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On the Analysis of a Cold Vortex with Steady Eastward Movement

by

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Abstract

The cold vortex which passed over Japan on February 2, 1964 had a typical structure of a somewhat small scale. A meso-scale disturbance and associated snowfall were observed in the vicinity of the cold dome center.

Since this vortex moved eastward almost steadily, analysis were made by introducing time-space transformation technique.

1. Introduction

It is well known empirically among weather forecasters that a heavy snowfall is expected over the Hokuriku District (*i.e.* the Japan Sea coastal region of central Japan) when a very cold cut-off cold vortex passes over the Japan Sea (FUKUDA, 1960; MIYAZAWA, 1962; KAWAMOTO *et al.*, 1963).

Typical cut-off cold vortices were observed also in the period of heavy snowfall in winter of 1963, and the analyses by the authors (MATSUMOTO *et al.*, 1965; NINOMIYA, 1964) showed that an intense snowfall occurred in the vicinity of the cold vortex centers when they passed over the Japan Sea.

Although the winter of 1964, the second winter of the Heavy Snow Storm Project observation, was an unusually calm winter with a small amount of snowfall, remarkable disturbances in the upper level passed over Japan on January 20 and February 2 and a considerable amount of snowfall was observed over the Hokuriku District. The one on the former day was a shear-line like a deep V-shaped trough and that on the latter was a somewhat small but typical cut-off cold vortex. The latter case can be analysed by using especially the abundant data including the aerophotographic observation of cloud and radiosonde observation at 1500 LST at Wajima which were carried out by the project. In this paper the method and the result of the synoptic analysis on the structure of the cold vortex will be discussed, while the results of aerophotographic observation of cloud and the meso scale analysis are to be reported on in another papers (The Heavy Snow Storm Research Group, 1965; MATSUMOTO and NINOMIYA, 1965a, 1965b).

2. Structure of the cold vortex

The cold vortex which moved eastward from the vicinity of the Korean Peninsula arrived over the Japan Islands on February 2. The vertical cross section along 140°E meridian at 0900 LST February 2 is presented in Fig. 1. The tropopause and the

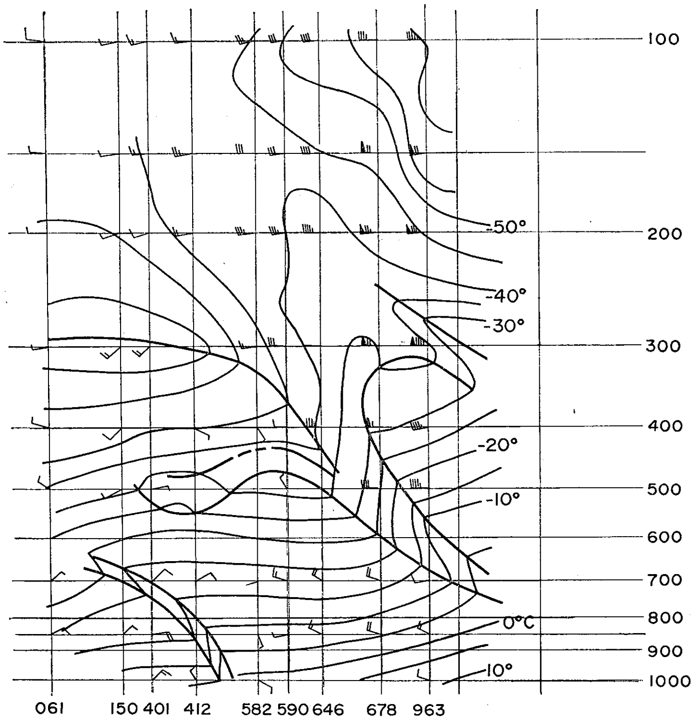

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Fig. 1. Meridional cross section along 140°E at 0900 LST, February 2, 1964. Full lines show isotherms for every 5°C, and heavy lines show the boundary of the frontal layer and the tropopause.

boundary of the stable layer are indicated by using heavy solid lines in the figure. A dome-shaped cold air, the center of which is located at 39°N, *i.e.* near Sendai, appears in the cross section. The polar tropopause, the upper part of a polar-front which continues to the polar tropopause and the middle-latitude tropopause are recognized clearly, but the polar-front and the cold dome boundary are hardly distinguished in the lower troposphere where both systems come very closely together. A sharp inversion layer is also observed in the lower layer within the cold air. These structures revealed in the cross section are features commonly observed in any cold vortex. Once the dome-shaped cold air-mass is defined by the lower boundary of the stable layer (Matsumoto *et al.*, 1965) the configuration of the dome is obtained as is illustrated in Fig. 2. Although the scale is somewhat small as

