EXPERIMENT OF SUPERCOOLED FOG DISPERSAL AT SARAJEVO AIRPORT AND SKIING SLOPES OF THE 14TH WINTER OLYMPIC GAMES

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Abstract. During December 12, 1983 through March 1, 1984 of the 14th Winter Olympic Games at Sarajevo, supercooled fog dispersal experiments were carried out at the airport and over the skiing slopes using simple, new ground-based liquid propane seeding devices. After successful preliminary tests in December and the first half of January, a fog dispersal operation was conducted operationally at the Sarajevo airport. A seeding network of a combination of stationary and mobile liquid propane dispensers was used. Eleven seedings were performed, nine of them being successful (visibility above the required minimum) and two partially successful. Especially significant were the seeding operations at the airport on February 6 and 7, 1984 (the day before the opening of the Olympic Games) enabling the landing and taking off of 30 airplanes, permitting the scheduled opening of the games.

Following preliminary confirmation of seeding effect on clouds over the skiing slopes on Mt. Bjelasnica, the visibility reducing clouds were effectively cleared during the official downhill competition on February 16, 1984.

1. INTRODUCTION

It is well known that seeding of a supercooled fog to improve the visibility is within the realm of present weather modification techniques. The seeding technique of clearing supercooled fogs may be classified into two general categories: ground seeding and airborne seeding. The airborne seeding technique has some advantages, such as rapid deployment and flexibility in terms of time and space, as well as some disadvantages due to operational cost and danger considerations, for example, the fog must be supercooled throughout the entire volume so that return of seeding airplane is secured. The ground-based seeding system may be more advantageous, particularly if the surrounding terrain of the field is convenient for the positioning and servicing of the seeding generators. There is also another advantage to the latter method, i.e., owing to the mode of operation, it may be applied to a fog which has a warmer upper layer even if the temperature is above the seeding agent temperature threshold.

During the 14th Winter Olympic Games, February 1984, clearing experiments were successfully conducted with supercooled fogs at the Sarajevo airport and at downhill competition courses applying a ground seeding method that employed a new but simple combination of stationary and mobile liquid propane dispensers. This article describes the equipment, the plan and results of the experiments.

2. PLANNING

In the planning of the fog dissipation experiment at Sarajevo, a climatological monograph prepared by the Federal Hydrometeorological Institute of Yugoslavia in Belgrade (1983) was used to examine the geography, the arrangement and the meteorological data of the airport. The airport is situated 8 km south-west of Sarajevo city, surrounded by high mountains except to the north-west where it is open towards the Bosna River valley. There are three rivers (Lukavica, Miljaka and Bosna) in the vicinity. This type of geographical relief separates the area around the airport from the influence of the Adriatic Sea and causes a continental-type climate. The geographical location of Sarajevo airport is shown in Fig. 1.

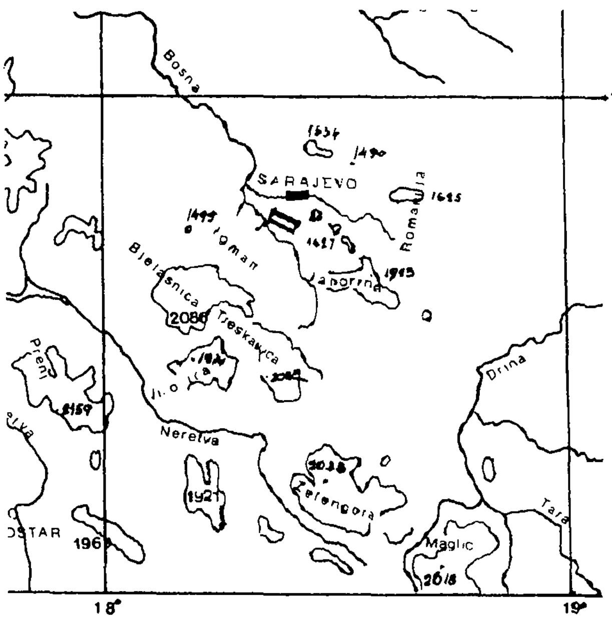

Fig. 1. Geographical location of Sarajevo airport.

