Chapter 5 Phenomena of synoptic scale

5.1 Analysis of fronts

5.1.1 Concept of fronts

A front is defined as a boundary between air masses. At such a boundary, a vertical circulation is excited along the surface of contact between air masses of different density and clouds occur, so, a front of synoptic scale is generally observed as a belt-shaped cloud area (cloud band). Therefore, analysis of fronts on the satellite image starts with paying attention to large-scale cloud bands. On a dry continent, however, no cloud may occur even if a vertical circulation is excited. On the other hand, there is also another kind of cloud band of upper clouds alone that comes being advected by the strong winds in the upper troposphere. Note in those cases a front cannot be determined by the presence or absence of a cloud band alone.

Browning (1990) made the concept of conveyor belts popular such as WCB (warm conveyor belt), CCB (cold conveyor belt) to explain the structure of a disturbance. A conveyor belt is referred to as a major atmospheric current as seen in a coordinate system relative to the movement of the disturbance. Carlson (1980) explained the structure of a low and accompanying fronts using the concept of WCB and CCB (Figure 5-1-1).

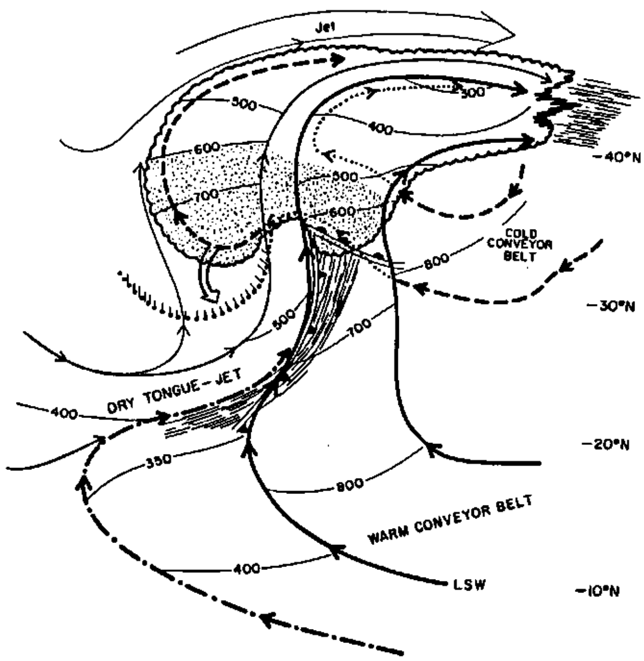


Figure 5-1-1. Conveyor belt model (open arrow added to a drawing by Carlson (1980)).
Bold continuous line: WCB. Dashed line: CCB. Value: Altitude of each current.
Tailed dot: Low level cloud edge.

A WCB is an air current that conveys a warm and wet air mass from low latitudes to high latitudes and is closely related to the formation of cloud area. The WCB starts as a southeast wind at low levels on a fringe of a high and moves north in the warm sector of the low. The direction of the current gradually turns to a clockwise direction. This current is related to the warm advection forward to a trough and its altitude gradually increases as it moves north. It causes a cloud to occur when an air mass in the current reaches the condensation level, and the cloud top height increases to the north. When the WCB encounters a jet stream axis, its northern movement is held down and it turns the direction to the east.

The CCB is an air current flowing parallel to and in front of the warm front toward the center of the low. Viewed from a satellite, a CCB is first observed as a low cloud in front of the warm front. When the CCB moves west, it becomes indiscernible from the satellite because it gets beneath the WCB. However, after that, it crosses the WCB at a large angle and becomes discernible again as a cloud area composed mainly of middle and low level clouds further extending to the west from the western edge of the cloud band of the WCB. As it elongates to the west, part of it increases the altitude, changes into a current of anticyclonic nature, and turns to the east when it attains the jet stream altitude. Another part of it does not increase the altitude and moves toward the center of the low cyclonically in the original form of middle and low level clouds (marked in the figure by the bold open arrow). Young et al. (1995) consider that the current which increases the altitude and turns into an anticyclonic curvature at the west of the WCB cloud is a secondary WCB (W2), not the CCB (Figure 5-1-2). They describe that a W2 occurs from beneath the WCB by the ascending current in front of a trough of short wave. According to Young et al., the term CCB refers only to the low-altitude current toward the center of the low.

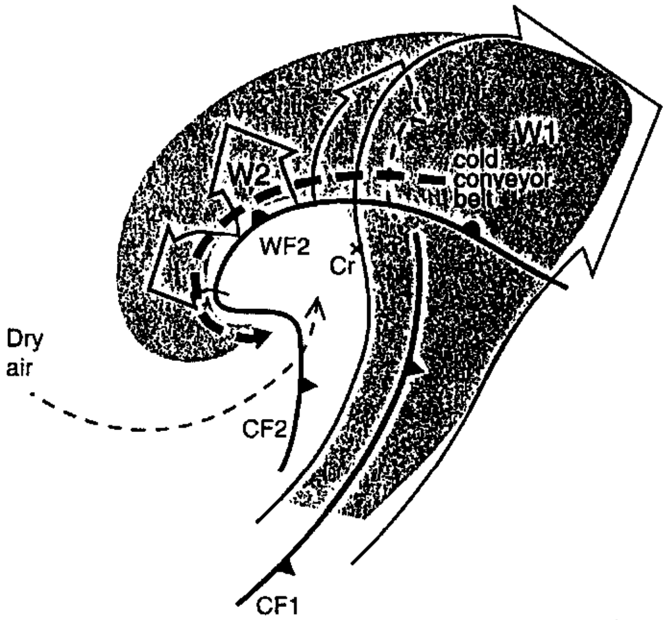


Figure 5-1-2. Model of secondary WCB (Young et al. (1995)).
W1 is a WCB and W2 is a secondary WCB.

Figure 5-1-3 shows an example of conveyor belts. The cloud area indicated by W-W in the infrared image indicates a WCB. Along W-W, the cloud top height decreases toward the south, and it increases and a stratiform cloud area spreads more toward the north. By comparison with the visible image, most of the cloud area is found to be composed of thick clouds. The east edge of the cloud area (E) is composed of thin Ci clouds, which indicates that the WCB turns its direction to the east when it encounters a jet stream axis at a high altitude. C1-C2-C3 is a cloud band associated with the CCB. There are a lot of upper clouds around C1, which are formed by the air upgliding over the CCB. CCB cannot be identified beneath the WCB because the clouds accompanying CCB is lower than the WCB. The CCB becomes discernible again at the place where it protrudes westward from the cloud band of the WCB (near C2). Along C2-C3, the cloud top height increases to the west, and the CCB turns its flow direction to the east and merge with the WCB when it encounters a jet stream. There is also a current that branches off the CCB and is involved in the cyclonic circulation (current from C2 toward d), and the cloud top height remains low along this current.

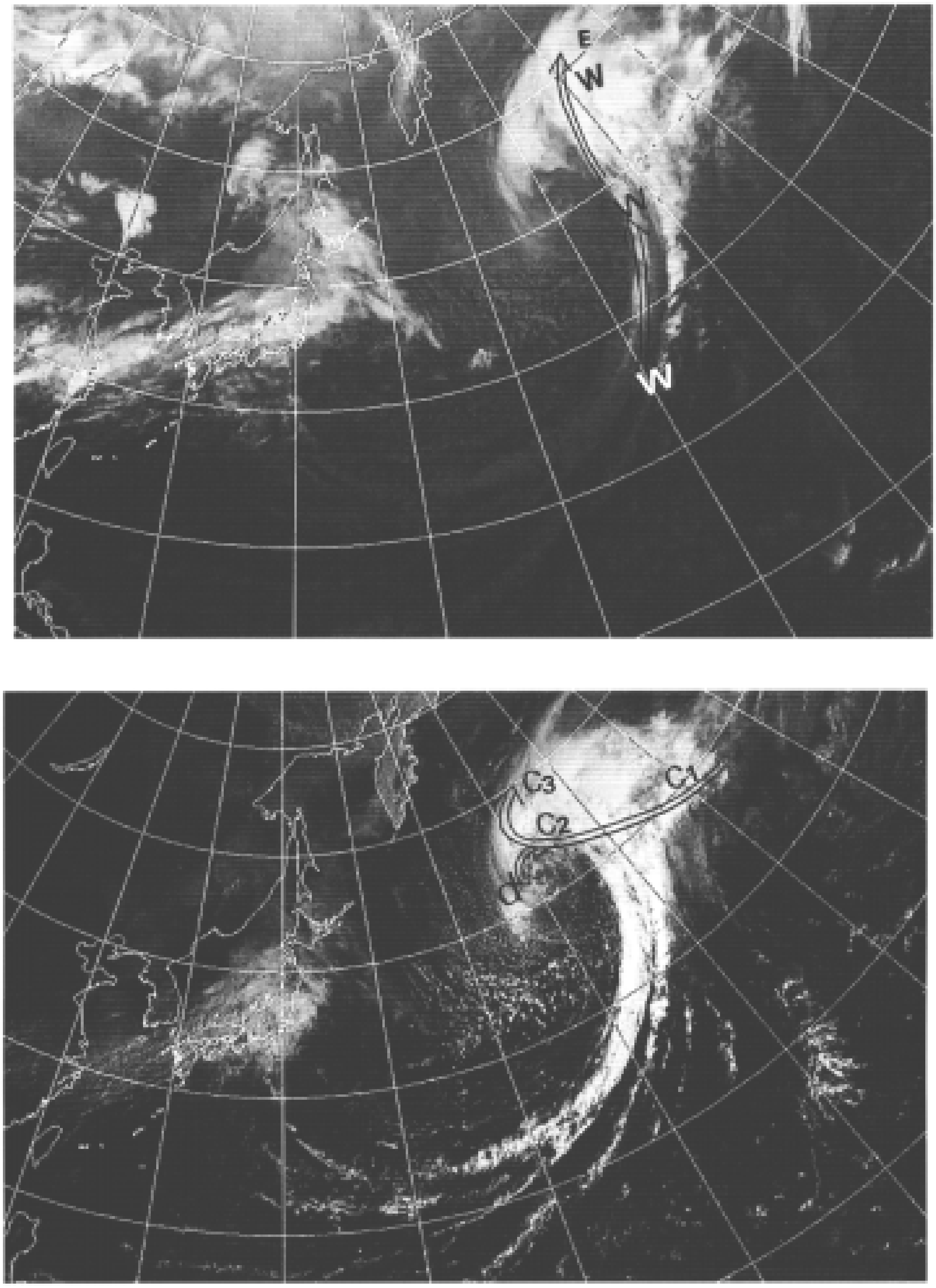


Figure 5-1-3. Example of conveyor belts (00UTC, March 27, 1998).
Top: Infrared image. Arrows indicate the WCB. Bottom: Visible image. Arrows indicate the CCB.

5.1.2 Warm front

A warm front is defined as the boundary of air masses moving to the cold-air side and has a structure in which the warm air climbs the cold air. This is that a WCB is upgliding over a CCB. The WCB which is the current moving north from the warm sector, upglides over the CCB which is a cold air current toward the cyclone center, and the boundary at which this upgliding starts to take place can be analyzed as the warm front. This lies at the southern end of the stratiform clouds where the clouds begin to form the WCB. Neiman (1993) proposed the presence of mesoscale convective clouds at places around the intersection area of CCB and WCB (escalator-elevator model in Figure 5-1-4). Thus, not only stratiform clouds but also convective clouds occur near the warm front.

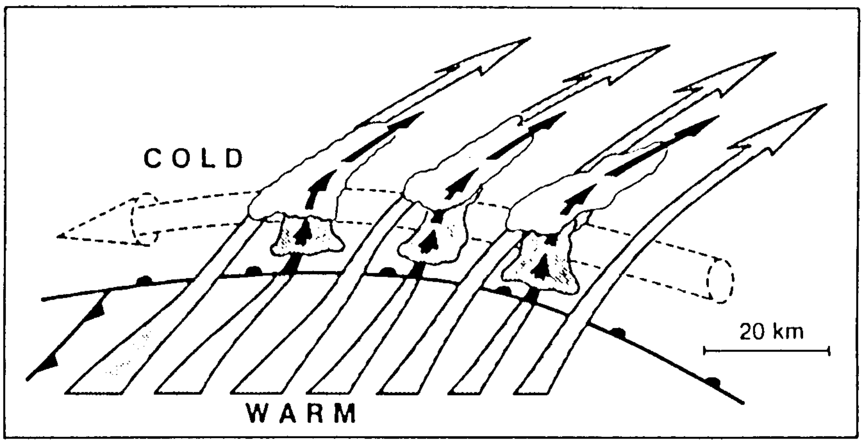


Figure 5-1-4. Elevator-escalator model (Neiman, 1993).
Broken line: CCB. Open arrow: WCB (escalator).
Shaded area: Indicates cloud. Black arrow: Ascent due to mesoscale convection (elevator).

If a warm front has such a modeled structure, it can be identified on the satellite image with the southern edge of a cloud area that contains convective clouds and occupies some area. Nevertheless, it is generally difficult to identify a warm front in the satellite image. This is because it frequently happens that clouds occur in the warm sector or the zone in question is covered by high and middle clouds, so it is often an awkward task to determine the southern edge of the cloud area associated with a warm front. For a low in its formative stage or a comma-shaped low (see Section 5.2), the formation of a CCB is not well formed and the low clouds associated with the warm front are ambiguous in many cases.

Figure 5-1-5 shows an example of a warm front whose determination is relatively easy. A cloud area associated with a low is seen over the ocean south of Japan. The southern edge (W-W) of the cloud area is distinct, and convective clouds are at places. The northern part of the cloud area is composed of high and middle clouds. In the satellite image, a warm front can be determined along the southern edge of the cloud area. By reference to an 850-hPa synoptic analysis chart, the warm front can also be analyzed at W-W from the equivalent potential temperature concentrated zone and wind shear.

If the low clouds associated with a warm front are ambiguous, the warm front can be determined by estimating the cold air region from the cloud pattern in the cold air spreading in front of the low or estimating the wind direction from the movements of low clouds. In Figure 5-1-6, the region of low-level cold air spreading behind a low can be estimated to have its southern limit at S-S. There is a low-level cloud line W at the western extension of this S-S. This cloud line moves east as a whole while the individual clouds making up the cloud line and the low-level clouds to the east of the cloud line move northwest (it can be estimated that there is a field of southeast wind in front of the warm front). From these facts, a warm front associated with the low that is passing over Japan can be determined along the cloud line W-W.

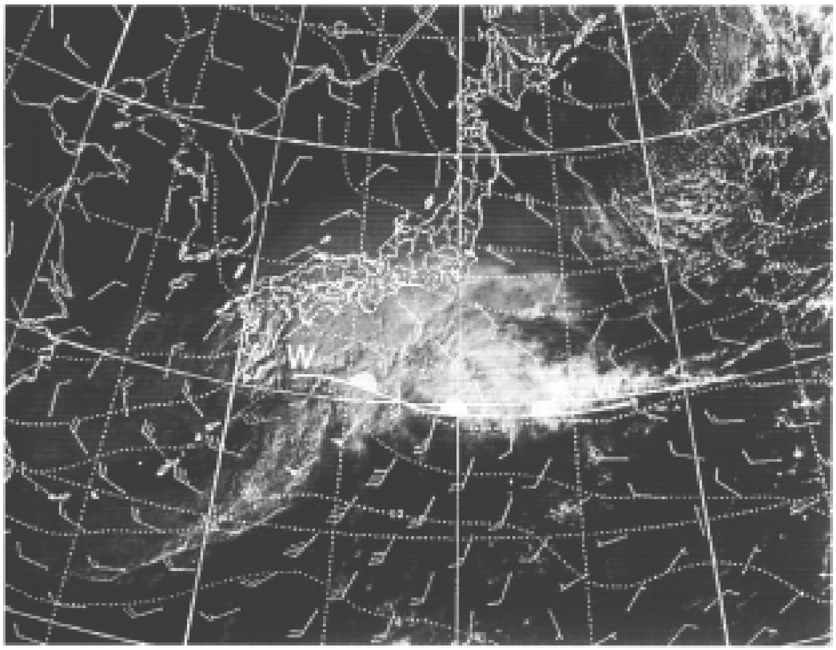


Figure 5-1-5. Example of analysis of warm front (00UTC, March 5, 1998).
Visible image, 850-hPa synoptic analysis (temperature and wind) and warm front are shown superposed.
For symbols, refer to the text.

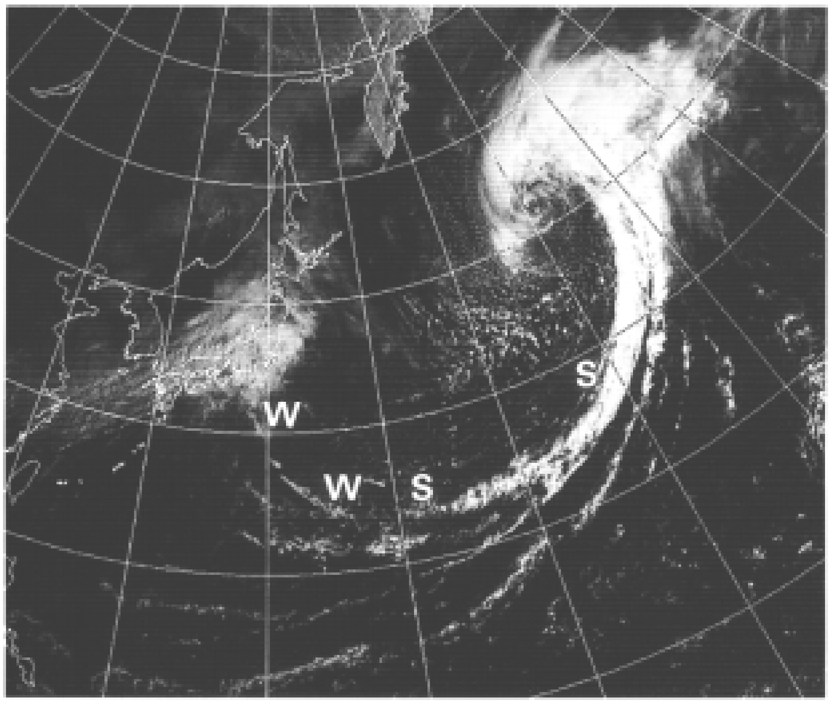


Figure 5-1-6. Example of warm front difficult to analyze (00UTC, March 27, 1998).
For symbols, refer to the text.

5.1.3 Cold front

The cold fronts are divided into the kata and ana types; the former accompanies severe weather near the front, and the latter does calm weather. The ana-type is presented in many textbooks, and a cold front is analyzed in the anabatic structure in most cases. However, katafronts are also seen frequently. Described below are features of each type on the satellite image as well as points to be kept in mind when analyzing cold fronts.

(1) Ana-type cold front

The backward inclined ascend model by Browning (1990) applies to the ana-type cold front (Figure 5-1-7). This corresponds to the case of intense cold air inflow, and the WCB is inclined backward relative to the cold air. An intense ascending flow occurs near the cold front, and the warm air ascends relatively calmly toward the rear of the front. In the cloud band accompanied the front, active convective clouds are arranged in a narrow strip on its front edge (line convection), and the rear edge of the cloud band is comprised of stratiform clouds. If viewed on the satellite image, a cloud band which convective clouds are arranged on the warm side is the ana-type, and the position of a cold front corresponds to the convective cloud line on the front edge of the cloud band. Over the ocean in the cold season, cellular convective clouds occur and develop behind a cold front, so their presence or absence and the degree of activity can serve as a clue to judging the ana-type cold front

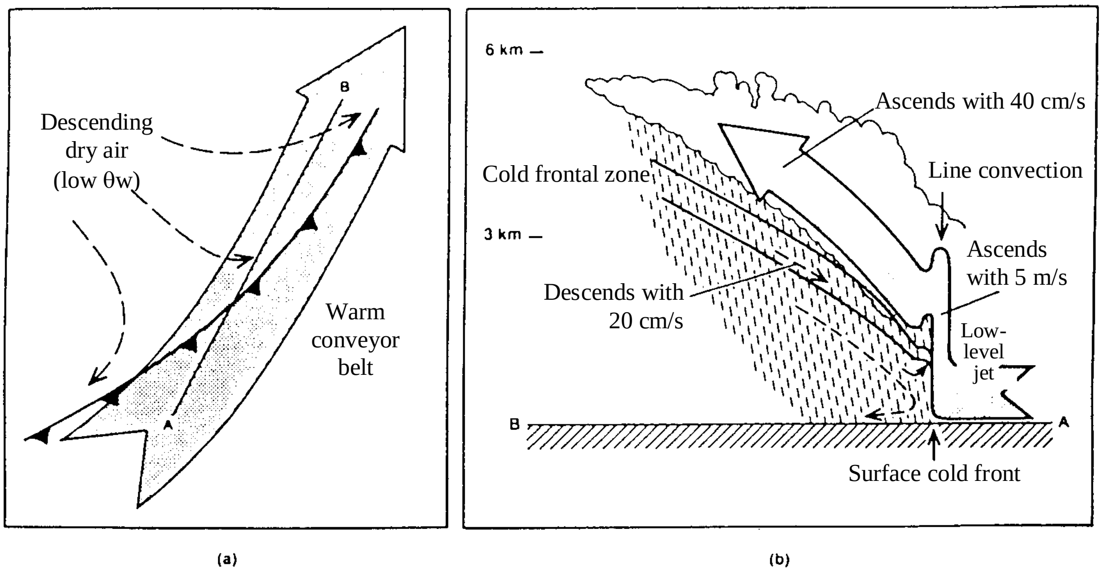


Figure 5-1-7. Schematic of flows in cold front of classical ana-type (cited from Kitabatake et al (1995)). The bald arrow indicates a cold front. A WCB is ascending in a backward inclined direction, and cold air (broken line) is descending beneath the WCB.
(a): Plane. (b): Cross section along A-B in Part (a).

In Figure 5-1-8, there is a cloud band extending southwesterly from a low near the Kuril Islands. Since active convective clouds range along C-C on the southeastern edge (on the warm side) of the cloud band, this cloud band can be judged to be of the ana-type. The position of a cold front can be determined along C-C.

In Figure 5-1-9, a rope cloud is seen along C-C on the front edge of the cloud band. Rope cloud is frequently observed on the forward edge of a cloud band that extends from a low at its maturity or decaying stage, and a cold front can be determined at the position of the rope cloud. There is also a cloud line D-D to the west of C-C. However, it is not thought to correspond to a cold front because it is fairly distant from the cloud band and it is discrete. Cellular convective clouds (A) spread over the ocean waters behind the front. An active convective cloud belt about 100 to 200 km wide (R-R) is seen in front of the rope cloud, however it is a rain band in the warm sector. Since this sort of rain band is frequently seen in the warm sector, care must be taken not to mistake it for a cold front.

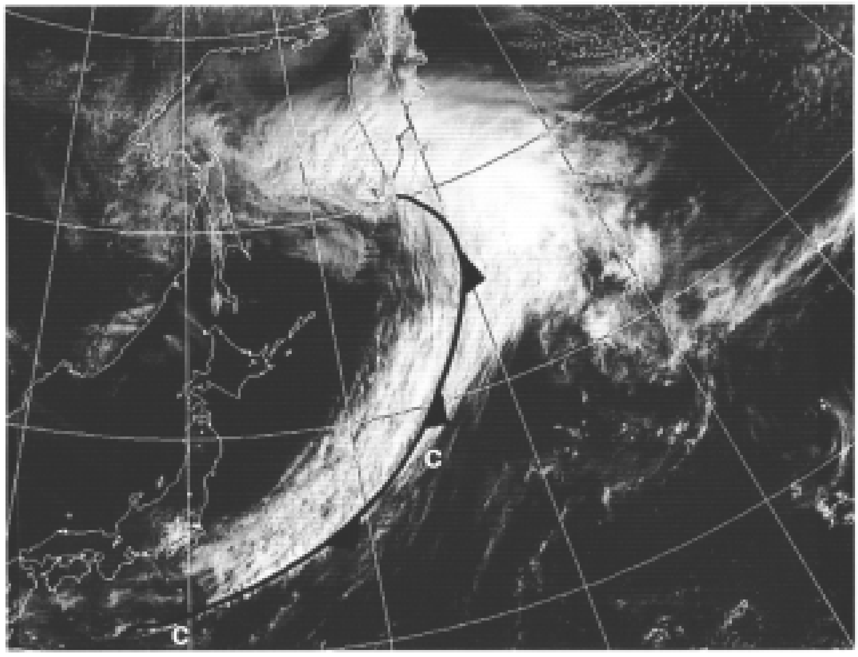


Figure 5-1-8. Example of anafront (00UTC, May 9, 1998).
Visible image and position of cold front is shown superposed. For symbols, refer to the text.

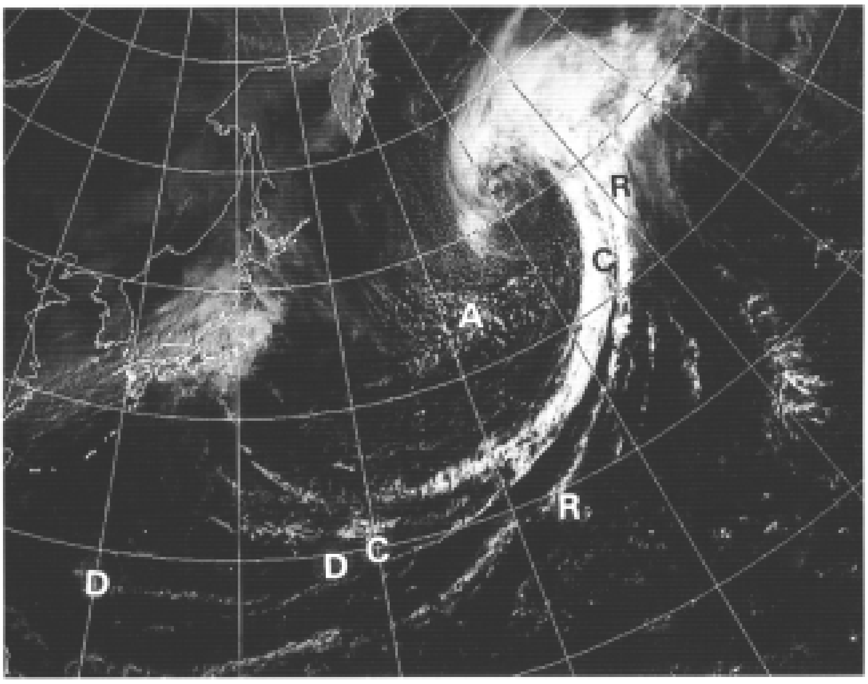


Figure 5-1-9. Example of anafront (00UTC, March 27, 1998).
Visible image and position of cold front is shown superposed. For symbols, refer to the text.

