SEEDING OPERATIONS IN THE GREEK NATIONAL HAIL SUPPRESSION PROGRAM

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Abstract. The Hellenic Agricultural Insurance Organization (EL.G.A.) is a public organization and the main insurance carrier of the agricultural production in Greece. The Meteorological Applications Centre (KE.M.E.) is the section of EL.G.A. which has conducted, since 1981, the Greek National Hail Suppression Program using airborne seeding, aimed at reducing insurance payments due to hail damage. The Program is being applied in Central Macedonia and Thessaly in the period April to September, covering an area of 5,000 square kilometers. The cloud seeding is performed by three aircraft releasing AgI in developing hail-bearing clouds as indicated by radar. The purpose of this study is the evaluation of the seeding operations that took place during the period April to August 2005. The seeding variables such as location, time and seeding rate are examined. In addition, the comparison of seeding rate between different types of storms is examined.

1. INTRODUCTION

The Greek National Hail Suppression Program (GNHSP) conducted by the Hellenic Agricultural Insurance Organization (EL.G.A.) in Central and North Greece is based upon airborne seeding. GNHSP is based on the conceptual model of beneficial competition (see for example English, 1986) using AgI as the seeding material. In the 1984-1988 operational and research period of the program a randomised crossover experiment took place for the protected area A1 (shown in Figure 1), giving encouraging results (Karacostas, 1984).

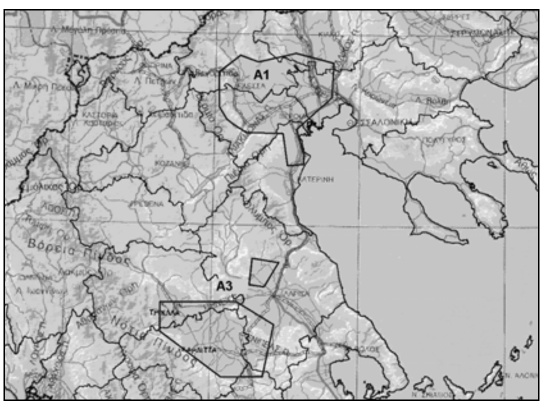

Figure 1. Map of Northern Greece showing the location of the two protected areas designated A1 and A3.

Nowadays and for the period 2004-2008, EL.G.A. designed the GNHSP to run for two areas with a special insurance interest (designated A1 and A3). GNHSP operates during the warm season of the year (April 1^{st} to September 30^{th}), according to climatological studies indicating this period as a hail risk period for the particular areas (Kotinis-Zambakas, 1989; Sioutas, 2003).

This study examines seeding parameters of the operational period April 2005 to August 2005 to support the research and development plans of the Meteorological Applications Centre (KE.M.E) regarding optimization of operations and preparation for future weather modification projects.

In general, there are three key parameters to be examined when assessing a seeding project. These are: seeding location, time of seeding, and seeding rate. This study analyzes the time and the seeding rate. Also the geographical location is analyzed but not relative to the storm.

2. OVERVIEW OF THE GNHSP

A brief description of the program routines is presented at this point for the understanding of the following study. The seeding operations are based upon the specialized forecast of hailstorm occurrence and the detection, tracking and recording of storms by two S-band meteorological radars (one for each area), 24 hours per day.

The equipment of the GNHSP consists of two EEC S-band meteorological radars, TITAN (**T**hunderstorm **I**dentification **T**racking **A**nalysis and **N**owcasting) radar recording, analysis, and display software as described by Dixon and Wiener (1993); forecasting means, a network of 138 hailpads installed in the project area A1 as described by (Rudolph et al., [1989]); and three prop-jet seeding aircraft of EL.G.A.'s contractor.

