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HAIL SUPPRESSION - INFLUENCE ON DYNAMIC PROCESSES IN THE ATMOSPHERE

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Abstract

The paper treats the problem of hail suppression taking into account dynamics and microphysics of the atmosphere and starting from the present knowledge and experience gained from the existing hail suppression system which is applied in the Socialistic Republic of Croatia (a state Yugoslavia). It is a radar directed hail suppression which has passed through the several stages of improvement in order to increase the efficiency of the system. A decisive step towards the improvement of the hail suppression system was made in 1981 by introducing the meteorological radars (EEC WSR 74S) with HP 1000 computer system and new TG-10 anti-hail rockets.

The paper discusses the further step in the development of the hail suppression system. Owing to the new technological approach and man-interactive system, the subjective influence of the operator and other factors affecting the system will be reduced or eliminated.

That system which is being developed will merge information originating from various sources: satellite and radar data, information from the protected area, meteorological stations, aricrafts, physical data concerning dynamics of the atmosphere and ballistic properties, etc.

Hail suppression is the first step towards the weather modification and influencing the dynamic processes in the atmosphere.

Key words

hail suppression, antihail rocket, radar network, satellite meteorology, man-interactive system

Introduction

It has been estimated that the worldwide losses from hail damage exceed two thausand million dollars annually. Nowadays when great significance is attached to food, growind importance of hail suppression activities undertaken to reduce crop damage is quite obvious. Weather modification programmes, treating the problem of artificial affecting of hail-formation processes in the atmosphere (WMO, 1981), become more and more numerous. Hail detection equipment and cloud seeding devices are advancing more rapidly than the understanding of hailstorms. On the territory of Croatia the first attempts of artificial affecting of hail were made in 1968, and up to 1981, a hail suppression system based on radar cloud detection and rocket cloud seeding has been developed.

Dynamics

Atmospheric processes are directly connected with water in the atmosphere, primarily with the water phase changes. Hail clouds are characterized by a very quick phase alternation of a large quantity of water frequently producing destructive effects. It has been estimated that a supercell cumulonimbus (Cb) contains the amount of energy equal to or larger than the explosion of an A-bomb (Breuer, 1979).

Hail clouds observed within the context of the atmospheric phenomena scale are classified into the mesoscale and misoscale category (Fujita, 1981) i.e. lasting from 30 minutes to 12 hours and covering from 4 to 400 km in length.

The process of the formation of hail clouds most frequently occurs in the cold front and seldom locally within unstable air masses. Although the hail forming clouds differ considerably among themselves they can be classified into several categories according to the following criteria: (WMO-1981)

- Lifetime of Cells - short - lived $t < 45$ min,
  - long - lived $t > 45$ min;
- Number of Cells - one cell,
  - more than one cell;
- Regeneration Characteristics of Cells (in both time and space)
  - regulary and randomly evolving;
- Morphology of the Cell Ensemble - line and clusters;

Most frequent are:
- singlecell clouds characterized by short life,
- multicell clouds - a cloud mass within which regular regeneration of cells takes place,
- supercell clouds - consisting of a big and long - lived cell.

It is typical of all thunderstorms that the lower atmospheric layers are connected (mixed) with high layers. This is especially characteristic of supercell Cb clouds, their top reaches the tropopause, thus vertically connecting the whole atmosphere.

Updraughts from 3 km in diameter for singlecell to 15 km in diameter for supercell Cb clouds prevail inside and in front of Cb clouds during the stage of their formation and maturity.

Updraughts covering the area of 80 km^2 and extreme cases up to 200 km^2 have been registered (Browning, 1977).

In case of long life Cb an anvil plume (composed of ice crystals) of a characteristic appearance is produced.

Multicell hailstorms are more frequent and they cause considerable damage. Although supercell hailstorms are less frequent they may produce disastrous effects (Sedunov and Chernikov, 1979).