The closeness and steepness of high mountains strongly influence the climate at the vicinity of the airport which is situated nearly in the center of Sarajevo valley. A valley of this type is very often (particularly during winter months) filled with cold air which has slid down from the slopes of the surrounding mountains. These so-called "cold air lakes" often occupy the valley for a couple of days. Since all Yugoslavian territory, including the Sarajevo valley, is frequently dominated by anticyclonic weather, the frequency of fog occurrence at the airport is quite high especially from November until the beginning of March. The frequency of fog occurrence is highest during December, especially in the early morning (04:00 - 06:00 h). In addition, the Zeljeznica, Miljacka and Bosna rivers evaporate moisture and enhance fog formation and duration. At the airport (runway orientation is southeast-northwest), the winds are characteristically NW-SE to NNW-SSE. These wind directions are normally caused by the surrounding topography. In other words, the high mountains, the cold air and the channel determine the wind direction. The most frequent wind directions (NW and SE) do not interfere with airplane landing and take-off but prolong the fog in the valley because they cause air stagnation and cooling. Thus, data for a 10 year period (1972-1981) taken from the Monograph indicated a very high probability of fog occurrence at the Sarajevo airport during the winter season. Fogs are usually radiative and cold. Temperature analyses have confirmed that these fogs were indeed mostly supercooled.

Considering the analysis of existing data for planning as mentioned above and the existing fog dissipation methods, we decided to use a ground-based system with liquid propane (LP) as the seeding agent. The airport surroundings guaranteed relatively easy positioning and servicing of the LP dispensers. LP was chosen because of its advantage with respect to silver iodide (AgI) and dry ice; its temperature threshold ($\approx -1°C$), low price and self-powered discharging.

3. LIQUID PROPANE DISPENSERS

In addition to the ordinary stationary LP dispenser network, use of mobile dispensers was attempted. The design of the dispensers considered possible meteorological and orographic influences on the generated ice crystal plume with a wind speed between 0.3 and 3 m/s. The LP discharging nozzle was placed at 5 m above the ground. LP flow rates could be varied by changing the diameter of the spraying nozzles (0.5, 1.0, 1.5 and 2.0 mm). For each dispenser, one set of these nozzles was provided. Figs. 2, 3, and 4 illustrate the dispenser set up.

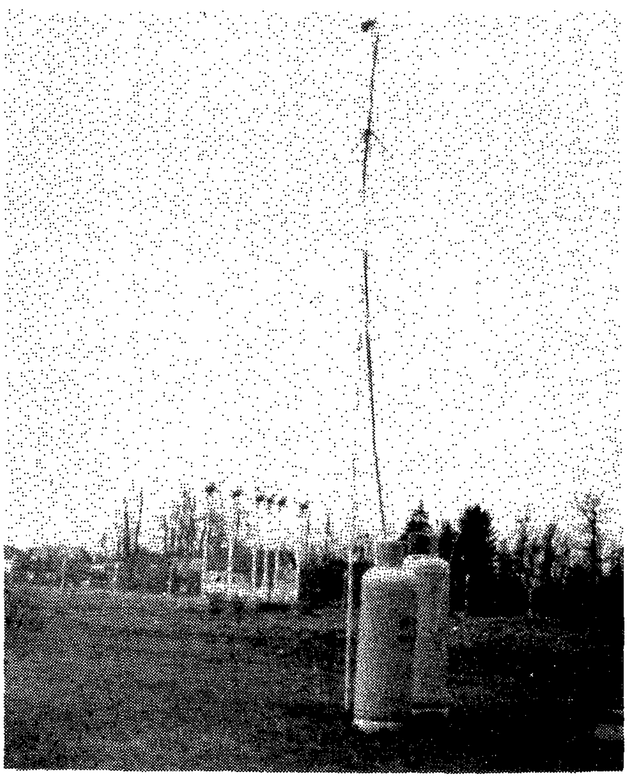

Fig. 2. The stationary liquid propane dispenser.

