Study on Pressure Dips within Typhoon Della

By *Tetsuya FUJITA*

Abstract:

In this paper, the writer introduced the characteristics of a pressure dip, a trough-like depression within a typhoon. As a result of the study on four dips within Typhoon Della, it became clear that the dips move at the steering velocity of the main storm, and that the winds observed inside the pressure field which is caused by a rapidly travelling dip are quite different from the gradient winds expected. Thus the writer pointed out the importance of the dip which tells us a very interesting fact concerning the unknown nature of typhoon.

INTRODUCTION

One of the most interesting and puzzling phases of tropical storms is the *Pressure dip*, the minor trough which appears within the storm area. Those meteorologists who have had opportunities to analyse the pressure field around a storm center by using the barographs from the stations in the storm area, may know the interesting features of a trough-like dip superposed upon the pressure traces.

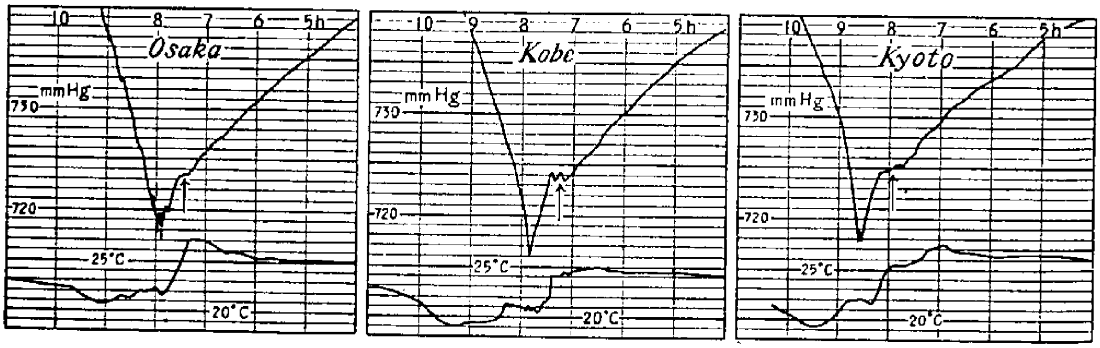


Fig. 1 Traces showing the minor trough within Muroto Typhoon of 21 June 1934. This trough was accompanied by an abrupt drop in temperature, and it is considered to be not a pressure trough but a kink occurring in connection with a cold-frontal passage.

As shown in Fig. 1, small pressure troughs were recorded at the 3 stations in Kinki District. The initiation of the troughs has already been studied by HORIGUCHI (7), and he concluded that the trough was caused by the secondary typhoon which had passed prior to the main typhoon.

A marked minor trough shown in Fig. 2 was introduced by PIERCE (11). The trough passed along the Atlantic coast of the United States, about one and half hours after the passage of the mainstorm, the New England Hurricane of 21 Sept. 1938. One might consider that the trough is indicative of a cold-front passage, but that is not the case. For the trough steered toward the NNE while the direction of the surface wind had been west or north-west. In this respect, the conclusion by PIERCE and SPILHAUSE is quite interesting since they considered that the trough is indicative of another cyclonic circulation within the main storm.

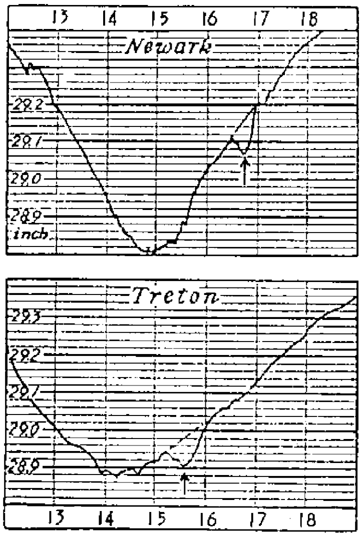


Fig. 2 Barograph traces from Newark and Treton, showing the minor trough within New England Hurricane of 21 Sept. 1938. (by PIERCE)

