Chapter 4 Water vapor patterns*

4.1 Water vapor patterns

In the water vapor imagery, the upper and middle air flow can be visualized using water vapor as the tracer even if there are no clouds. Therefore, it is possible to estimate the position of a trough, vortex, ridge, and jet stream in the upper or middle air from the pattern of bright and dark regions appearing in the water vapor imagery. Deepening or flatting of a trough in the upper or middle level can also be estimated from the time rate of change of bright and dark regions. Note that the condition of the upper and middle air can be known from the water vapor imagery but information on the condition of the lower air can hardly be obtained because of the absorption of radiations by water vapor.

4.1.1 Dark region

A portion that looks black in the water vapor imagery is called a dark region. A dark region indicates an area of high temperature and the dryness of the upper and middle air there.

In Figure 4-1-1, the part A is a dark region.

4.1.2 Bright region

A portion that looks white or gray in the water vapor imagery is called a bright region. A bright region indicates an area of low temperature and shows that the upper and middle air are humid or there is a tall cloud area having the cloud tops in the upper or middle level. The bright and dark regions are not discriminated by a quantitative criterion but they are qualitative concepts to indicate bright and dark portions on the image.

In Figure 4-1-1, the part B is a bright region.

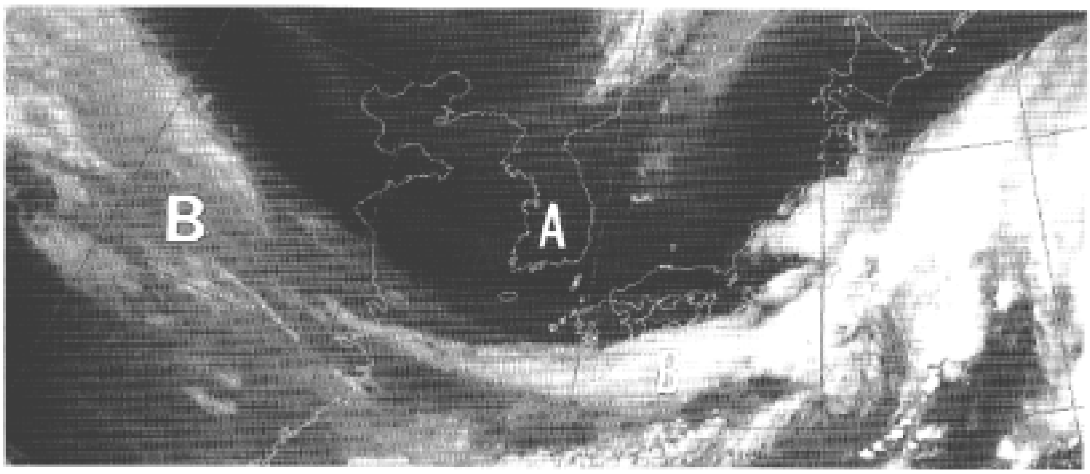

Figure 4-1-1. Water vapor image of dark and bright regions at 18UTC, October 19, 1999.

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4.1.3 Darkening

If the darkness of a dark region increases with time, it is called darkening. A darkening region corresponds to an active subsidence field and represents deepening of a trough or strengthening of a high pressure.

In comparison of (C) in Figure 4-1-2 with (C) in Figure 4-1-3, it is found that the dark region is increasing in darkness with time.

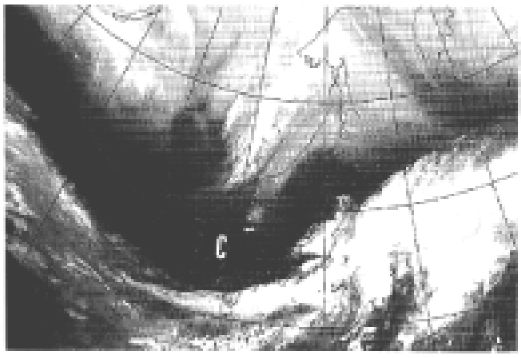

Figure 4-1-2. Enhanced water vapor image at 18UTC, October 19, 1999.

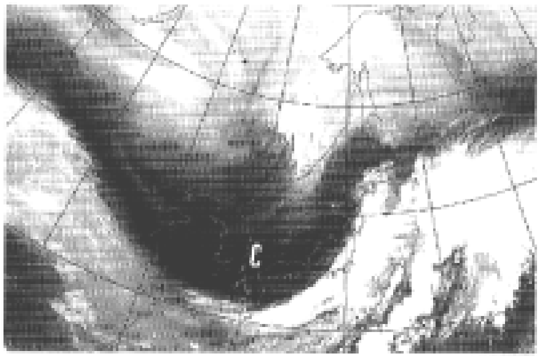

Figure 4-1-3. Enhanced water vapor image of advanced darkening at 00UTC, October 20, 1999.

4.1.4 Dry intrusion

A very dry air flow that descends to the lower level near a low is called dry intrusion. In the water vapor imagery, a descending dry air mass can be recognized as a distinct dark or darkening region, and the development of dry intrusion can be known. Keith Browning (1999), considering that dry air mass is descending from near the tropopause and it is closely related to the convective instability or the occurrence of convection due to the low equivalent potential temperature, emphasizes the effect of dry intrusion on the structure of fronts, cloud and precipitation of an extratropical cyclone.

The descending dry air mass separates at the rear side of a cold front into a flow toward the center of the cyclone and an anticyclonic flow. Then, the dark region in the water vapor imagery may exhibit a hammer head pattern (Figure 4-1-4 a).

Figure 4-1-4 b shows an example of dry intrusion. There is a dark region extending from the low in the Sea of Japan to the continent through the Yellow Sea, and it branches at the rear side of the low, one toward the center of the low and the other toward the East China Sea. This assumes a hammer head pattern.

4.1.5 Dry slot

A dry air mass flow flowing toward the center of a developing low from the cold side is called a dry slot. In the water vapor imagery, the dry slot is seen as a long, narrow, trench-like dark region as if wrapped around the center of the low. In the visible and infrared imageries, it is seen no cloud area or only low-level clouds. A dry slot is formed by dry intrusion.

Figures 4-1-4 b and c show an example of a dry slot. There is a long, narrow dark region (marked by an arrow) extending from the east to the south of the center of the low in the western Sea of Japan. This is a dry slot and forms a part of a hammer head pattern. In the visible imagery, this portion forms a fair area (marked by an arrow) where there is little cloud.

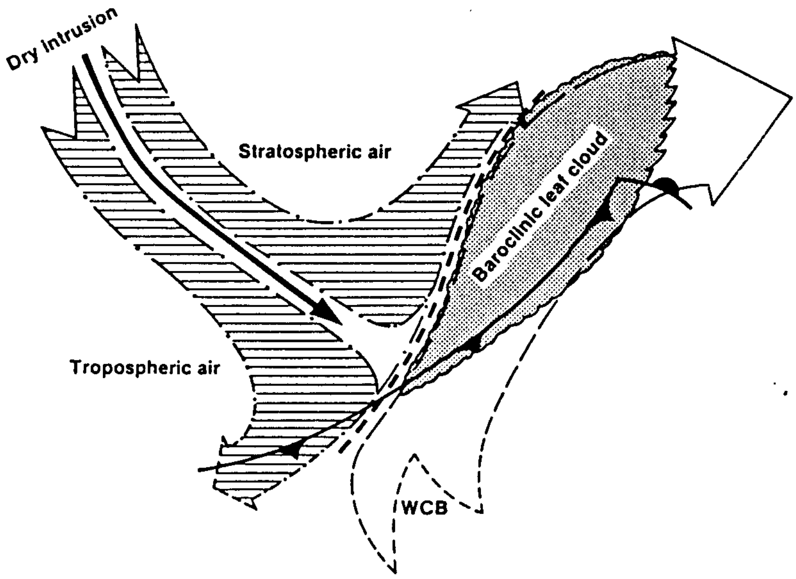

Figure 4-1-4 a. Conceptual model of dry intrusion and hammer head pattern (Young et al. 1987).

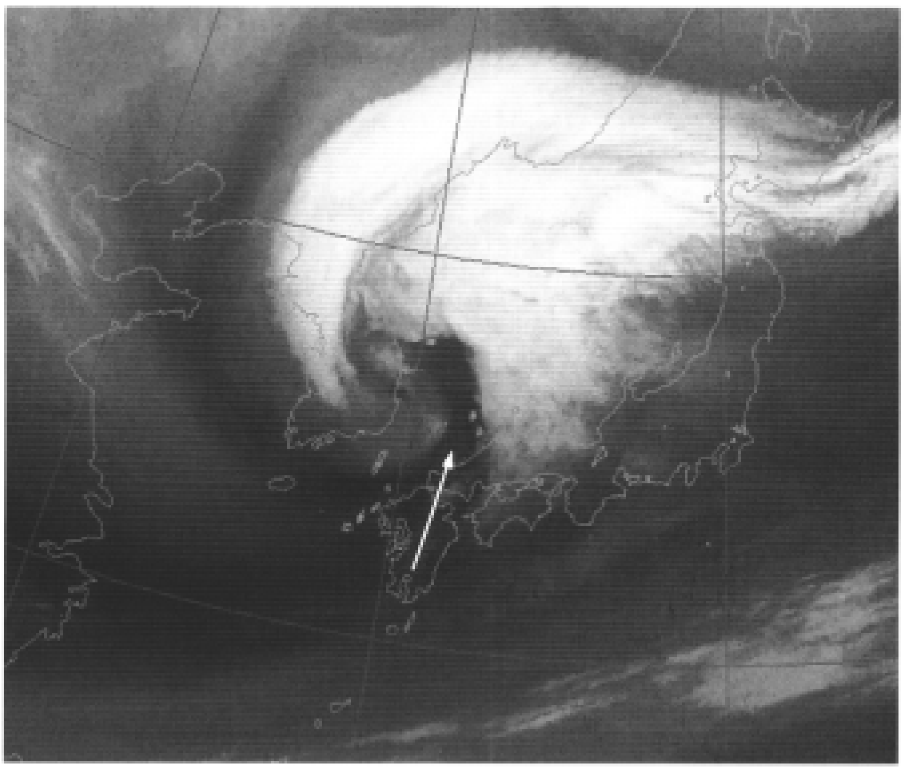

Figure 4-1-4 b. Water vapor image of dry intrusion at 00UTC, April 6, 1999.