(2) Kata-type cold front

The forward sloping ascending WCB model by Browning (1990) applies to the cold front of the kata type (Figure 5-1-10). A UCF (upper cold front) may be seen when a dry air mass of low equivalent potential temperature in the upper air descends and overtakes the surface cold front. The UCF is apt to foster the convective instability by providing the dry air aloft the WCB or warm and wet air mass in the warm sector and prompte the development of a rain band. Heavy rain, gusts and other severe phenomena accompany the rain band. There is sometimes a region composed of clouds of short stature accompanied by light rain (SMZ: shallow moist zone) between the rain band and the surface cold front. This sort of kata-type front is called a split front.

For the kata-type cold front, the variation of weather when a surface cold front passes is slight compared with when a rain band passes. In the satellite image as well, rain bands and UCF are clearly discernible, however the surface cold front is visualized with low clouds and the organization of clouds is coarse in many cases, so it is difficult to identify.

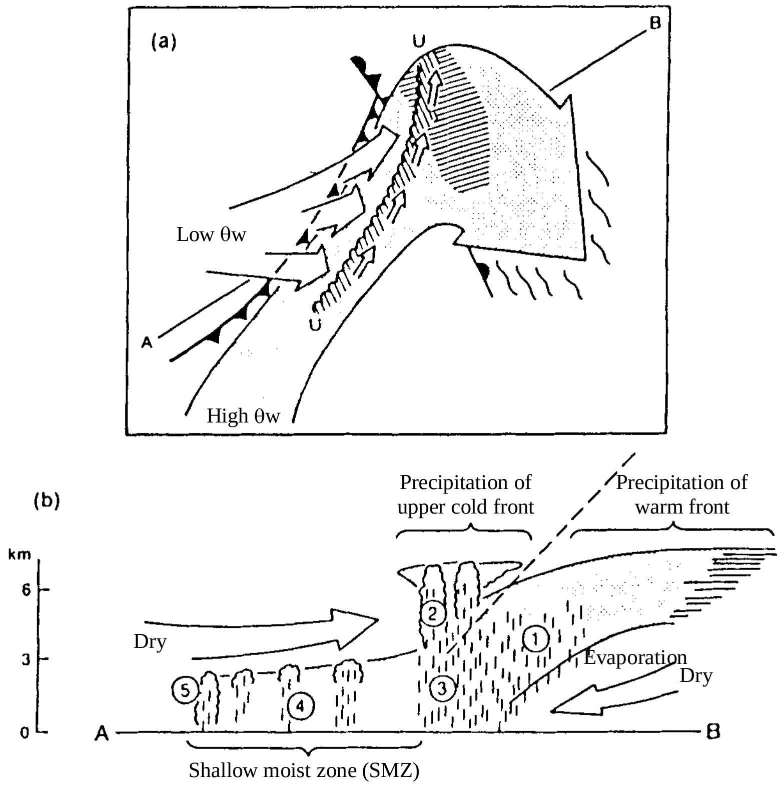
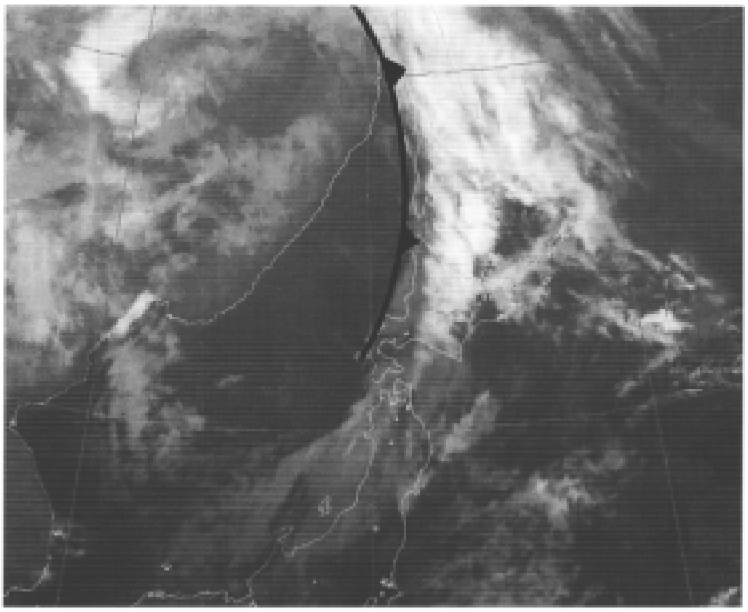


Figure 5-1-10. Schematic model of kata-type cold front (split front) (cited from Kitabatake et al. (1995)).
(a): Plane. Shaded bald arrow: Forward inclined WCB. Open arrows indicating dry air mass.
(b): Cross section along A-B in Part (a). The numbers in the figure are:
① Precipitation of warm front
② Upper cells accompanying UCF (indicated by U-U in Part (a)) and bringing convective precipitation
③ Precipitation from UCF
④ Shallow moist zone (SMZ) between UCF and surface cold front
⑤ Precipitation of short stature due to cold front

In Figure 5-1-11, a cloud band extending from the low in central Sakhalin is passing Hokkaido. A convective cloud of tall stature (A-A) lies in the central part of Hokkaido and is accompanied by heavy rain. It may be thought that this cloud area corresponds to the surface cold front, but it is not true. According to surface observation data (not shown) at Sapporo, a temperature drop (about 2 degrees), a pressure rise (1 hPa) and an intensification of wind speed (from 2 m/s to 5 m/s) were seen during the period from 23UTC 24th to 01UTC 25th when a cloud area of short stature (B) passed. During the period from 21 to 22UTC 24th when a convective cloud of tall stature (A-A) passed, only a drop of dew-point temperature was observed. Therefore, the surface cold front coincides with the western edge of the cloud area of short stature (B, cloud top height lower than 700 hPa) west of the convective clouds (A-A). According to the upper-air observation at 00UTC 25th at Sapporo, the layers above 700 hPa were dry and the cloud area of short stature (B) was held down at the top by this dry air mass. The dry air mass has overtaken the surface cold front by the strong southeast wind in the upper and middle air, and it exhibits features of a kata-type front. In this example, A-A corresponds to a UCF and B to a SMZ, and these exhibit a split front structure.



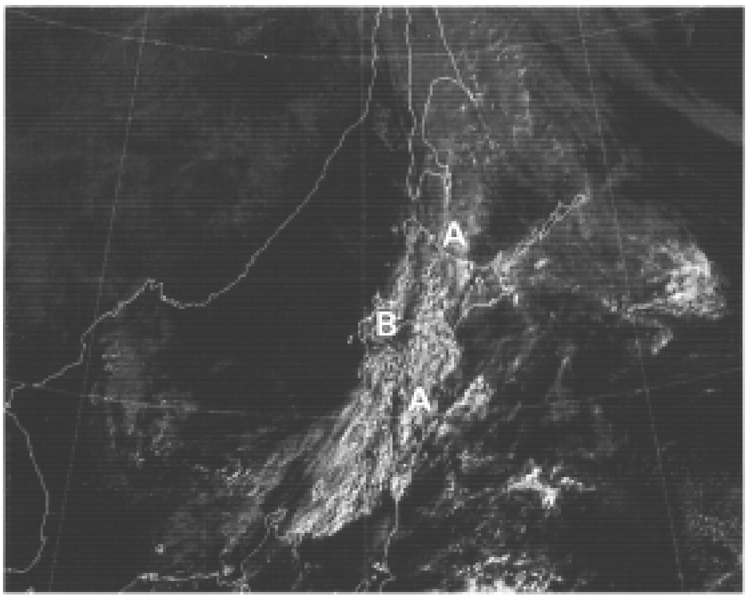


Figure 5-1-11. Example of kata-type cold front (00UTC, October 25, 1997).
Top: Infrared image. Bottom: Visible image. For symbols, refer to the text.

(3) Notice points on analysis

Points to be kept in mind when analyzing cold fronts on satellite images are given below (see Figure 5-1-12).

① Even in one length of a cold front, the portion near the cyclone center tends to exhibit the katafront structure due to a fall of dry air masses from upper levels, and the portion away from the center the anafront structure. This structural tendency is strong at and after the deepening stage of the low. Therefore, the cold front accompanying a developing low is generally situated on the western edge (marked by open arrows in the figure) of the cloud band near the center of the low and on the southern edge (marked by black arrows in the figure) of the cloud band far away from the center.

② For the ana-type, the front can be determined at the position of the rope cloud. However, there are various patterns and care must be taken in doing analysis: there may be multiple rope clouds and some of them are accompanied by no cloud band, some are apt to be mistaken for convective cloud lines in the warm sector.

③ In the warm sector, convective clouds prevail and some of them may move to merge with the cold front by the marginal current of a high while exhibiting a linear structure (for example, the cloud A in the figure). Such a convective cloud line is apt to be mistaken for a cold front. In this case, the line can be judged to be a convective cloud line in the warm sector if it followed an anticyclonic path and if the cloud line presents an anticyclonic curvature.

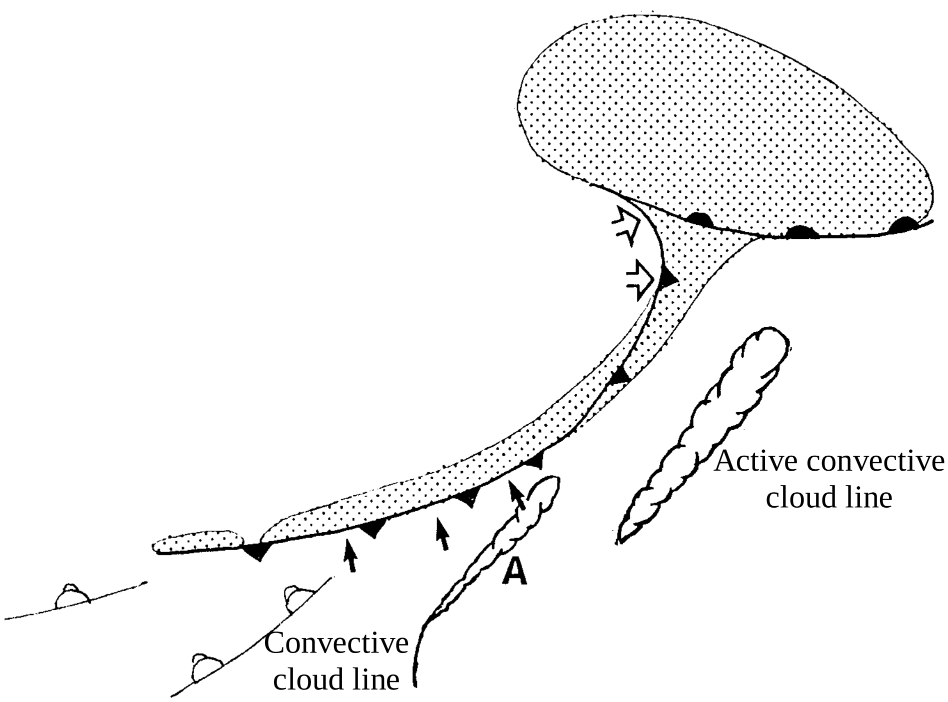


Figure 5-1-12. Schematic model showing points on cold front analysis.
Shaded area: Cloud area. Thick solid line: Convective cloud line.
Scallops: active convective cloud line. For symbols and arrows, refer to the text.

5.1.4 Occluded front

Occlusion comprises two types: cold and warm occlusion (Figure 5-1-13). The cold occlusion has a similar structure to a cold front because the cold air behind the cold front that has overtaken the warm front is colder than the cold air in front of the warm front. The warm occlusion has a similar structure to a warm front because the cold air in front of the warm front is colder than the cold air behind the cold front that has overtaken. The neutral occlusion may be classified as an intermediate between cold and warm occlusion. However, only the patterns of a cold and a warm occlusion are given here because these exhibit distinct features on satellite imagery.

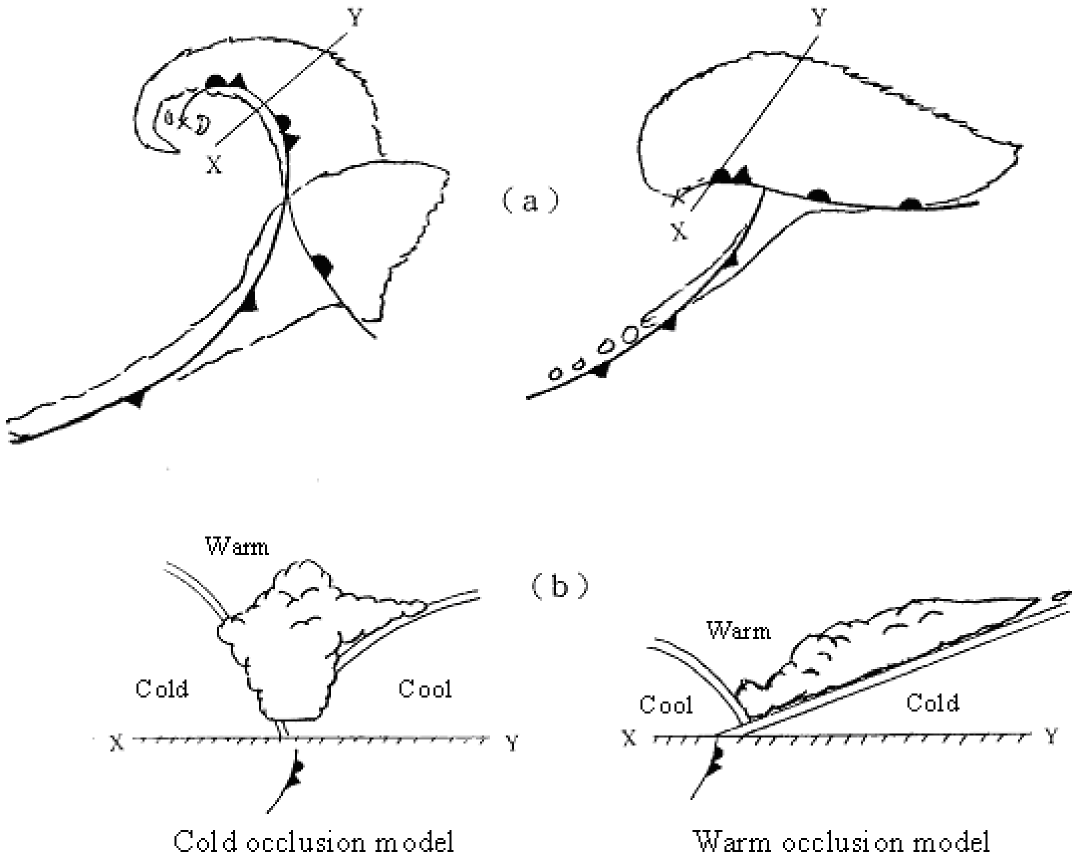


Figure 5-1-13. Schematic model of occluded fronts.
(a) is a plane. (b) is a cross section along X-Y.
Double line: Boundary between air masses. The air temperature is higher in the order of cold＜cool＜warm.

(1) Determination of occlusion point

Considering a feature of occlusion that the warm sector of the low is gone from the surface, Saito (1979) gave judgment criteria for occlusion, as follows:

- Pressure drop rate is largest at the occlusion point.
- Phase difference between 500-hPa trough and surface low decreases rapidly.
- There are just one shear area and a trough at surface and 850 hPa.
- Wedge-shaped upper warm air appears just above or slightly forward the surface trough, and the temperature gradient near that warm air ceases to increase.
- The upper strong wind situates to the south of the center of the low.

Of these occlusion judging criteria, it is only the position of the strong wind that can be grasped on satellite imagery. Its position can be estimated from the boundaries on a water vapor image or from the Ci streaks on an infrared image.

Besides these, an occluded front can be identified by a cloud band corresponding to the CCB which crosses the frontal cloud band extending nearly parallel to the strong wind axis, and extends poleward

A usual procedure to determine an occlusion point is given as follows (Figure 5-1-14).

① Determination of strong wind axis:
In the water vapor image, a boundary corresponding to a jet stream is seen along J-J. The upper strong wind axis can be identified along this boundary.

② Determination of cold front:
A cloud band 200 to 400 km wide is clearly discernible along B-B on both the visible and infrared images. This cloud band corresponds to a cold front.

③ Determination of warm front
W1-O-W2 in the visible image is a cloud band that corresponds to CCB (cold conveyor belt), eastern part of which (W1-O) corresponds to a warm front. This cloud band crosses the cold frontal cloud band and extends poleward (O-W2). The cloud band of CCB is easier to find on the visible image.

④ Determination of occlusion point and occluded front:
The occlusion point is estimated near the intersection (O) between the southern edge (W1-W2) on the warm side of the CCB and the boundary (J-J) corresponding to a jet stream. In this example, the cloud area of tall stature (A) has further advanced east of the occlusion point. Such a pattern tends to form when the low reaches the beginning of decaying stage beyond occluding stage. There is a cloud band (O-W2) of low clouds, which accompanies the CCB, extending from the polar side of the cold frontal cloud band (B-B) to the east. The southern edge of this cloud band corresponds to an occluded front.

(2) Cold occlusion

A cold occlusion is frequently seen accompanying a low which is accompanied by intense cold air moving south from the pole and develops in front of a trough. Features of a cold occlusion on a satellite image include “ the low system has a comma shaped cloud pattern extending north and south”, “the cloud band corresponding to a cold front is distinct but the warm front is difficult to identify”, “cellular convective clouds accompanying the intense cold air spread behind the low” and “a dry slot appears distinctly”. These features indicate that there is an intense cold air advection behind the low. On the other hand, the warm front structure is frequently indistinct (because the CCB is indistinct), and the occlusion point is difficult to determine.

For the low to the east of Japan (Figure 5-1-15), “it has comma –shaped cloud pattern”, “a cloud area (B) of open cells spread behind the low” and “a dry slot wraps around the center”. With these features, this can be judged to be a cold occlusion.

In the water vapor image, J-J is a boundary, and the jet axis lies along this boundary. The warm front is difficult to determine because the low level clouds are sparse. It must be estimated from the southern bound (W-W) of the open cellular cloud area. The cold front corresponds to a cloud band (C-C). The occlusion point (O) is determined near the intersection between the cold frontal cloud band (C-C) and the low level cloud line (W-W) corresponding to a warm front or near the intersection between J-J representing upper strong wind axis and W-W. The upper dry air mass, which forms a dry slot, wraps around the low center through the north of the occlusion point as a dark region in the water vapor image. In this example the dry slot has overtook the occlusion front and further advanced to the north.

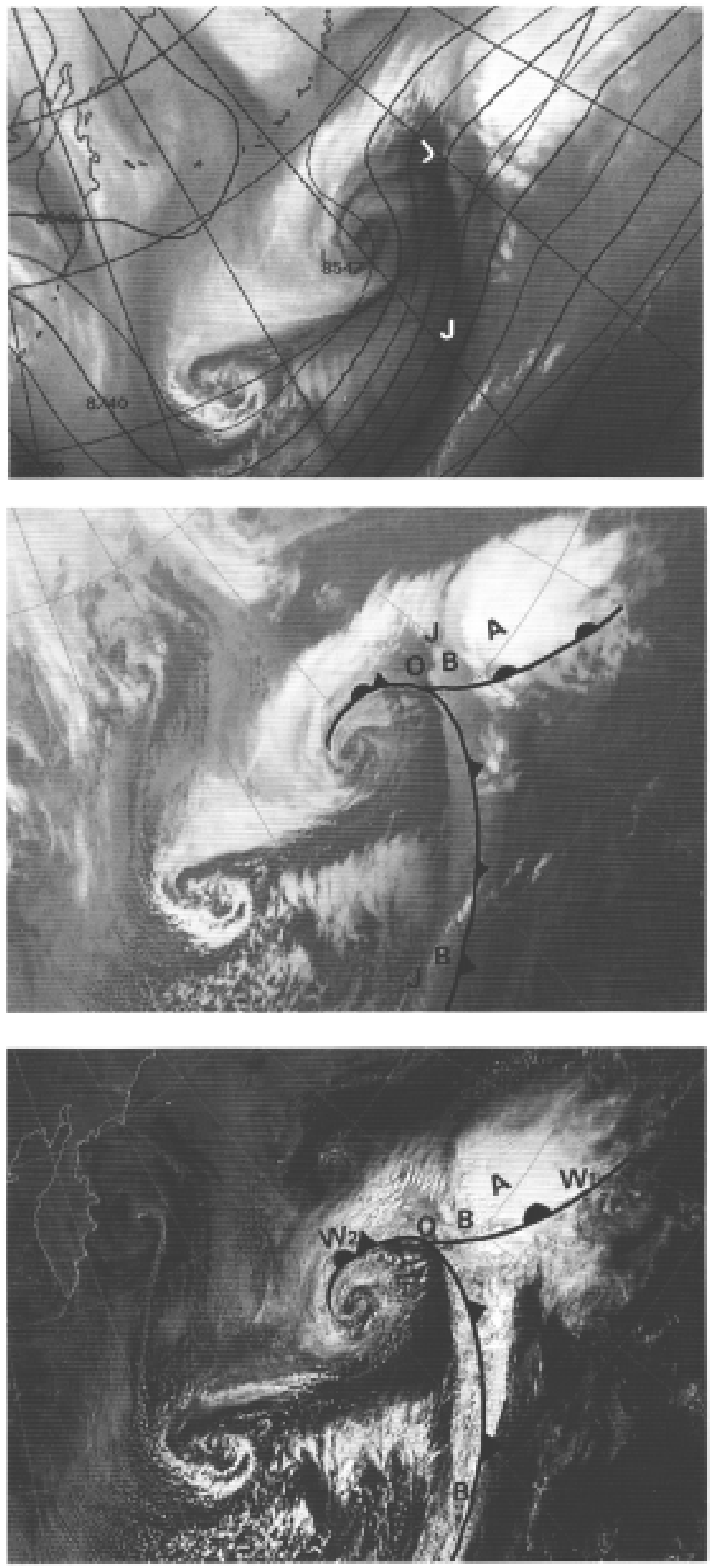
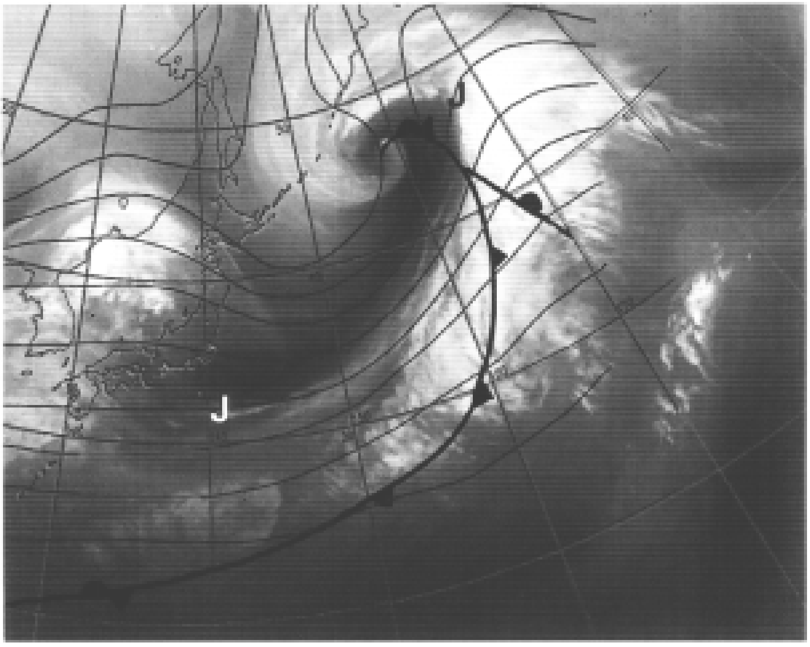


Figure 5-1-14. Determination procedure of occluded front (00UTC, February 19, 1998).
Top: Water vapor image, 300-hPa height. Center: Infrared image. Bottom: Visible image.
For symbols and arrows, refer to the text.



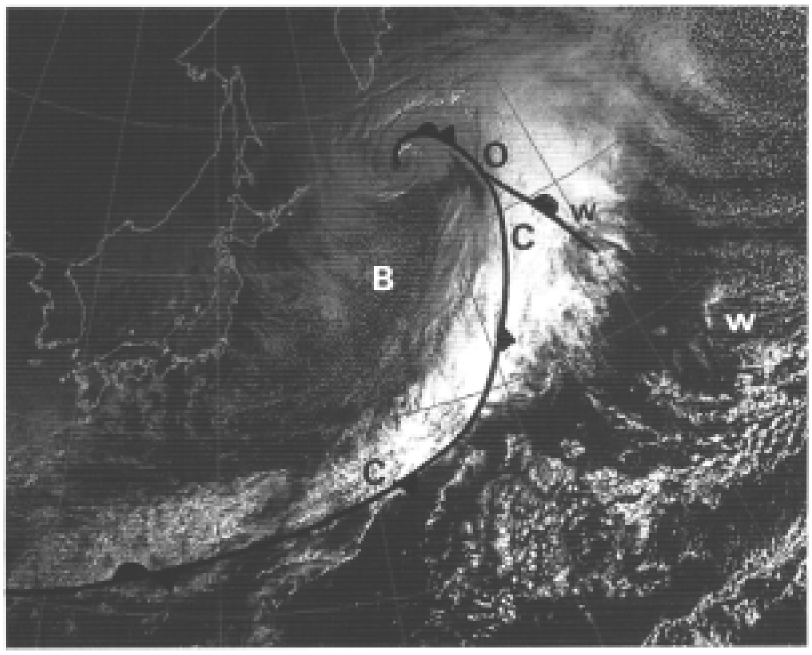


Figure 5-1-15. Example of cold occlusion (00UTC, January 17, 1998).
Top: Water vapor image, 300-hPa height.
Bottom: Visual image. For symbols, refer to the text.

(3) Warm occlusion

The warm occlusion corresponds to the case in which air behind the low is less cold. On the satellite image, it has some features such as “it forms a cloud pattern of λ or T shape extending east and west”, “the cloud band corresponding to a warm front is distinct as compared to cold occlusions”, “the cold fronts include both active and inactive ones”, “the dry slot is indistinct” and “the cellular clouds accompanying the cold air behind the low is indistinct and small in extent”. These features stand in contrast to those of cold occlusions and indicate that there is no intense cold advection.

