VayuMandal 46(1), 2020

Hail Mitigation: Systems Approach

P. Kumar
Department of Mathematics, MIT World Peace University, Pune
Email: prabhat.kumar.wpu@gmail.com

ABSTRACT

Systems approach in hail-mitigation exercise has been presented in this paper. Spontaneous inputs of the atmospheric parameters promptly guide the in-situ strategy of hail-mitigation for efficient seeding with appropriate quantity, precisely at initial cumulus growth phase 'prior to hail formation'. This also ensures completion of cloud-seeding before the commencement of downdraft vis-a-vis flight safety during entire operation. Safe and efficient hail-mitigation consists of well coordinated and ordered network of operations including now-casting, satellite communication, Quick Reaction Helicopter, AgI & NaCl rockets, Navigation systems and Human Machine Interface (HMI) system of firing controls.

Keywords: *Hail-mitigation, Systems approach, Reaction time, Quick Reaction Helicopter and AgI & NaCl-rockets.*

1. Introduction

1.1 Hail Control Strategy

Several billions of dollars are lost each year, due to hail-damage to life and property throughout the world (Kumar, 2017). First scientific attempt towards hail mitigation was made by Sulakvelidze (1969). He hypothesised that by artificially seeding of cumuliform clouds with Cloud Condensation Nuclei (CCN) for warm region of cloud and/or with Ice Nuclei (IN) for cold region of cloud, the condensed droplets or ice crystals increase within the cloud. For each gram of seeding substance in the pyrotechnic cartridge the resulting smoke may generate IN in the range of 10^{10} to 10^{16} nuclei. The count depends on atmospheric temperature, pressure and humidity. This estimate is based on the chamber particle counters from De Mott (1982). On an average it could be 10^{14} per gram (Rogers and Yuan, 2006). Nucleation and precipitation attain the optimal rate values, between -19^{0}C and – 3.8^0 C (Kumar, 2018). After nucleation they all compete to collect the available water vapour and grow larger altogether. As a result, cloud water is distributed in to several small ice crystals or small hails, above 0 ^{0}C isotherm level within the cloud. These ice crystals or small hails would either become much smaller or completely melt into water during their travel below zero degree isotherm level and turn into rain or drizzle. This hypothesis of hail control, however, does not specify the control of any specific size of hail. It is a general strategy so that the sizes of newly born hailstones are small enough at the place of their origin itself. It was first applied by Georgia (part of erstwhile Soviet Union) which subsequently laid strong scientific foundation for the control of hailstorm world over. Between mid-1970s and beginning of 1980s two large experiments were undertaken to evaluate the effectiveness of cloud seeding in Western Europe (Switzerland, France and Germany) known as The Great Experiment (Federer et al 1986) and another in U.S.A. known as National Hail Research Experiment (Knight et al 1979). The results from both the experiments showed that statistically there were no significant difference in the occurrence of hail between seeded and not seeded hail bearing cloud. Albeit uncertainty on the effectiveness of hail control by cloud seeding prevailed and World Meteorological Organisation in 2007 decided not to recommend Hail Suppression any more, still several European countries continued with their Hail Suppression programmes.

Unsatisfactory results did not mean that seeding approach for hail-mitigation was incorrect rather it indicated that disdain of correct time and level of seeding lead to unsatisfactory results. Concept of efficient seeding agents was also not well known during those experiments. Kumar (2018) has defined percentage cartridge efficiency of seeding agent (e.g. Pyrotechnic Cartridge). Effective seeding (Dennis 1975) in shortest possible time is known as efficient seeding. Most efficient seeding could be obtained if the agents are released in optimum temperature/pressure range vis-a-vis levels within the cloud. As regards the correct time of seeding, it is well known that seeding done prior to the hail formation is most appropriate time of seeding. If hails have already formed in the cloud then they have to fall on ground. Causes of unsatisfactory success in the hail control under several projects, worldwide, have been discussed by Kumar (2017). Basic requirements to achieve efficient hail mitigation operation are.

(i) Identify a growing cumulus cloud in its early stage and forecast 'if it would turn into a hailstorm or not'. Early stage is defined as ≤20dBZ onwards of cloud reflectivity value (Kumar and Pati, 2015).

