NOTES AND CORRESPONDENCE

Further Numerical Study on the Formation
of the Convergent Cloud Band over the Japan Sea in Winter

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Abstract

Further numerical experiments are performed to supplement the numerical study of Nagata *et al.* (1986) on the formation of the convergent cloud band (CCB) over the Japan Sea in winter. The purposes are to evaluate the relative contributions of the three lower boundary forcings (the land-sea thermal contrast, the blocking effect of the mesoscale mountains, and the characteristic SST distribution) to the formation of the CCB, and to investigate how the mountains north of the Korea Peninsula produce the low-level convergence zone.

Simulated mesoscale fields show that the contributions of each lower boundary forcing to the formation of the CCB are comparable. Convective heating is less important than sensible heating over the northwestern part of the Japan Sea in contrast with over the southern part. We make cross-section analyses and examine horizontal inertial stability of the CCB over the northwestern part of the Japan Sea. The dynamical effect of the mountains is shown to produce a local baroclinic environment, including a zone of near neutrality both to inertial and gravitational stabilities. Surface sensible heating appears to maintain the CCB in this zone. These findings suggest that the CCB is a mesoscale longitudinal roll parallel to the vertical shear vector associated with the local baroclinity.

1. Introduction

The formation mechanism of the convergent cloud band (CCB) over the Japan Sea in winter has attracted the attention of many meteorologists and forecasters, because the CCB often causes heavy snowfall on the Japan-Sea side of the Japan Islands under the east-Asian winter monsoon situation. Magono (1971) and Okabayashi (1972) proposed differential heating between land and sea as a key factor for its formation. Yamaguchi and Magono (1974) considered the formation of a mesoscale front due to the convergence of two cold air currents with different temperatures and Hozumi and Magono (1984) analyzed two cases of a CCB that has such a character. Nagata *et al.* (1986) made numerical experiments using models with different lower boundary conditions of the Korea Peninsula and showed that the land-sea contrast of thermal properties between the peninsula and the Japan Sea plays the leading role in the formation of the CCB. In the simulation study Nagata (1987) focused on the struc-

ture of the CCB and revealed the 3-dimensional airflow, verifying the result with an analysis of observations including special data collected by the Meteorological Research Institute. He demonstrated a major contribution of latent heat release to the maintenance of the mesoscale warm region along the CCB over the southern part of the Japan Sea. In this study we will show that the relative contribution of latent heat release decreases in the upstream direction and that it is less important than sensible heat supply over the northwestern part of the Japan Sea in contrast with over the southern part. Using the same model, Nagata¹ examined the influence of a zone of concentrated sea surface temperature (SST) gradients and found its positive effect on the intensification of the CCB in a preliminary study. Naito (1987) also emphasized the role of the zone of large SST gradients along 40°N latitude in making a pair of divergence and convergence regions that he analyzed by cloud motion vectors.

Yagi *et al.* (1986), on the other hand, made a de-

tailed analysis of geostationary satellite images and showed the close relationship between the Cu-Cb line embedded in the southern edge of the CCB and the air flow around the mesoscale mountains north of the Korea Peninsula (Hamgyong Range, Mt. Changbai, *etc.*). They raised the hypothesis that the CCB develops owing to the interaction between cumulus convection and a low-level convergence zone accompanied by a surface pressure trough. They considered that the low-level convergence is produced by the blocking effect of the mountains. By making experiments with and without the model mountains, Nagata *et al.* (1986) showed not only the importance of the blocking of stratified cold air by the mountains but also that of the subsequent differential diabatic heating over the northwestern part of the Japan Sea after the drainage of the cold air. However, their experiments were performed with the influence of the Korean Peninsula and the pure effect of the model mountains, therefore, could not be identified. A more serious problem might be the short integration time (12h) in their experiments. Thus, the relative contributions of the three lower boundary forcings (the thermal contrast between the Korean Peninsula and the Japan Sea, the blocking effect of the mesoscale mountains north of the peninsula and the characteristic SST distribution, *i.e.*, large gradients along 40°N latitude) to the formation of the CCB remain unexplored. For the purpose of evaluating the relative contributions of the lower boundary forcings, we design a set of numerical experiments in this study. Those include experiments with each single lower boundary forcing.