For the low to the south of Japan (Figure 5-1-16), “the cloud pattern shows the λ shape”, “The area behind the low is cloud free and no cellular could is seen ”, “the cloud band corresponding to a warm front is distinct”, and “the dry slot is indistinct”.   With these, the occlusion can be judge to be of the warm type.

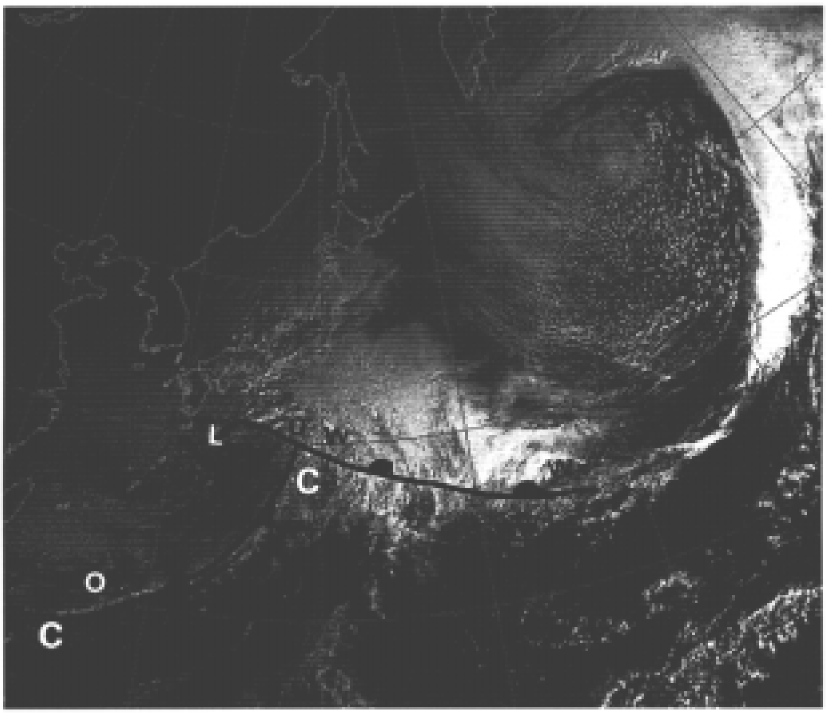


Figure 5-1-16.   Example of warm occlusion (00UTC, January 18, 1998).
Top: Water vapor image, 300-hPa height.   Bottom: Visible image.   For symbols, refer to the text.

In the water vapor image, J-J is a boundary, and the jet axis lies along this boundary. The warm front can be determined on the southern edge of the distinct cloud band (W-W) extending east and west. The convective cloud line (C-C) corresponding to the cold front is week in activity but is clearly discernible. The occlusion point (O) is determined at the intersection between W-W and C-C, and the occluded front on the southern edge of the cloud area extending to the center of the low (L) on an extension of W-W. In this example, the low happens to lie in the diffluent area at an exit of the jet, and so, the boundary is indistinct near the low. Therefore, the boundary is not effective in determination of the occlusion point.

5.1.5 Stationary front

A stationary front shifts little in the direction perpendicular to itself and is perceived as a cloud band extending over several thousand kilometers on the satellite image. Mesoscale lows and frontal waves present in the stationary front are discernible as a cloud area of clustered active convective clouds, or a cloud area having an anticyclonic curvature on the northern edge in the cloud band.

In the cold season, a stationary front frequently forms a wide and long cloud band and convective activity in the band is usually weak. On the other hand, a stationary front in the warm season is frequently accompanied by active convective clouds due to the inflow of a warm and moist air from the south, as typified by the baiu front and autumn rain front.

(1) Stationary front in cold season

Stationary fronts in the cold season are frequently formed as a cloud band connected to a cold front extending from a developed low. They have their longitudinal direction parallel to the upper jet axis and exist as a long and wide cloud band 500 to 1000 km wide and several thousand kilometers long. They are mainly made of high and middle clouds and their convective activity is not active except for the southern edge. The surface stationary front corresponds to the southern edge of the cloud band and is situated 5 to 10 degrees latitude south of the upper jet axis corresponding to the northern edge of the cloud band.

Figure 5-1-17 shows an example of a stationary front in the cold season. There is a developed low over ocean waters near the Aleutians and it is accompanied by a cold front. A stationary front connected to the cold front extends to the south of Okinawa. In the water vapor image, the dark region (B-B) corresponding to the upper jet stream is situated parallel to, and on the northern edge of a cloud band. This cloud band is 500 to 800 km wide and is composed mainly of high and middle clouds. No active convective cloud is seen except for near 160° West (A). A precipitation (rainfall of about 1 mm per hour) from stratiform clouds was observed at Okinawa which was covered by this cloud band. A stationary front is analyzed on the southern edge of the cloud band. From the surface observation reports at this time, the differences in wind or air temperature across the cloud band are not recognized. The surface front is situated about 7 degrees in latitude south of the jet axis. The slope of the frontal surface is less than 1/100, a little steeper than the slope of ordinary warm frontal surface.

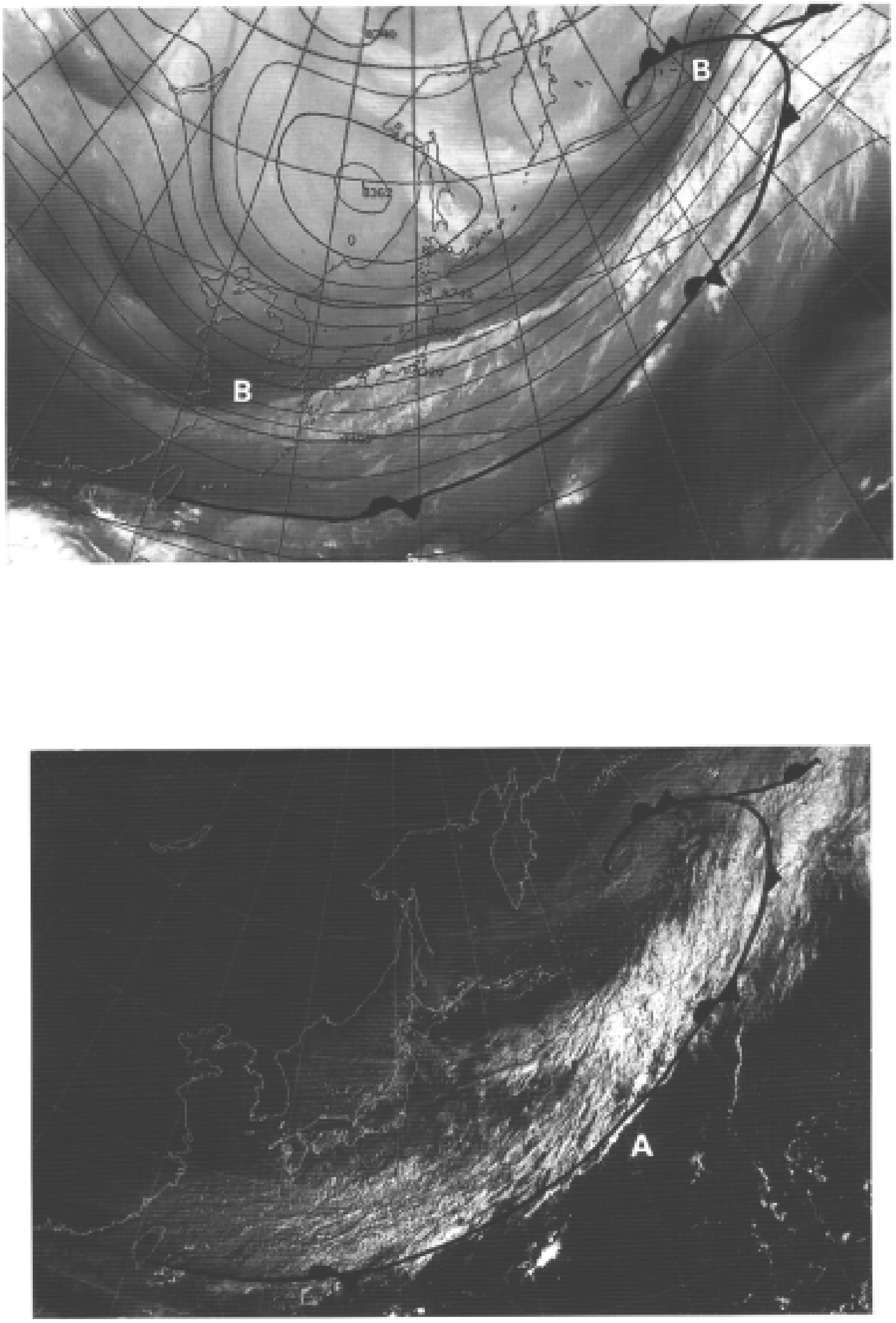
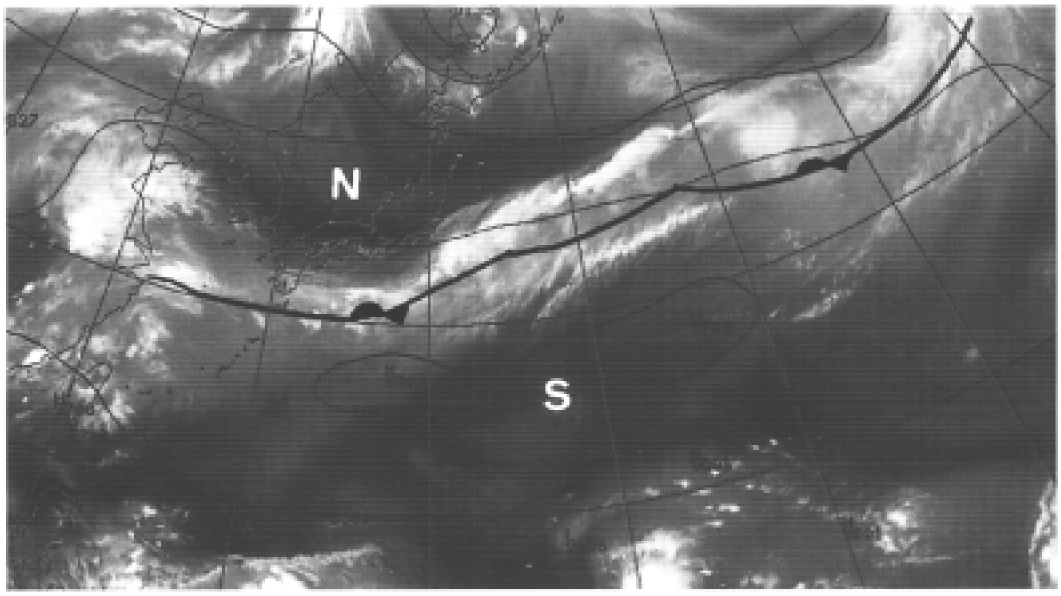


Figure 5-1-17. Example of stationary front in cold season (00UTC, November 19, 1998).
Top: Water vapor image, 300-hPa height Bottom: Visible image. For symbols, refer to the text.

(2) Stationary front in warm season

The baiu front is a representative stationary front in the warm season around Japan. It has the feature of having a large water vapor content gradient than the temperature gradient near the front. It is narrow in width as compared to stationary fronts in the cold season and is seen as a cloud band mainly of convective clouds.

Figure 5-1-18 shows an example of baiu front. A cloud band about 100 km wide which comprises mainly middle and low level clouds including active convective clouds extends from the Chinese continent to the sea to the east of Japan. A baiu front can be analyzed at the position of convective clouds joined in series. Because of its small temperature gradient, its correspondence to a strong upper wind axis is not clear. In the water vapor image, there are dark regions spreading around Japan and to the south of Japan across a narrow banding bright region that corresponds to a baiu front. The northern dark region (N) is a dry area formed by subsidence accompanying a mid-latitude high. The southern dark region (S) corresponds to a Pacific high.



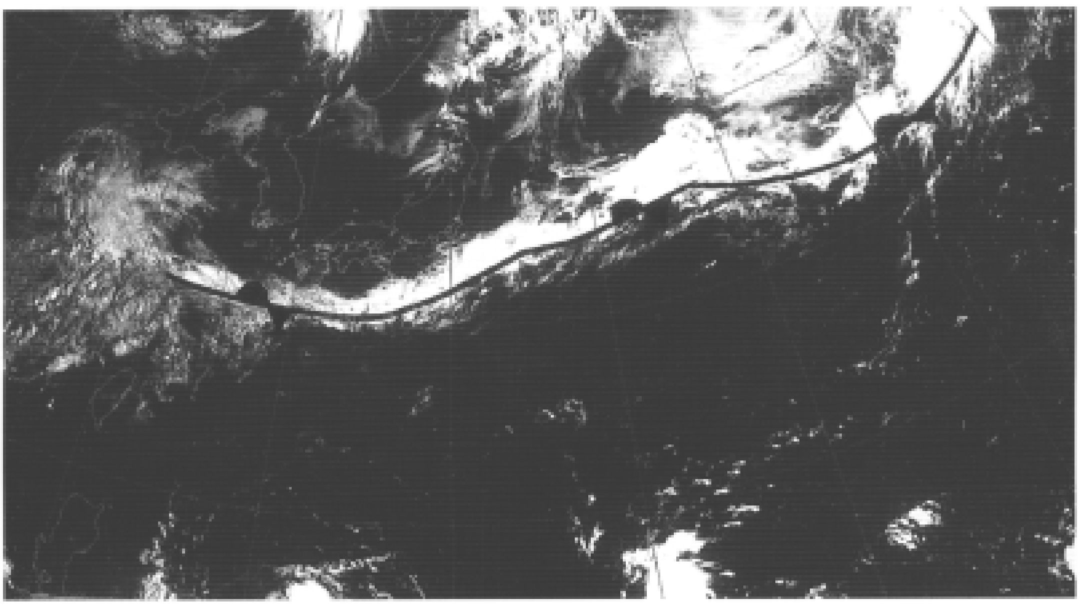


Figure 5-1-18. Example of stationary front in warm season (00UTC, June 24, 1997).
Top: Water vapor image, 300-hPa height. Bottom: Visible image. For symbols, refer to the text.

5.2 Classification of cyclone development

Bjerknes proposed a cyclone model at the beginning of the 20th century, and it may be said that this is still now the most general cyclone development model. This model was created chiefly by the insight into surface observation data. It represents a cyclone developing from a frontal wave in the middle latitudes in a schematic and understandable manner. This can be understood from the fact that cloud patterns which can be explained by the Bjerknes model are seen most frequently when observing cyclone development in satellite imagery. The cloud model of this type is called the typical type.

On the other hand, various patterns besides the typical types are seen when observing the life of cyclones in satellite imagery (Figure 5-2-1). That is, there are some developing patterns to be classified that cannot be explained by the Bjerknes model. These are comma-type and instant occlusion-type, which are phenomena chiefly taking place on the polar side of the mid-latitude baroclinic zone. The comma-type cyclone develops from a comma-shaped cloud moving south from the polar side of the baroclinic zone before it touches the mid-latitude frontal zone. The instant occlusion is that when a comma-shaped cloud moves south from the polar side of the baroclinic zone and touches a mid-latitude front; it merges with the frontal cloud band and makes the occlusion cloud pattern. Besides these, Shapiro and Keyser (1990) gave a development model having a T-bone cloud pattern as a type of cyclones developing in the baroclinic zone. The structure near the cyclone center is represented by detachment of fronts and differs from the Bjerknes model.

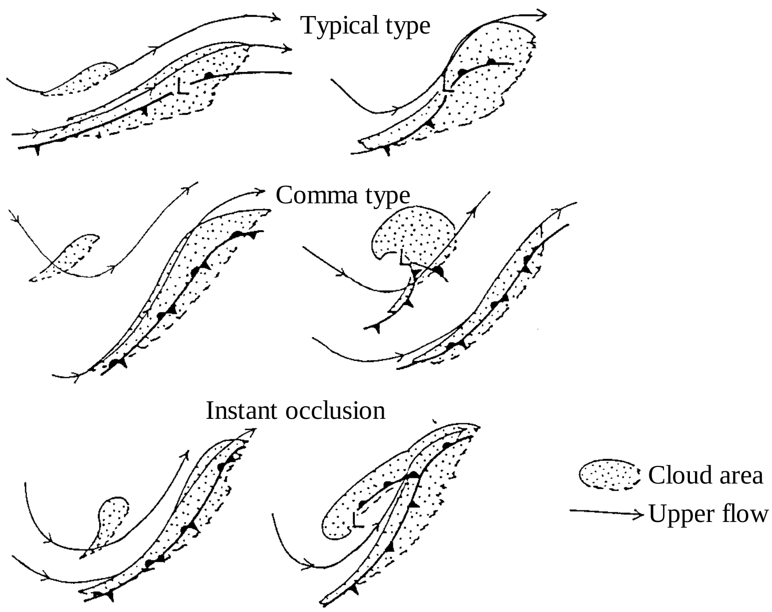


Figure 5-2-1. Schematic model of typical, comma and instant occlusion types.

This section chiefly explains the features of various cloud patterns that accompany synoptic-scale cyclone development. The purpose of this section is to show that there are many various development styles of low pressure besides the Bjerknes model and these can be classified by satellite imagery. These development models were proposed in Europe and America, and the behavior of cyclones around Japan, which is situated at lower latitudes, is susceptible to the influence of the subtropical zone and may differ in some respect from these models. Development of small-scale cyclones around Japan and the development of cyclones considering the geographic features around Japan discussed by Suzuki (1998, 1999) need to be investigated in the light of these new models.

The terms of developing and mature stages used here indicate the developmental stages as judged from satellite imagery, which do not always agree with the developmental stages of a cyclone shown on weather charts. Empirically speaking, the mature stage in satellite imagery occurs somewhat earlier than the time of lowest pressure of the cyclone.

5.2.1 Development of typical type

According to an investigation by Yamada and Suzuki (1994), about one third of the cyclones that rapidly develop in the winter over the ocean waters east of Japan fall under this type, and the period from occurrence to maturity is about 3 days. In satellite imagery, characteristic features at the formative and deepening stages are the formation and northern movement of a cloud area due to the advection of warm air in front of the cyclone and the dissipation and southern movement of the cloud area due to the inflow of dry cold air behind the cyclone. These features represent the development of baroclinic instability from a frontal wave and can be explained by the Bjerknes model. Okabayashi (1982) gave a cloud pattern model for cyclone development based on the Bjerknes model. An example of the typical type is presented here comparing with the Okabayashi model.

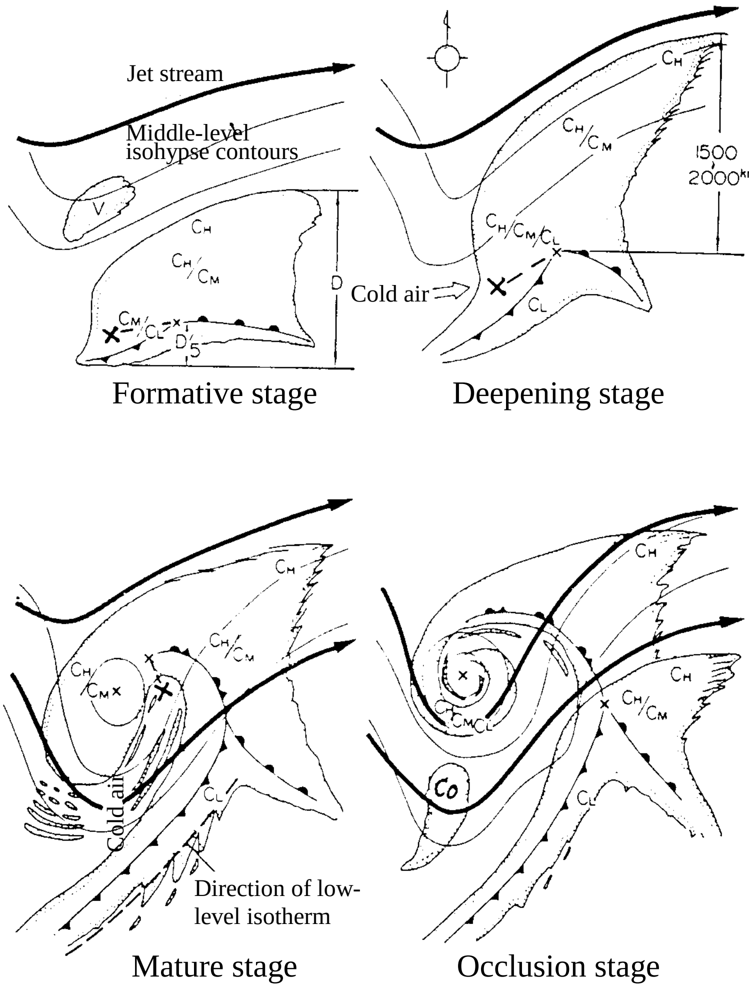


Figure 5-2-2. Cyclone model by Okabayashi (1982).
The mark x indicates the cyclone center. x-x means that the cyclone center falls within this. region. C_H, C_M and C_L indicate high, middle and low level clouds, respectively.

The time variations of central pressure of the cyclone of this example are shown in Figure 5-2-3. The formative stage and deepening stage, and so on correspond to the developmental stages of Okabayashi model.

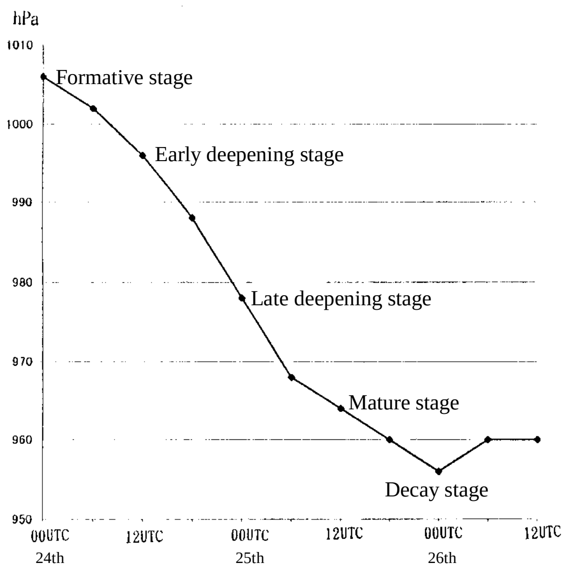


Figure 5-2-3. Time variations of central pressure of the cyclone.

① Formative stage

A cloud pattern called a cloud leaf (also called baroclinic leaf) appears in the formative stage of a disturbance in a baroclinic zone. The leaf-like cloud area in the East China Sea is a cloud leaf. This shape of the cloud area is formed by a warm and humid air current of WCB (warm conveyor belt), which indicates that warm air advection is becoming intense.

The cyclone center at the formative stage is hard to identify from the cloud pattern, however it lies near the center or southern edge of the cloud area in many cases. In this example, the warm front can be determined on the southern edge of the low level cloud seen in the visible image, and the cold front by using the active convective clouds seen on the southeastern edge of the cloud area as guides. These features are shown in the formative stage of the Okabayashi model. On the other hand, the Okabayashi model represents the northern edge of a cloud area away from a jet stream, however in general they are juxtaposed. In this example as well, the jet stream meets with the northern edge of the cloud leaf, judging from the distinctness of the northern edge of the cloud leaf and the position of the boundary analyzed on the water vapor image. In the Okabayashi model (at the formative stage), a cloud comprising chiefly high clouds named (V) approaches the cloud area of the cyclone from the northwest. Although not seen in the example given here, this cloud corresponds to an upper trough in many cases and it overtakes the could area of the cyclone and enhances the development in some cases, so it is noteworthy.

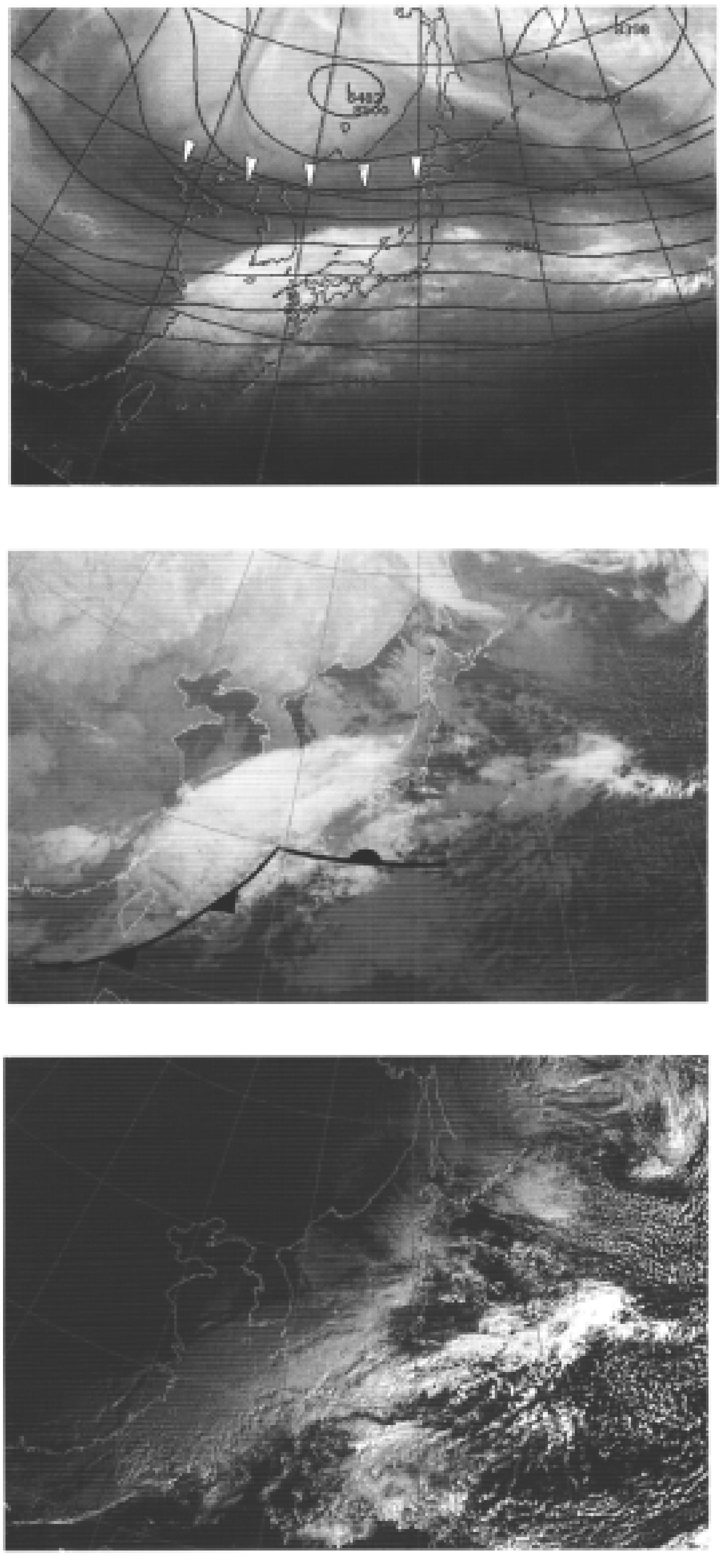


Figure 5-2-4. Typical type, formative stage (00UTC, January 24, 1997).
Top: Water vapor image with 300-hPa height contours superposed. Wedges indicate a boundary.
Center: Infrared image. Bottom: Visible image.