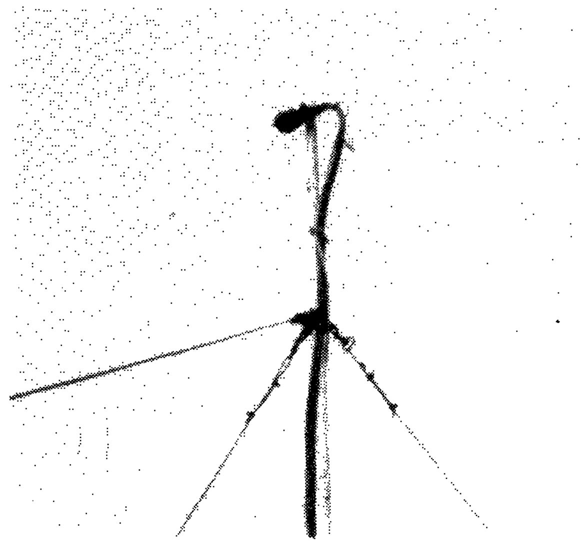

Fig. 3. Upper part of the dispenser.

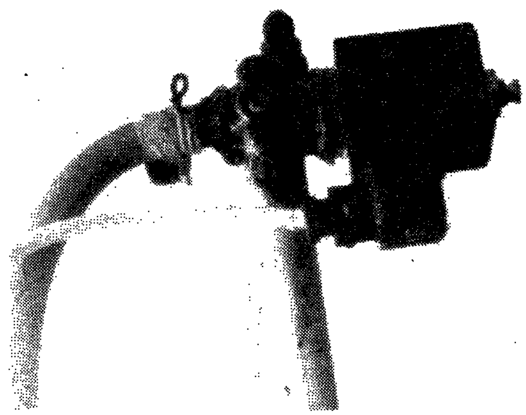

Fig. 4. The solenoid valve with liquid propane discharging nozzle.

The dispensers were constructed so that the propane would flow in a liquid state. In order to avoid the appearance of a gaseous state before the LP arrived at the nozzle and during the on-off operations, solenoid valves were applied. Two types of solenoid valves were used; one for 220 VAC and the other for 12 VDC. The nozzle with the valve was placed on the top of a 5 m tower which was guyed by a steel cord at three points. The tower had two parts for transportation and actuation of the solenoid valves. LP was stored in 35-40 kg tanks with siphon tubes placed for LP discharging instead of gaseous propane. The tank was connected to the solenoid valve and the nozzle by a high pressure flexible hose. At the hose connection on the tank, a pressure gauge and a turn-off valve were placed.

A stationary network consisting of 10 dispensers was placed in the vicinity of the airport runway (Fig. 5). This network was designed to obtain an optimal effect considering ice crystal diffusion in the horizontal direction under the prevailing wind. We also anticipated that existing eddy diffusion field aided by the released latent head during the fog glaciation, would carry out the necessary vertical dispersion. The results of experiments later confirmed this.

Along with the stationary unit network, two mobile units were used during the operations. One, located on a special terrain truck, seeded the area around the airport. The other was used for seeding inside the airport area including the runway. The second mobile unit was carried on an airport luggage trailer. Fig. 5 shows the route the seeding truck took around the airport territory.

4. METEOROLOGICAL DATA

4.1 Measurement of Temperature and Humidity

During the entire experiment, the temperature and humidity were measured at three points. Fig. 5 shows the position of meteorological shelters (MZ-1 and MZ-2) where the temperature was measured by a bimetallic thermometer, and the humidity by a Lambreth hygrometer. The third was a meteorological station at the airport (MS on Fig. 5), which was closest to the airport tower.

