RADAR TRACKING METHOD FOR CLOUD SEEDING EXPERIMENTAL UNITS OVER CUBA

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1. INTRODUCTION

During October 2006 and August-October 2007, the second phase of the Randomized Convective Cold Cloud Seeding Experiment in Extense Areas (in Spanish, EXPerimento aleatorizado de siembra de nubes convectivas en AReas EXtensas, EXPAREX) was undertaken over Camaguey, in the eastern part of Cuba (Martinez et al, 2007). One of the main goals of this phase of the experiment was obtaining well defined experimental units for evaluating the seeding effect. In this respect, an experimental unit is defined as the clouds inside a circle of radius 25 km, centered at the location of initial seeding at the first instant, which moved along with the seeded system and inside which all the suitable clouds whose top regions were seeded (or not) with AgI ejectable flares are located. The tracking method used to follow the evolution of these experimental units, also known as floating targets, is the main objective of this paper.

2. DATA

Basic data consisted in MRL-5 (10 cm) automated radar products obtained with software Vesta (Pérez et al., 1999; Peña et al., 2000). Two-dimensional maps of maximum reflectivity, rainfall rate at 3 km height, maximum top height and height of maximum reflectivity within a circle of radius 180 km centered in radar, were ingested every 5 min by the tracking software with the aim of calculating the coordinates of the center of the experimental unit as well as its main characteristics. Resolution of maps was chosen to be 1.5 km. Besides that, coordinates of the initial treatment point were needed to initialize the tracking.

3. ALGORITHM

The tracking algorithm is based on the following hypothesis: the experimental unit will follow the average movement of the nearest surrounding storms. For each maximum reflectivity radar image, the method identifies as storms all the groups of pixels with reflectivity and area values greater than certain thresholds. The reflectivity threshold value (25 dBZ) is applied first, and consequently, connected components (up to second nearest neighbors) are labeled. Afterwards, the area threshold (7 km^2) is applied to discard the smaller echoes. Then, every echo region (storm) is associated with an ellipse, the normalized second order moments of which are equal to the ones of the echo region. This constraint leads to an eigenvalue problem allowing obtaining the parameters of the ellipse.

At the treatment instant, which is taken as initial time for tracking, all present storms are identified, and the corresponding ellipses are defined by the algorithm. The experimental unit boundary circumference is displayed, centered at the treatment point and extending to a radius of 25 km. In the next scan, every storm in the radar's field of vision is tracked by choosing the new center positions that are located at the minimum distances from the centers in the previous scan, provided a certain limit distance is not attained (typically 5 km for a time lag of 5 min between scans). After all the storms have been identified in the new step, their displacement vectors are obtained. An average displacement vector of the storms contained inside the experimental unit circle is then calculated. When there is no storm inside, the searching radius is set to higher values until finding storms to average. The average displacement vector thus obtained is assigned to the experimental unit. As output of the processing program, an image with the last maximum reflectivity map and the subsequent positions of the superimposed experimental unit circle is obtained (Figure1), and also a text file including date, time, coordinates of the center and the main parameters of the seeding circle for every instant, as well as for the total tracking time. The algorithm stops to follow an experimental unit when the elapsed time with total rainfall rate less than 2 mm/h inside the seeding circle reaches 30 min.

4. RESULTS

The tracking method was applied to the twenty experimental units obtained during the second phase of EXPAREX, in which experimental flights were carried out from October 3 to October 14 in 2006 and from August 24 to October 4 in 2007. Table1 shows some tracking parameters for all of them. Date-Time stands for the date (ddmmyy) and time (hh:mm) of first seeding, TT is the total tracking time, V the mean velocity and W is the total volume of precipitation (3 km height) accumulated in the floating target during its lifetime.

Table1: Tracking parameters for the experimental units.

#	Date-Time	TT (min)	V (km/h)	W (kT)
1	031006-14:20	225	30	55113
2	061006-15:20	415	17	14114
3	101006-13:50	45	14	15
4	101006-14:50	280	16	1358
5	111006-14:50	295	18	2729
6	121006-14:45	40	12	20
7	141006-15:15	523	20	25319
8	240807-14:05	535	24	10380
9	270807-13:35	235	28	11120
10	300807-14:00	245	14	4628
11	310807-13:15	275	17	2761
12	100907-14:05	220	27	3027
13	110907-13:30	525	24	12953
14	150907-13:40	320	18	7917
15	170907-14:15	530	12	12636
16	180907-14:30	230	15	1862
17	220907-13:55	355	20	3980
18	270907-13:15	845	20	34982
19	280907-13:45	340	15	5235
20	041007-13:25	515	15	10307