② Early deepening stage

A feature of the early deepening stage is the bulge. The bulge is a cloud pattern in which the cloud area has expand northward from the cloud leaf and increased the anticyclonic curvature on the northern edge, and it indicates a northern movement of warm air by WCB and an intensification of ascending current in front of a trough. This is the feature of a baroclinic disturbance at its deepening stage. In the water vapor image, the boundary corresponding to the strong upper wind axis has moved to the south from the formative stage, indicating a deepening of the trough.

The cyclone center shifts west from the center of the cloud area at the formative stage, and it can be determined near the starting point of the western edge of the bulge. However, its identification from the cloud pattern is still difficult. The warm and cold fronts can be determined on the southern edge of the low level clouds in the same manner as at the formative stage (on the photograph, there are high clouds in the warm sector, so it is difficult to identify the low level clouds by the infrared image alone).

According to the Okabayashi model, this stage corresponds to an intermediate between the formative and deepening stages.

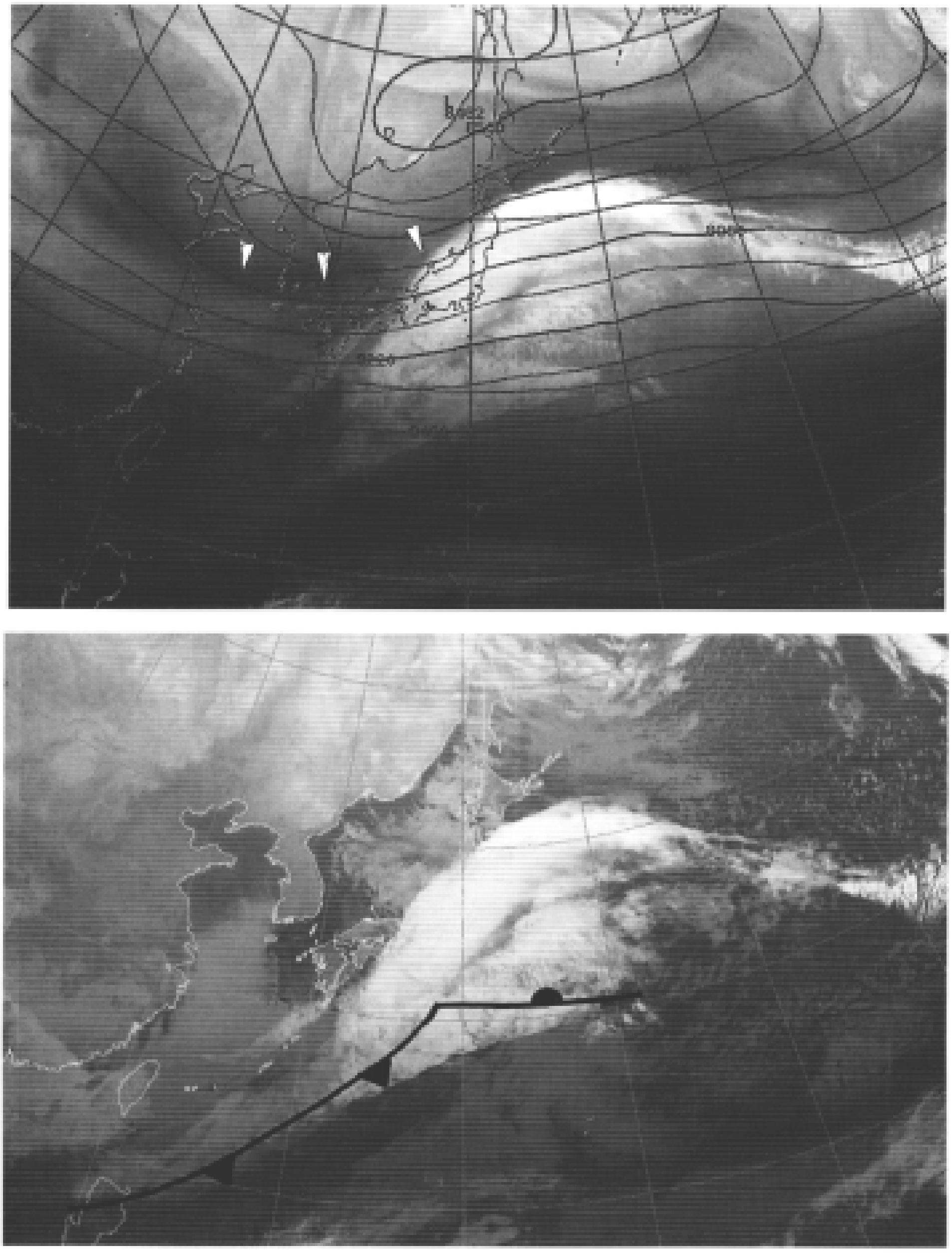


Figure 5-2-5. Typical type, early deepening stage (12UTC, January 24, 1997).
Top: Water vapor image with 300-hPa height contours superposed. Wedges indicate a boundary.
Bottom: Infrared image.

③ Late deepening stage

According to the Okabayashi model, it corresponds to the deepening stage. The bulge becomes distinct further, and cloud streets and cellular convective clouds occur behind the cyclone, indicating cold advection. The cold advection causes a hook pattern to form. The cloud area expands north and south further than at the early deepening stage. This meridional expansion of the cloud area corresponds to both intensification of warm air advection in front of the cyclone and cold air advection behind the cyclone.

Okabayashi describes in his model that the cyclone center still lies near the center of the cloud area in some cases. However, the cyclone center shifts to the west side of the cloud area as compared with the early deepening stage, and it can be determined almost for certain at the position of the indent (hook) on the eastern edge of the cloud area. The cloud band corresponding to the cold front becomes distinct in response to the intensifying cold advection.

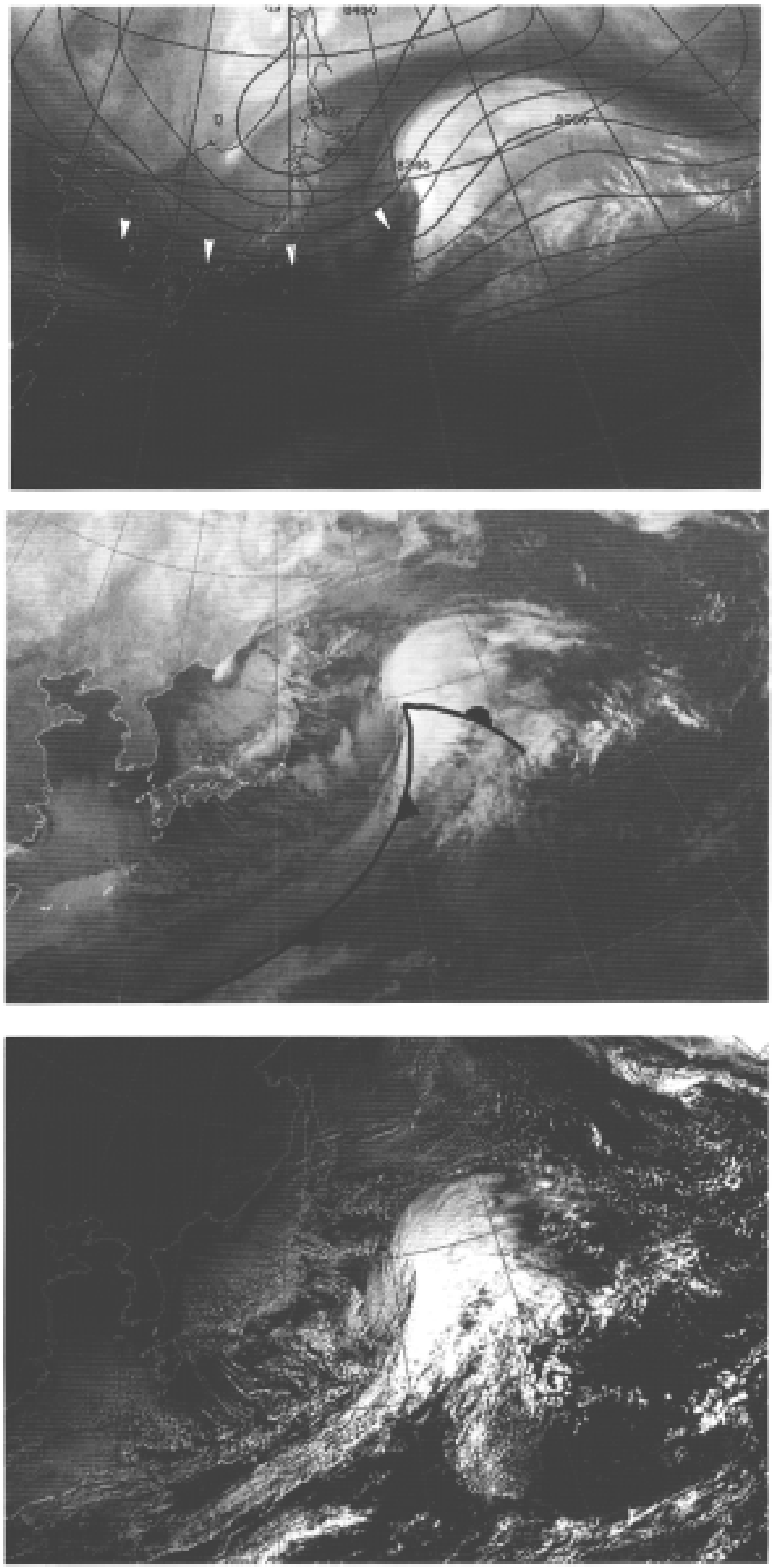
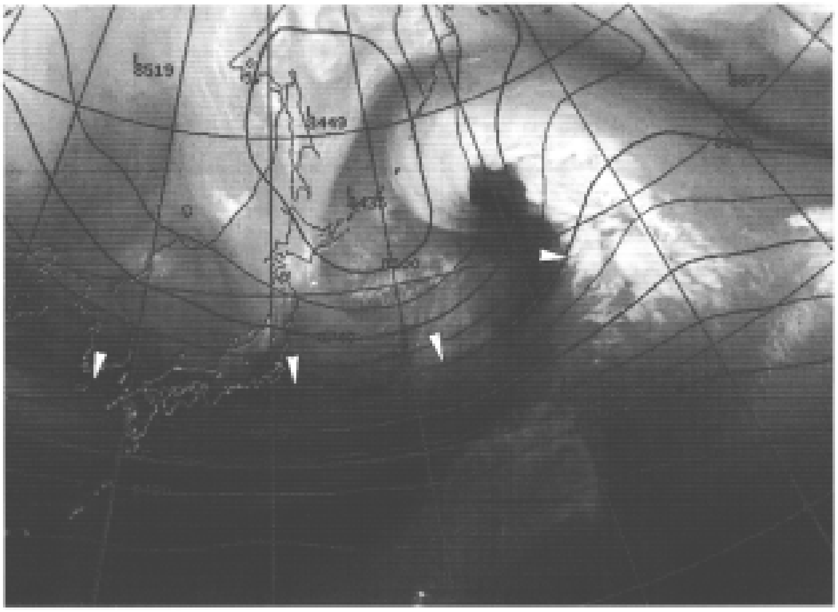


Figure 5-2-6. Typical type, late deepening stage (00UTC, January 25, 1997).
Top: Water vapor image with 300-hPa height contours superposed. Wedges indicate a boundary.
Center: Infrared image. Bottom: Visible image.

④ Mature stage

This stage corresponds to the "mature stage" in the Okabayashi model. A dry slot intrudes near the center to form a comma-shaped cloud pattern. On the satellite image, the cloud edge is distinct and the cloud top height is high, so one can judge the cyclone is at the most developed stage. However, the central pressure of the cyclone continues to lower and has not reached a minimum pressure yet. An open cellular cloud area (E) spreads behind the cyclone, indicating an intense cold advection.

The center of the cyclone can be determined from the low level vortex near the dry slot. The occluded front can be determined on the western edge of the cloud area that is bounded by the dry slot. On the water vapor image, darkening is progressing in the dark area situated downstream of the boundary. The progressing of darkening suggests an occurrence of dry intrusion. Dry intrusion is a phenomenon in which a dry air mass falls from the high levels in the rear of a developed cyclone. In this example, the position of the occluded front is not on the southern edge (A) of the high clouds but on the southern edge of the low level cloud area lying to the south of them. This pattern is formed when the dry slot overtakes the surface occluded front.



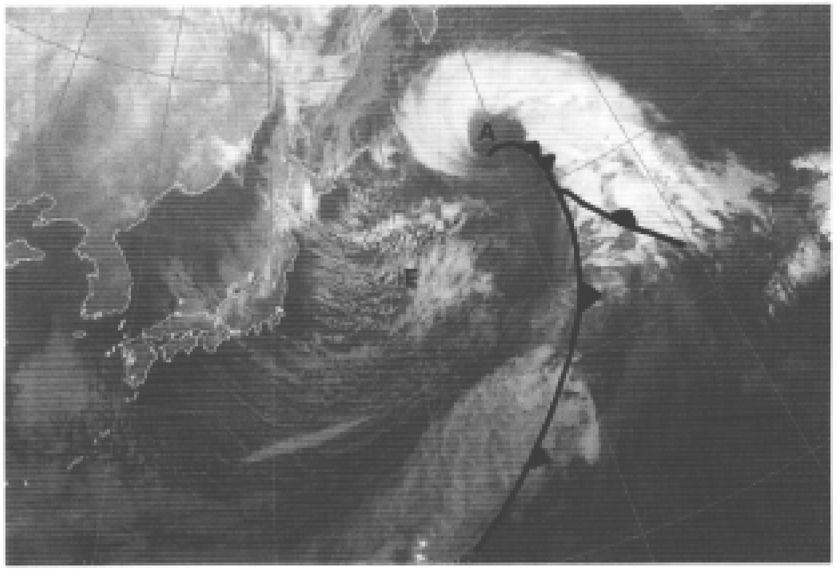


Figure 5-2-7. Ordinary type, mature stage (12UTC, January 25, 1997).
Top: Water vapor image with 300-hPa height contours superposed. Wedges indicate a boundary.
Bottom: Infrared image

⑤ Decaying stage

This stage corresponds to the occlusion stage in the Okabayashi model. At the center of the cyclone, the convective activity decays, resulting in a lowering of cloud top height and an occurrence of a low level vortex. Enhanced Cu (E) is seen in response to the cold air which accompanies a short wave trough behind the cyclone (it corresponds to the Co cloud in the Okabayashi model). The enhanced Cu may develop into a comma-shaped cloud. A portion of active convective area with high cloud top is seen near the occlusion point. The dry slot, which overtook the surface occluded front in the mature stage, corresponds to the surface occluded front by its forward edge again in this stage and it wraps around the cyclone center.

The cloud area lowers in cloud top height as a whole with the cloud edge getting frayed and indistinct, indicating a start of decline. Near the cyclone center, in particular, the lowering of cloud top height is remarkable and the dry slot stops darkening and begins to turn bright. These are features of the decaying stage. In many cases, however, the central pressure takes a lowest value in the life of the cyclone during a certain period just after the start of decaying stage seen on the satellite image. This resembles the process in the Dvorak method for estimating typhoon intensity (Koba, 1984), which maintains the typhoon intensity for 12 hours even after the pattern shows decaying in satellite imagery.

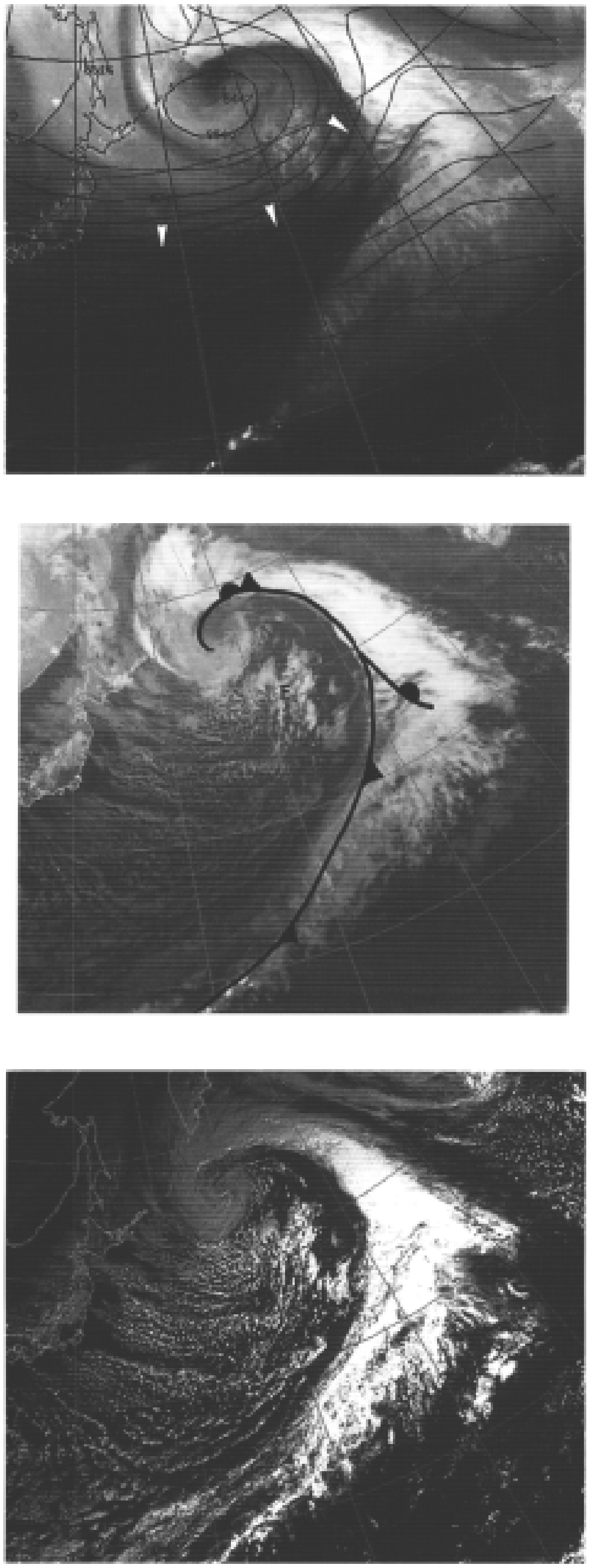


Figure 5-2-8. Typical type, decaying stage (00UTC, January 26, 1997).
Top: Water vapor image with 300-hPa height contours superposed.
Wedges indicate a boundary.
Center: Infrared image.
Bottom: Visible image.

5.2.2 Development of comma-type

A comma cloud is frequently seen in the cold season and is a phenomenon taking place on the polar side of the mid-latitude baroclinic zone. The cyclone with this cloud is called a polar low and its development is different from the extratropical cyclones. For a comma cloud to develop, the updraft due to positive-vorticity advection in middle levels and supply of sensible and latent heat from warm sea surface are important. A small-scale comma clouds occur in a region of weak baroclinicity. For a comma cloud that develops into synoptic-scale cyclone, however, the factor of baroclinic instability is involved. An example of development into a synoptic-scale cyclone is given here.

Reed and Blier (1986) gave a comma cloud development model (Figure 5-2-9). At the formative stage, convective clouds occur around the positive vorticity but are not organized yet. When the deepening stage is entered, a comma-shaped cloud is formed and a cyclone is analyzed at the head of the comma. Warm advection begins to take place in front of the cloud area, and cold advection intensifies behind. At the mature stage, the comma cloud advances in front of a long wave trough, and the tail of the comma assumes the features of a cold front.

A comma cloud that develops over ocean waters east of Japan occurs in a cold air field away from the major baroclinic zones. The cloud area at the beginning of occurrence is composed of open cells and enhanced cumulus clouds corresponding to a short wave trough, suggesting an important role of the supply of sensible and latent heat from the sea surface for the development. The cloud area develops into a comma shape while it moves to the front of a major trough. Around Japan, which lies at the outlet of the continent, a comma cloud easily develops in a very short time. This is because, though in the same positive-vorticity advection field, clouds are difficult to form over the dry continent and they form and develop rapidly only when they get to the warm Sea of Japan. According to Suzuki and Yamada (1994), the period from occurrence to maturity is shorter by about half a day for the comma cloud than for the extratropical cyclone.

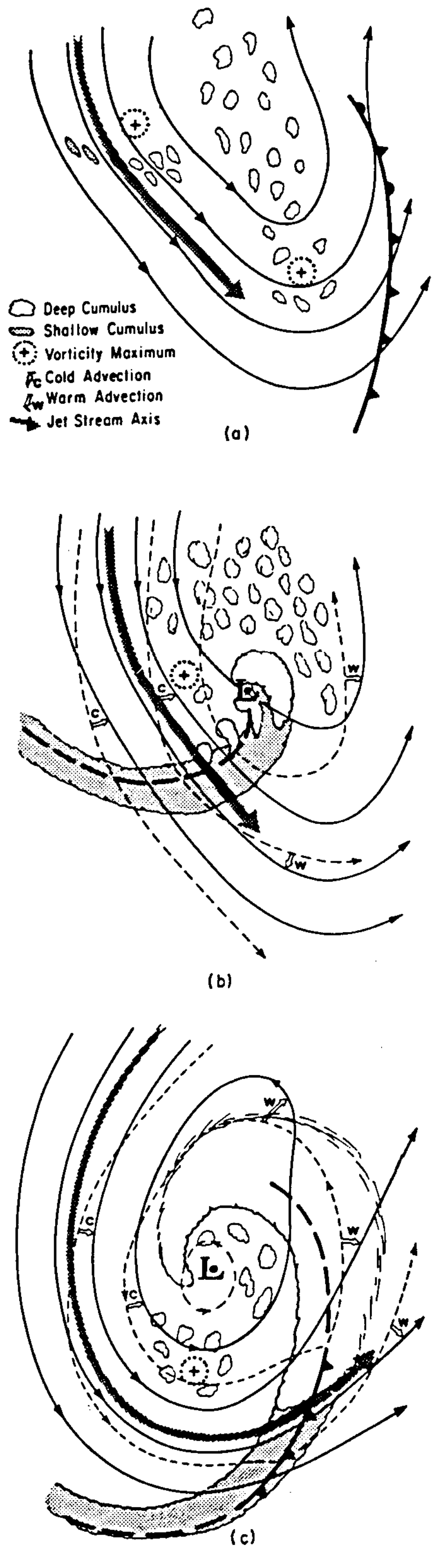


Figure 5-2-9. Schematic model of comma cloud (Reed and Blier, 1986)
(a) Formative stage, (b) Deepening stage, (c) Mature stage
Continuous line: 500-hPa isohypse contours Broken line: Surface isobar

(1) Comma cloud developing over ocean waters

① Formative stage

Cellular convective clouds accompanying cold air spread behind the developed cyclone (B) lying to the south of the Aleutians. A consistent cloud area (A) is forming over the ocean waters east of Japan. This cloud area is composed of active open cell clouds in the region corresponding to the intense cold air and is accompanied by upper level clouds. This is an occurrence of a comma cloud, but it isn't the comma shape at the beginning. This cloud area is made of the positive vorticity advection max (PVAmax) in front of the short wave trough whirling from behind the cold low at Kamchatka. At this stage, since the cloud density is sparse and the cloud edge has no anticyclonic curvature, the cloud area cannot be considered to be organized, and it is thought that no cyclone has occurred yet.

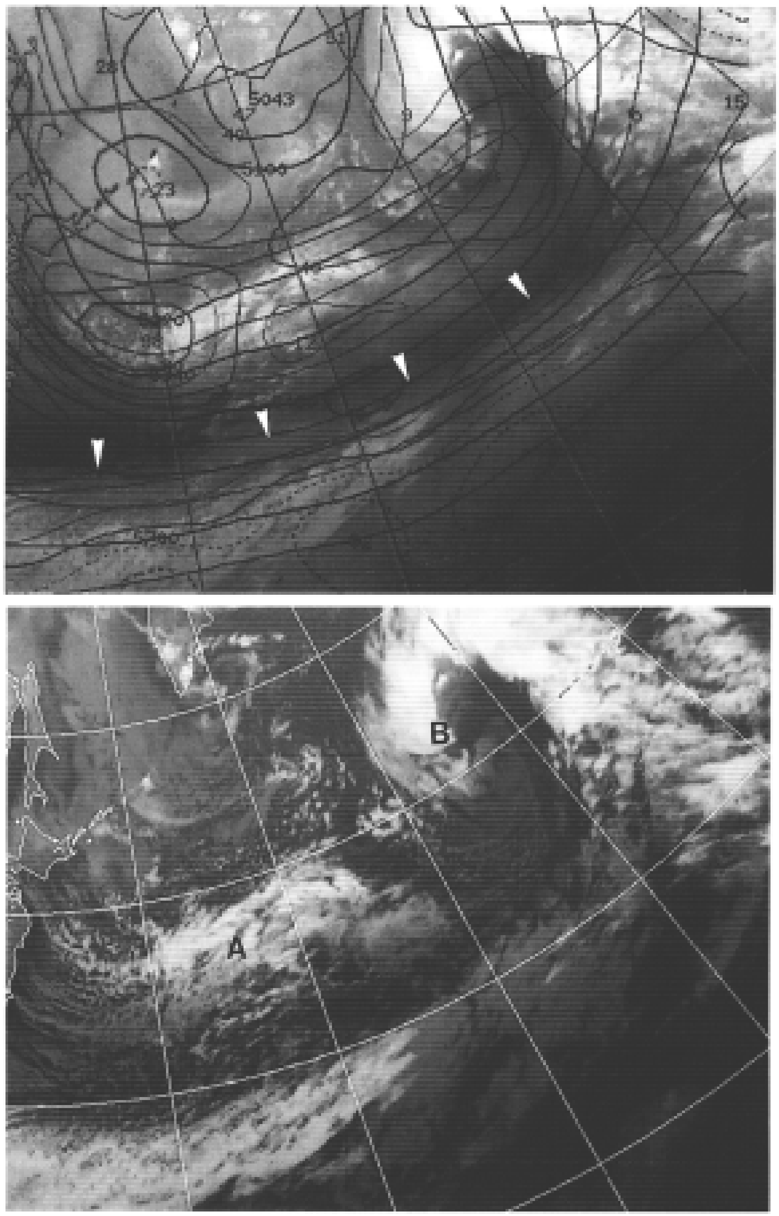


Figure 5-2-10. Comma cloud developing over ocean waters, formative stage (12UTC, January 4, 1999)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Bottom: Infrared image Wedge: Boundary

② Early deepening stage

The cloud area (A) is increasing its cloud density and raising its cloud top height. On the northern edge of the cloud area, the high clouds are having anticyclonic curvatures and forming the comma-type. There are enhanced cumulus (E) and open cells (F) to the east of the cloud area (A), indicating the presence of cold air. The cloud area (A) lies in front of this cold air (i.e. in front of the trough that is accompanied by the cold air). In front (G) of the cloud area, cellular clouds decrease, indicating a weakening of cold air. The cold air weakens in front of the cloud area (or it may possibly turn into warm advection), and there is intense cold air behind. These are consistent with the Reed and Bliar model and this cloud area is thought to enter the stage of baroclinic development. At this stage until which a cloud area has been organized as the comma-type, a cyclone can be analyzed at the notch (marked by x) of the comma. Because the cloud line corresponding to the tail of the comma has not been formed yet, no cold front can be analyzed. The PVAmax has become more intense than the formative stage.