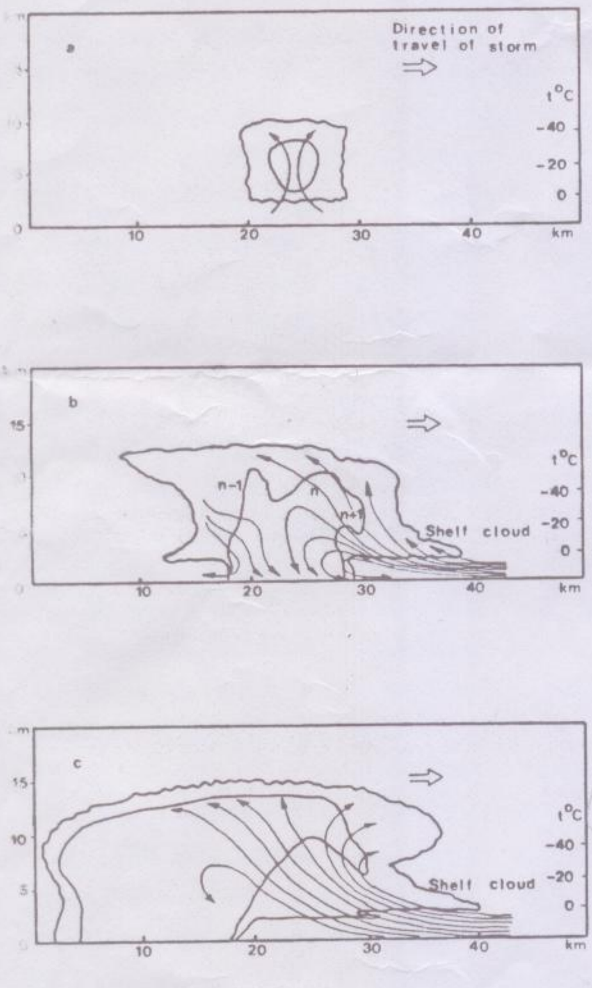


Fig. 1. Schematic representation of a singlecell (a); multicell (b) and supercell Cb cloud.

Hydropaysics

Formation of hailstones takes place due to the accretion of water (supercooled drops and water vapour) on hail embryos: graupels and frozen drops.

In the region of the formation and growth of hailstones water exists in all three agregate states. Supercooled drops are present in the clouds even at a temperature of -40°C.

Only at higher altitudes (at lower temperatures) water exists only in the form of water vapour and ice-crystals. Due to freezing latent heat is released:

$$H_2O\ (g) \xrightarrow{2260,9\ J/g} H_2O\ (l);$$

$$H_2O\ (l) \xrightarrow{334,9\ J/g} H_2O\ (s)$$

Because ice is more stable phase at low temperatures, supercooled portion of the Cb cloud constitutes a thermodynamically unstable formation, and a large quantity of water can accumulate a large amount of energy.

In the updraughts adiabatic cooling of the air occurs and the air becomes saturated and then supersaturated with water vapour. Under such conditions drops are generated on the condensation nuclei, which exist until the balance of the vapour lasts. At low temperatures ice-crystals are produced on ice forming nuclei (heterogenous nucleation). If an ice-crystal is surrounded by supercooled drops, it will grow because the partial pressure of the drop vapours is higher than the pressure of the vapour above the ice. In the free atmosphere there is a relatively small number of natural freezing nuclei, therefore under favourable conditions a hailstone may grow up to the size of 5 cm or even more.

Schafer's discovery in 1946 that dry ice in supercooled fog produces about 10^{12} of ice-crystals per gram of dry ice and Vanegut´s discovery in 1946 that the same effects can be produced by AgI aerosol have enabled to influence the weather.

These discoveries were immediately applied to increase precipitation and, later on, to hail suppression.

In 1964 Sulakvelidze laid foundations for the operative hail suppression in the USSR. Cloud mass was affected by artillery shells or rockets containing AgI or PbI_2 based meteorological reagent (Sedunov and Chernikov, 1979).

In 1970 a radar directed hail suppression system (3MK-7 radars, SAKO 6-3 rockets) was introduced in the Socialist Republic of Croatia).

A modernization project (Gelo, Skočir and Horvat, 1978) includes introduction of high-range meteorological radars and long-range rockets for cloud seeding. (Gelo and Horvat, 1978; Lipovšćak and colleagues, 1979).

Hail suppression

Many hypotheses have been proposed for suppressing hail. The most frequently quoted are the following: (WMO, 1981)

1) Growth-limiting competition among hail embryos
2) Acceleration of precipitation formation from a zone of hail embryos
3) Glaciation of cloud water
4) Trajectory lowering
5) Promotion of coalesence
6) Seeding for dynamic effects

It has been discovered, on the basis of the gained experience, that the hypothesis of competing embryos is the most promising one at present (Fukuta, 1980).

It should not be forgotten that cloud seeding (depending upon the type of seeding) produces in principle all the above mentioned effects (1-6).

Due to the emission of the AgI based meteorological reagent (heterogenous nucleation) the following process occur on the AgI crystals: (De Motte, Finnegen and Grant, 1983; Federer and Schneider, 1981)

- Vapour depossition (sublimation)
- Condensation followed by freezing
- Contact freezing

Every reagent produces all the mentioned effects but which one will prevail is determined by the physical and chemical properties of the reagent, meteorological conditions, and available time (Baklanov and colleagues, 1982). The activity of the reagent is strongly affected by temperature, liquid water content and supersaturation. According to our measurements the activity of the applied reagents is $2\text{-}4 \cdot 10^{12}$ active nuclei per gram of pyrotecnic mass.