At GNHSP weather forecasting takes place twice a day, using nowcasting models, satellite images and other tools, for producing a daily hail risk index. This index besides radar observations determines the readiness status of the aircrew to be set at either 15 or 45 minutes. The radar controllers survey the weather on a 24-hour basis monitoring the TITAN displays by the two-radar network. When the first echo of the day appears the controllers make the following decisions:

- change the crew readiness status to 15 minutes
- launch a seeding aircraft
- identify the preferred seeding place and the seeding techniques (top or base)
- request the start of seeding
- request a seeding rate depending on thunderstorm intensity (general rule: one top flare every 5 sec, one base flare every 4 minutes).
- request the stoppage of seeding
- request the aircraft return to base
- change the crew readiness status to 45 minutes

It is mentioned that there is not a prioritization between the areas or inside each area.

These decisions affect the quantity and quality of the seeding. The parameters chosen for assessment are: Start Seeding Response Time, Seeding Time Duration, Useful Seeding Time, Extra Seeding Time, Mean Top Seeding Rate and Seeding Material Mass Consumption.

3. DATA

The data used for this study are the radar data and seeding data of the operational period April 1st – August 31st, 2005. For the radar data the entities that have been selected to be examined are Storm Cell Complexes (SCC) defining as *the radar echoes, convective in nature, with cell reflectivity equal or greater than 35 dBZ at the -5° C level or higher (Tsagalidis, 2006).* SCC were subjectively defined by the same analyst, utilizing the radar data recorded by the TITAN system.

The seeding data is the number of the ejectable and base flares that were used per SCC and the corresponding seeding time, provided from GPS by the RDTS (Radar Data Telemetry System) data of the aircraft. Top flares and base flares consist of 20 g and 70 g of pyrotechnical mass, respectively (shown in Figure 2).

The first parameter examined was the number of SCC that were seeded, in the examined period. For the seeded SCC only, the following six seeding parameters were measured:

1) Start Seeding Response Time is the actual response of the crew for start seeding comparing with the theoretical ideal start seeding time, valued as zero-point.
2) Seeding Time Duration is the actual seeding duration time.
3) Useful Seeding Time is the actual seeding time included in the theoretical seeding time.
4) Extra Seeding Time is the actual seeding time that exceeded the theoretical seeding time.
5) Mean Top Seeding Rate is the mean number of seeding top flares ejected every 5 sec, per SCC.
6) Seeding Material Consumption is the amount of pyrotechnic material used per SCC.

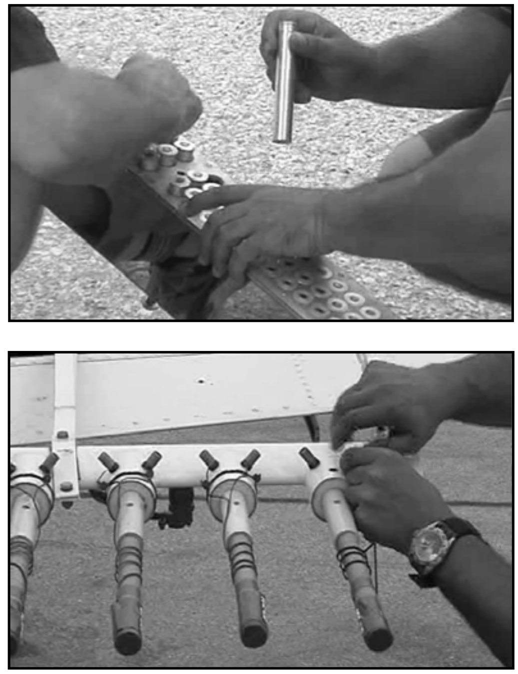

Figure 2. Top flares (top) and base flares (bottom) manufactured by Ice Crystal Engineering.

The theoretical start and stop times of seeding are defined by the radar "seeding criteria" as reflectivity greater than or equal to 35 dBZ in convective cells located either inside, or within 20 minutes of entering the project area, at altitudes corresponding to temperatures between -5 and -35 °C (Karacostas, 1984). In this particular study, for each SCC, the theoretical and the actual values have been set and measured, according to the meeting of "criteria", by the same well-experienced meteorologist, assuming, that any subjective error in measuring would be of a constant value.

