

CHARACTERISTICS OF HAIL PROCESSES AND HAIL FALLS IN MACEDONIA

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**Abstract.** Characteristics of hailstones and of the clouds from which they come in the Socialist Republic of Macedonia (Yugoslavia) are presented, based on radar and radiosonde observations during six years, 1977-1982.

Hail is a persistent summer problem in the Socialist Republic of Macedonia, southernmost of the eight components of the Federal Republic of Yugoslavia. Hail suppression programs, using two types of rockets each carrying 400 g of AgI, have been conducted since 1971, and since 1980 have covered the entire republic from April 15 to October 15. Some characteristics of the hailstones, and of the clouds from which they fall, are presented here, based on returns from the 3MD-7 radars which monitored the clouds during the 1977-1982 suppression efforts, and the daily radiosonde flights at Skopje, the capital.

The Macedonia Socialist Republic covers almost 25,000 km<sup>2</sup> (10,000 mi<sup>2</sup>), a fourth the size of Tennessee. Like the eastern quarter of Tennessee, it has a central south-flowing river, but the bordering mountains are much higher: up to 2700 m (9000 ft) in the northwest and southwest, near Albania, and to 2250 m (7400 ft) on the east, toward Bulgaria, and along the southern border with Greece. The Vardar River rises in the northwest and flows south-east into Greek Macedonia and to the Aegean Sea at Salonika (Fig. 1).

Each summer, Macedonia has about 50 hail days, varying from 30 to 74 in the six years studied. Most hail falls in May and 71.5% of all hail comes between 13 and 17 hours (Fig. 2), with an average duration of 5.2 minutes (Table 3). In 95.3% of the days, the largest stones had diameters of less than 20 mm (Table 1). Although the largest stone measured from 1977 through 1982 was 60 mm, larger ones have been reported in previous years.

Table 1. Variation of Cloud Characteristics with Diameter of Largest Hailstone

| Hailstone Dia.             |       | mm | 2    | 5    | 10   | 20   |
|----------------------------|-------|----|------|------|------|------|
| Occurrence Freq            | %     |    | 10.5 | 58.5 | 26.3 | 4.1  |
| Radar Reflec.              | mean  | db | 32   | 36   | 42   | 42   |
|                            | max.  | db | 50   | 55   | 70   | 55   |
| Diameter of Accum. Zone    | mean  | km | 5.0  | 6.1  | 6.2  | 7.4  |
|                            | max.  | km | 8.0  | 10.0 | 10.0 | 13.1 |
| Alt. of Max. Radar Reflec. | mean  | km | 5.5  | 6.0  | 7.0  | 7.8  |
|                            | max.  | km | 7.0  | 7.4  | 10.3 | 9.8  |
| Cloud Thickness            | total | km | 7.9  | 9.0  | 10.0 | 11.6 |
|                            | cold  | km | 6.8  | 7.5  | 8.4  | 9.9  |
| Hor. Cloud Speed           | km/hr |    | 26   | 29   | 32   | 43   |

