

## Analysis of the Tropopause and the Stratospheric Field of Temperature of a Mature Typhoon

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### Abstract

Analysing the swarm ascents during the passage of the Typhoon KITTY, it is clearly shown that in a typhoon circulation of mature stage of development, there exist the downward displacements and warm air in the field of tropopause funnel in the cyclonic core; and the upward displacements and cold air in the field of annular tropopause ridge in the storm area.

In a paper entitled "Aerological Observations made in the Typhoon KITTY by the Central Meteorological Observatory, Tokyo" <sup>(1)</sup>, the present author made the analysis of tropospheric field of temperature in the field of the Typhoon KITTY. In this paper, the present author would like to point out some interesting facts regarding the stratospheric field of temperature and the topography of the tropopause in the area of the Typhoon KITTY. In the latest days of meteorology, the base of the stratosphere in the normal cyclone is 3~4 km lower than in an anticyclone. But the nature of the problem seems to be changed by the aerological observations made in the Typhoon KITTY.

The ideal boundary between the troposphere and the stratosphere is a single surface of discontinuity of the first order, with discontinuous change of temperature lapse-rate. <sup>(2)</sup> Rather often, however, several points of the aerological ascent curve in the tropopause region may show this kind of discontinuity, so that the lapse-rate changes from its tropospheric to its stratospheric value by successive steps. J. BJERKNES and E. PALMEN have given the definition of multiple tropopause for these cases. <sup>(3)</sup>

The ascent curves at Tokyo from the 31st of August at 9 h to the 1st of September at 11 h show good examples of a multiple tropopause.

In these ascents two levels with distinct decrease of lapse-rate can be found. In Fig. 1 they are indicated with arrows and the corresponding potential temperatures are inserted. In Table 1 the geometrical heights of these characteristic points are given, as well as the difference of temperature, the mean lapse-rate between them, and the potential temperatures of the two characteristic points.

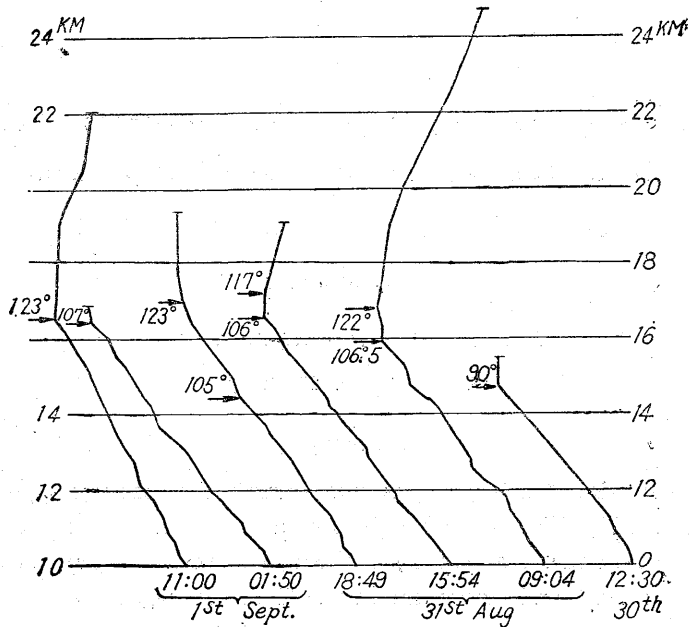


Fig. 1 The tropopause over Tokyo during the passage of the Typhoon KITTY, as shown by part of the CMO series of ascents.

Table 1

Ascent	Geometrical height of the characteristic points in metres		Temp. difference °C	Lapse-rate °C per 100 m	Potential temperature of the characteristic points	
					Group I	Group II
Aug. 31 09:04	15918	16783	+ 1.3	+ 1.5	106.5	122
15:54	16509	17218	- 0.4	- 0.6	106	117
18:49	14458 *	16997	+15.0	+ 5.9*	105	123
Sept. 1 01:50	16370				107	
11:00		16592				123

\* As stated in the former paper, in the uppermost tropospheric air, there exists strong descending motion over the core of the Typhoon KITTY. This vertical expansion of the upper tropospheric layer over the typhoon core produces a marked increase in lapse-rate: hence the lower surface of the double tropopause becomes quite obscure.

Except the small irregular variations in the potential temperature of the characteristic points, the potential temperature at each one of the tropopauses in a bundle is relatively constant although its height varies.

It is concluded from Fig. 1 that the lower surface of the double tropopause is in general better developed in the front of the Typhoon KITTY, whereas the upper surface becomes dominant in the rear of the Typhoon KITTY.