The above parameters have been examined separately for each one of the two protected areas and also in the aggregate, for each type of storm according to hailstorm classification in single cell (S), supercell (SU), multicell storms (M) and line storms (L) (Browning, 1977). In the sequence, the SCC categories are the Unicellular type that may consist of a Single isolated ordinary cell or a Supercell, the Multicell with a cluster of cells, not forming in a distinct line and the Line, containing cells along a line.

Cell types were defined in a subjective manner by the same analyst and the storm type characteristics that were used are analyzed in an extended way to Tsagalidis et al. (2006).

4. ANALYSIS

In the hail suppression season 2005, from April 1st to August 31st, 249 SCC were detected in the two Project Areas. 101 SCC were identified as single cells (S), 145 as multi (M), 2 as supercells (SU) and one as line (L). 10 SCC of them are not further examined since GNHSP was not operational that day.

Of the remaining 239 SCC (94.2%), 225 SCC (90.4%) were seeded (110 SCC in the protected area A1 and 115 SCC in A3), while only 14 SCC were not seeded. Seeding was not conducted on these 14 SCC because of delays (5 SCC), seeding another cell (4 SCC), no aircraft availability (5 SCC). The analysis that follows is only for the 225 SCC that were seeded.

4.1 Start Seeding Response Time

The Start Seeding Response Time is shown for both areas and also separately in the time distribution charts in Figures 3, 4 and 5. Also, the accumulative frequency of occurrence is shown.

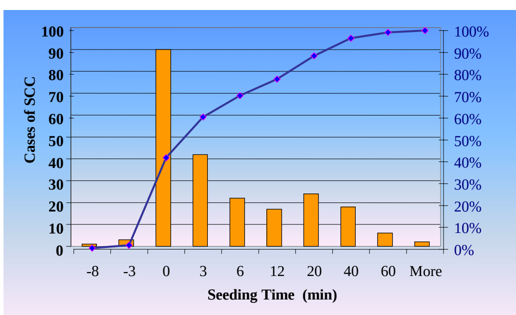

Fig. 3. Frequency of occurrence plot of Start Seeding Response Time for both areas A1, A3.

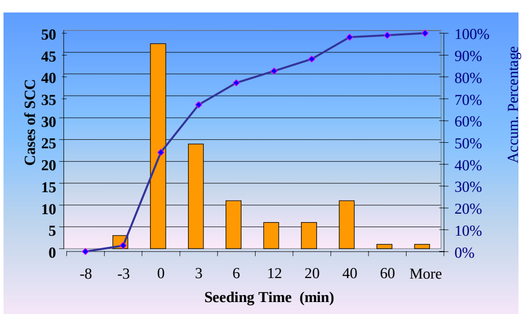

Fig. 4. Frequency of occurrence plot, of Start Seeding Response Time for area A1.

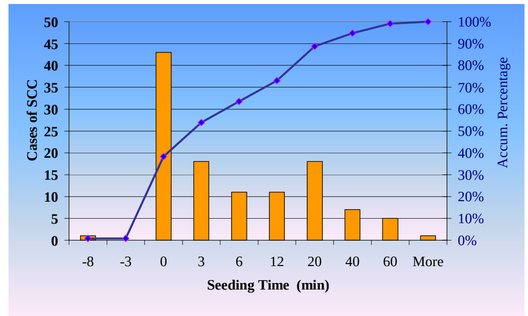

Fig. 5. Frequency of occurrence plot of Start Seeding Response Time for area A3.

From Figures 3, 4, and 5, an almost similar distribution of the Start Seeding Response Time is observed, with 158 SCC (70%) of the seeded storms, (77% A1, 64% A3) seeded within the first six minutes. It should be noted that the radar volume scan takes three to five minutes to be completed and the network for the data transmitting needs some time, therefore, six minutes represents a very good Start Seeding Response Time. It should also be noted that area A1 is closer to the aircraft base than area A3.