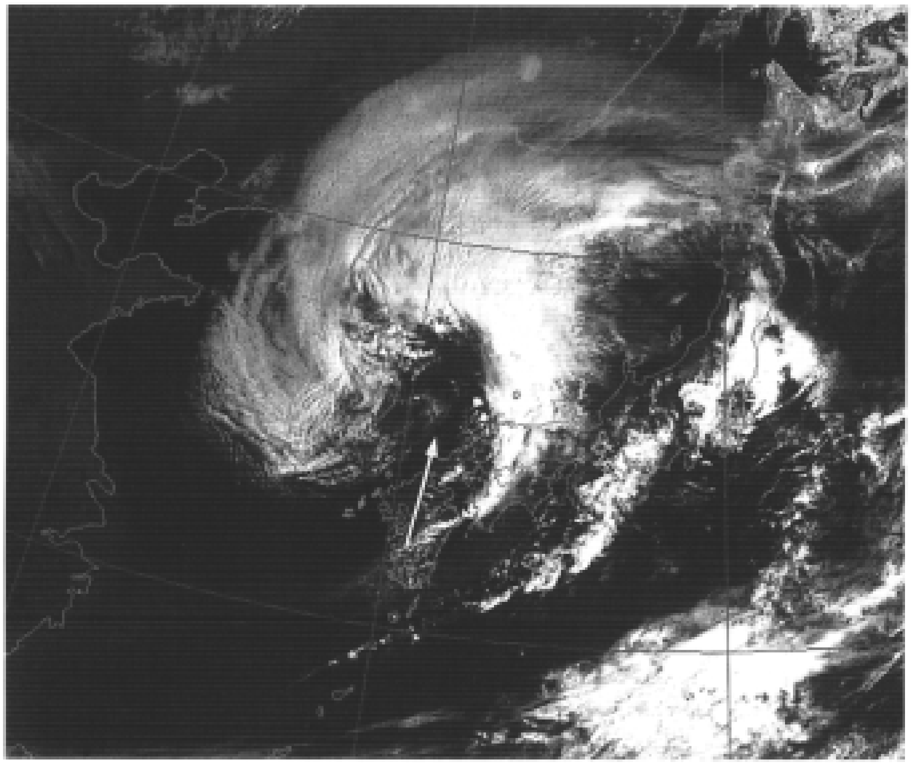

Figure 4-1-4 c. Visible image of dry intrusion at 00UTC, April 6, 1999

4.1.6 Upper trough

In the water vapor imagery, a trough can be analyzed at the maximum place of cyclonic curvature of the boundary between bright and dark regions (the dark region being convex on the south) (Figure 4-1-5 a).

In the water vapor imagery, it is possible to catch the presence of a trough in the upper and middle level from the shape of the boundary and estimate deepening or flatting of the trough from the degree of darkening.

In Figure 4-1-5 b, a trough can be analyzed from the curvature of the boundary in the area from the Shangdong Peninsula to the lower basin of the Yangtze-Jiang, and a trough can also be analyzed at the same position from 500-hPa objective analysis.

4.1.7 Upper vortex

Many vortices can be seen in the water vapor imagery. They can also be identified from the pattern of bright and dark regions wrapped in spiral form or from the rotation of bright and dark regions seen in the animation images. A vortex that can be identified in the water vapor imagery is called an upper vortex. The upper vortex is effective in detecting a low or trough in the upper and middle level.

Figure 4-1-6 shows an example of an upper vortex (marked by an arrow) that can be identified from the pattern of bright and dark regions wrapped in spiral form.

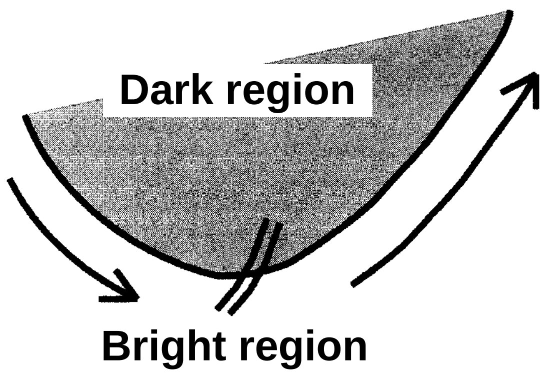

Figure 4-1-5 a.　Schematic of upper trough.

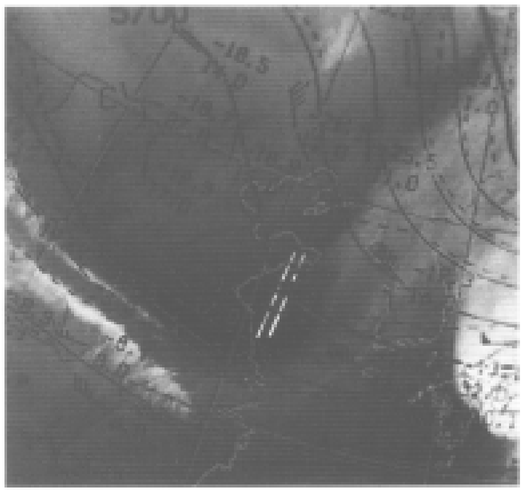

Figure 4-1-5 b.　Water vapor image of upper trough at 12UTC, October 17, 1999.
Solid lines are contour lines of 500 hPa height at 60-m intervals.　Double line is a upper trough.

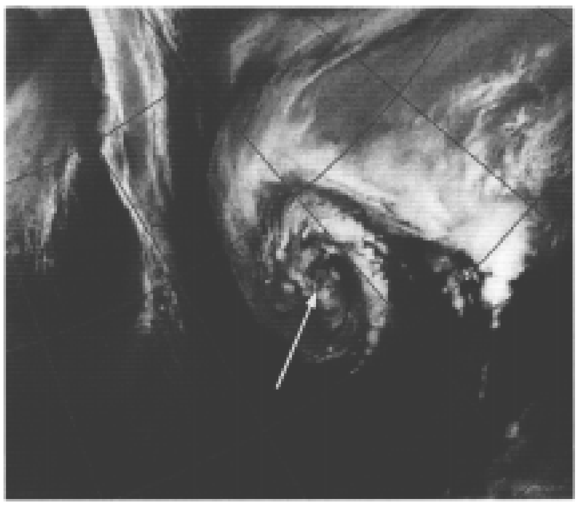

Figure 4-1-6.　Water vapor image of upper vortex at 00UTC, October 11, 1999.
Arrow is refer to the text.

4.2 Boundary

The border between bright and dark regions in the water vapor imagery is simply called a boundary. A boundary in this sense is the boundary between air masses having different humidity in the upper and middle level.　If the humidity varies noticeably in space, the contrast between bright and dark regions becomes distinct and a boundary appears clearly.　Boundaries appearing in the water vapor imagery are formed by vertical motions of air mass or atmospheric deformations and they each exhibit particular patterns.

Weldon and Holmes (1991.; a Japanese version (1993) by the Meteorological Satellite Center is available.) classify the boundaries into 7 different patterns (Table 4-2-1) and describe their features. These boundaries are divided based on their origin and structure into boundaries "related to jet streams", "exhibiting a blocking", "exhibiting a surge" and "others".　Boundaries do not always keep the same nature but do change.　For example, a base surge boundary turns into an inside boundary, and there is a boundary whose upstream portion is a dry surge boundary and downstream portion is a baroclinic leaf boundary. In such cases, note that they vary both in space and with time.

Here, each of the boundaries is described according to the classification by Weldon and Holmes.

Table 4-2-1. Classification of boundaries.

Boundaries related to jet streams	Parallel Jet Stream Boundaries
	Baroclinic leaf boundaries
Boundaries exhibiting blocking	Head boundaries
	Inside boundaries
Boundaries exhibiting surge	Dry surge boundaries
	Base surge boundaries
Others	Return moisture boundaries

4.2.1 Boundaries related to jet streams

One of the most effective uses of the water vapor imagery is observation of the behavior of jet streams. Across a jet stream as a borderline, the air masses on the polar side are generally colder and drier than those on the equatorial side. On the equatorial side, boundaries appear because the air is warm and moist and bright regions are formed by the presence of cloud areas corresponding to the fronts. Figure 4-2-1 shows a schematic of subtropical and polar frontal zone (Ramond et al. 1981). On the polar side above a frontal zone near a jet stream, subsidence intensifies and the dry region extends downward from the tropopause. The dark region on the north of the jet stream corresponds to this dry region and forms a boundary with distinct contrast. In general, subtropical frontal zone are wide and steep, so they tend to form a wider and more distinct boundary than polar frontal zone.

