Some Analytical Studies of the Heavy Rainfalls in Kyushu

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Abstract

Heavy rainfalls in Kyushu district which cause much damage have been often observed in the Baiu season. This paper describes the results of calculation and analysis of mainly the upper air divergence and vorticity, when we have heavy rainfalls in Kyushu. The results reveal the fact that the heavy rainfall takes place in the field of the low-level convergence and upper-level divergence of which absolute values are very large. And also there exists a strong positive vorticity in the lower layers, depending on the low-level jet stream.

Interestingly it is found that the rainfall regions are seen to be divided according to the positive or negative sign of values of upper-level vorticity. Namely the center of the rainfall area is situated in southern Kyushu when positive vorticity prevails, and reversely in northern Kyushu when negative vorticity.

1. Introduction

In our country we often have many heavy rainfalls which cause many kinds of severe disasters during the Baiu season. The precipitation mechanism of the heavy rainstorm shave been researched by many investigators from the various meteorological view points, and recently it seems to be clearer as mesodisturbance system Matsumoto, et al1),2). The authors also have undertaken to investigate the precipitation mechanism of severe convective rainfalls with weather radar in Kyushu Takeda & Shiotsuki3), Shiotsuki4) And Fukuda5) made clear the mesosynoptic patterns of severe precipitations of the Japan Sea coastal regions by analysis of upper air divergence and vorticity. Similarly the authors analysed upper air divergence and vorticity when the heavy rainfalls were observed in Kyushu, in order to contribute to heavy rainfall forcasting and to be a supplementary means for our radar observations. This paper describes the results of analysis and characteristic features of synoptic conditions for heavy rainfall in Kyushu.

2. Calculation scheme

Air divergence, vorticity and thermal advection are calculated by means of the objective computation method which was presented by Endlich and Clark6). This method is very convenient for computing the quantities described above, by determining the triangles of three observing stations. For use with computers, the assumption of linear variations of the observables between the reporting stations is adopted. Divergence (D), relative vorticity (ζ), and thermal advection (Th. Adv) are computed at triangle centers as follows :

$$D=(1/r)\,[(\sec\phi)_0(\partial u/\partial\lambda)_0+(\partial v/\partial\phi)_0-v_0(\tan\phi)_0]$$

$$\zeta=(1/r)\,[(\sec\phi)_0(\partial v/\partial\lambda)_0-(\partial u/\partial\phi)_0+u_0(\tan\phi)_0]$$

$$Th.\ Adv.=[f(T_a+T_b)/2g(Z_a+Z_b)]\,(u_a v_b-u_b v_a)$$

where u, v : wind component (m/s), u (eastward), v (northward), f : coliolis parameter, T : temperature (°K), Z : height (m), ϕ : latitude, λ : longitude, suffix o : point value of triangle center, suffix a, b : value of the top and bottom of the height interval. Computations were made

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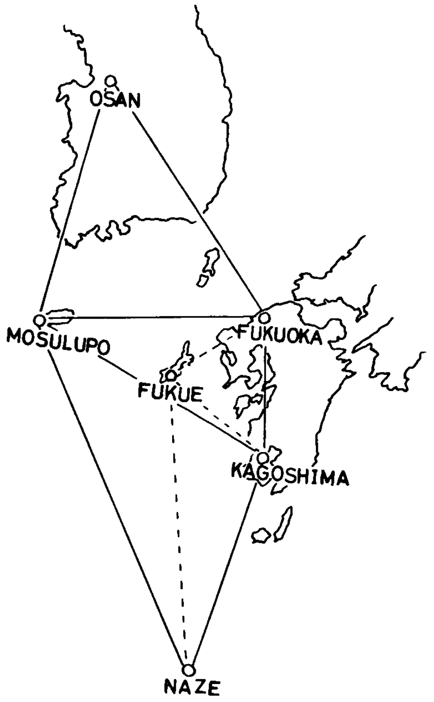
by the three triangles which are shown in Fig. 1, then D, ζ at the 12 levels of 1000, 900, 850, 800, 700, 600, 500, 400, 350, 300, 250, 200mb, and Th. Adv in the 11 layers between these 12 levels.