We use the same numerical model as Nagata *et al.* (1986) and Nagata (1987) except for the cumulus parameterization. The flux-form primitive equations are discretized on 13 σ -coordinate levels with their top at 100 mb and the model domain covers not only the whole Japan Sea but also a broad area surrounding it with 67×55 horizontal grid points at the interval of 42.3 km (60°N). The reader is referred to Nagata *et al.* (1986) for the physical processes incorporated in the model. For cumulus parameterization, we adopt a Kuo-type scheme (Geleyn, 1985) instead of Kurihara's (1973) moist convective adjustment used in the previous studies. In a preliminary study we compared the two schemes in the winter monsoon situation. We found that the latter accumulates somewhat more precipitation over the sea and less over the land than the former. The latter predicts worse the observed precipitation, at least over the land. The primary reason for this difference is that Kurihara's (1973) scheme adjusts unstable stratification by redistributing released latent heat only. Other simulated fields such as temperature and wind fields are almost the same between the two schemes. We integrate the numerical model for 36 hours, sufficient for prediction, so that the gen-

erated disturbance can be advected far downstream toward the Japan Islands. We choose the same case as Nagata (1987) (12 GMT 25 January 1984). The case is characterized by heavy precipitation in the Japan-Sea coastal region of central Japan due to a developed CCB.

2. Numerical experiments and results

Five numerical experiments (Exps. C, S, H, K and N) of 36-hour prediction are designed with different lower boundary forcings and performed from the identical initial field at 00 GMT 24 January 1984 shown in Fig. 3 of Nagata (1987). Exp. C is a control experiment with all the lower boundary forcings, *i.e.*, it includes the three factors: the Korean Peninsula, the mountains north of the peninsula and the characteristic SST distribution (large gradients along 40°N) seen in Fig. 2 of Nagata (1987). Exp. S includes only the characteristic SST distribution out of the three, Exp. H only the mountains north of the Korean Peninsula and Exp. K only the Korean Peninsula. As a standard for comparison, an experiment without any forcings of the three (Exp. N) is also carried out. In Exps. S, H and N, the Korean Peninsula is replaced by a sea surface whose temperature is interpolated linearly from the eastern and western sides. In Exps. S, K and N, ground elevation is limited to 600 m in the mountainous area north of the peninsula. In Exps. H, K and N, we use a climatic SST distribution, which has rather uniform gradients in the Japan Sea.

The predicted fields in the control experiment (Exp. C) resemble closely those shown in Figs. 7, 8, 9, 12c, 13c of Nagata (1987) except for the detail in precipitation. This means that the control experiment recaptures the observed mesoscale characteristic features to a good extent. Thus we skip the verification of the control experiment with observation. In order to evaluate the relative contribution of each lower boundary forcing to forming the CCB, first we make differences of wind and divergence between each experiment and Exp. N at 950 mb and 700 mb (Figs. 1 and 2). In Exp. N we see no significant mesoscale divergence or convergence field at these levels (figures not shown). This guarantees that the following differences of wind and divergence are primarily generated by each lower boundary forcing. The largest negative difference of divergence at 950 mb is seen over the northwestern and central parts of the Japan Sea in Exp. H-N (Fig. 1c). It is countered by a middle-level (700 mb) positive difference of divergence, although it changed into a middle-level negative difference of divergence downstream near the Japan Islands (Fig. 2c). The result shows that the effect of the mountains north of the Korean Peninsula in this study reaches farther downstream than that in Nagata *et al.* (1986), although the vertical circulation produced by the mountains is rather