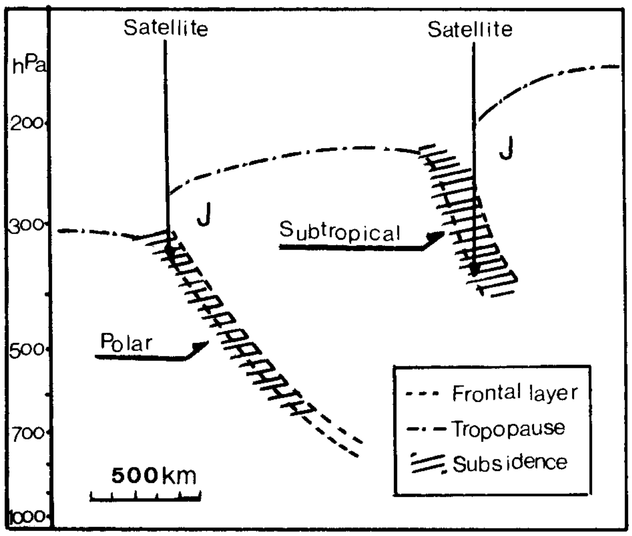

Figure 4-2-1. Schematic of subtropical and polar frontal zone (Ramond et al. 1981).

(1) Parallel Jet Stream Boundaries

This boundary is formed at the boundary between a cloud area (bright region) accompanying a jet stream and a dark region on the polar side. It exhibits distinct constant and a nearly straight form in many cases. The dark region appears in the form of a band on the polar side of the jet stream in many cases. The jet axis almost coincides in position with the boundary. In the westerly zone, however, because it frequently happens that the west end of the jet axis lies in a deformation field, the shape and contrast of the boundary may be somewhat more indistinct than at the east end and may not coincide with the jet axis.

An example of a Parallel Jet Stream Boundary is given (Figure 4-2-2). There is a boundary (marked by wedges in the figure) in the Sea of Japan and it corresponds to a jet core of 100 kt. The boundary extends from the Yellow Sea to the continent. Because the west end (near 110° E) of the boundary lies at a jet core inlet, the correspondence between the boundary and jet axis is indistinct.

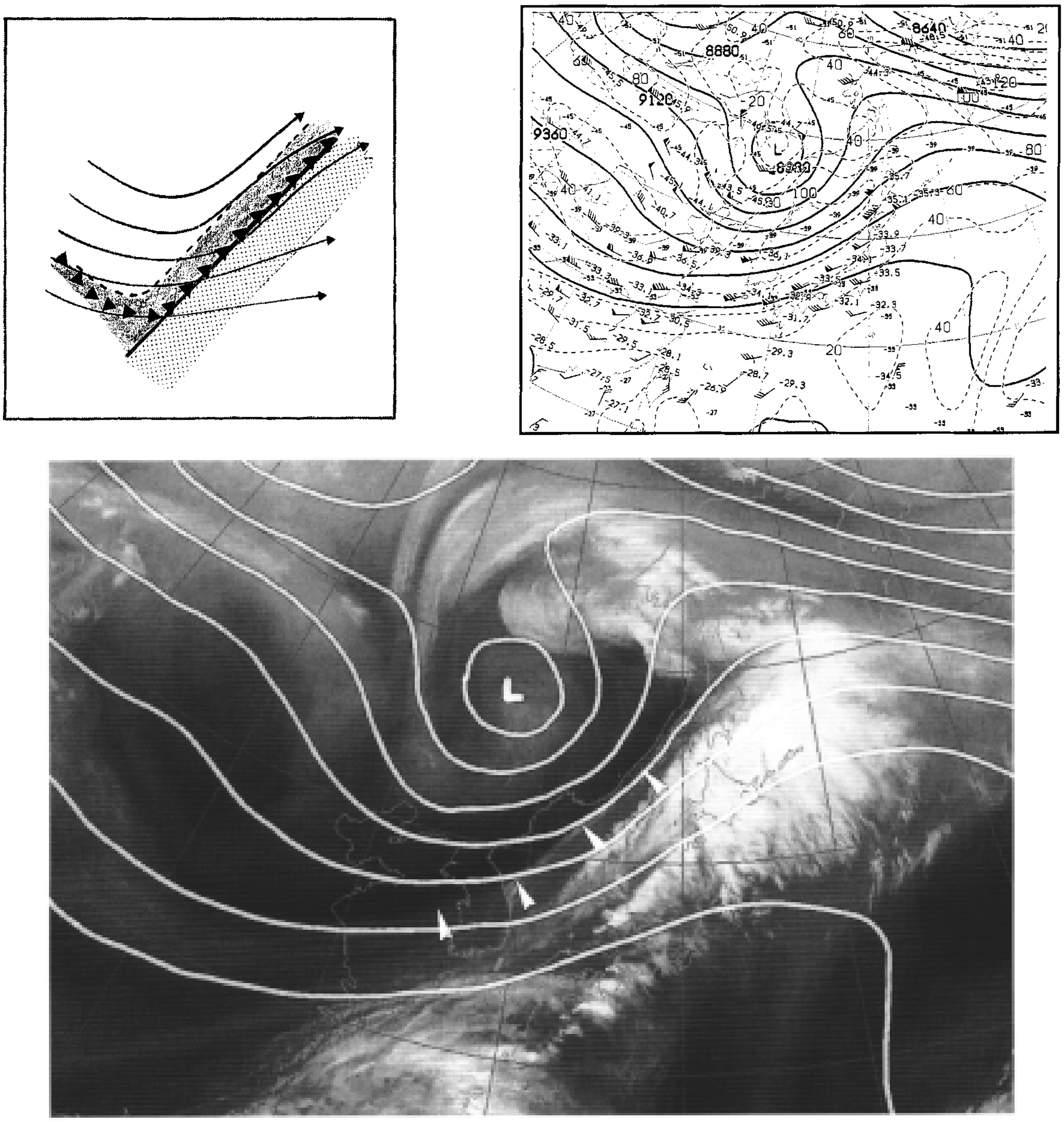

Figure 4-2-2. Parallel Jet Stream Boundary.

Upper left: Schematic model. The black portion denotes a bright region, the white portion a bright region, and the dotted portion a cloud area. Thick solid black line - boundary. Thin solid black lines - stream lines. Black triangle arrows - axes of maximum wind speeds.
Upper right: 300 hPa analysis at the same time as the water vapor image.
Lower: Water vapor image (at 00UTC, October 15, 1998) Wedges denote a boundary.

(2) Baroclinic leaf boundaries

The term baroclinic leaf is referred to as that Parallel Jet Stream Boundary which is accompanied by a leaf-shaped cloud area (cloud leaf) appearing at the initial developing stage of a low in the westerly zone. At the initial developing stage of a low, the cloud area exhibits a leaf pattern at the forward side of the trough and the boundary exhibits the form of “S” shape due to WCB (warm conveyor belt, refer to Section 5.1), which is a warm and moist air flow, as shown in the schematic. Near the border where the bright region exhibiting the form of “S” shape is convex to the polar side, the boundary generally coincides with the jet axis. However, the vicinity of the border where bright region is concave toward the equator is close to a deformation field, and the boundary is not always parallel to the jet axis. An example of a baroclinic leaf boundary is given in Figure 4-2-3. There is a leaf-like cloud area around Japan and it corresponds to a low at its initial stage. Its northern edge has an anticyclonic curvature and coincides with a jet axis. When a baroclinic leaf is formed, it often lies in a convergent field of jet streams. In this example, a Parallel Jet Stream Boundary is seen (marked by an arrow) and the portion having an anticyclonic curvature (northern Japan) coincides with a baroclinic leaf boundary.

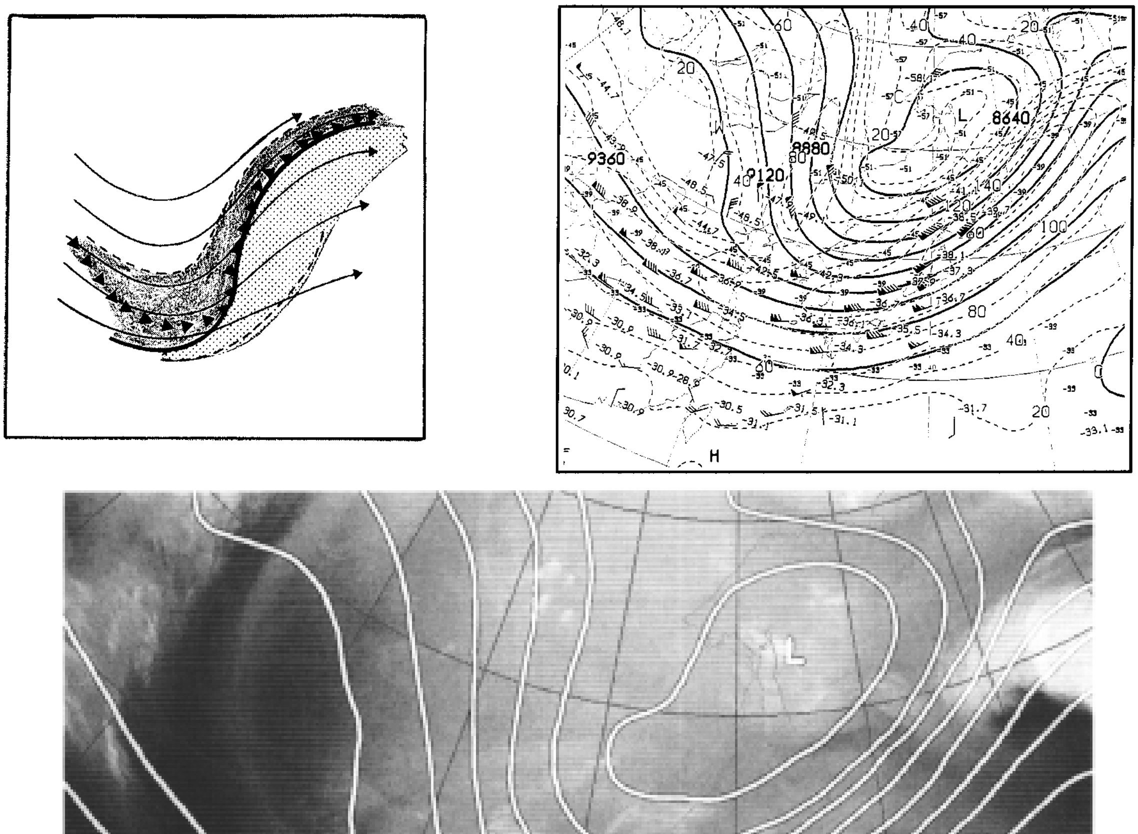

Figure 4-2-3. Baroclinic leaf boundary.
Image taken at 00UTC, February 11, 1999. Others are the same as Figure 4-2-2.

