Intelligent Identification of Convective Cloud Cores and Surrounding Stratiform Clouds

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Abstract. Convective cloud cores and surrounding stratiform clouds in the same precipitation process were identified by Lagrange tracking method to reveal differences of cloud microphysical processes in areas with different development intensities in the same precipitation system. Firstly, a scale operator was introduced for post-processing of the tracking method to determine the height most appropriate for tracking in 3D data. Secondly, different identification thresholds were set according to the radar reflectivity factor. Regions with the factor greater than 40dBZ were defined as convective cloud cores, and those with the factor more than 20dBZ and less than 40dBZ as stratiform clouds around cores. Finally, analysis was conducted on their differences in the motion trajectory, duration and development range in a weather process. The results showed that changes in the duration and the areas of convective cloud cores and stratiform clouds reflected the intensity of microphysical processes in different regions; the microphysical process of the regions with short-duration but large-area convective cloud cores were more intense, while that of the regions with long-life and small-area cores developed more smoothly.

1. Introduction
The formation of convective rainstorms is complex. There are usually convective cores with heavy precipitation and stratiform clouds with lighter precipitation and more uniform structure in the precipitation system, which have obvious differences in dynamic and thermodynamic structure [1-2]. Many studies have been done on the identification methods of convective clouds/stratiform clouds in different systems [3-5]. However, there are obvious differences in cloud microphysical processes and raindrop size spectrum characteristics in the regions with different development intensities in the same precipitation system. The failure to distinguish convective cores from stratiform clouds around cores and the lack of understanding of their evolution characteristics at each stage in a complete cycle are one of the reasons for the difficulty and low accuracy of precipitation prediction. Distinguishing convective cores from stratiform clouds around cores in the precipitation process effectively is vital to the improvement of the prediction accuracy and the numerical model scheme.

It is necessary to track the precipitation unit, i.e., the rain cell, continuously before identification of convective cloud cores and stratiform clouds around cores in the same precipitation process, which requires the introduction of Lagrangian viewpoint [6-8]. With Lagrange method, we can obtain the spatial position of each cell and the change of corresponding physical attributes with time in the convection cycle and make a detailed analysis on the temporal and spatial evolution characteristics of the tracked object in the complete life cycle. The splitting and coalescence process of cells is a difficult point to be considered in the algorithm when they are tracked with Lagrange method [9]. Iterative rain cells tracking (IRT) method can distinguish the splitting and coalescence process of cells simply and effectively [10],...
but it can only track two-dimensional variable fields. In this paper, a scale operator was added based on IRT method so that we can apply IRT identification results at different height levels, obtain the three-dimensional structure of the target rain cell and expand the application range of the algorithm.

Dual-polarization radar networking data has high-precision spatial-temporal resolution (for example, the temporal resolution of S-band radar networking data used in this paper was 6min, and the spatial resolution 0.01°× 0.01°), which provides an effective means for observing the process of heavy convective precipitation. Besides the observables of traditional Doppler weather radars such as radar reflectivity factor, radial velocity and spectral width, polarization parameters unique to polarization radars such as differential reflectivity, phase difference, differential phase difference and correlation can help judging the shape, size, phase structure and other information of precipitation particles [11-12]. In combination with Lagrange tracking method, we can further analyze the evolution characteristics of particle types in and dynamic and thermodynamic structure of convective cores and stratiform clouds around cores.

2. Methodology

2.1. Introduction of IRT method

Firstly, the IRT algorithm scans the data in each time step area, identifies the area with continuous data as the target rain cell according to the preset threshold and removes the data at the boundary with which it is impossible to judge whether the area is complete. Secondly, it judges the area and the maximum intensity, minimum intensity, average intensity and centroid position of the target rain cell based on the number of grid points in the continuum. By judging whether the continuum at the current moment overlaps with that at the previous moment, it calculates the motion trajectory and moving speed of rain cells. For cells with a small area and without overlapping effect, the algorithm judges their motion trajectory and moving speed based on the iterative results of the background circulation velocity and the moving speed of large cells. When the moving speed of cells is the same as the background circulation velocity, it is judged that the trajectories at the current moment and the previous moment have all been established. Then, the same iterative steps are carried out for the next moment until all trajectories in the data set are established.