(ii) Estimate the total reaction time (i.e. time duration for any cumulus to grow from 20dBZ to 45 dBZ) for the seeding operation? It is assumed that hailstones are already available in the cumulus cloud when the cloud reflectivity crosses 45 dBZ thresholds (Witt 1990; Witt et al 1998; Singh et al 2011; Srivastava et al 2011). Hence for hail suppression operation, seeding must be done prior to hail formation in the cloud i.e. during reaction time.

(iii) Find out the location and speed of motion of cloud.

Quantity of seeding should be such as to disperse more than half a kg of NaCl per km^3 in warm cloud region(volume of cloud from cloud base to 0^0C level). The estimate is based on the sea salt concentration over oceanic boundary layer – where hailstorms do not form, though thunderstorms do. This seeding quantity is known as over-seeding (Kumar, 2017). A rough over seeding estimate for cold cloud region(volume of growing cumulus above 0^0C level) can be made by assuming that each gram of seeding substance in the pyrotechnic cartridge may generate IN in the range of 10^{10} to 10^{16} nuclei. Insufficient IN seeding might increase the hail production instead of suppressing it. Detwiler (2015) has reported a case where storm invigorated, and the volume of the storm containing hail increased dramatically shortly after seeding began. His seeding method did not consider minimum quantity of seeding per km3 as significant.

(iv) For efficient seeding (Kumar, 2018), seeding-agents must be delivered in suitable quantity (over seeding) at appropriate temperature range in the atmosphere.

Therefore, as a primary step, for a successful hail mitigation operation, as far as possible one must track a growing cumulus right from the very early stage (step 1) to quickly predict the reaction time (step 2). Last 50 years of history of software-developments related to thunderstorm was having primary objective of predicting thunderstorm's occurrence e.g. 'time and place'. None were aimed for forecasting the reaction time; albeit, they did successfully compute the cloud motion (step 3), very well.

Kumar and Pati (2015) have presented the method of extracting the pixel information from the PPI display of radar imagery with the help of IRIS software and MATLAB. For hail mitigation programs one not only needs spontaneous prediction of hail but also maximum possible reaction time for seeding. This needed spotting the growing cumulus at much early stage than primary threshold of any of the existing software. Kumar and Pati (2018 a&b) have provided a simple Quadratic Growth Algorithm (QGA) which has been presented in the present paper as basis of Prehail Detection Algorithm (PHDA) which not only identifies the prospects of a growing cumulus to develop into a hailstorm in its early stage but also predicts the reaction time.

Firing rockets from ground is considered as most accurate and economical seeding-agents delivery method. The drawback in this method is that entire firing range of the rocket must be cordoned off to avoid any collateral damage to other aviation traffic in the area but for slant firing the area to be cordoned off will be very large. This cannot be, therefore, a viable practice for frequent seeding operations. Safe and practical approach can be, therefore, high speed helicopter mounted with seeding-rockets, which are fired vertically after landing below the cloud. In this case, air space to be cordoned off for air traffic will be very limited.

1.2 Systems Approach

Viewing atmosphere as dynamical system that keeps changing with respect to temperature, pressure profiles and aerosol density with respect to regions and seasons is known as the systems theory approach. Spontaneous inputs of these atmospheric parameters promptly guide the in-situ strategy of hail-mitigation for efficient seeding with appropriate quantity, timely at initial cumulus growth phase 'prior to hail formation'. This also ensures completion of cloud-seeding before the commencement of downdraft vis-a-vis flight safety during entire operation. Theory has been extensively applied in social, management and engineering problems (Baecker et al, 2007; Bertalanffy, 1969; Kauffmann, 1995; Luhmann, 1995; Miller and Page, 2007; Parsons, 1977; Wiener, 1948).

In the present paper, an attempt has been made to sequence each subtle hail-mitigation operational segments with inputs from the dynamical atmosphere with attention over flight safety and operational viability, as per systems approach.

2. Methodology

2.1 Hail Control Hub

Figure 1 shows conceptual Hail Control Hub (HCH) which has X-Band Doppler Weather Radar (DWR), a helipad with Quick Reaction Helicopter (QRH) which is side mounted with AgI and NaCl cloud seeding rockets – two each on either sides. Helicopter is fitted with satellite communication facility with radar controller. It has internal controls to fire the rockets. Figure 2 shows the QRH model.

Side arms of the helicopter which support seeding rockets are extendable much beyond the propeller circle overhead. Helicopter can fly with contracted arms and horizontally oriented rockets. After landing at the firing site, the arms are extended, rockets are oriented upwards and ground-support to absorb the firing shock is lowered to rest on the ground. HCH has also having vehicles to collect rain samples after seeding.

