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ANALYSIS OF A WELL DEVELOPED COLD VORTEX OVER THE SOUTH-WESTERN PART OF JAPAN

By

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Abstract

We have analysed an example of extraordinary strong upper cold vortex. Such a strong cold vortex occurs when the westerly wave over East Asia develops extremely and the cut-off cold vortex thus formed comes down to reach the south coast of Japan. In such a case heavy snow falls in front of the upper cold vortex, but it is dry in the vortex. On the other hand, when a cold vortex moves over the Japan Sea without extreme development, heavy snow falls mainly in the cold vortex. The difference of these two types of upper cold vortices is explained in this paper.

1. Introduction

The structure of cold vortices in well developed atmospheric waves have been studied by many authors (Hsieh [1949], Palmen [1951], Omoto [1966]). For the cold vortices passing near Japan, Matsumoto *et al.* [1965] have analysed the effect of the supply of heat from the Japan Sea and the relation of heavy snow fall along the Japan Sea coastal region to these cold vortices. Such cold vortices pass over the Japan Sea several times in a year.

We analysed a much developed cold vortex passing over the south-western part of Japan. It is very rare that the trajectories of the centers of cold vortices come down to such low latitudes as in this case. In such a developed cold vortex, the centrifugal force due to the rotation of the vortex is so strong that the subsidence of the cold core due to gravitational force is not particularly remarkable. The time it took this vortex to pass over the sea was shorter than that of vortices passing over the Japan Sea. So the structure of this cold vortex was similar to the structures of those passing over the North American Continent, as analysed by many authors, rather than to those analysed by Matsumoto and his collaborators. In the latter cases heavy snow occurred near the centers of the upper cold vortices. But in our case, heavy snow or rain occurred in the band region between the surface cold front and the eastern boundary wall of the cold vortex. Our results show that an analysis of the trajectory and the intensity of the cold vortex are important for the forecasting

of heavy snow.

2. Formation and life history of the cold vortex

On Mar. 13, 1965, a cut-off cold vortex had developed to its matured state at the location of 60°E, 55°N in Europe. The height of 500 mb surface was 5040 m near the center. The center of active oscillation moved to Asia, and the ridge at 100°E and the trough at 120°E were intensified rapidly on Mar 14. In this deep trough a cut-off cold vortex was created and moved southward (not eastward). The westerly wave became more and more amplified at 120°E.

Figs. 1-2 are the 500 mb charts at 12 GMT Mar. 14 and 15, 1965. In Fig. 1 the successive positions of the center of the cold vortex are also shown. Thus the center moved southward to arrive at the East China Sea, then changed

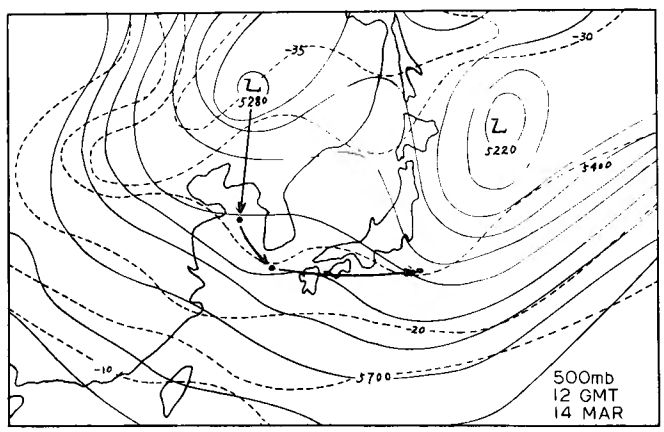


Fig. 1. 500 mb charts at 12 GMT Mar. 14, 1965. Solid lines are contours, and dashed lines are isotherms. Arrows indicate movement of center of circulation.

