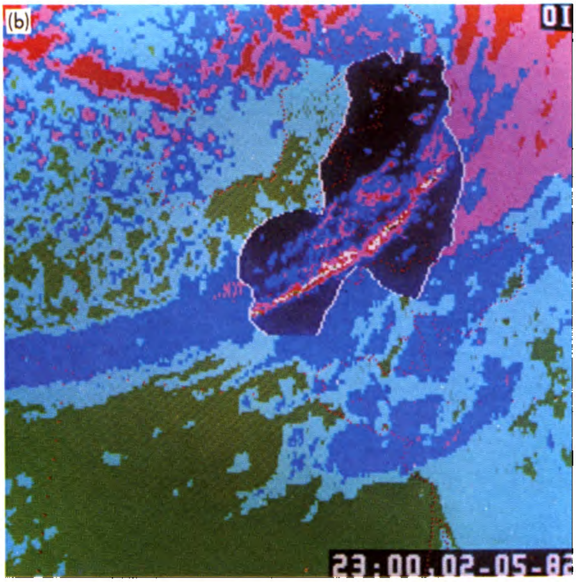


Figure 9(a). False colour infra-red satellite image from Meteosat showing a cold frontal cloud band oriented SW–NE across England and Wales. Red and pink, high cloud; dark blue, medium cloud; pale blue, low cloud and cold land; green, sea and warm land.

Figure 9(b). Same as Fig. 9(a) but with data from a network of four radars embedded within it on the same scale and projection where white represents very heavy rain; red, heavy rain; pink, moderate rain; blue, light rain; and black, no rain.

Narrow rainbands are associated with sharp cold fronts but such fronts are not uniformly sharp. The sharpest transitions of pressure, wind, temperature and humidity occur at the line elements of the narrow rainband. In the gaps between line elements there is a more gradual transition as shown by Fig. 10. When such a gap passes over a surface reporting station it can give the misleading impression that the surface front is of the diffuse kind normally associated with kata cold fronts (cf. section 2.3).

3.2 *Wide rainbands*

The broad zone of generally light-to-moderate rain associated with the slantwise ascent of the conveyor belt often contains organized bands of moderate-to-heavy rain several tens of kilometres wide (Fig. 7(a)). These are associated with mesoscale circulations within the warm conveyor belt about an axis parallel to the relative mean flow. There are several theories to account for them but one of the most promising is that they are associated with conditional symmetric instability (Bennetts and Hoskins 1979).

Types of wide rainbands are listed in Table I. The deep convective rainbands referred to in the table are of two kinds. Those occurring in the warm sector are sometimes associated with squall lines (see section 4.1). The post-frontal rainbands correspond to the cold air comma clouds which are discussed in section 5.1. However, the most common type of wide rainband within major frontal systems in the United Kingdom is the upper-level (U-type) rainband. Although U-type bands may occupy different positions within a frontal system (Fig. 11), they nevertheless all have rather similar dynamical characteristics and can conveniently be considered as one dynamical type. The characteristics of U-type rainbands may be summarized as follows:

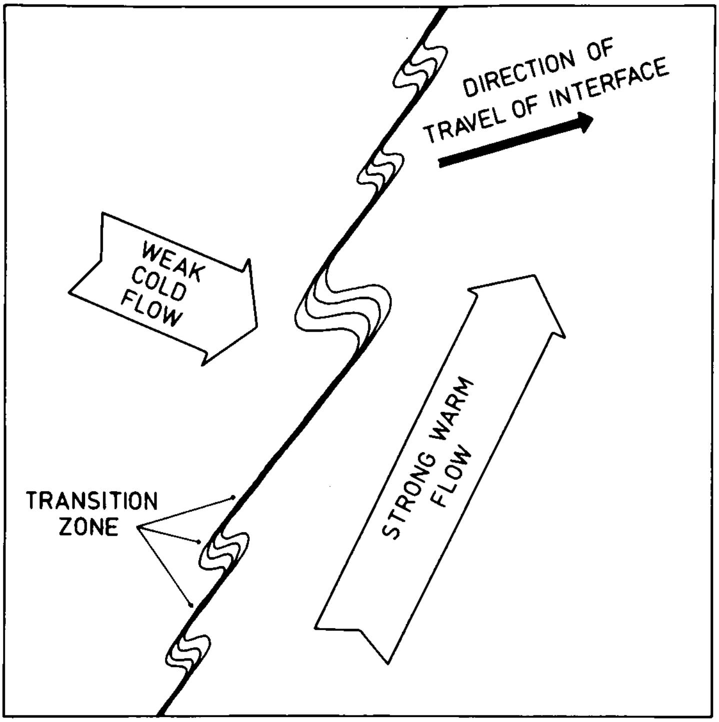


Figure 10. Schematic depiction of the transition zone at a sharp surface cold front. Line convection elements, with intense low-level convergence, strong updraughts and heavy precipitation, occur in the regions with a sharp transition zone. The regions where the temperature gradient is more gradual correspond to gaps between the line convection elements. The broad arrows, representing the flow at low levels on either side of the interface, are drawn relative to the ground (from James and Browning 1979).

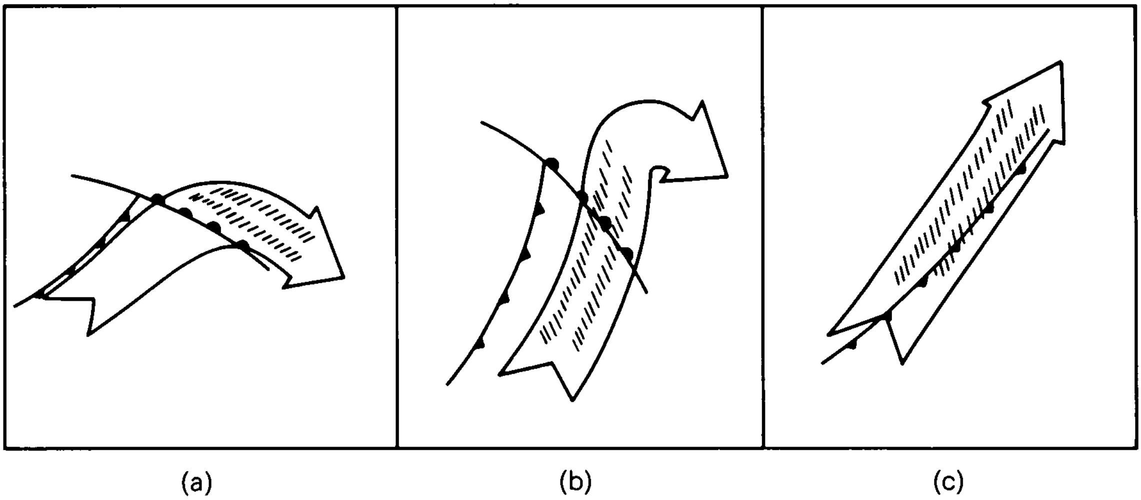


Figure 11. Idealized representation of three types of configuration of U-type wide rainbands (hatched shading) in relation to the warm conveyor belt flow (broad arrows): (a) and (b) forward sloping ascent situations with warm frontal and pre-frontal cold surge rainbands, respectively, (c) rearward sloping ascent with cold frontal rainbands. Narrow rainband elements occur in the boundary layer along the surface cold front coexisting with the wide rainbands in (c).

Table I. *Types of wide mesoscale rainbands*

Broad classification	Detailed classification (after Hobbs 1978)	Frontal archetype with which associated	Location and orientation	Some published examples
Upper- (or mid-) tropospheric convective rainbands (U-type)	Warm frontal rainband	Forward sloping ascent	Parallel to the warm front and either on or ahead of it	Browning and Harrold 1969, Herzegh and Hobbs 1978a, Heymsfield 1979
	Pre-frontal cold surge rainband	Forward sloping ascent	Parallel to and just ahead of an overrunning upper cold front	Kreitzberg 1964, Kreitzberg and Brown 1970, Browning *et al.* 1973
	Cold frontal rainband	Rearward sloping ascent	Parallel to and either behind or straddling an active surface cold front	Browning and Harrold 1970, Hobbs *et al.* 1978
Deep convective rainbands	Warm sector rainband	Either?	Ahead of and parallel to the surface cold front	Nozumi and Arakawa 1968, Herzegh and Hobbs 1978b
	Post-frontal rainband	Either?	Behind the main frontal system and parallel to the cold front	Houze *et al.* 1976

(i) They are associated with the ascending parts of the warm conveyor belt where its top reaches into the middle troposphere.