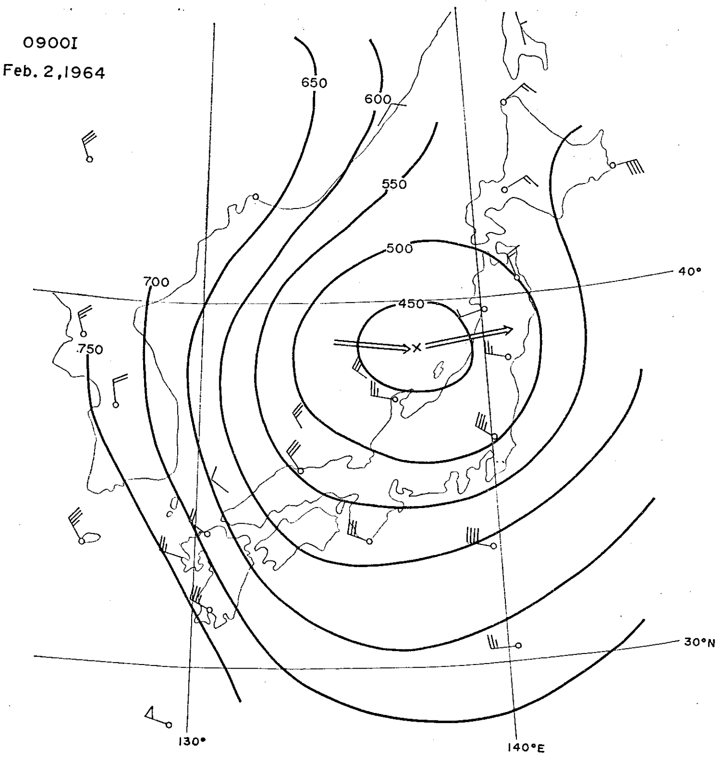

Fig. 2. Configuration of the cold dome boundary labelled with mb height. A cross symbol indicates the position at 0900 LST, February 2, 1964 and double arrows show 12 hr displacement. Observed winds at 700 mb level are also entered.

compared with the cold vortices in winter of 1963, a remarkably symmetrical cold air dome is observed. The top of the dome reaches 450 mb level (*i.e.* about 6000 m) and this height coincides with the height of the convective cloud tops which develop in the vicinity of the cold dome center.

3. Time section analysis by using the aerological data at Wajima

As mentioned in the introduction, rawinsonde observations at 1500 LST were specially carried out at Wajima in addition to the routine observations at 0900 and 2100 LST for the period of the cold vortex's passage. By using these data, time-sections of temperature and wind, and of the potential temperature and mixing ratio are analysed as in Figs. 3 and 4 respectively. The tropopause and the boundary of the stable layer are indicated by heavy lines in these figures.

The stable layer which bounds the cold air reaches to the maximum height at 0300 LST February 2 when the cold vortex passes over Wajima. The tropopause goes down towards the center of the cold dome in a form of funnel, and a warm core is observed at 250 mb level above the cold core in the troposphere. Thus a symmetrical temperature distribution, *i.e.* the typical thermal structure of a cold dome is analysed

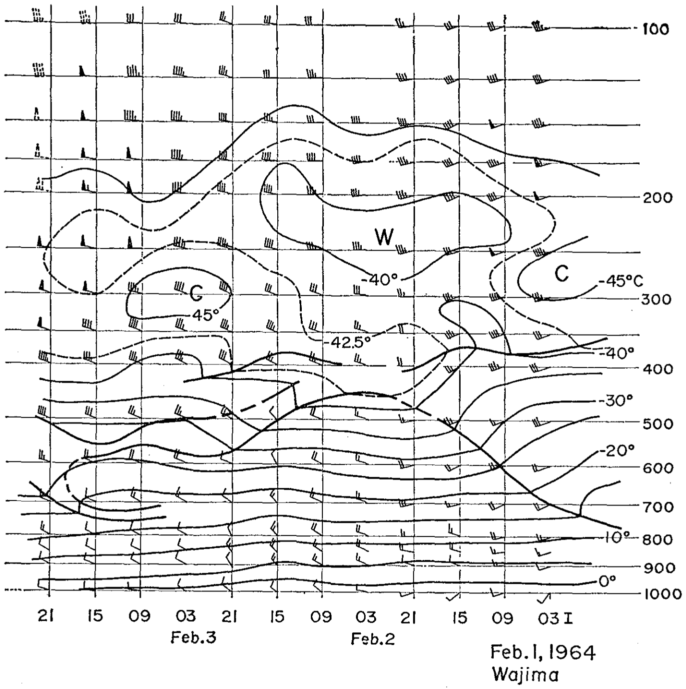

Fig. 3. Vertical time section at Wajima from February 1 to February 3, 1964. Full lines show isotherms for every 5°C and heavy lines show the boundary of the frontal layer and the tropopause.