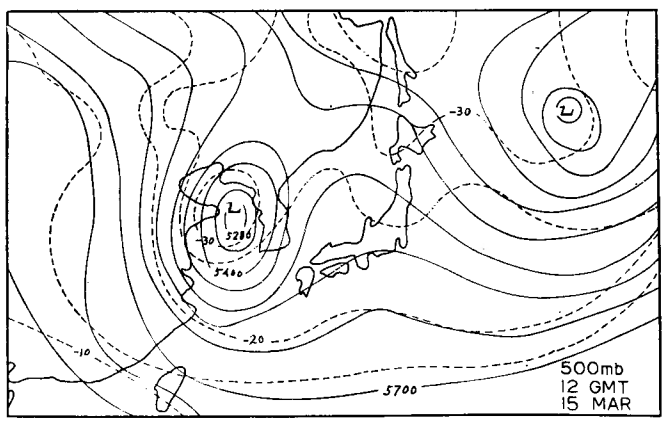


Fig. 2. Same as Fig. 1. but for Mar. 15.

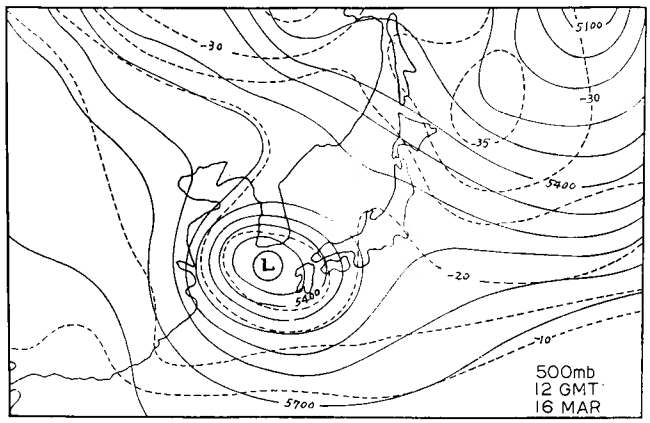


Fig. 3. Same as Fig. 1. but for Mar. 16.

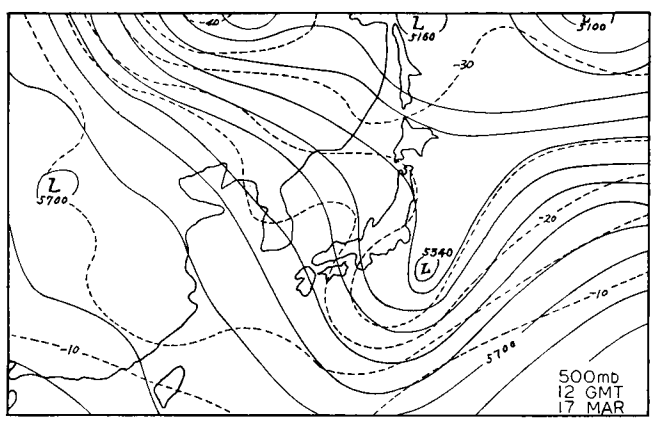


Fig. 4. Same as Fig. 1. but for Mar. 17.

direction and moved eastward along the south coast of the Japan Islands. In the winter season cold vortices often pass over the Japan Sea but seldom move along such a southern course as in this case.

Fig. 3 shows the 500 mb chart at 12 GMT Mar. 16. The developed cut-off cold vortex is seen to be surounded by a strong jet stream. The wind velocities along the jet stream axis are 30~50 m/sec, and in the southern part of the jet stream the wind is especially strong.

As shown in Fig. 4 (500 mb chart at 12 GMT Mar. 17) this vortex gradually decayed on Mar. 17. Then the cut-off vortex disappeared and became transformed into an ordinary trough. On Mar. 18 the other cold vortex came down from Siberia. This vortex did not reach the south-western part of Japan but moved over the Japan Sea. From Figs. 1-4 it can be seen that in the strongest stage (on Mar. 16) the contour lines and the isotherms coincide closely but in the earlier and latter stages the center of cold air deviates to the western side

of the center of circulation.