Figure 1: Hail Control Hub.

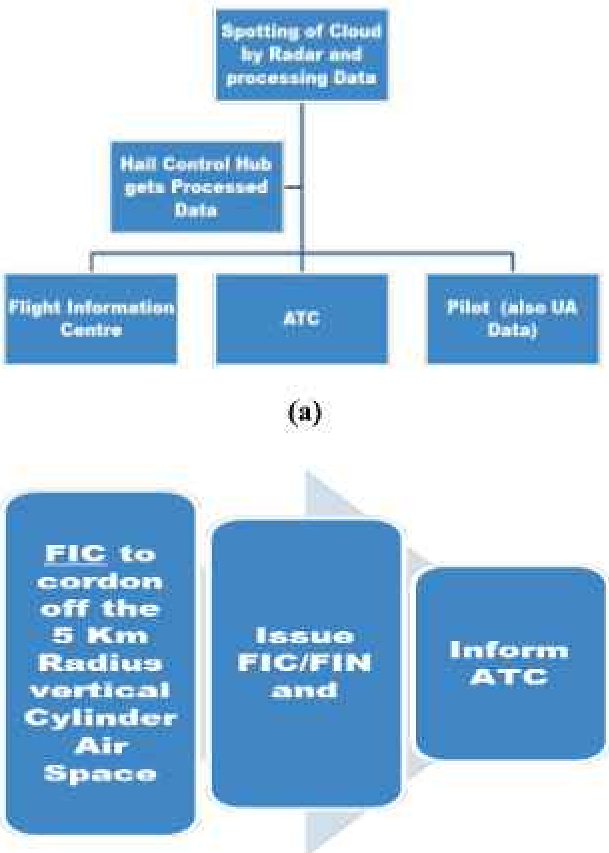
Figure 2: Quick Reaction Helicopter.

2.2 Operational sequence

Primary challenge for hail mitigation operation is to identify the growing cumulus which may grow into hailstorm. Climatology of the region and season may assist the day to day hailstorm prediction by conventional methods but now-casting of any possibility that a particular growing cumulus would turn into hailstorm has been presented by Kumar and Pati (2019 a&b). Based on their Quadratic Growth Hypothesis (QGH), hailstorm could be predicted and Reaction Time (RT) can be computed promptly. They broadly categorised growing cumulus into Slow ($r \leq 0.2 dBZ/min$), Moderate ($0.2 < r < 0.8\, dBZ/min$) and Fast ($r \geq 0.8 dBZ/min$). Skill score of prediction was observed 100% correct for slow growing cumulus and 62.5% accurate for moderate. Albeit QGH predictions are incorrect when the cumulus growth reverses or when it is fast.

(a) (b) (c)

Figure 3: (a) Identification of a growing cell, (b) Prediction of hailstorm formation, location, cumulus motion speed and reaction time and (c) Passage of information to helicopter pilot via satellite and also to Air Traffic Control (ATC) for clearing the helicopter flight and Flight Information Centre (FIC) for cordoning off the air-space.



(a) **(b)**

Figure 4: Sequence of primary actions after the prediction of expected hailstorm is made.

For this category, conventional numerical approach (Hand and Cappellutib, 2011; Kumar, 2017) may be adopted to nowcast the hailstorm. Figure 3 presents this sequence from left to right.

Information about Hailstorm formation, location, cumulus motion speed and reaction time are then passed to helicopter pilot, Air traffic Control and Flight Information Centre. Pilot is also provided with latest upper air temperature data. Flight Information Centre cordons off the area and allows pilot to take off. Entire process is presented in Figure 4.

Air Traffic Control then clears the helicopter flight. Helicopter then flies by the satellite controlled navigation. During flight pilot feeds the appropriate seeding agents delivery levels for warm region of the cloud i.e. ≈5^{0}C to 0^{0}C level for NaCl rockets and -5^{0}C to -15^{0}C level for AgI rockets. Pilot finally prepares to land below the cloud as position of cloud on the navigation scope coincides with that of the predetermined location of the cloud to be seeded. Navigating pilot has to consider the changing location of the cloud due to cloud motion. Figure 5 (a-f) shows the sequence of activities from left to right.

