Hailstorm Characteristics Over the Area of Central Macedonia During the Period 1998–2008

E. Sfiri and T. Karacostas

Abstract The objective of this study is the analysis of the mesoscale thermodynamic characteristics of the hailstorms, which occurred over the region of Central Macedonia, where the National Hail Suppression Program is applied, during the period 1998–2008, except for the year 2003. The data used are derived through the C-band weather radar at Filyro and from the representative soundings of the synoptic station of Thessaloniki. The frequency of hailstorms' occurrence, their movement, intensity and the maximum development are studied. The radar data are analyzed and studied through the software TITAN (Thunderstorm Identification, Tracking, Analysis, and Nowcasting), for the period 2006–2008.

1 Introduction

The Greek National Hail Suppression Program (NHSP) has been applied over a region of Central Macedonia by the Greek Agricultural Insurance Organization (ELGA) since 1984. For the first 5 years, the program was run on an experimental mode (1984–1988) and afterwards on an operational basis (Karacostas 1984, 1989). The main purpose of this project is the hail suppression from hailstorm clouds. The hail suppression is performed by seeding the clouds properly with AgI particles. The protected and seeding areas of Central Macedonia include parts of the prefectures of Pieria, Thessaloniki and Kilkis, totaling to 2,670 km^2. The study and understanding of the hailstorm characteristics within the protected area of Central Macedonia is of great importance and usefulness, since this area is one of the largest agricultural areas and most crop productive – due to the potentiality of agricultural cultivations – and at the same time of a very high frequency of

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Fig. 1 The area of the NHSP, along with the three specifically chosen areas (P2, P3 and P4) for a distinctive examination of the hailstorm characteristics

occurrence of hailstorms, resulting to very high economic compensations paid by ELGA. Most frequently, hail appears over northern Greece during the warm period of the year, from April to September (Sioutas 1999). The seeding area (Fig. 1) is surrounded by mountainous ranges to its northwest, west and southwest boundaries. Specifically, the mountain range of Vermion extending to the west side of the area, can be considered as a storm influencing mechanism, due to the conglomeration of the cold and dry upper air with the warm and humid low level air. In this study, an attempt is made to investigate and study the characteristics of the hailstorms developed within the area of interest (P2, Fig. 1), and particularly over two specifically defined areas (P3 and P4, Fig. 1), thus distinguishing the orographic effect to hailstorm development from the thermal-convective influence on the development.

2 Data and Methodology

A storm is characterized as hailstorm when it produces hailstones, which have significant size and can reach the ground. According to NHSP, a storm is seeded when it reaches reflectivity values greater or equal than 35 dBz, between the −5°C and −30°C isotherms, over the study area or the transition zone (Karacostas 1984). In this study, the examined hailstorms must fulfill the following specific criteria: (1) the reflectivity to be at least 45 dBz above the isotherm of −5°C and (2) at least one damaged hailpad was identified within the area of interest. The need to overcome and distinguish the effect of the seeding on the hailstorms intense and frequency, leaded to the definition of two categories, based upon the two previous criteria. Category A incorporates all hailstorms that fulfill at least one criterion, while hailstorms that fulfill both criteria simultaneously determine category B. It is obvious that there are more hailstorms in category A, since B category is a subset of A. The archived data from ELGA, which have been collected during the 1998–2008 operational years (April–September) and concern 237 hailstorms, have been used. The studied variables are: the maximum reflectivity, which demonstrates the intensity of the hailstorm, the height (identified by the weather radar), and the level of the −5°C isotherm (derived from the 12:00 UTC radiosonde). Moreover, using the software

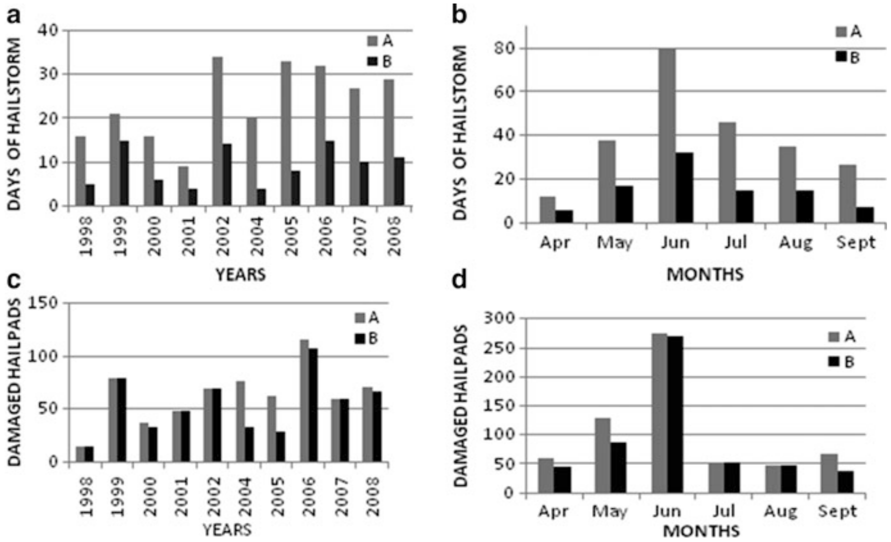

Fig. 2 Frequency of hailstorms and the damaged hailpads, per year and month, for categories A and B

TITAN, more hailstorm characteristics are retrieved, such as the average motion (speed and direction) of the identified cells, along with the maximum height of cells (max top), but only for the period 2006–2008.