4.2.2 Boundaries representing a blocking

A boundary of this type is formed in a relatively weak wind area in the upper level by the development of a circulation having a wind field in the opposite direction to the surrounding winds. Because a circulation field which blocks the surrounding winds is formed, it is identified as a boundary representing a blocking. Because of different origins of the circulation field, there are the head boundary, which is related to cyclogenesis, and the inside boundary, which is related to anticyclogenesis.

(1) Head boundaries

A head boundary is formed at the border between a convex bright region and surrounding dark region. The movement and change of this boundary is slow. It is formed by synoptic-scale flows accompanying cyclogenesis. As shown in the schematic model in Figure 4-2-4 a, because the wet air mass rises from the low level due to the occurrence of low, a head-shaped bright region is formed. The bright region branches into a flow associated with the low and an anticyclonic flow on the north side of the low. This flow of the bright region is blocked by the surrounding dry westerly winds and forms a descending flow at the border. In the upper-level flow field, a boundary is formed along the elongation axis of the deformation field.

The water vapor image of Figure 4-2-4 a shows an example of a synoptic-scale head boundary. A boundary (marked by wedges) is seen extending from the Korean Peninsula to the Sea of Japan. It is formed at the border between the east wind associated with the cyclonic circulation present near Tsushima at 300 hPa and the northwest wind from the continent. The presence and scale of an upper-level low are hard to judge with the weather map alone, however, these can be easily estimated through the boundary. At this time, the low in the surface at this time lies off the Kii Peninsula about 500 km downstream of this upper-level low accompanied by the head boundary and is accompanied by active convective clouds.

Besides the above-mentioned head boundary associated with the synoptic scale, there is a head boundary that is associated with meso-scale convective phenomena. In such a case, a very narrow zonal dark region appears along the windward fringe of the cloud cluster, and a boundary is seen between it and the cloud area. The scale of the boundary is several ten kilometers and its lifetime is short. It often appears at the climax of a cloud cluster, and the narrow zonal dark region is thought to be related to the air flow structure of the cloud cluster. Fujiyoshi (1999) reported the case where the inflow of dry air mass from the middle levels brought about rapid development and decay of cumulonimbus, and it is thought that the dry air mass was observed as a dark region in relation to meso-scale convective phenomena.

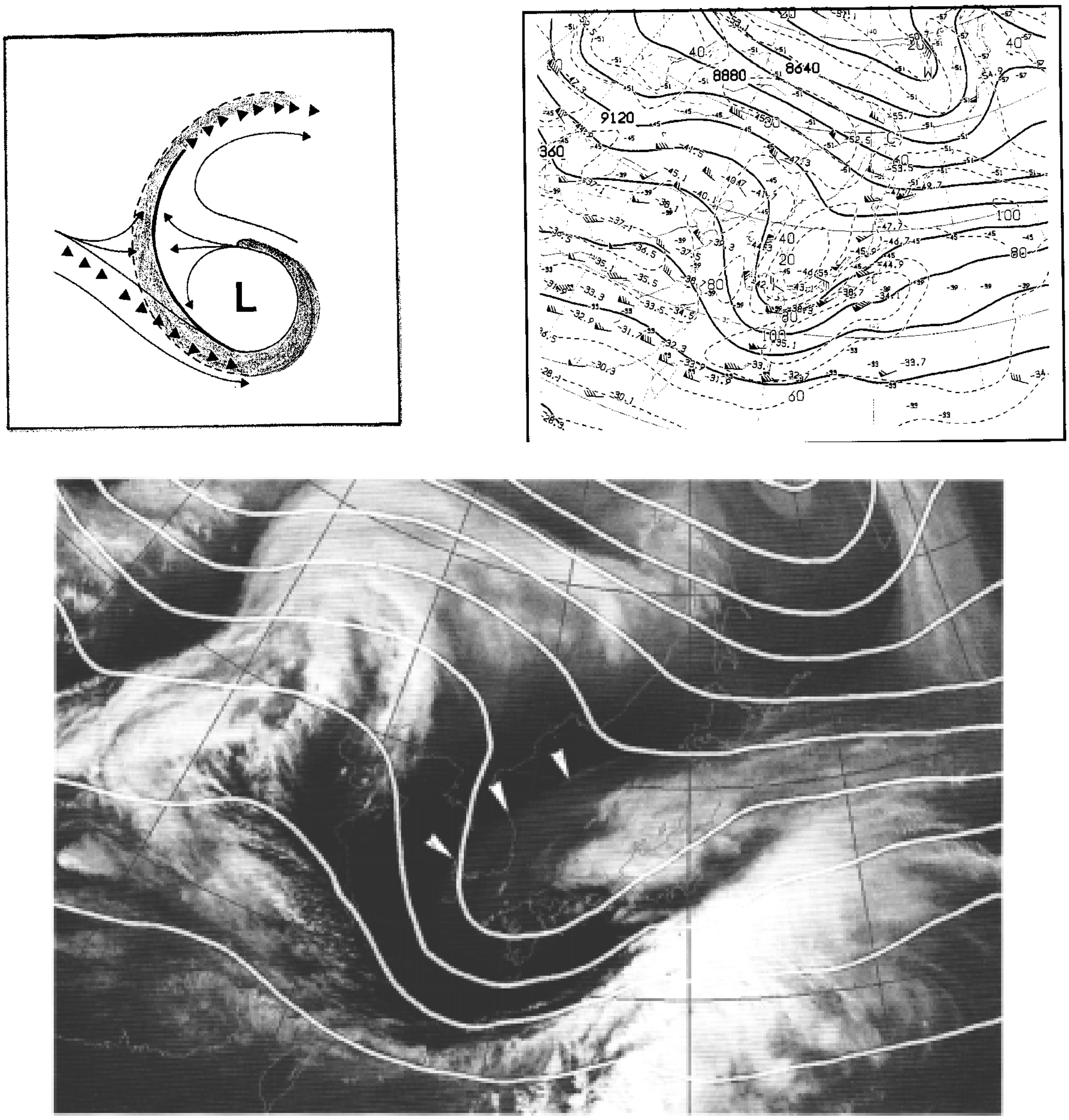

Figure 4-2-4 a.　Head boundary.
Water vapor image at 12UTC, April 10, 1999.　Others are the same as Figure 4-2-2.

The water vapor image of Figure 4-2-4 b shows a head boundary of meso-scale. On the Chinese continent, very narrow dark regions (marked by wedges) are seen on the windward side of developing cloud clusters 100 to 200 km in diameter. These dark regions form boundaries between them and the very bright cloud areas. These boundaries appeared at the climax of clusters of relatively large scale, and they disappeared with the decay of the clusters. Boundaries of this appear with cloud clusters which are an organized meso-scale convective system. Weldon and Holmes classify them under the head boundary. However, since they quite differ in origin and mechanism from the head boundary described above, which corresponds to the synoptic scale, a new classification may be necessary.