Fig. 1. Differences of wind and divergence ($\times 10^{-6} \text{ s}^{-1}$) at 950 mb at 36h (12 GMT 25 January 1984). (a) Exp. C-Exp. N, (b) Exp. S-Exp. N, (c) Exp. H-Exp. N, and (d) Exp. K-Exp. N. The contour intervals are $3 \times 10^{-5} \text{ s}^{-1}$. A negative difference of divergence is light-shaded. Dark-shaded areas show where the model ground is higher than the pressure level.

shallow near the Japan Islands. In contrast, in the case of Exp. S-N, a zone of middle-level positive and low-level negative differences of divergence is extended in the NW-SE orientation over the central and southern parts of the Japan Sea with middle-

Fig. 2. As in Fig. 1 but for 700 mb.

level negative and low-level positive differences of divergence on both sides (Figs. 1b and 2b). This shows that the characteristic SST distribution forms a relatively deep circulation along the CCB except over the northwestern part. In Exp. K-N middle-level positive and low-level negative differences of divergence are seen on the northeastern side of middle-level negative and low-level positive differences of divergence over the Korean Peninsula and its downstream area (Figs. 1d and 2d). The differences of divergence at 950 mb are somewhat smaller near the Japan Islands than those of Nagata *et al.* (1986). We will discuss the reason for this in Section 4. It is

noteworthy that the sum of the differences does not necessarily agree exactly with the corresponding total difference between Exps. C and N. Disagreement is obvious just off the central part of the Japan Islands, *i.e.*, over the southern part of the Japan Sea. This is probably mainly due to the interaction of the vertical circulation with concentrated latent heat release in active convection.

Second, differences of temperature at 850 mb are examined (Fig. 3). As in the case of divergence, we see no significant mesoscale temperature variation in Exp. N, where we see naturally rather uniform temperature gradients in the downstream direction. In the temperature difference field of Exp. S-N we see a negative difference along the zone of large SST gradients (Fig. 3b). This is due to less air-mass modification on the cold side of the gradients. The Korean Peninsula produces another negative difference of temperature that spreads not only over the peninsula but also over western Japan (Fig. 3d). Obviously the cold land surface of the peninsula creates this negative temperature difference. By contrast, the mountains north of the peninsula produce an area of positive difference over the northwestern and central parts of the Japan Sea (Fig. 3c). We will examine the dynamical role of the mountains on the temperature field in Section 3. We find that each negative temperature difference is collocated with middle-level negative and low-level positive divergence, accompanied by divergence of the opposite signs on both sides, and vice versa. This suggests that the vertical circulations derived from the divergence difference fields are induced by the mesoscale temperature differences that are produced by the diabatic processes (air-mass modification) and the dynamical process (blocking by the mountains). We note that the amplitude and spatial scale of the simulated mesoscale variations due to each forcing are comparable with each other. This means that the relative contribution of each lower boundary forcing to the formation of the CCB is comparable with each other in this case. We may not neglect any of the three lower boundary forcings in considering the formation mechanism of the CCB.

The next question may be how much convective heating along the convergence zone contributes to enhancing the CCB circulation. This is examined by rating the convective heating to the other diabatic process, *i.e.*, surface sensible heating, which is also responsible for the formation of the CCB through differential diabatic heating. Over the northwestern part of the Japan Sea, convective heating is negligible when compared with surface sensible heating in Exp. C (Figs. 4a and 5a). Convective heating has grown to compete with surface sensible heating over the central part of the sea (Figs. 4b and 5b) and finally to surpass surface sensible heating over the southern part (Figs. 4c and 5c). Thus convective

Fig. 3. Difference of temperature ($\times 0.1$ K) at 850 mb at 36h (12 GMT 25 January 1984). (a) Exp. C-Exp. N, (b) Exp. S-Exp. N, (c) Exp. H-Exp. N, and (d) Exp. K-Exp. N. The contour intervals are 0.5 K. A negative difference (colder) is light-shaded.

heating contributes considerably to enhancing the CCB over the southern part of the Japan Sea, while it is less important than surface sensible heating over the northwestern part. The latter point will be confirmed in the next section.