A theory of the secondary circulation within a typhoon has already been presented by NAMEKAWA (10) in 1936. In order to prove NAMEKAWA's theory, AOKI (1) (2) (3) has carried out a great number of typhoon analyses. On the way of his elaborate analyses, he has come across many minor troughs, and he considered that they might be the trace of a part of the comparatively large *secondary typhoon* superimposed upon the *main typhoon*; thus he divided up the typhoon pressure field into two, one forming the core of typhoon, and the other consisting mainly of the outer area. But there remain a lot of uncertainties concerning the present technique by which the *secondary typhoon* is separated from the original typhoon, because it is possible to obtain the various couples of two typhoons, the *main* and the *secondary ones*, according to each individual. The writer has tried to separate the secondary typhoon by using the technique originated by AOKI; however, it was rather difficult to obtain one — only one — reasonable shape for the *secondary typhoon* desired.

Typical minor troughs were discovered by the writer in his study on Typhoon Della. Similar to the minor trough pointed out by PIERCE, each of these troughs in Typhoon Della was not accompanied by any sign of a cold-frontal passage; therefore, it seems to be reasonable to call this kind of trough "**the pressure dip**". Now the *pressure dip* must be distinguished from the ordinary minor trough which sometimes occurs in connection with a frontal passage.

In order to make the characteristics of the *pressure dip* more clear, the following definitions are presented by the writer.

(a) *Pressure dip* is a small trough-like depression

(b) which is not accompanied by cyclonic surface winds,

(c) nor a sharp drop in temperature at the time of passage;

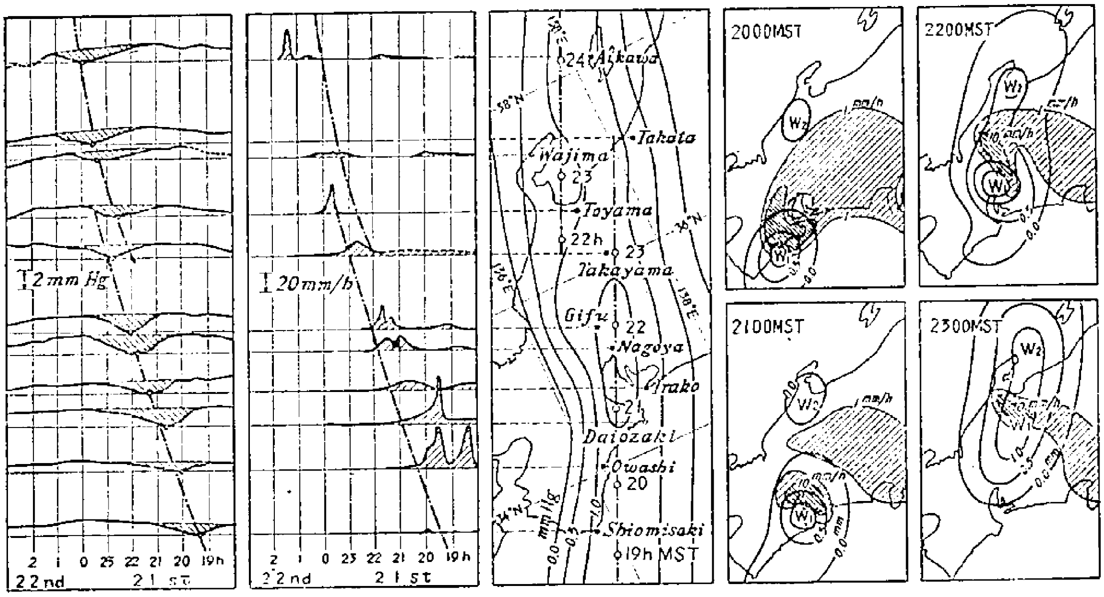
(d) and the propagation of which must be recognized by referring to the pressure traces.

The above-mentioned pressure troughs in Muroto Typhoon are accompanied by a sharp temperature drop; therefore, they are not the *pressure dip* in the strict sense of the writer's definitions.

It has become clear that the minor troughs in Typhoon Della satisfy the definitions, and they are named *Dip W*, *Dip X*, *Dip Y*, and *Dip Z*, respectively. The writer wants to discuss the structure and movement in detail.

