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Spatial Relationship between the Non-inductive Charging Region and the Updraft in Thunderstorm*

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***Abstract*—a 3D numerical model of cloud resolution is used to simulate a thunderstorm for investigating the spatial relationship between the Non-Inductive Charging Region (NICR) and the updraft. The results show that NICR is primarily distributed within and around the updraft channel when the updraft is strong enough. But the efficiency center of NICR never coincides with the updraft center. NICR is found firstly after the speed of updraft center exceeds the value of 5 m s^{-1}, and the vertical velocity spectrum of NICR primarily ranges from -4 m s^{-1} to 28 m s^{-1}. When the max updraft speed closing to 28 m s^{-1} in NICR arises, the updraft center of the storm has been over 31 m s^{-1}. Furthermore, no NICR with charging efficiency greater than 0.5 nC m^{-3} has been found in the updraft region with speed more than 20 m s^{-1}. It suggests that strong updraft is benefit for non-inductive charging process while too strong updraft speed may inhibit the strengthening of charging process further.**

Keywords*—non-inductive charging process; updraft speed; charging efficiency; inhibition

I. INTRODUCTION

Strong updraft is an important factor for lightning occurring in a thunderstorm. Many studies have shown a close relationship between lightning activity and parameters of updraft, such as updraft speed and updraft volume. Pickering et al. [1998] found that lightning frequency was the sensitive function of the maximum updraft speed in thunderstorm. Barthe and Barth [2008] believed that updraft could be used to estimate the potential of lightning initiation for a storm. In the last decade, the updraft volume in a special region was found to have a good correlation with lightning activity [e.g. Tessendorf et al., 2005; Deierling and Petersen, 2008]. The microphysical observation at mid-level (-10^{o}C) suggested that charge was separated in relatively thin regions surrounding updrafts where ice hydrometeors falling from above encounter significant cloud liquid water concentrations [Caye et al., 2011]. The recent model study indicates that the quasi-steady region with updraft speed between -1 m s^{-1} and 1 m s^{-1} is the most conducive for charge separation while ice particles in the updraft region with updraft speed from 1 m s^{-1} to 5 m s^{-1} are charged the most charge during all lifetime of a thunderstorm [Wang et al., 2015].

Although there have been some results about the relationship between lightning activity and updraft, the results are preliminary and most of them are still summaries or speculations from direct observations. The spatial relationship between charging region and updraft and its revolution are still unclear because of the lack of observation about microphysical and dynamic processes, including charging process, in storm.

For learning the spatial relationship between the charging region and the updraft, a 3D numerical model of cloud resolution is used to simulate an isolated thunderstorm. Then the distribution and evolution of the main charging region are analyzed, and its spatial relationship with the updraft is also discussed.

II. SIMULATION RESULTS

The simulation is based on the sounding data on September 6, 2008, in Beijing. The first lightning is simulated in the 16th minute and the last lightning ends in the 31st minute. During lightning activity, the frequency reaches its peak in the 24th minute. The profile of the charge structure at the position with the maximum net positive charge density shows bipolar with a main positive charge layer above the main negative charge layer. The distribution height range of the main positive charge layer is from 8 to 11 km, and the center of net positive charge density is located in 9-10 km.

The lightning data from SAFIR3000 is used here to estimate the reliability of the simulation. When the lightning frequency of the first thunderstorm in that day reaches its peak, most of the radiation sources of all lightning assemble in the height range from 8 to 11 km with the center in 9-10 km. This result has a good agreement with the simulation result mentioned above, which indicates that the simulation result should be trusted.

The updraft speed exceeds 5 m s^{-1} firstly in the 2nd minute. Subsequently, it keeps increasing until it reaches the maximum of about 31 m s^{-1} in the 13rd minute. Then the updraft speed decreases gradually. From the 23rd minute, the max updraft speed keeps below 5 m s^{-1}. Simultaneously, the charging process, especially the non-inductive charging process, starts from the 12th minute. So, for discussing the relationship between the strong updraft and the main charging region, the analysis period is limited from the 12th minute to the 23rd minute.

