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STATISTICAL DEPENDENCE OF RAIN OCCURRENCE IN MULTIPLE SITE CASE MODELLED WITH DYNAMICAL RADAR DERIVED PARAMETERS

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ABSTRACT

Recently introduced "frontal" model of mesoscale structure of rain, aimed for the applications in advanced TLC systems, allows to consider, among numerous meteorological parameters, the dynamic aspects of horizontal rain structure such as rain velocity field. Statistical dependence index, χ, referring to a joint rain occurrence in two or more sites, based on the spatial and temporal description of rain given by the "frontal" model, is the object of modelling in this paper. The novelty feature is the use of statistics on the shape and motion of radar rain patterns for the calibration of this model. Statistics are generated through a second model involved, that of "motion", presented in revised form. The interrelations of the two ("motion" model feeding "frontal" one) and some aspects of χ calculation are discussed.

INTRODUCTION: FRONTAL MODEL AND MOTION MODEL

The currently used models for the estimation of propagation impairments[1,2] do not consider the dynamical, space-temporal aspects of the horizontal structure of rain. Also other meteorological parameters such as shape of rainy areas, their density over a region, or their life-time, now better known, are not included yet. The present contribution goes with the currently establishing trend in the field[3] calling for less "general" models, truly based on the site radiometeorological data. The problem is to find the acceptable compromise between the realistic representation of a complex "scenario" (unregularily shaped rain patterns, reorganizing-while-moving, appearing and dissipating) and a reasonable simplicity of the model. The "frontal" model proposed by Paraboni[4,5] offers the capability of taking into account a number of meteorological parameters both in form of experimentally found distributions or estimated average values. The searched propagation descriptor is then determined, in statistical terms, as an integral over the multidimensional domain defined by the actual variability of meteo parameters.

The "motion" model describes the linear, horizontal displacements of rain patterns, assuming as a "unit" a rainy area (in our radar experiment a cluster of close rain cells). The associated motion detection algorithm allows to calculate both "individual" displacements of rainy areas in a time unit and "global" displacements of whole rain maps which play a role of "fronts" when feeded into the Paraboni model.

The meteorological system is represented by this model as "fronts" – strips of indefined length and the width S, moving across the region with the speed V in the direction Ω. Spatial density of the fronts is expressed as Pf, the probability that a point is located within a front. A number of rainy areas appearing inside the front is modelled as a Poisson's process, characterised by the density n, staying for the number of rainy areas appearing in the unitary area and time unit. A rainy area is represented as a rectangle with one side, D, parallel to the velocity vector, V, and the perpendicular side of the size $\alpha \cdot D$. Rainy areas appear within a front, move solidalily with the front without changing their shape and disappear after their lifetime, τ. The model defines "rain occurrence" referred to a (point) site and to a time interval, T, as rainy area interacting with the site at any time within T. The parameters finally involved are then: V, Ω, D, α, τ, n, S,P_f.

The model output of our interest is the expression for the statistical dependence index, $\chi(T,L)$, defined as the joint probability of two sites separated by the distance L being rainy during T, normalized to the value corresponding to their statistical independence: $\chi(T,L) = P_{00}(T,L)/P_0(T)^2$; χ is a complicated function[6] of variables T and L and of parameters listed before.

As regards the motion model, rain patterns are seen as pixel structures on radar rain maps, assumed to move independently along straight lines in a predominant direction, covering the distance represented by a displacement vector. This last is found through the calculation of a minimum of "cost function" for a current pattern and its "footprint", obtained displacing it on the close-in time rain map, as shown in Fig. 1. The rotational components of the motion are disregarded, because of their low impact in the considered climatic region (North Italy). In order to estimate "frontal" velocity field from radar rain maps the motion model assumes the whole rain map to be a front and calculates the global front displacement vector as a vectorial average of individual displacements of rain patterns existing on that map.

The motion model is tied to the frontal model through the Elliptical Velocity Transform. In synthesis, shape parameters, D and α, in the frontal model are evaluated for each radar rain pattern from its real extension area, A and its velocity vector components along the major and minor axes of the ellipse representing the pattern[7], as shown in Fig.1. Exhaustive and formalized presentation of both models and of calculation algorithms involved are reported in (6) .