Description of the present hail suppression model

The existing hail suppression system is based on the WSR 74 S radar coupled with HP-1000 computer; thus the successful controlling of launching station networks is provided. Each launching station is equipped with two six-guide launchers and sufficient numbers of TG-10 rockets which are used as the main cloud seeding means (Horvat and Hren, 1980; Horvat and Lipovšćak, 1982). The description of the radar-computer hail suppression system and integration of radars into network is given in the papers Lipovšćak (1981), Lipovšćak (1984).

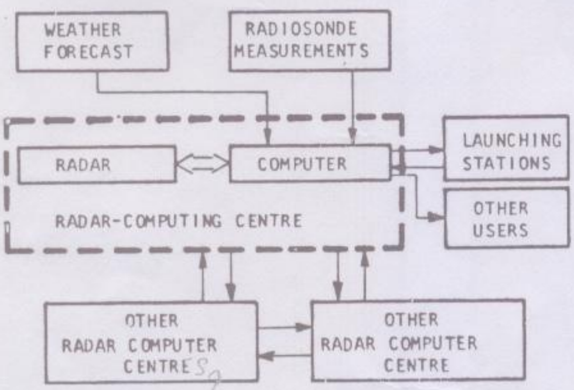


Fig. 2. Radar-computer hail suppression system.

The radar operates in a scan system with the time base determined by the thermodynamic state of the atmosphere - in case of instability scanning is done every 15 minutes. When the echo of the Cb cloud is observed, the antihail action criteria are checked, and if necessary, hail suppression action is undertaken. The computer receives the data about position, dimensions and strength of the reflected signal on the cloud, processes them and distributes them to the system. The diagram of the distribution and main segments of programme support is shown in Fig. 3. Čačić and collegues (1982).

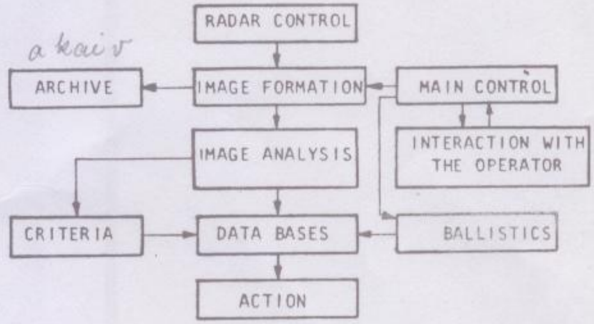


Fig. 3. Diagram of the programme support segments of the radar-computer hail suppression system.

The basic principle for the effective cloud seeding is to affect the cloud cells undergoing the stage of development immediately below the zone of growth and formation of hail-stones by seeding the updraught of humid unstable air with a meteorological reagent. After the adequate cloud seeding with the reagent, the rapid growth of the top of the cloud cell follows (due to the additional energy released during the phase transition of water into ice caused by the generation of a large number of crystalization nuclei-reagent). After the increase of the cloud top height, follow the dissipation and the decrease of the cloud top height, as well as appearance of a shover on the ground (English at Marwitz, 1982). The appearance of new cloud cells on the right flank of the existing one (in multicell storms) requires preventive seeding of the cloud on the right side in relation to the direction of the storm motion (WMO, 1981; Mozer, Matvijev and Horvat, 1981; Sedunov and Chernikov, 1979).

TG-10 Rocket

TG-10 rocket is a two stage rocket having a vertical range of 8.3 km (Horvat and Hren, 1980; Horvat and Lipovšćak, 1982). It has been in operative use in the hail suppression system in Yugoslavia since 1980. In order to obtain flat seeding trajectories at temperature ranging from -5° to $-15^{\circ}C$ (optimum is about $-8^{\circ}C$ - Fukuta, 1980), the rockets are most frequently launched at elevation angles of 45° and 50° (Gelo and Horvat, 1978). In order to enable rapid seeding of a large area the rockets are fired from a six-guide launcher in beams (e.g. by using an elevation angle of 55° and 10 second timing of the rockets, the area of ca. 20 km^2 can be seeded at the altitude ranging from 3.5-5 km). High vertical velocities, turbulence and the electrical fields inside and around the Cb cloud are very important for rapid spreading of a reagent (Styra and colleagues, 1976).