(1) FEATURE OF DIP W

The maximum amount of the pressure drop caused by the passage of the *dip* under discussion was only 1.9 mm Hg. However carefully the isobars may be drawn, it is almost impossible for us to trace its movement by using the ordinary isobar charts. The writer, therefore, considered that the isobars drawn for the amount of *Pressure dips* are very helpful in studying the shape and the movement.



a, Pressure traces b, Rain intensity c, Dip amounts d. Hourly charts for rain and dip

Fig. 3 Figures showing the features of Dip W.

In Fig. 3-a, the *dips* are shown by the hatched areas on the barographs from the stations along the path. Of course, the inclination of the line connecting the *dip* centers for each station shows the rate at which the *dip* steered toward the NNE. At first, it was supposed that the *dip* in discussion was a single *dip*; however, after a careful examination, it has become clear that the original *dip* which may be called *dip* W_1 dissipated when a new *dip* W_2 appeared to the north, taking the place of the old one. This fact suggests that the *dip* moves just as in the case of the thunderstorm studied under the direction of BYERS (4), with its three stages, formation, development, and dissipating stages.

The time-distance diagram of the rainfall rate tells us that the rain must be related closely to the origin of the *dip*. This fact will be clear by looking at the hourly charts for the *dip* and the rain in Fig. 4-d. In the figure, the *dip* enclosed by 1 mm isobar has almost the same area as that of the precipitation heavier than 10 mm/h, therefore, it can be considered that the decrease in pressure which had developed into the *dip* could be produced by the decrease in the weight of the air-column which converged into the precipitatable clouds to compensate the volume of the condensed water vapour which fell down on the ground as liquid. It may be true that the rain with such area and intensity as we see in the figure can produce the *dip* in question.

In order to expect an effective *local compensation*, the precipitatable clouds must move

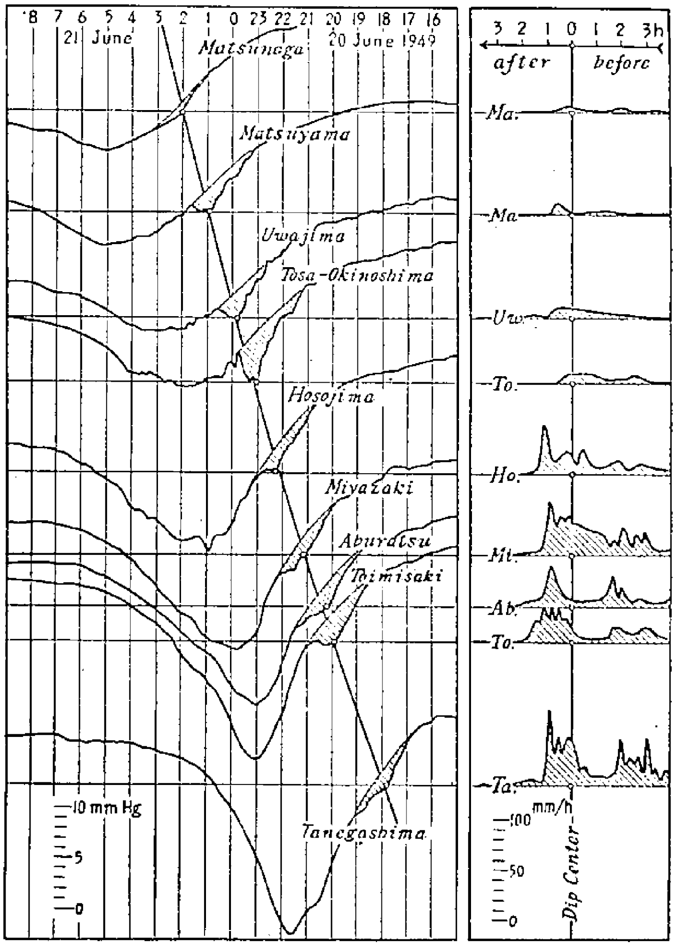


Fig. 4 left: Barographs showing the shape and the movement of dip X.
right: Intensity of rain precipitated around the dip center. The dip center for each station is shown by small circle.

together with the general current in which they are imbedded, or else the clouds can receive the moisture from successive environments. However, in case of a heavy topographical or stationary-frontal rain, no appreciable compensation from a local environment is to be expected.