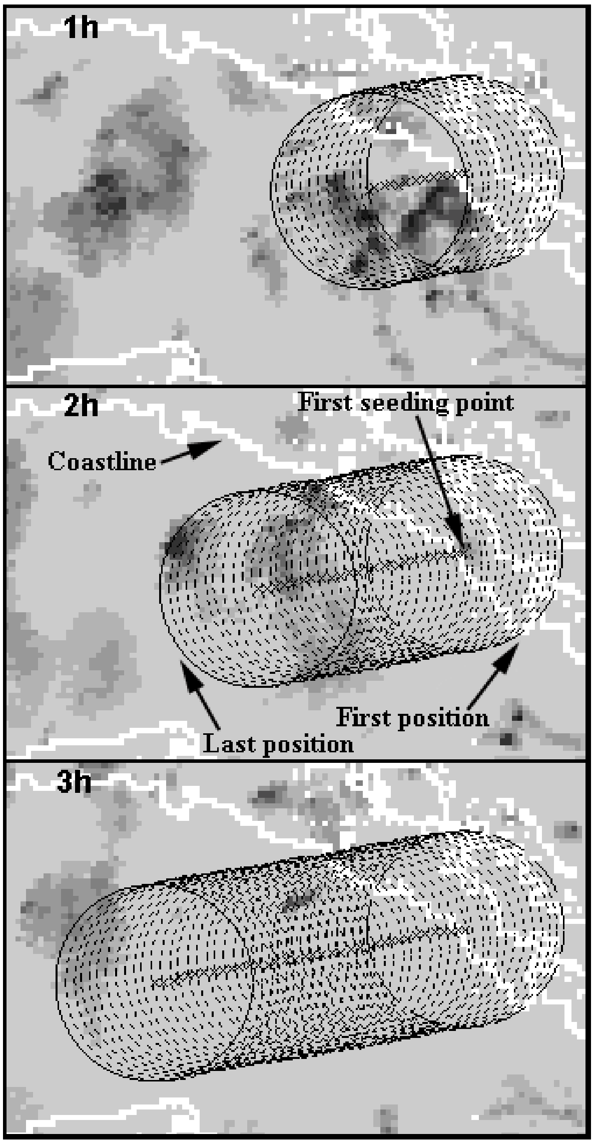

Figure1: Trajectory of first experimental unit for 1, 2 and 3 h of tracking until it was almost dissipated.

Figure1 shows the trajectory of the first experimental unit obtained on October 3, 2006 for 1, 2 and 3 h of tracking, until it was almost dissipated. This area moved fast (30 km/h in average) and maintained a course near to WSW.

