On the Structure of a Convergent Cloud Band over the Japan Sea in Winter; a Prediction Experiment*

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Abstract

A prediction experiment is performed with a very-fine-mesh (42 km at 60°N) primitive equation model for a heavy snowfall event in the Hokuriku District associated with a convergent cloud band over the Japan Sea. Using the result of the experiment, together with observed data including special soundings, we elucidate the structure of the convergent cloud band with a line of active convection on its southwestern edge.

The atmosphere around the cloud band has the following characteristic features:

- a low-level convergence, middle-level divergence zone accompanied by intense positive vorticity along the line of active convection,
- a warm and weak-wind zone along the line of active convection embedded in cold airmass,
- a weak stable layer on the northeastern side of the line of active convection as a boundary between two layers: a lower layer with northerly cold air flow toward the line of active convection and an upper layer with southwesterly warm air flow which has been heated in the line of active convection,
- a west-northwesterly air flow on the southwestern side of the line of active convection with weak vertical wind shear and nearly neutral stratification up to the top of the cold airmass,
- a strong-wind zone at the divergent level (700-600mb) 300-500km northeast of the line of active convection.

On the basis of cross-section and trajectory analyses, we can make a clear picture of the atmosphere around the cloud band.

Heat and water vapor budget analysis indicates that over the southern Japan Sea the mesoscale thermal structure around the cloud band is largely maintained by localized release of latent heat in large-scale cold air advection field.

1. Introduction

A so-called convergent cloud band which appears east of the Korea Peninsula over the western Japan Sea (Fig. 1) under northwesterly winter monsoon was found for the first time by Okabayashi (1969). Since then many Japanese meteorologists have been interested in the formation mechanism and structure of the cloud band which often caused heavy snowfall in the Japanese Islands. In this paper we mean by the term "Convergent Cloud Band" a broad band of

clouds over the sea which has a line of active convective clouds on its southwestern edge.

In a previous paper the author and his colleagues (Nagata *et al.*, 1986) revealed the formation mechanism of the convergent cloud band with numerical experiments. They simulated a band of convective precipitation with low-level convergence corresponding to a line of active convective clouds on the southwestern edge of an observed convergent cloud band. They showed that the land-sea contrast of thermal property between the Korea Peninsula and the Japan Sea plays the leading role in its formation and blocking effect of the mesoscale mountains north of Korea acts a secondary part.

We have many observational and analytical studies trying to describe the structure of the

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Fig. 1. Geography around the Japanese Islands.

cloud band (Magono, 1971; Yamaguchi and Magono, 1974; Hozumi *et al.**, Uemura, 1980; Yagi and Uchiyama, 1980; Motoki and Satomi, 1981; Yagi**, Endoh *et al.*, 1982; Endoh, Hozumi and Magono, 1984; Hozumi and Magono, 1984; Yagi, 1985; Yagi *et al.*, 1986). Leaving a few controversial points concerning the fine structure of cloud features, general properties of the atmosphere around the convergent cloud band drawn from these studies agree with the summary of Uemura's analysis (1980):

- A surface pressure trough is analyzed along the western (southwestern) edge of the cloud band, where surface wind converges.

- Mesoscale convection-like circulation with low-level convergence and middle-level divergence is formed with its center at the surface trough.

- On the eastern (northeastern) side of the surface trough large vertical wind shear is observed (*i.e.*, northerly wind below 850mb and west-southwesterly or southwesterly wind between 800mb and the stable layer forming an upper boundary of the synoptic-scale cold airmass).

- On the western (southwestern) side of the surface trough small vertical wind shear is seen with west-northwesterly or northwesterly wind.

Yagi and Uchiyama (1980), Motoki and Satomi (1981), Yagi**, Yagi (1985) and Yagi

*at the meeting of the Meteorological Society of Japan on October 30, 1980.

**at the meeting of the Meteorological Society of Japan on May 27, 1981.

et al. (1986) analyzed GMS cloud imageries in detail and found that a line of maximum horizontal wind shear at cloud level agrees with the Cb line, the southern edge of the convergent cloud band. Yagi *et al.* (1986) discussed the structure of the cloud band with a view that it results from a dynamic effect of the mountains north of Korea when low-level cold airmass capped by a stable layer reaches the mountains.

However, these observational and analytical studies are mainly based on sparse data around the Japan Sea except for satellite cloud imagery.