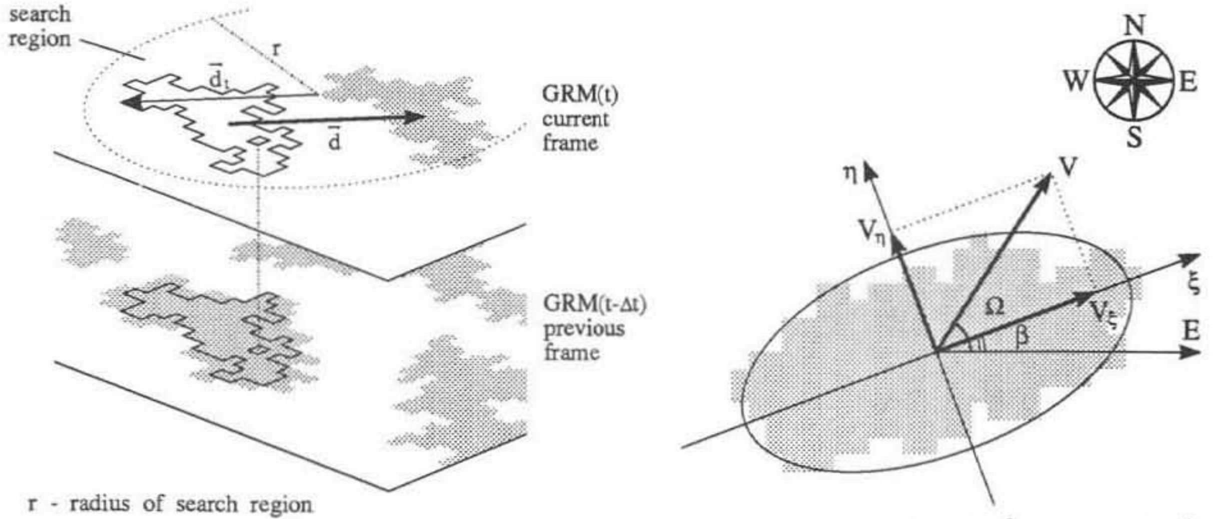
χ INDEX AND METEO PARAMETERS FROM RADAR DATA SET

These parameters are not deterministic but can be only estimated statistically what makes necessary the evaluation of χ in terms of statistical mean. Under the (simplifying) hypothesis that the parameters are statistically independent and with respect to the parameters D and Ω, selected because most strongly influencing the χ, its statistical mean is evaluated through:

$$< \chi (T,L,\phi) >_{D,\Omega} = \int \int \chi(T,L)\, p_D(D) p_\Omega(\Omega, \phi) dD\, d\Omega$$

where p stays for probabilty density function and ϕ is the angle between the baseline orientation and East.

Statistics of rainy area velocity and frontal velocity, statistics of D and α, plus all other parameters for feeding the frontal model are generated from Radar Data Set (RDS). RDS[6,8] includes some 1800 horizontal radar maps (or Ground Rain Maps, GRM's), separated by 6 min time when belonging to the same storm, with spatial resolution of $1km^2$ and with some five tousand rainy areas above the threshold of 5 mm/h satisfying the conditions of the motion evaluation algorithm. Fig. 2 shows the probability distribution of the velocity module and the polar histogram of phase for frontal displacements, displaying the mean value of 31 km/h (37 for individual areas) and North-East as preferential direction.



$$\alpha = (1/e)\,(V_\eta / V)^2 + e\,(V_\xi / V)^2$$

$$D = \sqrt{A/\alpha}$$

Fig. 1. Algorithm for evaluation of pattern motion (left) and Elliptical Velocity Transform (above).

