Disturbances observed in the Vicinity of Okhotsk Sea Anticyclone

By *Tetsuya FUJITA**

(received 20 November 1950)

Abstract :

In this paper the author presents his idea that the Okhotsk Sea Anticyclone must be a high type one with anticyclonic circulation even in the highest altitude of troposphere, and that the cold air mass in the wet season of Japan will come from the North Pole region passing in the western portion of the well-developed cold trough over the Aleutians. Some interesting disturbances such as blocking of westerly trough, foehn in free atmosphere, cold cyclone in the cold trough over the Aleutians are introduced here, in order to reveal the upper-air condition over the northern area.

INTRODUCTION.

On the 21 June 1949, *Typhoon Della* attacked Kyushu causing a destruction of many houses and ships. The author has been studying the structure and movement of this typhoon to reveal *the smaller disturbances* caused by her passage. Since then, some of the interesting phenomena are becoming clear, but for the further progress of such study, a careful analysis of the interaction between warm and cold air has become indispensable.

For the first step, the structure of the *Okhotsk Sea Anticyclone*, by which the cold air absorbed in *Typhoon Della* was supplied, has been analysed. And as it goes on, **the conventional idea that this anticyclone is a low type anticyclone with a shallow cold air in its bottom and a cyclonic circulation at its higher level, became somewhat doubtful.** Now, the author wishes to report some phenomena observed in the vicinity of this anticyclone to prove this fact.

DISTRIBUTION OF TEMPERATURE AT 800 MB. LEVEL.

To discuss the representative temperature of an air mass, the surface temperature, which is affected too much by the underlying land and sea surface, is not available; then the temperature at 800 mb. level which is, in many cases, higher than the height of the top of the turbulent inversion is convenient to use. Then the reporting stations locating approximately along the 55°N latitude were selected and the distribution curve of temperature along this latitude is shown in Fig. 1.

There were two regions with low temperature over the Aleutians and over the vicinity of Krasnojarsk, respectively, and they stayed there, for a comparatively long time. Especially, the one over the Aleutians moved slowly from east to west suggesting *the perfect decay of westerly wind* along this latitude. The high temperatures denoted by a, b, c, and d are surely propagating eastwards but these will be explained in the discussion of *foehn in free atmosphere.* After the

* Assistant Professor of the Kyushu Institute of Technology. Tobata City.

examination of temperature for the higher levels such as 700, 500 mb., the similar distribution of temperature became clear. This fact also suggests that *the Okhotsk Sea Anticyclone is surrounded by colder air,* and that it will not disappear even at a very high altitude.

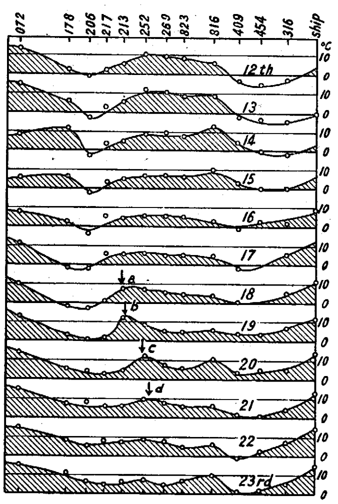

Fig.1. Showing the distribution of temperature at 800 mb. level, along latitude 55°N. (from 12 to 23 June, 1949.)

The most interesting map showing the mean condition of *Okhotsk Sea Anticyclone* during the period from 12 to 30 of June 1949, *the rainy season* in our country, is drawn in Fig. 2. In the figure the contour lines represent the mean topography of 700 mb. level during this period, and relative topography is also contoured for every 20 m. by the broken lines.

Conventionally, we used to consider that the cold air covering the northern part of the so-called *"rainy season front"*, came from the vicinity of Chishima Islands, and that the source of the cold air mass must have been *the Okhotsk Sea Anticyclone.* But the relative topography in Fig.2 reveals that *the cold air was reaching as far as the north-pole area* where the coldest air mass over the earth is located throughout the year. The deep trough over the Aleutians was a kind of cold trough with barotropic stratification, especially in its higher altitude, and it will reach the tropopause with its vertical axis. It is a characteristic of such a type of trough that no remarkable difference in temperature between the outbreaking and returning air is observed, which makes it possible to maintain its vertical axis.

