Numerical Simulation of the effect of charge structure on the characteristics of discharge in thunderstorm[1]

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Abstract The Bi- directional Stochastic Lightning Parameterization scheme of parameterization of discharge was introduced in a three-dimensional dynamic-electrification coupled model. The effects of the structure charge, the positive charge , negative charge and the change of space potential on discharge were investigated by the simulation process of a thunderstorm. The results indicate that the initial position of lightning modulated by the variation about the concentration center of positive and negative charge could affect the characteristic of discharge, and lightning was triggered between the upper of negative charge and the middle of positive charge as well as between the bottom of negative charge and the middle positive charge, however, the direction of positive leaders is upward and the negative leaders is downward in the former, and contrary to the latter .In the prime or mid-term development of thunderstorm., because of the strong convection and cloud height, the types of lightning in cloud are mostly the reverse polarity in cloud. With the further development of convection, the bottom of electrical area was increased constantly, and as the cloud particles begin to build , most of grauple particles descend gradually to low level in the late of thunderstorm, which drives the type of lightning is positive in cloud.

Key words thunderstorm numerical simulation discharge parameterization charge structure

1. Introduction

With the deeply understanding of the electrical activity in thunderstorm, the model can only the characterize in cloud before the first discharge was simulated if have no the reasonable process of discharge, but it can not simulate the electrical characterize of thunderstorm after discharge. So, the reasonable parameterization of discharge improves the electrical process of numerical model. The research on the process of discharge in thunderstorm have made a great progress at home and abroad, and can be classified into two categories: 1.The parameterization of whole discharge is supposed that the electric field in simulation area(or net charge concentration) is greater than any point of the given threshold, and the direction of propagation flash is not considered. Rawlings(1982),Takahash(1984) add the parameterization of discharge to a cloud model, but the

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purpose of study and the breakdown threshold are different. 2. The development of lightning channel and its influence on the surrounding environment field are considered in the parameterization of discharge. Mansell(2002)used the concept of the Bi-direction to simulate the process of discharge, and the the channel bifurcation and propagation by electric field control, which roots in the dielectric breakdown model of Wiesmann and Zeller(1986). The parameterization can simulate the complex structure of discharge and the charge transfer is closer to reality.

Domestic scholars have also done some research, for example, Zhang Yijun(2002)use the discharge parameterization of Helsdon(1992)to an axisymmetric time-dependent, dynamic-electrification numerical cloud model to study the electric activity of thunderstorm, but the Bi-direction leader and the forked structure of lightning are not considered. Tan Yongbo(2006) have done a comparative analysis about the length of lightning channel and the amount of charge size, he believe that the structure geometry of channel, extend range and the change of maximum vertical electrical field are consistent with the observation results.

The present study for the parameterization of discharge in thunderstorm need to further understand the mechanism of electrification and discharge, the relation of electric process between dynamic and microphysical.

2. The parameterization of discharge

2.1.1 The initial conditions of lightning

The initial conditions of lightning in the model is the same as Tan Yongbo(2006), when the electric field of any point in the model exceed the fixed threshold of air breakdown 160 kV/m, the point will be regarded as a lightning initial breakdown point possibly. The transmission threshold of lightning in the model is 150 kV/m.

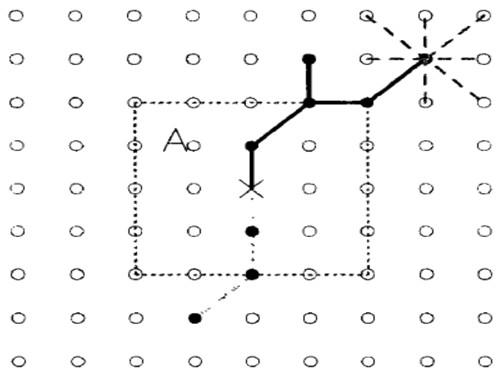


Fig.1 a schematic drawing that illustrates the initial breakdown point of lightning

（A: escape subdomain; X: the initial point of lightning, Disc: have extended the channel of lightning; blank solid: the channel of positive leader; Short dash line: the channel of negative leader; The points is connected by long black dotted line that is subsequent channel around the channel point.）

2.1.2 Bi-directional of lightning channel、Stochastic evolution、The calculation of potentials

We will use the concept of Bi-directional of leader, and the lightning is started from the trigger point, positive leader in propagating directions is parallel to power line and vice versa, channel charge is produced by induction (the electric field in the channel), leader of lightning channel in the mass is electric neutrality. The extensions of channel uses a stepping mode, which believe positive channel and negative channel extend only a secondary point respectively, a new channel point will be selected by the possibility of greater than zero pints, and the same treatment method of positive and negative channel. The selection method of next channel subsequent point is reference to equation (1), the calculation of electric potential is reference to equation(2).

