Effects of Diurnally Varying Radiation on Tropical Cyclone in Idealized Simulation
(理想実験における日変化する放射が台風に及ぼす影響)

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This work examines this mechanism by conducting idealized rotating radiative-convective equilibrium simulation, in which the effects of the large-scale influences are ignored, and the convection reacts to destabilization only by the radiation and surface enthalpy fluxes. The tropical cyclone develops spontaneously from uniform environment with random temperature perturbation in low-level to initiate convection. The experiment with normal diurnally varying radiation and the experiment with constant shortwave radiation were carried out with 100 simulation days. Several sensitivity experiments are also designed with different sea surface temperature, different microphysical schemes. The results show that the tropical cyclones in the experiments with diurnally varying radiation indicate obvious diurnal cycles of convection activity.

1. Introduction

There are many observational analyses suggesting that tropical cyclones (TCs) have apparent diurnal cycle, which could be considered as the result of diurnal solar radiation variation. Many previous studies demonstrated that radiation can affect tropical cyclone development. However, it remains unclear that how diurnal solar radiation variation leads to tropical cyclone diurnal cycle.

2. Methodology

In this work, idealized rotating radiative convective equilibrium experiments are conducted with Weather Research and Forecasting (WRF) Model Version 4.2. Domain size is 1500km×1500km with 2km horizontal resolution. The model top is 30km with 5km damping layer at the top. There are 60 vertical eta levels in the model. Time step is 10s, and integral period is 100 days. Coriolis parameter is 5×10^{-5} s^{-1}. The radiation scheme, surface layer scheme and boundary layer scheme applied in the simulations are RRTMG, revised MM5 Monin-Obukhov and YSU respectively. The boundary condition is doubly periodic. There is no wind in the initial time. The input sounding is the radiative-convective equilibrium sounding created by long time integration in a small domain (200km×200km). Random low-level temperature perturbation is inserted to initiate the convection.

The experiments with normal diurnally varying shortwave radiation and constant shortwave radiation were carried out. The constant shortwave radiation is the daily mean of the normal diurnally varying shortwave radiation. In order to obtain more robust results, this work applies 2 commonly used microphysical parameterizations, WSM6 and Morrison scheme. This work also applied 305K and 299K sea surface temperature (SST) for simulation.

3. Result

Figure 1 shows the time series of surface maximum wind speed for the experiments. In the beginning, the value is 0 because there is no wind in the initial time. For each experiment, the value increases to around 8 m/s for several days, thereafter the value increases rapidly to its peak value, indicating the cyclogenesis and rapid intensification stage of TCs. After reaching the peak value, it decreases and increases repeatedly, corresponding the dissipation and intensification of TC in the simulations. For the 305K SST simulations, the peak intensities are higher than the 299K SST

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simulations. For the wsm6 schemes simulations, for the DC and NDC members, the commencements of rapid intensification are relatively close. For the morrison simulations, the commencements time of rapid intensification in DC simulations are apparently earlier than that in NDC simulations. The result suggests that the shortwave radiation diurnal cycle can affect the cyclogenesis and rapid intensification of TC more apparently in morrison microphysical schemes simulations, indicating that the radiative effects may be related to different microphysical schemes.

Since previous studies suggest that there is obvious diurnal cycle in mature TC, this work intends to investigate the convection activity diurnal variability in mature TC. In this work, when the daily mean maximum wind speed is greater than 43m/s (Saffir–Simpson storm intensity of category 2 or higher), the TC is defined as mature TC, and the corresponding period is defined as a TC day. Table1 shows the number of TC days of each experiment. Generally, the TC days are more in 305K SST simulations, and more in DC simulations.

In order to investigate the convection activity, the vertical water content is analyzed here. Vertical water content defined as $\int_0^{z_{top}} \sum q_i \, dz$, where q_i is mixing ratio of liquid or solid water species (cloud water, rain, ice, snow and graupel), indicating the condensate water of column, which is higher for stronger convection.

