P1.49 INFLUENCE OF VERTICAL WIND SHEAR ON THE INITIAL VORTEX FORMATION OF TROPICAL CYCLONE

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1. INTRODUCTION

Growth of tropical disturbance has been explained by CISK or WISHE. But these mechanisms work only after an initial vortex which have some strength is established at the lower level. Thus, understanding how an initial vortex forms is very important for understanding the tropical cyclogenesis.

Bister and Emanuel (1997) reports that an initial vortex of Hurricane Guillermo (1991) is formed through following steps: (1) atmosphere under the stratiform cloud is cooled by evaporation of raindrops, (2) a cyclonic vortex is developed at the mid-level of troposphere, (3) the vortex extends toward the ground.

In this article, the influence of vertical wind shear on aforementioned initial vortex spin-up mechanism is investigated by using a dry three-dimensional nonhydrostatic model (Nakano and Nakajima, 2004).

2. EXPERIMENTAL DESIGN

The model domain size is set to be 1500km in both horizontal directions and 15km in vertical direction from the ground. Horizontal resolution is set to be 10km and vertical resolution is set to be 500m. The cyclic condition is employed at the lateral boundaries and $w = 0$ is assumed at the top and bottom boundaries.

The temperature is set to be 300K at the ground. The lapse rate for the initial state of the model is set to be 6.5K/km up to 10km height from the ground. Above 10km, temperature is set to be 245K. Linearly sheared westerly wind is introduced up to 7.5km height. We cool a localized cylindrical region with 5km height with the rate $C = C_0/\rho(z)$. The cooling represents the effect of evaporation of stratiform precipitation and we translate it at the speed of initial wind at 5km height assuming the speed of stratiform clouds is same as the speed of initial wind at 5km height.(Fig. 1)

The total of 36 experiments are conducted with different sets of C_0, r_0 and $U_{7.5}$. The C_0 is set to be 5K/day, 10K/day, or 20K/day. The r_0 is set to be 50km, 100km, or 200km. The $U_{7.5}$ is set to be 0m/s (no shear cases), 1m/s, 3m/s, or 6m/s.

Hereafter, for example, 'C10R100S3' means the experiment in which C_0=10K/day, r_0=100km, and S, the magnitude of vertical wind shear of 3m/s/7.5km are used.

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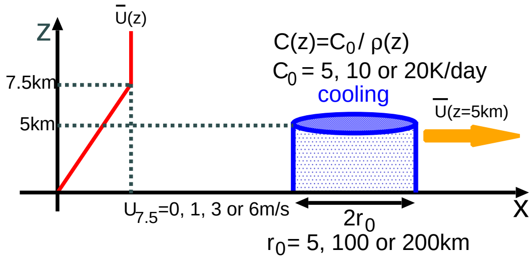

FIG. 1: Outline of experiments.

3. RESULTS

Fig. 2 shows vorticity on x-z cross section at the center of the cooled region. In 'C10R50S0', positive vorticity is produced at the top of the cooled region, and it is transported downward in the cooled region. In 'C10R50S1' (Fig. 2(a)), the vortex tube have only a bit of westward tilt. In 'C10R50S3', the vortex tube extend to the ground with larger tilt than 'C10R50S1' by 40 hours. But at 60 hours, it is heavily tilted by wind shear below 1.5km height (Fig. 2(b)). In 'C10R50S6' (Fig. 2(c)), the vortex tube has very large westward tilt and cannot extend to the ground.

The time evolution of maximum vorticity at the level z=750km for $U_{7.5}$ =6m/s (Fig. 3) shows that vorticity hardly increase until the end of simulation in cases with C_0 = 5K/day. Moreover, in 'C10R50S6', 'C10R100S6' and 'C20R50S6', maximum values of vorticity decrease significantly in the later period of the simulation. This result shows that strong shear has a destructive effect on the vortex development.

Table 1 shows the results of subjective judgments whether the vortex extended to the ground for experiments with shear. It is difficult for the vortex to extend to the ground in the strong vertical shear and that when the vertical shear has same magnitude, it is more difficult for the vortex to extend to the ground with smaller cooled region or with smaller cooling rate.

4. CONDITION FOR THE VORTEX TO REACH THE GROUND SURFACE

The stretching of planetary vorticity produces a vortex at the top of the cooled region. So the condition for the vortex to extend to the ground can be diagnosed by considering the path of the parcel starting from the top of the cooled region in the westerly sheared environment.

