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Morphological description of the rain structures in the Padana valley

C. Capsoni and M. D'Amico

Dipartimento di Elettronica e Informazione, Politecnico di Milano, Piazza Leonardo da Vinci 32, 20133 Milano, Italy

Abstract. A large data base of radar images collected in various years from January to December in the Padana valley was analyzed in order to identify the physical and morphological characteristics of the rain structures. This information are of great concern both in meteorological and in telecommunication applications. The analysis of the rainy characteristics of the cells identified and extracted from the radar maps by imposing a rain threshold at 0.5 mm/h showed that an exponential distribution of rain is able to properly describe the various quantities like peak, average, rms and standard deviation of rain rate. As for the description of the rainy pattern, various indicators were introduced such as the inertial and the contour (encircling) ellipses, the circularity and the elongation that in different ways have evidenced that the rain cells are mostly elongated with the larger dimension 1.5 times longer than the shorter one. The study of the degree of fragmentation of the cells showed an almost steady decrease of the "daughter" cells with increasing the rain intensity threshold passing from an average value of nearly 2 at 1 mm/h to 1.2 at 50 mm/h.

1 Introduction

The impact of rain precipitation is of great concern both in meteorological and in telecommunication applications. In the first case, the study of the rain structures, their time and space evolution and their morphological description are finalized, for instance, to hydrology where the control of the water level in lakes, flood forecasting of river catchments are of great interest and to nowcasting of intense rain precipitation evolution for a substantial support to the civil protection activity. In telecommunication applications a complete description of the rain structures is needed as basic input for propagation related models with a sound physical basis, for the prediction of the impairments suffered from radio waves at centimetre and millimetre wavelengths in their propagation through the precipitating atmosphere. In this respect, radar are unique tools in supplying precipitation maps from which it is possible to identify and describe the morphological pattern and evolution of the rain cells seen within the coverage area. In this work, a set of analytical descriptors has been chosen able to give a complete, but very concise characterization of the rain structures. Among them there are: area, peak and average value of rain rate, cell barycentre, cell dynamic, cell ellipticity and orientation, moments of inertia of the rain structure. The paper introduces all these parameters giving the rationale for their choice and their statistical description.

Correspondence to: C. Capsoni
(capsoni@elet.polimi.it)

2 The data base

The data base used for this study is constituted by reflectivity maps collected during the period 89–91 by the S-band Doppler meteorological radar sited at Spino d'Adda 30 km east of Milan (Italy), in the centre of the Padana valley. The main features of the equipment are: 500 kW peak power, 2 deg beamwidth, 0.5 μs pulse duration, 500 Hz of PRF (Pulse Repetition Frequency) and -102.5 dBm as MDS (Minimum Detectable Signal). In order to get images with very high spatial detail and almost clutter free, only the central portion of the area seen by the radar was selected thus limiting the maximum range to 40 km. In particular, this choice was forced by the presence of the Alps towards north and of the Apennines towards south with respect to the radar site. The drawback of this reduced field of view is a limitation in the maximum dimension of the rain cells and it has to be taken into account in the interpretation of some parameters Data coming from three different elevations (3, 5 and 7 deg) where used to build up a pseudo cappi at 1 km height above the ground. Reflectivity Z was converted into rain rate R through the use of the Marshall&Palmer Z-R relation that was proved to work very well on a statistical basis in the meteorological contest of the Padana valley (Pawlina,1984). The minimum threshold in rain rate was set to 0.5 mm/h. In turn, each polar image was converted in a picture on a Cartesian grid with pixel dimensions of 500×500 square meters. The complete database is constituted by 59 rain events spanning from January to December for a total of 16 051 radar pictures containing rain. Each picture took 76 s to be collected summing 339 h of observation.

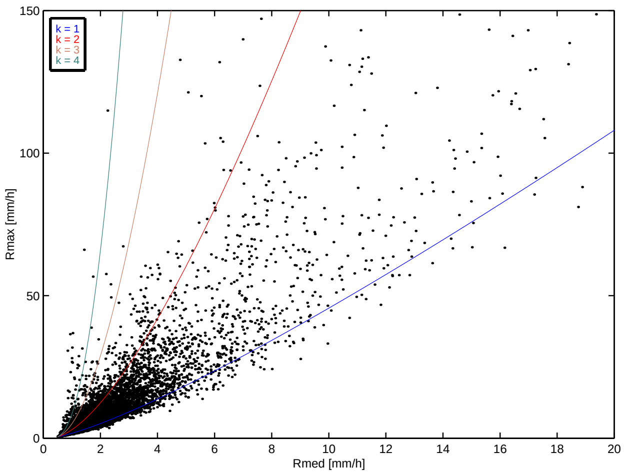

Fig. 1a. Scatterplot of the statistical descriptors (R_{med}-R_{max}).