3. Results

Ex. 1) July 4th-9th 1959

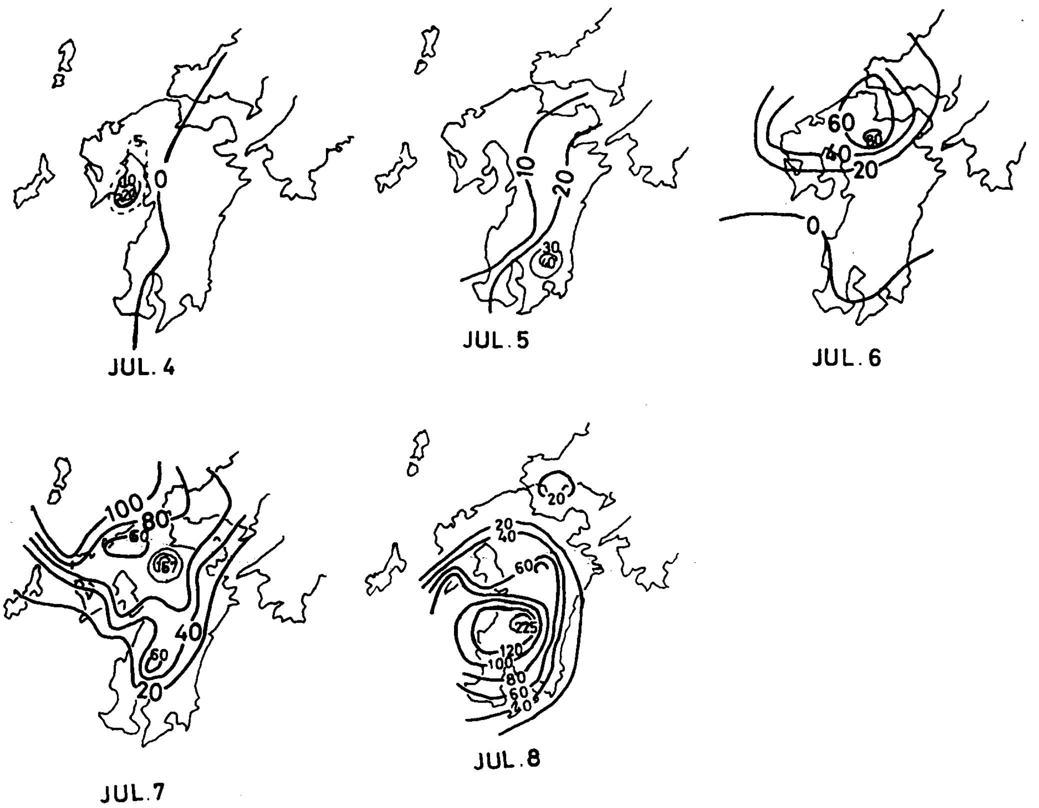
Baiu front stayed over the southern part of Korean Peninsula from the 4 th to 6 th and there were seen rain showers associated with thunder in Kyushu. Then the stationary front began to return towards Kyushu, and some amounts of rainfall were observed in the northern part of Kyushu on 7 th, and also in the southern part on 8 th.

Fig. 2 and Fig. 3 show the distributions of daily rainfall amount and the time change of calculated vorticity and divergence during period. In the divergence field, it was found that the patterns of low-level divergence and upper-level convergence were seen on the days of rather smaller rainfall amount (5 th-6 th), and that the patterns of low-level convergence and upper-level divergence of which absolute values become high were seen on the days of large rainfall amount (7 th-8 th). And also in



Local map of Kyushu

Fig. 1 Triangles for calculating Divergence, Vorticity and Thermal Advection (THA.)



JUL. 4 JUL. 5 JUL. 6 JUL. 7 JUL. 8

Fig. 2 Distribution of daily rainfall amount from July 4 to 8, 1959 (mm/day)