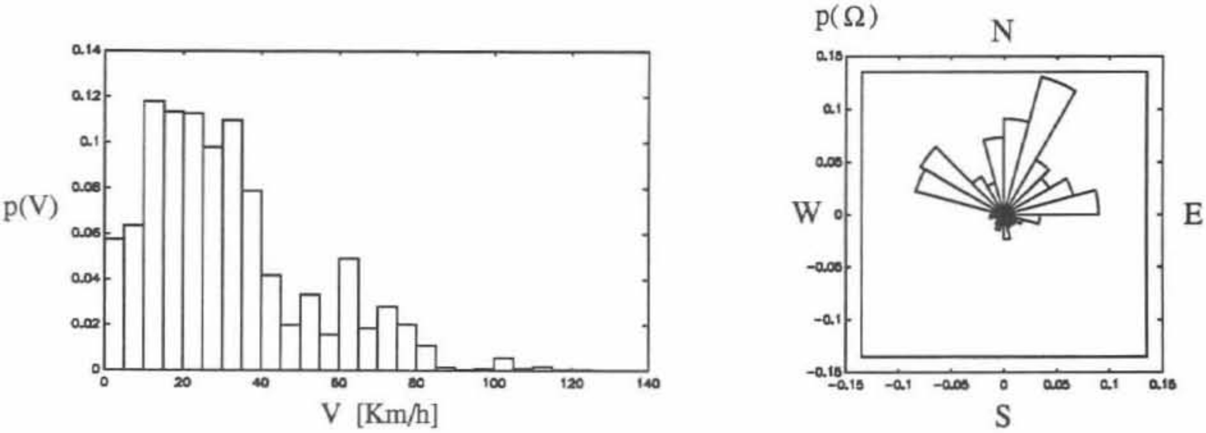


Fig. 2. Histogram of front velocity, V, and polar histogram of front movement direction, Ω.

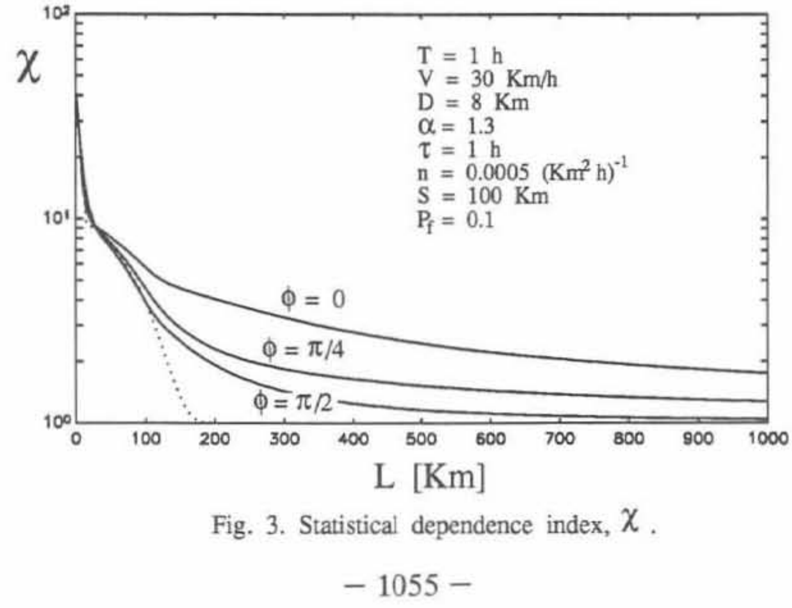


Fig. 3. Statistical dependence index, χ.

The statistical mean of the χ index based on frontal and motion models is evaluated for selected values of T and ϕ in the full range of the variable L. Handling of many meteorological parameters involved depends on their local availability and attendability – the choices made here, are all experiment-based, derived from RDS, except for P_f, S, τ which are just estimated; for values see Fig. 3.

DISCUSSION AND CONCLUSIVE REMARKS

Evaluation of individual contributions of meteo parameters to the behaviour of χ is not simple, due to the function complexity and to little knowledge about parameter inter-dependence. An analysis result (others in (6)) reported in Fig. 3 shows the χ statistical mean with respect to Ω for which the distribution of Fig. 2 is taken; three curves labeled with their ϕ values are compared with the one (dotted), calculated under the assumption of constant value also for Ω ($\Omega = \pi/2$, $\phi = \pi/4$). The importance of considering actual parameter distribution can be clearly appreciated in this case. As regard D, the impact on χ is limited anyway to the region of $0 \div 20$ km of L. V becomes more significant for large values of T (say 24 h in case only coarse rainrate data are available).
The influence on χ of different subsets of meteo parameters needs further investigation, it can be stated however that realistically calibrated models offer predictions closer to purely experimental data (4).

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