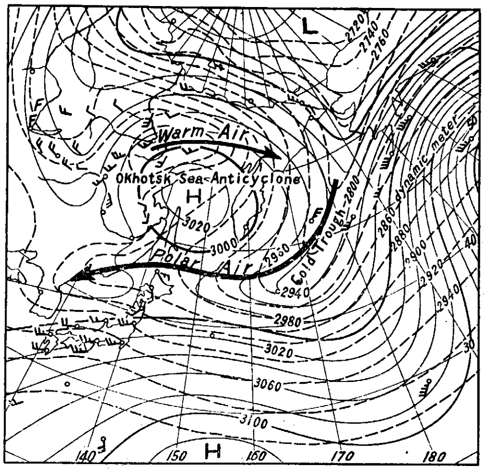

Fig. 2. Mean circulation of upper air at 700 mb. level, and the distribution of the mean value of the relative topography. (from 12 to 30 June, 1949.)

Therefore **the cold air associated with the rainy season will reach our country passing in the western part of the cold trough which is sometimes invisible on the surface map ;** and the low temperature of the sea surface near Chishima Islands locating just under the path of cold air, will be conducive to the arrival of cold air conserving its original property.

Change of temperature of cold air mass started in the Arctic Ocean on 18th is described in Fig. 3. At first, the polar air was almost stagnant with its surface tempereture about 0°C, but as it advances southwards, heat and moisture are taken from the underlying sea surface and they are accumulated inside the shallow layer under the turbulent inversion. Such an inversion which is sometimes followed with a thick fog is seen in the ascents

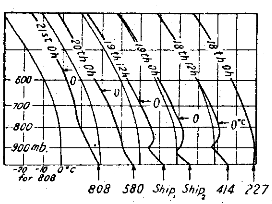

Fig. 3. Warming of a polar air.

made at Shemya Island and on two weather ships stationed east of Japan. As the polar air advances westwards, its temperature increased rapidly as shown in the ascents made at the stations Misawa and Itazuke. But the too rapid rise in temperature at the higher altitude will be considered to be caused not by the heating of polar air but by the transportation of warmer air of subtropical origin with high vapour contents.

High relative topography or high temperature over Jakutsk area will be caused by the heat given by the warm continental surface, but the warming will also be helped by the topographical foehn created by the mountain range along the coast of Okhotsk Sea when it blocks out the cold air over the cold sea surface. This high temperature region spread eastwards, and it interrupted the transportation of polar air along the cold trough.

For the forecast of the rainy season in Japan, the condition of the high type trough over the Aleutians must be taken into consideration. And the dissipation of the rainy season will be forecasted by the careful examination of the warm air over Jakutsk.

BLOCKING OF WESTERLY TROUGH BY OKHOTSK SEA ANTICYCLONE.

It is a well-known fact that a westerly trough is frequently blocked out by a warm type anticyclone covering the area where the trough might advance. The author wishes to introduce such a phenomenon caused by the Okhotsk Sea Anticyclone.

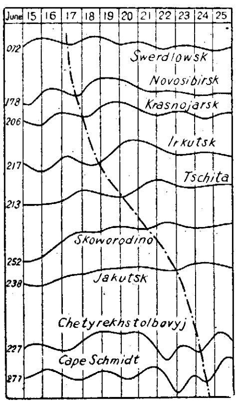

Fig.4. Barograph showing the passge of a westerly trough.

A moving trough is well represented by the regularly arranged barographs at many weather stations existing in the area where the trough is expected to pass. Such arrangement of barographs is shown in Fig. 4. to reveal the movement of the trough started from Swerdolovsk on June 19, 1949. This trough advanced eastwards passing over Novo-sibirsk and Krasnojarsk, and after that its easterly movement became slower. This implies *a blocking phenomenon* caused by a warm type anticyclone over eastern area. But, of course, we had never expected to find such *a high Okhotsk Sea Anticyclone* which might be able to show *a blocking phenomenon.*

By the time when the trough passes over Irkutsk, a low pressure area something like a cyclone is started to form in the trough. And after that this depression developed further until it passed over Tschita area. Therefore, fortunately, this depression made it possible for us to trace the movement of trough with great accuracy. The path of the depression estimated by the distribution of the lowest pressure on sea level is shown in Fig. 5 in which the daily location of the depression center at 0h Japan time, is represented with small circles. And it

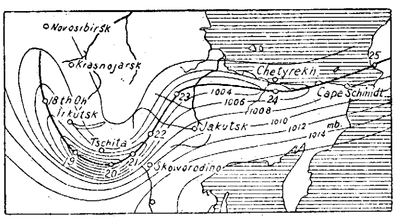

Fig.5. Distribution of the minimum pressure observed at the passage of the cold trough.