3. Further experiments on the role of the mountains north of the Korean Peninsula

In the previous section the mountains north of the Korean Peninsula are shown to play a significant

Fig. 4a-c. Diabatic heating by vertical diffusion ($\times 0.1 \text{ K h}^{-1}$) at 36h (12 GMT 25 January 1984) in Exp. C. (a) cross-section A, (b) cross-section B, and (c) cross-section C. The contour intervals are 0.25 K h^{-1} .

role in the formation of the CCB. In this section we investigate how the mountains produce the vertical circulation associated with the CCB by comparing two further experiments with Exp. H.

Processes that are possibly important for the formation of the CCB are 1) blocking of stratified fluid, 2) retardation of cold-air advection, 3) interaction between cumulus convection and mass and momentum fields distorted by the processes 1) and 2), and 4) interaction between surface sensible heating and the distorted fields. The hypothesis by Yagi *et al.* (1986) corresponds to 3). In the case of Exps. H and C both processes 1) and 2) obviously work to create the warm region in the lee of the mountains. Then, two experiments (HSH and HNH) are designed to isolate the processes 3) and 4), respectively. Both experiments are the same as Exp. H except that only sensible heat is supplied at surface in Exp. HSH while no surface heating is permitted in Exp. HNH.

Fig. 5a-c. As in Fig. 4 but for diabatic heating by cumulus convection.

In Exp. H latent heat as well as sensible heat is supplied at surface. In the case of Exp. HSH we use the same SST distribution as that of Exp. H, *i.e.*, a climatic SST that has rather uniform gradients in the Japan Sea.

Figures 6, 7 and 8 shows SW-NE vertical cross-sections of the predicted fields over the northwestern part of the Japan Sea for Exps. H, HSH and HNH, respectively. In Exp. HSH a strong vertical circulation is formed (Figs. 7b, 7c and 7d) whose intensity is comparable with that in Exp. H (Figs. 6b, 6c and 6d), while only a much weaker one is observed in Exp. HNH (Figs. 8b, 8c and 8d). The diabatic heating profile in Exp. HSH (Fig. 7e) also resembles that in Exp. H (Fig. 6e). These experiments verify that latent heat release is less important than sensible heat supply over the northwestern part of the Japan Sea and that surface sensible heating is necessary to the formation of the CCB circulation besides the adiabatic processes 1) and 2). This result supports the process 4) for the formation mechanism of the CCB over the northwestern part of the Japan

Fig. 6a-e. Vertical cross-sections of predicted fields in Exp. H at 36h (12 GMT 25 January 1984) along the vertical plane A shown in Figs. 4 and 5. (a) potential temperature (K), (b) wind components (m s^{-1}), (c) vertical velocity (mb h^{-1}), (d) one-hour displacement vectors in the cross-sectional plane, and (e) total diabatic heating ($\times 0.1 \text{ K h}^{-1}$). In panel b, solid lines denote contour lines of the wind component parallel to the cross-sectional plane and dashed lines denote those normal to it. The short thick line at the bottom of each panel indicates the position of the Korean Peninsula, which is removed in Exp. H.

Fig. 7a-e. As in Fig. 6 but for Exp. HSH.

Sea. On the other hand, latent heat release plays a significant role over the central and southern parts of the Japan Sea, as shown in Section 2.

Next we focus on the dynamical effect of the mesoscale mountains north of the Korean Peninsula. Even in Exp. HNH, distortions of temperature and wind fields naturally occur (Figs. 8a and 8b), which are produced by the adiabatic processes 1) and 2). The drainage of the coldest airmass occurs just to the east of the mountains (indicated by "X" in Fig. 8a) owing to the Coriolis acceleration acting on the ageostrophic momentum of blocked low-level air in the environment of cold advection

Fig. 8a-e. As in Fig. 6 but for Exp. HNH. See text for explanation of labels "X", "Y" and "Z".