Since meteorological radars began to be operated, mesoscale disturbances causing heavy snowfall were analyzed using them (*e.g.*, Miyazawa, 1967; Fukatsu, 1977). Fukatsu reported mesoscale vortex-like disturbances along the transition line between two kinds of line echoes with different orientations. He showed that the transition line of the radar echoes corresponds to the southwestern edge of the convergent cloud band. However, these analyses using radar echoes are usually two-dimensional in a horizontal plane as well as those using satellite cloud imagery. So far, therefore, the consistent three-dimensional structure of the convergent cloud band has not been described.

In this paper, to investigate the structure of the convergent cloud band, we make a prediction experiment with a very-fine-mesh model for a heavy snowfall event on the Japan-Sea coasts associated with the convergent cloud band. The event occurred on January 25, 1984 during the period of the special observation conducted by the Meteorological Research Institute. The observation included special soundings at four stations in the Hokuriku District (Kanazawa, Takada, Niigata and Ryotsu). Therefore, we can use the observational data besides the result of the prediction experiment for elucidating the structure of the cloud band.

The prediction experiment is performed with the same numerical model and procedure as Nagata *et al.* (1986). The model was developed by Yamagishi (1980) and reformed by Koga and Yamagishi (1984). It is a 13-layer 42km-mesh primitive equation model. The vertical coordinate is the sigma one with its top at 100mb. The lowest four layers lie below about

Fig. 2. Specified sea surface temperature ($^{\circ}\text{C}$) (dashed lines) and topography (m) (full lines) in the forecast domain of the model.

900mb over the sea. The only alteration is made on sea surface temperature. We use observed 11-day-mean (Jan. 21-31, 1984) surface temperature analyzed by the Marine Department, J.M.A. instead of climatic one in order to make the experiment more realistic. Specified sea surface temperature and model topography are shown in Fig. 2. The sea surface temperature is different from the climatic one in that the former has a strong-gradient zone with east-west orientation in the central part of the Japan Sea while the latter has a rather uniform gradient. The influence of the difference of sea surface temperature on the convergent cloud band is briefly mentioned in Section 2.

2. Result of the prediction experiment

In this section we see the result of a 36-hour prediction experiment from the initial field at 00GMT, January 24, 1984, together with the observation including special sounding data.

First let us describe the synoptic conditions. In Fig. 3 are shown 500-mb height (a) and sea-level pressure and 850-mb temperature (b) of the initial field of the prediction experiment, about 24 hours before the beginning of the heavy snowfall. At 500mb a blocking high-pressure over the Okhotsk Sea was moving westward. On its southern periphery a cold vortex over northeastern China elongated to the central Japan Sea on January 25. At the same time cold air advection in the lower troposphere

Fig. 3. Synoptic fields at 00GMT, January 24, 1984. a: 500-mb height (gpm), b: sea-level pressure (mb) (full lines) and 850-mb temperature ($^{\circ}\text{C}$) (dashed lines).

accompanied by air mass transformation over the Japan Sea and the Yellow Sea was intensified.

Under this condition a convergent cloud band developed east of the Korea Peninsula over the Japan Sea on January 25 and stayed there until the midday of January 26, undergoing a little fluctuation in intensity. On its southwestern edge a line of active convective clouds was noted in a routinely-constructed nephanalysis map at 12GMT, January 25 (Fig. 4). Heavy snowfall was observed around the landing area of the convergent cloud band (Fig. 5). Figs. 6a and 6b show a synoptic map at the surface and at 850mb, respectively, at the same time as the nephanalysis map. A surface pressure trough with surface wind convergence is seen along the line of active convective clouds (Fig. 6a). Along this trough we can see a warm area in the lower troposphere (Fig. 6b).

The numerical model well predicts these

Fig. 4. Routinely-constructed nephanalysis map at 12GMT, January 25, 1984. The areas painted black indicate active convective clouds. *CVD*: covered, *MCO*: mostly covered, *MOP*: mostly open and *OPN*: open.

Fig. 6. Synoptic maps at 12GMT, January 25, 1984. a: surface, b: 850mb. The trapezoidal area in the northwestern Japan Sea indicates where few observational data are available for analysis.

Fig. 5. Observed 6-hour precipitation (mm) from 06 to 12 GMT, January 25, 1984.

Fig. 7. 36-hour predicted fields for 12GMT, January 25, 1984. a: sea-level pressure (mb) and lowermost-level wind, b: 850mb height (gpm) (full lines), wind and temperature ($^{\circ}\text{C}$) (dashed lines). Wind vectors are drawn at every other grid point both in the X- and the Y- direction. The scale of wind speed is shown below the figure.