3. Structure of the cold vortex

Fig. 5 shows the vertical time section at Shionomisaki from Mar. 15 to Mar. 18, 1965, and Fig. 6 shows the vertical E-W cross-section through the center of the cold vortex at 12 GMT Jan 24, 1963 as analysed by Matsumoto and his collaborators. In the latter case heavy snow fell along the northern coast of the Japan Islands (Hokuriku district), but in our case heavy snow or rain concentrated in a much more southerly area of the country (central area of the Kinki-district). When these two cross-sections are compared, it can be noted that in our case the shape of the cold vortex is more simple and its intensity is stronger. The wall-shaped side boundary of the cold vortex is nearly perpendicular between 850 mb and 500 mb levels, and the axis of strong wind outside the wall in the cross-section is also nearly perpendicular between 1000 and 400 mb levels, while the wind speed is very high even near the surface. These features of the structure of this cold vortex are rather similar to those of the cold vortices over the North American Continent analysed by Palmen and others. In Fig.

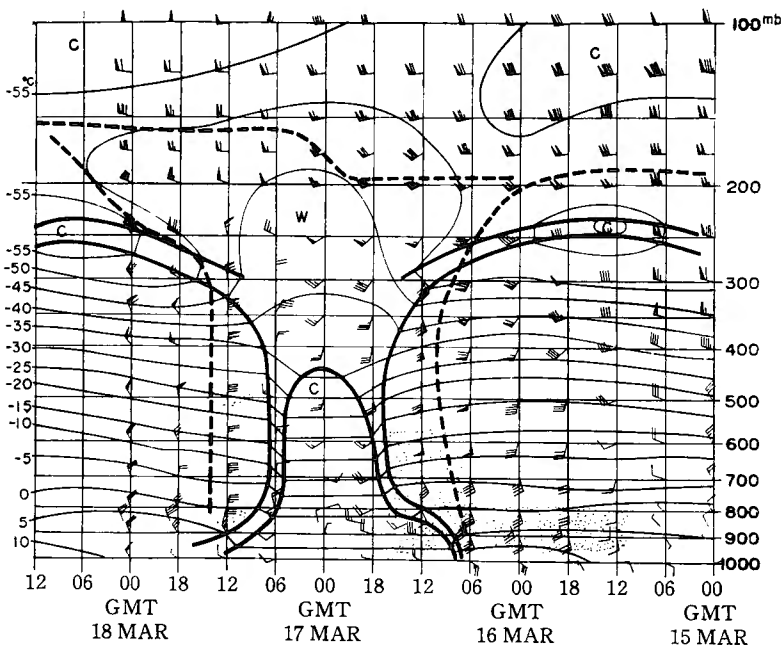


Fig. 5. Vertical time section at Sinonomisaki from Mar. 15 to Mar. 18, 1965. Heavy lines indicate boundaries of cold dome and tropopauses, thin lines indicate isotherms. Heavy dashed lines are axis of jet stream and axes of strong wind outside the cold dome. Wet portion with a humidity of more than 80% is indicated by stippling.

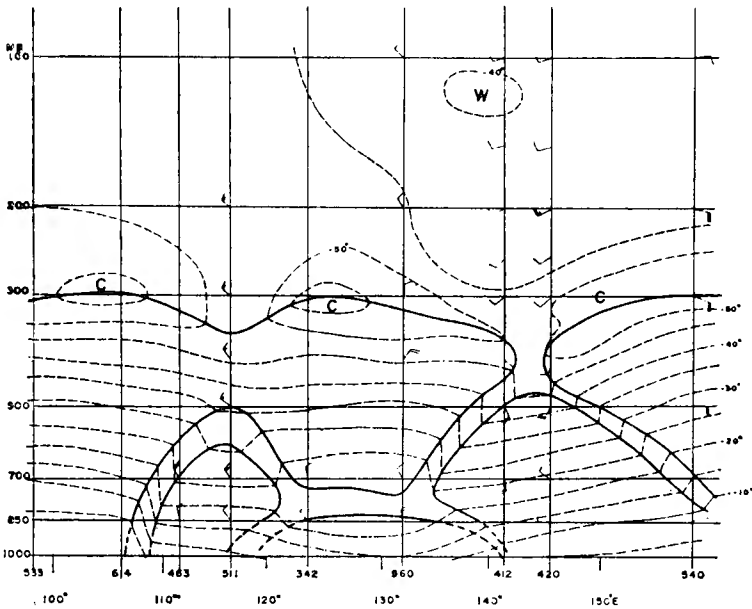


Fig. 6. Vertical west-east cross-section through center of cold vortex at 12 GMT Jan. 24, 1963, which is analysed by Matsumoto and his collaborators. Heavy lines are boundaries of stable layers, thin dashed lines are isotherms.