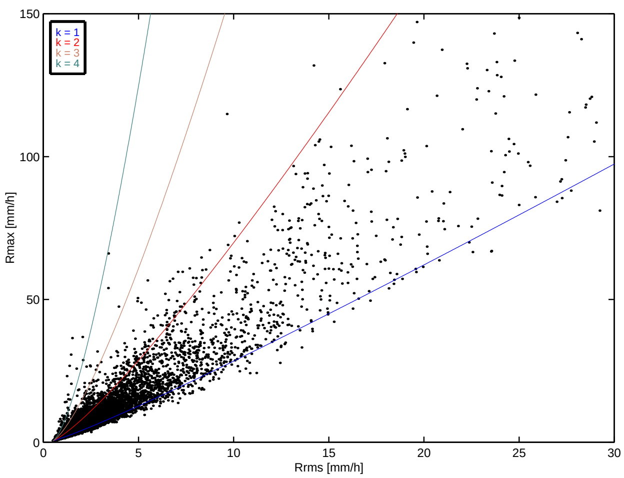

Fig. 1b. Scatterplot of the statistical descriptors (R_{rms}-R_{max}).

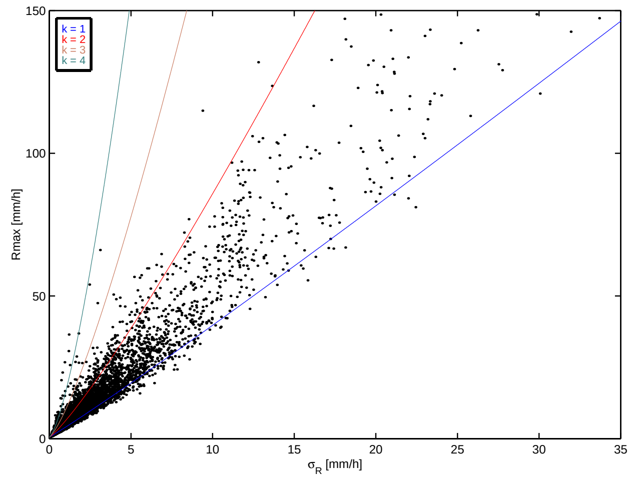

Fig. 1c. Scatterplot of the statistical descriptors (σ_R-R_{max}).

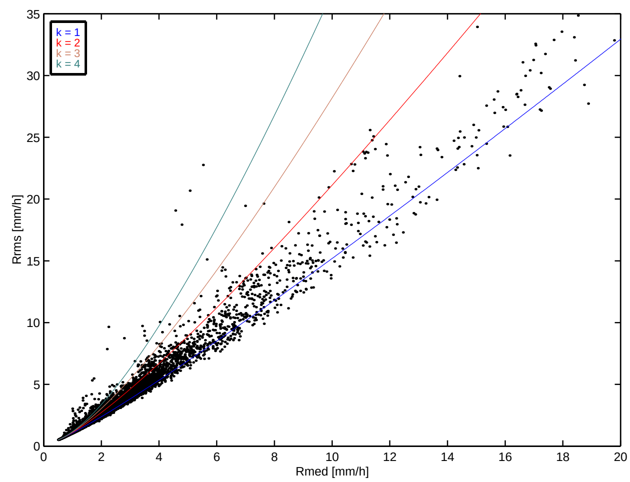

Fig. 1d. Scatterplot of the statistical descriptors (R_{med}-R_{rms}).