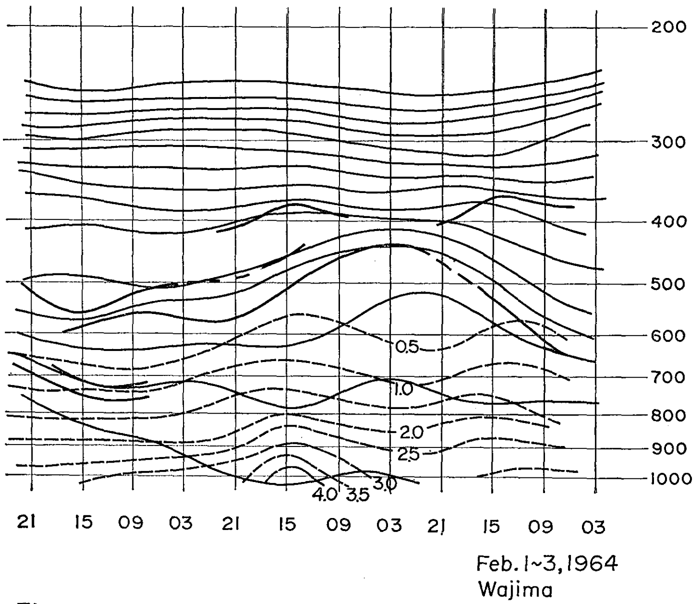

Fig. 4. Vertical time section at Wajima from February 1 to February 2, 1964. Full lines show isentropes for every °K and broken lines show the mixing ratio labelled in gr/kgr. Heavy lines are reproduced from Fig. 3.

again in this time section.

The southward and northward wind components prevail in front and at the rear of the dome respectively, but change in wind field slightly precedes that in temperature field. This fact means that the cold core is located somewhat behind the upper trough.

It is known by the aerophotographic observations of cloud carried out on February 2 and 3, that the height of the cloud top nearly coincides with the height of the lower boundary of the stable layer (MATSUMOTO and NINOMIYA, 1965a ; ASAI, 1965). In the vicinity of the cold dome center, the stratification is unstable, since the temperature at 500 mb is very low, and therefore the existence of an active cumulus convection is inferred.

4. Horizontal time section and vertical circulation around the cold dome

The successive positions of the cut-off low at 500 mb are indicated in Fig. 5 to show the movement of the cold vortex. It is known that the cold vortex moves eastward almost steadily. As the scale of the vortex is rather small, the lack of observation over the ocean makes the analysis extremely difficult. However, it would be possible to make extrapolation or interpolation by the technique of time-space transformation if a steady movement of the cold vortex is assumed. This method was introduced by FUJITA (1957) in his meso-analysis by using the surface self-recording material.

Let us consider a coordinate moving with the pressure system. Then the observation stations appearing on this coordinate system move parallel in an opposite direction to the movement of the pressure system in a fixed coordinate. Extrapolations are made along the trajectory of a station on the moving coordinate by plotting successive observation data at that station onto the corresponding position. The actual procedures are

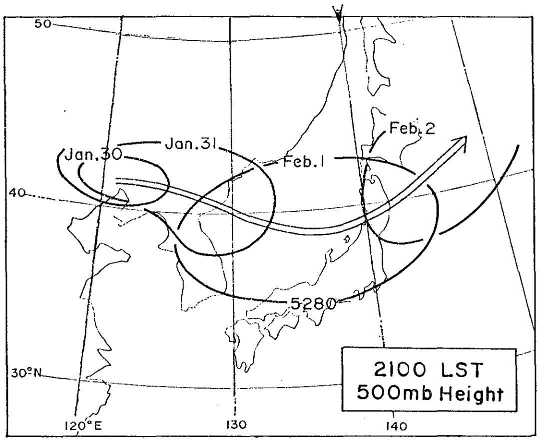

Fig. 5. Sucessive positions of the cut-off cyclone at every 24 hrs.

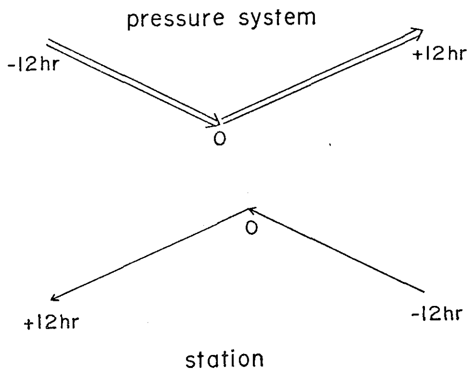

Fig. 6. The displacement of a cold dome on the fixed coordinate (double arrows) and the displacement of an observation station on the coordinate moving with the cold dome (thin arrows).