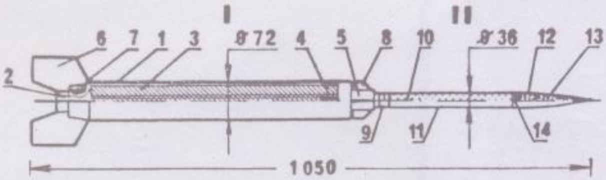


Fig. 4. Antihail rocket TG-10

I Motor part (booster): 1. motor; 2. nozzle; 3. propellant; 4. igniter; 5. connector; 6. fins; 7. self-destruction system,

II Container: 8. nozzle with fins and connection part; 9. timing system; 10. pyrotechnical mixture with AgI; 11. fiberglass plastic body; 12. plastic nose cone; 13. balast; 14. detonator.

Technical data:

troughout length	1050 mm	mass	4,35 kg
motor diameter	72 mm	propellant mass	1,50 kg
container diameter	36 mm	pyr.mix. mass	0,36 kg

timing of the start of seeding 5±0.5 s to 25±2s max.
seeding time 27±2 s

The application of satellite data in hail suppression

For the effective operation of the hail suppression system which is in operative use in Croatia (weather modification programme) it is of prime importance:

a) To know reliable criteria of hail danger
b) To start action in due time
c) To know the morphology and dynamics of motion and evolution of cloud cells
d) To be able to inject a necessary quantity of meteorological reagent in the defined part of a cloud.

The first stage of the introduction of satellite meteorology into the hail suppression system considers satellite data as an additional information to forecast-observation system for the purpose to controle and increase accuracy of the above mentioned requirements. At the same time the precision of weather forecasting increases.

By processing the data obtained by observing the area of vital interest for the hail suppression system in the infra red, (IR) visible and microwave regions, the following information contributes to the system's efficiency:

- Vertical distribution of temperatures and cloud top temperature (CTT).
  The basic meteorological parameters used as criteria of hail danger are based on knowing of the atmosphere vertical temperature structure and radar parameters of Cb clouds (Čačić and Lipovšćak, 1983).
  Radiosonde measurements which provide information about the height of isothermal surfaces are very rare in space and time (150-300 km distance and 12 hours in time) and are not representative enough for the mesoscale processes among which hail storms are classified. Satellite data provide better understanding and checking of hail danger criteria.

- Cloud classification, occurrence, size, position, direction of motion, growth rate and lifetime suggest to apply a method of automatic classification Liljas (1981) and Lipovšćak (1984) of analogue and high resolution digital satellite data which provides getting of the classified satellite image from which the above mentioned data are obtained.

- Vertical velocity of circulation in a cloud.
  The exact data on vertical velocity in a cloud result from the measurements with Doppler radars. In the absence of these measurements satellite data may be very helpful. According to Adler and Fenn (1979) a rather simple method, based on the measurements of a high resolution scanner in the IR region can be used to determine the vertical velocity of the air rising at the top of a cloud cell. The process of sudden crystallization of the supercooled water in the cloud is followed by the increase of the vertical velocity of circulation as well as by the rising of the cloud top. The rise of the vertical velocity may serve as an indirect measure of cloud seeding efficiency.

- Remote sounding of moisture in the atmosphere.
  The vertical distribution of temperature is obtained by the same procedure. Using the satellite IR channels, the moisture sounding data can be obtained.