Another factor investigated was the Start Seeding Response Time for the first SCC of the day. In a total of 47 first SCC, 72% were seeded also in the first six minutes, and only in 10 SCC was the Start Seeding Response Time observed to be greater than 20 min.

4.2 Seeding Time Duration

The Seeding Time Duration for each protected area (A1, A3) and storm type (SU, L, M, S) is shown in Figures 6 and 7.

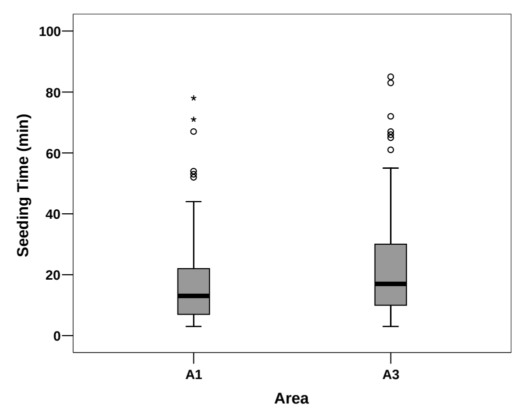

Fig. 6. Box plots of Seeding Time Duration, for protected area A1 and A3.

There is a difference in seeding time duration between areas A1 and A3. In A1 the mean seeding time was 18.0 min while in A3 it was 23.6 min.

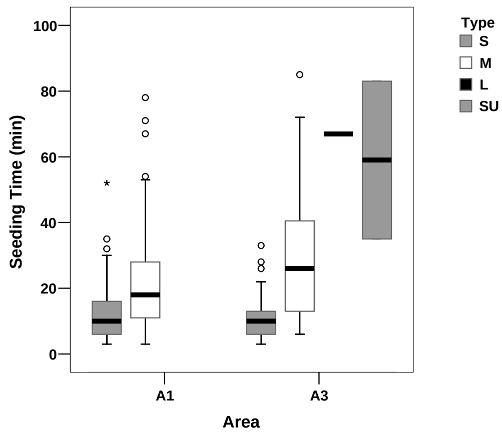

Fig. 7. Box plots of Seeding Time Duration for area A1 and A2 according to storm type.

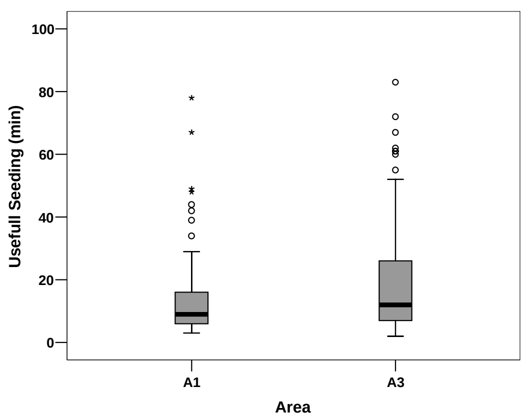

Fig. 8. Box plots of Useful Seeding Time for each area.

In the protected area of Macedonia, A1, the mean Useful Seeding Time was 13.6 minutes, while in the protected area of Thessaly, A3, it was 19.7 minutes. Another study of the same dataset (Tsagalidis, 2006) indicated that the mean lifetime of a SCC in A3 is 69.1 minutes while in A1 it is 55.1, and the storm motion in A1 is faster than in A3. These two factors can explain the observed difference in Figure 8. Also, Figure 9 indicates that it is due to the multicell type of storms.

In the same manner, the distribution of Extra Seeding Time for the 207 SCC with positive Useful Seeding Time is shown in Figure 10. In the aggregate, for all storm types, the mean value of the Extra Seeding Time for A1 is 4.4 min and for A3 is 3.9 min. This value is small and indicates there is little waste in the use of AgI. In 47% of the 207 effectively seeded SCC there was zero Extra Seeding Time.

