

Reconstruction of Rainfall Fields by Ground Raingauges and Radar Reflectivity Data

*Modelli per la Ricostruzione di Campi di Pioggia
con l'ausilio di Dati Radar di Riflettività*

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Riassunto: Questo lavoro, che ha preso spunto da un articolato problema di valutazione di un esperimento di incremento artificiale delle precipitazioni condotto in Puglia dal 1992 al 1994, intende procedere alla ricostruzione di campi di pioggia facendo uso della relazione esistente tra l'intensità di pioggia e la riflettività radar. I dati a disposizione che provengono da un radar meteorologico e da una fitta rete di 80 pluviometri sono rilevati ad un intervallo temporale di 10 minuti. Un approfondito esame della qualità dei dati e della loro struttura spaziale e temporale, precede alcune proposte di modelli spazio-temporali che intendono investigare la relazione tra riflettività radar e intensità di pioggia al fine di ricostruire le intensità di pioggia su una vasta area geografica.

Keywords: radar, rainfall, space-time, data quality control, kriging, external drift, dynamic linear model, Kalman filter, weather modification.

1. Introduction

The Rain Project has been an Italian randomised rain enhancement plan in response to the drought experienced in Southern Italy. The initiative was taken with the purpose of applying Israeli methods and technology of rain enhancement in Puglia and other regions of Southern Italy. The aim of this study is to provide a support to the evaluation of the experimental part of the Rain Project which was conducted for the period 1986-1994 and in particular is to reconstruct rainfall fields combining two source of data: rainfall intensity and radar reflectivity. In 1992, a high density network of 80 automated raingauges with high time (10 minutes) and space (~10 km inter-gauge spacing) resolution was installed; moreover a C-band digital weather radar, scanning the whole area every five minutes, was introduced.

Radar raingauge systems are increasingly used to reconstruct rainfall fields since they are able to provide spatially continuous images of precipitation for short and regular time intervals. On the other hand, ground monitoring network of raingauges at a set of locations within the study area provide more accurate, direct estimates of rainfall

intensity at their respective locations. However, the coverage of the area study by such raingauges is spatially sparse in comparison to the grid on which radar reflectance is recorded. In this work we investigate the relationship between radar reflectance and rainfall intensity in order to build a model able to provide estimates of rainfall intensity over a region larger than that one covered by ground raingauges network. After an intensive work of data quality control, we compare several approaches to the calibration and the reconstruction of the rainfall fields. An operational technique, related to the use of the calibration factor, is firstly proposed. Another modelling strategy follows the state-space approach proposed in Brown et al (2001) and the third one uses a Kriging with external drift technique. As a further development a complex Bayesian model, as illustrated in Mardia and Sahu (2004), will be proposed as a further development of the present work.

2. Quality control, spatial and temporal analysis of rainfall data

It is of fundamental importance to know how accurately rainfall has been measured by the specially designed raingauge network. The dense network of 80 raingauges, installed on the coast of the Puglia Region between Bari and Canosa, is located within an area of about 160 x 60 km.

In our work we use data which have been pre-processed to remove anomalies and outliers. The months involved into the analysis are those for which at least one seeding operation is performed; this choice is motivated by the attempt of including, in a further step, radar information which are available only when a seeding operation was performed. This control allowed to involve in the analysis only reliable measurements but, on the other hand, reduced drastically the number of available data.

In order to explore the rainfall process and to address the development of statistical models, basic exploratory analysis have been carried out. This type of analysis has been useful in order to highlight dry or rainy periods and, in particular, they emphasized the extremely dry aspect of the examined study area.

In addition to the descriptive analysis, the spatial and temporal structures of the rainfall process within the area of study have been examined. This part has required the choice of appropriate time and spatial “windows” to be used in the evaluation of spatial and temporal tools as: cross correlations, variograms, autocorrelations etc.

Considering this temporal behaviour and the variogram analysis we carried out, it has been pointed out a very erratic behaviour of the process.