III. ANALYSIS AND DISCUSSION

The relationship between the Region of the Non-inductive Charging process between Graupel and Ice crystal with charging efficiency greater than 0.1 nC m^{-3} s^{-1} (RNCGI) and the updraft are analyzed. The result shows that RNCGI firstly appears in the thunderstorm after the speed of the updraft center increases up to 5 m s^{-1}, then distributes within and around the updraft channel. The vertical velocity spectrum of RNCGI during the thunderstorm ranges from -4 m s^{-1} to 28 m s^{-1}. When the speed of updraft center is increasing, most of the vertical velocities in RNCGI are positive (upward), and RNCGI tends to have a relatively higher updraft speed than that when the updraft center speed is decreasing. The peak updraft speed range of RNCGI during the updraft strengthening is 8-10 m s^{-1} while the secondary peak range, from 18 m s^{-1} to 20 m s^{-1}, is even higher; but when the updraft is declining, there is only one peak range of 0-2 m s^{-1}. Most of RNCGI assemble around this range asymmetrically with a bias to the updraft speed (Fig. 1).

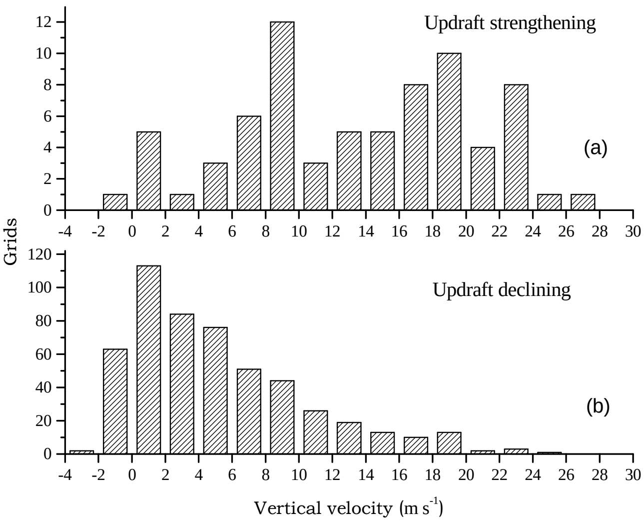

Fig. 1 the velocity distribution spectrums of RNCGI in the strengthening (a) and declining (b) stages of updraft

Although the analysis mentioned above indicates that the situation of updraft is benefit for the occurring of non-inductive charging process, not all updraft regions produce efficient non-inductive charging. For example, when the updraft center reaches its peak value of about 31 m s^{-1}, the max updraft speed in RNCGI is less than 28 m s^{-1}. Simultaneously, the efficiency center of RNCGI and the updraft center never coincide with each other. RNCGI with more efficient charging efficiency (> 0.5 nC m^{-3} s^{-1}) all distribute in the regions with the updraft speed less than 20 m s^{-1}. It suggests that further strengthening of charging process will be prohibited in the updraft region where the updraft speed is too strong and surpasses a threshold.

All analysis show that the main charging processes should work in the regions within and around the updraft channel. As we know, most of efficient charging process needs the collision and rebound of ice particles. It means that these ice particles must have adequate mixture with each other in these regions. Also, it is decided that the net charge in these regions must be very low because of the adequate mixture of ice particles although they have been charged with different polarity. Low net charge density will lead to low electric field and prevent discharge initiation. It means discharges should have low probability to initiate within updraft core. Only when these charged ice particles are transferred out of these regions and separated from each other by gravity, large net charge density will form, then discharging could have possibility to initiate.

According to the analysis mentioned above, it could be imagined that net charge and discharging should tend to arise in a half annular ellipsoid region with open area at the bottom and the updraft core as the core. When the updraft is strong enough, the upper part of the annular ellipsoid region could be breakthrough and the main discharging will occur in a annular section with the updraft channel as core. If the environment situation permits, charged ice particles will be transferred along a cyclonic path, on the impact of the Coriolis force, out of the updraft core, and the net charge layers will also form along the path surrounding the updraft core. Then all the initiation and the propagation of discharge distributed in this path will also distribute like a ring centered by updraft core. So it is reasonable to believe that any thunderstorm with strong updraft should have potential to form a “lightning ring” although the eventual formation of a lightning ring is affected by many other factors, such as environment flow, outflow height of charged ice particles, and so on.

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