$$p_i(E) = \left\{ \frac{1}{F}\left(|E_i| - |E_{crit}|\right), |E_i| > |E_{crit}| \right. \text{ ，当} |E_i| \le |E_{crit}|\text{，} \quad p_i(E) = 0$$

$$F = \sum_k \left(|E_k| - |E_{crit}|\right) \qquad (1)$$

$$\phi(m) = \phi_{ref} - s\sum_{i-1}^{m} E_{\text{int}} d_i \qquad (2)$$

2.2 Simulation results

We chose a process of thunderstorm at 22:30 6th July 2009 in Nanjing, the severe convective weather is mainly due to the cold air invasions of high-rise, cause local convective activity generated. The electrification parameterization only considered non-inductive electrification, the parameterization originated in the laboratory results of Saunders (1991), and the parameterization has been adopted the electrification model (Sun A.P, 2000)in thunderstorm.

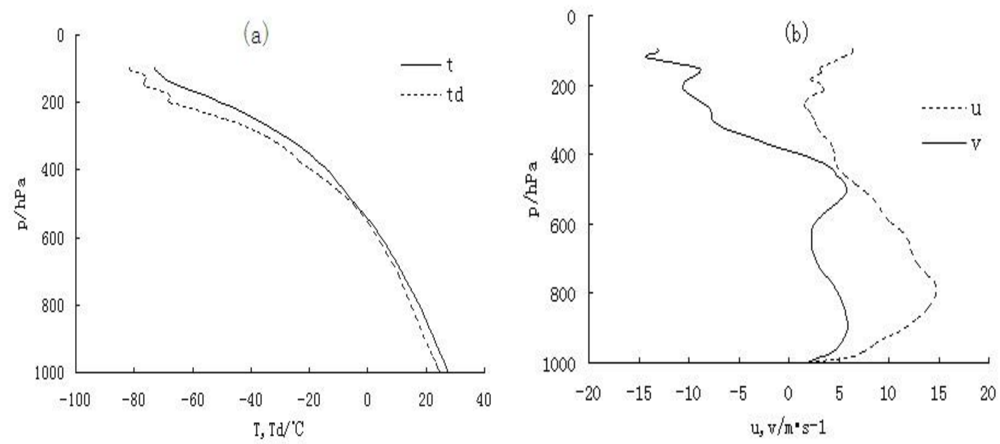
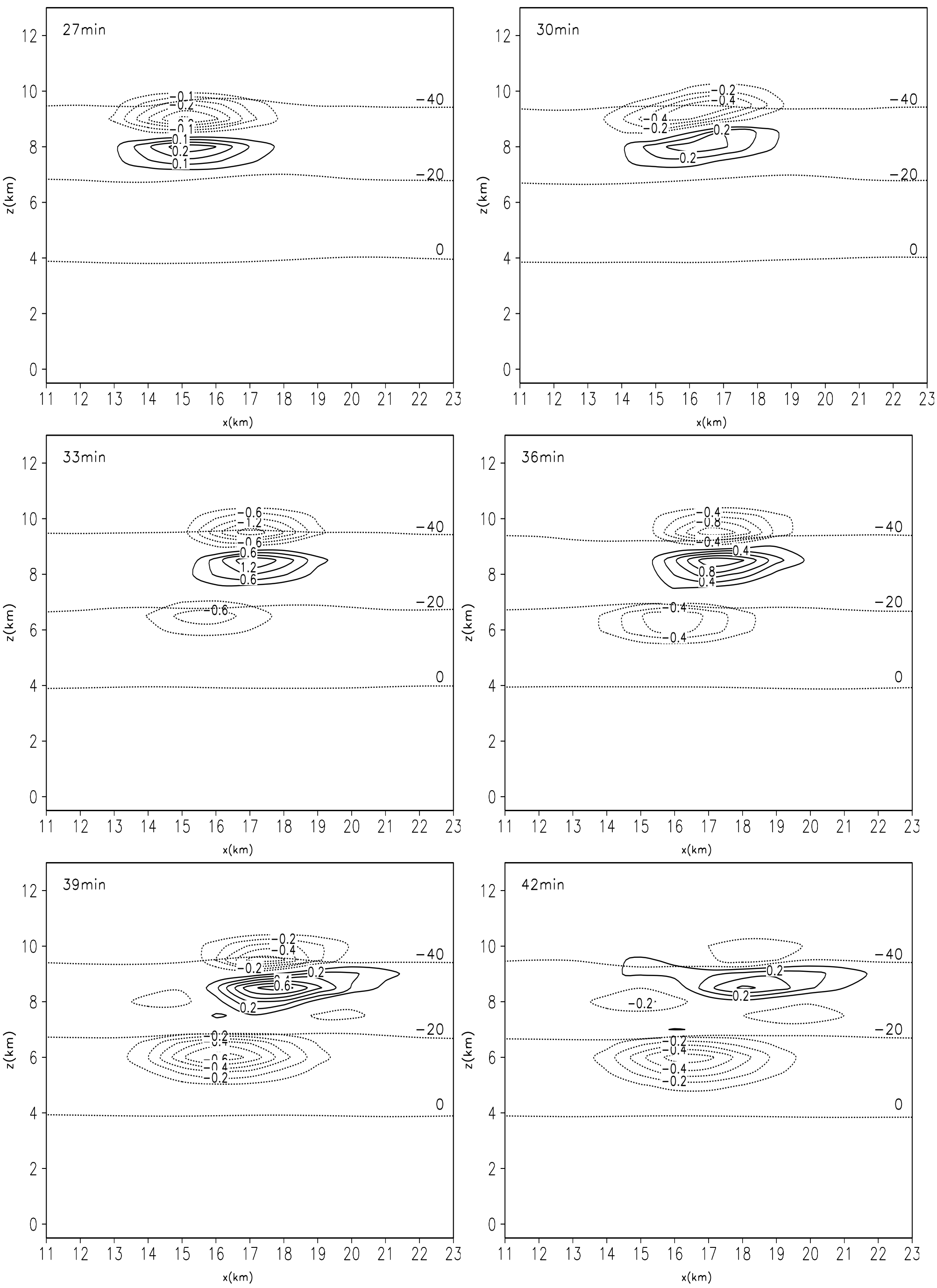