4.2 Measurement of Wind

Two instruments were used for wind measurement. Fus's anemometer was used at the meteorological station, located at A (between dispensers 6 and 4 in Fig. 5). The height of this anemometer

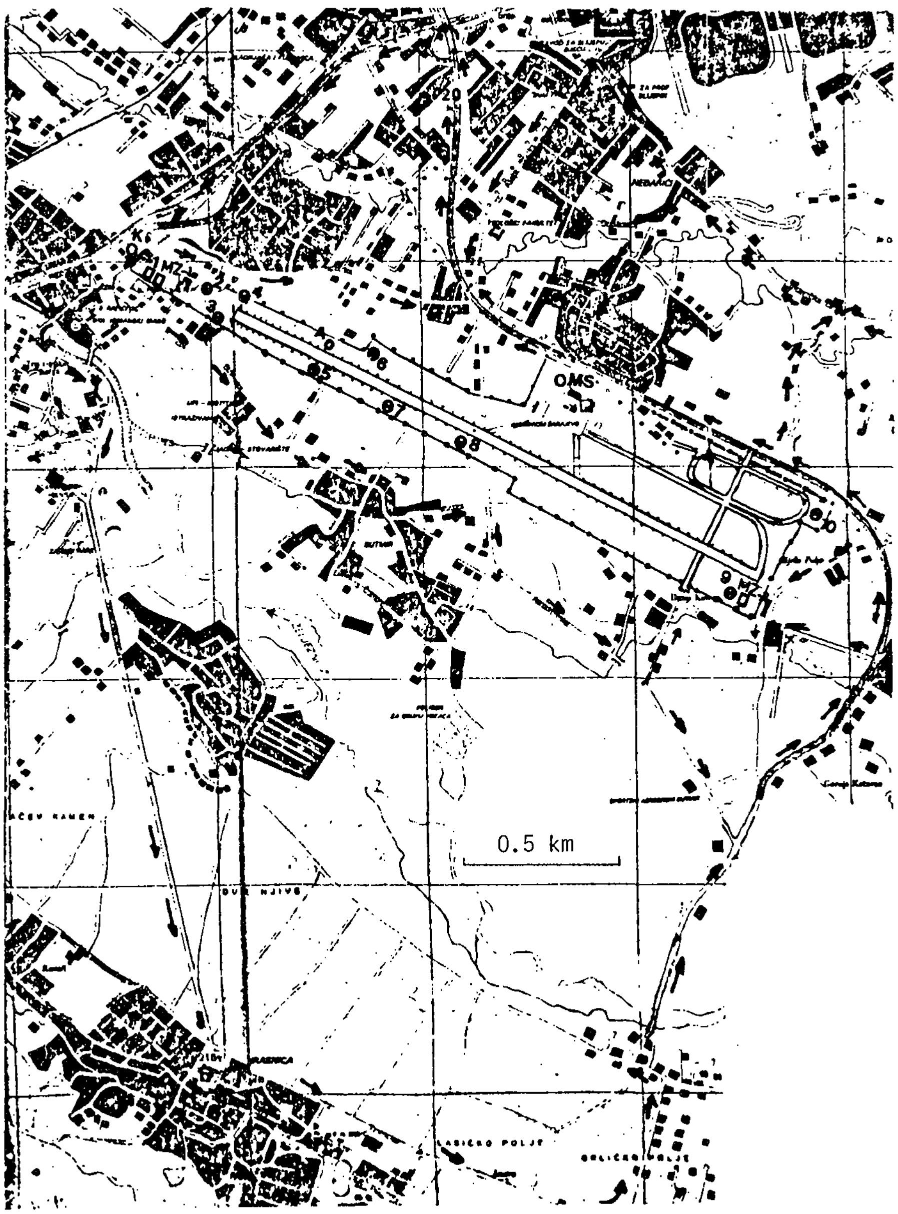

Fig. 5. Airport runway and liquid propane dispenser network. ⊠: stationary dispensers, □MZ 1-2: meteorological shelters, →: route of mobile unit, MS: airport meteorological station, K: TV camera.

was 10 m. The other instrument used was Lambreth's anemometer. The sensors were located at dispensers 6 and 1, and they were placed at 2 m above the ground.