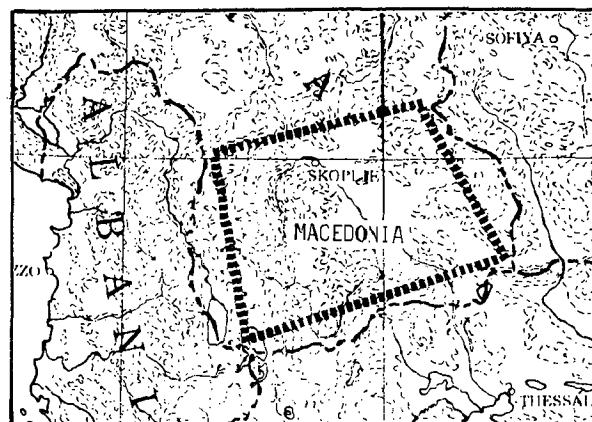


Fig. 1. Socialist Republic of Macedonia in Southern Yugoslavia

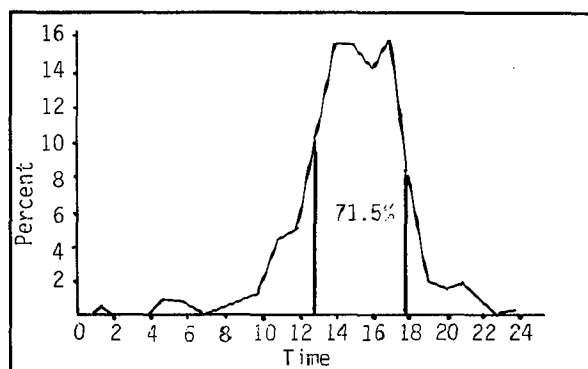


Fig. 2. Hail frequency by hours, 1959-1968

Table 2. Month-to-month variations in cloud characteristics (values in km)

|             | APR | MAY  | JUN  | JUL  | AUG  | SEP | OCT  | MAX  |
|-------------|-----|------|------|------|------|-----|------|------|
| Max ref     | 30  | 37   | 40   | 38   | 41   | 30  | (db) |      |
|             | 5.5 | 6.0  | 6.6  | 6.8  | 7.0  | 5.2 | -    |      |
| Acc zone d. | 5.1 | 5.8  | 6.2  | 6.6  | 5.6  | 4.0 | -    |      |
| T. cl thick | 7.0 | 8.9  | 9.9  | 8.8  | 9.7  | 7.4 | 9.4  | 14.0 |
| Warm " "    | 1.0 | 1.3  | 1.2  | 2.0  | 1.7  | 3.3 | 1.6  | 2.3  |
| cold " "    | 6.0 | 7.6  | 8.7  | 6.8  | 8.2  | 5.1 | 7.8  | 12.4 |
| Cl top alt  | 8.4 | 10.0 | 12.3 | 10.7 | 12.1 | 8.4 | 11.4 | 16.4 |
| CCL         | 1.4 | 1.6  | 1.9  | 2.1  | 2.4  | 1.0 | -    | -    |

Maximum radar reflectivity from a hailstorm was 38 dBZ; mean cloud height was 6.4 km (Table 1). Although hail was most frequent in May, maximum reflectivity (41 db) and mean altitude (7.0 km) were greatest in August (Table 2). In general, large clouds and those with greater reflectivities produce larger hailstones (Table 1). Both cloud height and diameter of hail accumulation zone increase (to 6.6 and 9.9 km, respectively) from April to June, then decrease (Table 2). Most of the variation in cloud thickness is above the freezing level, in the cold portion which produces the hail (Table 1). Similarly, larger hailstones come from faster moving clouds (Table 1).

Both mean aerological conditions over Skopje at 00 Z on all hail days, 1977-1982, and those on 22 AUG 1982 (Fig. 4) show large areas of instability, in the mean from 880 to 240 mb. The mean energy of instability is shown by the  $T'_{max}$  of 5 C, while the maximum possible is given by the dotted line labelled  $T'_{max}$ . On the August 22 sounding (Fig. 4b), cold air advection during the next 12 hours following a cold front passage, is shown by a dashed line. Mean height of the convective condensation level increases from 1.4 km in April to 2.4

km in August, then decreases to 1.0 km in September (Table 2).

Some dimensions of small, average, and large hail clouds are shown schematically in Fig. 5. The average Macedonian hail cloud has a convective condensation level of 1.8 km, with 1.6 km of warm cloud below the 4.6-km diameter accumulation zone and 7.9 km of cold cloud above it, maximum radar reflectivity of 38 db at 6.4 km, and a calculated maximum ascent rate of 18 m/s and horizontal motion of 31 km/hr.