6-HR PRECIPITATION (mm) (PREDICTION) 06 - 12GMT JAN 25, 1984

Fig. 8. Predicted 6-hour precipitation (mm) from 06 to 12GMT, January 25, 1984. Full lines indicate precipitation by "large-scale condensation" and dashed lines that by moist convection.

950 mb DIVERGENCE (PREDICTION) 12 GMT JAN 25, 1984

Fig. 9. Predicted 950-mb divergence of horizontal wind ($\times 10^{-6} \text{sec}^{-1}$) at 12GMT, January 25, 1984. The shaded areas indicate that convergence exceeds $-30 \times 10^{-6} \text{sec}^{-1}$. * shows that ground is higher than the pressure level.

features (Figs. 7a, b). Fig. 8 shows predicted 6-hour precipitation (mm) from 06 to 12GMT, January 25 and Fig. 9 950-mb divergence of horizontal wind at 12GMT, January 25. A band of intense convective precipitation with low-level convergence is predicted nearly at the same position as the observed line of active convective clouds, while precipitation over the Japanese Islands is not predicted well. The defect in the prediction of precipitation over land may be due to lack of cloud physics in the prediction model and insufficient topographic effect of the model mountains in the Japanese Islands.

Fig. 10. Vertical profiles of potential temperature (K), equivalent potential temperature (K), specific humidity ($\times 10^{-3}$), relative humidity (%), wind direction and speed (m/sec) observed (full lines) by the ship (Keifu-maru, see Fig. 11 for its position) and those predicted by the model (dashed lines) at the corresponding grid point.

Fig. 11. Positions of two cross-sections (a thick full and a dashed straight line), observation stations and two regions for heat and water vapor budget analysis. A: Akita, R: Ryotsu, W: Wajima, K: Kanazawa, Y: Yonago and F: Fukuoka.

Over the central Japan Sea sounding was carried out during the period of the special observation on a ship (Keifu-maru, see Fig. 11 for its position). Fig. 10 shows the vertical profiles of potential temperature, equivalent potential temperature, humidity and wind observed by the ship and those predicted by the model at the corresponding grid point. We see good agreement of the prediction with the observation except for differences in very fine structure and a small but uniform difference in wind direction related to a prediction error in the large-scale field.

Next we compare vertical cross-sections of predicted temperature and wind with the observation.

Fig. 12. Vertical cross-section of potential temperature (a: observation, b: prediction) along the thick full line and that (c: prediction) along the dashed straight line shown in Fig. 11 at 12GMT, January 25, 1984. The areas sandwiched between two thick lines in the top panel indicate stable layers. $P^* = P_{\text{sea level}} - P$.

Fig. 12 shows potential temperature and Fig. 13 total wind speed (full lines) and southerly component of wind (dashed lines), respectively, at 12GMT, January 25. In order to exactly compare the prediction with the observation, first we make cross-sections along the thick full line connecting the observation stations indicated in Fig. 11. They are shown in the top (a; observation) and the middle (b: prediction) panel in Figs. 12 and 13. Characteristic patterns of the temperature and wind field around the conver-

Fig. 13. Same as Fig. 12 except for total wind speed (full lines) and southerly component of wind (dashed lines). The shaded areas indicate southerly wind.

gent cloud band are well predicted. Cross-sections in the bottom (c: prediction) panels are constructed along the straight dashed line in Fig. 11, which enable us to see the structure of the predicted convergent cloud band easily. In Figs. 14, 15 and 16 vertical cross-sections of static stability, divergence of horizontal wind and vertical component of relative vorticity for the prediction are shown, respectively.

We can point out the following characteristic features of the atmosphere around the convergent cloud band, some of which were already noted by Uemura (1980) (see Section 1) and

Fig. 14. Vertical cross-section of static stability $-\frac{1}{\theta} \frac{\partial \theta}{\partial p}$ ($\times 10^{-5} \text{ mb}^{-1}$) calculated from predicted potential temperature along the straight dashed line in Fig. 11 at 12GMT, January 25, 1984. The double thick line indicates the weak stable layer in cold airmass.

Fig. 15. Same as Fig. 14 except for divergence of horizontal wind ($\times 10^{-5} \text{ sec}^{-1}$).