(ii) They contain upper- or middle-level convective cells, often in clusters, which are generated within a shallow layer of potential instability where air with low θ_w overruns the warm conveyor belt. The underlying air is generally statically stable, occasionally markedly so at some levels.

(iii) They are 50 km wide (within a factor of 2) and typically a few hundred kilometres long, with an orientation parallel to the baroclinicity at their level. (The baroclinicity in the lower troposphere is often much stronger and may be oriented differently.)

The structure and evolution of U-type rainbands have been described by Kreitzberg and Brown (1970). They use the term 'leafed hyper-baroclinic structures' to describe the wrinkling of the surfaces of constant θ_w in the warm conveyor belt above a frontal zone caused by the mesoscale circulations. Each major wrinkle, or warm tongue, in the conveyor belt gives rise to a separate U-type rainband. The wrinkles locally enhance the potential instability and promote the upper- or mid-tropospheric convective generating cells.

4. Mesoscale convective systems

4.1 *Mid-latitude squall lines*

The shallow cold frontal line convection discussed in section 3.1 is characterized by a sudden wind shift. However, although the low-level winds ahead of such cold fronts are invariably strong, the sharp veer which occurs at the passage of the line convection is, more often than not, accompanied by a drop in wind speed. The most vigorous squalls, therefore, do not occur in situations of line convection; nor in general do they occur in the situations that promote line convection, i.e. when the warm conveyor belt air undergoes rearward sloping ascent behind the surface cold front as described in section 2.2. Instead, major squall lines in middle latitudes occur in association with lines of deep convective cells which break out within warm sectors, often 200–300 km ahead of the surface cold front, in the kind of synoptic situation described in section 2.3. This is the situation in which, relative to the large-scale frontal system, the warm conveyor belt air undergoes forward sloping ascent ahead of the surface cold front and is overrun by dry, recently descended air with low θ_w in the middle troposphere. In the United Kingdom this synoptic situation usually gives rise to an upper cold front characterized by middle-level convection as in the split front model in Fig. 5. However, when the value of θ_w near the ground is high, as often happens in the United States Midwest in the spring storm season, deep convection may occur from the surface. This can lead to vigorous convective cells with strong squalls at the surface forming along or just behind the line corresponding to UU in Fig. 5(a).

A cross-section through a squall line system, from Newton and Newton (1959), is shown in Fig. 12.

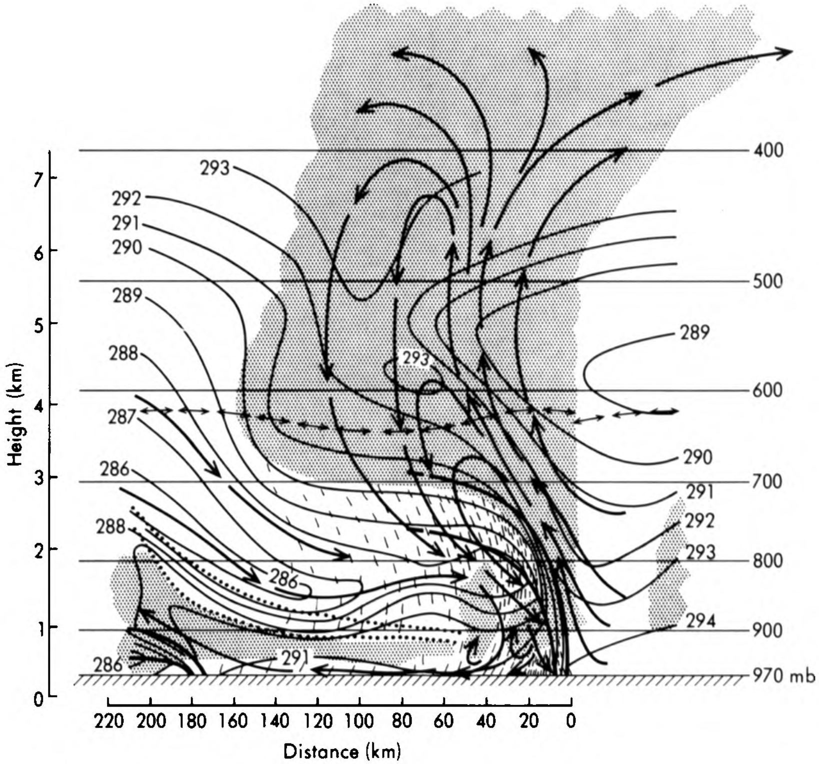


Figure 12. Vertical section through a squall line obtained from a sequence of radiosondes (from Newton and Newton 1959). Distance scale calculated from the speed of advance of the system. Heavy lines are boundaries of stable layers, the cold front being far to the left of the squall-line system. Dots indicate a stable layer in the squall sector with shallow clouds beneath and relatively dry sinking air above. Thin lines are isopleths of θ_w (K). Double-headed arrows represent the melting level. Stippled shading represents cloud. 'Raindrops' below cloud base suggest precipitation intensities. Arrows showing overall circulation are schematic.

The system, travelling from left to right in the figure, has an organized circulation in the direct solenoidal sense. The moist air of high θ_w at low levels ahead of the storm ascends steeply through the conditionally unstable air mass. In the case shown here, in which the squall line was propagating faster than the cold frontal system, much of the updraught air tends to be left behind the storm as a trailing anvil. In other systems the anvil may advance mainly ahead of the storm. In either event the flow in the anvil usually also has a strong component into the plane of Fig. 12. Precipitation falling from the updraught evaporates into dry air that enters the storm circulation at middle levels. Evaporative chilling causes this air to sink by virtue of its increased density. The cold squall-sector air formed in this manner spreads out within an elongated mesohigh pressure region beneath the line of storms. In so doing, the leading edge of the cold air forms a density current or pseudo cold front which triggers renewed convection there and controls the rate of propagation of the squall line as a whole.

Mid-latitude squall lines tend to be segmented into clusters of thunderstorms with overall dimensions 30–100 km (Fankhauser 1964, Pedgley 1962). Just as individual thunderstorms often consist of a number of updraught cells with new ones forming on the right hand side and old ones dissipating on the left, so too in squall lines the clusters form on the right (southern) end and, after a lifetime of about 5 hours, dissipate at the left end.

4.2 *Tropical squall lines*

Tropical squall lines have an organization similar in many ways to that of mid-latitude squall lines except that, being embedded in an easterly flow, they travel towards the west rather than the east: see the conceptual model in Fig. 13. In both cases the squall lines tend to travel by a combination of cell translation and discrete propagation. New updraught cells in the tropical systems form systematically on the leading edge (left side of Fig. 13) triggered by a density current outflow (gust front) at the surface which in the tropical squall lines travels westwards faster than the winds at any level. These cells grow to become the main cells of the squall line before eventually decaying at the rear. Air having a low θ_w, originating from middle levels at the front of the storm feeds negatively buoyant downdraughts within these cells. On reaching the surface some of the downdraught air spreads forward to produce the gust front and some of it is left behind as an extensive wake of cool stable air in the boundary layer. The

