The impact of topography on the predictability of moist convection and precipitation development

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1. Introduction

Rapidly developing moist convection such as afternoon thunderstorms could bring sudden heavy rainfall and lead to disasters like river overflow and flood. It has been shown that the predictability of moist convection is limited in a few hours since the error grows quickly upscale through the process of moist convection. Recently, some studies have indicated the impact of topography on predictability. Bachmann et al. (2019, 2020) indicated that orography can increase the accuracy of precipitation prediction from the perspective of practical predictability [1, 2]. However, there are still some questions that haven't well investigated. For example, for rapidly developing convections that usually develop over mountain areas, like afternoon thunderstorms, how the topography impact the development of convection and the initial error growth? And also, if topography impacts predictability, will this characteristic help us have a better forecast for afternoon thunderstorms or not? While many studies have investigated the error growth and predictability related to moist convection, literature focus on the impact of topography is still limited. Understanding the effects of topography on the predictability of moist convection is essential to provide more reliable day-to-day weather predictions over the mountain areas. From the perspective of intrinsic and practical predictability, this study aims to focus on the simulation of afternoon thunderstorms and address the above questions.

2. Methodology

To investigate the impact of topography on the predictability of moist convection, identical twin experiments are conducted with Advanced Research Weather Research and Forecasting (WRF) model version 4.1.2. A real-sounding data from Shionomisaki (潮岬) at 0900 JST on 19th August 2018 is used to initialize the simulation. The sounding is chosen to approximate the situation that of the moist convection derive by the heating of the sun, like afternoon thunderstorms, which is occurred on this day at Shionomisaki. The simulation is initialized by adding white noise with an amplitude of 0.01K on the potential temperature field below 2 km to the homogeneous initial condition gotten from the sounding. Full physic is used including the WSM6 scheme for microphysics, RRTMG scheme for long wave and short wave radiation, Mellor–Yamada–Janjic scheme for the planetary boundary layer model. The domain size is set to 300 km×300 km×25 km with 50 vertical levels and 1-km horizontal grid spacing. The longitude and latitude are set to 135.76°E and 33.35°N which is the location of Shionomisaki station. The Coriolis force is set to 7.9958×10^{-5} according to the latitude, and the land use is set to Wooden Wetland.

The control simulation of identical twin experiments is started from 0000 JST 22th June 2018. The first day of simulation is seen as spin-up time. The perturbed simulation is conducted by adding small differences to the water vapor mixing ratio (q_v) at 0600 JST on 23rd June. The difference is added at every grid with random numbers from a Gaussian distribution whose standard deviation is 0.01 g/Kg. Experiments with and without topography are conducted with the same model setting but only different topography. In the experiment with topography, a Gaussian shape mountain with 993.1268-m height and 25-km width is added to the southwest of domain (gray dashed contour in Fig. 1b).

To estimate the difference growth rate, the difference total energy (DTE), which defined as

$$\mathrm{DTE} = \frac{1}{2}\left(u'^2 + v'^2 + \frac{c_p}{T_r}T'^2\right),$$

is computed. u'^2, v'^2, and T^2 is the difference of model U wind, V wind, and temperature, respectively. C_p and T_r is the heat capacity and reference temperature (287 K). The DTE is computed in 3-D dimensional spaced and then took mass-weighted average in the vertical direction [3].

3. Results

Results of the vertical weighted average DTE show that the pattern of higher difference growth area highly matched the distribution of the moist convection for both experiments with and without topography (Fig. 1). This confirms the previous studies' results; the initial error could grow through the moist convective process quickly. The results of the temperature lapse rate show that there is higher instability over the mountain since early morning in the control simulation with topography. This leads to the early development of conventions and then results in the earlier DTE growth over the mountain area. On the other hand, the DTE area mean over the mountain area decreased in the afternoon, which indicates that the existence of the topography decreases the non-linearity over the area if there is no convection developing (Fig. 2). The results of the root mean square difference (RMSD) of q_v show similar results to DTE. It is also clear to see that the RMSD of q_v starts to grow quickly since the convection starts to develop. In contrast, the RMSD over the area far away from the mountain grows more slowly since little convection developing over there.

The spectra analysis of the DTE shows that the growth of difference is similar between two experiments in the early stage of the integration, but start to become very different since 1000 JST due to the convections start to develop over the mountain in the experiment with topography. The time series of DTE spectra between 0900 JST and 1200 JST shows that the difference of experiment with topography grows to a larger scale faster. On the other hand, the growth of the difference of experiment without topography shows a clear characteristic scale of a single convection cell. The result of precipitation shows that the pattern of accumulated rainfall between two simulations of the experiment with topography is more similar. The spatial correlation coefficient (SCC) of rainfall between control and perturbed simulation of the experiment with topography is higher during the whole simulation time.

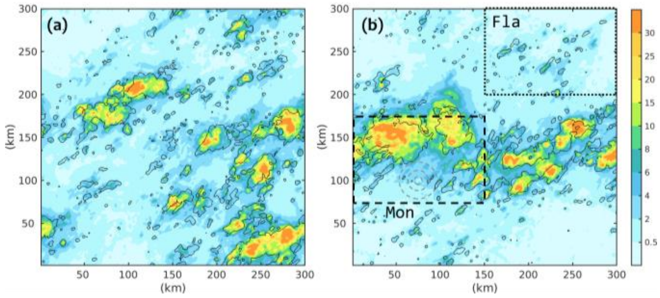

Figure 1. The vertical weighted average DTE (shaded) of experiments (a) without topography and (b) with topography. The black contours indicate the 30-dBZ composite reflectivity of the control simulation. The dashed-line and dotted-line boxes in (b) show the range of area mean computed for Fig. 2.

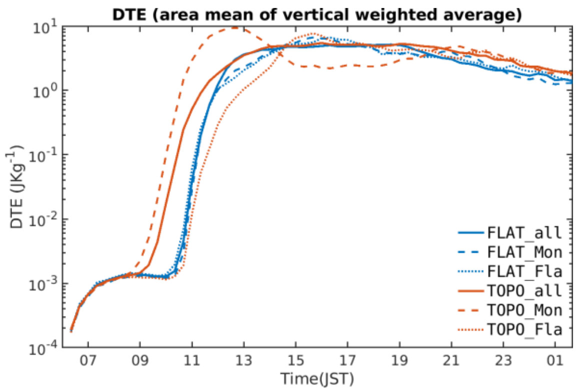

Figure 2. Time series of domain mean (solid line) and area mean (dashed and dotted line represents for Mon and Fla area shown in Fig. 1, respectively) of the vertical weighted average DTE. The blue and orange color indicates the results of experiment without and with topography, respectively.

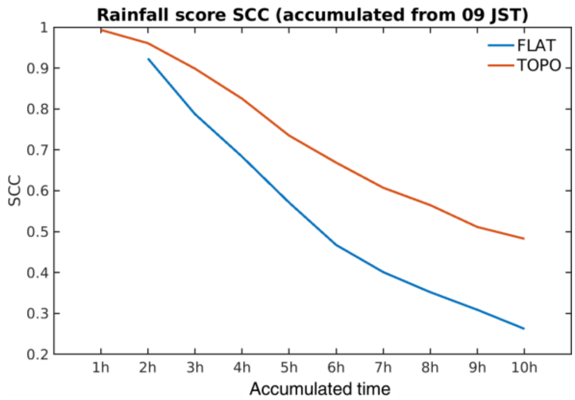

Figure 3. The SCC between rainfall accumulated for 1 to 10 h from 0900 JST of control simulation and perturbed simulation. The blue and orange color indicates the results of experiment without and with topography, respectively.

参考文献

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