This difference is due to the different seeding time spent to seed the multi storms for each area.

4.3 <u>Useful and Extra Seeding Time</u>

Further analysis of the seeding time duration leads to the identification of the Useful Seeding Time. From the 225 seeded SCC, 207 SCC were treated efficiently (positive value of Useful Seeding Time) and in 18 SCC the useful time was negative or zero (i.e.; the seeding was late). Half of this loss was due to delays and half due to seeding of other SCC in the same project area at the same time. The distributions of the Useful Seeding Time according to Area and Storm Type for the 207 SCC are shown in Figures 8 and 9.

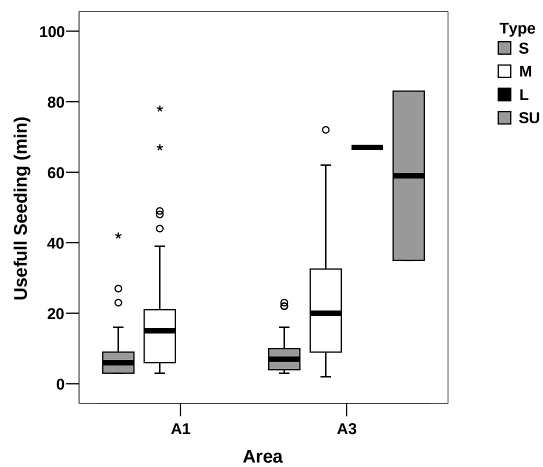

Fig. 9. Box plots of Useful Seeding Time for each area and according to storm type.

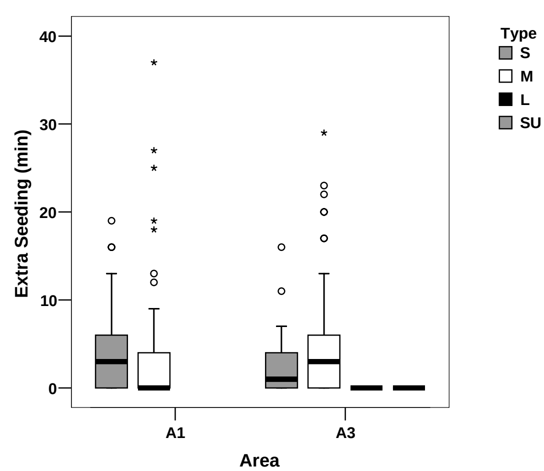

Fig. 10. Box plots of Extra Seeding Time for each area according to storm type.

Further analysis indicated that the Extra Seeding Time occurred mostly in the mature stage of SCC, and particularly to the storms that had high values of reflectivity and height. This likely produces psychological pressure to the controllers to prolong the seeding.

4.4 Seeding Mass and Rate

The distributions of Seeding Material Mass Consumption and the Mean Top Seeding Rate are shown in Figures 11 to 14.

It should be noted that only the Mean Top Seeding Rate was examined (and not the Base one) since 99% of the Seeding Material Mass Consumption was used in top seeding by top flares of 20 g.

The main reason for this is that visibility was poor in the majority of the cases due to embedded and not isolated cells, or due to nighttime flights. Also, because "*cloud base altitudes are near mountain top height which can be an important safety consideration in the relatively small project areas in Greece*" (Sioutas, 1998).

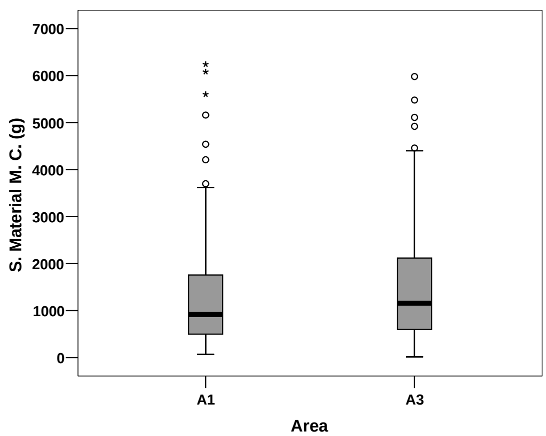

Fig. 11. Box plots of Seeding Material Mass Consumption for each protected area.