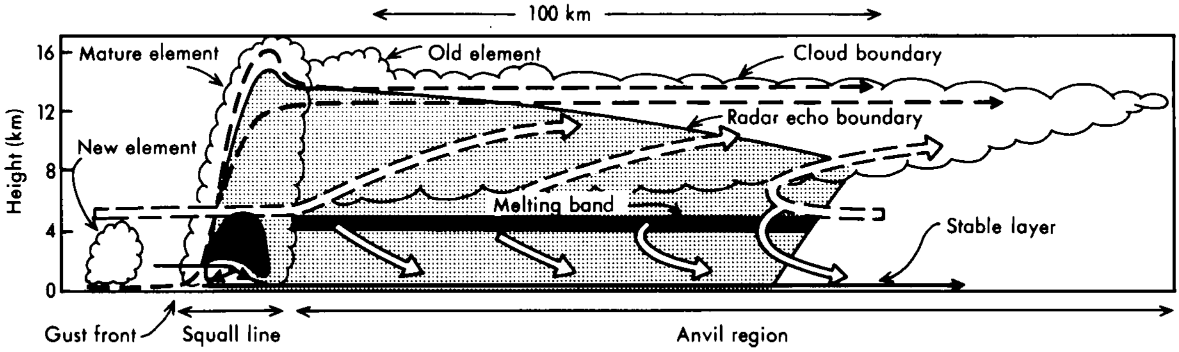


Figure 13. Schematic depiction of a typical cross-section through a tropical squall system. Dashed and continuous streamlines, respectively, show convective-scale updraughts and downdraughts associated with the mature squall-line elements, and also their inflows and outflows. Wide dashed and solid arrows, respectively, show mesoscale updraught and downdraught circulations. Dark shading shows strong radar echoes in the melting layer and in the heavy precipitation zone of the mature squall line element. Light shading shows weaker radar echoes. The scalloped line indicates the visible cloud boundary (from Houze and Hobbs 1982).

trailing anvil region aloft has a predominantly stratiform nature. The continued generation of light precipitation aloft in this region implies a zone of mesoscale ascent in the upper troposphere. There is a corresponding zone of mesoscale descent in the lower troposphere.

4.3 *Tropical non-squall convective systems*

The visible satellite photograph in Fig. 14 shows tropical cloud systems ranging from fields of scattered small cumulus to mesoscale cloud clusters. One of the clusters produced a squall line, which

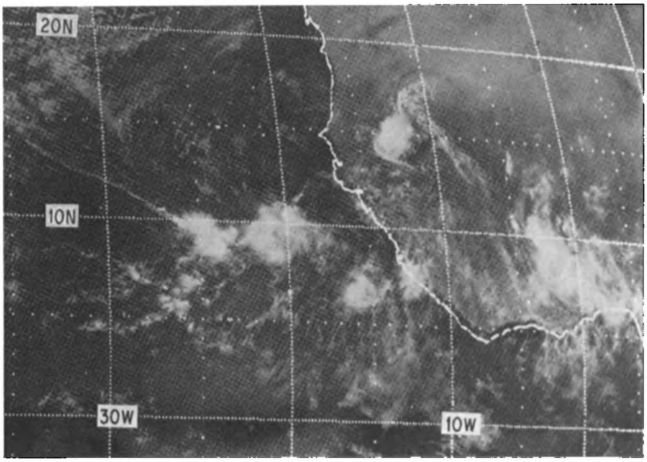


Figure 14. Visible image from the SMS-1 geostationary satellite showing tropical cloud systems ranging from fields of small cumulus to large cloud clusters. The latter are evident from their large cirrus shields at 9°N 24°W, 9°N 21°W, 7°N 16°W, 8°N 12°W and 14°N 13°W. The last of these was a squall cluster with an arc cloud line on its leading (south-west) side (from Houze and Hobbs 1982).

can be seen as a cloud arc on the south-western boundary of the cluster. All the other clusters lacked squall line characteristics. Non-squall cloud clusters are by far the commonest form of mesoscale system in the tropics.

The model of a non-squall cloud cluster in Fig. 15 shows three of the four stages of the life cycle identified by Leary and Houze (1979). The four stages are:

(i) Formative stage: scattered convective cells triggered by some initial mesoscale convergence at low levels (Fig. 15(a)).

(ii) Intensifying stage: further convective cells form while existing cells grow and merge, leading to a large continuous area in which the convective cells are interconnected by stratiform precipitation of moderate intensity falling from a spreading anvil deck.

(iii) Mature stage: a mixture of convective and stratiform precipitation as before but with the area of stratiform precipitation becoming extensive and containing mesoscale updraughts and downdraughts (Fig. 15(b)).

(iv) Dissipating stage: rate of formation of new convective cells diminishes but the area of stratiform upper cloud persisting for some time with light rain or virga (Fig. 15(c)).

Altogether the four stages last about a day, the convective circulations dominating in the early stages and the mesoscale circulations dominating in the later stages.

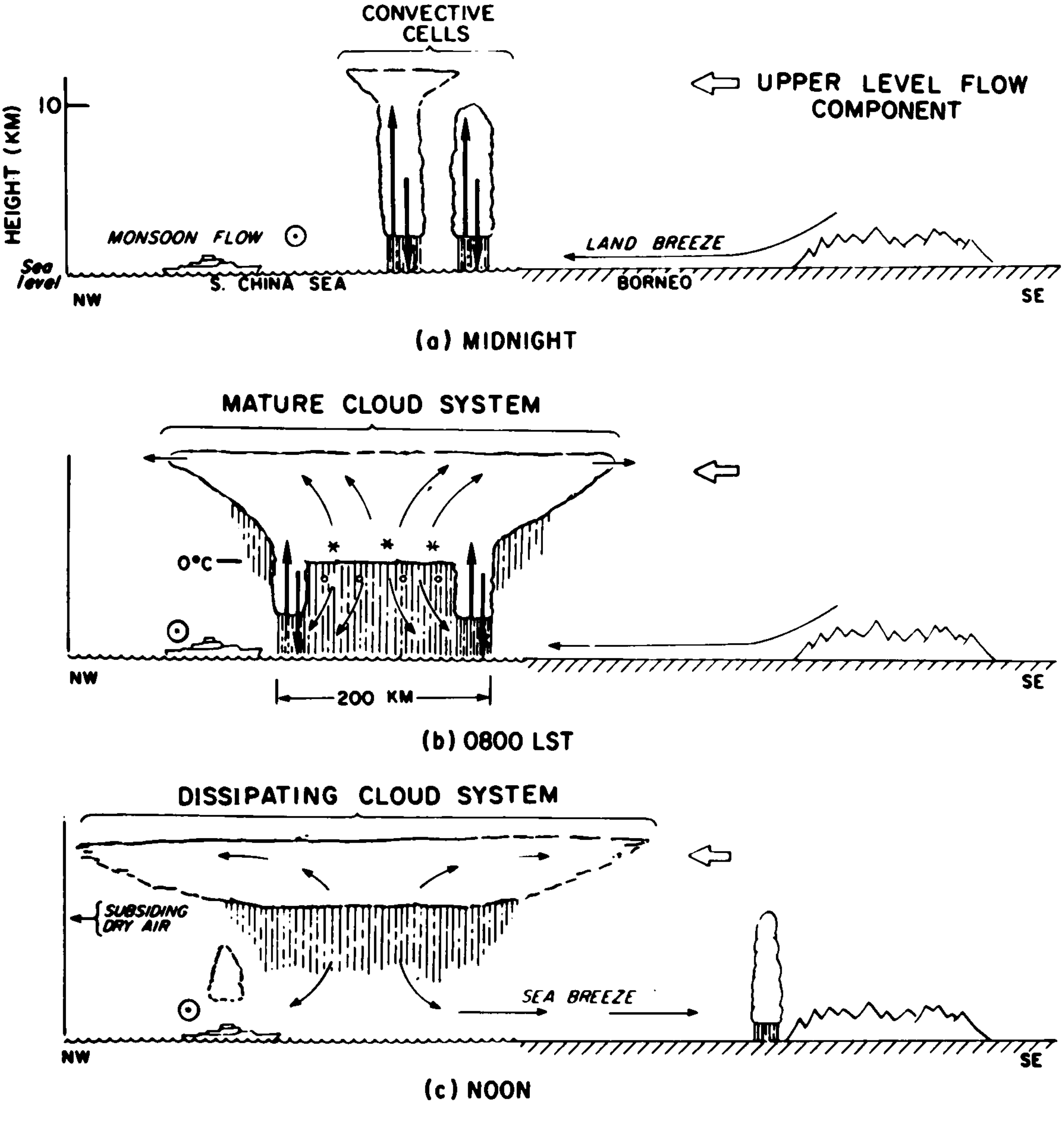


Figure 15. Schematic depiction of the development of a diurnally generated non-squall tropical cloud cluster off the coast of Borneo. Various arrows indicate airflow. The circumscribed dot indicates north-easterly monsoon flow out of the page. The wide open arrow indicates the component of the typical east-south-easterly upper-level flow in the plane of the cross-section. Heavy vertical arrows in (a) and (b) indicate cumulus-scale updraughts and downdraughts. Thin arrows in (b) and (c) show a mesoscale updraught developing in a mid- to upper-level stratiform cloud with a mesoscale downdraught in the rain below the middle-level base of the stratiform cloud. Asterisks and small circles indicate ice above the 0 °C level melting to form raindrops below this level (from Houze *et al.* 1981).