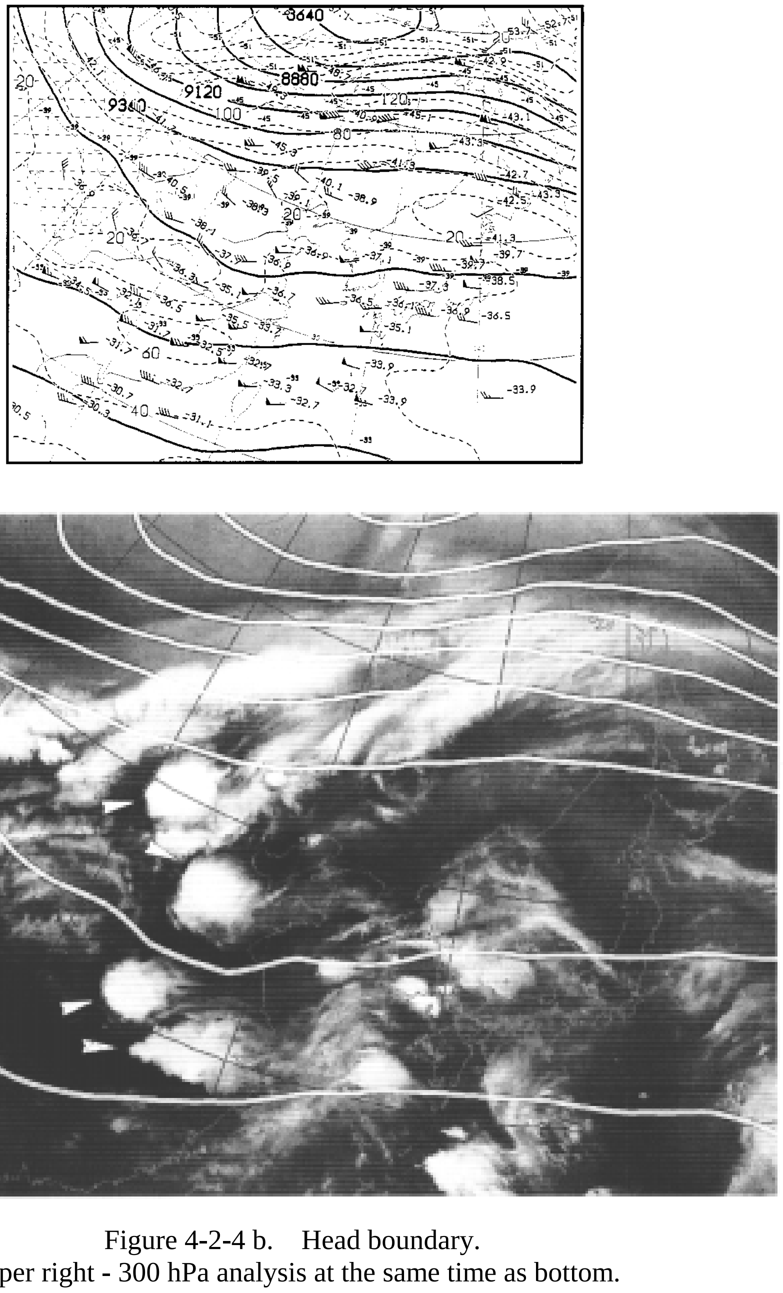

Figure 4-2-4 b. Head boundary.
Upper right - 300 hPa analysis at the same time as bottom.
Bottom - Water vapor image (at 18UTC, April 22, 1998).

(2) Inside boundary

A dry area is formed by subsidence in relation with an upper-level high. When the dry area expands, it forms a boundary between it and the relatively humid flow accompanying the trough on the upper stream. This type of boundary formed by the flow in an anticyclonic circulation is called an inside boundary. As shown in the schematic model, this boundary is formed between a dark region which is convex toward the upper stream and the surrounding bright region. The boundary is slow in movement and change. The inside boundary can be used to monitor the life cycle and trend of a blocking high.

An example of an inside boundary is given in Figure 4-2-5. A dark region (dry area) spreads out with a developed ridge extending north and south along 130°E. An inside boundary (marked by wedges) is formed between the anticyclonic flow accompanying this ridge and the wet westerly wind (bright region) at the forward side of the trough on upper stream of the flow.

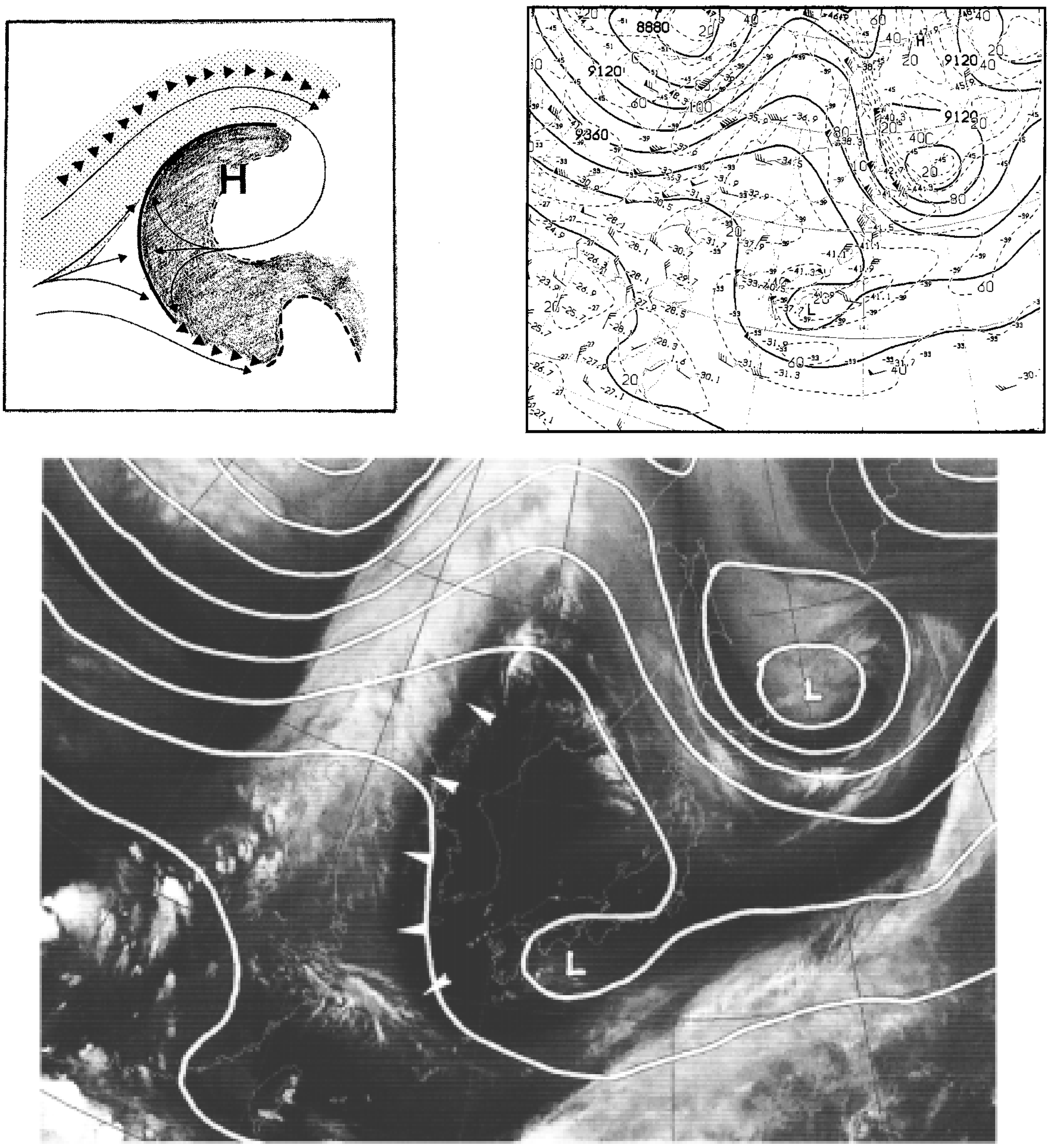

Figure 4-2-5. Inside boundary.
Image taken at 12UTC, May 21, 1998. Others are the same as Figure 4-2-2.

4.2.3 Boundaries exhibiting a surge

In the water vapor imagery, a dark region may look as if it was surging with a stream all at once from the upper stream, and this is called a surge. A boundary is formed between this dark region and the bright region at the advancing forward side and is called a surge boundary. As a surge boundary, there are the dry surge boundary, of which the dark region spreads in convex form toward the east, and the base surge boundary, of which the dark region spreads in convex form toward the equator. The boundaries associated with a surge enhance the convection and is related to the occurrence of turbulence because it is accompanied by a dry air mass in the upper air. Thus, it is an important concept for analysis of the water vapor image.

(1) Dry surge boundaries

For the dry surge boundary, rapid darkening due to the development of a descending flow plays an important roll. The causes of a descending flow to develop include “cold air advection in the upper- and middle-levels”, “deceleration at the downstream of a jet core”, and “subsidence at the rear side of a developed low”. The dark region associated with such a descending flow forms a distinct boundary with the cloud area that accompanies the low system at the forward side, and the boundary is called a dry surge boundary. As shown in the schematic on Figure 4-2-6, the dark region is convex toward the downstream and the boundary moves with high speed.

For a dry surge boundary, a warm and moist air mass may be present in the lower level. In such a case, due to the inflow of the dry air mass in the upper air associated with the surge convective instability is apt to be enhanced. Therefore, it is necessary to pay attention to the development of convective clouds near the surge. Ikeda and Okumura (1999) suggested that CAT (clear air turbulence) and other types of turbulence are apt to occur between the boundary and upstream dark region.

An example of a dry surge boundary is shown on Figure 4-2-6. The head of the dark region moving southeast from the continent forms a boundary at the rear side of the developing low off Sanriku (southeast of Hokkaido). This dark region is a dry air mass accompanied by cold air, and it moves southeast with high speed while intensifying darkening. This indicates an intense descending flow at the rear side of the low.