(Smith, 1982; Yagi *et al.*, 1986). Meanwhile, relatively warmer air comes from higher levels down to low levels (as inferred by Yagi *et al.*, 1986) and also warm air stagnates behind (downstream of) the mountains (indicated by "Y" in Fig. 8a). As a result, a local baroclinic zone with NE-SW thermal gradients is formed between these cold and warm airmasses. Wind and mass fields must be out of balance around the mesoscale mountains. However, they adjust themselves to a good extent except near the mountains long after the blocking of cold air advection initiates, as will be shown in the next sec-

tion. Thus, the mesoscale mountains act to create a local baroclinic environment extended in the downstream direction. In the next section we will examine inertial stability in this local baroclinic zone first and then discuss the role of the surface sensible heating in the formation and maintenance of a mesoscale longitudinal roll parallel to the vertical shear vector associated with this zone.

4. Discussion

An interesting salient feature in Exp. HNH is a zone of large anticyclonic horizontal shear (indicated by "Z" in Fig. 8b) embedded in the cold air side of the local baroclinic zone. The anticyclonic horizontal shear should work to reduce horizontal inertial stability. In order to evaluate the inertial stability in this zone, we calculate absolute momentum, defined as $u - fy$ and geostrophic absolute momentum $u_g - fy$, where u is the wind component normal to the cross-sectional plane and u_g its geostrophic component, f the Coriolis parameter and y the horizontal coordinate parallel to the cross-sectional plane (Fig. 9). We find that the normal component of wind (Fig. 9a) is approximately in the geostrophic balance (Fig. 9c). The most interesting feature is seen around "Z" in Figs. 9b and 9d, where contours of absolute momentum are apart from each other and they are rather more horizontal than vertical. This shows that the anticyclonic-shear zone is actually nearly neutral to horizontal inertial stability. Parcels are very easy to move horizontally in this zone.

The addition of surface heating reduces the vertical stability. If the stratification approaches neutral owing to surface heating, as seen in Exp. HSH (Figs. 7a and 7e), the isentropic surfaces incline more and may finally become steeper than absolute momentum surfaces, meeting the requirement of symmetric instability. In Exp. HSH therefore the direct vertical circulation associated with the CCB may have the character of this instability. Actually, the roll axis of the vertical circulation is parallel to the thermal wind vector associated with the local baroclinity, suggesting the possible occurrence of the instability. The trigger of the vertical circulation is probably the adjustment process of the dynamical imbalance caused by the mountains (Yagi *et al.*, 1986). If we want to detect evidence of the occurrence of the instability, we must do a detailed analysis of energy conversion. However, the analysis is beyond the scope of this study and is left for future research. In the present case the requirement for instability is met, without latent heat effect, primarily owing to the anticyclonic horizontal shear created by the local topography. This is rather special and at variance with conditional symmetric instability advanced by Bennetts and Hoskins (1979), who introduced latent heat effect to relax the criterion for instability.

Parcels gain sensible heat continuously over the

Fig. 9. Momentum and absolute momentum (m s^{-1}) normal to the cross-sectional plane A at 36h (12 GMT 25 January 1984) in Exp. HNH. (a) momentum (u), (b) absolute momentum ($u - fy$), (c) geostrophic momentum (u_g), and (d) geostrophic absolute momentum ($u_g - fy$). The contour intervals are 2 m s^{-1} . See text for explanation of label "Z".

warm sea surface as they move from the cold-air to the warm-air side in the lower branch of the vertical circulation in the longitudinal roll (Figs. 7d and 7e). The heating appears to maintain the local baroclinity. Emanuel (1986, 1989) advanced a theoretical model of air-sea interaction instability for tropical cyclones and polar lows, in which a finite-amplitude vortex survives frictional dissipation in a symmetrically neutral situation. The role of surface heating in keeping the baroclinic zone in this case looks sim-

ilar to that in his theoretical model.