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Table 3. Duration frequency of hail falls

|           |      |      |     |     |     |     |     |    |
|-----------|------|------|-----|-----|-----|-----|-----|----|
| Dur. min. | 0    | 5    | 10  | 15  | 20  | 25  | 30  | 35 |
| Freq. %   | 47.3 | 43.5 | 4.3 | 1.9 | 1.4 | 1.0 | 0.5 |    |

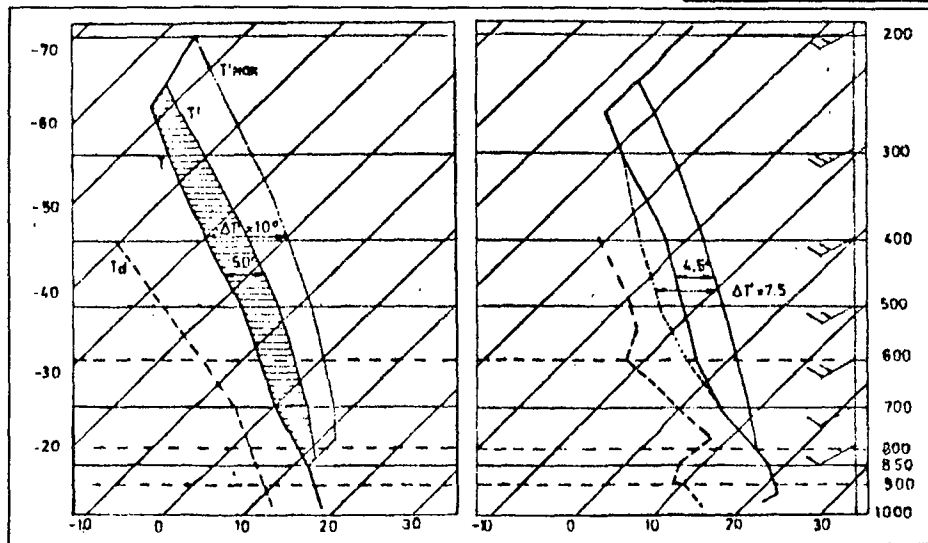


Fig. 4. Emagrams of 00 Z soundings at Skopje for (left) means of all hail days, 1977-1982, and (right) 22 August 1982, only.

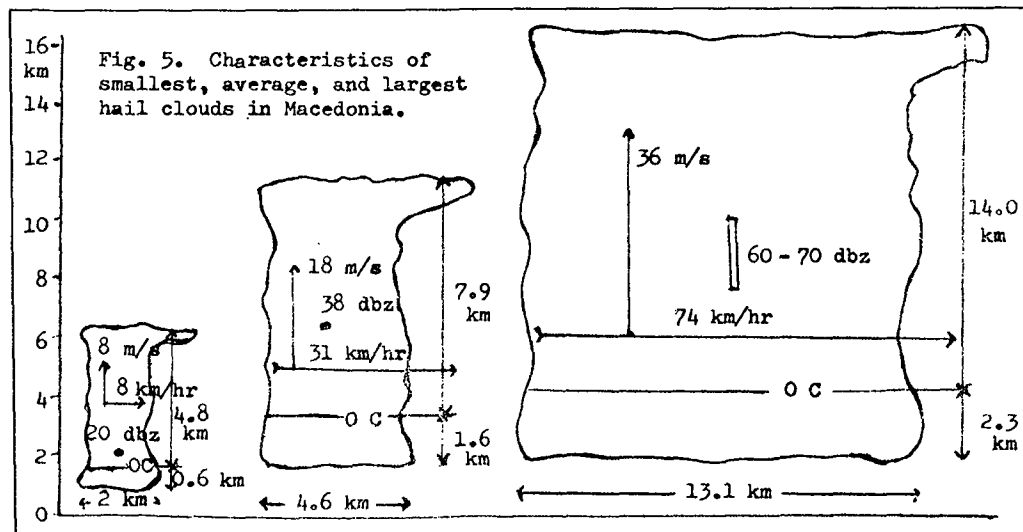


Fig. 5. Characteristics of smallest, average, and largest hail clouds in Macedonia.