(2) FEATURE OF DIP X

As shown in Fig. 4, the dip appeared several hours before the occurrence of the minimum pressure for Typhoon Della. The maximum amount of the *dip*, 4 mm is recorded at Tosa-Okinoshima station. The distribution of the pressure for the maximum amount at each station is shown in Fig. 5-a. It will be seen that the *dip* moved toward the NNE while the main storm steered along the curved path passing through the central range in Kyushu.

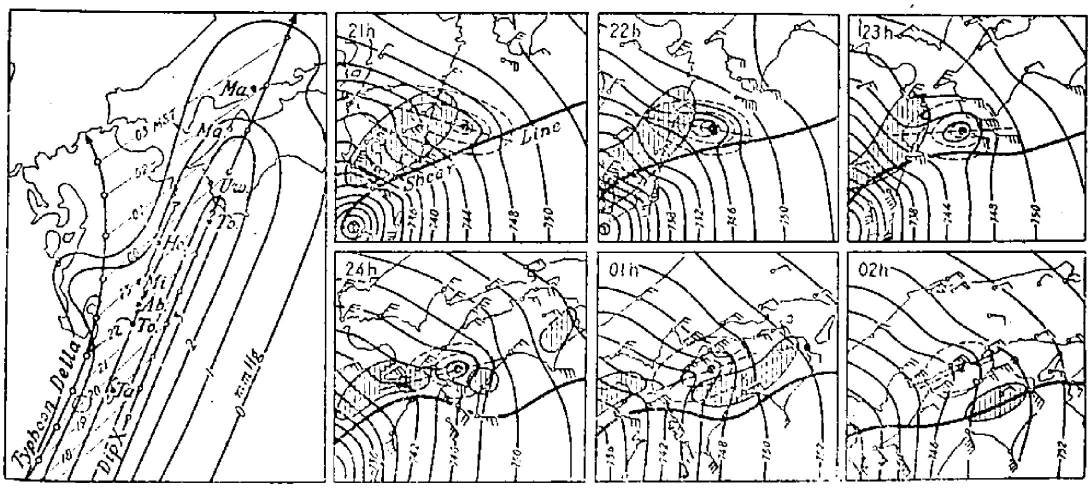


Fig. 5-a left: Distribution of the maximum values for the dip amount at each station.
Fig. 5-b right: Hourly charts, prepared from 21h 20 June to 02h 21 June 1949, showing the dip amounts, the isobars, and the areas of rain heavier than 20 mm/h.

The relation between the *dip* and the precipitation is shown in Fig. 5-b. It will be seen that the rain intensity is very large in the vicinity of the *dip*, and that the maximum intensity for each station occurred a little after the passage of the *dip* center. Here we must remember that the heavy rain associated with *Dip W* occurred just before the passage of the *dip* center.

The mechanism of the *dip* initiation can be studied by the hourly charts showing the relation between the isobar, *dip* amount, rain, and the shear line extended from the typhoon center. Despite of the efforts to draw the charts in detail, any quantitative relation among the weather elements was not established. It is only known that the *dip* is located in the vicinity of the heavy rain covering the narrow sector north of the shear line at which the winds shifted toward the south suddenly. Thus, it might be considered that the *dip* was originated by the similar mechanism as has been seen in the case of *dip W*; however, the fact that the active center of the heavy rain had moved along the eastern side of Kyushu, will tell us that the area of maximum *dip* amount and that of the heavy rain had not been coincided. In these respects, there remain many problems which must be studied in future.

(3) FEATURE OF DIP Y

This *dip* was originated in the vicinity of Shimonoseki at 01 MST 21 June, and steered toward the north-east. The barographs from the stations along its path are arranged in the t-x diagram shown in Fig. 6-a. The separation of this *dip* from the original traces was very difficult, becasue its amount was rather small compared with the *dip* duration.