Ordinarily we expect that the tropopause is much lower in the cyclone core than in its outskirts. But we encounter marked exception. The tropopause over the storm region of the Typhoon KITTY is much higher than in its outskirts, and height of the tropopause is slightly reduced locally over the core of the Typhoon.

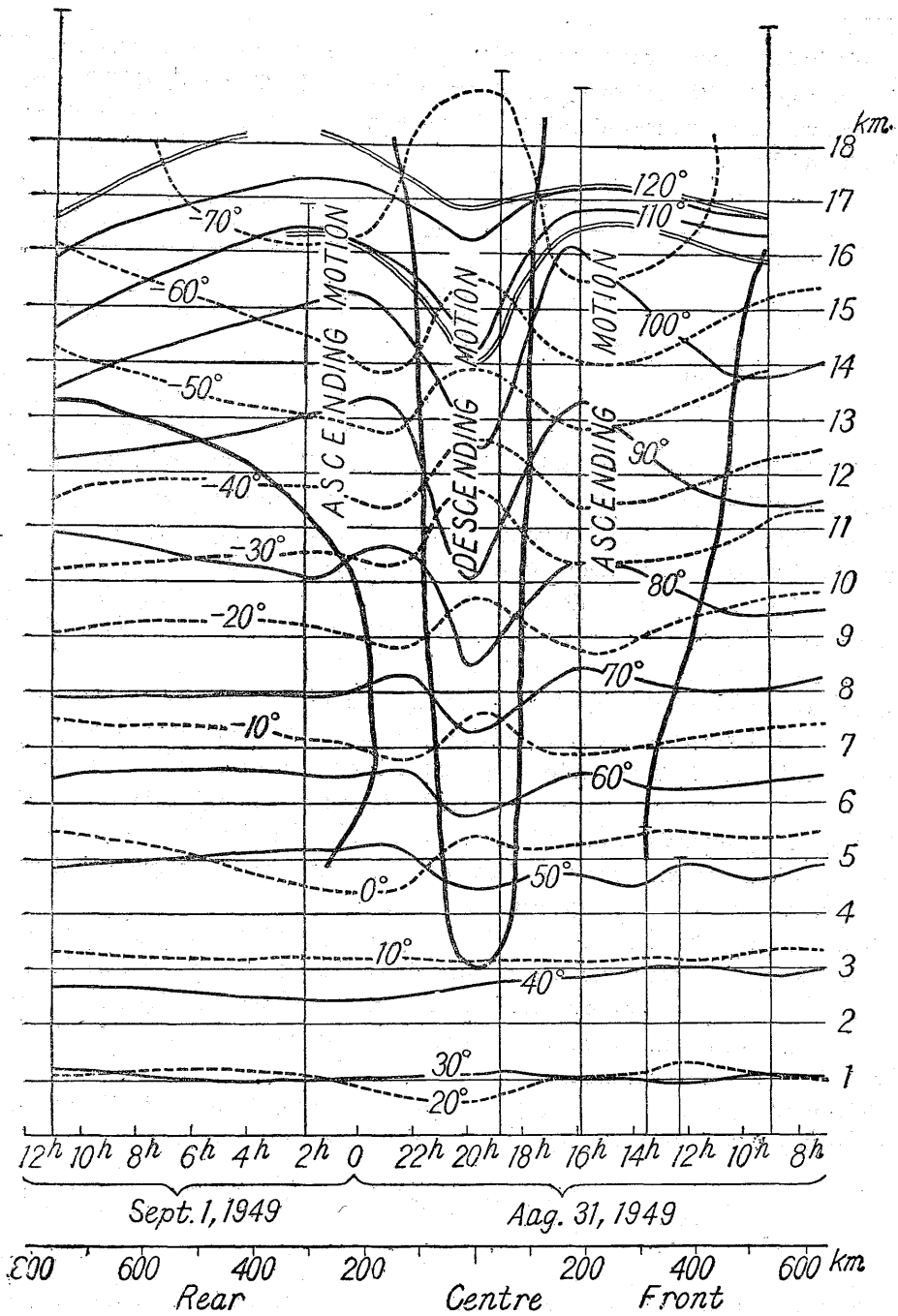


Fig. 2 Tokyo isopleths. Solid lines are isentropic lines ( $^{\circ}\text{K}$ ), broken lines are isotherms ( $^{\circ}\text{C}$ ), double lines are multiple tropopause and heavy lines with considerable slope are the boundary surfaces between the ascending and descending currents.

