Coupling and contrastive analysis of the non-inductive electrification mechanism parameterization schemes in Weather Research and Forecasting (WRF) model

Pengguo Zhao[1,*], Yan Yin[1], Hui Xiao[1]

1. Key Laboratory for Aerosol-Cloud-Precipitation of China Meteorological Administration, Nanjing University of Information Science & Technology, Nanjing, China

ABSTRACT: The Weather Research and Forecasting (WRF) model offers the numerical environment to develop thunderstorm cloud electrification scheme in a consistent way with two-moment bulk mixed phase microphysical scheme. The charge separation mechanisms are entirely due to non-inductive electrification processes and result from rebounding collisions of ice-graupel and sonw-graupel. The schemes of non-inductive electrification mechanism considered in the electrification processes include S91 scheme, TAK scheme, RR scheme, SP98 scheme. The charge structure simulated by different scheme is obviously different. An idealized continental storm is simulated to investigate the electrification process. The results show that S91 scheme produces an inverted dipole charge distribution at early stage of thunderstorm development process and then the charge structure turns to multilayered charge distribution which is sensitive to updraught velocity in the convection trigger zone. The TAK scheme produces an inverted dipole charge distribution in the whole numerical simulation process. The RR scheme and SP98 scheme produces the same charge distribution that is dipole charge structure, and the charge distributions of RR scheme and SP98 scheme are close to each other. The results of this study provide a foundation for further lightning forecasting research in mesoscale model. We agree on the viewpoint of Mitzeva et al. (2009) that it is difficult to confirm which existing parameterisation schemes are better suited to realistic simulation of real thunderstorm.

INTRODUCTION

Laboratory investigations (Reynolds et al., 1957; Takahashi, 1978; Saunders et al., 1991) and

* Contact information: Pengguo Zhao, Nanjing University of Information Science & Technology, Nanjing, Jiangsu, China, Email: zpg0402@163.com

simulation studies (Takahashi, 1983; Helsdon et al., 2001; Mansell et al., 2005) confirmed that the main charging process of the thunderstorm is caused by rebounding collisions between ice crystals and graupels in the mixed-phase region, and then aerosols have effects on electrical activities consequentially. Helsdon et al. (2001) found that the results were different by using different noninductive charge separation schemes. Mansell et al. (2005) compared five laboratory-based parameterizations of noninductive graupel-ice charge separation and found that three of the noninductive charge separation schemes produce tripolar charge structure. Mitzeva et al. (2009) found that it is difficult to confirm which existing parameterisation schemes are better suited to realistic simulation of real thunderstorm.

THE MODEL DESCRIPTION

The Weather Research and Forecasting (WRFV3.4) model offers the numerical environment to develop thunderstorm cloud electrification and aerosol activation scheme in a consistent way with two-moment bulk mixed-phase microphysics scheme (Morrison et al., 2005; 2008). The charge separation mechanisms are entirely due to non-inductive electrification processes and result from rebounding collisions of ice-graupel and snow-graupel. The schemes of non-inductive electrification mechanism considered in the electrification processes include S91 scheme (Saunders et al., 1991; Helsdon et al., 2001), TAK scheme (Takahashi, 1987), RR scheme (Brooks et al., 1997), SP98 scheme (Saunders and Peck, 1998).

Initialization

The thermodynamic sounding profile (Weisman and Klemp, 1982) was used to trigger an ideal continental thunderstorm in the study. The simulation domain is 160 km by 80 km by 20 km, with the horizontal resolution of 1 km, and 41 vertical levels.

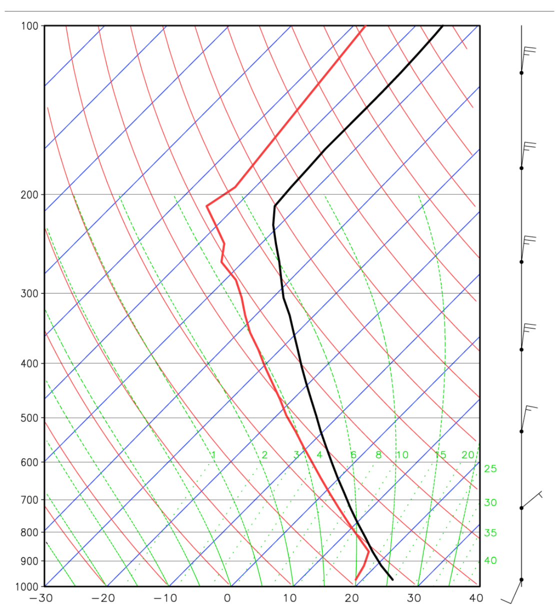

Fig 1. The thermodynamic sounding profile used in the simulation

RESULTS AND DISCUSSIONS

Figure 2 shows the charge structure simulated by S91 scheme (Saunders et al., 1991; Helsdon et al., 2001), TAK scheme (Takahashi, 1987), RR scheme (Brooks et al., 1997) and SP98 scheme (Saunders and Peck, 1998) in 75 min of the simulation. The charge structure of S91 is inverted dipolarity, and the negative charge extents to 14 km. The TAK scheme produces the same charge structure as S91, while the charge distributes at lower level. The charge structures of RR and RAR scheme are both dipolarity, but the charge density of RAR scheme is larger. We agree on the viewpoint of Mitzeva et al.(2009) that it is difficult to confirm which existing parameterisation schemes are better suited to realistic simulation of real thunderstorm.