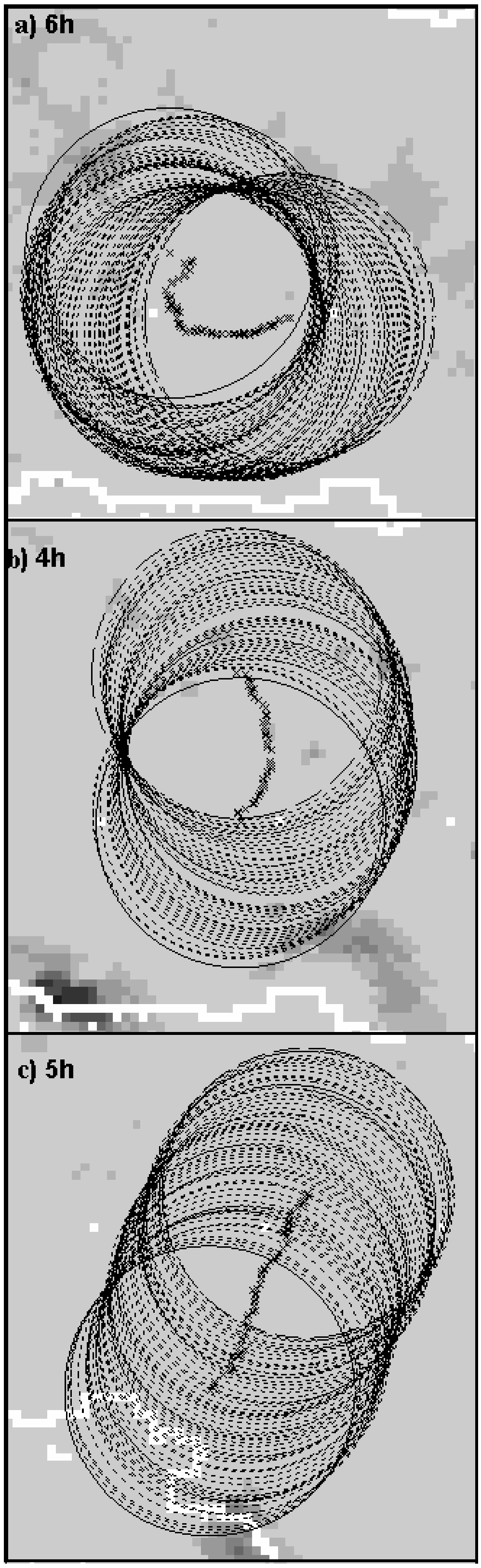

Figure2: Trajectories of experimental units 2 (a), 4 (b) and 5 (c) until almost dissipation. Tracking time is indicated.

For each trajectory, the broken line circle indicates the area occupied by the experimental unit at first instant (time for initial treatment), which center is the first seeding point inside the area. Circles limited by dotted lines indicate the intermediate positions of the tracking area and the continuous line circle marks the final one.

Figure2 shows the trajectories for experimental units 2, 4 and 5 (from 2006) until almost dissipation. Areas 3, 6 and 7 were not showed because they dissipated early or have a very long duration. A plot of Log(TT) versus Log(W) for the twenty 2006-2007 experimental units is shown in Figure3 with circles. Notice that we don't know which ones of them were really seeded, because of the randomized and blind nature of the experiment.

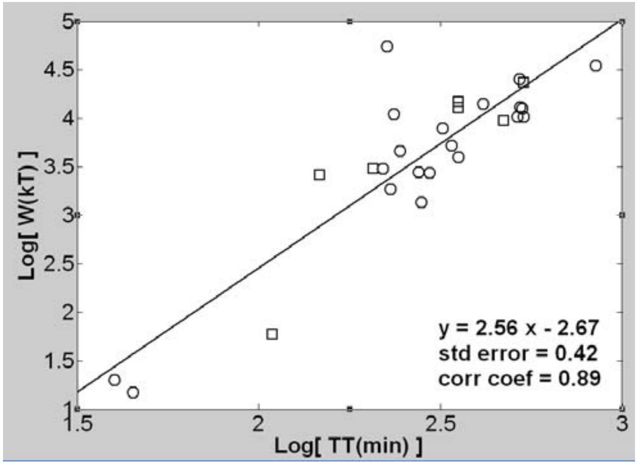

Figure3: Plot of TT versus Log(W) for all the experimental units in 2006 (circles) and 2005 (squares).

Table2: Tracking parameters for 2005 units.

#	Date-Time	TT (min)	V (km/h)	W (kT)
1	030905-15:01	354	9	12446
2	160905-14:50	121	30	60
3	170905-14:52	452	25	11611
4	210905-16:19	355	12	16571
5	220905-14:30	486	17	21550
6	230905-14:46	405	15	2481
7	270905-13:53	221	10	3033

Square marks in Figure3 belong to data from seven units more, all of them seeded, which were obtained during the first stage of EXPAREX (exploratory, non randomized experiment) in September 2005. Some tracking parameters for these 2005 experimental units appear in Table2. All the data in Figure3 were adjusted linearly and the corresponding equation and standard deviation were written on the plot. From the plot we can see that there is a gap without points between 1.8 and 3 in y axis. This seems to indicate that the three cases in the lower-left corner of the graph might belong to a different statistical ensemble in relation to the rest of the sample. The 2005 case is seeded, and the treatment of the two 2006 cases is not yet known. This may be an effect of the still limited size of the sample or may be caused by specific synoptic or mesoscale situation in these cases, or may be simply a problem of wrong experimental unit selection which has to be taken care of in the future, evaluating the possibility of considering these cases as outliers. As the randomized experiment goes on, the statistical properties of the ensemble of experimental cases will become clear.

5. CONCLUSIONS AND REMARKS

A method for tracking cloud seeding floating experimental units over Cuba has been developed. The algorithm uses maximum reflectivity maps to identify storms in the radar's field of scanning. Looking for the nearest storm's positions in the next scan, it follows the movement of each one. Then the average movement of nearest surrounding storms is assigned to the experimental area and its parameters calculated.

With data from 27 experimental units, it was found a linear relationship between the total precipitation volume accumulated at 3 km height and the total duration for each area. A gap without experimental units was found in the graph around 500 kT in rainfall volume. Points below this gap could indicate outliers, which should be clarified in subsequent analysis as the sample increases.

Radar-rain gauge calibration will give us the way to compare ground precipitation with the tracking parameters for a better evaluation.

6. REFERENCES

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