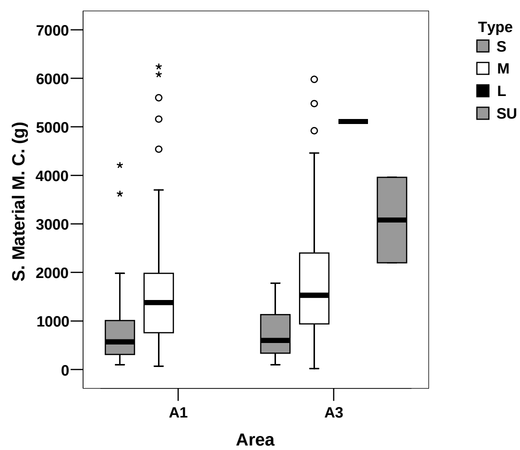

Fig. 12. Box plots of Seeding Material Mass Consumption for each area and per storm type.

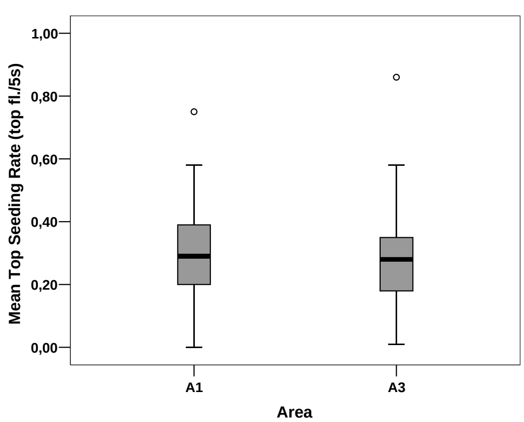

Fig. 13. Box plots of Mean Top Seeding Rate for each protected area.

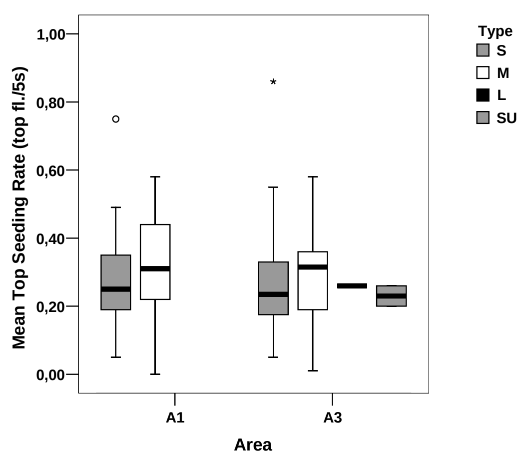

Fig. 14. Box plots of Mean Top Seeding Rate for each area and per storm type.

From Figures 11 and 14, storm type discrimination is evident. For this reason, the Confidence Interval of the means with a 0.05 significance level was calculated for the Seeding Material Mass Consumption and the Mean Top Seeding Rate per storm type, for the two areas combined. A statistical summary is given in Table 1.

TABLE 1: Lower (5%) and Upper (95%) Confidence Interval and Standard Error of the means for Seeding Material Mass Consumption and Mean Top Seeding Rate according to storm type.

Seeding Material Mass Consumption (g)						Mean Top Seeding Rate (top fl. / 5s)					
Type	**N**	**Mean**	**S.E.**	**Lower**	**Upper**	**Type**	**N**	**Mean**	**S.E.**	**Lower**	**Upper**
S	82	850.5	87.681	678.6	1022.3	S	82	0.27	0.015	0.24	0.30
M	115	1836.1	133.521	1574.4	2097.8	M	115	0.30	0.013	0.28	0.33

The difference of the means for the Seeding Material Mass Consumption per storm type (S, M,) is statistically significant with 0.05 significance level as it is shown from Table 1. The multicell storms received on average significantly more Seeding Material Mass Consumption than the single cell storms. The difference of the means for the Mean Top Seeding Rate per storm type was not statistically significant.