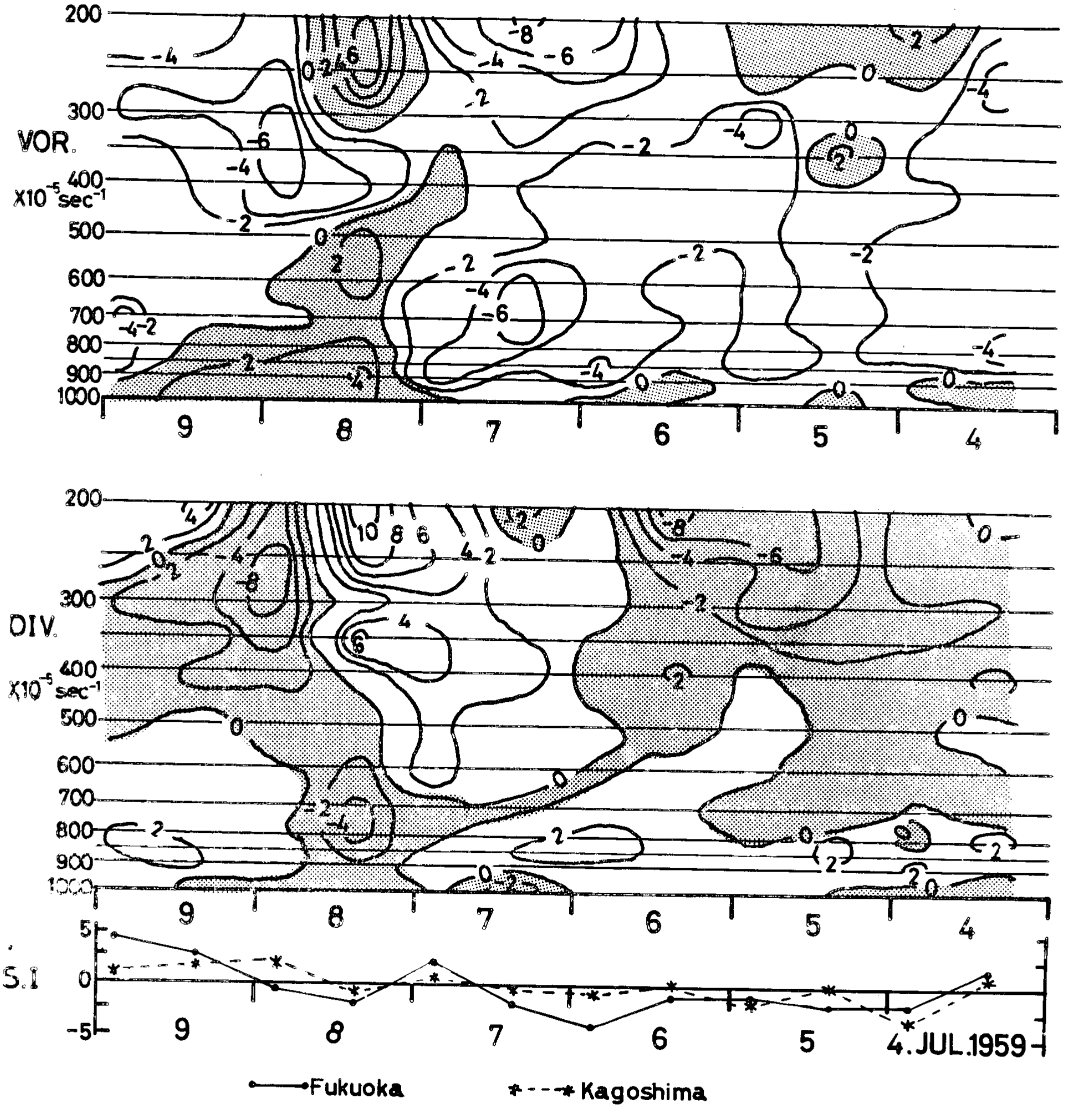


Fig. 3 Time change of Vor. (upper fig.) and Div. (middle fig.) calculated by the triangle Fukuoka-Kagoshima-Mosulpo. Lower figure shows Showalter Index (S. I.) at Fukuoka and Kagoshima (Convergence and positive vorticity are stippled)

the vorticity field, interestingly it is found that the change of value of vorticity at 300-200mb level corresponds to the change of the situation of the center of rainfall area. Namely the positive (cyclonic) values of vorticity correspond to the rainfall areas observed in the southern part of Kyushu (5 th and 8 th), and the negative (anticyclonic) values to that in the northern part in Kyushu (6 th- 7 th). These features may be dependent on the movement of the upper jet-stream, because the values of vorticity appear positive on the northern side of jet, and negative on the southern side of it. Actually as shown in Fig. 4, the upper wind becomes stronger as the stationary front moves southward.

It is noted that there are seen strong winds at 850mb level on the 8 th over Kagoshima, and this corresponds to the high values of vorticity at 900mb and to the large rainfall amounts of southern Kyushu. This may indicate that the role of low-level jet-stream is important for heavy rainfall system.

Time change of Showalter stability index, which is shown in Fig. 3 , means that the atmosphere

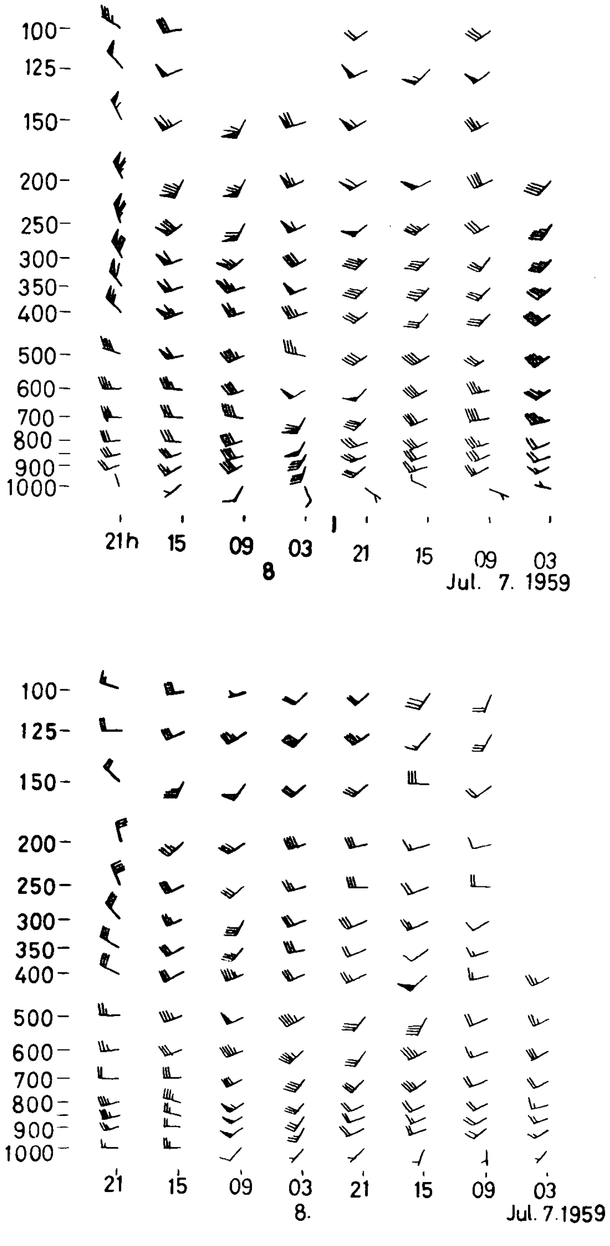


Fig. 4 Time change of upper wind at Fukuoka (upper Fig.) and Kagoshima (lower Fig.) A full barb, half barb and flag indicate 10, 5 and 50 knots, respectively

is unstable throughout the period because of its negative values.

Ex. 2) July 13 th-17th 1959

As shown in Fig. 5 and 6, the same features as in the case of Ex. 1) appear in the divergence and vorticity field corresponding to the distribution pattern of rainfall amount. The stationary front stayed in Kyushu throughout this period. In particular, maximum rainfall amount (406mm/day) is seen in northern Kyushu on 13 th, in association with the high negative value of upper-level vorticity.