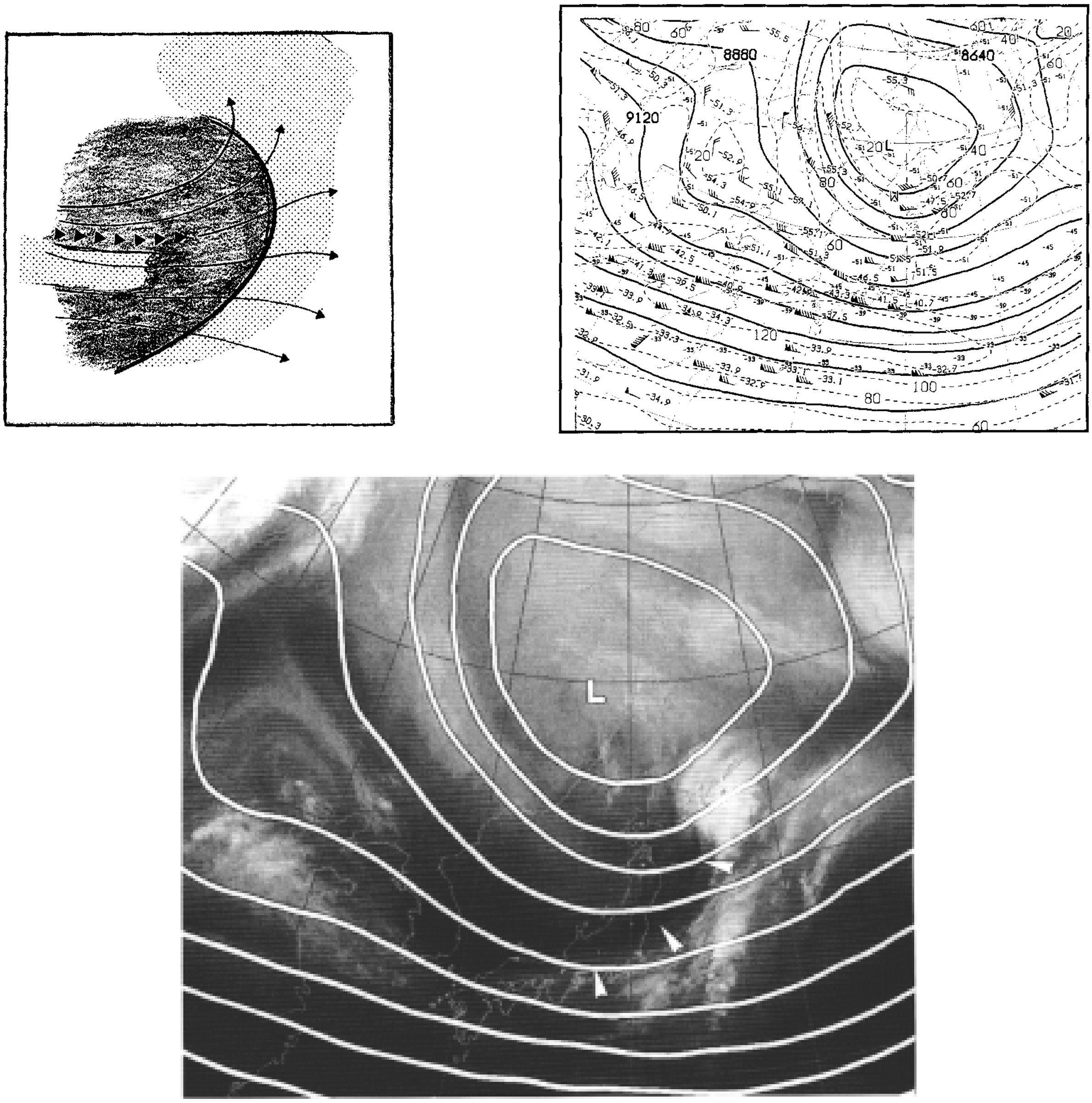

Figure 4-2-6. Dry surge boundary.
Image taken at 00UTC, December 26, 1998. Others are the same as Figure 4-2-2.

(2) Base surge boundaries

When an upper-level ridge intensifies, the north wind component increases on the east of the ridge, and the dry air mass moves south. A base surge boundary is formed between this air mass and the moist air mass on the equator side. At the beginning, the boundary exhibits a narrow band form. As shown in the schematic on Figure 4-2-7, however, the dry area (dark region) moves south and expands as the ridge intensifies. As with the dry surge boundary, CAT and other types of turbulence are apt to occur between the boundary and the upstream dark region (Ikeda and Okumura, 1999). A base surge boundary may move south to the ITCZ (intertropical convergence zone) and activate the convection there. In the tropical zone, in particular, monitoring this boundary is important for the occurrence and development of convective systems.

An example of a base surge boundary is shown on Figure 4-2-7. A dry air mass (dark region) moves south from a developed ridge near 120° East, and it forms a base surge boundary (marked by wedges) with the moist air mass (bright region) on the south.

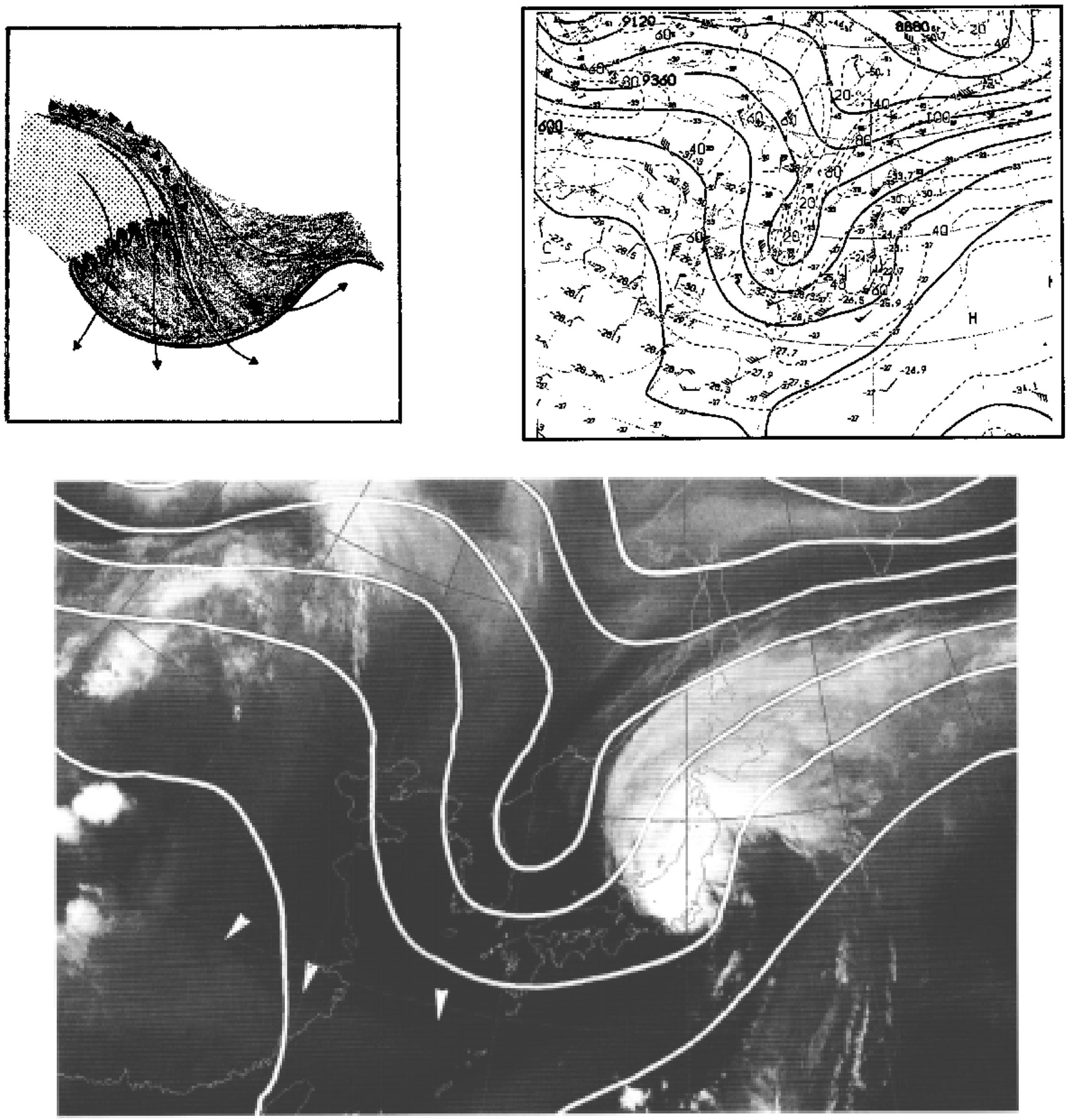

Figure 4-2-7. Base surge boundary
Image taken at 00UTC, September 16, 1998. Others are the same as Figure 4-2-2.

4.2.4 Others

(1) Return moisture boundaries

When a moist air mass (bright region) moves south on the east of an upper-level ridge, it forms a return moisture boundary with the dry area (dark region) there. This boundary is formed by an upper moist air mass flowing toward the equator without being affected by vertical movements on the synoptic scale. Moisture that moved north at the forward side of a trough returns toward the equator across the ridge. Hence the name. The return moisture boundary exhibits an opposite pattern of bright and dark regions on the image to the base surge boundary and it is associated with no descending flow. It neither corresponds to fronts, lows or other noticeable meteorological disturbances.

An example of a return moisture boundary is shown on Figure 4-2-8. There is a bright region which spreads from the Sea of Japan to Mongol and across North China and is convex toward the equator. This bright region forms a boundary with the dark region (dry area) which spreads from Middle China to the Japanese Islands and on the polar side of a jet stream. This bright region is related to the air flowing south from a developed ridge to the north of Lake Baikal.