The data used to track cells is the main tracking field, and an additional tracking field can be added. The format of variables in the additional tracking field is identical to that of variables in the main tracking field. The algorithm can obtain the maximum intensity, minimum intensity, average intensity and centroid position of cells in the main tracking field, as well as the maximum, minimum and average values of variables in the additional tracking field.

2.2. Addition of a scale operator

IRT algorithm can only track two-dimensional data. To get three-dimensional results including the vertical direction, it is required to add a post-processing process. In this paper, the scale operator α will be added to establish a relationship between the main tracking field and the additional tracking field in the vertical direction so as to obtain the tracking results of the same cell in the vertical direction.

With a variable $P$ at the height level $Z_1$ as the main tracking field and the same variable in the height level $Z_2$ as the additional tracking field, IRT algorithm will get the area $A_1$ and the variable mean $P_1$ of a cell at $Z_1$, as well as the area $A_1'$ and the variable mean $P_1'$ at $Z_2$. $A_1'$ is the result of mapping $A_1$ to $Z_2$ and $A_1'=A_1$ as the algorithm can only calculate the area of the cell based on variables in the main tracking field and cannot calculate the actual area of variables in the additional tracking field. The actual area of the cell at $Z_2$ should be $A_2$, and the actual variable mean should be $P_2$. To obtain $A_2$ and $P_2$, preprocessing data should be added in the original algorithm process. In such case, the algorithm will output the scale operator $a$. Then, $A_2= A_1*a$ and $P_2= P_1*a$ (Figure 1).
Fig. 1. Schematic diagram of identification results of main and additional tracking fields at different heights. Z₁ and Z₂ are the heights of the rain cell; A₁ and A₂ are the actual areas of the cell respectively at Z₁ and Z₂; P₁ and P₂ are the actual variable means of the cell at Z₁ and Z₂; A₁’ and P₁’ are the area and variable mean of the cell at Z₂ calculated by the algorithm before introduction of the scale operator.

The key to introducing the scale operator is that the identification range at the height level of the main tracking field is the maximum identification range of the cell in the vertical direction. The radar reflectivity factor in the dual-polarization radar networking data of a weather process was input into the algorithm for tracking and identification, and the scale operator at different height levels in the life cycle of the cell were obtained (Table 1). It can be seen that the range of the cell identified at the height of 1km is the largest, which can be used as the basis for tracking and recognizing convective cores and surrounding stratiform clouds in the main tracking field.

| Time level | Height level | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   |
|------------|-------------|-----|-----|-----|-----|-----|-----|-----|-----|
| 1          | 1.00        | 0.92| 0.83| 0.66| 0.54| 0.42| 0.28| 0.14|
| 2          | 1.00        | 0.94| 0.85| 0.71| 0.56| 0.44| 0.29| 0.15|
| 3          | 1.00        | 0.94| 0.87| 0.76| 0.63| 0.50| 0.30| 0.13|
| 4          | 1.00        | 0.95| 0.89| 0.77| 0.64| 0.50| 0.27| 0.13|
| 5          | 1.00        | 0.94| 0.88| 0.78| 0.66| 0.49| 0.28| 0.13|

3. Analysis of identification results
A precipitation process in August, 2018 was selected for rain cell tracking, and the identification results were analyzed. IRT algorithm can start the identification procedure only with the corresponding identification threshold and minimum identification area given. Only when the threshold and area of the cell identified are greater than or equal to the given value can it start to identify the target. In this paper, regions with the radar reflectivity factor greater than 40dBZ and the area greater than 100km² were defined as convective cloud cores, and those with the radar reflectivity factor greater than 20dBZ and less than 40dBZ around cores were defined as stratiform clouds around cores based on IRT algorithm. The radar reflectivity factor at the height of 1km was used as the main tracking field for rain cell identification.