5 the wet portion, with a humidity of more than 80%, is concentrated in the band region outside the wall of the cold vortex, but in the cold dome it is very dry. This fact will be discussed in the next section in relation to cloud formation. On the other hand, in Fig. 6 the wet portion is found to exist in the cold dome also, and the stable layer on the cold dome is bounded by the top of the clouds in the cold dome.

We suppose that these differences between the two cases are caused by three factors. The first is the difference between the intensities of the vortices. In the strong cold vortex the centrifugual force of rotation near the top of the cold dome is so strong that the subsidence of the cold air mass is not remarkable, so that warming by subsidence never occurs in the lower part of the cold vortex. The second factor is the supply of heat from the sea surface. When a cold vortex passes over the Japan Sea it is much deformed in its lower portion, as explained by Matsumoto and others. But when a cold vortex passes almost wholly over the land, it is less deformed.

The third factor is explained by the analysis of charts 700 mb (Fig. 7) and 850 mb (Fig. 8) at 12 GMT Mar. 16. 700 mb chart shows that two vortex centers exist, the eastern one of which can be traced from Mar. 15 as indicated by the arrow in Fig. 7. Another center in the western part of the vortex

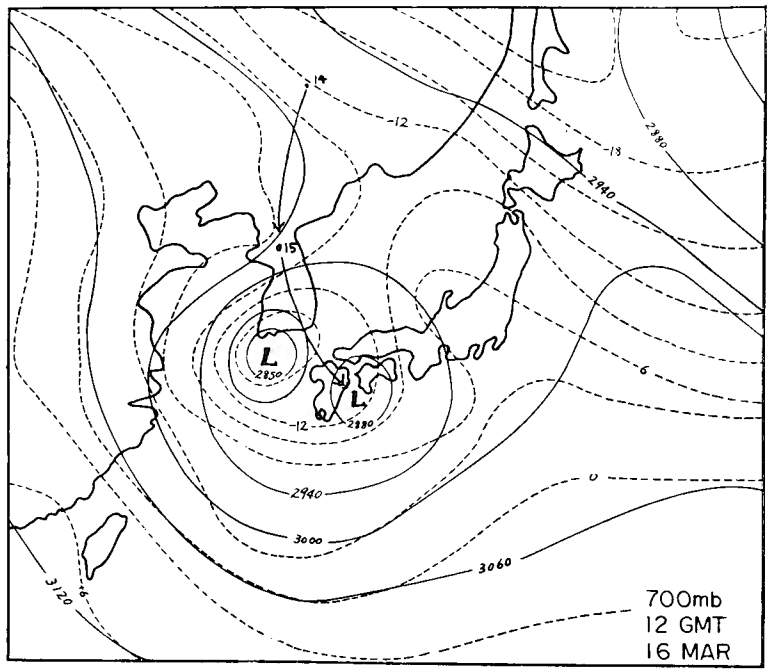


Fig. 7. 700 mb chart at 12 GMT Mar. 16, 1965. See Fig. 1 for explanation.