4.4 *Mesoscale convective systems in mid-latitudes*

Systems resembling tropical cloud clusters also occur in mid-latitudes where they are referred to as mesoscale convective complexes (Maddox 1980) or mesoscale convective systems. The above life cycle model of Leary and Houze applies to them as well. Their distinctive visual feature is the rather symmetrical upper-level cloud shield generated by the combined anvil outflows from the constituent thunderstorm cells. The top of the cloud shield is high, cold, and sharp edged, and it shows up prominently in satellite imagery (Fig. 16(a)). Table II shows the criteria used by Maddox to identify mesoscale convective complexes in infra-red satellite pictures. The Table gives an indication of the large area of many of these systems; however, the particular criteria are unduly restrictive since there are many smaller systems that appear to have structures and mechanisms similar to those ascribed to mesoscale convective complexes (Zipser 1982).

Fig. 16(b) shows the precipitation distribution that was associated with the distinctive cloud pattern in Fig. 16(a). A mesoscale region of fairly uniform, essentially stratiform, rain is seen to have developed beneath the cirrus shield downwind (to the north-west) of the active convection. In such situations thunder may be widespread throughout the areas of both convective and stratiform rain and the whole area may be characterized by a mesohigh produced by evaporative cooling.

Although mesoscale convective systems are dominated by sub-synoptic-scale circulations their development is nevertheless influenced by synoptic-scale forcing. The system portrayed in Fig. 16 formed in a locally intensified baroclinic zone on the flank of a cold pool and it was fed by an airflow with high θ_w (W_1W_2 in Fig. 17) which originated at low levels just ahead of a surface cold front. The

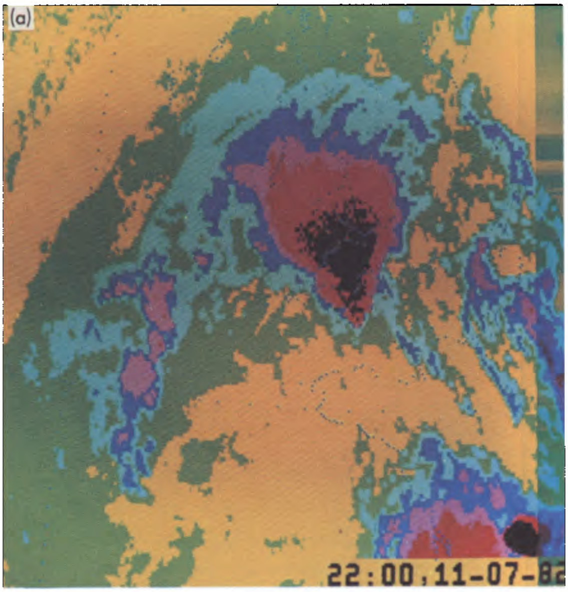


Figure 16(a). False colour infra-red satellite image from Meteosat showing a mesoscale convective system over south-west England. Area of coverage is 1280 km × 1280 km. Black ⩽ -52 °C; red ⩽ -43 °C; pink ⩽ -35 °C; dark blue ⩽ -27 °C; pale blue ⩽ -16 °C; green ⩽ -5 °C; yellow > -5 °C.

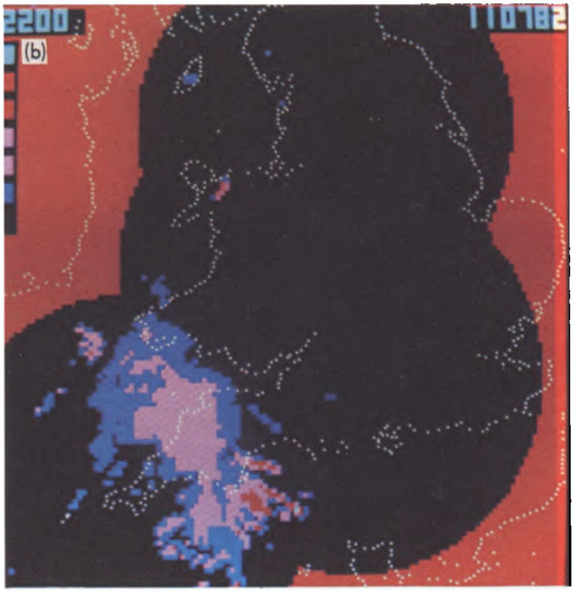


Figure 16(b). Rainfall echo distribution, at time corresponding to Fig. 16(a), as given by the UK weather radar network. Red ⩾ 16 mm h^{-1}; mauve ⩾ 4 mm h^{-1}; blue ⩾ 1 mm h^{-1}.

Table II. *Criteria used to identify mid-latitude mesoscale convective complexes in infra-red satellite data (from Maddox 1980)*

	Physical characteristics
Size	(a) Cloud shield with continuously low infra-red temperatures ⩽ −32 °C must have an area ⩾ 100 000 km²
	(b) Interior cold cloud region with temperature ⩽ −52 °C must have an area ⩾ 50 000 km²
Initiation	Size definition (a) and (b) are first satisfied
Duration	Size definitions (a) and (b) must be met for a period ⩾ 6 h
Maximum extent	Contiguous cold cloud shield (infra-red temperature ⩽ −32 °C) reaches maximum size
Shape	Minor axis/major axis ⩾ 0.7 at time of maximum extent
Termination	Size definitions (a) and (b) no longer satisfied

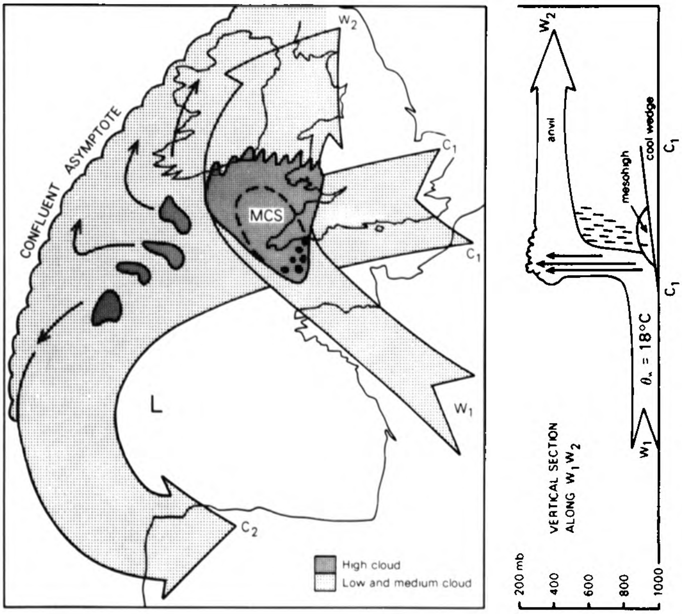


Figure 17. Schematic model of the mature mesoscale convective system (MCS) portrayed in Fig. 16 (from Browning and Hill 1984). Key to plan view (left): heavy stippled shading, high cirrus shield; dashed lines within MCS, boundary of surface rain and mesohigh; blobs in south-east of MCS, convective cores; arrow W_1W_2, air with high θ_w entering MCS below 800 mb and leaving in upper troposphere; arrow C_1C_2, cool air circulating around cold pool; small arrows, diffluent flow of mid-tropospheric cloudy air approaching the confluent asymptote. Key to vertical section (right): arrow W_1W_2, same as arrow in plan section; vertical arrows, representation of convective cores; dashed shading, mesoscale downdraught; dome shape, rain-chilled mesohigh dome; wedge shape, wedge of cool surface easterlies associated with arrow C_1C_2 in plan view.

configuration of this flow resembles that of the warm conveyor belt in Fig. 4 except that instead of ascending gradually as in most frontal systems the slantwise ascent is seen to have been short-circuited within the convective updraughts of the mesoscale convective system. This happened where the airflow with high θ_w encountered, and began to ride over, a wedge of cold air (C_1C_2) corresponding to the cold conveyor belt of the model in Fig. 4.