2.1 *Initial Analysis of Hailstorms*

The 237 hailstorms are studied and their characteristics are analyzed for the two categories A and B. The frequency of occurrence of hailstorms (first row) and the number of damaged hailpads (second row) are depicted as a function of the examined years within the hail season in Fig. 2. The frequency of hailstorm occurrence is larger at the latest years for category A, while such indication is not obvious for category B. Most hailstorms seem to take place during June, for both categories. Probably, that is the reason for the very high values of the damaged hailpads in the same month. Although the hailstorm frequencies indicate big differences between the categories A and B, this is not identified in the distributions of the damaged hailpads. The years 2006 and 1998 represent the two extremes, indicating the maximum and minimum number of damaged hailpads, respectively. As far as the limits are concerned, the categories A and B are in agreement, although B exhibits lower or equal frequencies than A, in all circumstances.

The frequency of maximum reflectivity as a function of the examined years is depicted in Fig. 3, for the categories A and B. Moreover, the identified height of the maximum reflectivity values and the $-5°C$ isotherm are indicated, as a function of

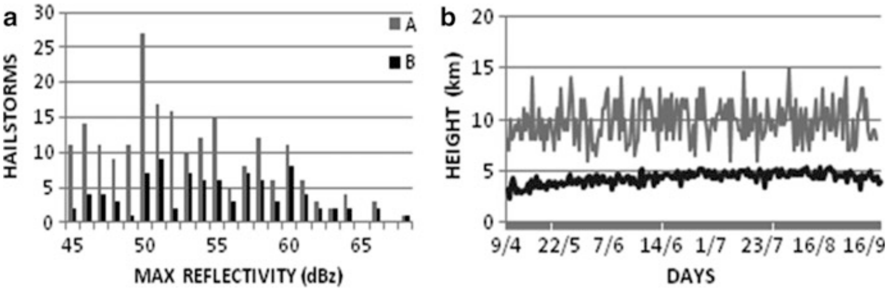

Fig. 3 Frequency of maximum reflectivity (**a**) and its height (*grey*) along with the −5°C isotherm (*black*) variation (**b**) through the period April–September for categories A and B (2006–2008)

the hail season, for the categories A and B. As referred to above, the height of the maximum reflectivity must exceed that of the −5°C isotherm; this is shown in Fig. 3b. The frequency of the maximum reflectivity maximizes at 50 dBz for category A and at 51 dBz for category B. Generally, high frequencies appear between 45 and 60 dBz. Beyond 60 dBz, the frequencies are very low or even zero, indicating the scarcity of very severe storms over the examined area (Foris et al. 2005).

2.2 Data Analysis from TITAN Archives

The software TITAN quantifies storm characteristics and determines storm motion, location and evolution (Pinto et al. 2007). The protected area includes few sub-areas with high altitude. The mountain range to the west side of the area contributes to the development of severe orographic hailstorms that affect the whole of area. These storms are expected to be significantly different from the ones developed over the plains. It has long been known that there is a general relationship between the area of a thunderstorm and its precipitation output (Ćurić and Janc 1992). Therefore, in this study, a sub-area (P2) over the plains has been chosen (Fig. 1), in order to achieve homogeneity in the characteristics of the hailstorms.

From the total 1,127 thunderstorm cells recorded by TITAN in the period 2006–2008, the 221 hailstorm cells developed over area P2 are studied. Figure 4a indicates that 33% of the hailstorm cells move from the WSW, with second preference that from north-north-west. According to Fig. 4b, which depicts the frequency of the hailstorm cells as a function of the mean speed of motion, the peak corresponds to the 11–19 km/h range, while only 22 hailstorm cells move with mean speed more than 38 km/h. The cloud heights, measured by radar, serve as a proxy for convective strength and precipitation, with reasonable success, as predicted by simple models (Sherwood et al. 2004). The highest percentage (39%) of the hailstorm cells is associated with maximum top at 6 km (Fig. 4d). For the examined period (2006–2008), the maximum top height rarely reached the height of 11 km, with only one category (on 1/9/2007) reaching 15 km and