The most interesting feature of the *dip* was observed at Shimonoseki. At this station; the pressure dropped rapidly when the *dip* approached, but after the passage of the center, the trace changed into flat. The traces, therefore, imply the possibility that the pressure

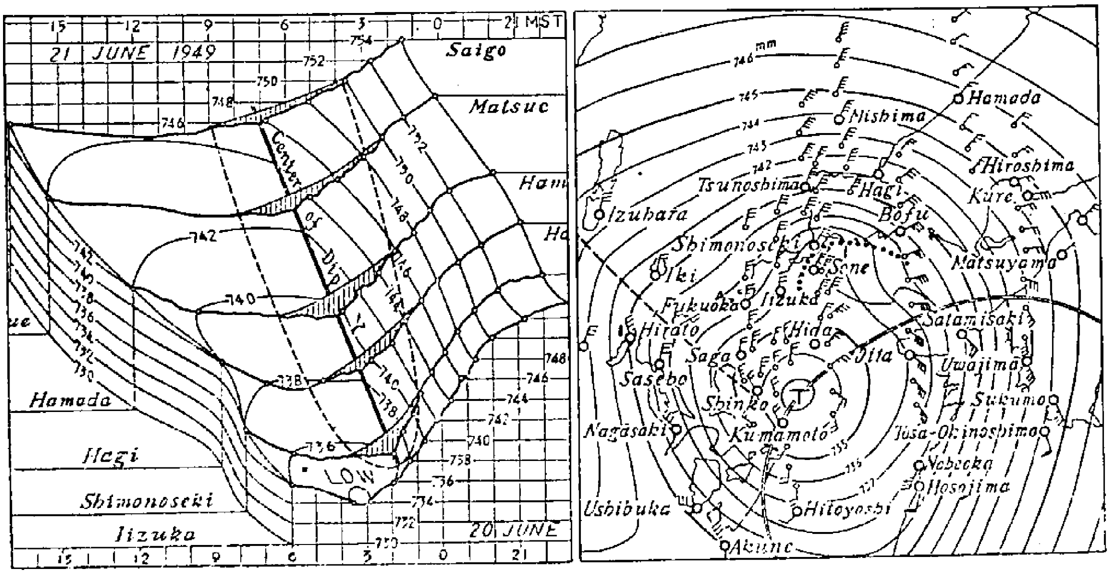


Fig. 6-a left: Barographs arranged on the t-x diagram.
Fig. 6-b right: Chart at 0200 21 June 1949. It must be noticed that there exists no minor depression which might be in the vicinity of Shimonoseki, judging from the wind direction and pressure at the station.

gradient had decreased down to a very small value; however, the chart at 0200 M.S.T in Fig. 6-b, the isobars of which were drawn referring to the pressure traces, tells us that the gradient directed toward the west has still existed after the passage of the center. That is to say, the direction of the isobars had changed about 90 degrees.

Should the winds in the *dip* area have been the gradient winds which satisfy the changing pressure field, the direction would have shifted also about right angle; however, as shown in Fig. 6-b, neither the direction nor the speed changed considerablly. This fact is very important since it leads us to the conclusion that the inertia of the air is very large when the wind around a typhoon center is studied.

(4) FEATURE OF DIP Z

This is not only the largest *dip* within Typhoon Della but also the largest one ever observed, because the amount of the *dip* at Iki was as much as 5.0 mm Hg, namely 6.7 mb. The pressure traces are shown in Fig. 7. The *dip* in discussion is supposed to be similar to that discovered in New England Hurricane, because it occurred several hours after the passage of the mainstorm, moreover, in the sector where the *dip* had steered toward the north north-east, there prevailed cold northerly winds showing the quite similar structure to that observed by PIERCE.

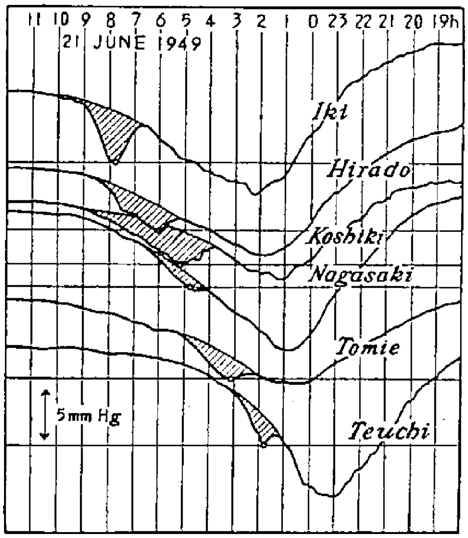


Fig. 7 Pressure traces showing the passage of Dip Z.