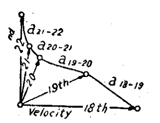

Fig.6. Hodograph showing the acceleration of depression.

became quite clear that the trough has been blocked out by *the Okhotsk Sea Anticyclone.*

To obtain the acceleration given by the anticyclone, a hodograph is shown in Fig. 6. In the figure, the acceleration of the depression center is to be represented by the vectors connecting the points of successive arrows. As a result, it will be seen that the depression was given a *blocking force* from south-eastern direction at first, which continued to act until 22nd when its direction of movement has changed towards the due north. Having been given such *blocking forces*, the depression entered the area of strong cyclonic circulation around the north pole and it was accelerated eastwards steered by the strong westerly wind.

FOEHN IN FREE ATMOSPHERE.

As has already been mentioned in the above discussion, the depression has started to form in the trough when it was passing over the western area of the lake Baikal, and its development is clearly understood by the distribution chart for the minimum pressure in Fig. 5. Then why was the depression formed and did it develop ?

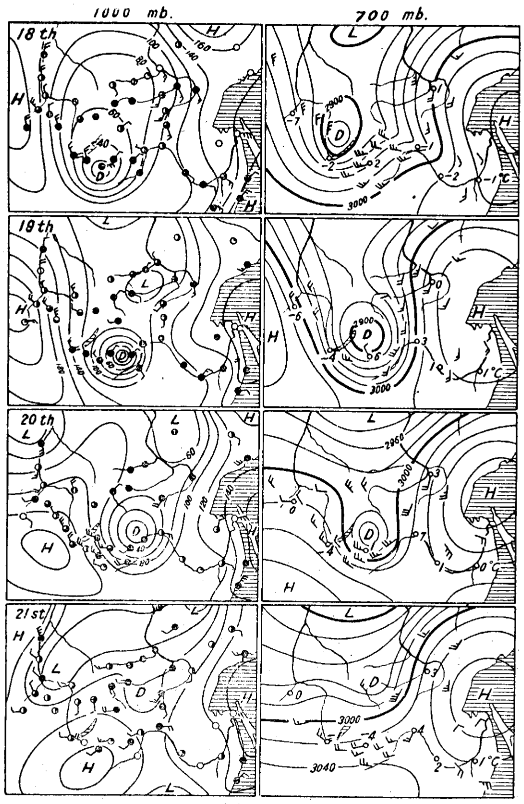

Fig. 7. Charts at 1000 mb. and 700 mb. level showing a blocking phenomenon caused by the Okhotsk Sea Anticyclone. (from 18th to 21st June 1949)

As a basis for the discussion about this problem, daily charts on 1000 and 700 mb. levels are drawn in Fig. 7 in which the height of the levels are contoured for every 20 dynamic meters, and temperatures are also shown in 700 mb. charts. As shown in the chart of the 18th, a tongue-shaped cold air was pushing southwards in the rear of the depression, and an area with higher temperature was developing at the 700 mb. level over Tschita. This area was surrounded by colder areas, and had been warmed further until the maximum temperature, as high as 7 degrees centigrade, was observed over Tschita at the 700 mb. level. By and by this warm air was steered northwards by the anticyclonic circulation around *the Okhotsk Sea Anticyclone* and its last appearance was observed over Jakutsk.

It should be noticed that the development of the depression or *the cyclogenesis* must have been caused by the warming of the higher atmosphere. Two imaginary ascents before and after the warming are shown by A and B in Fig.8 respectively. The sink of the surface having a pressure P is proportional to the hatched

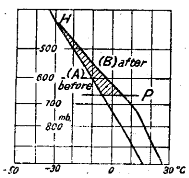

Fig. 8. Sink of the height of a pressure level by warming.

area in the figure, so long as the height of the point H remains constant. Therefore at the bottom of the warmed atmosphere, which we might call the *warmed air mass*, a low pressure area will develop. Of course the sink of an arbitrary pressure level will become shallower as the level increases. Therefore the development of the depression must have been caused by such warming.