The westward displacement of a parcel starting from the top of the cooled region $\Delta\xi$ is expressed as

$$\begin{aligned}\Delta\xi &= \int_0^t u(z,t)dt = \int_0^t \frac{d\overline{u}}{dz}\Delta\eta dt = \int_0^t \frac{d\overline{u}}{dz} wtdt \\ &= \frac{1}{2}\frac{d\overline{u}}{dz}\frac{\Delta\eta^2}{w} \quad (t = \Delta\eta/w), \qquad (1)\end{aligned}$$

where t is time, $\Delta\eta$ is downward displacement from the top of the cooled region, and w is downward flow in the cooled region. If we replace $\Delta\eta$ with D, the height of the cooled region, assuming that the cooling is balanced with adiabatic warming by downward motion, $w = C_0/\frac{d\overline{\theta}}{dz}$, (1) results in

$$\Delta\xi = \frac{1}{2}\frac{d\overline{u}}{dz}\frac{D^2}{C_0}\frac{d\overline{\theta}}{dz}, \qquad (2)$$

which shows the westward displacement of a parcel when the parcel arrived at the ground assuming temporarily that the same downward motion exist outside of the cooled region as that in the cooled region.

Dividing (2) by L(=r_0), radius of the cooled region, we obtain a non-dimensional number SI (Shear Index) which represents the magnitude of the influence of the vertical wind shear,

$$SI \equiv \Delta\xi/L = \frac{1}{2}\frac{d\overline{u}}{dz}\frac{D^2}{C_0 L}\frac{d\overline{\theta}}{dz}. \qquad (3)$$

Because a cooled region has a cylindrical shape, $SI > 1$ means that more than half of parcels starting from the top of the cooled region are blew away from the cooled region. The values of SI for all parameters of this paper are shown in table 2. When we compare the table with Table 1, we find that $SI \simeq 3$ is the criterion for the vortex touchdown.

5. DISCUSSION

In the real atmosphere, if we suppose a stratiform precipitation with the radius of 100km and the cooling rate of 10K/day, $SI = 3$ corresponds to the shear of 4m/s/5km, which roughly coincides with the widely known threshold value. The present result suggests a new candidate for an answer to the question that why tropical cyclogenesis does not occur in the strong vertical shear region, to which we have conventionally answered "Because warm core is blown off in the developing stage.": tropical cyclones do not develop because initial vortex is not formed in strongly sheared environment.

REFERENCES

Bister, M., and K. A. Emanuel, 1997: The genesis of Hurricane Guillermo: TEXMEX analyses and a modeling study, *Mon. Wea. Rev*, 125, 2662-2682.

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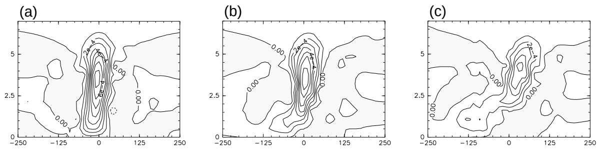

FIG. 2: x-z cross section of vorticity(s^{-1}) in experiment (a) 'C10R50S1', (b) 'C10R50S3', (c) 'C10R50S6' at y=750km for 60h. respectively. Negative values are stippled.

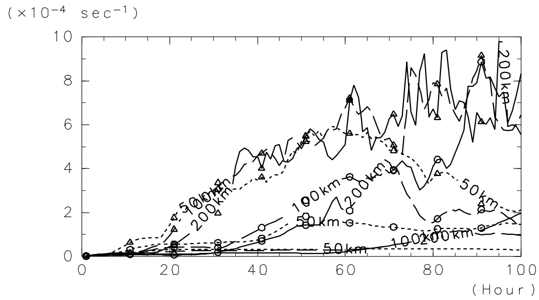

FIG. 3: The time evolution of maximum vorticity(s^{-1}) at z=750m for $U_{7.5}$=6m/s.The markers show the cooling rate, C_0 (triangle: 20K/day, circle: 10K/day, none: 5K/day). And the line types show the radius of cooling region, r_0 (solid line : 200km, broken line: 10K/day, dashed line: 5K/day).

$U_{7.5}$	C_0	r_0		
		50km	100km	200km
1m/s	5K/day	○	○	○
	10K/day	○	○	○
	20K/day	○	○	○
3m/s	5K/day	×	○	○
	10K/day	○	○	○
	20K/day	○	○	○
6m/s	5K/day	×	×	×
	10K/day	×	○	○
	20K/day	○	○	○

Table 1: Result of subjective judgment for cases with vertical shear. ○ (×) denotes that the vortex can (cannot) reach to the ground.

$U_{7.5}$	C_0	r_0		
		50km	100km	200km
1m/s	5K/day	2	1	0.5
	10K/day	1	0.5	0.25
	20K/day	0.5	0.25	0.125
3m/s	5K/day	6	3	1.5
	10K/day	3	1.5	0.75
	20K/day	1.5	0.75	0.375
6m/s	5K/day	12	6	3
	10K/day	6	3	1.5
	20K/day	3	1.5	0.75

Table 2: The value of SI for cases with vertical shear.