Ex. 3) July 1 st-5 th, 1961

Fig. 7 shows time change of divergence, vorticity, thermal advection, Showalter stability index,

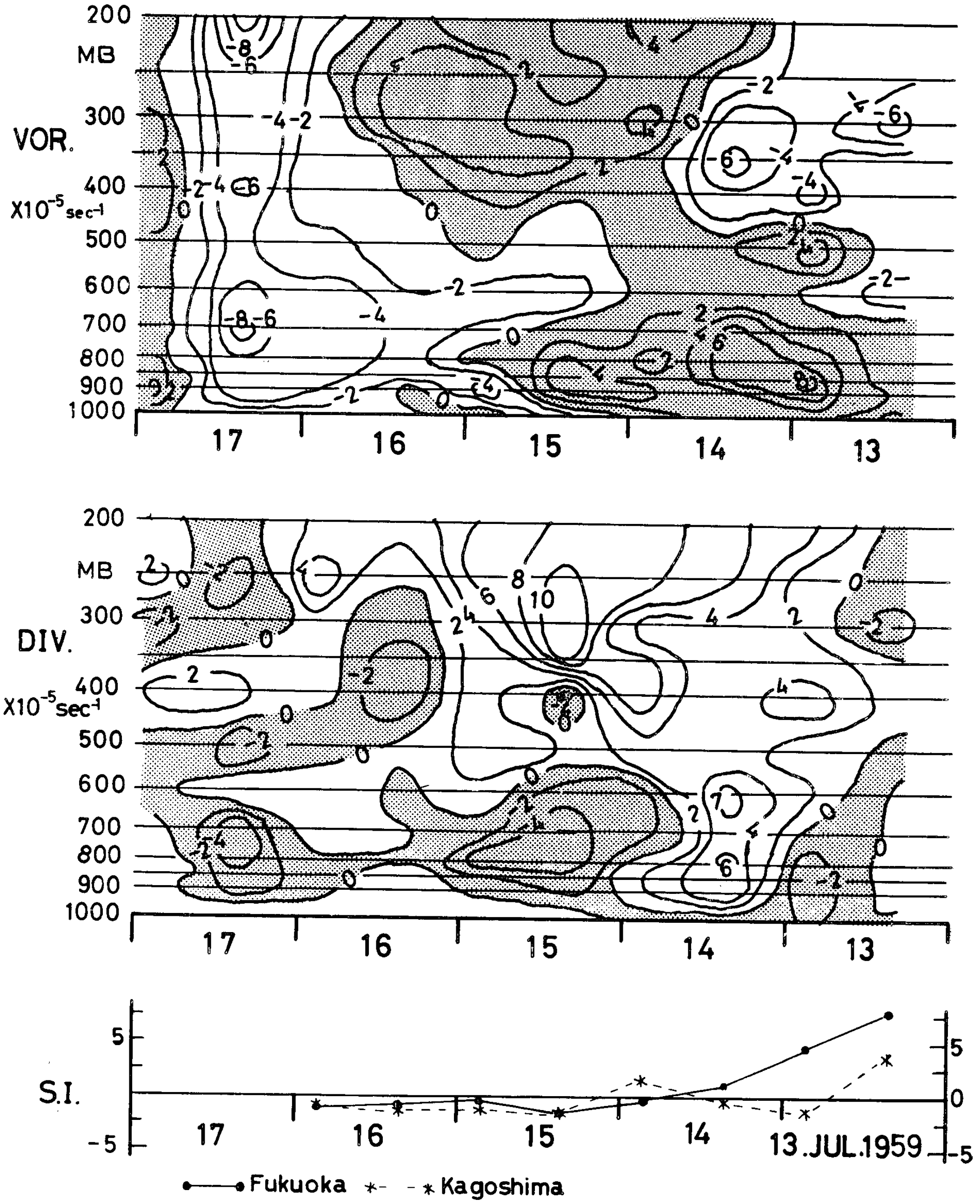


Fig. 5 Samely as Fig. 3, *July* 13—17, 1959

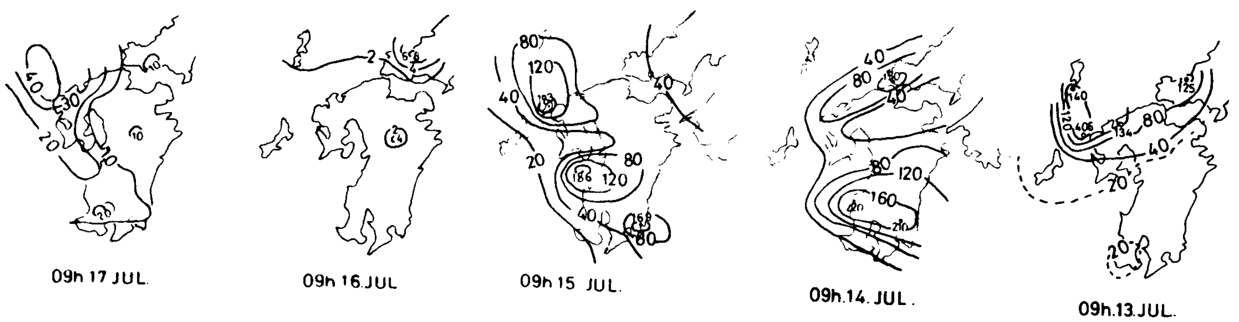


Fig. 6 Distribution of daily rainfall amount of July 13, 16 *and* 17, 1959

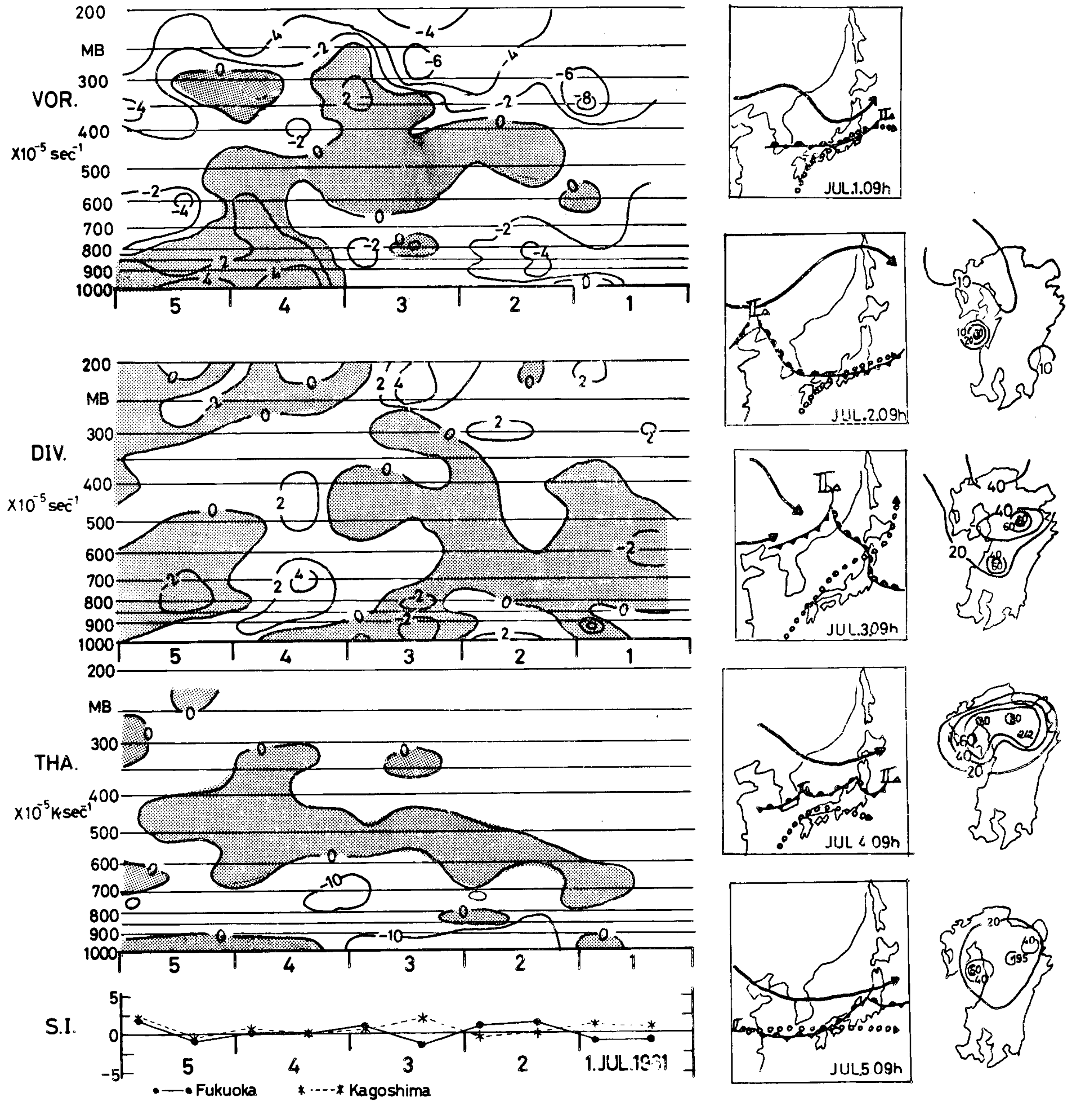


Fig. 7 Time change (July 1—5, 1961) of Vor. (left upper), Div. (left middle), THA. (left lower, cold advection is shown by stippled area), and S. I . (left lowest). Right figures show the distribution of daily rainfall amount and the situation of surface front (▼▼▼▲▲▲), lower jet (••••••) and upper jet (➡)

and daily change of situation of surface front, low-level and upper-level jet streams, comparing with the distribution pattern of daily rainfall amount. It is recognized that the low-level jet and surface front are seen almost near the raifall region in northern Kyushu. Also the rainfall region is limited by the negative sign of upper-level vorticity obtained through the period, when upper-jet runs far north from Kyushu. As Baiu front was not so active in this year, the rainfall amount was rather small. Also thermal advection is generally weak, though there is seen weak cold thermal advection between 700mb-400mb layer.

Ex. 4) July 1 st-7 th, 1962

This is the example of an apperance of heavy rainfall when Baiu front stayed between the northern and southern part of Kyushu. As shown in Fig. 8 and 9, there exists the surface front between the south side low-level jet and the north side upper-level jet. This is the typical pattern favord for the occurrence of heavy rainfall which is suggested by Fukuda⁷⁾ and Ushijima⁸⁾. The characteristic features of divergence and vorticity field are similar to the preceding examples, as expected. Namely, the change of sign of upper-level vorticity results with the change of situation of the prevailing rainfall area. And the low-level convergence & upper-level divergence condition, and the high value low-level vorticity cause the heavy rainfall. Moreover, it is noted that the strong cold thermal advection (on 2nd-3rd) in the layer between 400mb-250mb changes to the strong warm advection (on 3rd-4th), as the convergence zone is formed in the lower layers. This causes the atmosphere to become very unstable.

Four examples described in this section were analyzed by taking the triangle of Fukuoka-Kagoshima Mosulpo. In fact, while the slightly different results were obtained in the case of taking other triangles which are shown in Fig. 1, the triangle Fukuoka-Kagoshima-Mosulpo is most suitable for comparison with the rainfall distribution of Kyushu Island. So, in this report, the results obtained by other triangles are not presented, but will be described in detail in the next report.