To reveal the origin of the warming, the ascents made at Tschita and Irkutsk shown in Fig. 9 are very important. In these figures, hatched areas represent the boundary layers between warm and cold air. At Irkutsk, the *warmed air mass* over this layer was not so remarkable as at Tschita. It is difficult to consider a transportation of new warm air mass as the cause of warming, and **the most convenient explanation about this is the descending current that came from the south or south-west sliding downwards over the surface of the cold air mass. Such a descending current will be created on a large scale when the cold air mass is brought far into the area covered by the Okhotsk Sea Anticyclone with strong circulation, and the southerly wind is blocked out by the invading air.**

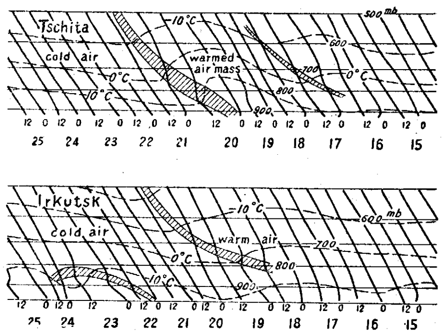

Fig. 9. Ascents made at Tschita and Irkutsk weather stations.

This type of warming should be considered to be created by a *foehn in free atmosphere* which might sometimes surpass the so-called topographical *foehn*. The top of the *foehn* reaches very high altitude, especially when it is caused by a high cold air mass. In many cases, it reaches the altitude two or three times higher than that of the underlying cold air mass. If the reported humidities are available, the thermo-dynamical structure of the *foehn* becomes clear, but the observed humidities in this area were not so accurate as to enable us to take them into calculation.

The most interesting phenomenon that will be seen associated with the above-mentioned *foehn* is the possibility of the *foehn in the cold air mass itself.* Should the direction and the speed of the wind in cold air mass be just the same at any place, the cold dome would advance without changing its shape and stratification. But in upper layer, as we know, the wind is blowing with more westerly component than that of the lower layer, because so-called *thermal wind* is superimposed. *Thus a warming due to the change of the stratification will occur even in cold air mass.*

This type of foehn in a well-developed polar air sometimes brings a remarkable sinking of tropopause. *The blue sky and fine weather in the eastern area of travelling anti-cyclone in Autumn will be explained in this way.*

The boundary of the *foehn* on the ground is shown in Fig. 10, in which the isotherms for the surface temperatures are contoured. In the same way, the condition in the 700 mb. layer is drawm in Fig. 11. In these figures we might be surprised to see the difference of the location of the cyclonic center, but this should be considered to be caused by the superposition of *relative topography* between 1000 mb. and 700 mb. In Fig. 12, the *relative topography* is obtained graphically, connecting the points of intersection of two groups of contour lines. As the *relative topography* is proportional to the mean virtual temprature, the condition of the *warmed air mass* is well understood. Now it is possible to calculate the vertical velocity using the following Panofsky's equation.

$$(w-w_p) = \frac{dT}{dt}(\gamma-\gamma_d)$$

Putting the practical values obtained by the radiosonde and pilot balloon observations, we get the descending velocity of about 70 cm/sec and ascending velocity of 20 cm/sec, and these are shown in Fig. 13.

After the development of the low pressure area, the cold air was given a centripetal force to change its south-eastward movement towards the east and then north-east, finally north.

Here we must remember that **the development of the depression, the warming by foehn, and the change of the direction of the moving depression are closely interrelated with each other.** And the above-mentioned phenomenon is a clear proof that the *Okhotsk Sea Anticyclone* assumes an appearance of *high type anticyclone.*

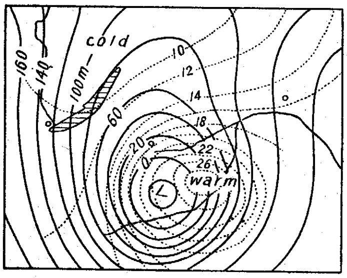

FIG. 10.