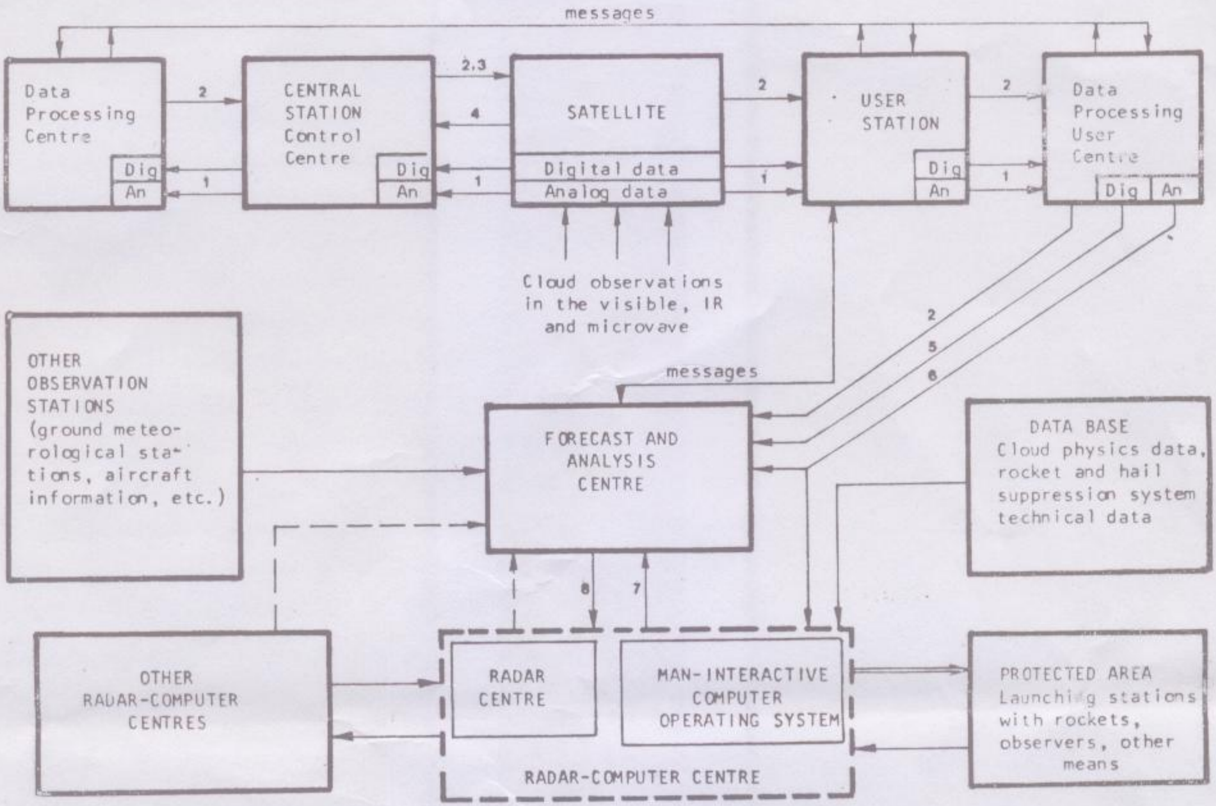
- Cloud phase composition data
  Using the IR and microwave regions, the data about phase composition of developing cloud cells, as well as about the distribution of the liquid and icy phase in the cloud can be obtained.

- Ground temperature
  Measuring the ground temperature, the information about the thermal potential of the region to which an air mass is approaching is obtained, and above which the vertical formation and appearance of Cb clouds may occur.

The introduction of the satellite meteorology into the hail suppression system enables a good analysis of anti-hail actions, improvement of the methodology and a good survey of the protected area - potential (active) sites can be viewed during the period of several years in the same manner with the same sensor. On the basis of the analysis the correction of the launching station networks and hail danger criteria, etc. can be done.

Proposed hail suppression model

A new technological approach should reduce or eliminate the subjective influence of the operator and other factors present in the existing system. The new hail suppression model will be based on a developing man-interactive system which will incorporate information from various sources such as: satellite and radar data, information from the



1. Raw images
2. Processed images and WEFAX Data
3. Platform interrogation
4. Platform responses
5. Data prepared for hail suppression system T(h), CTT, W, cloud classification, speed, direction, quantity, position
6. Approximate cloud position and type
7. Information about situation in the protected area
8. Data base for man-interactive computer operating system (forecast data, haildangerous criteria, etc.)

Fig. 5. Scheme of the proposed hail suppression system.

protected area and meteorological stations, physical data about the atmosphere, rocket and system technical data, etc. The new control system and satellite information will significantly influence the methodology and way of utilization of the existing hail suppression means. It is possible that the hail suppression requirements will influence the development of the satellite - observing technology and the way of data processing, in order to:

- create data base for man-interactive control system
- observe protected area and estimate hail damage (area and extent of damage)
- analyze hail suppression actions, etc.

Conclusion

The paper analyzes certain dynamic processes and microphysics of the atmosphere from the point of view of hailstorm occurence, pointing out the methology and possible ways of hail suppression. The existing hail suppression model applied in Croatia is described (weather modification programme). It is based on radar-computing centres (WSR 74 S radar and HP 1000 computer) and TG-10 rockets used as the main cloud seeding means. The probable direction of the development of hail suppression system in Croatia, as well as the application of satellite information in meteorology are pointed out.

cent security of hail suppression but it is perfectly clear that the existing system has fully justified the costs of its introduction, development and maintenance. Past experience has revealed that there were cases when hail damage was inflicted in spite of the correct functioning of the hail suppression system. That means that we are not fully aware of certain weaknes of the system or its methodology or that we do back proper understanding of dynamic processes and microphysics of the atmosphere.

We believe that the modernization and improvement of the hail suppression system will significantly increase its effectivness.

Nowadays we can hardly talk about 100 per

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