5. SUMMARY

The mean values of the six analyzed parameters are presented in Table 2 for each of the two protected areas and in the aggregates, for the 207 SCC that were seeded effectively (positive Useful Seeding Time).

TABLE 2: Mean values for the 207 SCC with positive Useful Seeding Time.

Protected areas	Start Seeding Response Time (min)	Seeding Time (min)	Useful Seeding Time (min)	Extra Seeding Time (min)	Seeding Material Mass Consumption (g)	Mean Top Seeding Rate (top fl./5s)
Total	5.9	20.8	16.7	4.1	1444.4	0.29
A1	4.4	18.0	13.6	4.4	1333.9	0.30
A3	7.3	23.6	19.7	3.9	1550.6	0.28

From Table 2 some logistical inferences can be made. The mean Start Seeding Response Time in the protected area A3 is greater than the one in A1 by 2.9 min. Taking into account that A3 is approximately 20 min flight distance from the airport of Thessaloniki, when A1 is only 10 min, this 2.9 difference in the Start Seeding Response Time shows a very good time estimation by the controllers of the GNHSP.

The mean Seeding Time in A3 is 5.6 min greater than A1's. The effective seeding time can be estimated by the ratio of the mean Useful Seeding Time to the mean Seeding Time, calculated to 80.3% for both areas (75% for A1 and 84% for A3). Also, the seeding time coverage can be estimated by the ratio of the mean Useful Seeding Time to the mean Ideal Seeding Duration, calculated to 70% for both areas (69% for A1 and 70.5% for A3). The Extra Seeding Time proved to be less in A3. Seeding Material Mass Consumption per SCC is higher in A3, but the Mean Top Seeding Rate is less.

6. CONCLUSIONS

This study was based on the data of the hail suppression season 2005, which proved to be the most active season in the history of the Greek National Hail Suppression Program. The results of the study are intended to contribute to future operations and planning purposes.

During the period April 1st - August 31st of 2005, 239 SCC appeared in the two Project Areas A1 and A3 of the Greek National Hail Suppression Program. Of them 225 SCC (94.2%) were seeded.

In 157 SCC (70%), seeding started within 6 minutes after the seeding criteria was met. The mean Start Seeding Response Time was 5.9 minutes and this value is considered as a reasonable threshold. The same result was found for the 1st SCC of the day.

In 207 SCC, corresponding to 86.7% of the detected SCC and to 92% of the seeded SCC, the Useful Seeding Time was positive. Additionally, the effective seeding time, estimated by the ratio of the mean Useful Seeding Time to the mean Seeding Time, was 80.3%.

The Mean Extra Seeding Time was only 4.1 min, while almost in half of the effectively seeded storms there was no Extra Seeding Time. Therefore, Seeding Material Mass Consumption was not wasted and the majority of storms were seeded according to the designed criteria.

Finally, the Mean Seeding Material Mass Consumption per SCC was 1444.4 g and with 0.3 top flares ejected every 5 seconds (Mean Top Seeding Rate). Seeding Material Mass Consumption was significantly greater for multi-cell storms but the Mean Top Seeding Rate was not significantly different.

The values of the examined parameters are not the same for the two project areas. Possible reasons could be finally attached to the geographical location of each area which affects both climatological storm characteristics and aircraft proceeding time.

In general, TITAN and RDTS (seeding data acquisition system) have been used since 1997 and this study is the first effort to the direction of parallel analysis of this dataset. Future plans indicate to continue the same way of analysis, in order to have more representative results for GNHSP performance.

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