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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 thunderstorm could bring sudden heavy rainfall and lead to disasters such as river overflow and flood. Recently, Bachmann et al. (2019) showed that topography can increase the practical predictability of the precipitation brought by moist convection. However, from the perspective of intrinsic predictability, there are still some questions about the impact of topography that haven't been well addressed. For example, how does topography affect the error growth rate associated with moist convection? 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. In this study, we conduct numerical simulations and identical twin experiments (e.g. Zhang et al. 2003) to investigate the impact of topography on the error growth associated with afternoon thunderstorm.

2. Methodology

The WRF model version 4.1.2 is used with full physic including the WSM6 scheme for microphysics, RRTMG scheme for radiation, MYJ scheme for the planetary boundary layer model. The domain size is 300 km×300 km×25 km with 50 vertical levels and 1-km horizontal grid spacing. For the initial condition, a real-sounding data from Shionomisaki (潮岬) at 0900 JST on 19th August 2018 is used. Two identical twin experiments, with and without topography (hereafter TOPO and FLAT), are conducted. In the experiment TOPO, a Gaussian shape mountain with around 1000-m height is added. For each experiment, the control simulation is initialized by adding white noise to the potential temperature below 2 km. After the spin-up, the perturbed simulation is produced by adding random number, whose standard deviation equal to 0.01 g/kg, to the water vapor mixing ratio of the control simulation at every grid. The difference between the control and perturbed simulation is regarded as error. To estimate the magnitude of this difference, a metric called moist difference total energy (moist DTE; Zhang et al. 2007, Ehrendorfer et al. 1999) is calculated by

$$\text{moist DTE} = \frac{1}{2}\left(u'^2 + v'^2 + \frac{c_p}{T_r}T'^2 + \frac{L_v^2}{c_p T_r} {q_v}'^2\right).$$

Here, u', v', T', and ${q_v}'$ are the differences of model U wind, V wind, temperature, and water vapor mixing ratio, respectively, between the two simulations. c_p, T_r, and L_v are the specific heat at constant pressure (1004.9 $\mathrm{JKg^{-1}K^{-1}}$), reference temperature (270 K), and the latent heat of condensation (2.4359×10^6 $\mathrm{JKg^{-1}}$), respectively.

3. Results

All simulations successfully simulated the process of development of the afternoon thunderstorm. For both experiment FLAT and TOPO, the distribution of vertical mass-weighted averaged moist DTE matches the location of convections (Fig.1). The moist DTE averaged over mountain area in the experiment TOPO starts to grow quickly earlier and decrease in the afternoon (Fig. 2), which matched the time of convection development over the mountain area. Figure 3 shows that the power spectra of the experiment TOPO start to amplify earlier and propagate to a larger scale, while those of the experiment FLAT start to grow late and have peaks at the characteristic scale of the individual convective cell (~5km). The distribution, time series, and power spectra of moist DTE all suggest that the error growth is highly related to moist convection.

We also calculated moist DTE for individual cloud area. The scatter plots of cloud size to moist DTE (Fig. 4) show that when the cloud size is larger, moist DTE also tends to be greater. For the cloud areas that developed over the mountain area in the morning, they have smaller moist DTE than others. This means that for convections with similar size, those developing over the mountain have smaller moist DTE. It also implies that the topography may decrease the error growth rate associated with moist convection.

Reference

Bachmann, K., C. Keil, and M. Weissmann, 2019: Impact of radar data assimilation and orography on predictability of deep convection. *Quart. J. Roy. Meteor. Soc.*, **145**, 117–130.

Ehrendorfer, M., Errico, R. M., and Raeder, K. D., 1999: Singular-Vector Perturbation Growth in a Primitive Equation Model with Moist Physics. *J. Atmos. Sci.*, **56**, 11, 1627-1648.

Zhang, F., Snyder, C., and Rotunno, R., 2003: Effects of Moist Convection on Mesoscale Predictability. *J. Atmos. Sci.*, **60**, 9, 1173-1185.