Fig.2 (a) Temperature, dew-point temperature and (b) environmental wind velocity profile observed at22：30 6th July 2009 in Nanjing

2.2.1 space charge distribution

The structure of spatial charge is inverse dipole and the central charge concentration is increased in the development early of thunderstorm(27min~30min). The structure of spatial charge turned into the inverse tripolar and the smaller negative charge comes appeared in the bottom of thunderstorm at Thirty-third minutes, and the structure till to Thirty-sixth minutes. At the top of the concentration of negative charge center and the scope of negative charge are decreased, the scope of positive charge is enlarged and the center concentration is decreased ,then the bottom of negative charge is enlarged, the central charge concentration is decreased and the structure of charge has become the obvious dipolarity.


27min
30min
33min
36min
39min
42min
z(km)
x(km)
-40
-20
0

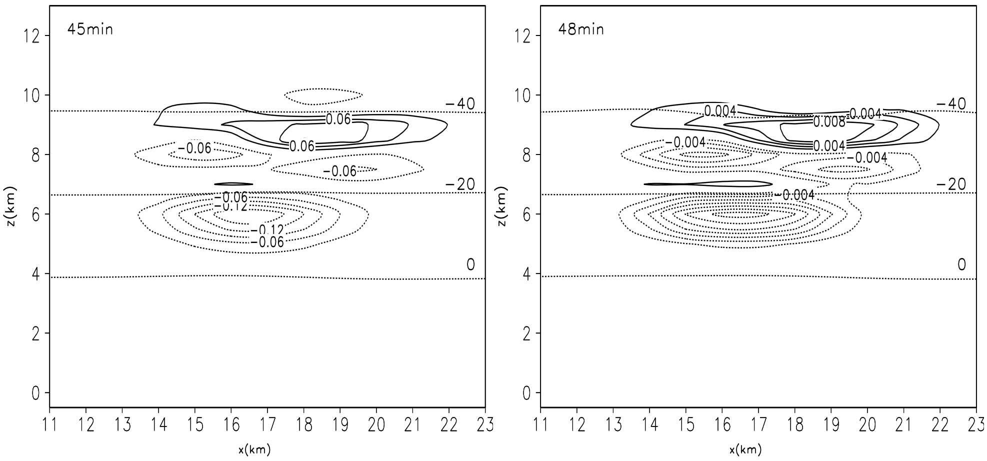


Fig.3 spatial charge density(nC/m^3) at y=18km in the deformation of S91

2.2.2 The influence of charge distribution on lightning categories

The discharge of thunderstorm were simulated 52 times,and it happened at thirty minutes to forty-five minutes and then the lightning categories are intracloud lightning. the style points of discharge and lightning frequency have reached a maximum at thirty-nine minutes in the discharge of thunderstorm, the strongest discharge area mainly concentrated in the 8km and 6.5~7.5km,especially, the numbers of lightning reduce fastly above 8km, and a few lightning still occurred above 6 km.. The main reason is that the lightning is triggered in two main areas and the electric field of areas are stonger than others : firstly,8km corresponds to the junction of the middle of positive charge and the upper negative in the early of discharge,secondly,6.5~7.5km corresponds to the junction of the bomttom of negative charge and the middle of positive in mid-late discharge.