Fig. 16. Same as Fig. 14 except for vertical component of relative vorticity ($\times 10^{-5} \text{ sec}^{-1}$).

others:

- a low-level convergence, middle-level divergence zone accompanied by intense positive vorticity along the line of active convection (Figs. 15, 16),

- a warm and weak-wind zone along the line of active convection embedded in cold airmass (Figs. 12, 13),

- a weak stable layer on the northeastern side of the line of active convection as a boundary between two layers: a lower layer with

northerly cold air flow toward the line of active convection and an upper layer with southwesterly warm air flow which has ascended in the line of active convection (Figs. 12, 13, 14),

- a west-northwesterly air flow on the southwestern side of the line of active convection with weak vertical wind shear and nearly neutral stratification up to the top of the cold airmass (Figs. 12, 13),

- a strong-wind zone at the divergent level (700-600mb) 300-500km northeast of the line of active convection (Fig. 13).

These features, together with a band of convective precipitation, are also predicted by the model using the climatic sea surface temperature which has a nearly uniform gradient, although they appear somewhat modestly (figures not shown).

We remember here that in the case of strong airmass transformation over the northwestern Japan Sea the blocking effect of the upstream mesoscale mountains produces a thermal contrast between south off Vladivostok and off Wonsan and that the thermal contrast intensifies the mesoscale circulation around the convergent cloud band locally (Nagata *et al.*, 1986). However, this thermal contrast will diminish gradually away from the Continental coasts.

Considering the above-mentioned facts, we infer that the characteristic wind system over the southern Japan Sea is mainly induced by the mesoscale warm zone which is maintained by localized release of latent heat, as described in Section 3.

Similar characteristic winds were observed in many cases of the Japan-Sea coastal heavy snowfall (e.g., Fukuda, 1966; Matsumoto and Ninomiya, 1967; Nagata, 1987). Matsumoto and Ninomiya (1967) pointed out that they are associated with a mesoscale warm core caused by convective heating in the dome shaped cold air. Yagi *et al.* (1986) also analyzed a case showing such a wind system.

At the end of this section we consider the difference between the prediction and the observation. If we define the top of the convergent cloud band by the upper boundary of the convectively mixed layer, the model predicts the top of the convergent cloud band somewhat lower than the observation (Fig. 12). There are

two possible explanations of the difference. One is that the values measured by a sonde were not representative of the grid-mean field due to convective scale disturbances. The other is the defects of the prediction model *e.g.*, coarse vertical resolution, cumulus parameterization and/or insufficient topographic effect. To examine the former possibility we have to make several soundings at a time in an area as large as one grid square of the model. The latter can be partly examined by the refined model with finer vertical resolution, *etc.*

3. Analysis of the predicted convergent cloud band

In this section we describe the mesoscale structure of the convergent cloud band in detail by making trajectory analysis and heat and moisture budget analysis.

First we calculate trajectories of air parcels which start from two levels (980mb and 850mb) over the central Japan Sea using three-hourly predicted wind fields. The levels are chosen to show the structure of the convergent cloud band efficiently. Fig. 17 shows 12-hour trajectories of air parcels which start from several points at 980-mb level over the central Japan Sea. From these trajectories we can make a schematic picture of

Trajectory

00 - 12GMT JAN 25, 1984

Fig. 17. 12-hour trajectories (from 00 to 12GMT, January 25, 1984) of air parcels starting from several points at 980-mb level over the central Japan Sea. Cross marks show hourly positions and numbers three-hourly pressure levels.

Fig. 18. Schematic picture of three-dimensional air flow based on the trajectories of air parcels which start from two levels (980mb and 850mb) over the central Japan Sea. The shaded surface shows the weak stable layer in cold airmass and the thick dashed line indicates the position of the line of active convection.

three-dimensional air flow (Fig. 18). Cold air parcels starting from the two levels on the north-eastern side of the line of active convection subside gradually, turning anticyclonically, enter the line of active convection, ascend rapidly and go out east-northeastward over the low-level cold air. On the other hand air parcels which have passed over the Korea Peninsula enter the line of active convection with a small angle, ascend rapidly and go along the southern periphery of the cloud band or go out east-northeastward over the low-level cold air like the air parcels from the northeastern side. This analysis shows that the two-layer structure on the north-eastern side is composed of low-level northerly cold air flow toward the line of active convection and middle-level west-southwesterly warm air flow which has already ascended in the line of active convection.