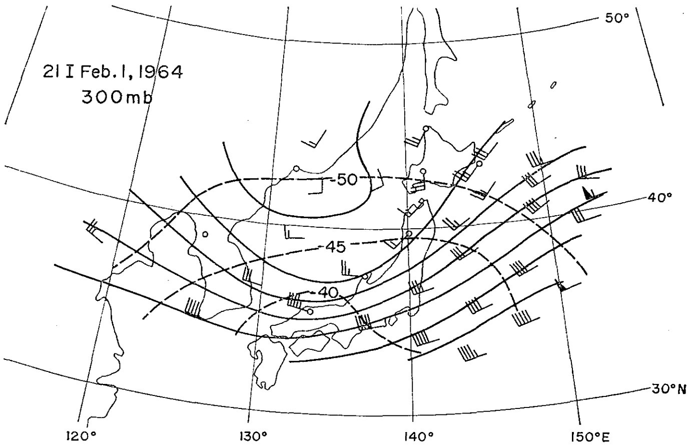

Fig. 7. 300 mb composite chart at 2100 LST, February 1, 1964. Full lines are 300 mb contours and broken lines isotherms.

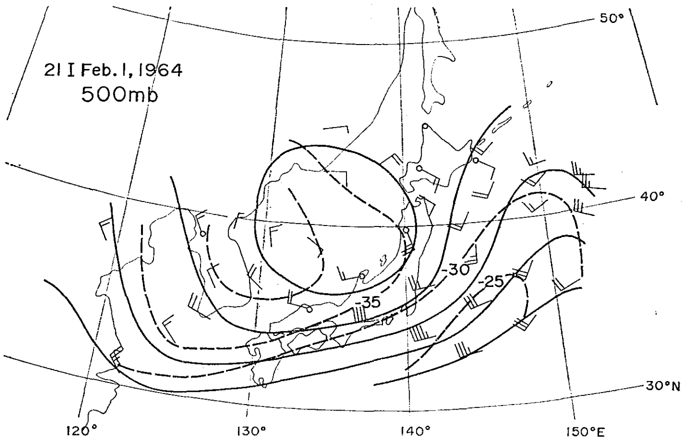

Fig. 8. 500 mb composite chart at 2100 LST, February 1, 1964. Full lines are 500 mb contours and broken lines isotherms.

shown schematically in Fig. 6.

Figs. 7 and 8 are the composite maps of 300 and 500 mb at 2100 LST February 1 obtained by the method mentioned above. (Full lines and broken lines are the contours and isotherms respectively.) The white circles in the figures are the observation stations on which observed values at the reference time are given and the values plotted on other points are obtained by the extrapolation or interpolation. These figures show that estimation over the ocean has considerable accuracy. It is pointed out that the dold core at 500 mb is located somewhat behind the trough, and the warm core at 300 mb is observed just over the cold core. Also, it is known that the wind is almost geostrophic.

Once the horizontal distribution of temperature and wind are obtained, the vertical circulation around the cold dome is obtained under the assumption of adiabatic motion. The heat supplied from the sea surface is redistributed mainly in the lower troposphere and the assumption of adiabatic motion would be permitted with certain accuracy in the upper troposphere. Thus the vertical velocity ω is obtained by applying the equation of adiabatic motion,

$$(\boldsymbol{V}-\boldsymbol{C})\cdot\nabla T+\omega\left(\frac{\partial T}{\partial p}-\frac{R}{c_p}\cdot\frac{T}{p}\right)=0$$

to the temperature and wind field shown in Figs. 7 and 8. $\boldsymbol{C}$ in the equation is, of course, the velocity of the system of cold vortex. Then, by using the value of ω thus obtained, the stream lines relative to the moving cold dome are shown on the east-west cross section through the center of the system (Fig. 9). The arrows show the relative displacement during 12 hours proportional to the scale of the figure. This result indicates that a branch of the vertical circulation along the tropopause funnel is found over the cold dome.

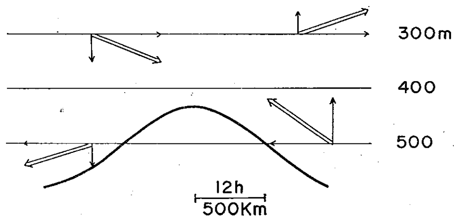

Fig. 9. Schematic distribution of vertical circulation relative to the movement of the cold dome. The full line indicates the cold dome boundary. The 12 hr displacements of air particles are given by double arrows.

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定常的に東進する寒冷渦の解析

松本誠一・二宮洸三

昭和39年2月2日に本邦上空を通過した寒冷渦は，小型ではあつたが典型的な構造をもち，その中心部に中規模擾乱に伴う降雪がみられた。この寒冷渦の構造を，南北断面図，および輪島の時間断面図によつて詳しく解析した。またこの寒冷渦はほぼ定常的に東進したので，時空間坐標の変換を応用して温度・風の水平分布を推定し，cold dome 上部の垂直流を求めた。

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