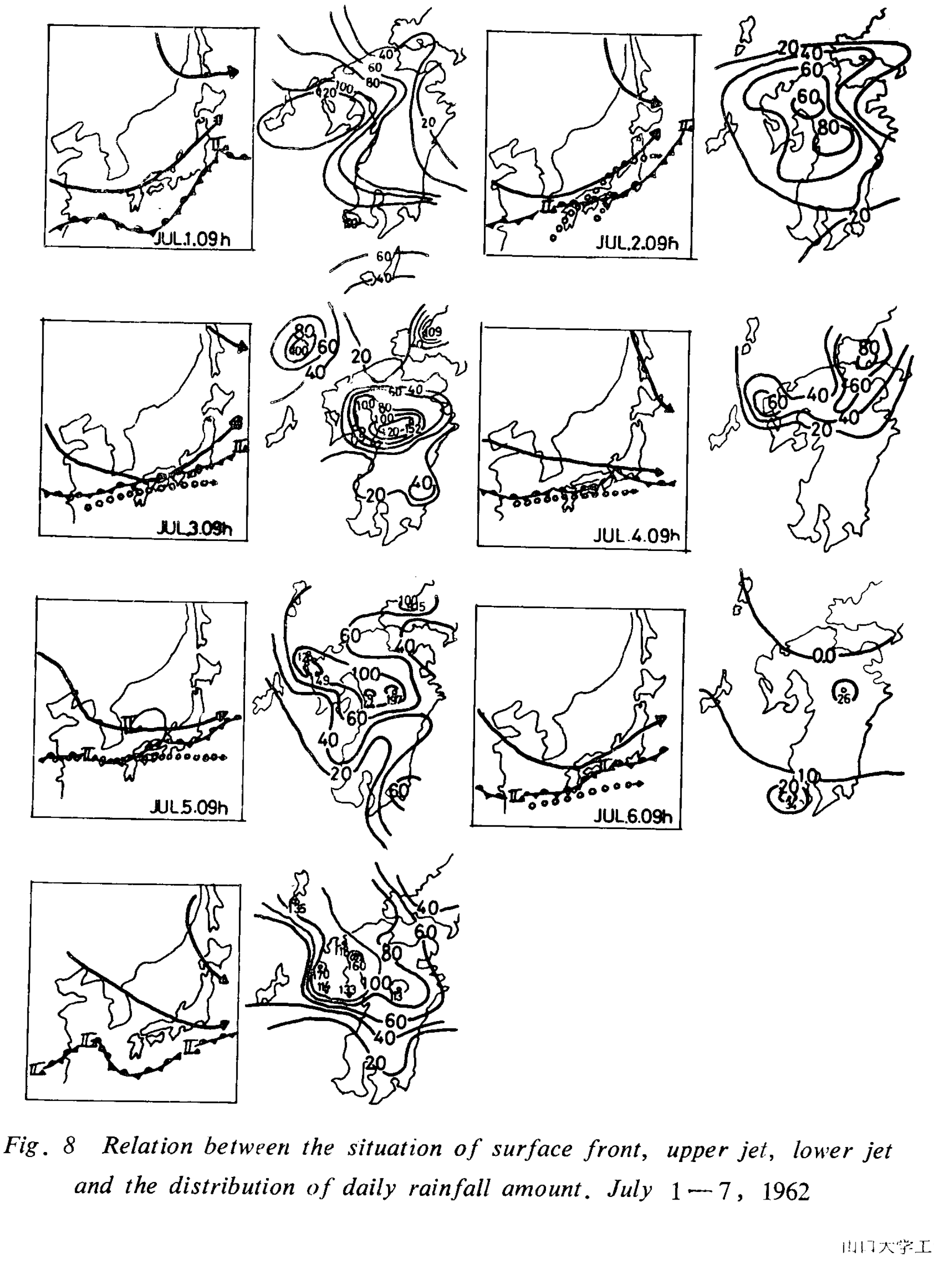


Fig. 8 Relation between the situation of surface front, upper jet, lower jet and the distribution of daily rainfall amount. July 1—7, 1962