The comma cloud area (A) is present on the north of the boundary corresponding to a jet stream, indicating that this is a phenomenon appearing on the polar side of a mid-latitude frontal zone.

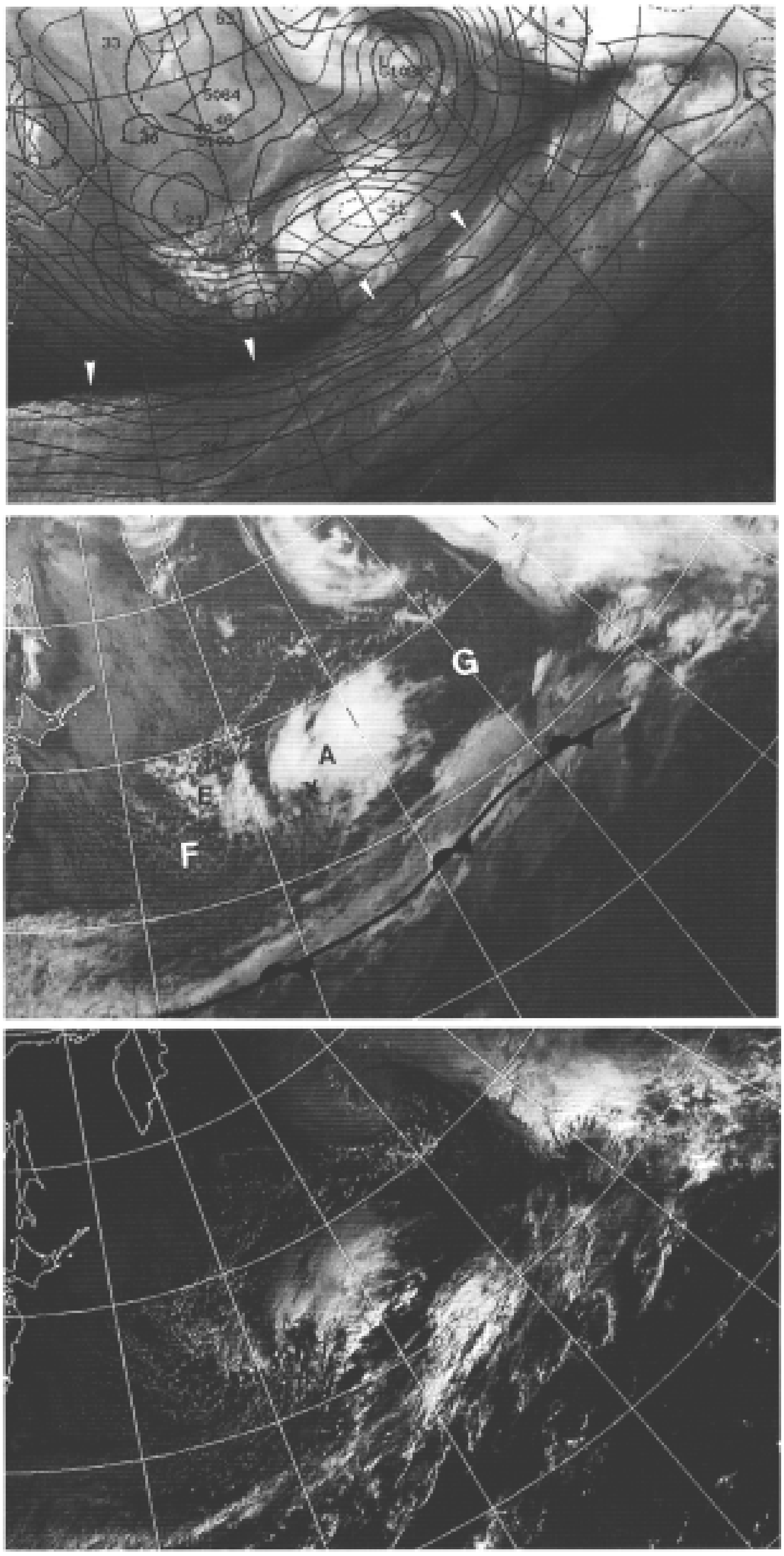
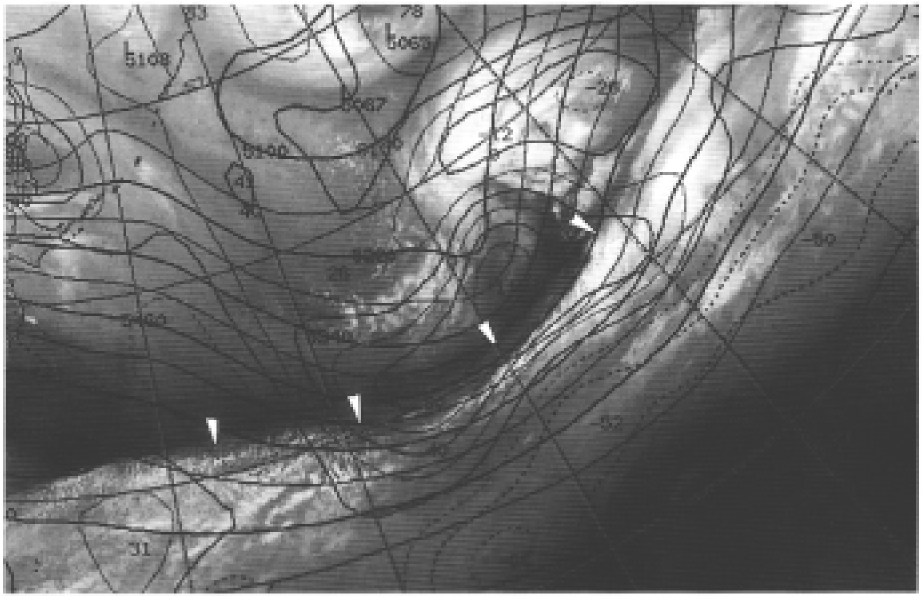


Figure 5-2-11. Comma cloud developing over ocean waters, deepening stage (00UTC, January 5, 1999)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Center: Infrared image and surface front
Bottom: Visible image Wedge: Boundary

③ Late deepening stage

The cloud area increased the anticyclonic curvature on the northern edge (A) and the comma shape became distinct as an entire cloud area. The head of comma is comprised of a deep cloud area of nearly equal top height and the tail is comprised of a cloud area including active convective clouds. The transition to the comma shape indicates that the cloud area has developed into an organized disturbance. The comma cloud remains corresponding to the intense PVAmax. At this stage, the cyclone can be analyzed as a cyclone accompanied by fronts and its central pressure drop is large (on the surface weather chart, a pressure drop of 26 hPa from 24 hours before).



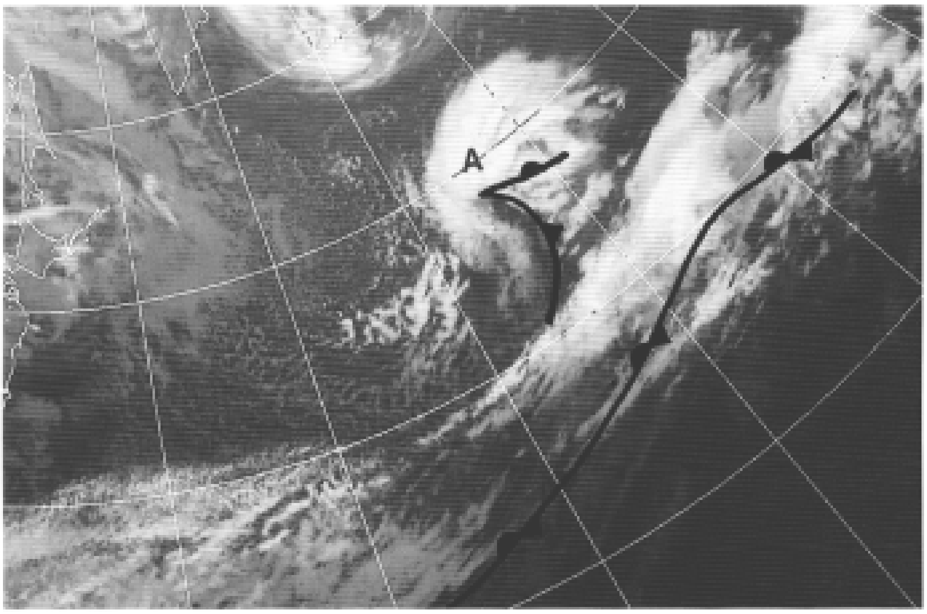


Figure 5-2-12. Comma cloud developing over ocean waters, deepening stage (12UTC, January 5, 1999)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Bottom: Infrared image

④ Mature stage

A dry slot is formed, resulting in the same pattern as the extratropical cyclone at its mature stage. The cloud area is on a scale of 1000 to 1500 km, being small compared to the cloud area of the extratropical cyclone. The development of the comma cloud (A) corresponds to the deepening of the trough extending from the cyclone to the southeast of the Kamchatka Peninsula. The boundary corresponding to a jet stream is situated south of the comma cloud (A) at this time as well, and this is different from the extratropical cyclone at its mature stage.

For the development of the comma-type, the time from when the cyclone is analyzed as a surface low to when it attains maturity is short. On the satellite image, however, it can be recognized as a organized cloud area before it can be analyzed.

In this example, there was a cloud band that corresponded to a front in the 20° N zone. The comma cloud (A) and cloud band were close to each other but they each developed as an independent cloud area. If they influence each other and are organized into one cloud area, they are regarded as development of the instant occlusion type.

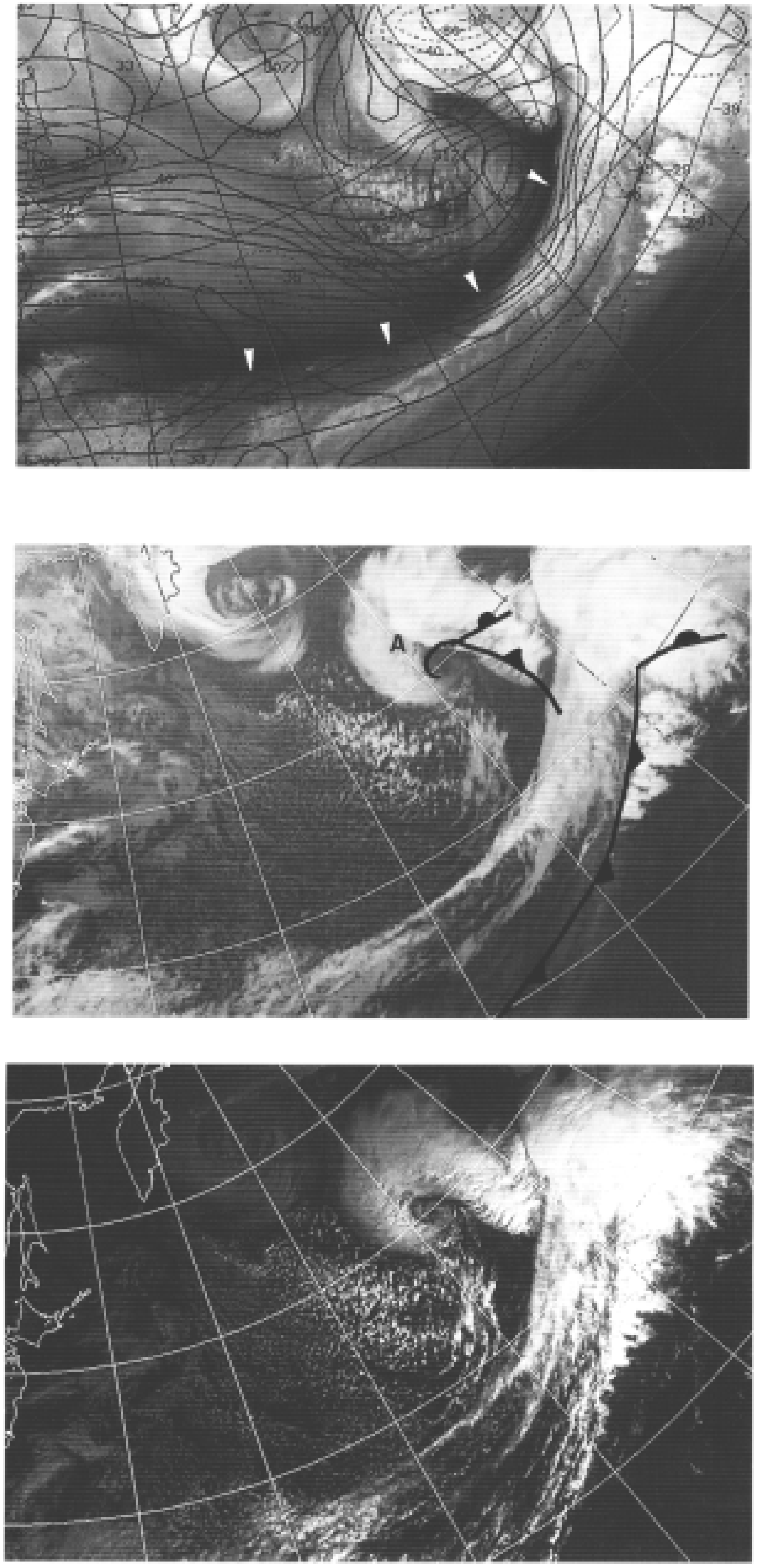
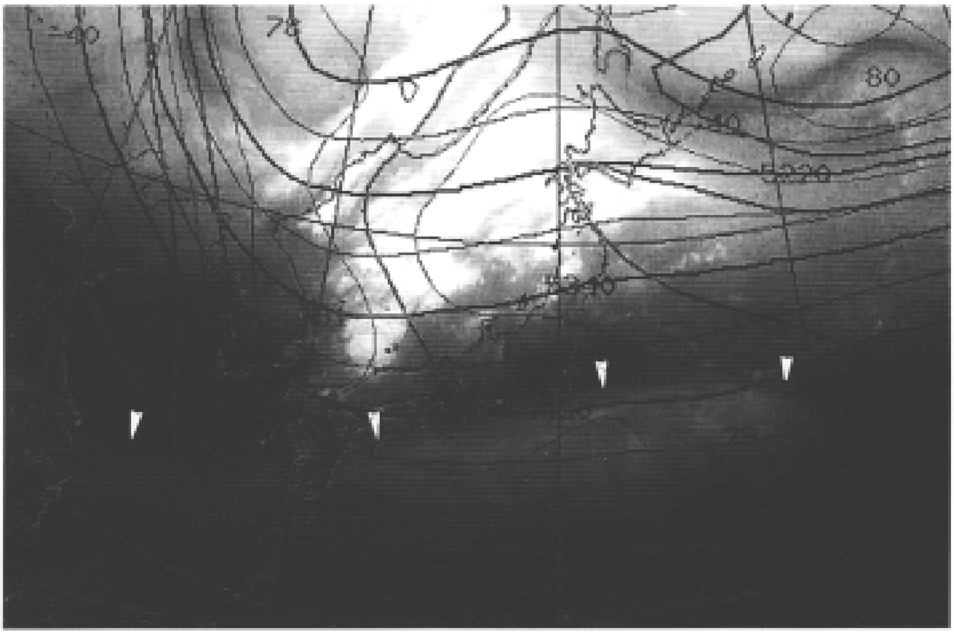


Figure 5-2-13. Comma cloud developing over ocean waters, mature stage (00UTC, January 6, 1999)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Center: Infrared image and surface front
Bottom: Visible image

(2) Comma cloud developing around Japan

① Formative stage

When Ci (A) coming from the continent approaches the Sea of Japan, a cloud area (B) containing convective clouds develops rapidly in the western part of the Sea of Japan. This Ci corresponds to an upper trough and can be kept track of from the continent. The occurrence of convective clouds is rapid, and it frequently happens around Japan that they develop into an organized cloud area in 3 to 6 hours from cloudless state (it was at about 08UTC, or about 3 or 4 hours before this time, that the convective cloud area (B) occurred). At 500 hPa, the cloud area (B) lies in front of a trough, or at the place corresponding to the updraft by the PVAmax. It is thought that a cyclone (x) occurred at this point of time when the convective clouds expanded and began to organize.



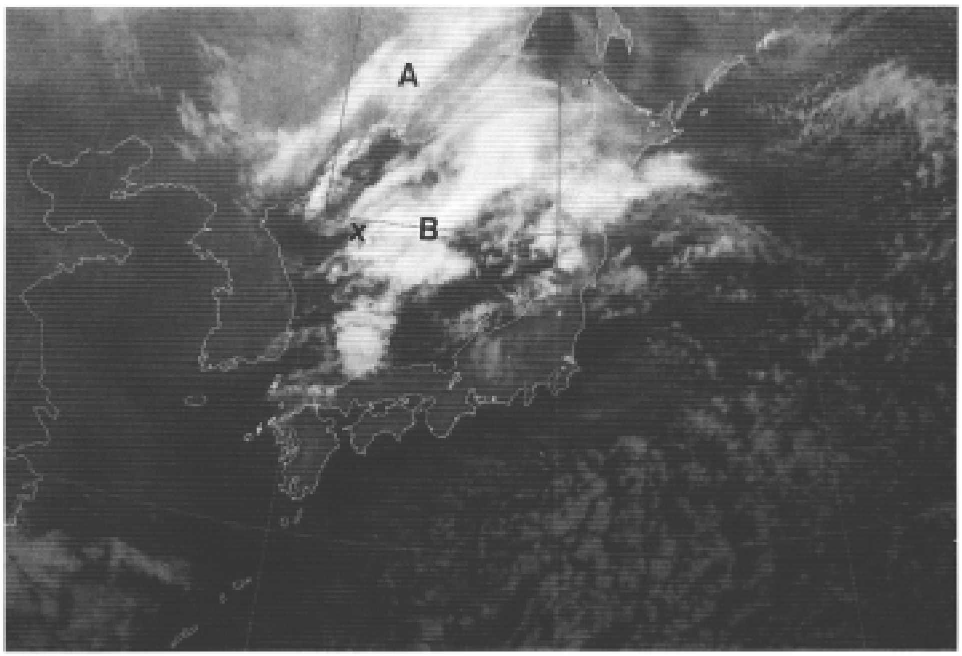


Figure 5-2-14. Comma cloud developing around Japan, formative stage (12UTC, February 20, 1997)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Bottom: Infrared image

② Deepening stage

The cloud area (B) is organized in comma form. The notch in the comma becomes distinct, and the convective activity becomes active and the cloud top height rises in the portion corresponding to the tail of the comma. Behind the comma cloud, cloud streets had appeared accompanying the inflow of cold air. The comma cloud lies in front of a 500-hPa cut-off low and remains corresponding to the PVAmax. The comma cloud can be analyzed as a cyclone accompanied by fronts at this point of time when its shape has become distinct.

The comma clouds around Japan have the feature of a short time required from occurrence to development of the cloud area compared with the comma clouds occurring and developing over the ocean waters east of Japan. It is thought that this is because cold air coming from the continent rapidly brings about instability when it flows in the warm Sea of Japan. In the portion corresponding to the tail of the comma, convective clouds develop rapidly and the cold frontal structure becomes distinct. And rapid shift in wind direction, gale, intense rain and similar phenomena are apt to occur, so this is the most important period for monitoring by the satellite.

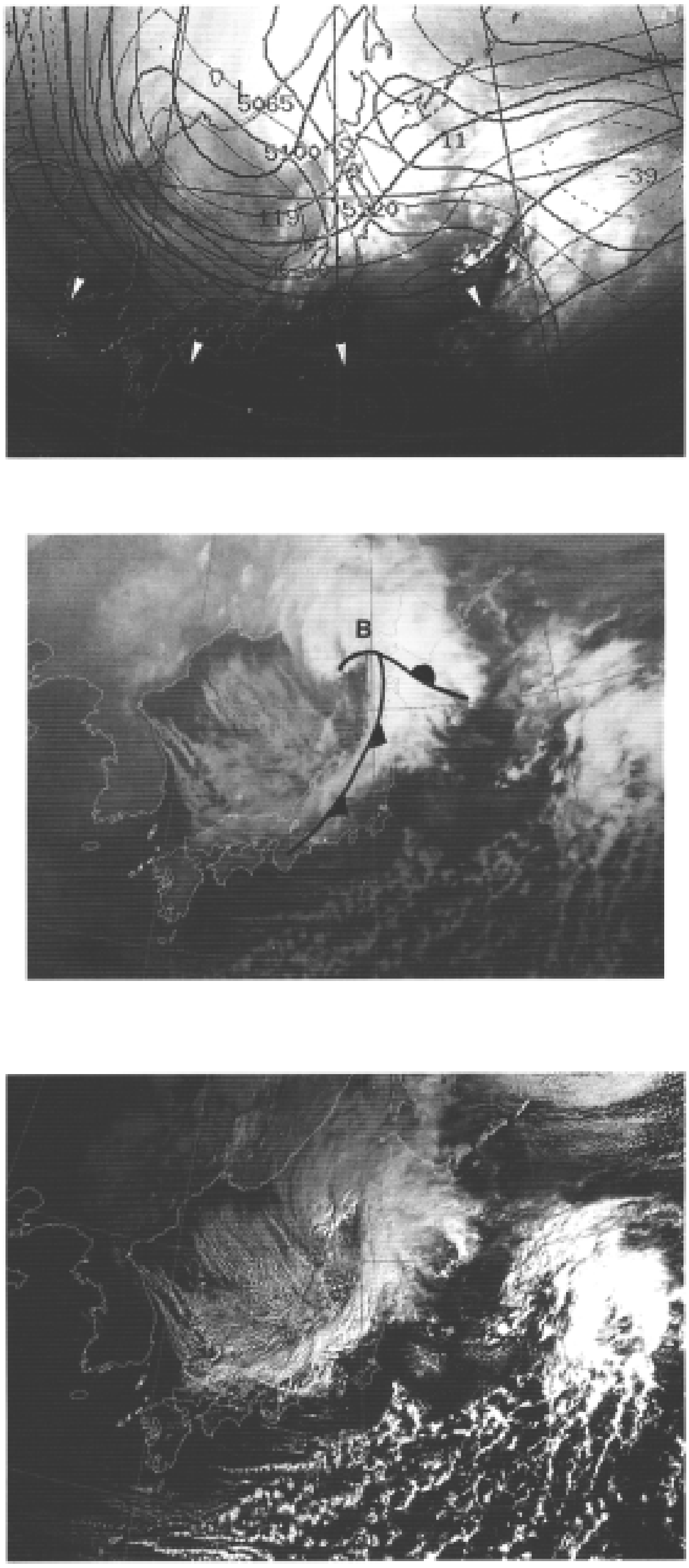
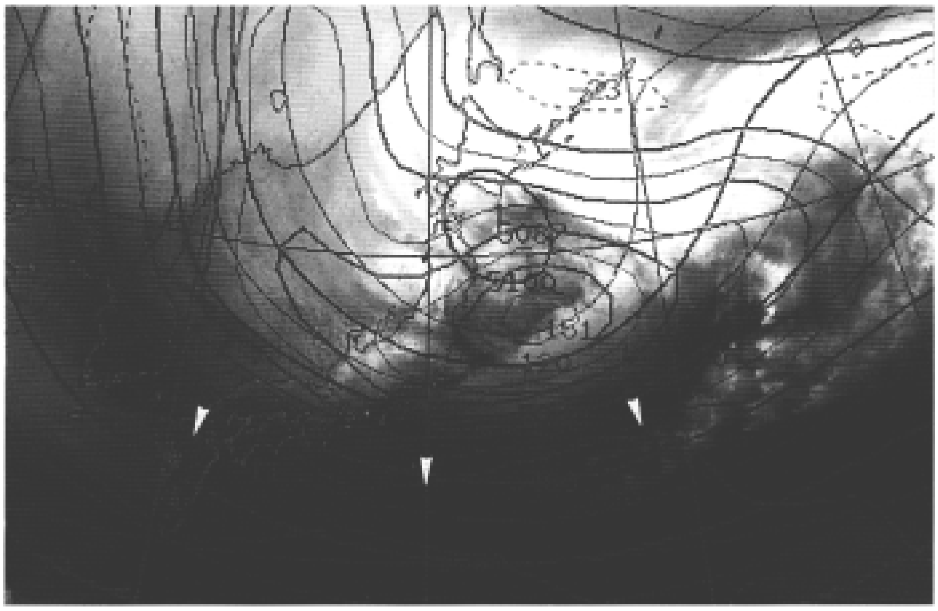


Figure 5-2-15. Comma cloud developing around Japan, deepening stage (00UTC, February 21, 1997)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line)
Center: Infrared image with surface front superposed
Bottom: Visible image

③ Mature stage

A dry slot is seen off Sanriku. In the cloud area (B), the cloud top height rises in the portion corresponding to the head of the comma, indicating that maturity is attained. The comma cloud rapidly developing around Japan is accompanied by intense cold air, and cloud streets are seen behind the comma cloud after it has passed the Japanese Islands. Its development after this is the same as a comma cloud over ocean waters east of Japan. The PVAmax has become less intense than at the deepening stage.