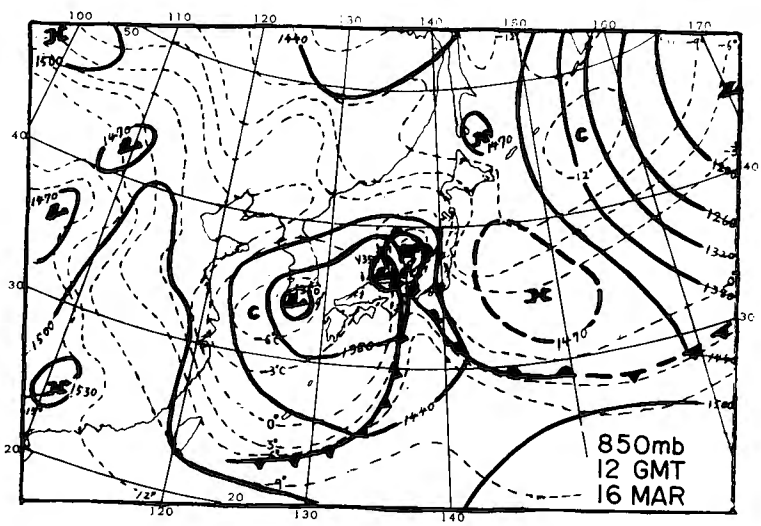


Fig. 8. Same as Fig. 7 but for 850 mb.

is a newly created center caused by the intensification of the upper cold vortex, so its position is coincides closely with that in the 500 mb surface. But, generally speaking, the contour lines and isotherms coincide closely. This coincidence did not occur on Mar. 15 or Mar. 17, but only in the strongest stage of the

upper cold vortex. The 850 mb chart in Fig. 8 shows the pattern of the occluded type of cyclone. The center of this cyclone can be traced from several days previous, but another center of circulation appears in the central region of cold air as in the 700 mb chart. We can explain this fact as follows. The upper cut-off cold vortex came down with increasing intensity and the wall of the upper cold dome was combined with the lower cold front of the pre-existing cyclone. This is proved when we analyse the vertical time cross-section through Fukuoka, which shows the structure in the earlier stage. In this case the inclination of the boundary of the cold dome is not so steep as that in the case of Shionomisaki shown in Fig. 5. On the other hand, the structure in the later stage shown in the vertical time cross-section through Hachijojima is more complicated. The lower portion of the cold dome is not so distinct, and the eastern half of the lower portion with a southerly wind is warmer and the western half with a northerly wind is colder.

4. Cloud distribution near the cold vortex

Fig. 9 shows the radar echoes for every ten minutes from 23 50 GMT Mar. 15 to 06 00 GMT Mar. 16, of PPI scope at Muroto. Range circles are for each 50 km. Near the eastern coast of Shikoku, it is seen as a stationary line-shaped echo caused by the orographic horizontal convergence of a strong southeasterly wind. But the two line-shaped echoes located very close to each other are seen to move eastward, and the positions of these echoes coincide closely with the position of the surface cold front. As it can be seen from the echoes for 04 to 05 GMT, the rear line-shaped edge of the all cloud mass is also very distinct. This rear edge coincides closely with the eastern wall of the cold vortex. This fact also proves the absence of cloud in the cold vortex as we saw in the vertical cross-section (Fig. 5). The radar observations show that the top of the line-shaped echoes over the surface cold front are very high, but the tops of the other echoes are not so high. When we observe the continuous movements of each echo through a cinematic projector, we see that all the echoes in the above-mentioned line echoes move northward along this line over the surface cold front, but nearly all the scattered echoes in front of the surface cold front move approximately to the north west. This fact establishes the existence of the horizontal convergence of the streams along the surface cold front. Moreover, hail with a diameter of 8 mm was observed at 0148 Mar. 16 at Muroto. This fact also proves the existence of both a violent upward motion and the horizontal convergence near the surface cold front. Now we can draw a schematic model of cloud distribution in front of the upper cold vortex as shown in Fig. 10. Nakayama [1966] also analysed the same cold vortex using data ob-