The writer supports the presentation of PIERCE that the *dip* of this kind must be a trace of secondary circulation; however, it must be added also that the *dip* is not always followed by a cyclonic circulation at the surface. Of course, a circulation around the *dip* may exist at a higher level, the steering level for the *dip*.

The movement and shape of the *dip* is shown in Fig. 8. It should be noted that the shape of the isobars was elliptic at first, but as *dip* travelled, it changed into a depression with circular isobars, meanwhile the vorticity concentrated around the *dip* center. As this *dip* was originated over the ocean south-west of Kyushu where we have no

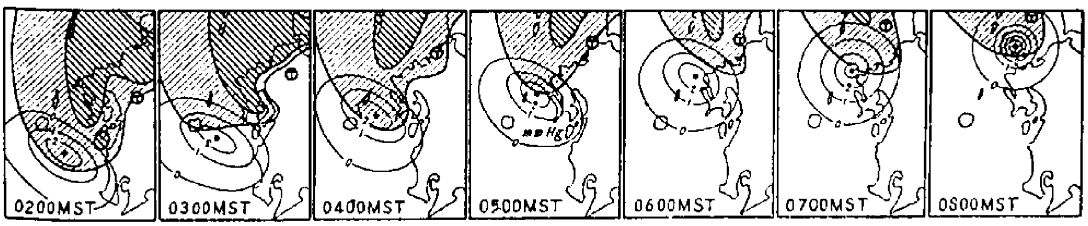


Fig. 8 Charts for 21 June 1949, showing the shape and the movement of Dip Z. Isobars are drawn for the dip amount, and the areas of rain heavier than 1 mm/h and 10 mm/h are represented by the hatched areas.

reporting stations, it is very difficult to study the mechanism of its initiation, however, the fact that it was originated in the sector where we cannot expect a heavy rain, shows us the possibility that this *dip* might be originated through a process which has never seen before.

The writer wants to present his opinion concerning the initiation of this *dip*, from a point of view that it may be initiated in connection with the structure of a decaying typhoon. For the present discussion, it will be useful to consider the mechanism of the divergence and convergence inside a typhoon. According to D'Alembert's principle, with respect to an air parcel with an unit mass which circles at a constant distance from the typhoon center, g *grad* H, the force directed toward the center, and v^2/r, the centrifugal force must balance at any moment. Therefore, at the pressure level on which all the air *parcels* circle round the center with constant radii, two potentials for both gradient force and the centrifugal force must be just the same in values but different in signs. Such a

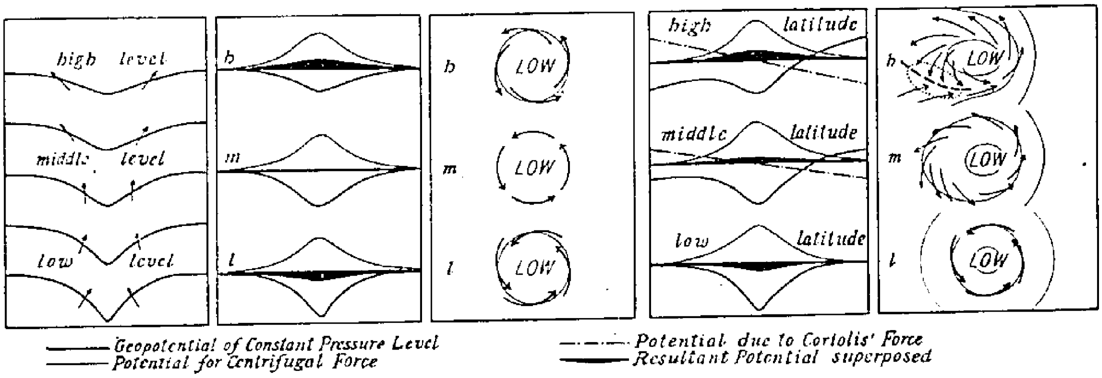


Fig. 9 Schematical figures showing the resultant effect of both centrifugal potential and geopotential of constant pressure level inside typhoon.

pressure level will be seen above the frictional layer. As shown in Fig. 9, when the ascending air reaches the higher level with a smaller gradient, the angular momentum of the air is liable to be conserved resulting in a larger *centrifugal potential* than that of the higher level. Thus the loci of each air *parcel* expand rapidly, and the air can move toward the higher pressure areas outside the typhoon.