5. Other mid-latitude systems

5.1 *Sub-synoptic-scale comma clouds associated with cold air vortices*

The distinction between frontal, i.e. baroclinic, and convective phenomena tends to be blurred in reality. Thus we have shown that frontal rainbands usually take on a convective character. Likewise some phenomena often classified as essentially convective can take on frontal characteristics. Nowhere is this dual character more evident than with the comma-shaped cloud and precipitation systems associated with cold pools within polar air streams. Such systems are generally of sub-synoptic scale, being spaced at intervals of the order of 1000 km when they occur in multiple form. They develop most often over the oceans in winter, originating in regions of low-level heating and enhanced convection and acquiring the comma-shaped cloud pattern as they mature.

Sub-synoptic-scale comma cloud systems occur in association with baroclinicity throughout some or all of the depth of the troposphere, and at the same time conditional instability through a substantial depth. A wide spectrum of situations can occur but in all of them the two forms of instability coexist. At one end of the spectrum are the polar lows that form in very cold northerly outbreaks over warm oceans (e.g. off the Norwegian coast) in which convection is vigorous and a CISK (Conditional Instability of the Second Kind) mechanism appears to be the more important driving force (Rasmussen 1983). At the other end of the spectrum are those comma clouds in which baroclinic slantwise ascent is the primary driving force. This seems to be the case for the short-wave polar troughs commonly encountered in the westerly flows behind major cold fronts approaching the north-west of Europe and the USA (Reed 1979, Locatelli *et al.* 1982). An example of a comma cloud associated with a polar trough is shown in Fig. 18.

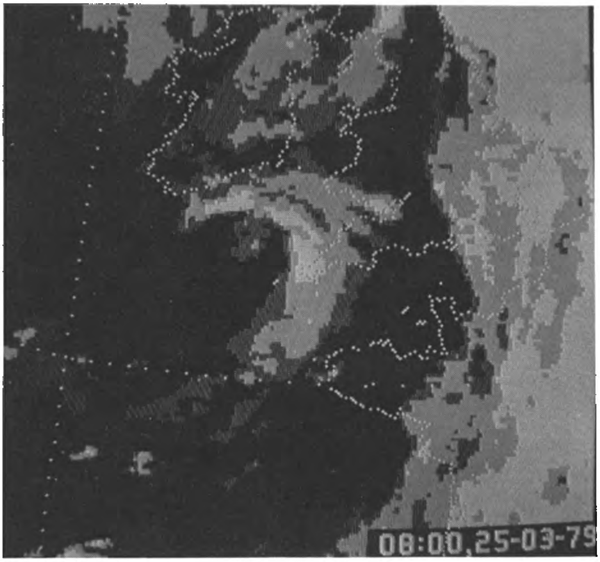


Figure 18. Infra-red satellite image from Meteosat showing a small, cold air comma cloud over south-west England. Pale grey, high cloud; medium grey, medium cloud; dark grey, low cloud.

The axis of the trough is situated along the trailing edge of the comma cloud. The sub-synoptic-scale flow responsible for the comma cloud is like a diminutive version of the warm conveyor belt discussed in section 2.1. The comma cloud zone is characterized by convective precipitation and also by a distinct low-level jet as in the case of the synoptic-scale warm conveyor belt ahead of a cold front. Fox (1982) has shown that this is true even for very small polar air systems.

Sub-synoptic-scale comma cloud systems usually develop near the leading edge of a cold pool behind a major frontal system (Fig. 19). According to Matsumoto *et al.* (1982) the cloud penetrates through the upper boundary of the cold dome and reaches the level of the tropopause, which is low in such regions. When cloud from the preceding frontal system gets carried around the back of the cold pool, to give what synopticians refer to as a back-bent occlusion, comma clouds may develop from elements of this cloud as they travel around the southern flank of the cold pool (Fig. 20).

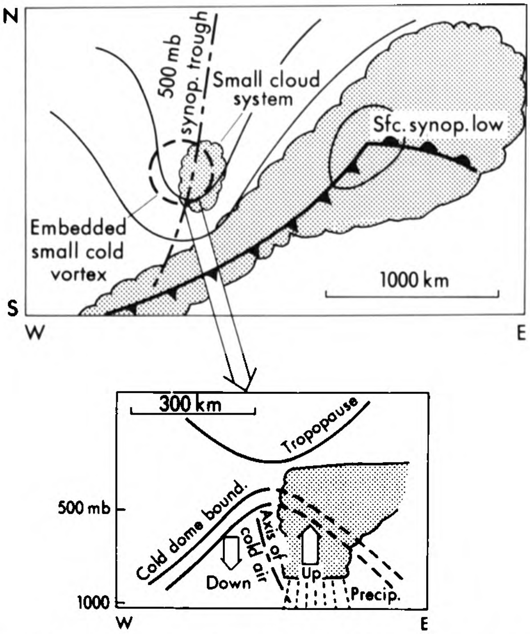


Figure 19. Schematic representation of a sub-synoptic-scale cold vortex (from Matsumoto *et al.* 1982).

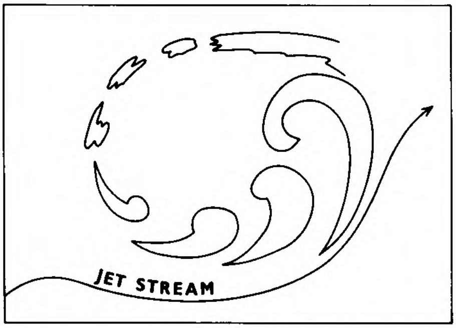
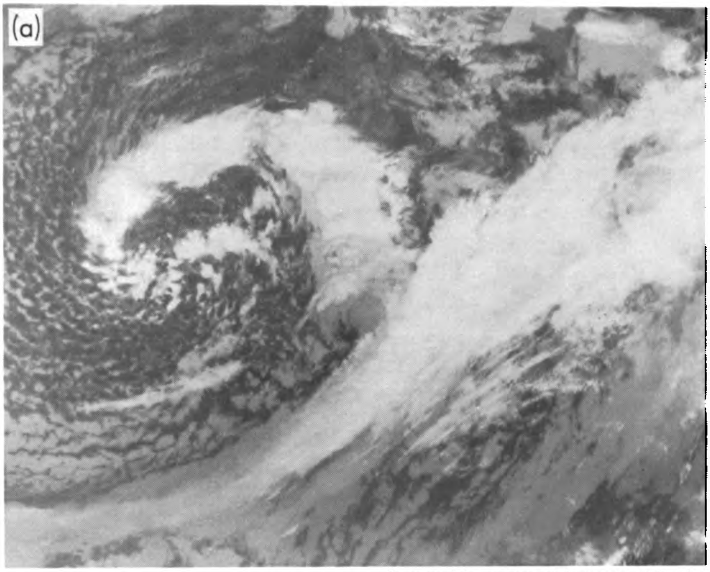


Figure 20. Schematic representation of successive stages in the life cycle of a sub-synoptic-scale comma cloud as it travels around a cold pool behind an upper-level jet stream (from Zick 1983).

