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Nowcasting of kinetic energy of hail precipitation using radar

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ABSTRACT

The detection of hail precipitation generated by a storm is a complicated task due to the limited spatial extension and the space-time irregularity of impacts generated on the ground. Some of the most extensive methods to create climatology of these impacts are observer networks or hailpad networks. Both methods are affected by numerous inconveniences, overall when it is necessary to work with an extensive area, in which it is necessary to maintain an operating network that has numerous maintenance costs.

In this sense, there are numerous works done that have developed different models with the objective of detecting hail precipitation using meteorological radar. Some of these methods use discriminant statistic techniques that, through the combination of different radar parameters, can achieve very satisfactory results. On the other hand, it would be very interesting to know not only the probability of hail, but also some of the characteristics of the hailstones precipitated, such as the number or their kinetic energy, since these parameters are directly related to the damage generated in infrastructures and/or crops.

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 databases 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 carry out this study, data on hail was gathered and analyzed from the hailpad networks in the province of Zaragoza (in the north-east of Spain) and the province of Mendoza (in Argentina, close to the Andes range on the border with Chile). These are two geographically distant regions, but which share a common characteristic: a high frequency of storms with hail precipitation, mainly during the summer months (Sánchez et al., 2009a).

In order to compile the database, we have established two categories of kinetic energy: *hail with low energy* ($<$20 J m^{-2}) and *hail with high energy* ($>$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 constructed a logistic function that establishes 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 an explained variance 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.

With the objective of making a meteorological interpretation of the results obtained (achieved only using statistic criteria), we have previously done an Principal Components Analysis (PCA).

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1. Introduction

Although hail phenomena occur in many regions of the world, causing significant damage to agriculture and infrastructures, the small spatial and temporal scale (Smith and Waldvogel, 1989; Webb et al., 2009; Sioutas et al., 2009) make its detection on the ground difficult. According to data from the International Association of Agricultural Production Insurers, Spain is the European country in which the highest loss is recorded. It is very probable that the loss is greater than 150 million Euros annually. In the Northeast of the Iberian Peninsula and more concretely, in the Ebro Valley, there are approximately 20 to 30 million Euros lost (with strong annual oscillations. The loss produced in agriculture uses registers that are reasonably reliable in Europe. However, it is important to consider that hail fall, especially in extreme cases, produces losses in infrastructure, property, cars, etc. There are some known episodes. For example, it is well known in the case of BMW (5,000 cars were affected by hail fall in Hamburg's port when they were about to be shipped to the United States) and more recently, in the Volkswagen factory in Emden with 30.000 cars (Klatt, 2008).

Traditionally, there are three methods for the observation and the measurement of hail on the ground: observer networks (Changnon, 1971a, 1971b), insurance companies (Holleman et al., 2000) and hailpad networks. The hailpad is a meteorological sensor (Schleusener and Jennings, 1960) which consists of a material that records the shape of the hailstones hitting it. For this reason, it is the most objective method among the three, providing numerical variables of the hailstones (the number of hailstones, ice mass, the kinetic energy and the maximum diameter).

Furthermore, from these basic variables it is possible to construct other derivatives, such as frequency histograms of these variables (Sánchez et al., 2009b). This data could be used to indirectly study characteristics of these precipitations, since it deals with particular distributions for each area of study, which could be interpreted as the signature of hailstorms in the area. Despite the numerous parameters provided by these networks, its main inconvenience is its elevated operating cost. Specifically, hailpads should be manually replaced after a hailstorm in order to avoid effects from various hailstorms. Due to this high maintenance cost, the hailpad networks present a limited extension. Some of the largest operating hailpad networks are located in the province of Mendoza in Argentina (800 hailpads installed in a grid of 5 km × 5 km) and the province of Zaragoza in Spain (with a total of 100 hailpads installed every 4 km × 4 km). These are two geographically distant regions, but which share a common characteristic: a high frequency of storms with hail precipitation, mainly during the summer months (López et al., 2007; Sánchez et al., 2008, 2009a). Similarly, in the Province of Zaragoza (Spain), summer storms are very frequent, with some areas in the Southwest of the basin reaching an average number of 32 thunderstorm days per year (Font, 1983). This characteristic situates the Northeast of Spain as one of the areas with the highest frequency of storms in all of Europe. In some instances, the storms have been severe, precipitating large-sized hail and causing high amounts of damage in different locations of the province, such as Alcañiz (García-Ortega et al., 2007) and Maluenda (López et al., 2008).

Looking at another area, the province of Mendoza in Argentina has been identified as a hotspot of convection in the Southern Hemisphere. For this reason, there are numerous studies that have used ground truth data coming from these networks. Thus, these databases are used to calibrate hail prediction models from radiosounding (López et al., 2007), develop and validate algorithms to identify hail via radar data (Ceperuelo et al., 2006, 2009; López and Sánchez, 2009) or study synoptic and mesoscale conditions in which these types of phenomena develop (García-Ortega et al., 2007, 2009).

Thus, as we have shown, due to its elevated maintenance cost, this method is limited to a reduced area. On the contrary, weather radar (Battan, 1973) is frequently used in meteorological studies in extensive areas (Rezacova et al., 2007; Öztürk, and Yılmazer, 2007; Dotzek and Friedrich, 2009; Pujol et al., 2009; Rubel and Brugger, 2009; Pedersen et al., 2010; Bech et al., 2011; Salonen et al., 2011). In fact, during the last thirty years, radars have been applied to the detection of storm cells bearing hail (Greene and Clark, 1972; Lemon, 1978; Waldvogel et al., 1979; Billet et al., 1997).

Direct identification of storms with hail precipitation is not a simple task. Additionally, it is necessary to show that the majority of the radar available in official organisms and research centers in Europe are conventional radar. In this sense, some methods have combined different basic variables provided by these types of radar (such as the *Top*, the *Height of maximum reflectivity*, *Storm inclination*, *Maximum reflectivity*, etc.) with the goal of constructing algorithms to identify hail. The results show that conventional radar is adequate to carry out the identification and following of these types of precipitation (López and Sánchez, 2009). These results have been able to be reached thanks to the meticulous database of ground truth provided by hailpad networks that have allowed for the precise identification of hail at the ground level or higher in a determined track.

On the other hand, we should not forget that the risk of hailstorms, evaluated through damages caused by these storms, comes marked fundamentally by both kinetic energy of precipitation and maximum size of hailstones (Changnon, 1971b; Katz and Garcia, 1981; Wojtiw and Ewing, 1983, 1986; Hohl et al., 2002a, 2002b). With respect to kinetic energy, once the presence of hail is identified, it would be very interesting to have access to tools that allow us to know the maximum kinetic energy precipitated in a determined study area in nowcasting with the goal of quickly evaluating the damage caused by hailstones. Some studies have already evaluated the existing relationship between kinetic energy and reflectivity in an isolated way (Waldvogel et al., 1978a, 1978b; Waldvogel and Schmid, 1982; Iniuchin and Makitov, 1987; Schmid et al., 1992; Makitov, 2007). Nevertheless, and given the good results achieved via the construction of discrimination models that combine different variables, the objective of the study refers to the construction of short-term identification and forecasting tools (nowcasting) for kinetic energy of hail precipitation via the use of radar variables.

In our case, we used the databases obtained by hailpad networks and the images of C-band and S-band radar. 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