## KITTY.

Relatively warm stratospheric air lies over the core of the Typhoon KITTY; and colder air is situated over the storm region of the Typhoon KITTY and the stratospheric temperatures decidedly increase all the way to its outskirts. See Table 2 and Fig. 2.

Table 2 Stratospheric Field of Air Temperature (°C)

Ascents	Geometrical height in km							
	16	17	18	19	20	21	22	
Aug. 31	09:04	-66.0	-66.8	-65.3	-63.4	-59.8	-54.7	-49.7
	15:54	-72.9	-77.2	-73.0	-71.2			
	18:49	-63.9	-69.0	-69.8	-70.0			
Sept. 1	01:50	-69.3						
	11:00	-59.3	-62.9	-62.2	-61.5	-58.0	-54.7	-52.6

PALMEN speaks of "dynamical downsucking action" (dynamische Saugeffekt) as a cause of the vertical displacements of the tropopause in the cyclone core.<sup>(4)</sup> J. BJERKNES and PLAMEN have demonstrated that warm air in the "tropopause funnels" (Tropopausentrichter) can not be explained by the horizontal advection and must be attributed to downward motion. The locally reduced height of the tropopause in the core of the Typhoon KITTY is typical illustration of the type of situation studied by J. BJERKNES and PALMEN. We can, however, suggest another explanation of the annular "tropopause ridge" and cold air over the storm region of the Typhoon KITTY, if we take into account of the heavy ascending motion in the storm region. The locally increased height of the tropopause and relatively cold substratospheric air over the storm region of the Typhoon KITTY must be attributed to dynamical upraising action (dynamische Hebungseffekt) due to the intense upward motion, for each surface of the double tropopause is characterized by proper potential temperature, respectively.

Thus, in a typhoon circulation of a mature stage of development, there exist the downward displacements and warm air in the field of tropopause funnel due to the dynamical downsucking action in the cyclonic core; and the upward displacements and cold air in the field of annular tropopause ridge due to the dynamical upraising action in storm area.

The relation of temperature  $T$  and velocity  $v$  to the slope  $\sigma$  of the tropopause in a gradient wind field was given by H. ERTEL<sup>(5)</sup> as

$$tg \sigma(r, z) = tg \beta(r, z) - \frac{2\omega \sin \phi + \frac{2v}{r}}{g} \cdot \frac{T \left\{ \left( \frac{\partial v}{\partial z} \right)_1 - \left( \frac{\partial v}{\partial z} \right)_2 \right\}}{\left( \frac{\partial T}{\partial z} \right)_1 - \left( \frac{\partial T}{\partial z} \right)_2}$$

where  $\beta(r, z)$  is the slope of the isobaric surface to the horizontal, and the other symbols have their customary significance in a cylindrical coordinate system  $(r, \theta, z)$ , denoting the index 1 the stratosphere, the index 2 the troposphere. This is admittedly a simple case, which may not be applicable for the problem of the tropopause funnel as erroneously written by H. ERTEL. Moreover there is a serious

misprint in his text book, i. e., the slope of the isobaric surface to the horizontal should be read

$$\operatorname{tg} \beta(r, z) = \frac{2 \omega \sin \phi \cdot v + \frac{v^2}{r}}{g},$$

instead of

$$\operatorname{tg} \beta(r, z) = \frac{2 \omega \sin \phi \cdot v + \frac{v^2}{r}}{g}.$$

The observed distribution of pressure in the substratospheric field of the Typhoon KITTY is fully illustrated in Fig. 2 of the former paper<sup>(1)</sup>, where the height of isobaric surface is maximum over the cyclonic core and the height of isobaric surface is much lower in the storm region than in its outskirts. The observed distribution of temperature shows that the difference of temperature lapse-rate

$$\left(\frac{\partial T}{\partial z}\right)_1 - \left(\frac{\partial T}{\partial z}\right)_2$$

is positive. Actual determination of the gradient winds is, of course, difficult due to the unreliability of the pressure observations, but consideration of the general trends of the pressure distribution seems to permit us to write

$$\left(\frac{\partial v}{\partial z}\right)_1 - \left(\frac{\partial v}{\partial z}\right)_2 < 0, \quad \omega \sin \phi \cdot r + v > 0.$$

Thus the estimated height of tropopause based on ERTEL'S formula will be maximum over the cyclonic core and much lower in the storm region than in its outskirts. These are quite the contrary to the observed facts. Hence the phenomena of the tropopause funnel and tropopause ridge can not be explained by ERTEL'S formula, which has been given for the steady motion assuming a gradient wind field.

### References

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