During the operation, a sensitivity difference was noticed for the instruments measuring the speed and direction of the wind. The differences were particularly noticeable when the speeds were small, i.e., less than 1 m/s. The Lambreth anemometer for the crossed distance recorded small wind speeds, whereas Fus's anemometer did not. These differences under the operation became apparent because the average speed was often as small as 0.5 m/s which was not recorded by Fus's anemometer. Differences in wind direction were also found and sometimes caused difficulties in making decisions regarding seeding strategy. These differences in the windspeed are believed to be at least partially due to the instrument height difference.

4.3 Measurement of Visibility

The visibility was determined by a TV camera which was located at the K position (see Fig. 5) and placed in the control tower, where the meteorological observer worked. The camera showed the visibility at the landing approach of the runway (NW part of the runway).

5. TEAM STRUCTURE AND OPERATION

The operational team consisted of four members: director for overall operations, an engineer responsible for the operation and technical function of the dispensers, a meteorologist responsible for meteorological data acquisition and a driver-mechanic. The overall design of the operation and the structure of the team were achieved by cooperation between the Hydrometeorological Institute of Serbia, Yugoslavia and the University of Utah, U.S.A.

The preliminary tests of fog seeding in December were carried out during the night because the expected seeding effect could be more accurately determined as well as testing the rationale for the placement of the stationary dispensers. The experiment used a period during which aircraft were not expected to land or take off. The conditions of the tests were as follows: a temperature below 0°C and a horizontal visibility below 800 m. Since the December preliminary tests of supercooled fog dissipation were very encouraging, the Olympic Committee requested an operation beginning January 1, 1984. It was originally requested that the fog be cleared during the regular scheduled times for take off and landing of airplanes, but the operation was later enlarged in scope to accommodate a large number of unscheduled flights, as well as for dissipation of supercooled clouds at the ski slopes. It should be mentioned that these additional operation caused considerable strain on and challenge to this small team.

The team was in 24 hour contact with the meteorological service of the Federal Hydrometeorological Bureau at the airport and regularly received forecast information, as well as the observation records. Official data for the visibility measurements taken at the runway were also conveyed to the team. During the planned operation, the meteorological service provided to the team data concerning visibility, temperature, wind and other meteorological parameters.

All members of the team maintained radio communication, so that when the operation director was on the runway during the seeding, he could be in direct contact with the other members of the team, who were either at the mobile or stationary dispensers. This communication was also important for receiving the visibility information from the tower, and in determining the effect of seeding as well as planning the place for next seeding with the mobile unit. The director, depending on the development of the situation, guided other members of the team regarding the directions and distances of the mobile dispenser movement. In addition, in response to various situations, he made the decision as to whether or not the stationary dispensers and reading anemometers and other instruments should be included. The cooperation between the team and the control tower was clearly beneficial for both sides.

The operations for clearing meancing clouds over the ski slopes, another new attempt, required placing the network of stationary dispensers near the courses for the men's downhill race and slalom (Bjelasnica), and for the women's slalom (Jahorina). The mobile dispensers could not be used because of the very steep slope and thick snow cover. Only snowmobiles could move through this snow. The stationary network was placed on the courses the day before the competition, after careful analysis of the weather conditions and a forecast for the area. A snowmobile provided by the Olympic Committee carried the equipment for placing the devices for fog dissipation. During the operation at the ski slopes, in addition to the radio communication between the members of the team, separate connections were maintained with the Central Headquarters of weather forecasting for the Olympic games and with the Meteorological Observation Headquarters at the corresponding courses (there were headquarters at all paths). Cooperation with the aforementioned headquarters was of importance for preparing seeding plans, as well as for the analyses of the effects.