The structure of charge is reverse dipolarity in the early thunderstorm before the first charge in single cell of thunderstorm, ice crystals and graupel particles are taken into high-rise by updraft. The particles of ice crystal and graupel is increased by the microphysical process of condensation ,nucleation,coagulation,which makes the height of charge and electrifiction between ice crystal and graupel particles is highter, and accessibility reaches to the initial breakdown threshold of lightning. So,the initial point is situated between the upper negative charge and the middle of positive charge, and the type of IC is reversed polarity IC.Along with the number of ice crystal and graupel particles increasing, the center concentration of upper negative charge and the middle of positive charge are also increased gradually, and the structure of charge is changed from inverse dipole to inverse tripolar at thirty-thirty three minutes,because of the graupel particles is increased gradually and the part of particles can gradually drop by gravity sedimentation.(Table 1)

The structure of charge is obviously inverted tripolar form thirty three minutes to thirty six minutes in the middle of thunderstorm, and the number of normal polarity IC begin more than reversed polarity IC. With the further enhancement of convection, the bottom of negative charge is further strengthened and the frequency of lightning reaches a peak, so the the number of normal polarity IC is more than inverted polarity IC between 36 minutes and 39minutes. Then, the structure of charge is diople in the end of thunderstorm at 39min to 45min,and the types of IC give priority to normal polarity IC.