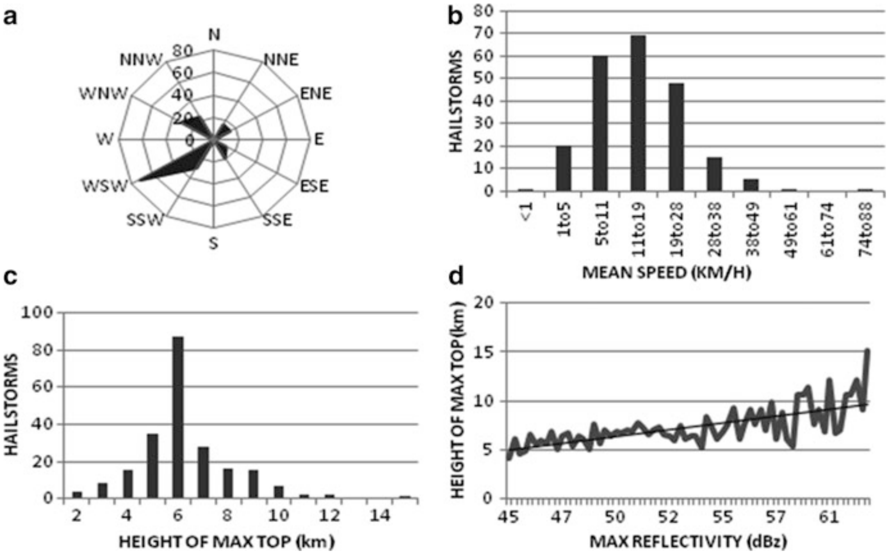

Fig. 4 Frequency of hailstorms mean direction (**a**), of mean speed (**b**), max top (**c**) and max top/reflectivity correlation (**d**) for 2006–2008

maximum reflectivity 71 dBz. The regression analysis between maximum reflectivity values and heights of maximum tops (Fig. 4d) exhibits a positive trend with R = 0.68. It is worth noting the increased deviations (above 52 dBz) towards the highest values.

2.3 *Hailstorm Differences Over Two Distinct Areas*

Two distinct areas (P3 and P4, see Fig. 1), with respect to their geomorphology, but of the same size, were chosen, in order to study and compare their respective hailstorm characteristics. Area P3 has a low altitude and is located close to the center of the protected area, where 20 hailstorm cells were recorded and studied. Also, the P4 mountainous area is located to the west side of the protected area, where 67 hailstorm cells were recorded and studied. Figure 5 depicts the frequency of occurrence of the hailstorm cells as a function of maximum reflectivity values (Fig. 5a) and the mean speed of their motion (Fig. 5b), for the plain (P3) and orographic (P4) hailstorm cells. As expected, the cells over the mountainous area exhibit broader spectra for maximum reflectivity values and mean speed motion. The frequencies appear to be higher for values between 45 and 60 dBz, with the peak occurring at 46 dBz, while the maximum reflectivity reaches 67.5 dBz. This variation exhibits quite a few similarities with the one corresponding to the whole protected area (Fig. 3a). On the contrary, the frequency of the hailstorm cells

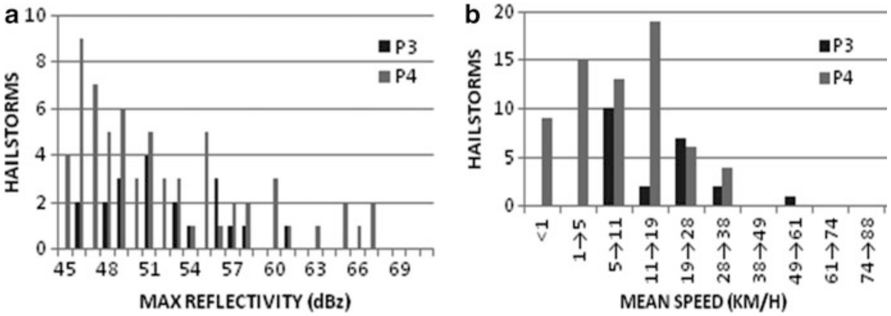

Fig. 5 Frequency of hailstorms as a function of maximum reflectivity (**a**) and their mean speed (**b**), for the plain (P3) and orographic (P4) hailstorm cells, for the examined period 2006–2008

over the plain area (P3) peaks at 51 dBz and between 5 and 11 km/h. The recorded maximum reflectivity and larger mean speed of cell motion were 61 dBz and 49.4 km/h.

3 Conclusions

Although the variation of hailstorm cells through the examined years (1998–2008) does not show important range for the categories A and B, the month with the highest activity is June. This is in good agreement with earlier studies (Sioutas et al. 2007), reporting 26% of hailstorms occurring in June and 25% in May. A study with more homogeneous areas, with respect to hailstorm cells development, life time and motion, would be very useful and quite indicative for hailstorm characteristics in these areas. It is concluded that the protected area is frequently affected by orographic hailstorms that are developed over its west side. These orographic hailstorms are more severe than the ones over the plain, and their speed does not exceed 36 km/h during the study period.

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