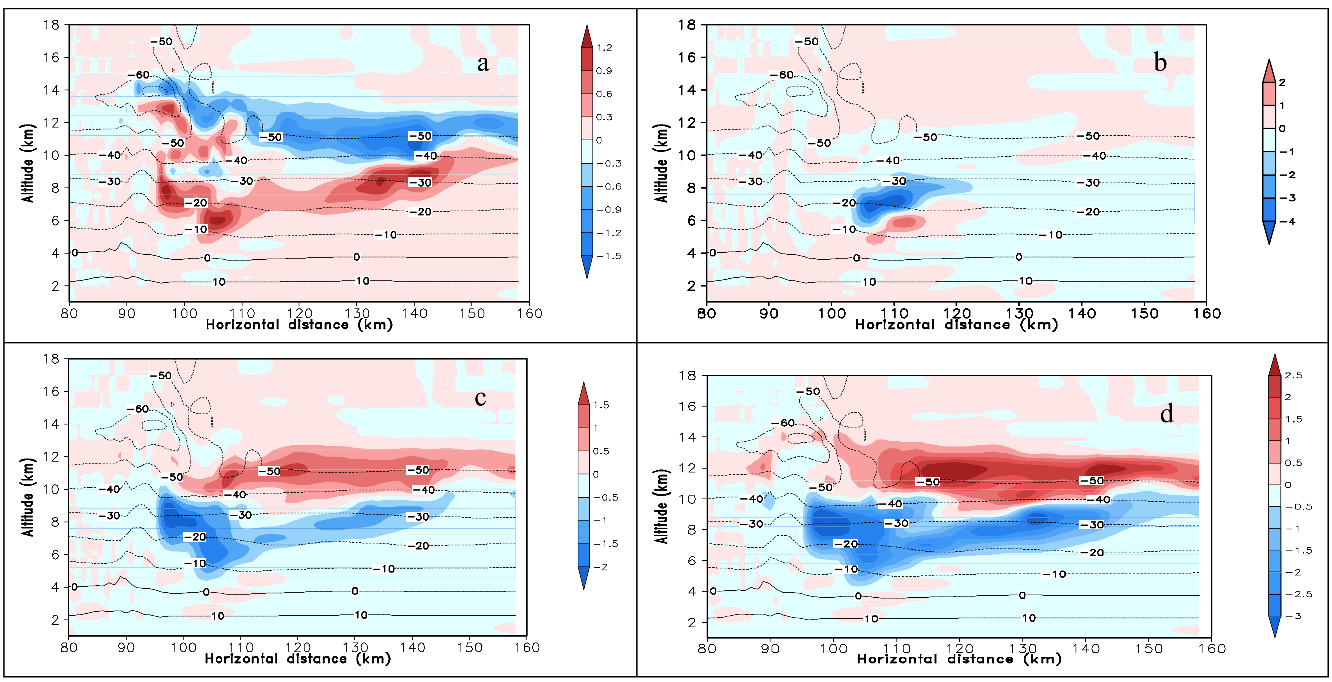

Fig.2. The charge structure of S91 scheme (a), TAK scheme (b), RR scheme (c) and SP98 scheme (d) in 75 min of simulation.

The polarity of ice particles is determined by liquid water content and temperature in S91 and TAK scheme. In this case, the position of the liquid water content is higher (Fig. 3). Hence the graupel particles charge positively at lower temperature region. In the RR and RAR scheme, the polarity depends on riming accretion rate and temperature, the graupel particles charge negatively at lower temperature because the riming accretion rate do not exceed the critical riming accretion rate.

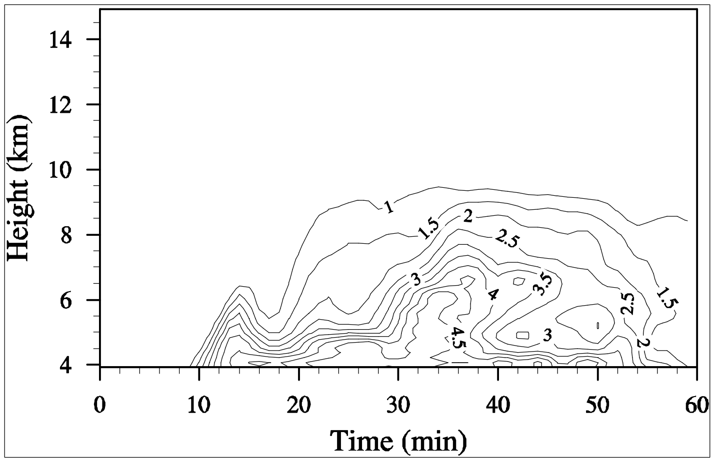

Fig. 3. Time-height max cloud water content (in g cm^{-3})

CONCLUSIONS

The charge structure simulated by different scheme is obviously different. An idealized continental storm is simulated to investigate the electrification process. The results show that S91 scheme produces an inverted dipole charge distribution at early stage of thunderstorm development process and then the charge structure turns to multilayered charge distribution which is sensitive to updraught velocity in the convection trigger zone. The TAK scheme produces an inverted dipole charge distribution in the whole numerical simulation process. The RR scheme and SP98 scheme produces the same charge distribution that is dipole charge structure, and the charge distributions of RR scheme and SP98 scheme are close to each other. The results of this study provide a foundation for further lightning forecasting research in mesoscale model. We agree on the viewpoint of Mitzeva et al. (2009) that it is difficult to confirm which existing parameterisation schemes are better suited to realistic simulation of real thunderstorm.

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