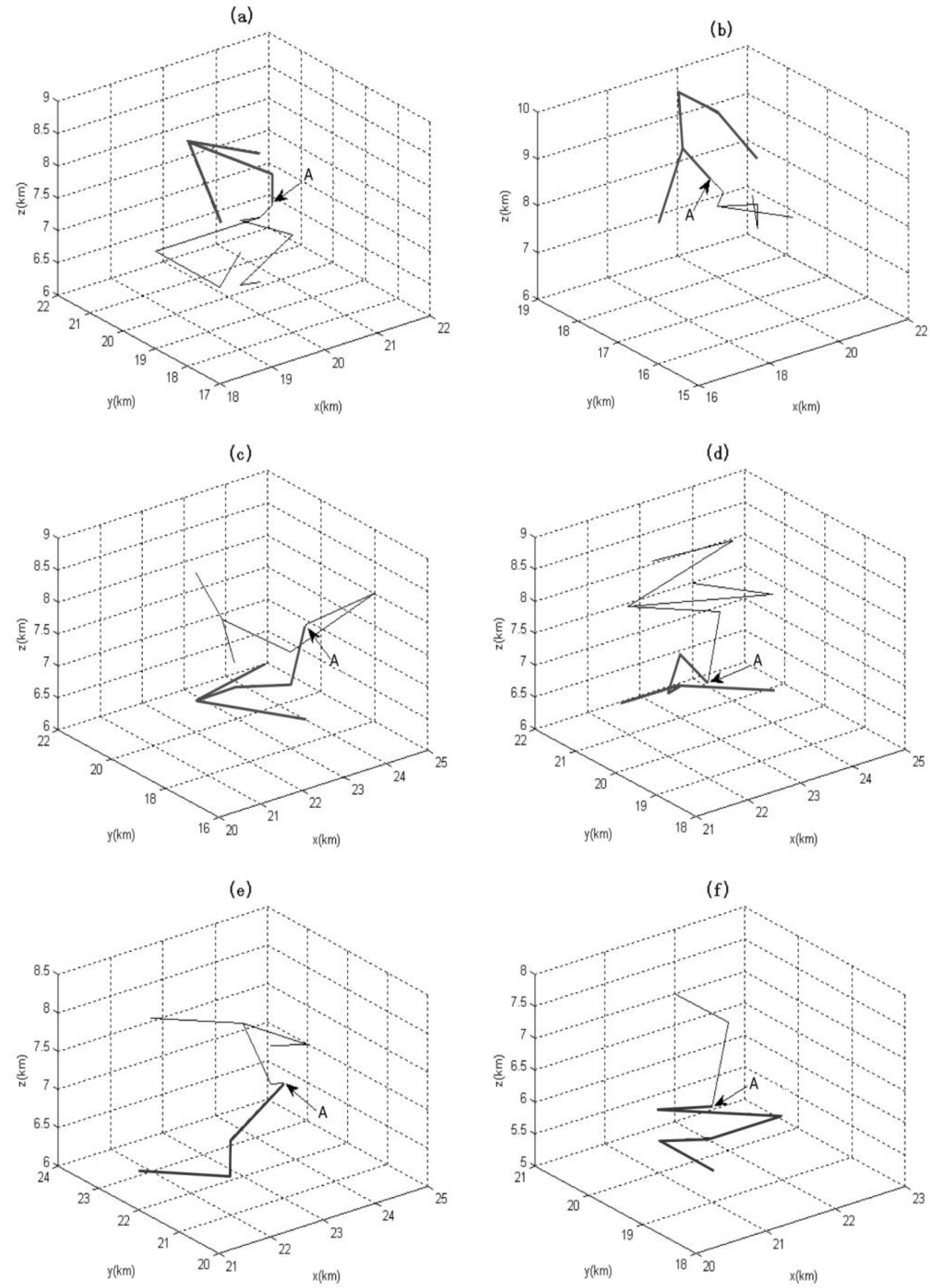


Fig 4 The distribution of lightning channel （a.30min; b. 33min, c. 36min,d. 39min, e. 42min, f.45min; blank line is positive leader， gray line is negative leader， A： Initiation point）

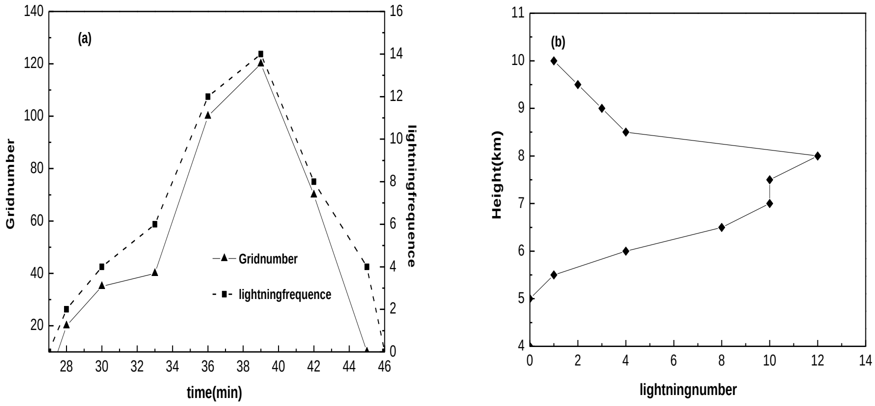


Fig 5.5 the variety of discharge grid points and discharge frequency each moment with time. (a)(blank line : discharge grid points, dotted line: discharge frequency);(b) the change of discharge number with height

Table 1 The different moment of structure charge and charge concentration in discharge of thunderstorm

Time (min)	The number of IC (polarity)		Structure of charge	charge concentration (nc/m^3)		
	normal	reversed		upper negative charge	middle positive charge	bottom negative charge
30±1.5	0	6	Inverse dipole	-0.4	0.2	0
33±1.5	2	5	Inverted tripolar	-1.2	1.2	-0.6
36±1.5	8	5	Inverted tripolar	-0.8	1.0	-0.4
39±1.5	12	4	Inverted tripolar	-0.4	0.6	-0.4
42±1.5	5	1	Inverted tripolar	-0.1	0.2	-0.4
45±1.5	4	0	dipolarity	0	0.06	-0.12

3.Conclusion

By changing the discharge parameterization, we obtain the effects of the structure charge, the positive charge , negative charge and the change of space potential on discharge were investigated by the simulation process of a thunderstorm. The results indicate that the initial position of lightning modulated by the variation about the concentration center of positive and negative charge could affect the characteristic of discharge, and lightning was triggered between the upper of negative charge and the middle of positive charge as well as between the bottom of negative charge and the middle positive charge, however, the direction of positive leaders is upward and the negative leaders is downward in the former, and contrary to the latter .In the prime or mid-term development of thunderstorm., because of the strong convection and cloud height, the types of lightning in cloud are mostly the reverse polarity in cloud. With the further development of convection, the bottom of electrical area was increased constantly, and as the cloud particles begin to build , most of grauple particles descend gradually to low level in the late of thunderstorm, which drives the type of lightning is positive in cloud.

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