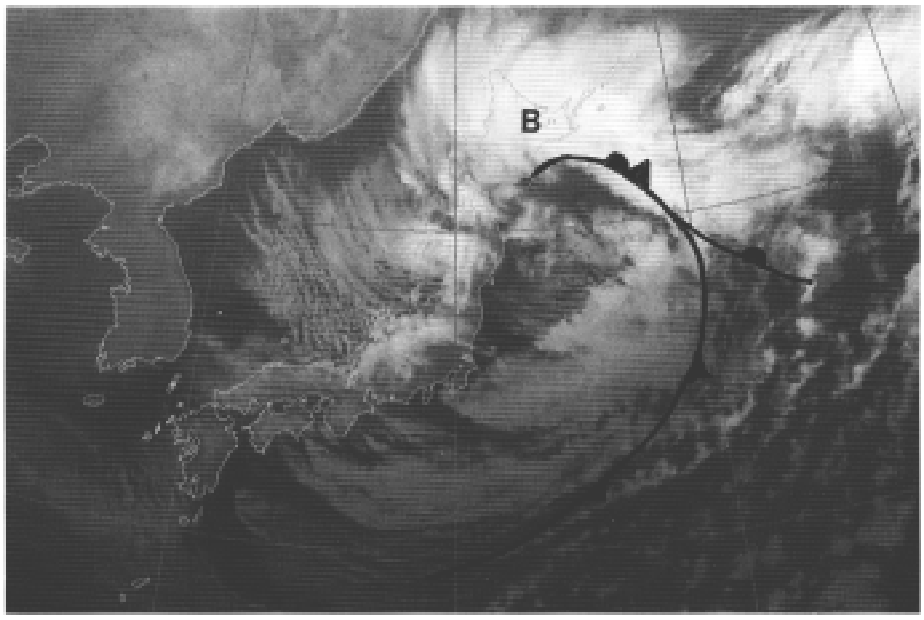


Figure 5-2-16. Comma cloud developing around Japan, mature stage (12UTC, February 21, 1997)
Top: Water vapor image with 500-hPa heights and vorticities (positive indicated by continuous line and negative by broken line) Bottom: Infrared image

5.2.3 Development of instant occlusion type

Instant occlusion is one of the cyclogenetic processes discovered by satellite imagery and is referred to as merging of a comma cloud and frontal cloud band to form the cloud pattern of the occlusion stage. Unlike the typical type, it makes a sudden transition to the occluded cloud pattern without going through the pattern of the deepening stage. Hence the name. In the meantime, it was shown that there are two types of this pattern; one is represented by the model (called the BH model) proposed by Browning and Hill (1985) and the other by the model (called the MYB model) proposed by McGinnigle, Young and Bader (1988). In the BH model, a principal role is assigned to the PTCB (polar-trough conveyor belt), which is a low-level flow from a frontal cloud band toward the pole, and no importance is attached to the baroclinity accompanying the comma cloud. In the MYB model, warm advection accompanying the comma cloud and updraft due to the positive-vorticity advection play an important role, and a new cloud occurs between the comma cloud and frontal cloud band and follows the process of joining the two clouds to shift to an occluded pattern.

The BH model applies to cyclones that do not develop and the MYB model to cyclones that develop.

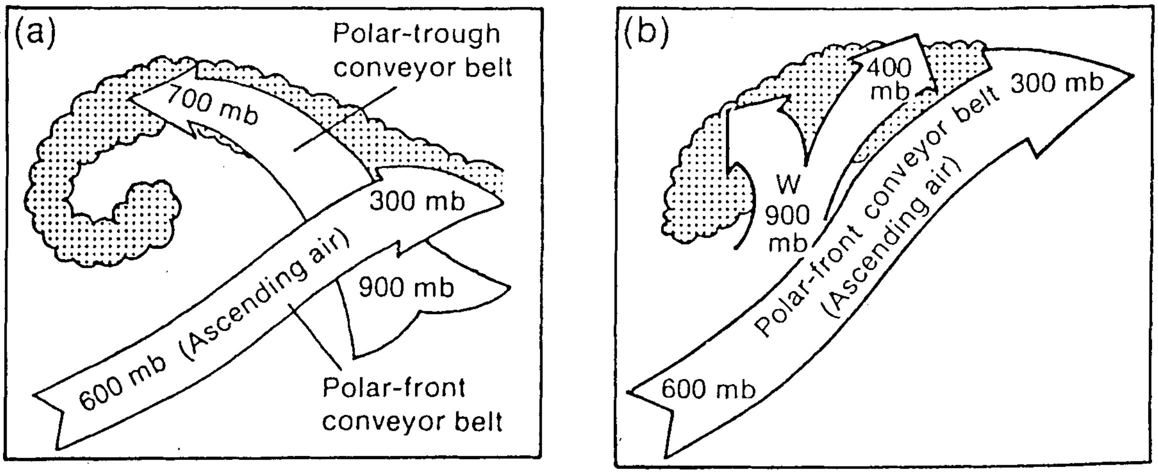
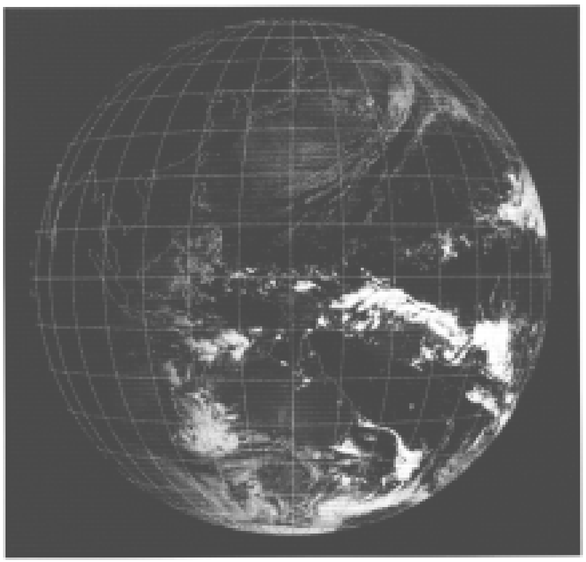


Figure 5-2-17. Models of instant occlusion (cited from Kitabatake, 1997)
(a) is BH (Browning and Hill) model, and (b) is MYB (McGinnigle, Young and Badar) model.

SPCZ (Southern Pacific Convergence Zone)

The SPCZ is a low-level convergence area ranging in the tropics of the southern hemisphere and is abundant in clouds and rain. Its seasonal variations are large compared with the ITCZ. In Attached Figure 1, an active cloud cluster ranges from the sea east of New Guinea toward the southeast. (Kazufumi Suzuki)

Reference: Ryoji Kumabe (1998): Tropical cyclones in the southern hemisphere and El Niño, Kisho, March issue, 20-21



Attached Figure 1. SPCZ (visual image at 00UTC, January 22, 2000).

(1) In case that cyclones do not develop (BH model)

① Incipient stage

A cyclone corresponding to a comma-shaped cloud area (A) lies around Sakhalin and is moving east-northeast. On the other hand, a cloud band (D-D) composed mainly of high and middle clouds and corresponding to a front extends over the Japanese Islands in the direction from southwest to northeast. At this point of time, no one can foresee the interaction between the comma cloud and cloud band.

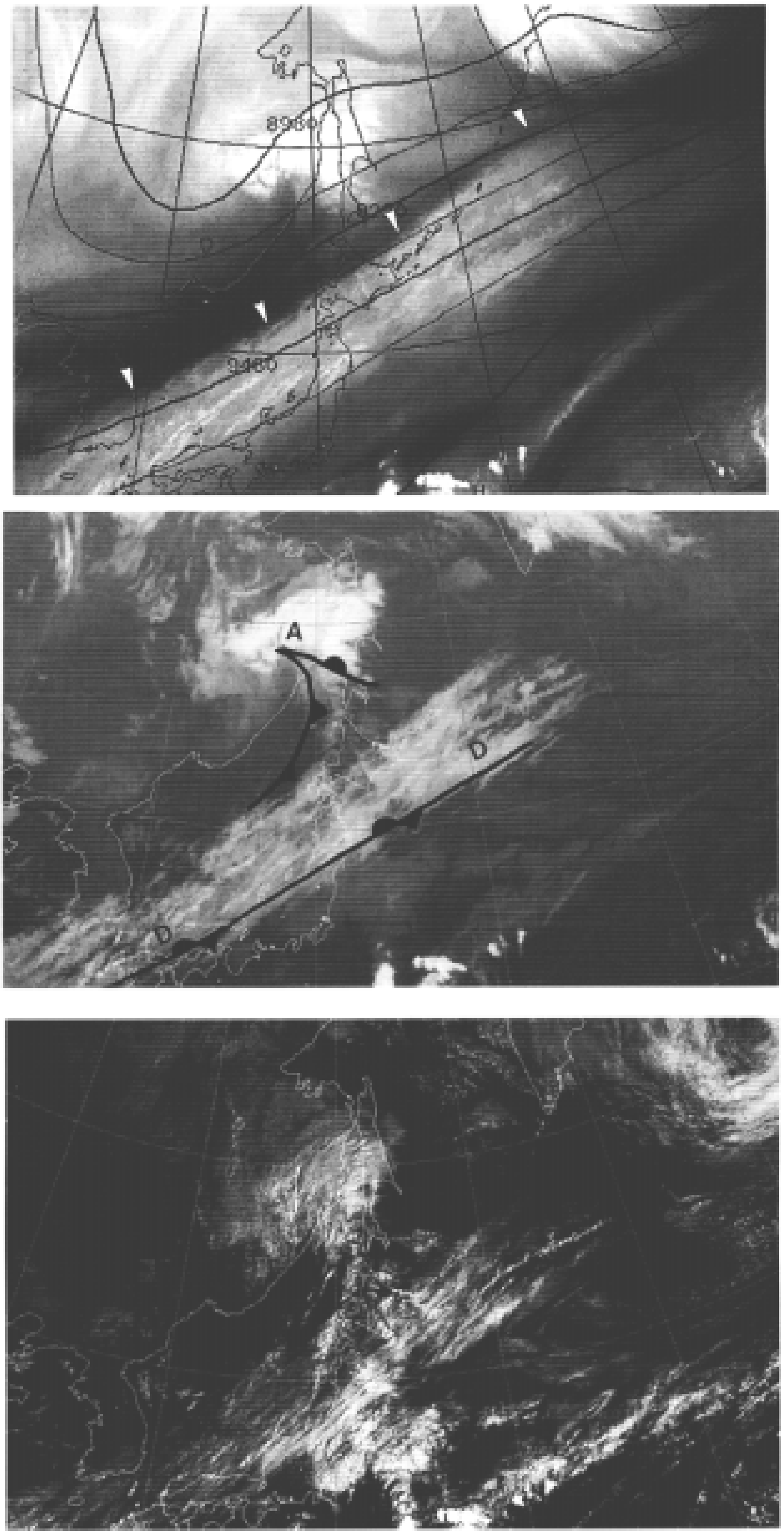
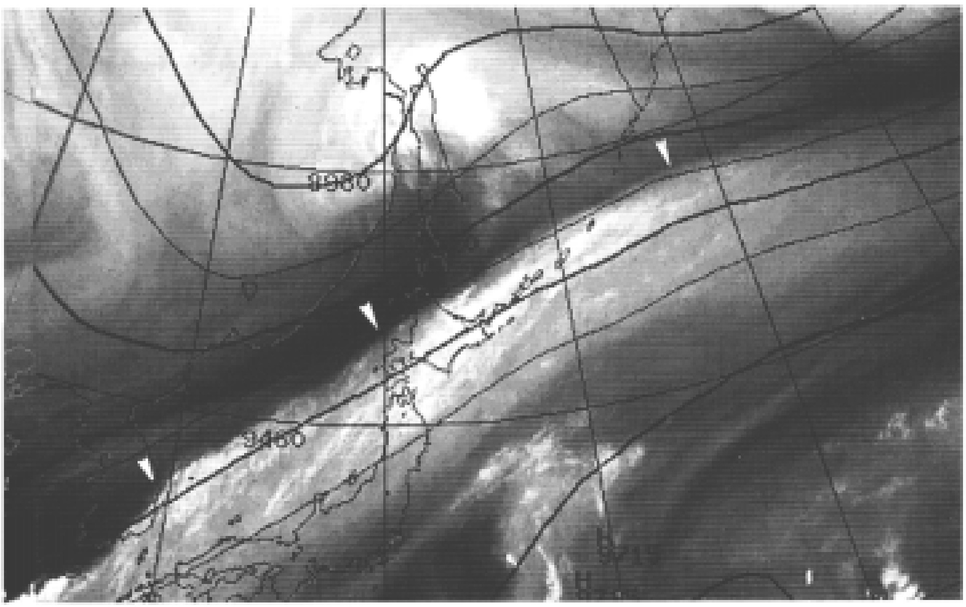


Figure 5-2-18. Instant occlusion that does not develop (BH), incipient stage (00UTC, September 21, 1997)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Center: Infrared image   Bottom: Visible image

② Occlusion start stage

The distance from the comma cloud (A) and cloud band (B) remains unchanged. The comma cloud raises the top height at the head and elongates and becomes distinct at the tail, and the cloud band increases the cloud density and raises the top height at the portion of contact with the comma cloud. These features are regarded as an indication of interactions that will take place between the comma cloud and cloud band. However, since there is a space between the cloud band and the tail of the comma, it seems that PTCB has not been formed adequately and this cannot be called an occluded pattern.



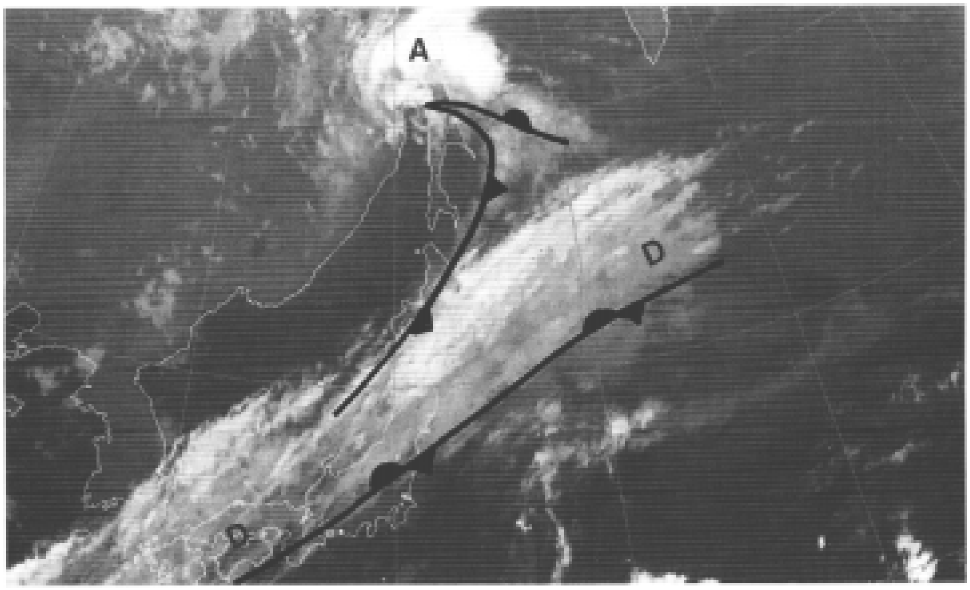


Figure 5-2-19. Instant occlusion that does not develop (BH model), occlusion start stage (12UTC, September 21, 1997)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Bottom: Infrared image

③ Occlusion complete stage

The comma cloud (A) raises its top height and becomes an organized cloud band at that portion of its tail which connects to the cloud band (D-D). It seems that a PTCB is formed. In the visible image as well, a PTCB can be identified as a thick cloud band of high cloud density. The cloud band corresponding to the frontal zone rapidly raises the top height at the portion of contact with the comma's tail and becomes distinct on the northern edge of the cloud area, and the anticyclonic curvature has increased. From satellite imagery, it can be said that the instant occlusion is complete at this point of time.

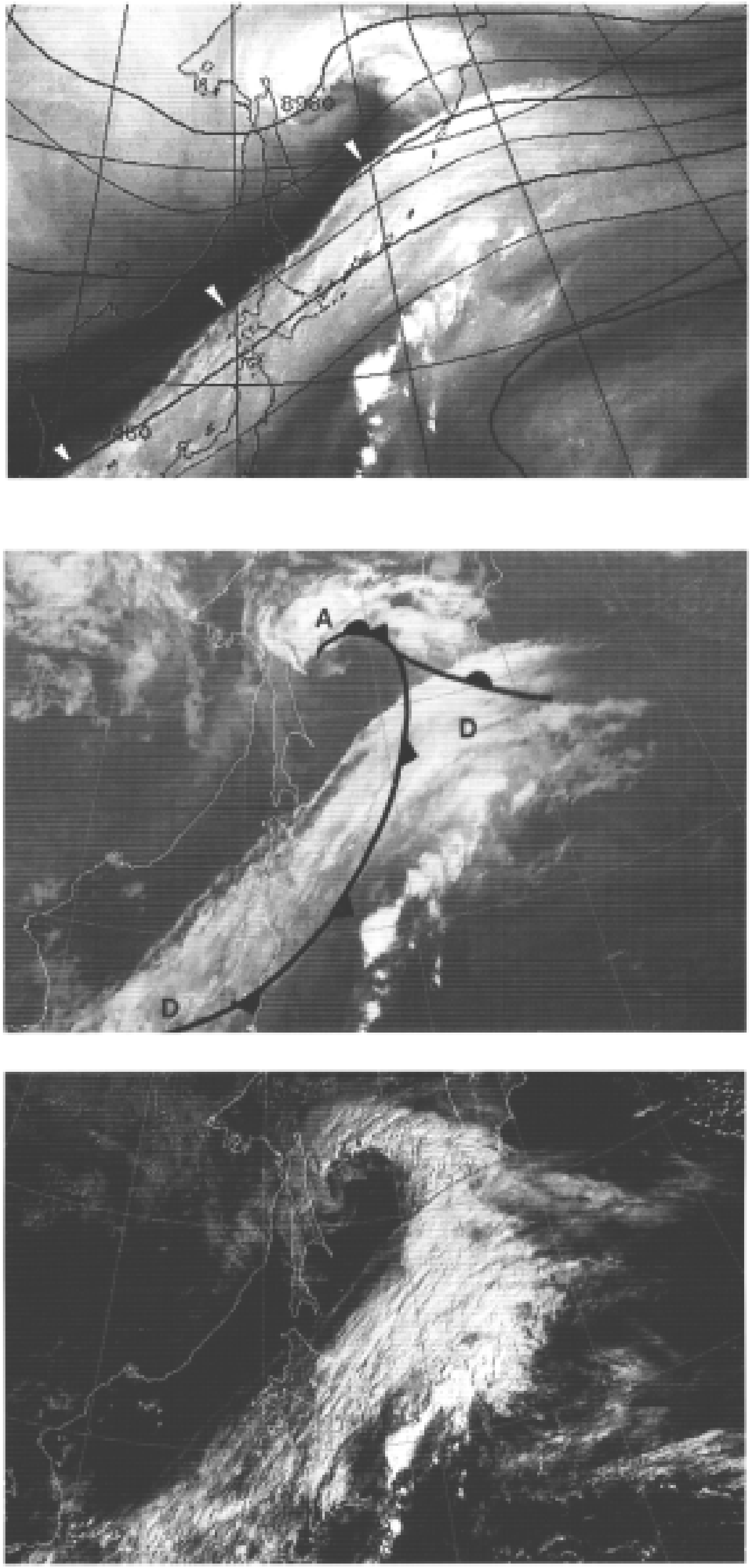
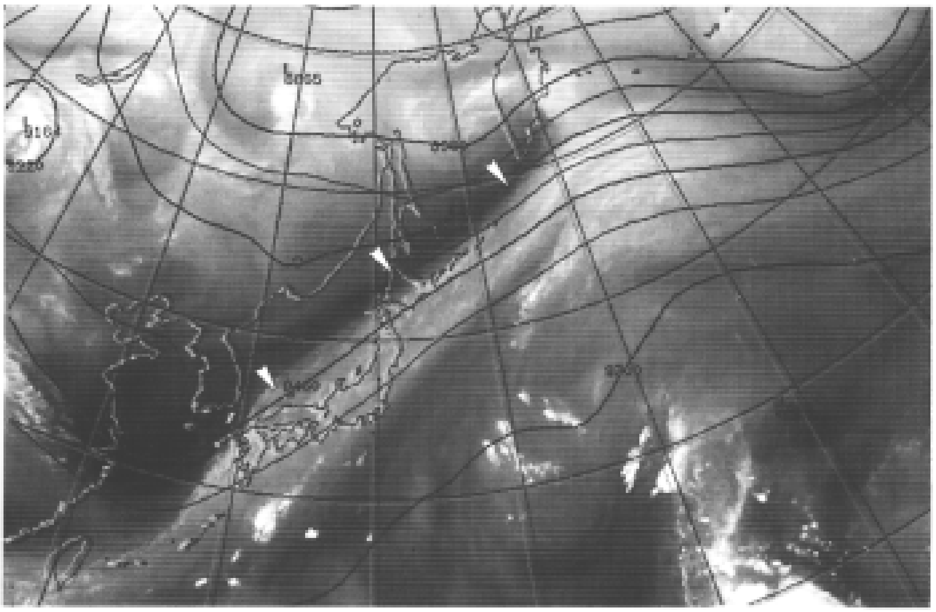


Figure 5-2-20. Instant occlusion that does not develop (BH model), occlusion complete stage (00UTC, September 22, 1997)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Center: Infrared image Bottom: Visible image

④ Decaying stage

The cloud area (A) in an occluded pattern lowers the top height and the cloud band (D-D) corresponding to an occluded front becomes indistinct. Thus, the tendency to decay manifests itself. The central pressure of the cyclone remains about the same after occlusion and the cyclone shows no indication of development. In the BH model, unlike the MYB model described later, development after occlusion is seldom seen and the decaying stage starts earlier.



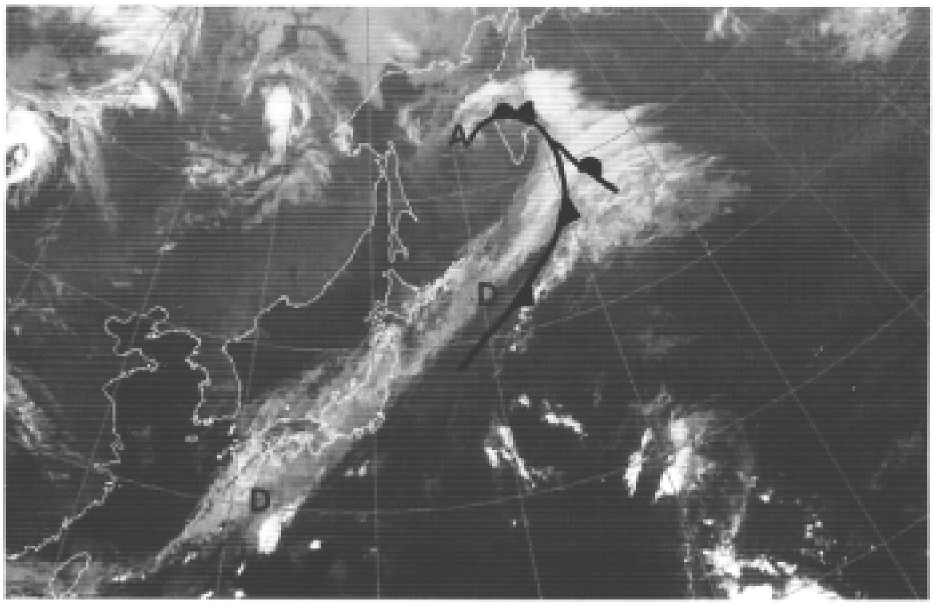


Figure 5-2-21. Instant occlusion that do not develop (BH model), decaying stage (12UTC, September 22, 1997)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Bottom: Infrared image

(2) In case that cyclones develop (MYB model)

① Incipient stage

The frontal cloud band (B-B) lies over the ocean waters south of Japan and extends east-northeast. The comma cloud (C) (with a no distinct tail) lies around Hokkaido and is moving east-northeast while increasing the top height. Off Sanriku, or at the middle between the frontal cloud band and comma cloud, a cloud area with high top height (M) has occurred and is developing as if it joins the comma cloud on the north and the frontal cloud band on the south. A cyclone (marked by x) can be analyzed corresponding to the comma cloud, and a front corresponding to the cloud band respectively. The cyclone (marked by x) is analyzed corresponding to the cloud area (M) off Sanriku (the occurrence of this cyclone is not explained in the MYB model). At 850 and 700 hPa, southwest winds prevail and the warm advection is intense off Sanriku (not shown). This corresponds to the development of the cloud (M) on the warm sector side looking from the comma cloud, which is a feature of the MYB model.