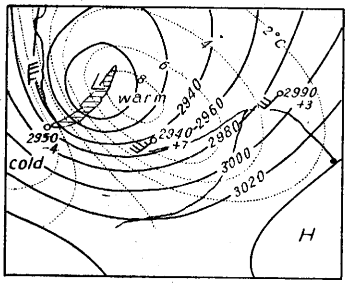

FIG. 11.

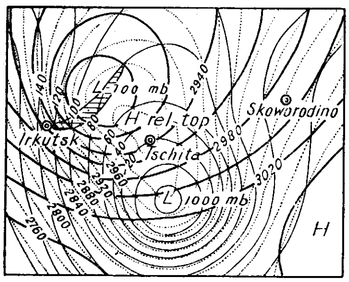

FIG. 12.

Fig. 10, 11, 12. Charts at 12h June 19, 1949.

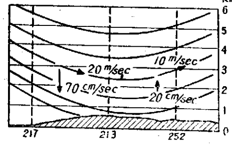

Fig. 13, Estimated foehn over Tschita area.

COLD CYCLONE IN THE COLD TROUGH.

In the end of June, 1949, an American weather ship stationed south-east of Kamtschatka reported a marked cooling in the upper atmosphere. The reported soundings are shown in Fig. 14. It will be seen, in the figure, that the cooling reached the top of the troposphere. This phenomenon implies that the axis of the cold trough had arrived over the ship, and the structure of the cold trough became quite clear. The author calculated the altitude of several standard pressure levels and they are also shown in Fig. 14.

To examine the upper air wind, as has already been pointed out by many researchers, the analysis of the altitude of a pressure level is, in many cases, more convenient than that of the pressure at a constant altitude. Because the acceleration of an air particle given by the pressure gradient, $\frac{1}{\rho}$ grad P depends much upon the value of ρ, the density of the air which decreases rapidly with the altitude. But putting the following equation

$$\text{grad } P = \rho g \text{ grad } H$$

into the formula of acceleration, we obtain

$$\text{acceleration} = \frac{1}{\rho} \text{ grad } P = g \text{ grad } H.$$

So long as we neglect the effect of curved path and the frictional term that will be very small at a higher altitude, the gradient wind will be given as follows.

$$g \text{ grad } H = 2\omega v \sin \varphi$$

$$v = \frac{g}{2\omega \sin\varphi} \text{ grad } H$$

Here the gravitational force will be regarded to be almost constant, therefore the velocity of the *gradient wind* will not depend upon the altitude. Thus the contour charts shown in Fig.15 will be analysed, as if they were surface charts.

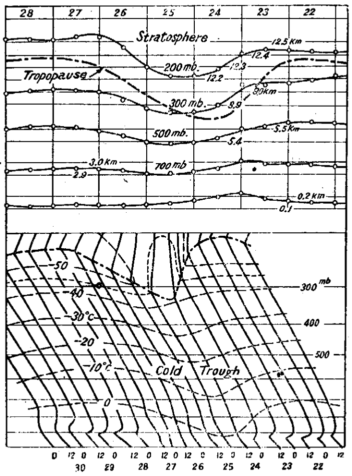

Fig. 14. Ascents made by the American weather ship stationed to the south-east of Petropavlovsk.

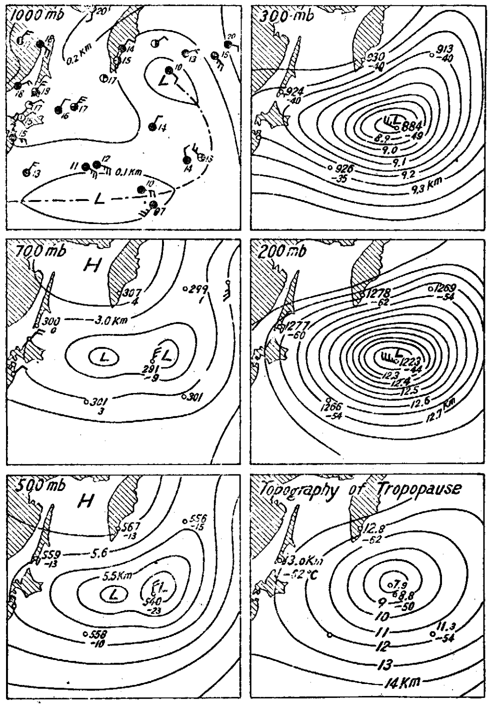

Fig. 15. Showing the contour lines at the standard pressure levels. At 12h June 24, 1949.