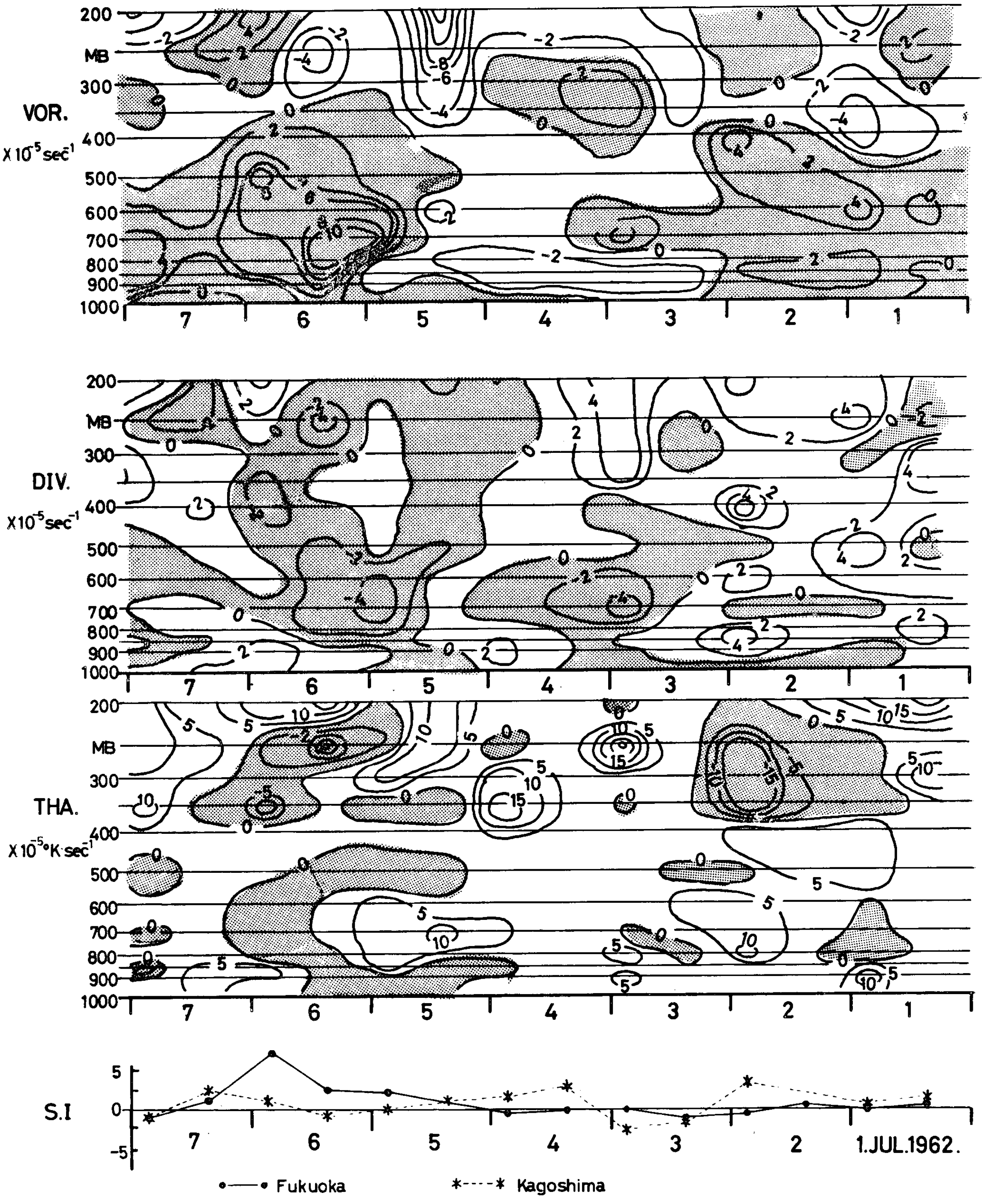


Fig. 9 Time change of Vor., Div., THA., (calculated by the triangle Fukuoka-Kagoshima-Saishuto), and S. I., July 1→7, 1962

4. Correlation between the upper-air divergence, vorticity and the observed rainfall amount

As found in the figures of the previous section, the heavy rainfall is associated with the characteristic patterns of divergence & vorticity field. It may be expected that forecasting heavy rainfalls is possible knowing the upper-air divergence and vorticity pattern, including other important meteorological conditions such as water vapor influx, atmospheric stability, and so on. As a initial effort we see mainly the correlation between the divergence, vorticity and rainfall amount. Upper figure of Fig.10 shows the correlation between low-level vorticity, the 700mb level dew point temperature (instead of the influx water vapor transport), and maximum daily rainfall am observed in Kyushu. The lower figure in this is in the case of replacing the dew point temperature to the low-level divergence. Calculations were made from the data during Baiu season of 1959–1962, and 1968. Dew point temperature is the mean value of Fukuoka's and Kagoshima's. Although the effect of 700mb level dew point temperature is not notable, the low-level divergence and vorticity appear remarkably able to influence the rainfall amount. Similar patterns are indicated in Fig. 11 in which is shown the correlation between the maximum hourly rainfall amount observed in Kyushu and the values obtained by using the small triangle Fukuoka-Kagoshima-Fukue during July 8 th-11th, 1968. Rainfall data show 3 hour later rainfall amounts after the time of sounding, taking into consideration the eastward movement of rainfall region from the triangle to Kyushu. Thus we can say that the more the quantities of value of low-level convergence and vorticity, the more the maximum rainfall amounts are observed somewhere in Kyushu.