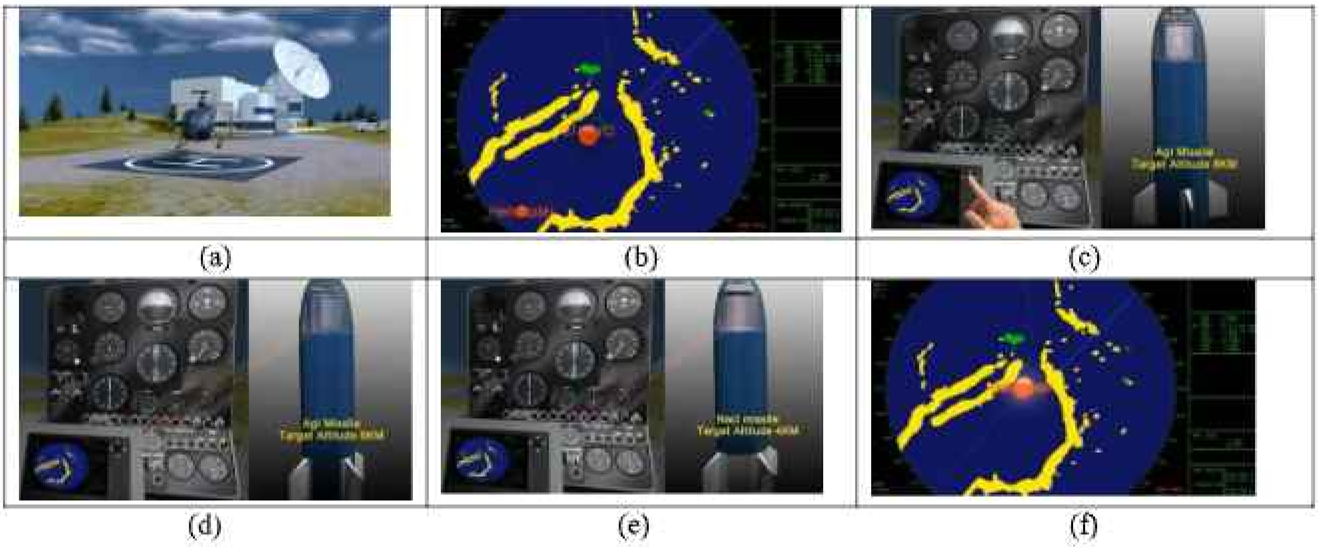


Figure 5: (a) Helicopter Takes off (b) It flies navigating as per the cloud location provided by radar which is shown on its own screen as large red dot. Helicopters own location is shown as small red dot. Cloud motion speed is accounted while chasing the cloud (c) Based on latest upper air temperature profile given to pilot warm cloud and cold cloud seeding levels are decided for efficient seeding (d) While flying pilot feeds the suitable height/level in the AgI rocket's memory as where to release the payload after it would be fired (e) While flying pilot feeds the suitable height/level in the NaCl rocket's memory as where to release the payload after it would be fired (f) Pilot lands on ground when small red dot and big red dot coincide. That is the place when cloud would be just overhead the helicopter.