In Fig. 19 predicted 6-hour-mean convective heating profile is shown. On the northeastern side of the line of active convection, convective activity is confined below the weak stable layer indicated by the double thick line in the figure while convection reaches the top of the cold airmass on its southwestern side (see also Figs. 12 and 14). A very wet region is seen on the weak stable layer on the northeastern side of the line of active convection in the predicted moisture field (Fig. 20).

On the basis of the cross-section and trajec-

Fig. 19. Same as Fig. 14 except for 6-hour-mean diabatic heating by moist convection ($\times 0.1 \text{ K/hr}$) from 06 to 12GMT, January 25, 1984. The double thick line is drawn at the same position as Fig. 14.

Fig. 20. Same as Fig. 14 except for relative humidity (%). The double thick line is drawn at the same position as Fig. 14.

tory analyses, we can make a reliable schematic picture of the mesoscale structure of the convergent cloud band seen along the Japan-Sea coasts of the Japanese Islands (Fig. 21). We can obtain only grid-averaged airflow from the numerical model with parameterized convection.

Thus in this picture airflow resolved by the model and regions of convective activity are shown in the cross-section.

Fukatsu (1977) reported that on the northern side of the line of active convective clouds stratiform radar echoes are dominant while on its southern side convective echoes are prevailing. This feature can be derived from our model structure (Fig. 21). That is, in the middle-level wet region, which is located in the outflow of the line of active convection, stratiform clouds are expected to be maintained by water substance supply and slow upward motion, though the numerical model does not have cloud water content as a prognostic variable.

Along the southwest edge of the convergent cloud band convective activity is enhanced by low-level convergence. On the other hand convective activity is suppressed on its northeastern side. We can interpret the suppression of convection on the northeastern side of the line of active convection by calculating differential advection of equivalent potential temperature. The region *C* indicated in Fig. 11 (the area is $1.855 \times 10^4 \text{ km}^2$) includes the line of active convection and the region *N* (the area is $1.887 \times 10^4 \text{ km}^2$) covers its northeastern side. The area-mean generation of convective instability $\frac{\partial}{\partial t} \left(\frac{\partial \theta_e}{\partial p} \right)$ by differential advection between the fifth ($\sim 890 \text{ mb}$) and the seventh ($\sim 770 \text{ mb}$) layer is 0.592 K/100mb/hr for the region *C* and

Fig. 21. Schematic picture of the mesoscale structure of the atmosphere around the convergent cloud band seen along the Japan-Sea coasts of the Japanese Islands. Regions of convection and grid-scale air flow are shown. Double lines indicate stable layers. A wet and a dry region at middle levels are also shown by two kinds of shade.

$-0.533 \text{ K}/100 \text{ mb/hr}$ for the region N , respectively, at 09GMT, January 25, 1984. The negative generation of convective instability in the region N is mostly caused by horizontal advection. On the northeastern side of the line of active convection, convective instability is decreased by middle-level southerly warm air (high equivalent potential temperature) and low-level northerly cold air advection. The differential advection of equivalent potential temperature is associated with the aforementioned characteristic mesoscale circulation.

Note here that such a mechanism of suppressing convection hardly works on the southwestern side of the line of active convection, where convection reaches the top of the cold air mass. That is because according to the geostrophic thermal wind relation in the large-scale cold air advection field, middle-level large-

scale flow is supposed to be crossing from west to east the cloud band whose orientation is nearly parallel to the low-level large-scale flow and the middle-level flow is advecting the warm air to the east.

We also examine heat (potential temperature) and water vapor budget in the two regions. In this analysis subgrid-scale effects are averaged for six hours from 06 to 12GMT, January 25, while grid-scale advections are calculated from the instantaneous field at 09GMT, January 25. The exact balance is not attained because of a small but non-zero local time change, a small horizontal diffusion and the difference in time for evaluation between advection terms and subgrid-scale effects. Thus we only see the dominant terms in the quasi-steady state.

Figs. 22 and 23 show the result for the region C . In this region more than half of the

Fig. 22. Moisture budget in the region C shown in Fig. 11. Numbers show moisture flux ($\times 10^5 \text{ kg/sec}$) at the northeast (right) and the southwest (left) vertical boundary and at the horizontal boundaries between neighboring layers. Vertical transport of moisture by turbulent eddy diffusion is indicated by VD and moisture sink due to moist convection (black arrows) is indicated by MC with the same unit ($\times 10^5 \text{ kg/sec}$). Length of horizontal white arrows are proportional to moisture flux with the unit of g/kg-m/sec .

