J5A.1 DUAL-WAVELENGTH RADAR OBSERVATION OF A SUPERCELL HAILSTORM

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1. INTRODUCTION

When one observes the spatio-temporal evolution of a convective storm population by means of radar or satellite images, it is difficult to identify the potentially hazardous cells and notably the hailstorm.

In the present paper, we discuss hailstorm detection using two single wavelength radars located far from each other. One is a C band located at Toulouse, the other a S band located at Nîmes. They are two hundred kilometers distant. We show that, due to the non-Rayleigh scattering of hailstone, the distribution of the dual-wavelength reflectivity ratio displays an identifying signal for the hail-bearing cells. Correlatively with this signal, the lightning activity of the supercell is modified.

2. STRUCTURAL CHARACTERISTICS OF A SUPERCELL STORM

The supercell is the result of a storm evolution leading to an explosive development of the convection and to the growth of a giant three-dimensional circulation which schematically includes an updraft and a downdraft. The supercell behaves like an open system in which a continuous convective circulation is maintained. The supercell organisation remains for duration often greater than one hour. The system moves over long distances with a speed close to the mean winds, yielding heavy precipitation of water and hail and strong gust of wind. Moreover the supercell horizontal motion often shows significant variations with regard to the mean wind direction. In the northern hemisphere, most of the supercells divert on the right of the mean winds and more rarely on the left. It is the opposite in the southern hemisphere.

3. THE DATA

On April 21, 1999, a convective cold frontal line swept South-West of France. Between 17:00 and 17:30 UTC, on the south end of this eastward stormy system, a rain cell turned off on the right of the mean wind. In less than 30 minutes, this cell burst into a supercell hailstorm which crossed the Oriental Pyrénées area along a North-West/South-East direction causing heavy damage, with hailstones of about 3 to 5 cm in diameter.

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The frontal line evolution, and particularly the supercell hailstorm, was observed from birth to disappearance by two meteorological radars of the French operational radar network (ARAMIS). The first one is a five centimetre wavelength radar, located at Toulouse, with a half power beamwidth of 1.3°, whereas the second one is a ten centimetre wavelength radar, situated at Nîmes with a half power beamwidth of 1.8°. Figure 1 shows the temporal evolution of the area $A(\tau)$ of the supercell where the radar reflectivity factor observed from Toulouse is higher than a threshold τ equal to 47 dBZ. Figure 1 underlines the explosive growth leading to the supercellar storm.

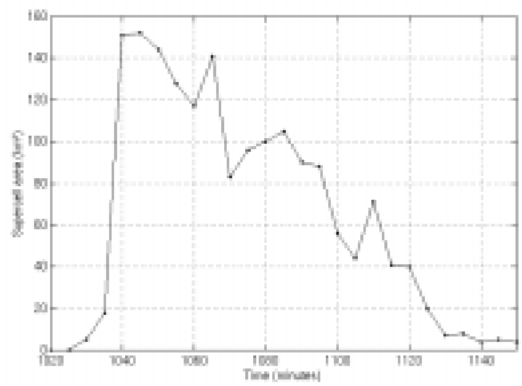

Fig.1. Temporal evolution of the supercell area $A(\tau)$ where the reflectivity is higher than 47 dBZ. 1020 minutes corresponds with 17:00 UTC. Each point is an observation of the radar of Toulouse.

4. DATA REDUCTION AND PROCESSING

The data acquired on the form of plan position indicators (PPI's) every 5 minutes have been used. Measurements of reflectivities in contiguous range bins sampled each 250 m were made over an annular interval from 1 to 256 km. The PPI radar scans, in polar coordinates were converted along a cartesian grid, with an uniform pixel size of 1×1 km^2, using an interpolation algorithm similar to the one described by Mohr and Vaughan (1979). Then the radar images were thresholded by elimination of the pixels with reflectivity factor $Z<\tau$. At this step, the initial PPI images are turn into binary ones representing the two-dimensional locations of the reflectivities greater than the threshold τ. The rain cells, defined as the areas inside contours in which the reflectivity $Z\geq\tau$, are individualised according to a four-connected method. For this latter, two rainy pixels are said to be connected, hence belonging to the same rain cell, if they are immediate neighbours.

