

# Comparisons of hail kinetic energy derived from radar reflectivity with crop damage reports over the eastern Free State

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## Abstract

Hail kinetic energy (HKE) derived from radar reflectivity is used to identify hail on the ground over the eastern Free State. The location of crop damage reports is used for validation. Three case studies on days with the highest crop damage claims are analysed. HKE corresponds well with hail on the ground under moist atmospheric convective development, but failed to detect hail under dry atmospheric convective development. The duration and intensity of hail events above farms are also analysed. Several reflectivity threshold levels for hail identification were investigated. A threshold between 45 dBZ and 50 dBZ with a scaling factor resulted in the best correlation between HKE and crop damage location, while a reflectivity cut-off at 50 dBZ or 55 dBZ underestimated hail occurrence.

## Introduction

Convective storms, also known as thunderstorms, are an almost daily occurrence over the summer rainfall regions of Southern Africa. Despite their generally short duration of less than an hour over a location, they are responsible for significant damage and interference in the lives of humans. Hail spawned from these storms destroys approximately 2.1% of the total annual agricultural production in South Africa (Theron et al., 1973) and causes millions of Rands in property damage. On average, locations over the eastern Free State receive between 3 and 5 hail days per year. This increases to between 5 and 7 d over the southern and eastern regions of the eastern Free State (Le Roux and Olivier, 1996).

Carte and Held (1978) studied convective storms over the Witwatersrand area and observed hail to be produced by single, multicell storms and linear arrays of thunderstorms. Most of the multicell storms (77%) propagated to the left or front of the existing storm. These convective storms are often responsible for significant hail damage, gusting winds and flash floods (Held, 1981). Research on the frequency and distribution of hail was done with the help of close to a thousand volunteers, distributed over the Witwatersrand area, reporting hail sizes and location during 1960-1970 (Carte and Kidder, 1970; Carte and Basson, 1970).

A hail suppression project initiated in December 1971 in the Nelspruit area of Mpumalanga, used the strict guideline of the height of the 45 dBZ contour exceeding 7.5 km for the identification of hail storms (Mather et al., 1976). This guideline was expanded by Held (1978) to include cloud top height and temperature for identifying severe hail storms. However, no such strict relationship for the height of the 45 dBZ contour and cloud tops was found and it was concluded that most likely a variety of characteristics must be used to separate hail and no-hail convective storms. Carte and Held (1978) found that in 86% of hail storms a strong horizontal reflectivity gradient existed, but that the use of echo

characteristics are not reliable in determining the probability of hail. This was further illustrated when two apparently similar storms were investigated, one causing a cloudburst and the other severe hail (Held, 1981).

The detection of hail is difficult due to the complex spatial distribution and temporal distribution of hail. The most common method used to measure hail was by means of extensive hailpad networks (Sleusener and Jennings 1960; Changnon, 1977). Hailpads were used to identify location, hail distribution sizes and impact kinetic energy. Hailpad data are limited by instrumental problems due to the saturation of the pads, physical problems due to unknown hail shapes and drag, and statistical problems as to the representivity of the hailpad to the events in the nearby area (Waldvogel et al., 1978b). To operate such an extensive network requires a large logistical effort at large cost.

The use of radar to detect hail was found to be a very feasible option in comparison to operating a hailpad network. The comparison between HKE ( $\dot{E}$ ) ( $J \cdot m^{-2} \cdot s^{-1}$ ) and radar reflectivity ( $Z$ ) was extensively researched by Waldvogel et al. (1978a; b). Assuming Rayleigh scattering of cloud particles and an exponential hail distribution spectrum, semi-empirical and theoretical estimates of this relationship were made from several case studies. This resulted in a HKE-Z relationship:

$$E = 5.0 \times 10^{-6} Z^{0.840} \quad (1)$$

with dBZ defined as  $10 \log Z$ . The empirical relationship is similar to the well-known Z-R relationships (Marshall and Palmer, 1948). Waldvogel et al. (1978a; b) concluded that Z-E relationships between different hailstorms show surprisingly similar behaviour and that such a relationship is within 25% of the real energy values at a point. Geotis (1963) found the 55 dBZ surface contour to be a good cut-off for hail detection on the ground in New England. Similar results using hailpads, hail spectrometers and radar reflectivity with a 60 dBZ cut-off for hail, provided the best criteria for Switzerland as determined by Waldvogel et al. (1978a). Wotjic and Ewing (1983) did several comparisons between hail and crop damage and found the best relationship at 49 dBZ. It is thus clear

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