SENSIBLE HEAT SUPPLY FROM SEA SURFACE: (221 W/m^2)

Fig. 23. Heat budget (K/hour) in the region C shown in Fig. 11. VA means "vertical advection", HA "horizontal advection", VD "vertical turbulent eddy diffusion" and MC "moist convection". $G = VA + HA$, $S = VD + MC$.

condensed water vapor is supplied by low-level convergence although water vapor supply from the sea surface is not negligible. We can point out about the heat budget that strong cooling by vertical advection (by upward motion) as well as horizontal advection is nearly compensated by diabatic heating which is mostly composed of latent heat release. In contrast, in the region *N*, horizontal cold air advection overcomes diabatic heating (figures not shown).

These budget analyses indicate that over the southern Japan Sea the mesoscale thermal structure around the convergent cloud band is largely maintained by localized release of latent heat in large-scale cold air advection field.

4. Summary and discussions

In this paper we elucidate the structure of a convergent cloud band over the Japan Sea in winter, using the result of the prediction experiment, together with observed data including special soundings.

The atmosphere around the cloud band has the following characteristic features:

- a low-level convergence, middle-level divergence zone accompanied by intense positive vorticity along the line of active convection,
- a warm and weak-wind zone along the line of active convection embedded in cold airmass,
- a weak stable layer on the northeastern side of the line of active convection as a boundary between two layers: a lower layer with northerly cold air flow toward the line of active convection and an upper layer with southwesterly warm air flow which has been heated in the line of active convection,
- a west-northwesterly air flow on the southwestern side with weak vertical wind shear and nearly neutral stratification up to the top of the cold airmass,
- a strong-wind zone at the divergent level (700-600mb) 300-500km northeast of the line of active convection.

On the basis of cross-section and trajectory analysis, we can make a clear picture of the atmosphere around the cloud band.

Heat and water vapor budget analysis indicates that over the southern Japan Sea the mesoscale thermal structure around the cloud band is largely maintained by localized release

of latent heat in large-scale cold air advection field.

The predicted convergent cloud band is characterized by a warm zone with intense cyclonic horizontal shear (Figs. 12 and 16) rather than a typical front with a thermal gradient. In our prediction experiment a weak mesoscale front-like structure is seen on the northeastern side of the line of active convection as a result of the difference of history between two groups of air parcels originated from the same cold airmass over the Eurasian Continent. Hozumi and Magono (1984) presented a model of the convergent cloud band on the basis of the observation of cold air in the Korea Peninsula. Their model is different from ours but is similar to a typical front with a low-level wedge of colder air on the southwestern side. The author considers that their model is fit only for the cloud band formed very close to the Peninsula. The reason is that if it is formed at a long distance from the Peninsula (as in this case), airmass flowing from the Peninsula will undergo so much transformation along the fetch over warm sea that thermodynamic property will vary very much.

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冬期日本海上の収束雲帯の構造について（予報実験）*

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日本海上の収束雲帯に関連した北陸地方の大雪の例について、微格子ブリミティブモデルを用いて予報実験を行った。この論文では、特別高層観測を含む観測データとともに、予報実験の結果を用いて収束雲帯の構造を詳しく記述する。

収束雲帯のまわりの大気は次の特徴的な性質を持っている。すなわち、

- 対流活動の活発な線に沿う、強い正の渦度を伴った下層収束、中層発散の領域、
- 寒気中に位置する、対流活動の活発な線に沿う暖かくて風の弱い領域
- 対流活動の活発な線の北東側にある、二つの層の境界としての弱い安定層（二つの層とは、対流活動の活発な線に向かう北よりの寒気流の層と、すでにその中で加熱されてきた南よりの暖気流の層）、
- 南西側にある、鉛直シアが小さく、寒気の上面までほぼ中立の成層をした西北西流、
- 対流活動の活発な線の300–500km北東の発散レベル（700–600 mb）にある強風域。

断面図とトラジェクトリーの解析によって、雲帯のまわりの大気の明確な像が描ける。また、熱・水蒸気収支解析によって、日本海南部上では、収束雲帯のまわりのメソスケールの熱的な構造は、主に、大規模寒気移流場の中の局在化された潜熱の解放によって維持されていることがわかる。

* 本論文は「モデルによる大規模気象過程の研究に関する国際セミナー」（京都、1986年7月30日—8月2日）において発表された。