5. HAIL-BEARING CELL IDENTIFICATION

5.1 Methodology

A spherical scatterer, with diameter D, belongs to the Rayleigh approximation field insofar as its radioelectric size $\alpha=\pi D/\lambda$ is small with respect to the wavelength λ. Thus, for standard radar wavelengths, the rain falls into the Rayleigh approximation, not the hailstones which are non-Rayleigh scatterers. Advantage can be taken of the wavelength dependency of the reflectivity, in the Mie diffusion field, to detect hail (Atlas and Ludlam, 1961). Indeed, the observation of a same hail event with two radars whose wavelengths are different leads to reflectivity values which can differ from 10 dBZ to one another (Atlas and Ludlam, 1961).

To identify hail areas, we thus propose to compute the dual-wavelength reflectivity ratio not from a dual-wavelength radar but from two radars distant from each other. As the Mie's effects as well as the distances of the rain cells are different from one radar to the other, it is useful to compute for each radar the ratio of the mean reflectivity value over the hail area $<Z_{Hail}>$ to the mean reflectivity value over the surrounding rainy area $<Z_{Rain}>$. Processing locally, with relative values, allows to avoid biases depending on the radar characteristics and on the observation distance.

5.2 Dual-wavelength reflectivity ratio computation

For each PPI taken every 5 minutes, the Nîmes radar data of the 21 April, 1999, stormy event are thresholded and the rain cells are identified according to the four-connected method. The threshold value τ_1 = 40 dBZ, is chosen significantly lower than the more intense areas (of about 56 dBZ). It enables to delimit the heavy convective zone $A_{40dBZ}^{Nîmes}$.

Inside this latter, the maximum reflectivity value Z_{max} is used to define a new threshold $\tau_2=Z_{max}$- 3dBZ which allows to isolate a very heavy cell with area $A_{Hail}^{Nîmes}$. This one is thought to be the hail cell. Its mean reflectivity value $< Z_{Hail}^{Nîmes} >$ is computed.

The rainy area $A_{Rain}^{Nîmes}$ is defined by dilating the $A_{40dBZ}^{Nîmes}$ surface by a dilatation factor f_d equal to 3 km. This value takes into account the size of the 1.8° beamwidth, 200 km from Nîmes. Figure 2 illustrates the successive treatments for the supercell observed by the radar of Nîmes at 17:45 UTC.

Because the reflectivity values are not sampled homogeneously from 0 dBZ to 20dBZ, the mean reflectivity value on $A_{Rain}^{Nîmes}$, that is $< Z_{Rain}^{Nîmes} >$, is computed for pixels with a reflectivity value greater than 20 dBZ. So, one can define the pixel rain rate $R_{Rain}^{Nîmes}$, greater than 20 dBZ, in the rainy area $A_{Rain}^{Nîmes}$ for the 10 cm wavelength radar.

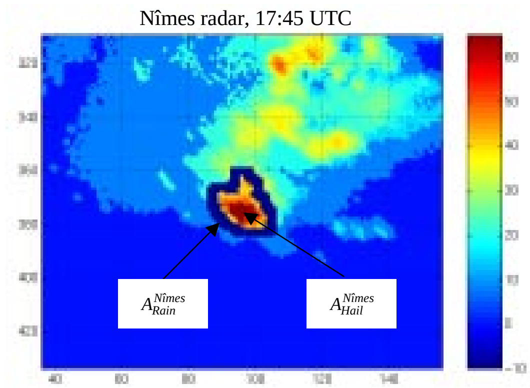

Fig.2. Illustration of the rainy and hail area identification from the 17:45 UTC Nîmes radar observation of the supercell hailstorm. The radar image size is 256 x 256 km^2 so that the supercell is about 200 km away from the radar location.

At this stage, we consider the synchronous PPI from the Toulouse (Tlse) radar. Each cell defined from the Nîmes radar observations is identified on the Toulouse synchronous PPI. The image is thresholded until the cell area, A^{Tlse}, is as close as possible to the $A_{40dBZ}^{Nîmes}$ area under consideration.

The A^{Tlse} area is then thresholded from its maximum reflectivity value to its minimum value. Doing this, several heavy cells are defined. Among these, the hail cell, A_{Hail}^{Tlse}, is the one having an area as close as possible to the one of $A_{Hail}^{Nîmes}$. The hail cell mean reflectivity value, $< Z_{Hail}^{Tlse} >$, is then computed. Thus, the hail cell observed by the 5 cm wavelength radar is not necessarily the area where the reflectivity value is maximum in compliance with Atlas and Ludlam (1961) results.

The A^{Tlse} area is dilated with f_d=3 km so as to define the A_{Rain}^{Tlse} area. Figure 3 illustrates the successive treatments for the supercell observed by the radar of Toulouse at 17:45 UTC.