This phenomenon is to be defined: "*the air parcels circulating round the typhoon center will get outside when they reach the level with a smaller gradient in constant pressure level than before*". Such a motion has been discussed already, but it can be applied also to the case when the typhoon decays rapidly. And the air inside a rapidly decaying typhoon will get out in a similar manner to that seen in a higher altitude of an ordinary typhoon.

The stream line of the air in a decaying typhoon is shown in Fig. 9. It will be seen in the figure, that a large mass of air goes out, especially, from the western sector in which the pressure gradient decreses rapidly. The radii of curvature for the outgoing air parcels become so larger that they must be accelerated along their courses. Thus a marked *shear line* will appear in the south-western sector of the typhoon. The elliptic depression initiated on the shear line is the *dip* in discussion. On the other hand, when the typhoon decays lowly, the isobars will expand, because the air goes out slowly without producing any appreciable *shear line*.

The distribution of the surface winds at 0500 MST 21 June is shown in Fig. 10. As shown in the left chart, wind speed is very high in the north-east area of the *dip*, and

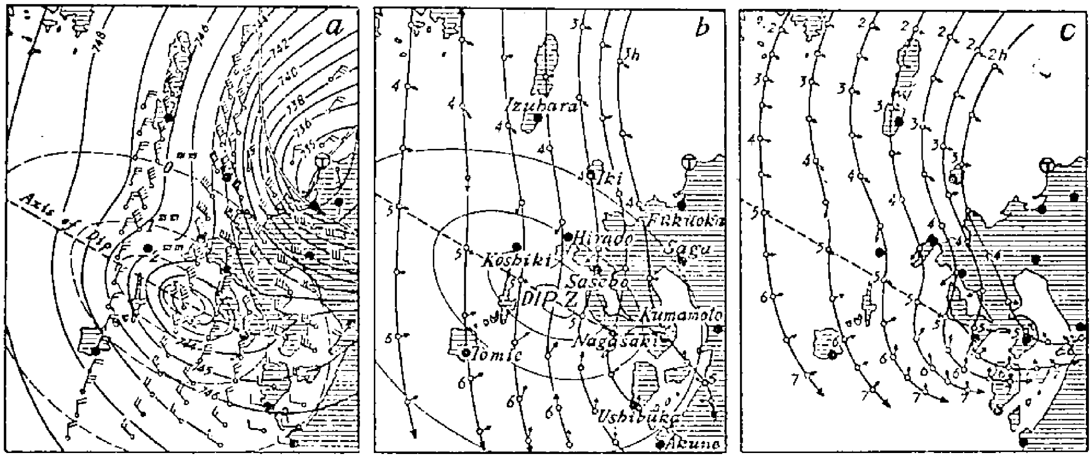


Fig. 10- a : Micro-feature of the winds affected by Dip Z.
b : Trajectoroies with respect to the dip. They were obtained by drawing the 30 minute interval charts.
c : Trajectories with respect to the earth's surface.

very low in the south-west. As the *dip* approached, the wind direction, which had been north-west, shifted toward the due north and finally NNE ; however, just after the passage of the center, it changed toward the NW again, meanwhile the wind speed which had been about 50 knots, slowed down to about 15 knots.

The writer has never come across such a good example before, by which the interaction between winds and a travelling pressure field can be studied, The trajectories of the air *parcels* which had passed at 0500 across the *dip* axis are shown in the right figure. The circles are the locations plotted for every 30 minutes. The accelerations given to the air are shown by arrows. Although the arrows indicate the accelerations produced by both dip and typhoon, it is to be understood that they directed toward the *dip* center, when air passes near the center.