3 Data analysis

3.1 Rain parameters

Rain cells, defined as an ensemble of connected pixels having an associated rain rate greater than a given threshold (Capsoni et al., 1987), (Goldhirsh and Musiani,1992), were extracted from each radar map with a proper SW code and classified according to a set of parameters that are linked to both the morphological and the geometrical characteristics of the rain structure. Rain structures crossing the contour of the observation area were disregarded; being in fact only partially "visible", their parameters would be incorrectly evaluated. The few pixels contaminated by clutter left by the preprocessing procedure were replaced by the value of rain rate obtained by linear interpolation of the adjacent ones. Figures 1a to d give a comprehensive picture of the morphology of the rain cells constituting the data base. The main parameters such as peak (R_{max}), average (R_{med}), and rms (R_{rms}) value, and the standard deviation σ_R of the rain rate distribution inside each rain structure are reported in scatterplot format. For each figure, the curves representing the relation between the variables on the axes for a synthetic rain cell with elliptical cross section, having a general analytical expression of the form:

$$R(x, y) = R_{max} \exp - \left(\frac{x^2}{a^2} + \frac{y^2}{b^2} \right)^{\frac{1}{k}} \tag{1}$$

are plotted for different values of k. In Eq. (1) $R(x, y)$ is the value of rain rate at position x, y of a synthetic rain cell with the peak in (0,0), and a, b are the distances from the peak along the x,y axes respectively, at a rain rate value equal to R_{max}/e. A cell with Gaussian rain profile corresponds to the choice of $k = 1$, while $k = 2$ refers to an exponential shaped rain cell. Higher values of k represent super exponential cells. As one can appreciate most of the points lie between the Gaussian and the exponential shape. For example, with reference to Fig. 1a for a given R_{med} the Gaussian profile underestimates the peak rain rate, while the opposite is true for the exponential profile. However if we take into account that the measured peak represented on the scatterplot is the value of rain rate averaged over the area of the Cartesian pixel, while the analytical curve is referred to the peak value of Eq. (1), it seems very reasonable to deduce that the exponential profile is the most apt to describe the rain cell population. This result confirms what already found on a different data base and different threshold parameters in the same geographical area (Capsoni et al., 1987). Obviously, the synthetic shape of the cells looses some features of the real rain structures, but from the other side it allows a very easy analytical manipulation as it is required in the case of modelling.

3.2 Geometrical parameters

The commonly elongated form of the rain structure can be easily synthesized by defining an equivalent ellipse. The various shapes of the rain structures can be described by varying the ratio between the major and the minor axis of the ellipse i.e. the ellipticity. Different ellipses can be defined for a given rain cell; among them the inertial ellipse (Capsoni et al., 1987), (Feral, 2000) and the contour (encircling) ellipse have been considered here. The inertial ellipse is defined through the inertial radii ρ_i that descend from the cumulative rain Q and from the moments of inertia J_i of the structure, a parameter well known in mechanics for the description of mass geometry:

$$\rho_i = \sqrt{\frac{J_i}{Q}} \qquad J_i = \sum R_k d_k^2 \qquad Q = \sum_k R_k \quad [\mathrm{mm}^3/\mathrm{h}] \qquad (2)$$

In Eq. (2) d_k is the distance of the pixel from the chosen axis i. The contour ellipse is obtained by identifying first the rectangle containing the rain structure: its centre will be also the centre of the ellipse whose axes are directed as the principal axes of inertia and are long enough to reach the rectangle sides. The inertial ellipse gives information on how the water masses are distributed within the rain structure by taking into account both their relative position and amount; the contour ellipse gives information about the physical area interested by rain, on its extension and orientation. A sketch of the two ellipses for rain cells of different pattern is presented in Fig. 2 where the differences between the two representations can be appreciated. With reference to the contour ellipse, we have analyzed the relation between its area and the rainy area. Figure 3 shows the distribution function of this quantity where the average value is 1.42. It is evident that most of the rain cells tend to have a non symmetrical shape, but rather elongated as it is confirmed by the very small standard deviation (0.32). The orientation of the ellipses has been found to be almost uniform (Konrad, 1978) with a slight prevalence for the directions between 10 and 40 deg with respect to north and independent from the other rain parameters. An alternative way to account for the geometrical form of the rain structure is to consider its circularity (Cir) and its elongation (Elg) defined as:

$$Cir = \frac{2\pi A}{P^2} \qquad Elg = \frac{J_M - J_m}{J_M + J_m} \qquad (3)$$

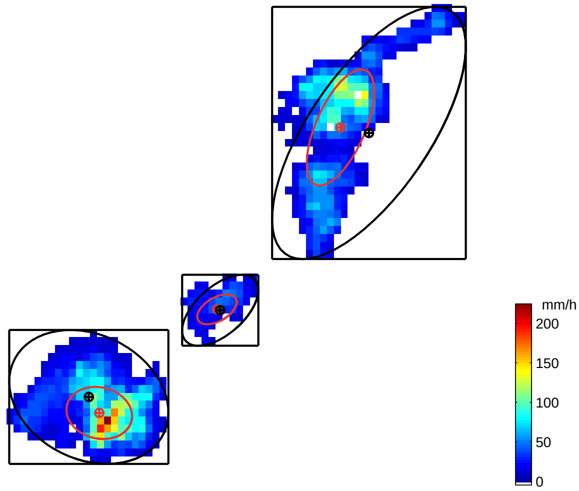

Fig. 2. Inertial and contour ellipses.

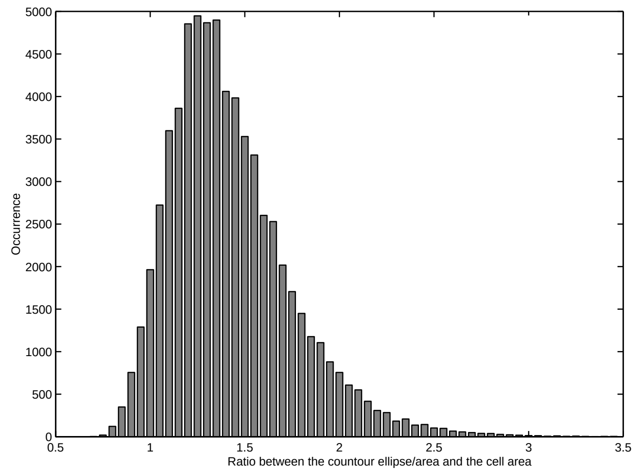

Fig. 3. Distribution of the ratio between the areas of the contour ellipse and the rainy area.

where A and P are the area and the perimeter respectively of the cell, J_M and J_m are the max and min value of the rain cell moment of inertia. The probability density function of these two quantities computed for different rain thresholds are reported in Figs. 4 and 5, respectively. The curves show a very similar behaviour almost independent on the rain threshold; the peak of the density tends to increase slightly as the threshold increases. A comparison of the two distributions shows that the peak density occurs for low circularity values and high elongation values This results has to be expected because the two parameters describe the characteristic of the structure in two opposite ways: the circularity decreases as the elongation of the structure increases.

3.3 Spatial distribution

When modelling the precipitation field by means of multiple rain cells, it is important to know how to rearrange the synthetic cells in space in order to reconstruct a sort of synthetic radar map. To this aim it is of interest to know the distance among the cells in terms of distance between their

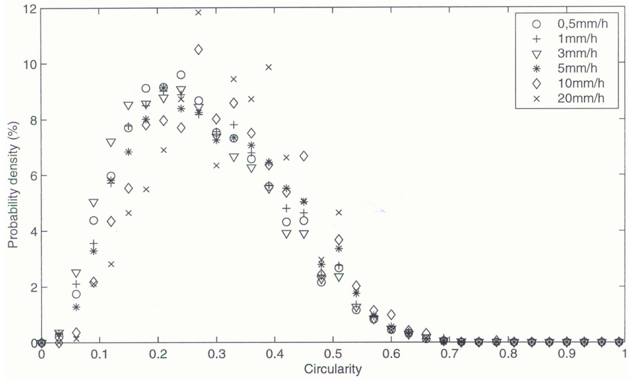

Fig. 4. Probability density of the circularity: each symbol refers to a different threshold in rain rate.