On 1000 mb. chart, it will be seen that the area, where we see a well-developed cyclone at the higher altitude, was covered with a HIGH stretched from the north-west. Two LOWs have already started to form at 700 mb. level; of course, these are caused by the rapid decrease of atmospheric pressure with altitude inside the cold air. One LOW slightly to the east of the ship would be a LOW originated in the cold trough, and another would be the trace of *Typhoon Della* which entered this area passing over Hokkaido Island. On 500 mb. chart, the LOWs approached each other and they became somewhat deeper. The deepening of the cold cyclone continued further with the altitude. And at 300 mb. level the central altitude of the LOW became 8840 dynamic meters which was about 500 m. deeper than its surrounding areas. And the two centers got together at this level. If we imagine such a low pressure in surface weather chart, it would become about 950 mb., the central pressure of a well-developed typhoon.

It is very interesting to consider the compensation of pressure inside the troposphere. The developed cyclone at the higher troposphere was not only compensated, but also redeveloped into an anticyclone on sea level. *And this phenomenon coinsides with the conventional idea that a well-developed cold cyclone exists over the south-western sector of an occluded cyclone.* The cold cyclone in 200 mb. level was located, in this case, in the lower portion of the tropopause, however, the circulation was very intense with the maximum *cyclonic vorticity* at the distance about 300—1000 km. from the center. In this level, the vertical mixing must be almost prevented by the steep gradient of entropy inside the stratosphere.

Topography of the tropopause is also shown in the last map in Fig. 15 in which the altitude of the *tropopause funnel* is contoured for every 1 km.

At first, the author considered that the time section made by the ship represented the section of the cold trough along an arbitrary line, however, after the analysis it became quite clear that the section had been made through the center of the cold cyclone originated in the southern portion of the trough. And the circulation around the cyclone was perfectly separated from the general circulation around the pole. But of course, in its earlier stage, the cold air in the cyclone must have been supplied from the source of cold air over the Arctic Region.

On the other hand, *Typhoon Della* which had, by this time, already changed into a cold cyclone must have given her circulation and cold air to the eastern cyclone when she amalgamated together with it.

After that the cyclone moved towards NNW and passed over Petropavlovsk causing a marked sink of tropopause and cooling of the whole troposphere. The ascents and the variation of topography are shown in Fig. 16. It will be seen that the minimum altitude of tropopause observed on the 28th was about 7 km.

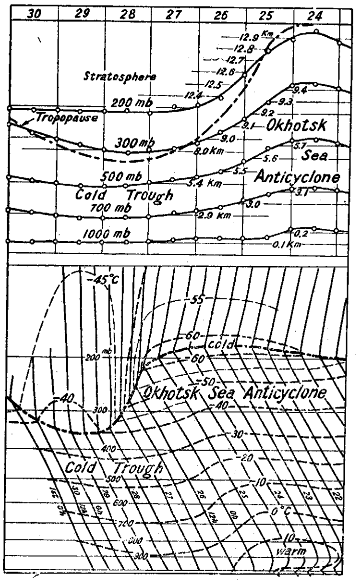

Fig. 16. Radio sonde ascents made at Petropavlovsk.

The author discussed some disturbances observed in the vicinity of *the Okhotsk Sea Anticyclone*, but there were many other disturbances in the Arctic Region: namely, an extraordinary pressure variation, a warm type cyclone, *jet stream* of cold air, and etc., but these are omitted in this paper.

The author wishes to express his profound gratitude to the members of the Fukuoka Meteorological Observatory, especially, to Dr. Y. Kawabata, director for his kind suggestions and advices, to Dr. T. Yokoo for his aids given to the progress of this study, and to Mr. H. Mitsuno, the forecaster for the co-operation and suggestions given in the analysis of Russian area.

The author is also very grateful to Dr. Horace R. Byers, chairman of the Department of Meteorology in the University of Chicago who has given me kind comments and encouragement.

Kyushu Institute of Technology Tetsuya Fujita.
November, 1950.

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