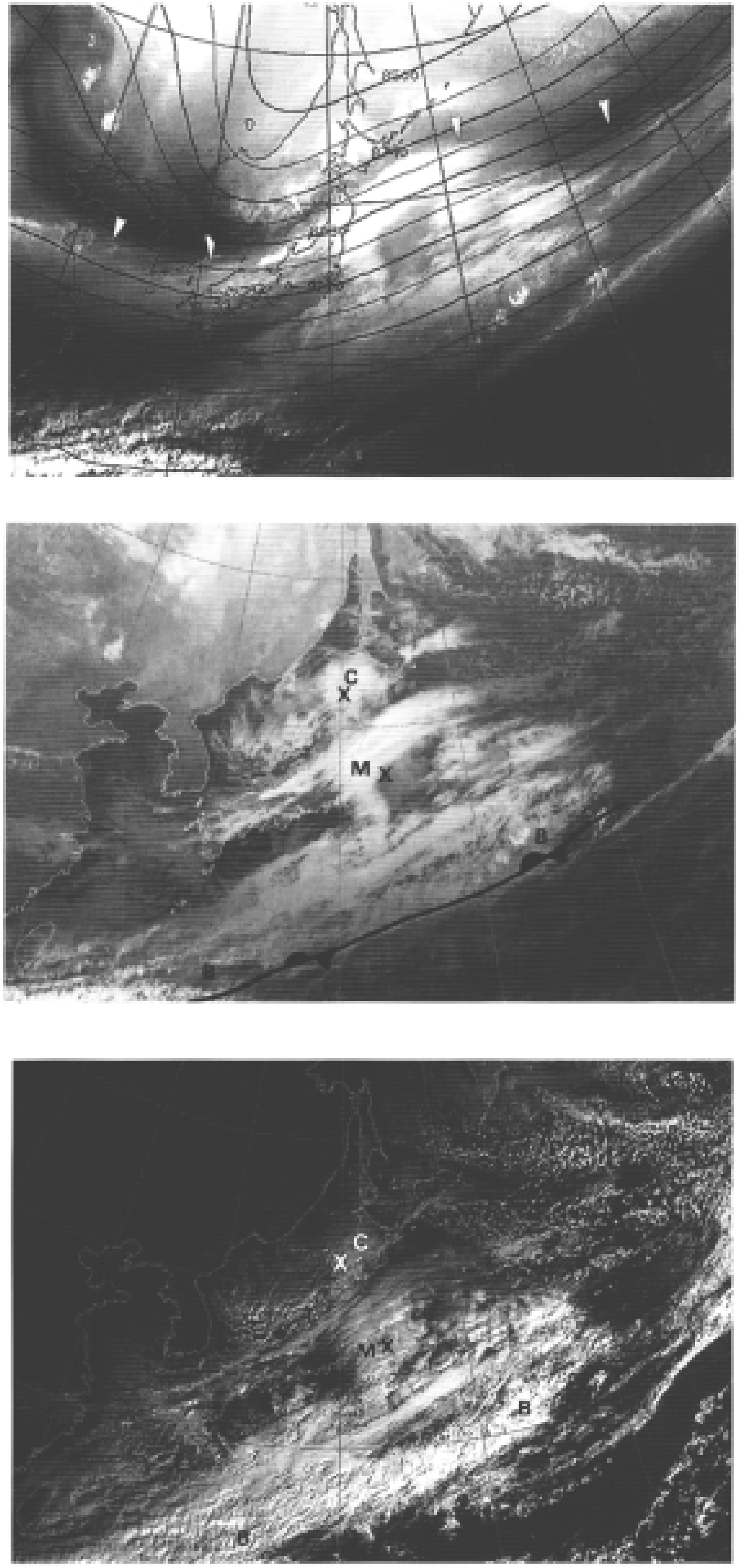


Figure 5-2-22. Instant occlusion that develops (MYB model), incipient stage (00UTC, December 11, 1998)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Center: Infrared image Bottom: Visible image

② Occlusion start stage

The comma cloud (C) and the cloud area (M) off Sanriku merged to form a comma cloud (N). The comma cloud (N) has an anticyclonic curvature and increases the top height on the northern edge, indicating its development. The frontal cloud band (B-B) on the south has raised its top height, and the two cloud areas come close, indicating that a shift to an occluded pattern has begun. The comma cloud and cloud band can be analyzed as a cyclone accompanied by a front and a stationary front, respectively. On the satellite image, the comma cloud and cloud band are not joined completely, and the cloud band has a small anticyclonic curvature. From these, it seems that an occlusion has not be attained.

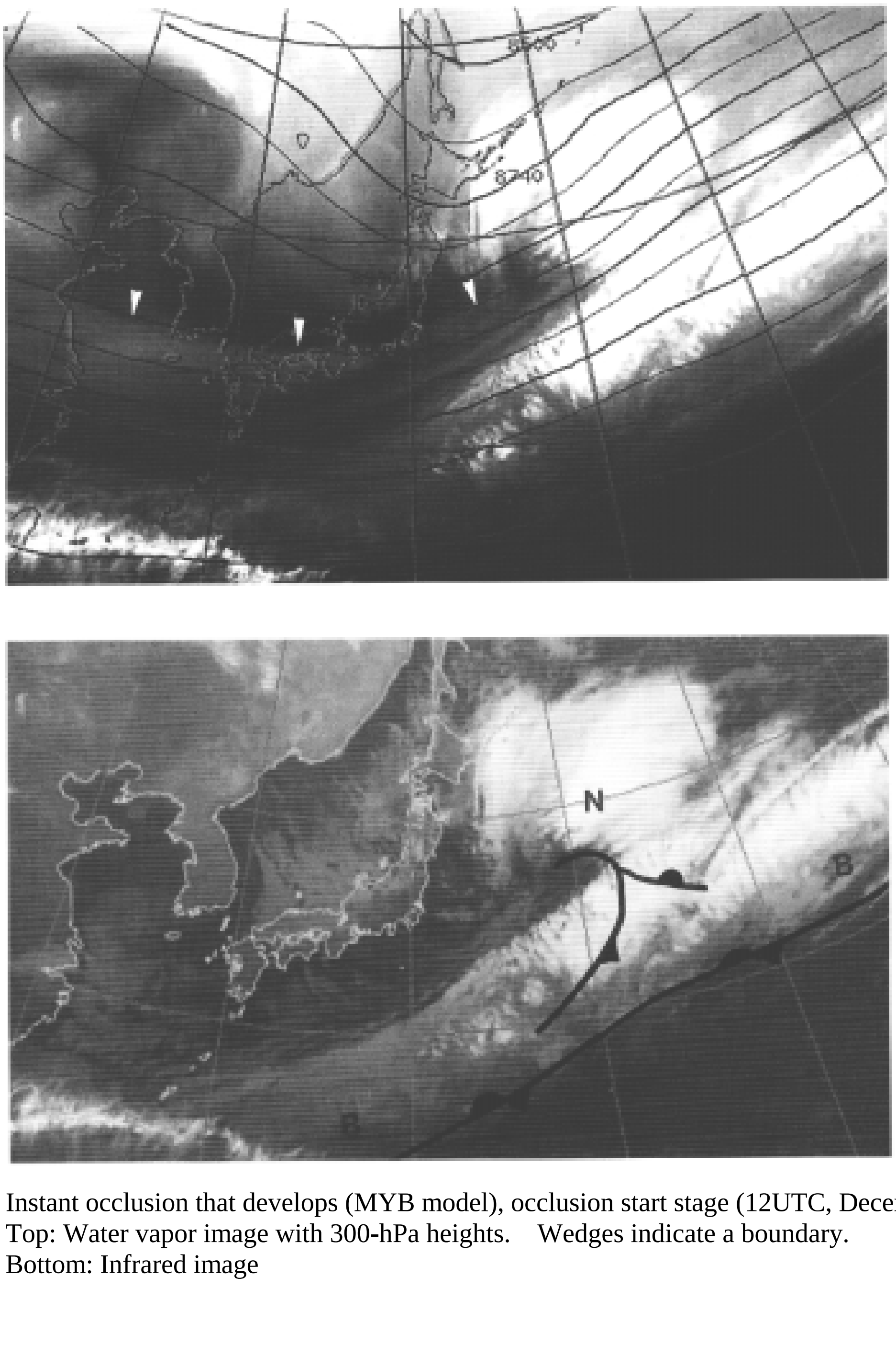


Figure 5-2-23. Instant occlusion that develops (MYB model), occlusion start stage (12UTC, December 11, 1998)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Bottom: Infrared image

③ Occlusion complete stage

The cloud band of the frontal zone raises its top height in the portion of contact with the comma cloud, and the two are recognized as one cloud area (N). On the northern cloud edge of the cloud band, the anticyclonic curvature (F-F) becomes distinct, and a dry slot (D) becomes visible. Therefore, it can be said that an occlusion is complete in this cloud area. After this, the cyclone shows the same pattern as the typical type at its mature stage. A cellular cloud pattern (E) corresponding to intense cold inflow was seen behind the cyclone, and this cyclone continued to develop.

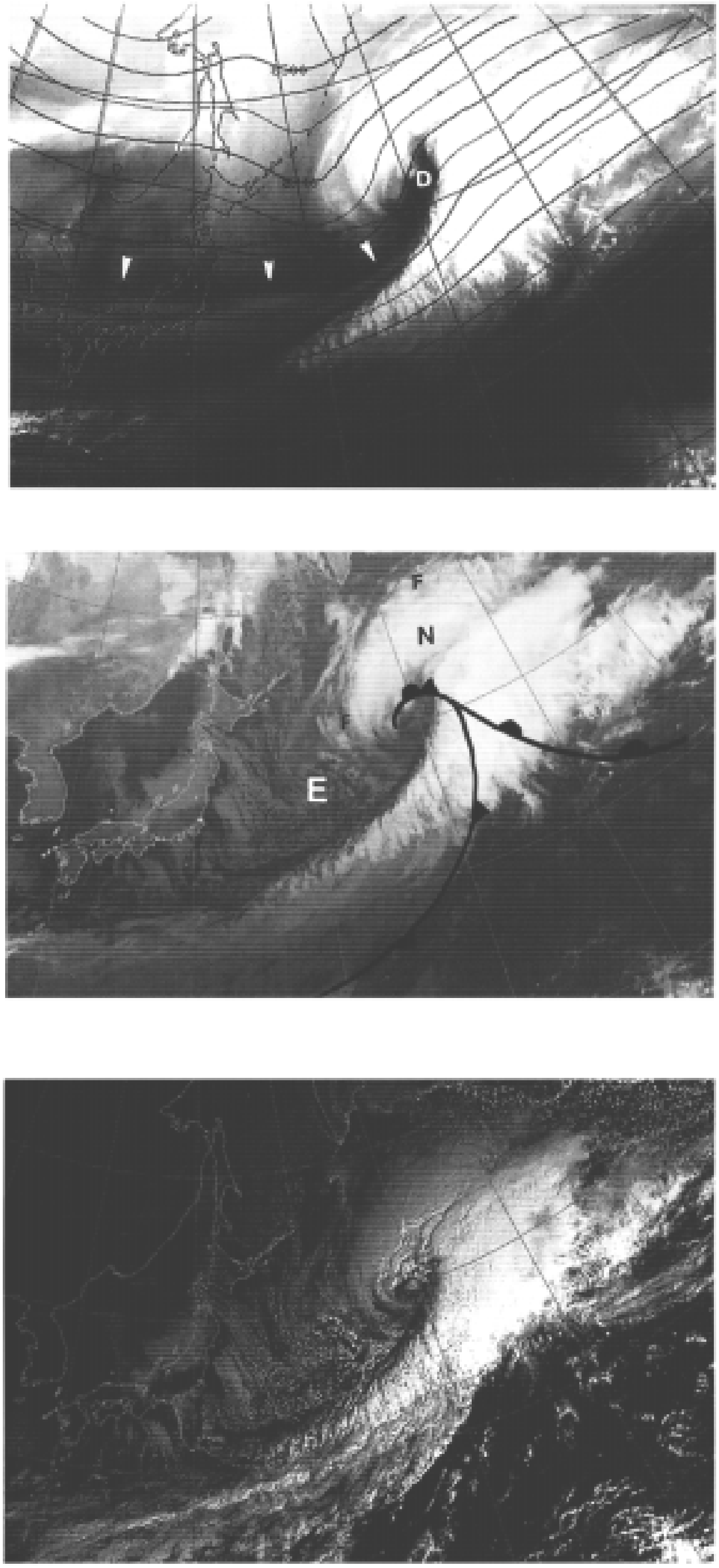


Figure 5-2-24. Instant occlusion that develops (MYB model), occlusion complete stage (00UTC, December 12, 1998)
Top: Water vapor image with 300-hPa heights. Wedges indicate a boundary.
Center: Infrared image Bottom: Visible image

5.2.4 Development of T-bone type

Shapiro and Keyser (1990) gave a cyclogenesis model (called the SK model hereafter), which differed from the Bjerknes model (Figure 5-2-25). Features include:

- Frontal fracture: The cold front does not join with the warm front.
- Warm core seclusion: At the cyclone center, it is not that the rear cold air takes over and covers the ground with cold air (occlusion) but that a warm core falls behind.
- Bent-back warm front: It is the warm front and not the occluded front that extends backward (to the west) from the cyclone.

A characteristic cloud pattern called the T-bone (the form of the letter T) is frequently seen on the satellite image. It seems that the SK model applies to this pattern (which resembles the cloud pattern of warm occlusion). Here, an attempt is made to analyze a cyclone, which showed the form of a T-bone, following the SK model. Note that the SK model cannot explain the development and structure of cyclones completely. For example, the structure of a bent-back warm front, extending behind of a cyclone center, is disputable. At the warm core seclusion stage, fronts wrap around the cyclone center in multiple turns, and such fronts can hardly been analyzed. On the other hand, frontal fracture and warm core seclusion seem to have a structure that is easy to understand by reference to objective analysis.

The SK model requires insight into the mesoscale structure, and details cannot always be recognized from a weather chart or satellite image alone. For the SK model, it will be necessary in the future to ascertain the limit of its applicability as well as investigate on how it can be used for weather chart analysis.

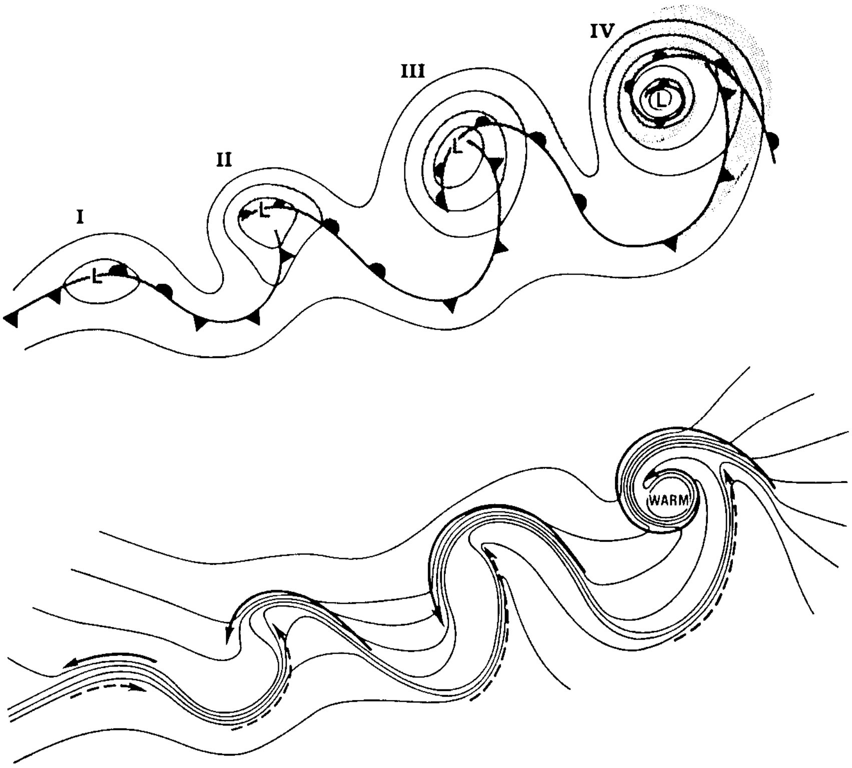


Figure 5-2-25. Schematic model of T-bone (Shapiro and Keyser, 1990)
I: Incipient frontal cyclone
II: Frontal fracture
III: Bent-back warm front and frontal T-bone
IV: Warm-core frontal seclusion
Top illustration: Isobar (continuous line), cloud area (hatched region)
Bottom illustration: Temperature (continuous line), cold flow (arrow with continuous-line shaft), warm flow (arrow with broken-line shaft)

① Incipient stage

A cloud area accompanied by bulge is moving east over the East China Sea. This cloud area shows the same pattern and features as the typical type at its early deepening stage.

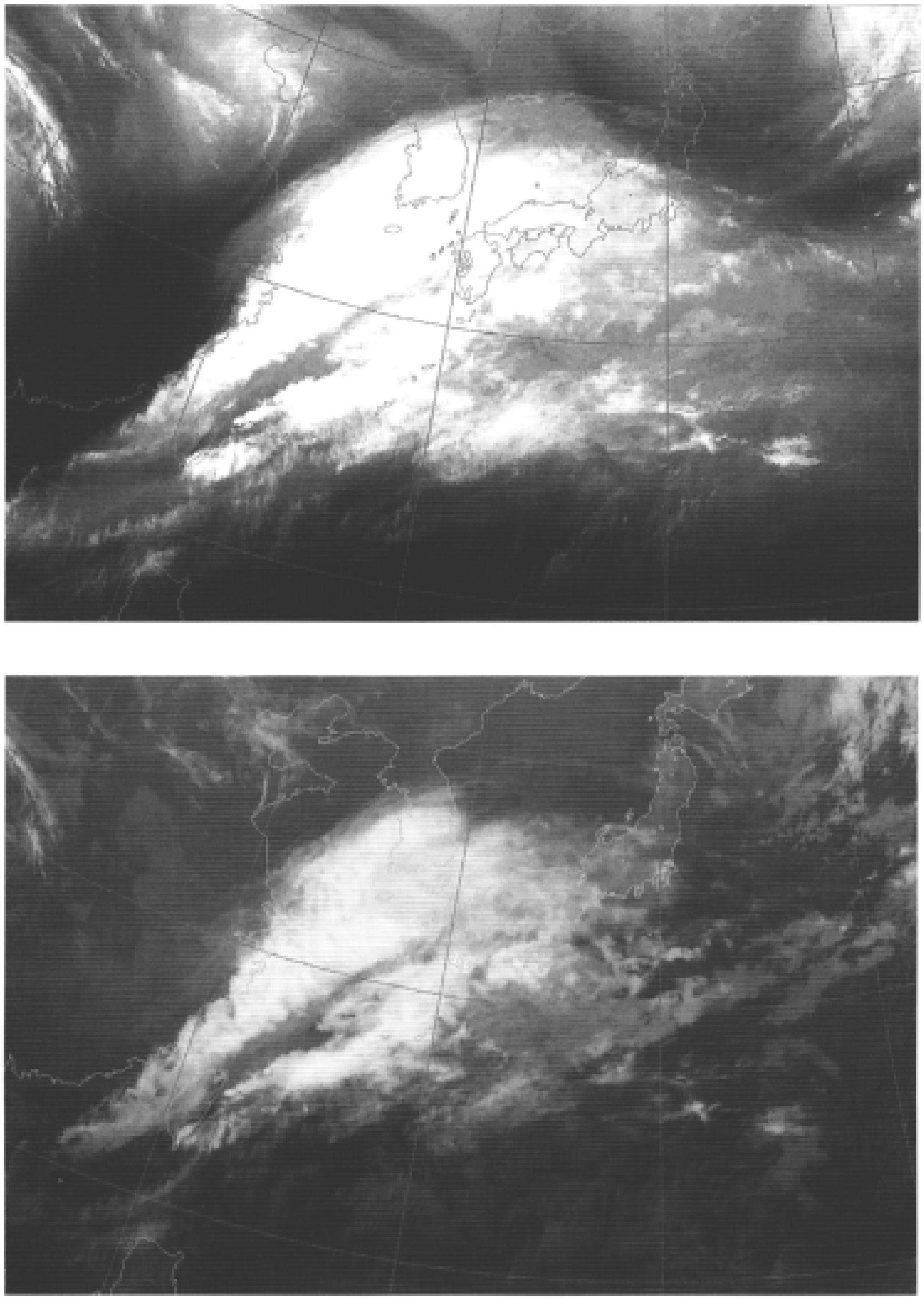


Figure 5-2-26. Development of T-bone type, at incipient stage (12UTC, March 4, 1998)
Top: Water vapor image Bottom: Infrared image

② Frontal fracture

The cloud area has moved to the ocean waters south of Japan and taken a form elongated east and west compared with the typical type. The northern edge has increased the anticyclonic curvature. A cloud-free area has intruded from the west and a notch (marked by an arrow) begins to form into the cloud area. The cyclone center can be determined here. A warm occlusion pattern is also seen on the image. However, cold air has not moved south in objective analysis at 850 hPa and the occlusion process has not been entered.

The warm front can be determined on the southern edge of the low cloud area. The cloud band including convective clouds associated with the cold front intersects at about right angles with the cloud area corresponding to the warm front extending from east to west and extends to the southwest.

In objective analysis at 850 hPa, it is the C-C portion where cold advection is intense and the cold front structure is distinct, and the cold front structure is indistinct in the northern portion. That is, the cold front has decreased in temperature gradient near the place of contact with the warm front, and this falls under the structure of frontal fracture of the SK model. On the satellite image, however, the distinction between fractured and not-fractured portions is difficult.

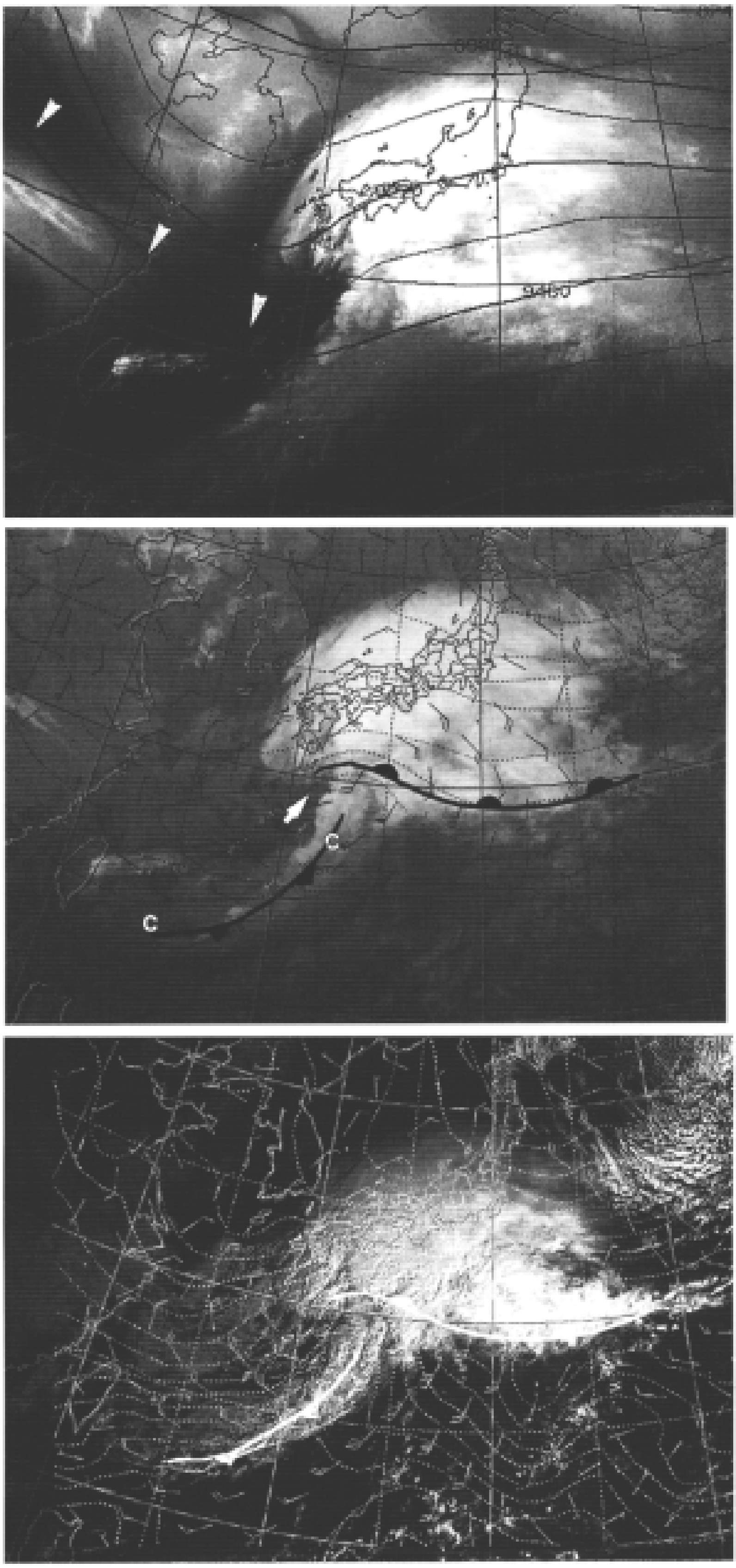


Figure 5-2-27. Development of T-bone type, frontal fracture (00UTC, March 5, 1998)
Top: Water vapor image with 300-hPa heights
Center: Infrared image with 850-hPa winds and air temperatures
Bottom: Visible image with 850-hPa winds and equivalent potential temperatures

③ Bent-back warm front

In the cloud area that has moved to the ocean waters south of Kanto, a deep cloud area (L-M-N) is situated in front of the cyclone and extends from east to west, and a cloud band, corresponding to the cold front, intersects at about right angles with this cloud area and extends nearly to the south. Thus, the pattern of the letter T has become distinct.

In objective analysis at 850 hPa, the L-M-N portion has a distinct warm front structure. A low-cloud vortex is seen directly south of (N) on the satellite image. From this and the time of occurrence of minimum pressure at Hachijo Island (about 14UTC), the cyclone center can be analyzed near (N). According to the SK model the bent-back warm front will lie on the southern edge of the cloud area from (M) to (N) or on the eastern edge (N-P) of the low-cloud area extending south further from (N). However, these cloud areas extend counterclockwise as if they wrap around the cyclone center with cold air. Considering this and the temperature field at 850 hPa, this front would have the structure of a so-called bent-back cold front rather than a bent-back warm front. In the SK model, the cyclone center seems to lie near (M) at which an extension of the fractured cold front intersects with the warm front. However, the cyclone center is seldom seen near here. In many cases, a low-cloud vortex is seen near (N) to the west of the intersection (M), and the cyclone center is analyzed there.