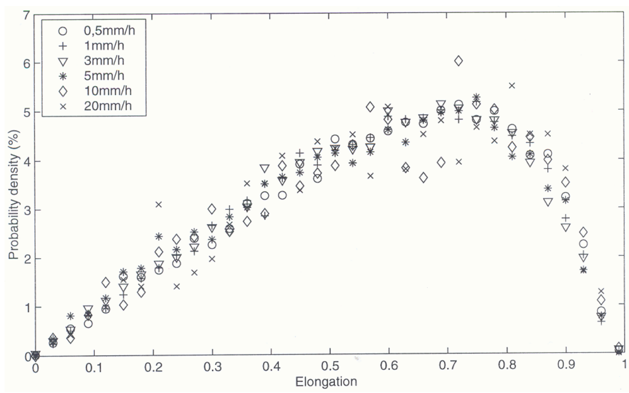

Fig. 5. Probability density of the elongation: each symbol refers to a different threshold in rain rate.

geometrical centres. The analysis has considered 7475 maps out of the total 16 051 containing at least two rain cells, 34 500 cells for a total amount of 71 587 couples. In fact the average number of rain structures per image is 2.21. The results can be summarized as follows: the average distance is about 29 km with a standard deviation of 16.19 km.

3.4 Mother cells and daughter cells

The last parameter presented in this paper is the relation between what we called mother cells and daughter cells. The definition of these two quantities is obvious: the rain structure at the lowest rain intensity level is the mother of daughters that are obtained from it by increasing the rain threshold. The mother threshold is 0.5 mm/h. The average number of daughters represents the degree of fragmentation of the rain structure. Two different quantities have been computed according to the quantity taken as the reference to evaluate the average: number of mothers with daughters or number of cells at the preceding threshold. The results are presented in Fig. 6. As it can expected, the average number of daughters decreases as the threshold increases because cells become smaller and the probability of fragmentation is lower.

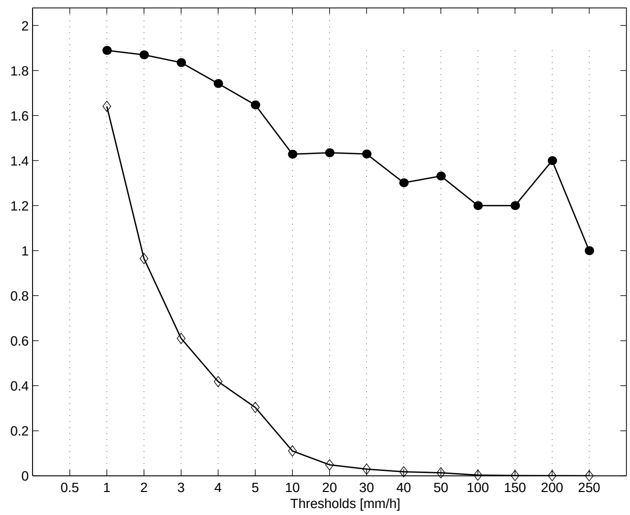

Fig. 6. Average numbers of daughters at the different rain rate threshold. The line with dots is obtained after normalization with the total number of cells with daughters, the line with diamonds is obtained after normalization with the total number of cells.

4 Conclusions

A large data base of radar images collected in various years from January to December in the Padana valley has been analyzed in order to identify the physical and morphological characteristics of the rain structures. The analysis of the rainy characteristics of the cells recognized on the radar maps has shown that an exponential distribution of rain is able to properly describe the various quantities like peak, average, rms and standard deviation of rain rate. As for the description of the rainy pattern, various indicators have been introduced such as the inertial and the contour (encircling) ellipses, the circularity and the elongation that in different ways have evidenced that the rain cells are mostly elongated with the larger dimension 1.5 times longer than the shorter one. The study of the degree of fragmentation of the cells has shown an almost steady decrease of the "daughter" cells with increasing the rain intensity threshold passing from an average value of nearly 2 at 1 mm/h to 1.2 at 50 mm/h.

References

Capsoni, C., Fedi, F., Paraboni, A., and Pawlina, A.: Data and theory for a new model of the horizontal structure of raincells for propagation applications, Radio Science, 22, 1987.

Feral, L., et al.: Rain shape and orientation distribution in southwest of France, Phys Chem. Earth,25, 1073–1078, 2000.

Goldhirsh, J. and Musiani, B. H.: Dimension statistics of rain cell cores and associated rain rate isopleths derived from radar measurements in the mid-Atlantic coast of the United States, IEEE Trans. On Geo. Remote Sens., 30, 28–37, 1992.

Konrad, T. G.: Statistical models of summer rainshowers derived from finescale radar observations, J. Appl. Meteor., 18, 661–670, 1978.

Pawlina A.: Some features of ground rain patterns measured by radar in north Italy, Radio Science, 19, 855–861, 1984.