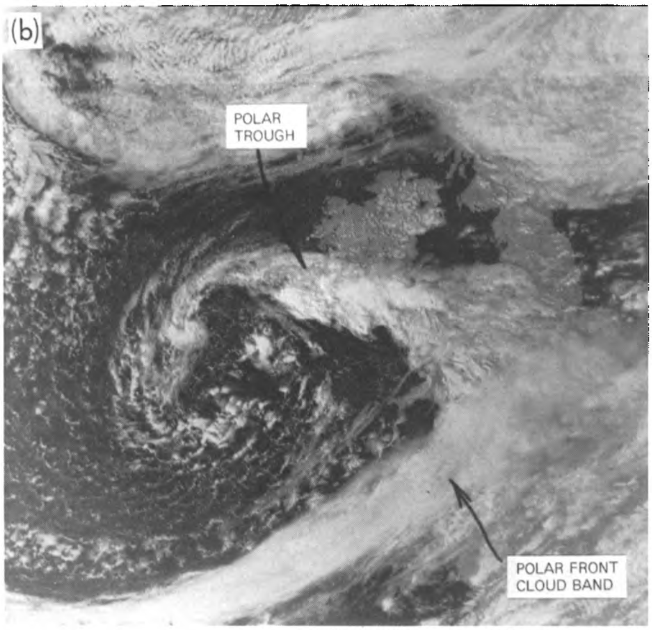
5.2 *The polar trough conveyer belt and instant occlusion*

An instant occlusion is the name given to the lambda-shaped cloud pattern produced when a cloud band associated with a polar trough interacts with a cloud band associated with the polar front (Zillman and Price 1972, Reed 1979, Thepenier and Cruette 1981, Weldon 1975). Fig. 21 shows an example of a variant of the instant occlusion referred to as a pseudo occlusion. Fig. 21(a) shows an early stage in its



Photograph by courtesy of University of Dundee

Figure 21(a). Infra-red photograph from a NOAA satellite at 0817 GMT on 9 September 1983 showing a convective cloud band (associated with a polar trough conveyor belt) wrapped around the leading edge of a cold pool and situated in close proximity to a stratiform cloud band (associated with a polar front conveyor belt).



Photograph by courtesy of University of Dundee

Figure 21(b). Same as Fig. 21(a) but taken at 1502 GMT and showing the two cloud bands merged to form a lambda-shaped pattern.

development just before the two cloud bands merge to produce the characteristic lambda pattern shown in Fig. 21(b). This process is interpreted by Browning and Hill (1985) in terms of a dual conveyor belt configuration, with two small conveyor belt flows intersecting at right angles as shown in Fig. 22. The

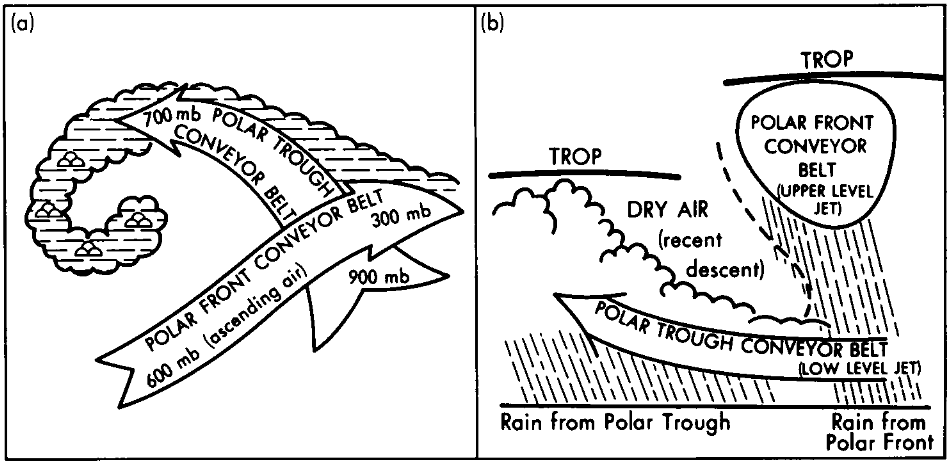


Figure 22. Schematic model of the cloud system in Fig. 21(b) showing intersecting polar trough conveyor belt and polar front conveyor belt: (a) plan view, (b) vertical section along axis of polar trough (from Browning and Hill 1985).

feature labelled 'polar front conveyor belt' corresponds to a warm conveyor belt ascending as an upper tropospheric jet streak. The polar trough conveyor belt corresponds to a low-level jet with an associated cloud band extending above it on the poleward side of the polar front. This low-level jet is situated beneath the left exit of the upper jet streak and may be part of an ageostrophic circulation forced by the latter (Uccellini and Johnson 1979). Although having a disposition similar to the cold conveyor belt in Fig. 4, the polar trough conveyor belt is in fact characterized by a local maximum in θ_w, the air being drawn polewards at low altitudes as it were from the tip of an ill-defined warm sector. Far from being associated with a classical occlusion process, the air within the polar trough conveyor belt has its greatest positive anomaly of temperature and humidity in the lowest kilometre or two. Cooler, drier air circulating around the low centre overruns the polar trough conveyor belt leading to outbreaks of convective precipitation within it.

The instant or pseudo occlusion can be thought of as part of a spectrum of types (Figs 23 and 24) in which the form of the disturbance depends on the position of the short wave trough or vorticity maximum with respect to the polar front (Zillman and Price 1972). The simple comma cloud development represented in Fig. 23(a) shows the short wave trough and associated vorticity maximum occurring well within the cold air and not interacting significantly with the main polar front (Fig. 24(a)). By contrast when the vorticity maximum is at the latitude of the polar front (Fig. 23(c)), a frontal wave forms in which the main warm conveyor belt associated with the polar front gets involved in the circulation and dominates the cloud pattern (Fig. 24(c)). In the intermediate situation of the instant or pseudo occlusion (Figs 23(b) and 24(b)) there are two distinct cloud belts, associated with the polar trough and the polar front.