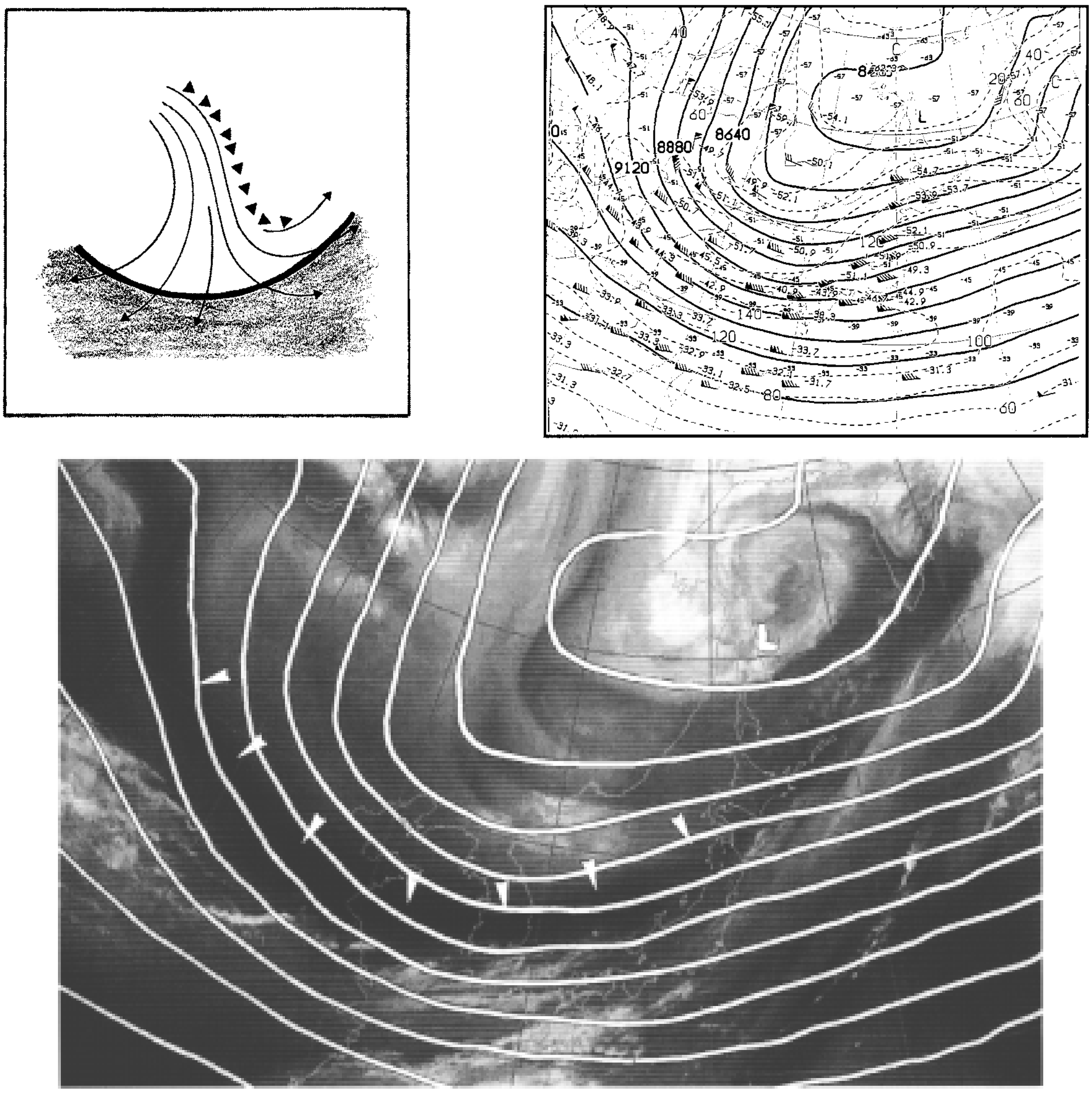

Figure 4-2-8. Return moisture boundary.
Image taken at 00UTC, October 17, 1999. Others are the same as Figure 4-2-2.

4.3 Analysis using water vapor images

4.3.1 Cold lows

In the water vapor imagery, vortices are visualized as a pattern of water vapor and therefore they can be analyzed and kept track of as upper vortices even if there is no cloud. These vortices correspond to cold lows (cold vortices) in many cases.

An example is shown in which an upper vortex moved southeast from the Korean Peninsula to Japan on Figure 4-3-1. In the water vapor imagery, a vortex pattern is seen in the bright region in the southern Korean Peninsula and an upper- vortex can be identified (arrowhead pointing the vortex center on the figure). By comparison with a 500 hPa analysis (Figure 4-3-2 a), the vortex center turns out to coincides with the center of the cold low. The upper vortex over the Korean Peninsula moved east to near Kanto 24 hours later (Figure 4-3-1 b). The cloud pattern was still distinct and allowed the upper vortex to be identified. A comparison with a 500 hPa analysis (Figure 4-3-2 b) confirms the coincidence of the vortex center with the center of the cold low.

How this case is described in detail in Section 6.2, and the reader is requested to refer to there.

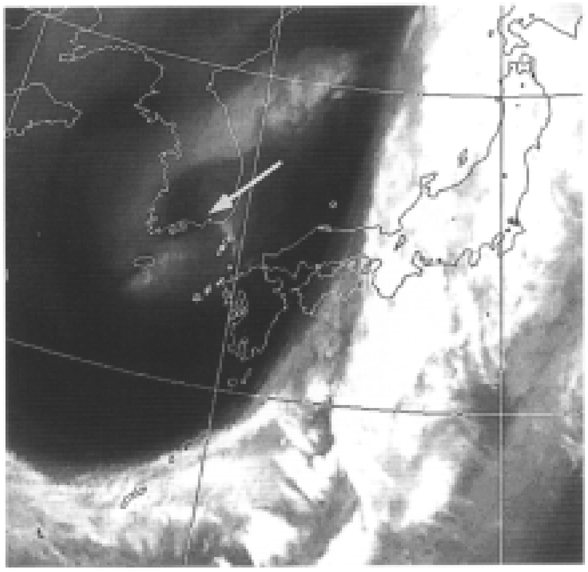

Figure 4-3-1 a. Water vapor image of cold low at 12UTC, April 6, 1997.
For symbols, refer to the text.

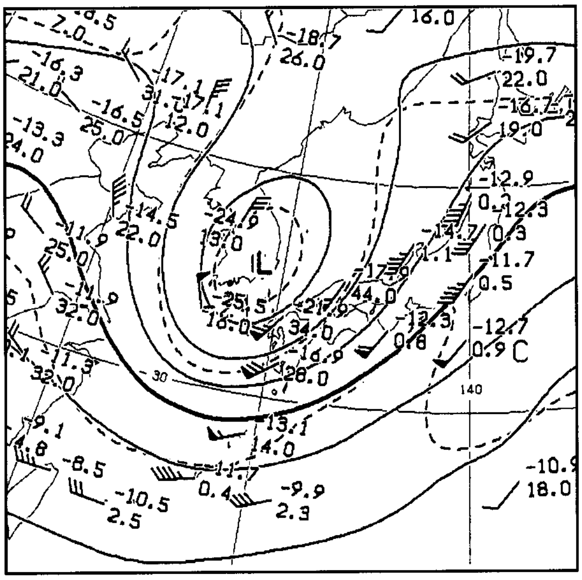

Figure 4-3-2 a. 500 hPa weather chart at 12UTC, April 6, 1997.

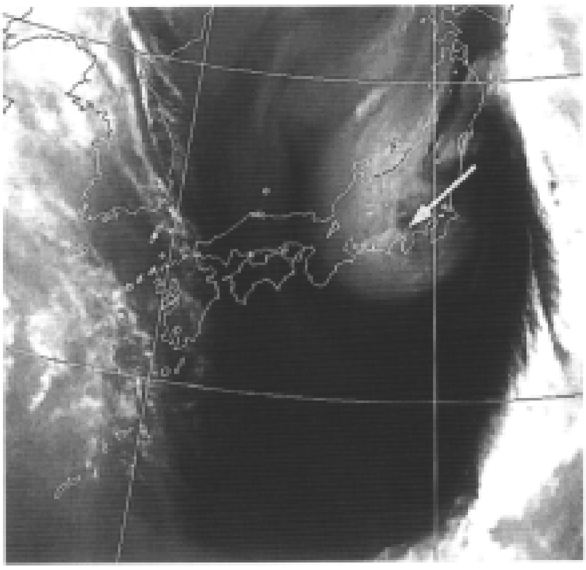

Figure 4-3-1 b. Water vapor image of cold low at 12UTC, April 7, 1997.
For symbols, refer to the text.

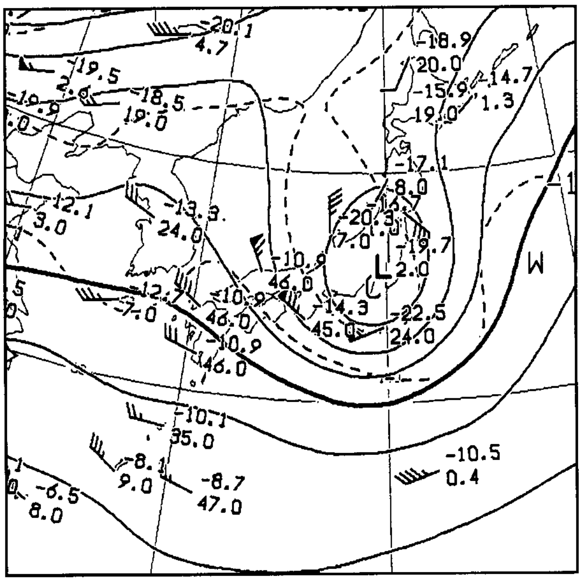

Figure 4-3-2 b. 500 hPa weather chart at 12UTC, April 7, 1997.