In order to take into account the non homogeneous sampling of the reflectivity, A_{Rain}^{Tlse} is thresholded until the pixel rain rate R_{Rain}^{Tlse} is as close as possible to $R_{Rain}^{Nîmes}$. $< Z_{Rain}^{Tlse} >$ is computed by considering the A_{Rain}^{Tlse} pixels greater than the threshold obtained that way.

Ever since, for each rain cell seen by the two radars, one can compute the dual-wavelength reflectivity ratio r which is defined as:

$$r = \frac{< Z_{Hail}^{Nîmes} > / < Z_{Rain}^{Nîmes} >}{< Z_{Hail}^{Tlse} > / < Z_{Rain}^{Tlse} >}$$

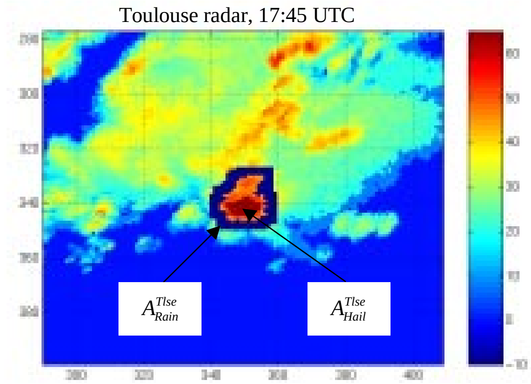

Fig.3. Illustration of the rainy and hail area identification from the 17:45 UTC Toulouse radar observation of the supercell hailstorm. The radar image size is 256 x 256 km^2 so that the supercell is about 130 km away from the radar location.

5.3 Results

Figure 4 shows the dual-wavelength reflectivity ratio evolution computed for the supercell from 17:00 UTC to 18:40UTC.

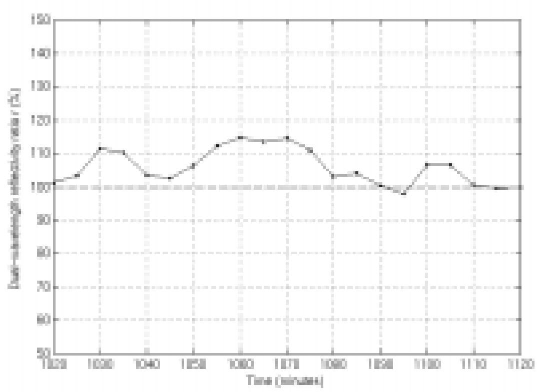

Fig.4. Supercell dual-wavelength reflectivity ratio (r) evolution from 17:00 UTC to 18:40 UTC. 1020 minutes corresponds with 17:00 UTC. Every point corresponds to r computed from synchronous observations of the supercell by the radars of Toulouse and Nîmes each 5 minutes.

The r value for the storm cells of the 21 April, 1999 stormy event are, within error, equal to 100%, indicating no hail regions. On the other hand, from Figure 4, the evolution of the dual-wavelength reflectivity ratio displays an identifying signal for the supercell hailstorm. This latter is a hail-bearing cell. According to the results, the 21 April, 1999 hailstorm seems to be composed of three hail events. The first one and the last one occur respectively at 17:00 UTC and 18:15 UTC. They last about 15 minutes. The second one begins at 17:25 UTC and lasts 45 minutes, until 18:10 UTC, with a r maximum value of 115% at about 17:45 UTC.

Consequently, this event seems to be the most intense, with an important hailfall. In other respects, the three hail events duration coincide with the evolution of the supercell hailstorm, from its birth at 17:00 UTC and its maturation at 17:45 UTC to its disappearance at 18:35 UTC. Météo-France indicated hailfall only on the zone covered by the supercell during its progression, leading to the conclusion that the dual-wavelength reflectivity ratio seems to be a rather good qualitative descriptor of hail-bearing cells.

6. LIGHTNING ACTIVITY

Most of the rain cells associated with the frontal system displayed an important lightning activity. Observation from the lightning network METEORAGE, enabling the measurement of the cloud to ground (CG) lightning, shows the distribution of the CG impact as a function of space and time. When the storm discussed in the present paper becomes a supercell generating a heavy hailfall, the lightning activity disappears completely. When the storm loses the features of a supercell and that the hail fall ceases, the lightning CG activity is observed to resume.

7. CONCLUSION

From PPI images of a hailstorm observed by two radars with different wavelengths, the rain cells dual-wavelength reflectivity ratio is computed and seems to be a rather good qualitative descriptor of hail-bearing cells. This criterion seems adapted for hail detection using an operational radar network insofar as this latter is organized in such a way that each rain cell in the field can be observed both with an S band and a C band radar.

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