The trajectories of the air with respect to *Dip* Z are plotted in the middle figure. It must be emphasized here, that the *dip* does not produce any circulation of the surface winds but it only gives a wavy path to the air. Thus the wind around the *dip* is not the gradient winds suitable to the new pressure gradient given by both *dip* and typhoon. The higher the speed of the *dip* the larger the deviation of the wind from the gradient wind; therefore no pressure waves propagating at a high speed can give any appreciable change to the surface wind.

Those who examined the left figure will understand that there exists no relation between the direction of the wind and that of the isobar, and that it is no good to imagine a small depression in order to satisfy the winds, especially when they are affected by a repidly changing pressure field. That is to say, the isobars around the typhoon center can only be drawn by referring to the pressure traces.

MOVEMENT OF DIPS

The paths and the speeds of the dips discussed above were summarized in Fig. 11, together with the upper-air winds at 500 mb. and 300 mb. pressure levels. It will be seen that the *dip* moved toward the same directions as that of the typhoon before she reached Kyushu, and that the *dip* in the east travelled at a higher speed than that in the west.

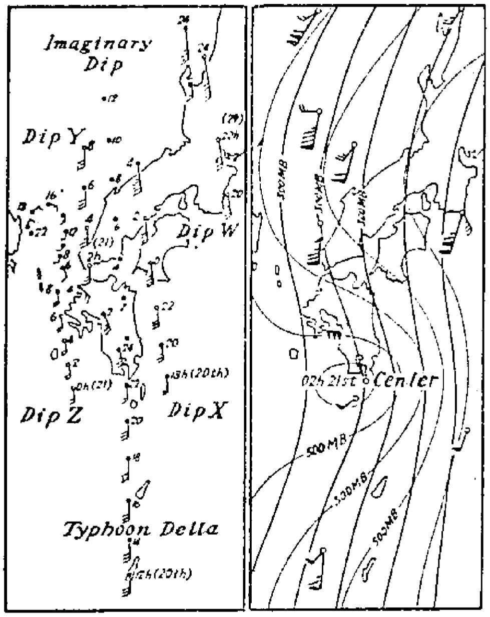


Fig. 11 Movement of the dips within Typhoon Della of 20 Jun 1949. In the right figure, the winds at the 500 mb. and 300 mb. levels are shown.

It must be noticed that the movement of the main storm is irregular compared with those of the *dips*; however, when she was passing along Okinawa Islands, her speed was just the same as of the *imaginary dip* which would have passed along the line between *Dips X* and *Y*. Now it is clear that *dips* in the eastern sector of the typhoon was steered by both the general current and the typhoon circulation superposed in the same direction and that the ones in the west by the current and the circulation superimposed in opposite direction.

The upper-air winds in the figure show us that any southerly wind does not exist at the 500 mb. level in the western sector of the typhoon; however, at the 300 mb. level, there may exist southerly winds throughout the typhoon sector. Thus, it may be concluded that the height of the steering-level for the dip under discussion is higher than 5 km, may be 8 to 10 km. The wind speed at such a higher level is about 100 knots which is two times as large as that of the *dips*.

CONCLUSION

As has been discussed before, the study of the *dip* within a typhoon is of great importance, especially when we desire to get the knowledge of the micro-feature of typhoons. The behavior of the *dips* seems to involve a lot of suggestions concerning the movement of typhoons.

As it is clear that a *dip* appeares in any sector of typhoon and that it travels together with the current in the steering level of the mainstorm, the movement of the typhoon can be studied by using the *dip* within the storm.

Conventionally, few dips were recognized within a typhoon; however, if we carry out a micro-analysis using a number of pressure traces from the stations scattered widely inside the storm area, several dips will be discovered for each typhoon.

Now the writer wants to repeat the fact that the dips which is to be utilized for this purpose must satisfy the writer's definitions, otherwise it is not possible for us to trace them as an indicator at the steering level. It is no good to consider a *kink* associated with a cold-frontal passage as a *dip*, because the *kink* will advance together with the front of the cold air.

ACKNOWLEDGEMENTS

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