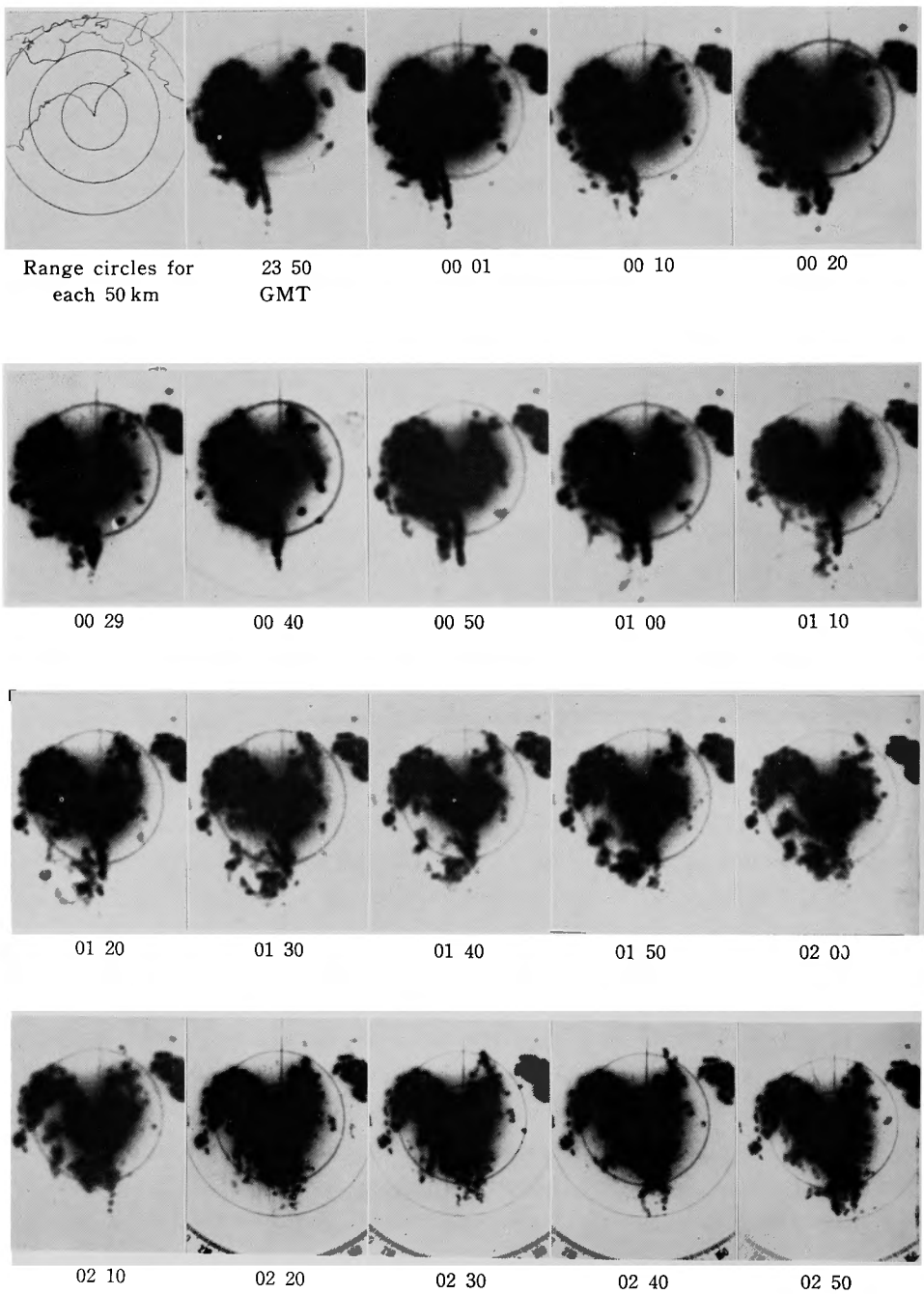
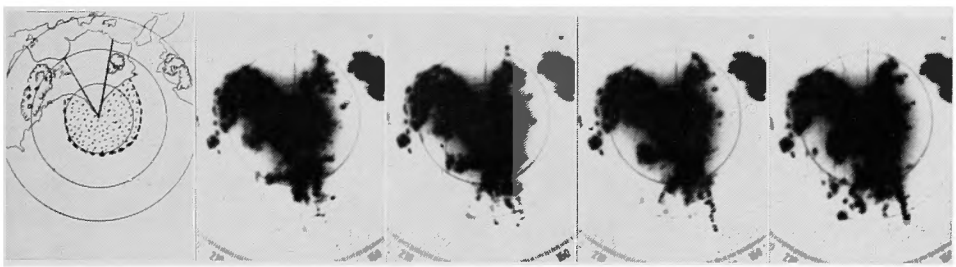