The moving path of the cell can be obtained based on the moving position of its centroid (Figure 2). The precipitation process was mainly caused by the concentration of water vapor brought by the southwest-northeast summer monsoon in the coastal area of South China. Rain cells moved from southwest to northeast on the whole (Figure 2a). Due to dynamic and thermodynamic differences of sea and land, the hot and humid South China Sea monsoon produced heavy rainfall along the coast of South China after encountering the coastline. Cells with the radar reflectivity factor greater than 40dBZ mostly occurred at the boundary between land and sea (Figure 2b).
In the whole precipitation process, there were 229 stratiform rain cells and 55 convective ones. There were more stratiform rain cells than convective ones. The areas of stratiform rain cells mostly ranged from 100 to 500km², followed by 500-1,000km². The average area and the maximum area had similar distribution features (Figure 3a). Convective cloud cores and stratiform clouds differed greatly in area distribution. The areas of convective cores mostly ranged from 150 to 200km², followed by 100 to 150km². The average area and the maximum area had significantly different distribution features. The average areas of convective cores mostly ranged from 150 to 200km², followed by 100 to 150km². The maximum areas were mostly distributed in the range of 150-200km², followed by 300-400km². This indicates that the extreme value of the reflectivity factor in convective cloud cores Mostly occurred in cells with a larger area (Figure 3b).

There was no obvious correlation between the duration and the area of stratiform cells. Stratiform cells mostly had a long duration and a small area, indicating that they developed smoothly, which conforms to the evolution law of the radar reflectivity factor (Figure 4a). There was a certain correlation between the duration and the area of convective cells. Except for some individuals, the longer the life
cycle, the larger the area of cells. Cells with a short duration but a large area of convective cloud cores developed with drastic changes, and their microphysical processes were more intense, causing them to expand and weaken rapidly in a short time. Cells with a long life cycle and a small area developed more smoothly (Figure 4b).

Fig. 4. Duration and maximum and mean areas of all stratiform cells (a) and convective cells (b) in the life cycle. The green bar is the duration of each rain cell, the red solid line is the maximum area of each rain cell, and the blue solid line is the average area of each rain cell.

4. Summary
In this paper, convective cloud cores and surrounding stratiform clouds in the same precipitation process were identified based on Lagrange tracking method. A scale operator was introduced for post-processing of the tracking method to determine the height most appropriate for tracking in 3D data. Different identification thresholds were set according to the radar reflectivity factor. Cell regions with the factor greater than 40dBZ were defined as convective cloud cores, and those with the factor more than 20dBZ and less than 40dBZ as stratiform clouds around cores. An analysis was conducted on their differences in the motion trajectory, duration and development range in a weather process. Main conclusions are made as below:

(1) We can determine the height most appropriate for tracking by introducing a scale operator to post-process the identification results and obtaining the corresponding relationship between variables in the main tracking field and the additional tracking field based on the scale operator at different height levels.

(2) Convective cores and surrounding stratiform clouds can be distinguished and identified effectively through the setting of different radar reflectivity factor thresholds based on Lagrange method.

(3) Changes in the duration and area of convective cloud cores and stratiform clouds reflected the intensity of cloud microphysical processes in different regions. The extreme value of reflectivity factor in convective cloud cores mostly occurred in cells with a larger area. Cells with a shorter duration but a larger area of convective cloud cores had a more intense cloud microphysical process, while those with a longer life cycle and a smaller area developed more smoothly.

In this paper, a scale operator was introduced to post-process the tracking results, which can provide conditions for setting up the three-dimensional structure of the tracking object, but it is necessary to further test and analyze the post-processing results. For structural differences and evolution
characteristics of the identified convective cloud cores and surrounding stratiform clouds, it is necessary to analyze more data to make universal conclusions.

Acknowledgments
This research is supported by the National Natural Science Foundation of China (Grant No.42075077), the National Key Research and Development Program of China (Grant No. 2018YFC1507604).

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