The results presented above suggests that the CCB over the northwestern part of the Japan Sea may be interpreted as a mesoscale longitudinal roll that is maintained by surface sensible heating in the zone of near neutrality both to inertial and gravitational stabilities. The longitudinal roll looks similar to the roll convection in vertical-shear flow studied by Asai (1970a, b and 1972) for idealized situations and by Yagi (1985) for a real atmosphere, in that their axes are both parallel to the vertical shear vector of horizontal component of wind. However, the mesoscale longitudinal roll in this study has the following different characteristics: it is maintained by surface heating in the zone of neutral stratification and near neutral *horizontal* inertial stability and it is triggered by the imbalance produced by the blocking effect of the mesoscale mountains. The formation mechanism of the CCB over the northwestern part of the Japan Sea therefore has some correspondence with the hypothesis proposed by Yagi *et al.* (1986) except for the heating process and the inertial stability.

The present study shows that the amplitude and spatial scale of the mesoscale variations due to each forcing are comparable with each other. This means that the previous numerical study (Nagata *et al.*, 1986) overrated the effect of the Korean Peninsula and underrated that of the mountains north of it to some extent. We may discuss some reasons for this. 1) The integration time (12h) in Nagata *et al.* (1986) was too short for the disturbance generated by the mountains to be advected far enough downstream. 2) When Nagata *et al.* (1986) examined lower boundary factors such as roughness and thermal property at the Korean Peninsula, they removed the model mountain in the Korea Peninsula, not that north of the peninsula, shown in Fig. 3 of their paper. This increases the volume of movable cold airmass over the Korean Peninsula and consequently enhances the low-level outflow from the local high pressure over the peninsula and its downstream area. The change in divergence due to this can be seen in Fig. 16a of Nagata *et al.* (1986), if the signs are reversed. 3) The cumulus parameterization scheme (Geleyn, 1985) in this study is different from that of Nagata *et al.* (1986). The moist convective adjustment (Kurihara, 1973), incorporated in the latter, releases slightly excessive latent heat over a warm sea surface in cold seasons. The excessive net heating over sea should result in the overestimation of differential diabatic heating between sea and land.

5. Concluding remarks

In this numerical study we evaluate the relative contributions of the three lower boundary forcings (the land-sea thermal contrast, the blocking effect of the mesoscale mountains and the characteristic

SST distribution) to the formation of the CCB and investigate how the mountains north of the Korean Peninsula produce the low-level convergence zone.

Simulated mesoscale fields show that the contributions of each forcing are comparable. Convective heating is shown to be less important than sensible heating over the northwestern part of the Japan Sea, in contrast with over the southern part. Over the northwestern part of the Japan Sea, the dynamical effect of the mountains produces a local baroclinic environment including a zone of near neutrality both to inertial and gravitational stabilities and a longitudinal roll parallel to the vertical shear vector is maintained by surface sensible heating in this zone. These findings suggest that the CCB over the northwestern part of the Japan Sea may be interpreted as a mesoscale longitudinal roll parallel to the vertical shear vector associated with the local baroclinity.

Finally we also make the same numerical experiments with the same model as described so far for another heavy-snowfall case (19–20 January 1983), which was chosen in the numerical study of Nagata *et al.* (1986). We obtain qualitatively the same results (figures not shown) as those in the case of 24–25 January 1984.