Fig. 9. Radar echoes for every ten minutes from



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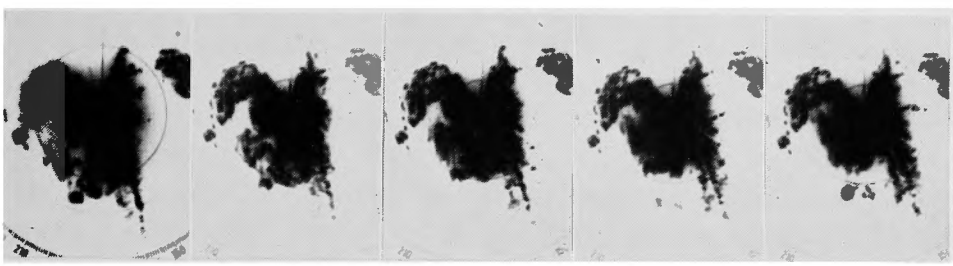

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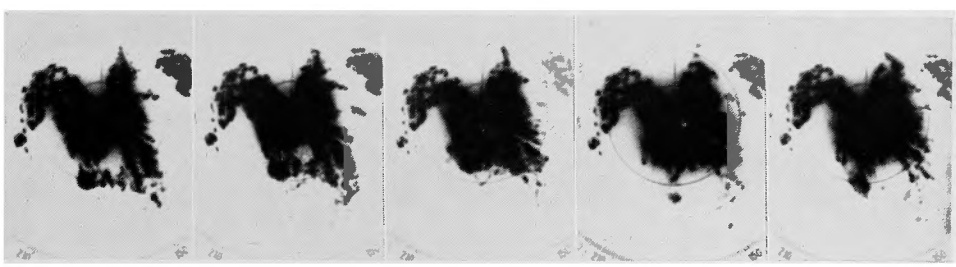

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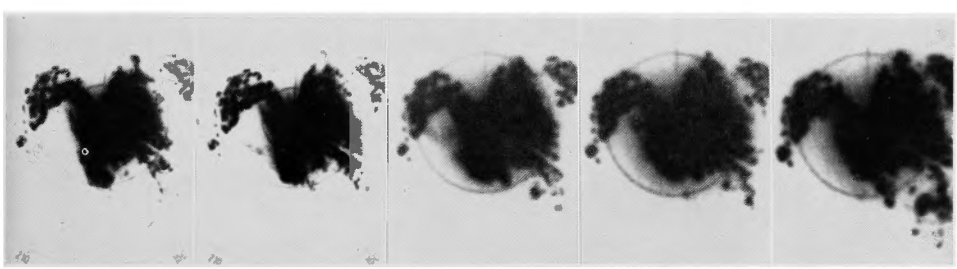

05 20 | 05 30 | 05 40 | 05 50 | 06 00

23 50 GMT Mar. 15 to 06 00 GMT Mar. 16.