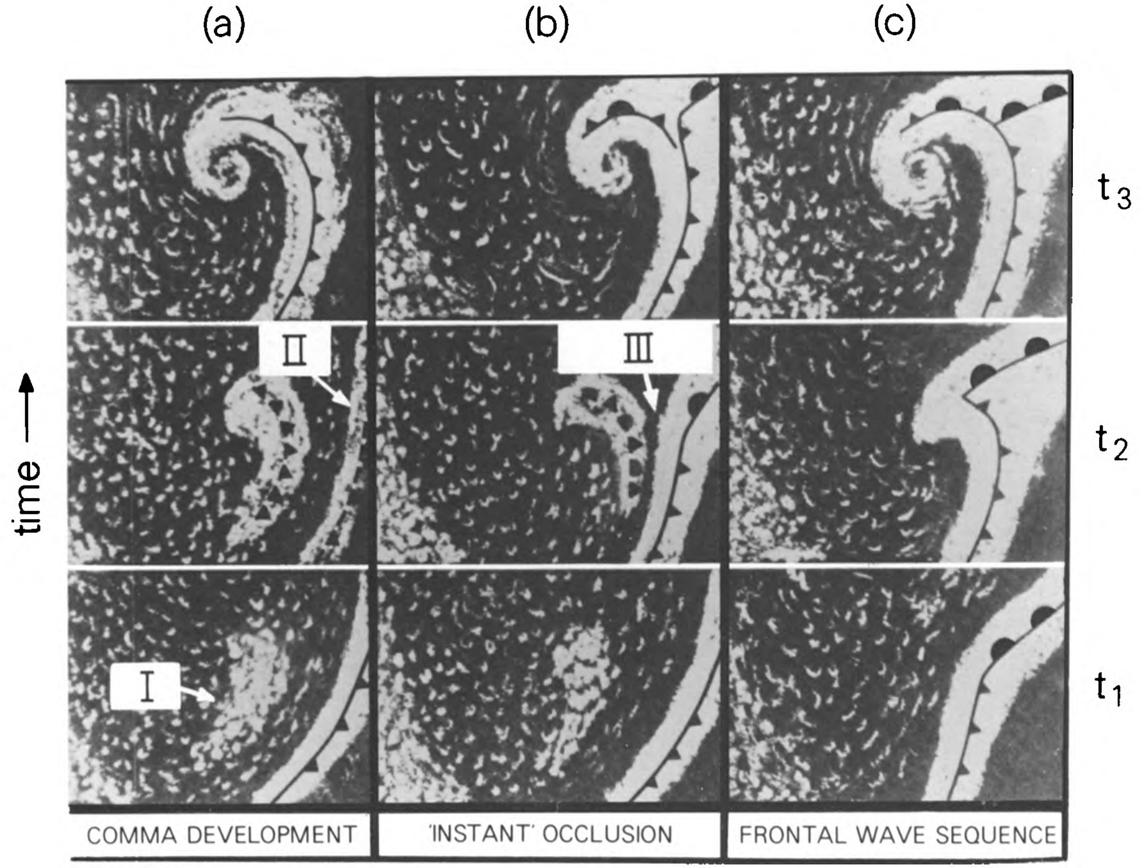


Figure 23. Schematic depiction of three basic sequences of vortex development evident in satellite imagery: (a) development of a comma cloud entirely within the cold air, (b) development of an instant occlusion, (c) development of a frontal wave. The Figure (adapted from Zillman and Price 1972) was derived from observations over the Southern Ocean but it is printed vertically inverted so as to apply to the northern hemisphere. Frontal symbols indicate one scheme for representing the various evolution sequences using the tools of conventional frontal analysis. I, II and III, respectively, indicate a region of enhanced convection, a decaying cloud band and a convective cloud band merging with a frontal cloud band.

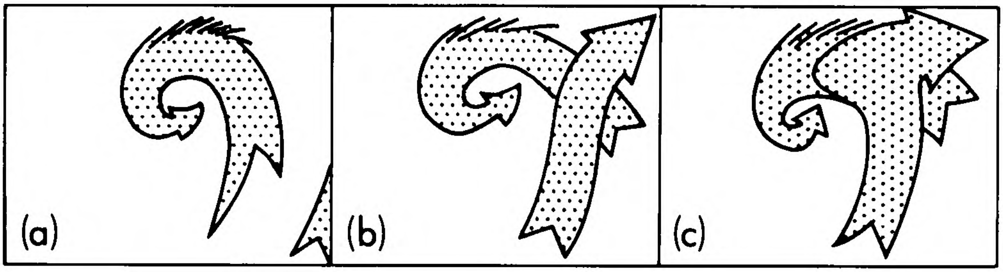


Figure 24. Schematic depiction of the conveyor belt flows associated with the cloud patterns at time t_1 in Figs 23(a), (b) and (c).

6. Concluding remarks

One of the benefits of conceptual models of the kind described in this article is that they provide a framework for the interpretation of imagery from satellite and radar. Although such imagery has been available for many years, there remains considerable scope for improving the extent to which forecasters are able to exploit it. Therefore, with the practising forecaster in mind, it is planned to begin a series of articles in the *Meteorological Magazine* which will give various examples of the use and interpretation of imagery in weather analysis and forecasting. The first in this series, on the use of imagery to identify a particularly persistent form of mesoscale shower band set up by land–sea boundaries will be published shortly (Browning *et al.* 1985).

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Reviews

Weather (second edition), by Louis J. Battan. 150 mm × 227 mm, pp. vii + 135, *illus.* Prentice-Hall Inc., Englewood Cliffs, New Jersey, 1985. Price £17.15.

This is a popular exposition of his subject which no meteorologist would blush to give to his non-meteorological friends. To any objection that it should more appropriately have been entitled 'Meteorology' rather than 'Weather' the author has deftly countered by giving his own definition of weather as being 'the state of the atmosphere and its variations over relatively short periods — from minutes to months'. Months? Well, that goes some way towards justifying the contents of the chapter on 'climatology' and, to be fair, there is plenty of weather in this slim book which presents, for scientifically literate readers, an informed and up-to-date account of many sides of meteorology.

It is recognizably the same book as the original edition of 1974, but there are some major differences. New material has been introduced in a number of places and there has been some rearrangement of sections of the original text. This has resulted, in particular, in a new chapter entitled 'weather analysis and forecasting' at the expense of the old one on 'applications' of meteorology. The new chapter includes some modern topics, such as numerical weather prediction and nowcasting, which sound impressive, but in fact the bulk of the text is of familiar air-mass and frontal depression concepts. The general standard of this and the two chapters which lead up to it ('air motions' and 'general circulation of the atmosphere') is sixth form A-level physics. It is a pity that neither here nor anywhere else in the book is the nature of meteorological observational data touched upon. Instead the subject is built up on a basis of idealized conceptual models and such statements as 'huge masses of observational information . . . are fed into computers that analyse . . . the state of the atmosphere . . .' can only leave an impression which is at best unreal or, more likely, quite false.

The book is relatively strong on the physical aspects of weather phenomena. There are chapters on 'the nature of the earth's atmosphere', 'clouds', 'rain, snow and hail' and, essential for the American public, 'severe storms'. Topics which appear for the first time in this edition are acid precipitation, freons, downbursts and microbursts. And in the chapter on 'climatology' there is now a mention of El Niño, the Southern Oscillation and the importance of the temperature of the sea surface. The brief mention of such currently important topics does not mean that they are in any sense treated fully or adequately. This is a book with limited space allowing only a quick sketch of a very broad subject.

It is, however, a brave and largely successful attempt to present an up-to-date sketch. Inevitably, however successful it may be in general, there are some questionable details. For instance, within a few lines of describing supercooled droplets, is the statement '. . . below 0 °C, most clouds are composed of ice crystals'. And in the main diagram displaying the ten main cloud genera is a sketch of stratus with a higher cloud base than the neighbouring cumulus. Even so, this is a welcome update of a good little book. The new edition is well produced, with many clear diagrams and pictures, though British readers will regret that there are not more from this side of the Atlantic.

Shall we, in fact give this book unblushingly to our friends? Unfortunately, I doubt it — not at the advertised price!

P. G. Wickham

Looking at weather, by Ingrid Holford. 145 mm × 208 mm, pp. 48, *illus.* Weather Publications, Brockenhurst, 1985. Price £1.95.

This book is an attempt by the author to produce, for the layman, an introductory guide to the weather and the mechanisms which go into its making.

It is a slim paperback, divided into 15 chapters which range from temperature and wind, through precipitation, cloud and fog, to radiation, depressions and anticyclones, and pressure belts of the world, with a final chapter on meteorological instruments. With such a diverse range of topics it is not surprising to find that each topic is only touched on briefly. For the layman this is probably enough to whet his appetite.

Throughout the book Ingrid Holford tries to relate weather principles to the domestic environment. For instance, she likens the amount of water vapour in the atmosphere to the 'variable number of guests in an hotel'; and this is typical of the level of the text. The descriptions of certain meteorological phenomena whilst never being totally incorrect could have perhaps had more thought put into them. The statement on page 32 that 'anticyclones are so called because they are different from depressions' or on page 38 that 'convection clouds are called cumulus because they accumulate upwards in thermals' both fall into this category.

A criticism of this book is that the sketches (which I assume are by the author) are of a very poor standard and add nothing to the understanding of the topic under consideration. These, I am sure, could have been greatly improved. Also throughout the book there are references to feet, miles, inches and other 'imperial units' whereas for school use the metric equivalents would have been more useful.

This book provides a very brief introduction to the weather and its workings. It may be useful in schools; however, it would have to be supplemented by further reading.

H. Wilson

Atmospheric electrodynamics, by Hans Volland. 160 mm × 235 mm, pp. ix + 205, *illus.* Springer-Verlag, Berlin, Heidelberg, New York, Tokyo, 1984. Price DM 98.00, US $35.70.

Atmospheric electrodynamics is the eleventh in a series of geophysical monographs dealing with a variety of topics, including geomagnetic micropulsations, geomagnetically trapped charged particles, geochemistry of the moon and planets, optical aurora, coronal expansion and the solar wind, non-linear phenomena in the ionosphere, and plasma instabilities. Written by a distinguished meteorologist, it brings together two subjects which are usually treated separately: 'low-frequency electromagnetic fields of lower-atmospheric origin and those of upper-atmospheric origin. The first, known as geoelectricity, deals with thunderstorm phenomena and related problems..., (the) second subject...with ionospheric and magnetospheric electric fields and currents'.