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References

- Asai, T., 1970a: Three-dimensional features of thermal convection in a plane Couette flow. *J. Meteor. Soc. Japan*, **48**, 18–29.
- Asai, T., 1970b: Stability of a plane parallel flow with variable vertical shear and unstable stratification. *J. Meteor. Soc. Japan*, **48**, 129–139.
- Asai, T., 1972: Thermal instability of a shear flow turning the direction with height. *J. Meteor. Soc. Japan*, **50**, 525–532.
- Bennetts, D.A., and B.J. Hoskins, 1979: Conditional symmetric instability—a possible explanation for frontal rainbands. *Quart. J. Roy. Meteor. Soc.*, **105**, 945–962.
- Emanuel, K.A., 1986: An air-sea interaction theory for tropical cyclones. Part I: Steady-state maintenance. *J. Atmos. Sci.*, **43**, 585–604.
- Emanuel, K.A., 1989: Polar lows as arctic hurricanes. *Tellus*, **41A**, 1–17.
- Geleyn, J.-F., 1985: On a simple, parameter-free partition between moistening and precipitation in the Kuo scheme. *Mon. Wea. Rev.*, **113**, 405–407.
- Hozumi, K., and C. Magono, 1984: The cloud structure of convergent cloud bands over the Japan Sea in winter monsoon period. *J. Meteor. Soc. Japan*, **62**, 522–533.
- Kurihara, Y., 1973: A scheme of moist convective adjustment. *Mon. Wea. Rev.*, **101**, 547–553.
- Magono, C., 1971: On the localization phenomena of snowfall. *J. Meteor. Soc. Japan*, **49**, 824–835.
- Nagata, M., 1987: On the structure of a convergent cloud band over the Japan Sea in winter; a prediction experiment. *J. Meteor. Soc. Japan*, **65**, 871–883.
- Nagata, M., M. Ikawa, S. Yoshizumi and T. Yoshida, 1986: On the formation of a convergent cloud band over the Japan Sea in winter; numerical experiments. *J. Meteor. Soc. Japan*, **64**, 841–855.
- Naito, S., 1987: The influence of the sea surface temperature on the cloud distribution over the Sea of Japan in winter season. (case study) *Meteorological Satellite Center Technical Note*, **15**, 79–86 (in Japanese).
- Okabayashi, T., 1972: Snow clouds seen from meteorological satellites and their application to the research on snowfall. *Kisyo Kenkyu Note*, **113**, 74–106 (in Japanese).
- Smith, R. B., 1982: Synoptic observations and theory of orographically disturbed wind and pressure. *J. Atmos. Sci.*, **39**, 60–70.
- Yagi, S., 1985: Large-scale snow clouds with roll axes roughly perpendicular to the direction of winter monsoon burst: observational studies of convective cloud roll axes and some theoretical consideration. *Tenki*, **32**, 175–187 (in Japanese).
- Yagi, S., T. Muramatsu, T. Uchiyama and N. Kurokawa, 1986: “Convergent band cloud” and “Cu–Cb line” over Japan Sea affected by topographic features in the coast of the Asian continent. *Tenki*, **33**, 453–465 (in Japanese).
- Yamaguchi, K., and C. Magono, 1974: On the vortical disturbances in small scale accompanied with the meso scale front in Japan Sea in winter season. *Tenki*, **21**, 83–88 (in Japanese).

冬期日本海上の収束雲帯の形成についての 数値的研究（追加）

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Nagata *et al.* (1986) の冬期日本海上の収束雲帯の形成に関する数値的研究を補うため、追加の数値実験を行なった。目的は、収束雲帯の形成に対する 3 つの下面境界の強制力（海陸の熱的対照、メソスケールの山によるブロッキング効果、及び特徴的な海面水温分布）の相対的な寄与を評価すること、及び、朝鮮半島北方の山岳が下層の収束帯をどのようにして作るかを調べることである。

モデルで再現されたメソスケールの場合は、収束雲帯の形成に対する下面境界の各強制力の寄与が、互いに同程度であることを示している。また、日本海の北西部では南部とは対照的に、積雲対流による加熱が顕熱加熱より小さい。さらに、日本海北西部の収束雲帯について断面図解析と水平慣性安定度の解析を行なった。それによると、山岳の力学的な効果によって局所的な傾圧場が作られ、その中に慣性安定度と重力安定度が中立に近い領域が形成されている。この領域で海面からの顕熱加熱が収束雲帯を維持しており、これらのことから、収束雲帯はシアベクトルに平行なメソスケールのロールであることが示唆された。