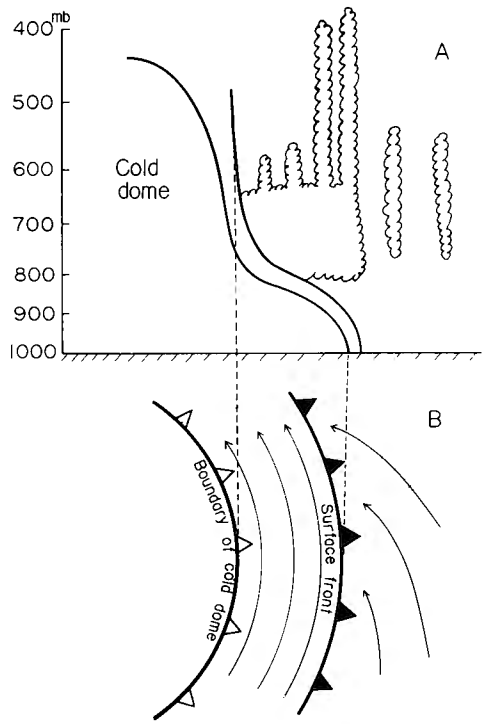

Fig. 10. Schematic model of cloud distribution in front of upper cold vortex. (A) Vertical cross-section. (B) Horizontal streamlines relative to cold dome.

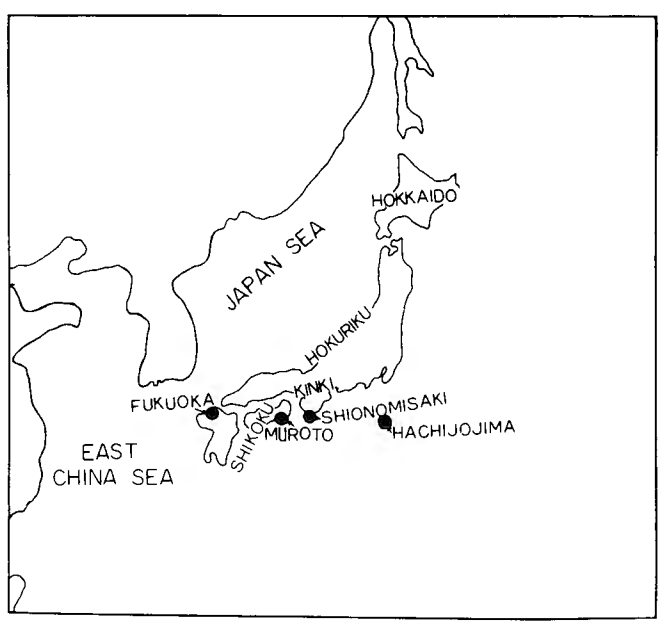

Fig. 11. Positions of observatories.

tained from the commercial air-lines, and offers a similar schematic model of the cloud distribution.

5. Summary

There are two heavy snow fall areas in Japan. One of them is Hokkaido District (northern part of Japan) and the other is Hokuriku District (along the Japan Sea Coast). It is well known that the former heavy snow occurs when the upper cold vortex moves over Hokkaido and arrives at the east side of Hokkaido, and that the latter heavy snow occurs while the upper cold vortex moves over the Japan Sea. Such heavy snow falls occur several times during a winter season.

But when a wave in the upper westerly current becomes extremely developed, the cold vortex formed in the trough comes down directly to lower latitudes and becomes a very strong cold vortex. In such a case heavy snow falls in the south-western part of Japan, where heavy snow fall seldom occurs in an ordinary winter season. We have analysed in this paper one example of such extraordinary strong cold vortices. Our result shows that the structures of cold vortices vary with their intensity. Thus we must note both the intensities and the trajectories of the cold vortices in order to forecast heavy snow fall in Japan.

Acknowledgement

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References

Hsieh, Y., 1949 ; An investigation of a selected cold vortex over North America, J. Meteor., 6, 401–410.

Matsumoto, S., T. Asai, K. Ninomiya, M. Ida and M. Takeuchi, 1965 ; Behavior of the extraordinary cold vortex over the Far East coastal area observed during the period from 22 January to 24 January, 1963, J. Meteor. Soc. Japan, Series II, 43, 100–115.

Nakayama, A., 1966 ; Cold vortex and the neighbouring cumulonimbus clouds, Abstracts of papers of the general meeting of the Japan Meteor. Soc., 9, 20–21.

Omoto, Y., 1966 ; On the structure of an intense upper cyclone, J. Meteor. Soc. Japan., 44, 320–340.

Palmen, E., 1951 ; The aerology of extratropical disturbances, Compendium of meteorology, American Meteor. Soc., 599–620.