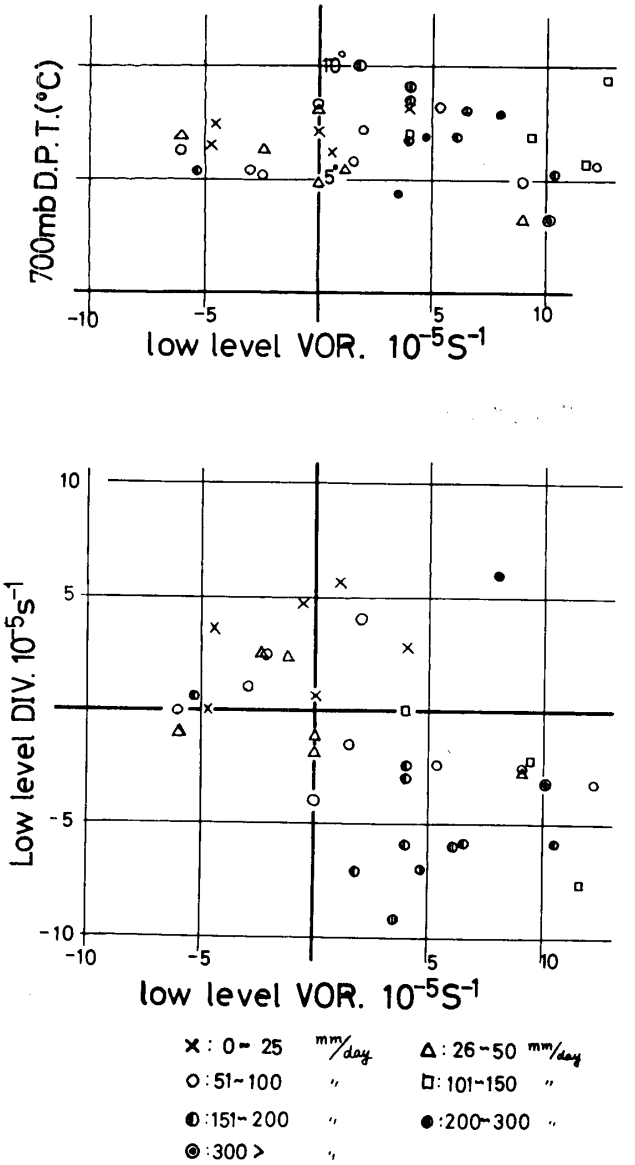


Fig. 10 Upper figure : Relation between 700mb *Dew Point Temperature, low level Vor., and maximum daily rainfall amount. Lower figure : Relation between low level Div., low level Vor., and maximum daily rainfall amount*

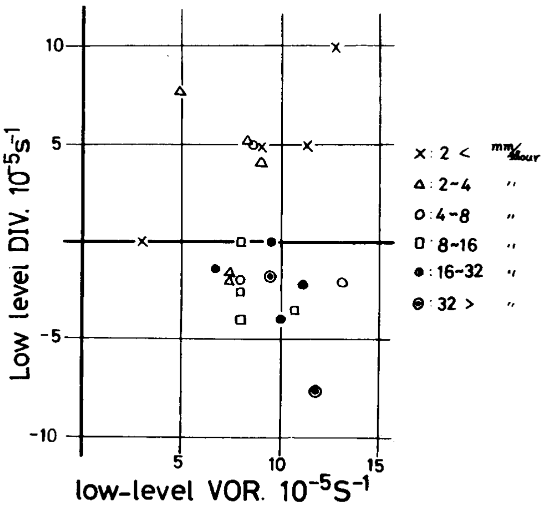


Fig. 11 Relation between low level Vor., low level Div. which are computed by the triangle Fukuoka-Fukue-Kagoshima, and 3 *hour later rainfall amount after the time of obtaining the sounding data*

Where the heavy rainfall appears is the important problem in forecasting as well as when it occures. Fig. 12 shows the correlation between the upper-level divergence, vorticity, and maximum daily rainfall amount, when the center of rainfall area is situated in the northern part of Kyushu (upper figure) and when in the southern part (lower figure), respectively. Data and symbols of rainfall amount are same as in Fig. 10. As indicated in the figure, while in the northern Kyushu all of the rainfalls occur in the region of negative upper-level vorticity, in the southern Kyushu the heavy rainfalls are seeen in the positive region. Expectedly there occurred the heavy rainfalls in bothparts of Kyushu when the values of upper-level divergence are positive.

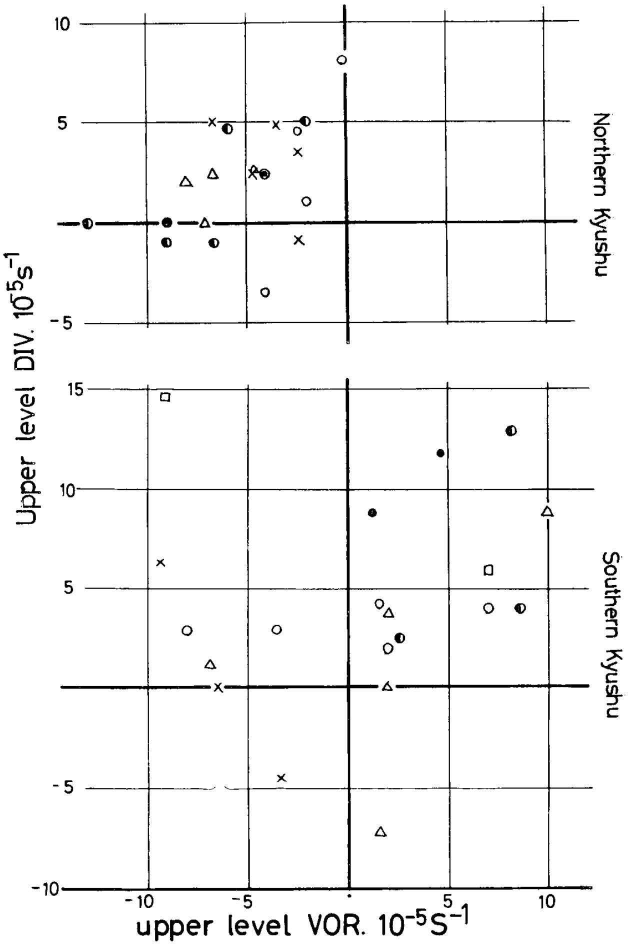


Fig. 12 Relation between upper-level Div., upper level Vor., and maximum daily rainfall amount, when the center of rainfall area is situated in the northern part of Kyushu (upper figure) and in the southern part (lower figure), respectively

5. Conclusion

The characteristic features of atmospheric divergence and vorticity are found by analyses when the heavy rainfalls were observed in Kyushu.

(1) Rainfall regions are divided into the two parts of northern and southern Kyushu according to the difference of the sign of upper-level vorticity which is caused by the deflection of upper-level jet stream ; positive corresponding to southern Kyushu and negative to northern.

(2) The pattern of low-level convergence and upper-level divergence appears when the heavy rainfall occurrs, and their quantities of absolute value are very large.

(3) Also there exists the region of strong positive vorticity in the low-level layer, and this is caused by the low-level jet stream.

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