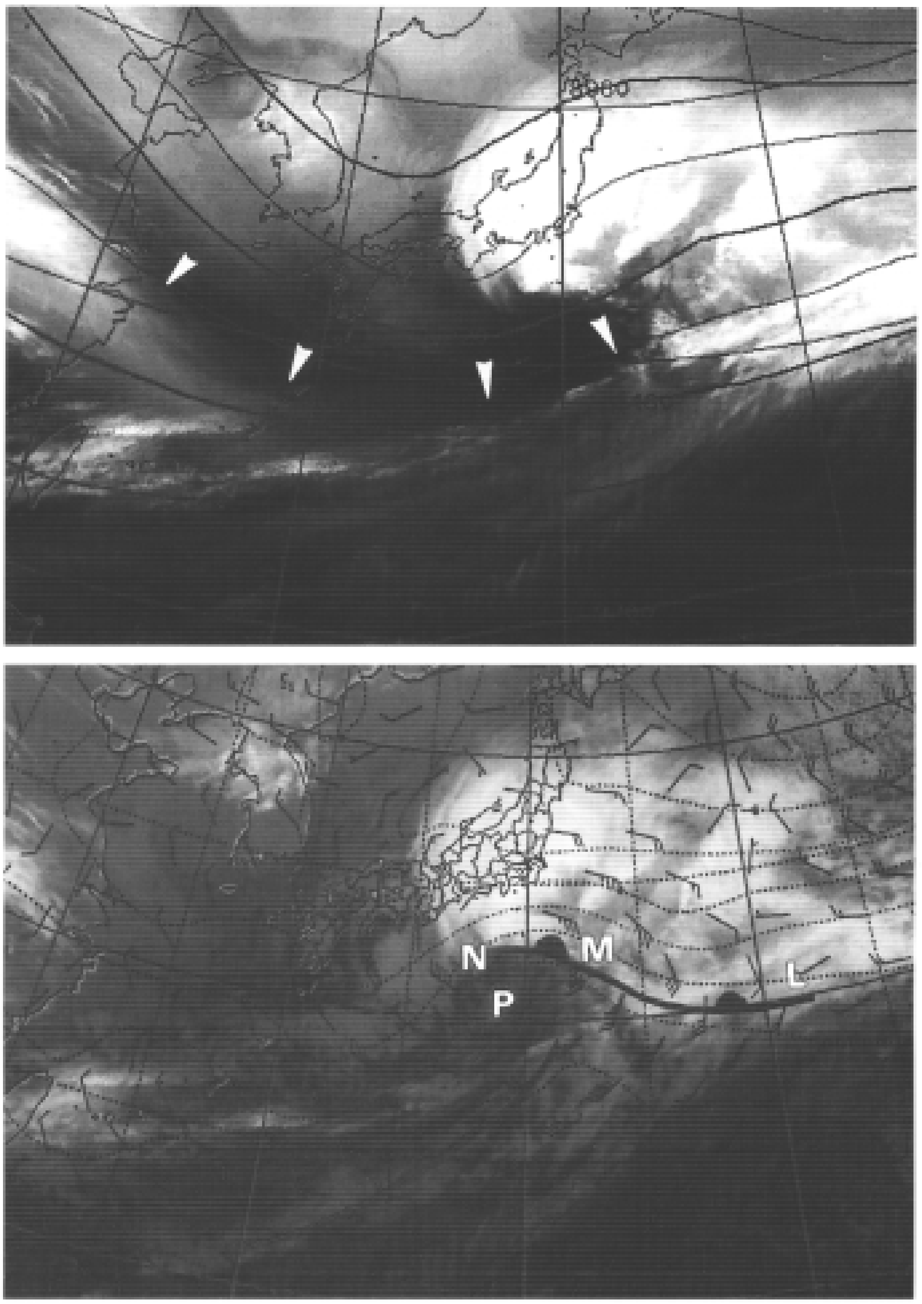


Figure 5-2-28. Development of T-bone type, bent-back warm front (12UTC, March 5, 1998)
Top: Water vapor image with 300-hPa heights
Bottom: Infrared image with 850-hPa winds and air temperatures

④ Warm core seclusion

On the satellite image, anticyclonic curvature has become distinct on the northern and western edge of the cloud area. The low-cloud vortex has also become distinct and a dry slot is circling around this cloud vortex as if wrapped, exhibiting an occlusion-like cloud pattern. Unlike up to now, the cloud area begins to expand north and south. The cloud band of high top height on the north of the warm front intersects with the cloud band corresponding to the cold front extending south, continuing to form a T-shaped pattern. The low-cloud vortex corresponds to the cyclone center (L).

At this stage, the warm core seclusion pattern of the SK model seems to advance. According to the SK model, the warm front will be analyzed on the edge of the cloud encircling the center as shown in the figure. Actually, however, a front encircling the center in such a manner is not analyzed. According to the isotherms in objective analysis at 850 hPa, a distinct warm core is not formed near the cyclone center. However, the frontal fracture structure forms a wind field that tends to seclude a warm core at the center. That is, cold advection is intense in the area (C) away from the center, so it tends to leave a warm core near the center. A low-cloud vortex composed of Cu and Sc is present on the satellite image and it corresponds to the warm core. These cloud areas are feeble in convective activity and differ from cellular convective clouds formed by an intrusion of cold air. From this fact, it is estimated that the cloud areas are made up of air masses that are relatively warmer than the surroundings.

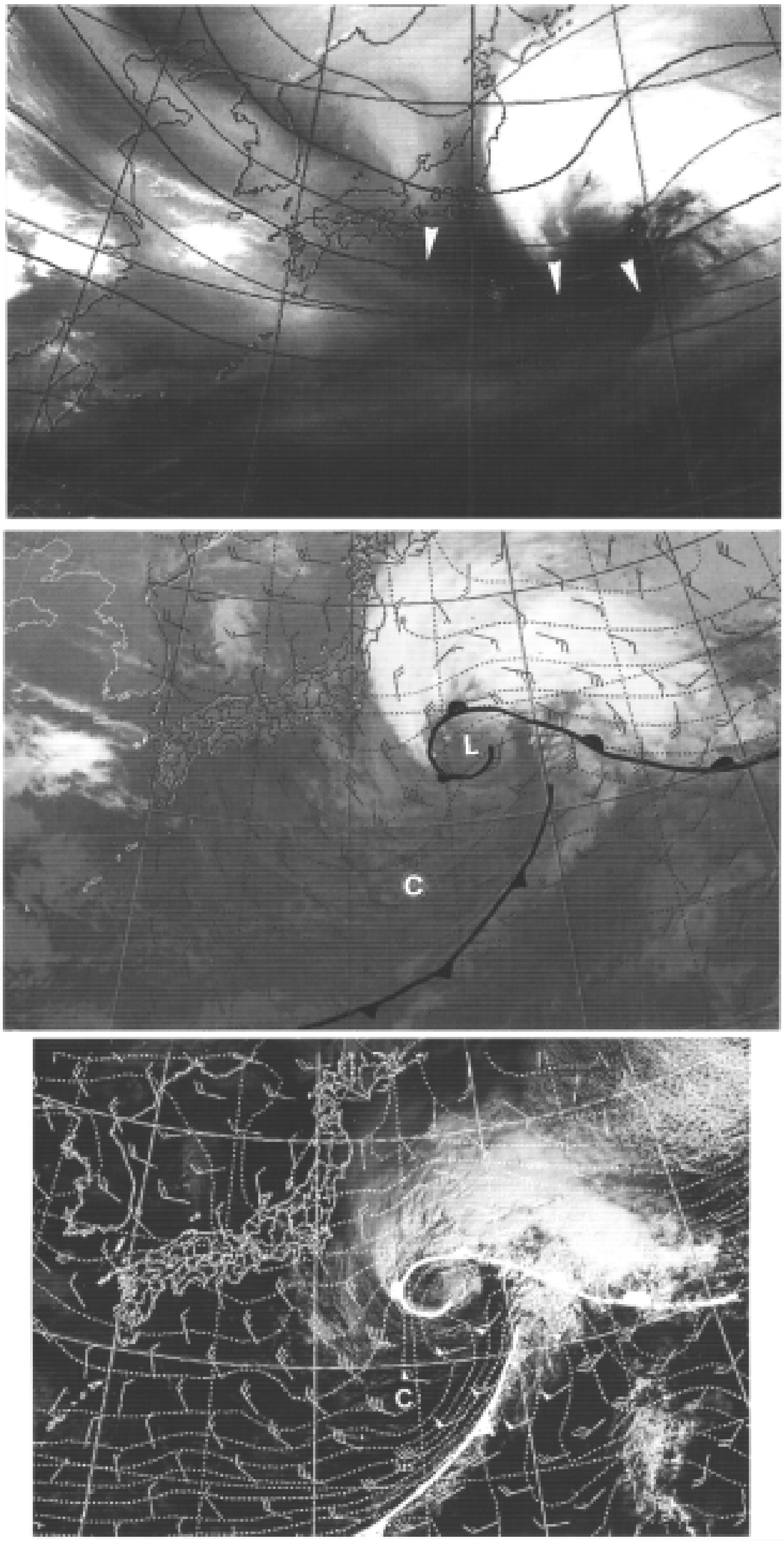


Figure 5-2-29. Development of T-bone type, at warm core seclusion (00UTC, March 6, 1998)
Top: Water vapor image with 300hPa heights. Center: Infrared image with 850hPa winds and air temperature.
Bottom: Visible image with 850hPa winds and equivalent potential temperatures

5.3 Estimation of central pressure of extratropical cyclones

5.3.1 SMB method

For tropical cyclones, a method to estimate typhoon intensity from pattern recognition of satellite imagery (Dvorak method) is used by weather practitioners. For the extratropical cyclones developing in middle latitude, there is also a certain correspondence between their developmental stages and cloud pattern changes seen from the meteorological satellite. A central pressure estimation method using cloud pattern recognition of satellite imagery is given here for extratropical cyclones. This method is called the SMB method (Smigielski and Mogil, 1992) after the initials of its developers and is referred to by the NESDIS (National Environment Satellite Data and Information Service) of the US when estimating the central pressure of a cyclone that develops over ocean waters where little data is available.

The SMB method was developed based on 50 typically developed cyclones in the northwest Atlantic in the period from December to March in order to find a correspondence relation between cloud patterns and barometric pressures. The SMB method can be applied to cyclones that occur in a baroclinic zone in the cold season and develop while moving toward high latitudes. This method is comprised of a procedure using pattern recognition of cloud areas and a procedure using a standard pressure variation model.

The procedure using pattern recognition uses a flow chart (Figure 5-3-1). First, decide whether the cloud system originate in a baroclinic zone. Next, decide whether the cloud system develops slowly or not judging from the changes of the cloud pattern within the past 12 hours. If the changes of the cloud area are distinct, decide whether the cyclone is deepening or has entered a decay stage. If you decided that it was deepening, find an appropriate cloud pattern in the flow chart and estimate the central pressure. If the cloud pattern assumes a comma shape, measure the degree of the high and middle cloud bands encircling the head of the comma using a 10-degree logarithmic spiral and determine the pressure.

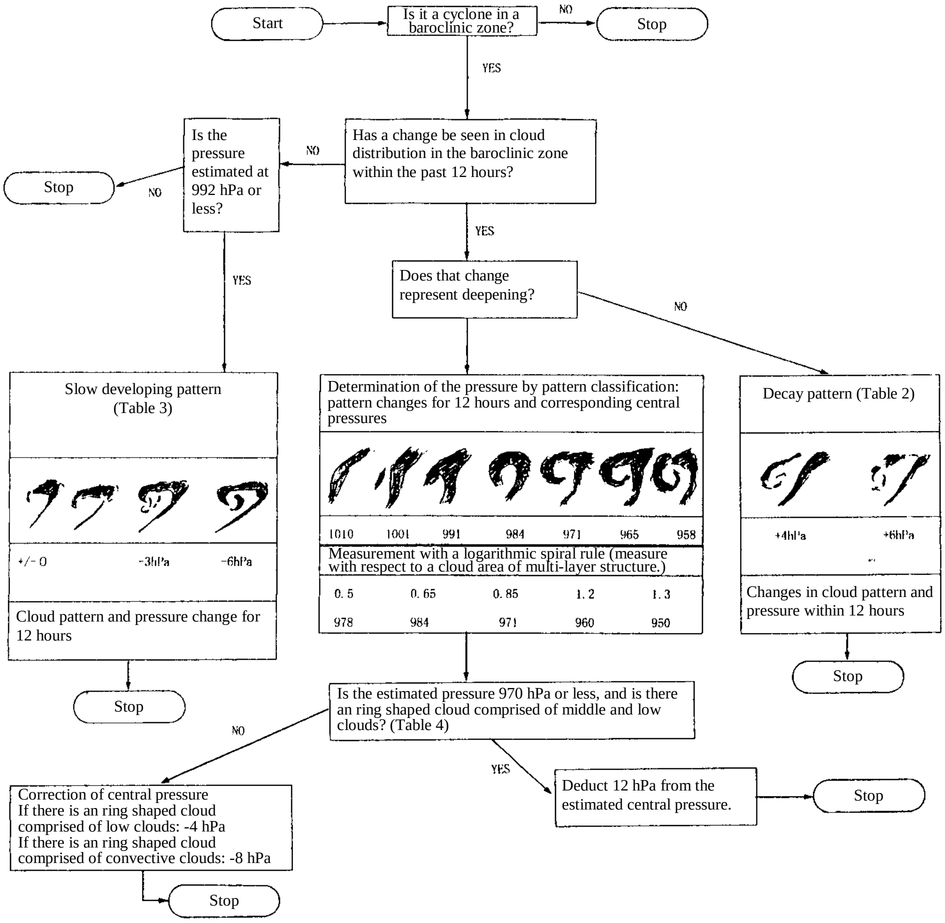


Figure 5-3-1. SMB method flow chart

The procedure using the standard pressure change model uses Figure 5-3-2. This pressure change model is a statistically derived standard deepening pattern of typical type cyclones in the northwestern Atlantic Ocean. According to this pattern, cyclones attain a minimum pressure in 3 days from the occurrence and the pressure drop rate is 20 to 30 hPa per day.

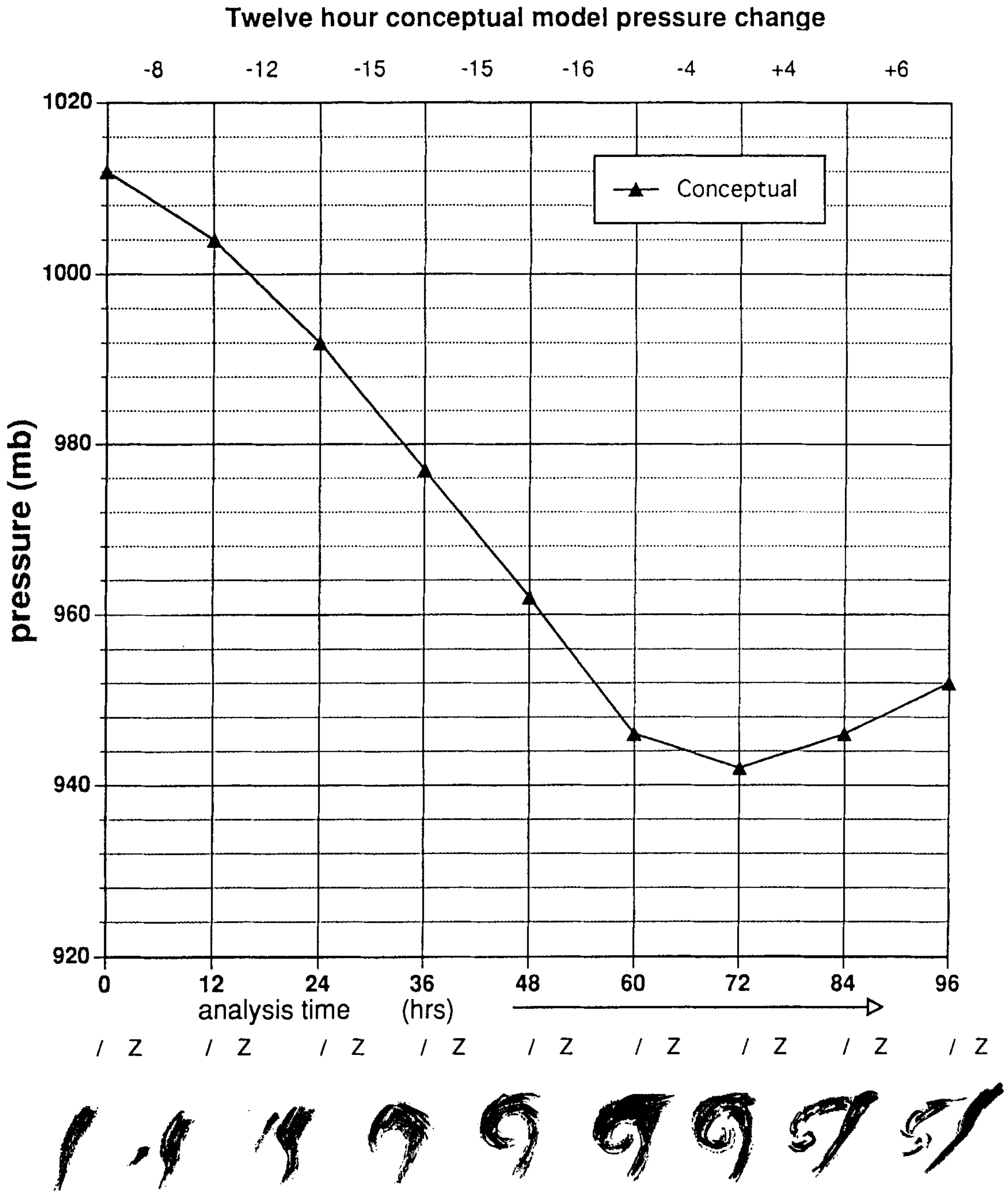


Figure 5-3-2. Standard pressure change chart used in SMB method
Expected central pressure is shown (as ordinate) in relation to the elapsed time (as abscissa) from the occurrence of the cyclone. The bottom illustration shows conceptual cloud patterns.

5.3.2 Application of SMB method to cyclones around Japan

Kumabe et al (1996) applied the SMB method to typically developed cyclones around Japan (60 cyclones classified under the typical type in the period from 1990 to 1993). They examined the difference between surface weather charts by the Meteorological Agency and estimations by the SMB method, and described that the SMB method would estimate about 8 hPa shallower on an average and that the SMB method tended to estimate lower for high central pressures and estimate higher for low central pressures.

An example of application of the SMB method (Kumabe et al, 1996) is given. This cyclone originated in the East China Sea, moved northeast through the south coast of Japan and developed over the ocean waters east of Japan. Figure 5-3-3 shows the cyclone a couple of days after its origination. It is at the deepening stage of the typical type. Estimate the central pressure of this cyclone using the flow chart (Figure 5-3-1). The cloud area has just begun to turn to a comma shape, the cloud top height is still low at the comma's head, and the cloud pattern falls under the 4th (984 hPa). The degree of the vortex is measured to be 0.75 with a logarithmic spiral (978 hPa results when interpolating in the chart and choosing the seemingly closest pattern). If the standard model (Figure 5-3-2) is used, the central pressure can be estimated from the elapsed time of 48 hours and correspondence to the cloud patterns at 962 hPa. The central pressure of this cyclone was 976 hPa on the surface weather chart.

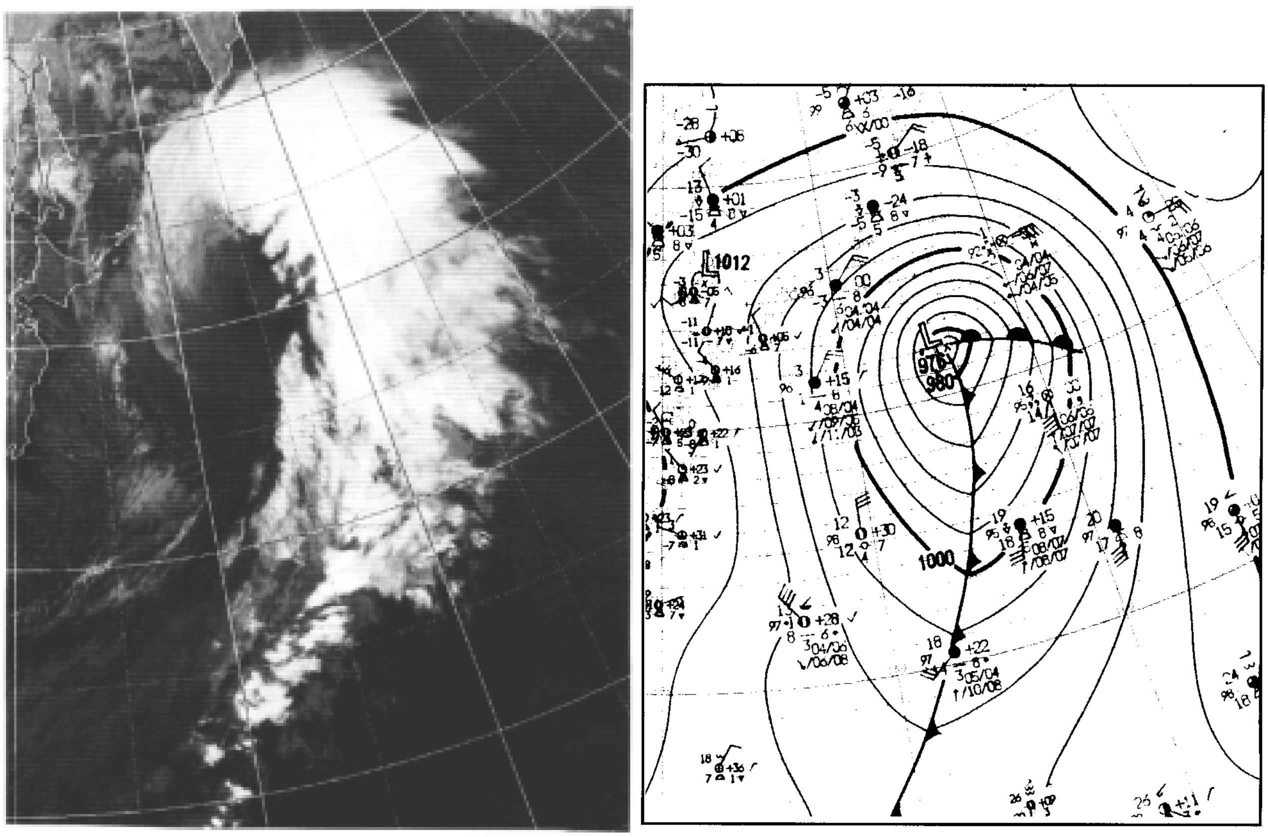


Figure 5-3-3. Infrared image (top) and surface weather chart (bottom) at 00UTC, January 15, 1994

5.3.3 Estimation of central pressure of comma-type cyclone

The SMB method is intended for development of cyclones of the typical type. Kumabe et al (1997) proposed a method to estimate the central pressure and pressure gradient of cyclones of the comma pattern not covered by the SMB method. For development of the comma-type, larger cloud area sizes result in lower central pressures in proportion. This relation may be applicable to extratropical cyclones as well. On the other hand, they describes that the pressure gradient is largest for a size of the order of 2000 km in diameter, and the gradient is smaller for both larger and smaller sizes than this. They observed cloud pattern, cloud area size, presence or absence of high clouds as items related to the development of comma clouds and created a flow chart (Figure 5-3-4) based on these observations to estimate the development of a comma-shaped cloud area. They describe that estimation of central pressure goes well for most of cyclones with a comma-shaped cloud area if this chart is used.

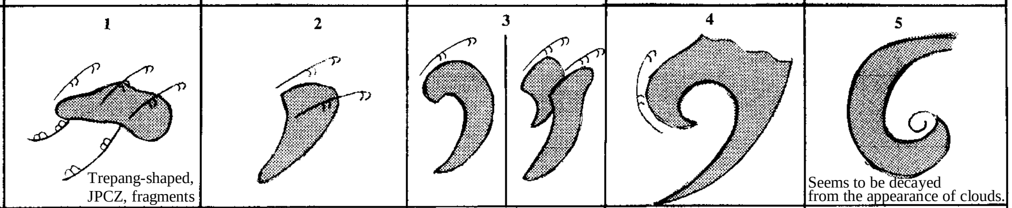
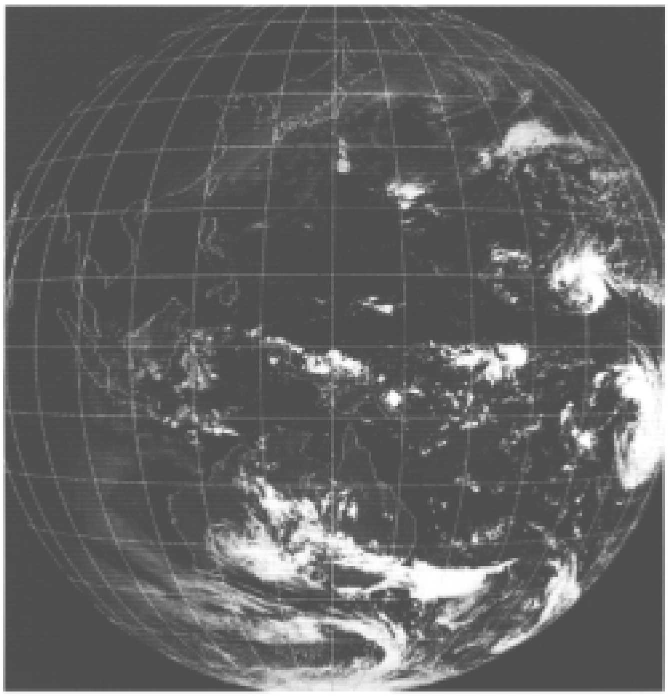
Time (hr)	0	12	24	36	48
Pattern 	1 Trepang-shaped, JPCZ, fragments	2	3	4	5 Seems to be decayed from the appearance of clouds.
Pressure (hPa)	1004	994	987	981	970
P gradient (hPa/500km)	8	12	15	15	20

Figure 5-3-4. Central pressure estimating chart for cyclones with a comma cloud
Cloud patterns, central pressure and pressure gradients are shown by the elapsed time from origination.

Vortex pair creation

It sometimes happens that cloud vortices are formed on both northern and southern hemispheres simultaneously across the equator. It is said that vortex pair creation tends to occur during El Niño. Attached Figure 1 shows a satellite image of vortex pair creation. The vortex in the northern hemisphere is the precursor of typhoon No. 28, and there is a cloud vortex of a tropical cyclone also in the southern hemisphere. The year 1997 was a period of occurrence of El Niño, which was the most intense around this time. (Kazufumi Suzuki)
References: Shuhei Akashi (1986): Tropical cyclones generated in meridional symmetry, Kisho, July issue, 20. Yuki Kuroda (1992): Typhoon No. 1 that occurred as a twin, Kisho, March issue, 20.



Attached Figure 1. Vortices that occurred as a pair (Visible image at 00UTC, December 7, 1997).