6. RESULTS OF THE EXPERIMENT

6.1 Wind Effect

As mentioned above, the operational plan at the airport and that at the ski slopes were based on the anticipated direction and speed of the winds. During the seeding operation, the two wind parameters, i.e., direction and speed, were constantly monitored. *Depending on this information, the* seeding was done either continually or intermittently. The mobile dispensers were often used.

The results of the seeding operation clearly showed that the wind effect was of particular importance for success. The first operation showed that the place for the best fog dissipation was entirely dependent on the wind direction and speed. There was no problem with fog dissipation, even when the temperature was as high as -1°C, if the direction of the wind was suitable with respect to the placement of the network of dispensers. There were cases where the cleared zone was larger than the target area. There were times at the airport when the clearing effect was present but not to a sufficient degree. Since the airport is about 3 km long and taking the runway approach into consideration (which also needed to be cleared), there were moments when the visibility was better at one part of the airport than at another, due to varying winds. The team helped make the effect uniform by using the mobile unit. In addition, the observation at the runway as well as that from the meteorological service and the control tower at the airport, helped to smooth out the operation. The wind speed was normally between 0.5 and 1 m/s, with occasional weak gusts of 2-3 m/s. This relatively calm condition was highly advantageous for achieving effective fog dissipation. Because of this condition, the starting time of seeding could be determined to obtain the necessary visibility in time for flights. It was found that starting the seeding about an hour before the planned landing or take off was quite satisfactory.

Comparison between the stretching speed of the cleared area and that of the wind on the ground, based on two anemometers (h = 2 m) regularly showed agreement.

6.2 Effect of Temperature

In the original plan for the experiment, microsonde measurements were scheduled so as to obtain the vertical temperature distribution in fog layers. It was hoped that with this data, the effect of LP seeding in the zone warmer than -1°C (in the upper layer of fog) could be examined, particularly in radiation fog with a characteristic temperature inversion. However, due to the fact that the present experiment was begun on January 1, 1984, to assist the Olympic Games, this study was put aside.

6.3 Liquid Propane Consumption

The average liquid propane consumption for the entire experiment was about 40 kg per seeding hour (about 10 g/s). A larger discharging rate was used during the earlier seeding operations but was lowered near the end.

6.4 Snowfall

The seeding operations produced snowfall. Significant snowfall was noted in the area from 0.5 to 4 km downwind of the dispensers. The shape of the area with snowfall depended on the wind speed. Heavier fallout characterized dense fog and required that the runway be cleaned.

6.5 Examples of Successful Operations

Eleven seeding operations were performed at the airport, nine of which were successful (visibility attained was above the minimal limit for airplane operation, 800 m in the horizontal and 60 m in the vertical direction) and two operations were classified as partially successful. Fog dissipation effects were noted in these cases but they were beyond the airport area.

The seeding operation during the night between February 8 and 9, 1984 was an example of successful seeding. The synoptic chart showed a zone of very high pressure at the airport location. The fog formed between 22:30 and 23:00 (Table 1). The seeding operation began at 23:15 because arrivals of unscheduled international flights from New York and Paris had been announced. The expected landing times at Sarajevo were 00:30 and 01:10. Seeding started with the mobile unit at the runway which stretched from the SW to the NW. Stationary dispensers began seeding in the following order: 3, 1, 4, 5, 8 and 9 (see Fig. 5). The first seeding effect was noted 20 minutes after the beginning of the operation and was manifested as heavy snowfall. Because of cold air flow from the SE, seeding was continued in order to maintain the necessary visibility. At 00:30, horizontal visibility at the middle of the runway was 400 m and at the approach part of the runway was 800 m. With these conditions, the airport opened for the first announced landing. The seeding continued until 02:00 in order to maintain the necessary visibility for the second announced landing. Total LP consumption was about 100 kg with a dosage rate of 36 kg per hour.

Table 1. Summary of the super cooled fog seeding operation on February 8-9, 1984. Seeding period was from 23:15 to 02:00.