3. Weather radar calibration for rainfall estimation

3.1 Operational techniques

The area covered by the radar, located in the airport of Bari Palese, include the experiment area and an area around it of about 200 km². The data point values, referring to a pixel of 0.5km x 0.5km, are in radar reflectivity units of dBZ. This is a measure of the power scattered back to the radar by precipitation particles in the atmosphere. Meteorologist commonly convert from a radar reflectivity factor Z to a rainfall rate R (in mm h⁻¹) using a power law that, unfortunately, is not exact. Actually, rainfall and radar measurements are sensibly different: on one hand the first ones give a direct

measure, spatially punctual and time integrated, of ground rainfall; on the other hand, the second ones give an indirect measure of precipitation, on the air, and integrated in space and at a given point in time. Most of the conversion formulas, called Z-R relationships, result in the following relation:

$$Z=a R^b \quad (1)$$

where a and b are unknown coefficients. In general, estimates of a can vary from about 30 to 500 and b can vary from about 1.2 to 2.0. Typical values of a and b are respectively 200 and 1.6, which give the well-known Marshal-Palmer relation. The Marshal-Palmer relationship provides a first approximation to the rainfall rates throughout the radar field. The calibration factor CF is normally defined as being the ratio between rainfall as measured at ground level R and rainfall measured by radar Z . This factor and its inverse, known as assessment factor AF, have been used to adjust all the rainfall rates produced by the first approximation. The method is equivalent to choosing a new value of a in Eq.(1). In order to perform this analysis six days, two per every year of the project, have been chosen and data, collected for the duration of the seeding operation performed during the six days plus three hours afterwards, have been considered. It was possible notice that there is generally a reduction in the errors in radar-derived rainfall estimates but large spatial errors remain.

3.2 A time-series approach

The modelling strategy proposed reflects the fact that the ground data are spatially sparse, but temporally dense. Our approach starts from what proposed in Brown et al (2001). A dynamic linear regression model is used to re-formulate Eq.(1) in a time-series regression form where the coefficients are assumed time-varying and can be represented as stochastic AR(1) processes. The Kalman filter provides an efficient algorithm for finding the estimates. Kriging surface of the state variables, associated with the n sites at which ground measurements are available, have been obtained through Ordinary Kriging, for each time-interval. Reconstruction of the rainfall field has been performed for the event that involves two seeding operations (11th of April 1992) plus three hours afterwards. In the fitting procedure six sites are left out for validation purposes. Analysis has shown relatively small MSE values and approximate predictions for this six sites (Table1). As a further comparison term we implemented a straightforward version of the model proposed in Brown et al. (2001). However there were no improvements in term of MSE.

3.3 External drift method

Calibration can be done using external drift method, that applied in the IRF-k (intrinsic random function of order k) produces rainfall maps of a variable when a secondary variable, correlated with the first one, is available on the whole field. The method consists in adding a supplementary equation to the kriging equations.

This is an “external drift” condition because it is incorporated into the universal kriging system on the basis of considerations that are not connected with the computation and the inference of the variogram (or generalized covariance) of the rainfall.

Estimation of the rainfall field has been performed for the event that involve the seeding operation of the 11th April 1992 plus three hours, leaving out the same six locations that we used for the validation. Analysis showed a drastic reduction of MSE values for this six sites (Table1) and this method at the same time has the advantage of being computationally efficient. However, it does not account for time variation.

Table 1: *MSE for the six validation sites*

Validation Site	MSE from Brown et al. model	MSE from the state-space plus kriging	MSE from the Kriging with external drift
S107	0.79	0.20	0.03
S304	0.60	0.30	0.00
S606	0.31	1.04	0.01
S512	0.41	0.57	0.01
S211	1.05	0.45	0.05
S217	0.66	0.22	0.14

4. Conclusion

The considerable difference in the MSE values between the space-time approaches and the kriging with external drift may be due to several reasons. First of all, estimates of the time varying coefficients didn't show an AR(1) behaviour. Their time behaviour is very erratic and it changes considerably from one site to the other making difficult to choose another type of model structure.

Moreover, the quality of radar data, is really important and strictly connected to the quality of images scattered back by the radar. The radar-based rainfall estimations are affected by errors that influence the relationship with the true rainfall. This fact could influence the basic model assumptions made that could be corrupted by the poor quality of radar data in this analysis.

As future direction of research, our aim is to build an integrated space-time model which is consistent with the data and which captures the essential features of the observed pattern of spatial and temporal joint dependence. With this purpose we will follow the model proposed Mardia and Sahu (2004), that implies the use of drift functions in space and of correlations (first order Markov structure) in time in a full Bayesian framework.

References

- Wood S.J., Jones D.A., Moore R.J, (2000) Accuracy of rainfall measurement for scales of hydrological interest, *Hydrology and Earth System Sciences*, 4(4), 531-543.
- Collinge V.K. Young P.C.(1993), Weather radar calibration: Systems Approach, *Concise Encyclopaedia of Environmental Systems* (ed. P.C. Young), Oxford: Pergamon, 706-710.
- Brown P.E., Diggle P.J., Lord M.E., Young P.C., (2001) Space-time calibration of radar –rainfall data, *JRSS, Applied Statistics (C)*, 50(2), 221-241.