4.3.2 UCL (Upper Cold Low)

Shimamura (1981) calls the cyclonic circulation with the upper cold air, which is analyzed in the tropical and subtropical zones of the cold lows, “UCL (Upper Cold Low)”, and he describes its features as follows:

① At the initial generating stage of a UCL, a wet area is often seen in the middle levels on the east of the UCL center and a dry area around the center and on the west. This dry and wet distribution corresponds well with the cloud areas.

② Convective clouds are activated around a UCL and it sometimes happens that the UCL develops into a tropical cyclone around this convective cloud area.

Naito (1993) and Takamine (1995) say that UCLs are frequently observed along the tropical upper troposphere trough (TUTT), which is formed by an air flow going south while subsiding from the upper levels around Japan and another air flow going north while subsiding from the upper levels in the intertropical convergence zone.

Thus, watching such UCLs is important in monitoring tropical disturbances.

Figures 4-3-3 a and b show water vapor images of two upper vortices A and B (their centers marked by wedges) which corresponded to UCLs and moved west in the 30° North and 10° North zones. These images show that the upper vortex A has a convective cloud area noticeably developed and expanded mainly on the east and the upper vortex B is drier on the west than on the east.

Figures 4-3-4 a and b are 200 hPa analysis at this time, and two UCLs are analyzed at nearly the same position as the upper vortices A and B in the water vapor images.

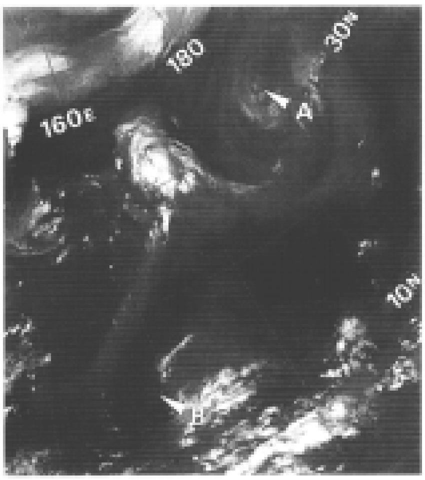

Figure 4-3-3 a. Water vapor image of UCL at 00UTC, August 25, 1999.
For symbols, refer to the text.

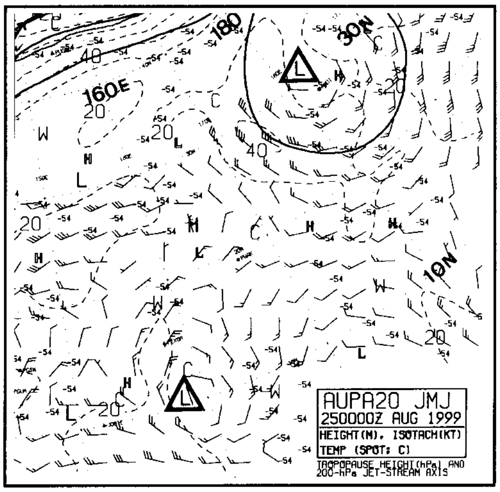

Figure 4-3-4 a. 200 hPa weather chart at 00UTC, August 25, 1999.

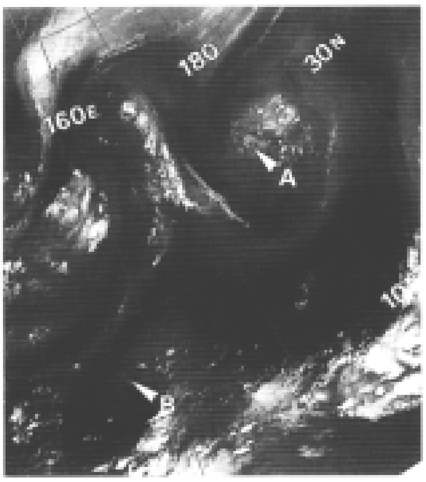

Figure 4-3-3 b. Water vapor image of UCL at 00UTC, August 26, 1999.
For symbols, refer to the text.

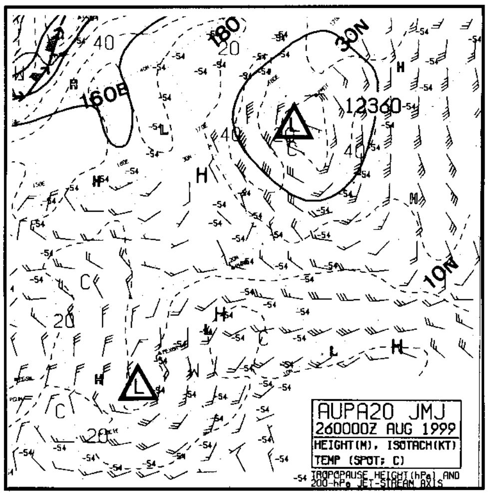

Figure 4-3-4 b. 200 hPa weather chart at 00UTC, August 26, 1999.

4.3.3 Enhancement of convection

Because a dry air mass (dark region) has low equivalent temperature, the instability is increased due to an inflow of a dry air if the conditions of the lower levels remain the same. If a dark region flows into an environment where convective clouds exist, it enhances convection due to convective instability. Such a condition easily occurs at the forward side of the dark region, and the convection is often activated around the boundary. In particular, a dark region that forms a surge boundary is apt to develop convective clouds because it is accompanied by cold air in most cases and the instabilizing effects by cold air are added.

Figure 4-3-5 shows an example of a base surge boundary. An upper trough is formed on the east of Japan, so the air mass formed at the ridge in the continent readily flows in there. And, a base surge boundary (marked by wedges in the figure) is formed over south of Japan islands. At 18UTC 5, Sep, the convection was not active yet. Cg and Cu clouds only scattered near the boundary at. But Cb clouds occurred and developed near the boundary six hours after. It seems that the convection was enhanced by the inflow of the dark region.

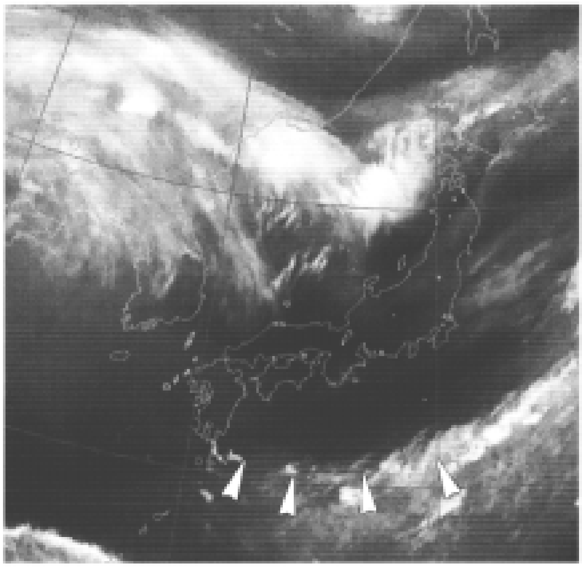

Figure 4-3-5 a. Water vapor image at 18UTC, June 5, 1999.

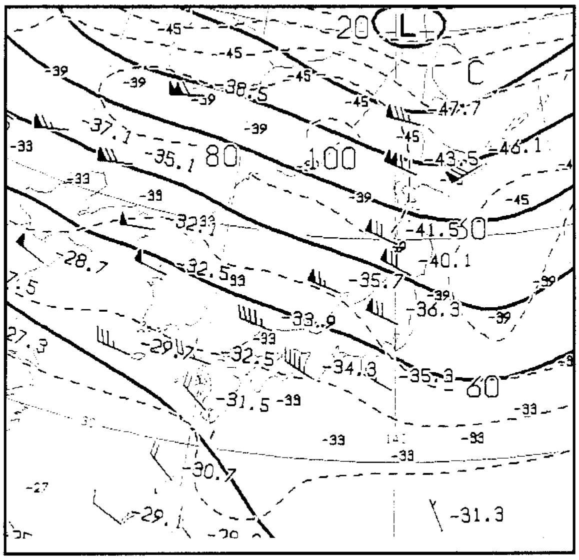

Figure 4-3-5 c. 300 hPa weather chart at 00UTC, June 6, 1999.

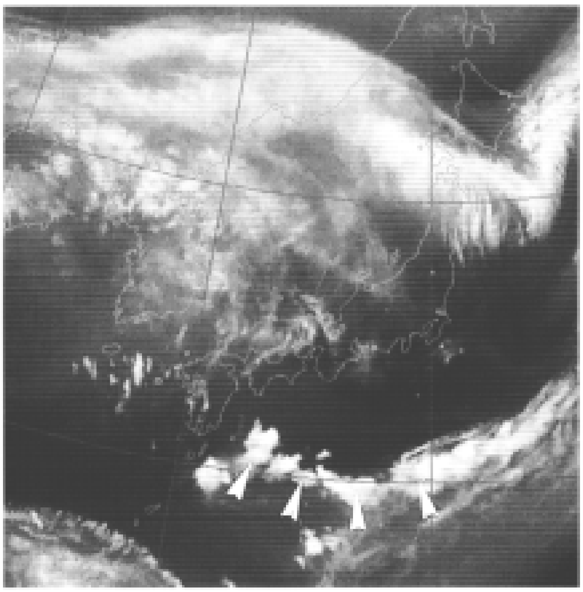

Figure 4-3-5 b. Water vapor image at 00UTC, June 6, 1999.