The first main section of the book summarizes what is known about the ion composition of the atmosphere, which renders the atmosphere electrically conducting, particularly at the upper levels. Thunderstorms and related phenomena are discussed in the second section, which includes accounts of thunderstorm electrification, lightning, sferics and electromagnetic pulses generated by nuclear explosions. The third section deals with dynamo action associated with tidally induced motions in the ionosphere, one manifestation of which are rapid small amplitude fluctuations in the magnetic field observed at the surface of the earth. Finally, an account is given of the interaction of the solar wind with the magnetosphere, the study of which has benefited enormously from many new observations from spacecraft and rapid advances in magnetohydrodynamic theory.

Throughout the book the author stresses the interconnections between the various areas of geophysics involved, at a level accessible to anyone with a basic knowledge of electrodynamics, but without attempting to provide a comprehensive treatment. The material will appeal to those meteorologists who, despite the exigencies of their immediate responsibilities, still find time to satisfy their curiosity about important activities in neighbouring areas of geophysics, and have access to a library which can afford to purchase expensive monographs.

R. Hide

Books received

The listing of books under this heading does not preclude a review in the Meteorological Magazine at a later date.

The climatic scene, edited by M. J. Tooley and G. M. Sheail (London, Boston, Sydney, George Allen and Unwin, 1985. £23.00) is a volume of essays compiled in honour of Gordon Manley, a major and distinctive twentieth-century figure in climatology. The range and scope of the topics covered reflect the eclectic interests of Manley, whose orientation was always towards the importance of climate and its impact on mankind. The state of the art of climatic change is considered at different scales by the contributors: from instrumental records on a local scale from Durham and Manchester to discussions on the regional and continental scale. Methodological problems relating to climatic change are treated and the effects of climate and climatic change on plant distribution, disease vectors and agricultural pests are also considered.

Global change, edited by T. F. Malone and J. G. Roederer (Cambridge University Press, 1985. £35.00) comprehensively explores the interaction between the physical and living world by examining the Earth, its environs and life in the biosphere as a single system. It is a synthesis of the symposium of the same title, sponsored by the International Council of Scientific Unions in September 1984, and addresses the possibility of an interdisciplinary approach to understanding our planet's subtle, and often synergistic, physical, chemical and biological processes.

Handbook of applied meteorology, edited by David D. Houghton (New York, Chichester, Brisbane, Toronto, Singapore, John Wiley and Sons Ltd, 1985. £98.25) is the first comprehensive and authoritative reference on applied aspects of climate and weather for meteorologists and other professionals in fields where atmospheric conditions play a significant role. For technicians and professionals outside the meteorological profession it serves as a ready source of useful data and technical knowledge on all aspects of meteorology essential in engineering and scientific applications. The book also surveys recent advances — particularly in measurement techniques and data sources — never before available in published form.

Chemistry of atmospheres, by Richard P. Wayne (Oxford, Clarendon Press, 1985. £30,00, £14.50 (paperback)) links atmospheric chemistry with the traditional natural sciences to allow the reader to place in context advances and problems in atmospheric science. Its presentation makes it intelligible to scientists of any discipline. Many of the ideas are familiar to chemists and physicists, and teaching them serves a useful function by showing a practical application of fundamental physical chemistry.

Changes in global climate, edited by K. Ya. Kondrat'ev (Rotterdam, A. A. Balkema, 1985. £22.00, US $29.50) is a study of the effects of radiation and other factors during the present century. Possible variations in the solar constant, gaseous composition and aerosol content of the atmosphere have been discussed in detail. The author has examined the properties of atmospheric aerosol and its possible effect on climate and also studied the effect of anthropogenic factors on the ozone layer and their influence on the influx of radiant heat in the stratosphere.

World-wide weather, edited by K. Takahashi (Rotterdam, A. A. Balkema, 1985. £17.50) is divided into three parts. Part I deals with global meteorological phenomena, Part II describes meteorological characteristics of specific locations and Part III discusses the relationship of meteorology with our lives. The main aim of the book is to introduce to the general reader the various global meteorological phenomena which are of current interest.

Air pollution by photochemical oxidants, edited by Robert Guderian (Berlin, Heidelberg, New York, Tokyo, Springer-Verlag, 1985. DM 158.00) introduces air chemistry related to photochemical oxidant formation, including modelling and transport, and after treatment of the physicochemical properties of photochemical oxidants and precursor substances, the current analytical techniques for their determination are presented and strategies for reduction of ambient concentrations are discussed. The book treats the effects of the two most important phytotoxic components of photochemical oxidants, ozone and PAN, both individually and in combination with other air pollutants, on the ecosystem, and on autonomous or conditioned plant resistance, with methods for recognizing, determining and judging these effects. Air quality criteria for vegetation protection are developed from the dose-effect relationships.

Recent advances in planetary meteorology, edited by Garry E. Hunt (Cambridge, London, New York, New Rochelle, Melbourne, Sydney, Cambridge University Press, 1985. £20.00, US $39.50) is a collection of papers presented at the Seymour Hess Memorial Symposium at the IUGG General Assembly, Hamburg, in August 1983. Topics covered include: the photochemical processes involved in the formation of clouds on Venus, Jupiter, Saturn and Uranus; the meteorology of Mars, Jupiter and Saturn; and energy conversion processes in the outer planets. The final paper in the book discusses the major observational results and theoretical problems of planetary atmospheres and relates them to important problems of geophysical fluid dynamics.

New views on an old planet: continental drift and the history of the earth, by Tjeerd H. van Andel (Cambridge, London, New York, New Rochelle, Melbourne, Sydney, Cambridge University Press, 1985. £15.00, US $19.95) is a book intended for the general reader. Ancient climates, ice ages, continental drift, the evolution of life, and the ways in which these processes interact, are discussed in a style which provides an easy introduction to the earth sciences.

Award

We are pleased to note that the thirtieth International Meteorological Organization Prize has been awarded to Sir Arthur Davies, KBE, Secretary-General Emeritus of the World Meteorological Organization (WMO).

Dr D. A. Davies (as he was for most of his career) joined the Meteorological Office in 1936 after graduating from the University of Wales with first-class honours in mathematics and physics. In 1949 he was appointed Director of the East African Meteorological Department and, following the formation of WMO in 1951, was elected President of RA I, the Regional Association for African states. In 1955 he was appointed Secretary-General of WMO by the Second Congress in succession to the first incumbent, Dr G. Swoboda, and served in this capacity until he retired in December 1979. During his term of office WMO grew from a membership of 83 states and territories to one of 143, there were large political changes over the whole world, and great scientific and technological advances. Sir Arthur Davies's contribution to co-ordinating all the international co-operative endeavour which is so essential to modern operational meteorology has been very great, and he was particularly helpful to many new emergent meteorological services during their formative years.

He was awarded the United Nations Peace Medal in 1979, and the following year was made a Knight Commander of the British Empire.

Obituary

We regret to record the death of Mike Farley, Scientific Officer, of the Central Forecasting Branch (Met O 2) on 2 March 1985.

Mike Farley joined the Office as a Scientific Assistant in 1958, working on the quality control of rainfall observations in M.O.3b. In 1961 he was posted to Upavon where, with the exception of a two-year detachment to El Adem, he worked until 1971. Four years at Fairford were followed by promotion to Scientific Officer and a posting to the Data Processing Branch (Met O 12) in 1975.

Mike will be remembered particularly for his enthusiastic contribution to the teamwork in the computer installation of Met O 12, which encompassed the need to produce operational output by strict deadlines and at the same time to provide objective guidance to others working under the pressures of the computer room. In April 1984 he was posted to Met O 2b where he quickly commanded the respect of his colleagues for his hard work.

Mike's outside interests included golf and football. He was also a very active and highly respected member of the Meteorological Office Branch Council of the Institution of Professional Civil Servants, to which he was first elected in 1973. He held several posts, including that of Vice-Chairman, and in 1982 he was elected to the National Science Group Executive Committee. He always presented direct, honest and objective opinions, and listened intently to other points of view. His approach to problems was admired equally by both management and trade unionists.

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CONTENTS

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