Impact of physical processes in a GCM on the frequency of tropical cyclones

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A long-term trend of tropical cyclone (TC) frequency under the global warming condition has been a matter of great concern. Some modeling studies predict smaller number of TC genesis under the condition than in the current climate although some contrary results are reported. It is well known that even state-of-the-art GCMs have large uncertainties especially in physical processes such as deep convection, which have large impact on the model behaviour in the tropics.

Aside from the impact of global warming on TC frequency, here in this study we investigate the effect of the two physical processes, cumulus parameterization (CP) and radiative process (RP), on the frequency of modeled TC formation. In the study, a T106-L21 version of the previously operational JMA global model (JMA/NPD 1993, 1997) is used as GCM. The model is integrated for one year with three different combinations of CP and RP (Table 1). RAD-B96 and -S96 differ in several points such as the manner of cloud-overlapping in the vertical, absorbers considered and so on.

Table 1: List of experiments

Experiment ID	Cumulus Parameterization	Radiative process
Exp.A	Kuo-type scheme	RAD-B96 (operational before 1996)
Exp.B	prognostic Arakawa-Shubert scheme	RAD-B96 (operational before 1996)
Exp.C	prognostic Arakawa-Shubert scheme	RAD-S96 (operational since 1996)

Table 2 compares TC frequency among the three experiments for some selected basins. The criteria used to qualify a disturbance as TC in the model is just the same as in Yoshimura et al. (1999). The table clearly demonstrates large sensitivity of TC frequency to both of CP and RP.

Table 2: Frequencies of tropical cyclones simulated by the model

Experiment ID	Northwest Pacific	Northeast Pacific	South Pacific	Global
Exp.A	51	21	18	182
Exp.B	22	2	11	71
Exp.C	5	1	2	25

To gain some insight into how the different schemes might produce different number of TCs, we examine the relationship between the rainfall amount and relative vorticity at low levels, because the former is a direct outcome of convective activities (therefore strongly depends on the formulation of deep convection) and the latter could be a good indicator of vortex spin-up. Model data used for the study has a horizontal resolution of 1.125 degree in longitude and latitude with an interval of 12 hours over the entire integration period. Table 3 shows 12-hour relative vorticity change at 850 hPa ($\varsigma_{t+12} - \varsigma_t$), stratified by the corresponding 12-hour rainfall amount and magnitude of relative voriticity (ς_t), and averaged over any relevant grid points within the basin. Contribution from horizontal advection is subtracted from $\varsigma_{t+12} - \varsigma_t$ to focus on the vorticity change associated with vertical motion fields. Although we show here the result only for the Northwest Pacific, remarkably larger values in Exp.A are commonly observed in all other basins.

Table 3: 12-hour relative vorticity change at 850 hPa ($10^{-6}s^{-1}$), stratified into several sub-groups according to rainfall amount between t and t+12 hour for $\varsigma_t < 10 \times 10^{-6}s^{-1}$ group.

Experi-ment ID	12-hour rainfall amount (mm)								
	0 - 5	5 - 10	10 - 15	15 - 20	20 - 25	25 - 30	30 - 35	35 - 40	40 -
Exp.A	+1.7	+7.2	+13.9	+23.5	+35.1	+45.1	+55.9	+67.8	+104.2
Exp.B	+1.0	+4.8	+7.6	+10.3	+11.9	+19.1	+19.0	+22.1	+40.0
Exp.C	+0.4	+2.5	+4.8	+8.9	+13.1	+15.0	+21.6	+30.0	+29.5

Figure 1 shows the latitudinal distribution of annual precipitation for the Northwest Pacific. There is no significant difference between Exps.A and B except for near the equator where TCs rarely form because of minimal Coriolis force there. On the other hand, Exp.C produces much smaller rainfall amounts over theTC genesis area. From the results presented here we can tentatively draw the conclusion that the difference in TC frequency between Exps.A and B might be attributable to the difference in the strength of linkage between vorticity production and convective heating between the two cumulus parameterization schemes. On the other hand, the difference between Exps.B and C might be explained by the difference in large-scale circulation such as Hadley cell yielded by using the different radiation code.

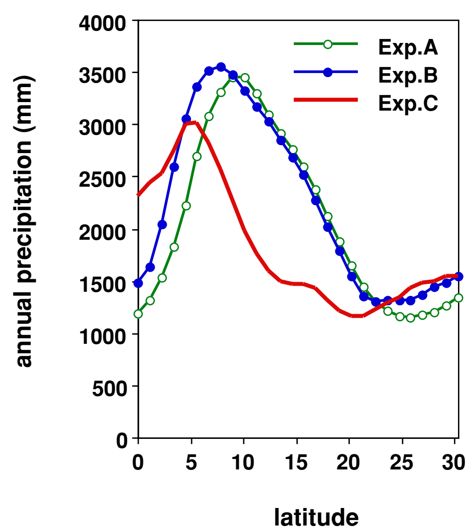

Figure 1: Annual precipitation (mm) simulated by the model over the Northwest Pacific basin.

References

JMA/NPD 1993, 1997: Outline of operational numerical weather prediction at Japan Meteorological Agency. Appendix to progress report on numerical weather prediction.

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