Time (h)	Visibility (km)		Temperature (°C)			Relative Humidity (%)			Remark
	MS	K	MS	MZ_1	MZ_2	MS	MZ_1	MZ_2	
22:00	4.0	4.0	-1.8	-2.2	-2.5	96	96	98	Fog
23:00	0.4	0.8	-2.4	-4.0	-3.9	96	96	100	Fog
24:00	0.2	0.2	-3.7	-5.0	-4.0	96	96	100	Ice Fog
01:00	0.4	0.8	-3.7	-5.2	-5.0	96	96	100	Ice Fog
02:00	1.0	1.5	-3.8	-5.0	-4.0	96	96	97	Haze
03:00	1.0	1.5	-3.8	-4.0	-4.2	96	96	100	Haze

Wind: Calm throughout the entire period.

Besides the airport operations, two seedings were attempted for the first time at the ski slopes of the 14th Winter Olympic Games. The day before the official downhill competition of February 15, 1984 at Mt. Bjelasnica, a stationary dispenser network was placed as shown in Fig. 6. Dispensers were positioned, taking into consideration weather forecast for the next day (February 16, the day of competition), and considering the supercooled stratus occurrence which usually covers the upper part of the ski slope (Fig. 6). On February 16, the morning hours were sunny without clouds. Wind speed was 1-3 m/s at the top of Mt. Bjelasnica (starting

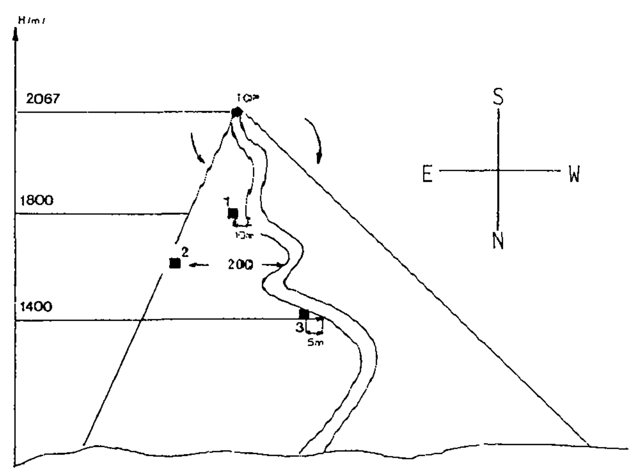

Fig. 6. The dispenser network at the downhill course on Mt. Bjelasnica.

position of the race) began to be covered with clouds at 12:15 and visibility dropped to 50-100 m. However, the visibility at the top of the mountain changed depending on the cloud conditions. Seeding could not be performed at the top of the mountain because of the difficulty in taking the dispensers to the location. The clouds started covering the downhill path near the dispensers at 12:25. Dispenser No. 1 started seeding at 12:25, Dispenser No. 2 at 12:30 and Dispenser No. 3 at 12:40. Seeding was carried out until 13:00, which was the end of the competition. The wind speed and wind direction did not change during the seeding operations. Ten minutes after the first dispenser started seeding, snowfall was noted, and 10 minutes after the second dispenser started seeding a heavy snowfall was observed around the position of Dispenser No. 3. The dispenser positions are shown in Fig. 6. The visibility increased significantly by about 12:40, and did not vary until the end of seeding. The cloud which covered the part of the path at the altitude 1400-1800 m completely vanished and the sun appeared again. The temperature was from -9 to -11 °C during the seeding. A faster appearance of snowfall under the condition (10 minutes after the start of seeding) was noted compared with seeding operations carried out at the airport (20-30 minutes) apparently due to lower temperatures which cause faster crystal growth.

7. CONCLUSION

The experiment of supercooled fog dispersal at the Sarajevo airport and the new attempt for clearing supercooled clouds at the ski slopes of the 14th Winter Olympic Games confirmed the satisfactory effects and economy of our simple LP method using a new combination of stationary and mobile groundbased dispensers.

Eleven seedings were carried out at the airport, nine of them successful and two partially successful. One completely successful operation was performed at the downhill path of Mt. Bjelasnica during the official competition.

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