Discrete Fourier transformation ($X_k = \sum_{n=0}^{N-1} x_n \cdot e^{-\frac{2\pi i}{N}kn}$) is used to analyze the diurnal variation of each TC day. The proportion of diurnal power spectrum ($|X_{24}|^2$) to the total power spectrum can be regarded as the significance of diurnal variation of convection. Figure 2 shows the proportion of diurnal power spectrum of vertical water content in the r<150km region in each TC day for the experiments. It can be seen that the diurnal variability is apparently stronger for the DC simulations than that of NDC simulations for both 305K and 299K SST simulations and both morrison and wsm6 schemes simulations. Figure 3 shows the composite mean of the daily anomalies of vertical water content in the r<150km region in each TC day for all the DC simulations, and the error bars indicate the standard deviation of the composite mean.

It can be apparently seen that the value is negative about 7 to 19 local standard time (LST), and positive in other LST, which means the convection activity is more vigorous in nighttime and less vigorous in daytime. In the outer region, the features are similar but the amplitude of the daily variation is much smaller (not shown).

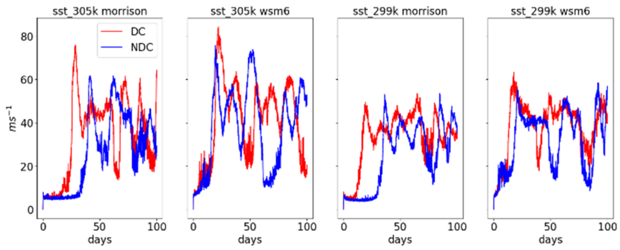

Figure 1. Evolution of maximum surface wind speed for the experiments.

Table 1. The number of TC days for the experiments.

member	sst_305k	sst_299k
morrison_DC	39	19
wsm_DC	54	48
morrison_NDC	21	7
wsm_NDC	47	21

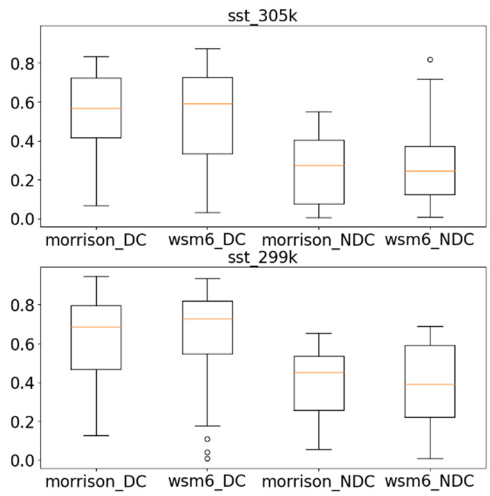

Figure 2. The proportion of diurnal power spectrum of vertical water content in the r<150km region in each TC day.

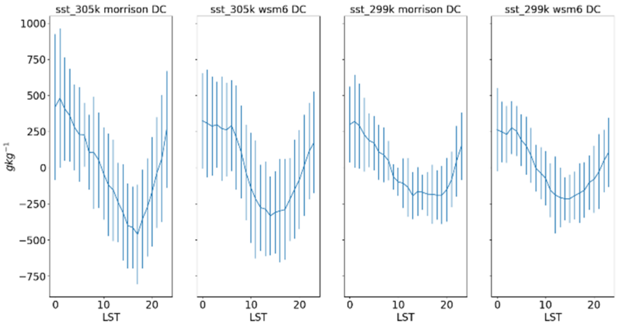

Figure 3. Composite mean of the daily anomalies of vertical water content in the r<150km region in each TC day for all the DC simulations. Error bar indicates the standard deviation.

4. Summary and discussion

In the rotating radiative convective equilibrium simulations with 2 different microphysical parameterization schemes, 2 different SST and 2 different shortwave radiation configurations, the TC can spontaneously develop from the uniform no wind initial state. The TC days in NDC are less than DC, and they are less for lower sea surface temperature. The diurnal cycle of convection is strong for both core region and outer region for the DC members, which is more vigorous in night. This is consistent with the observation. The commencements of intensification between DC and NDC simulation are different for the morrison schemes simulations, which means the diurnal cycle could play a role on cyclogenesis and intensification and it may be related to the microphysical schemes. Investigation of the effect of diurnal cycle radiation on cyclogenesis and intensification will be future work.

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