ESTIMATION OF KINETIC ENERGY OF HAIL PRECIPITATION USING C- AND S-BAND RADAR DATA

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I. ABSTRACT

The estimation of kinetic energy of hail precipitation using meteorological radar has caught the interest of some authors. In our case, we used the databases obtained by hailpad networks and the images of C-band and S-Band radar to build an algorithm to estimate the vertical component of kinetic energy produced by a hail precipitation.

In order to compile the database, we have established two categories of kinetic energy: low (< 20 J m^{-2}) and moderate or high (> 20 J m^{-2}). With this information, we have looked to establish a differentiation between hail precipitation that hardly produces damage and, on the contrary, that which does (Dessens et al.,2007). Once these two categories were established, we applied a logistic function and statistical techniques that establish a correspondence between radar variables and the two categories of kinetic energy.

The results show great uncertainty in determining kinetic energy using C-band radar. However, for the S-band radar the results have shown that the probability of detection is 85,7% with a FAR of 14,3% and a variance explained of 61,2%. This result allows us, with corresponding caution, to make a first estimation of the areas in which a hailstorm could produce damage.

II. LOGISTIC REGRESSION MODEL

Firstly, it should be stated that the logistic regression model allows us to know the probability for a determined phenomenon using a group of independent variables or explanatory variables. In our case, these explanatory variables are radar variables from which we can estímate the probability of hail precipitation with moderate or high energy (> 20 J m^{-2}).

There are various methods for constructing a logistic equation. In the present work, we opted for the *stepwise* method of incorporating variables, used recently by various authors (López, et al., 2007; López and Sánchez, 2009).

III. ESTIMATION OF KINETIC ENERGY OF HAIL PRECIPITATION USING A S-BAND RADAR DATA IN MENDOZA (ARGENTINA)

a) Data and methodology

The database used in this analysis is formed by 100 cases of the hailpad network from the Southern oasis of Mendoza and the S-band radar installed there, selected during experimental campaigns in 2005-06 and 2006-07. For each year, parameters that were measured using the hailpads and *radar variables* from hailstorm cells are available.

In establishing two categories to carry out an analysis, a threshold of 20 J m^{-2} was used. In 42 of the hailpads the kinetic energy registered in less than 20 J m^{-2}. Thus, in order to construct a binomial logistic regression model, a new categorical variable was created, which assigns a value of 1 to hailpads with kinetic energy levels superior to 20 J m^{-2} (hail with moderate or high kinetic energy, *energetic group*) and a value of 0 to those which are inferior to 20 J m^{-2} (habitually without damage in crops, *non-energetic group*).

As previously indicated, in order to incorporate these variables into the model, the *stepwise* method of variable incorporation is used. As a criteria for this incorporation, statistic significance is used for β coefficients for the variables introduced using Wald statistics.

b) Results and discussion

The logistic model is constructed after three iterations. Thus, in the final logistic equation three radar variables are introduced: the VIL, the maximum reflectivity height and the top of the storm.

Once the variables are incorporated in the base model, we then have to measure the validity of the adjustment to the model. In order to do so, a test is used that was proposed by Hosmer and Lemeshow (Hair, 1998). In this case, the results show that the null hypothesis is rejected, indicating a good adjustment of the model in the three iterations.

Finally, the β coefficients estimated for the three independent variables are evaluated using the Wald statistic, which shows that all of the variables introduced in the equation are statistically significant at a level of 0.05.

Thanks to the equation constructed, a cell with hail is classified as moderate- or high- energy when its probability is superior to 0.5.

Finally, different indices are calculated that give way to distinct aspects of the validity of the model. The values in TABLE I show sufficiently satisfactory results. The POD is 85.7%, with a FAR of 14.3%, which is considered to be a low meteorological value. The explained variance is 61.2%, and this value cannot be increased by including more variables. As such, the method allows us to establish a real-time forecast of kinetic energy that associates hail precipitation with storms. This result allows us, with corresponding caution, to make a first estimation of the areas in which a hailstorm could produce damage.

Skill scores	Model
False Alarm Rate	0.143
Frequency of Hits	0.857
Frequency of Misses	0.143
Probability of Detection	0.857
Probability of False Detection	0.103
Heidke's Skill Score	0.754
True Skill Score	0.754

TABLE I: Skill scores (Mendoza, Argentina).

c) Meteorological interpretation

Although the equation is rigorously constructed via the use of statistic criteria, and both the results of the adjustment to the model and the results of the Skill scores are adequate, all of this lacks validity if it does not have meteorological significance. Thus, it is necessary to evaluate if the variables selected fit with the methodology based on the inclusion of different “ingredients” in the model which allow us to know if hail can be considered to be energetic or not.

The results show that the radar reasonably discriminates between storms that do and do not have precipitation associated with energetic hail using three variables. The model combines them to form an algorithm that takes the following into account: the vertical content of liquid water that the storm contains, the affected area where hydrometeors are in the storm, and the height at which the greatest accumulation of hydrometeors is found. Thus, the variables included in the logistic equation can be grouped into two: those which incorporate microphysical aspects (concentration of supercooled liquid drops and the size of hydrometeors) and the vertical structure of the storm (area of growth and height at which the part of the storm with the greatest number of hydrometeors is found). These would be the necessary ingredients, and the variables included in the model are selected as efficient variables for predicting the previously mentioned ingredients.

IV. ESTIMATION OF KINETIC ENERGY OF HAIL PRECIPITATION USING A C-BAND RADAR DATA IN THE EBRO VALLEY (SPAIN)

a) Data and methodology

The data used corresponds with 119 hailpads selected during experimental campaigns in 2006 and 2007 in the Zaragoza network (Sánchez et al., 2009), and their corresponding variables of C-band radar located in Zaragoza (López y Sánchez, 2009). The methodology applied is the same that is detailed in the province of Mendoza. That is to say, the *stepwise method* of incorporating variables using the *Wald statistic* to guide the incorporation of variables in the equation.

b) Results and discussion

The model only carries out one iteration, selecting the VIL. This is also the first variable selected in the energy model constructed in Mendoza. The global adjustment of the model evaluated using the Hosmer and Lemeshow statistic shows results that are only relatively satisfactory. Similarly, the Cox and Snell R-square and the Negelkerke R-square show values of 0.091 and 0.146 over 1, indicating a deficient adjustment.

The contingency table presents very high values for missed cases. Only 79.8% of the data classified in the table is correct. This result is especially negative when the percentage of correctly predicted high-energy hail precipitated is evaluated, which is only 13%.

The results show great uncertainty in determining kinetic energy using C-band radar. This fact is consistent with the non-linear reflectivity behavior of the C-band radar to large diameter hail, and therefore the most energetic. This leads to the conclusion that this type of wavelength is not the most appropriate for establishing relationships between the kinetic energy of the hail on the ground and the radar variables.

V. ACKNOWLEDGMENTS

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