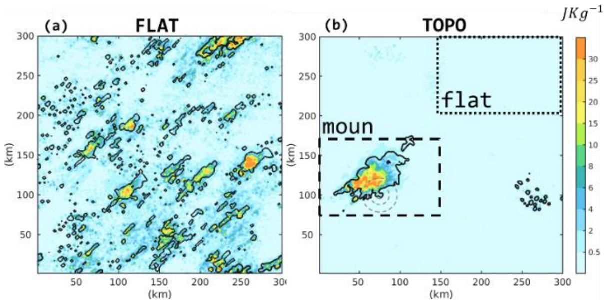

Figure 1. The vertical mass-weighted averaged moist DTE (color shaded) and the composite reflectivity of the control simulation (black contour; 25 dBZ) of experiments (a) FLAT (at 1040 JST) and (b) TOPO (at 1140JST). The dashed-line and dotted-line boxes in (b) show the range of area average computed for Fig. 2.

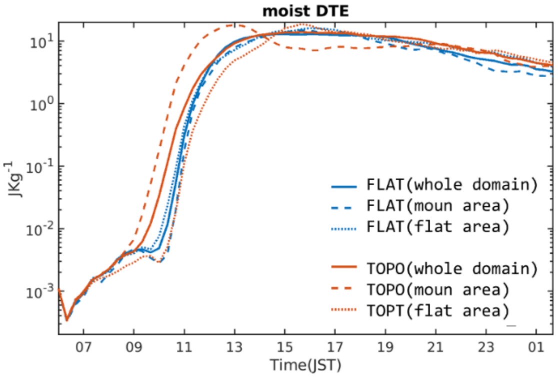

Figure 2. Time series of the moist DTE averaged over the whole domain (solid curves), mountain area (dashed curves), and flat area (dotted curves) for the experiment FLAT (blue) and TOPO (orange).

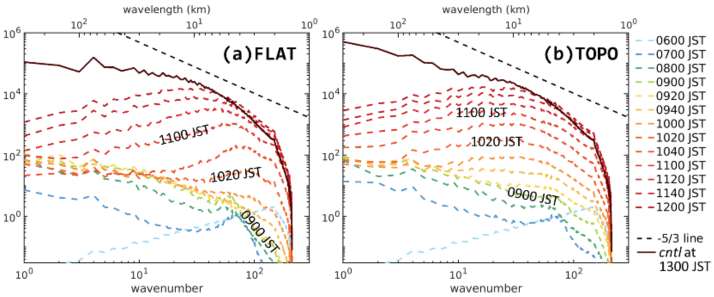

Figure 3. Power spectra of the moist DTE below 10 km (color dashed curve) for the experiment (a) FLAT and (b) TOPO. The dark red solid curve shows the power spectrum of the control simulation at 1300 JST on June 23rd. The black dashed line is the -5/3 line for reference.

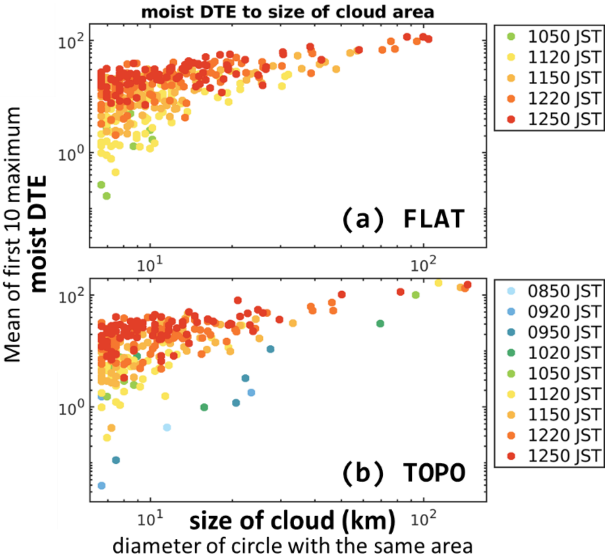

Figure 4. Scatter plot of the cloud size to the moist DTE in each cloud area of the experiment (a) FLAT and (b) TOPO. The different color represents cloud area at different time.