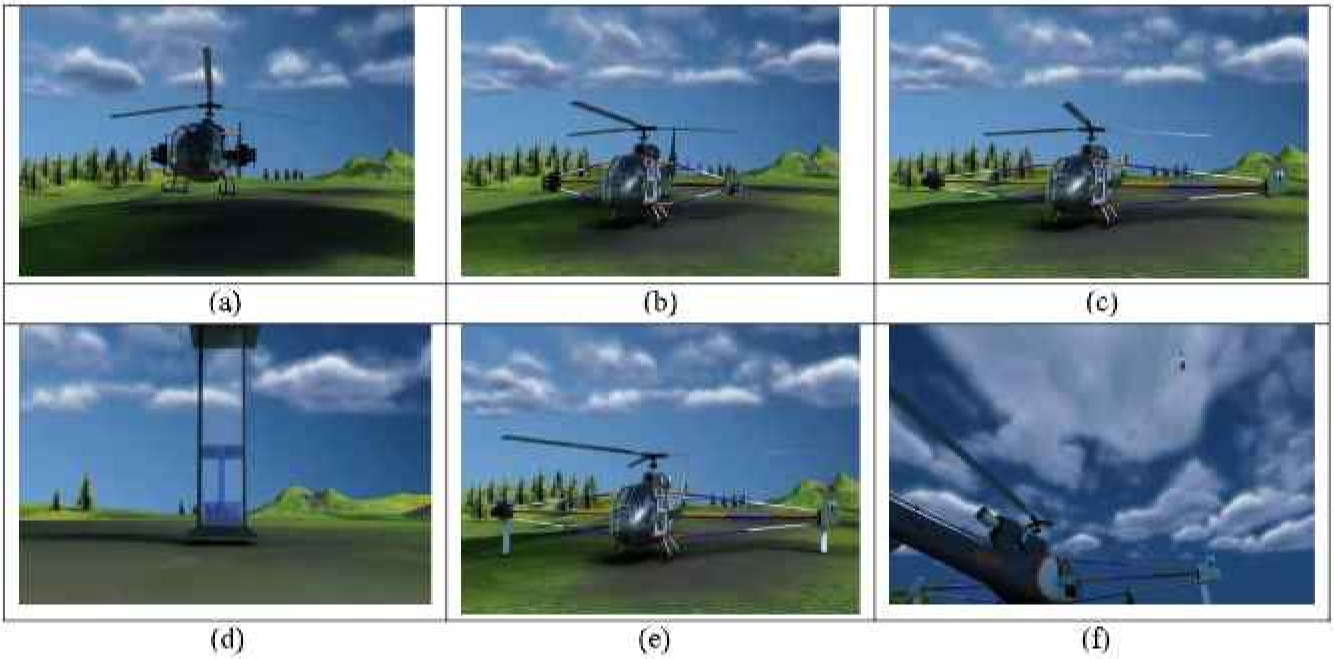


Figure 6: (a) Pilot lands below the cloud after two dots coincide on the navigation screen (b) Immediately extends side arms (c) Fully extended side arms out of the propeller circle and upwards oriented rockets (d) Ground support is lowered to absorb the rocket firing jerks (e) Helicopter is ready to fire rockets Pilot does this job sitting in the cockpit through Human Machin Interface (HMI) touch screen (f) Rockets have been fired.

Helicopter lands just below the cloud. Immediately after landing it extends the side arms (holding rockets) beyond the propeller circle without stopping the engine. Then orients rockets upwards and lowers the ground support. Then rockets are fired which are already programmed to release their payloads at appropriate level in warm and cold clouds respectively. Ordered sequence of activities are shown in Figure 6 (a-f).

Immediately after firing of all the eight rockets (four NaCl and four AgI) are complete pilot must take off and fly back to helipad with top speed to avoid downdraft. Schematic brief of Figures 5 & 6 are shown in Figure 7.

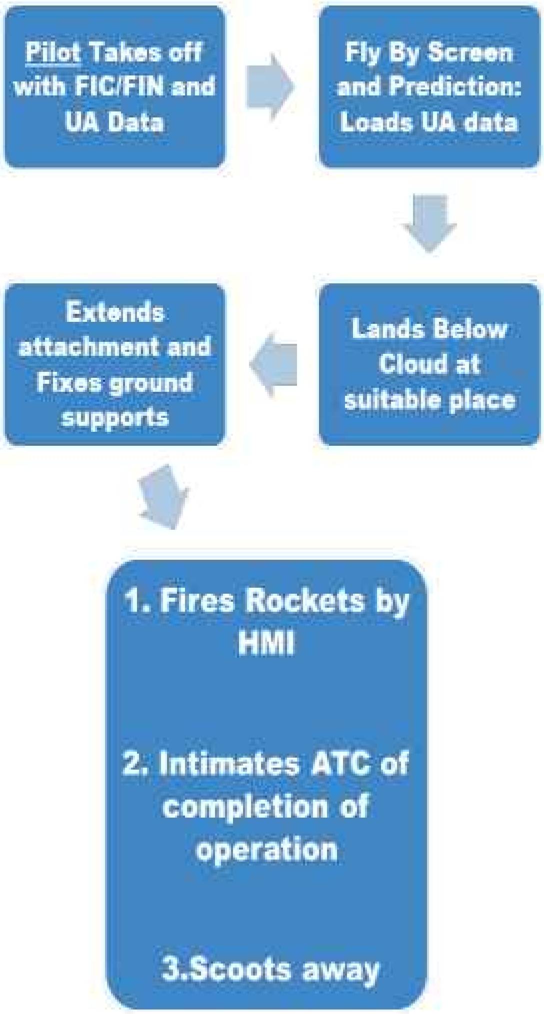


Figure 7: Schematic of the helicopter chasing the growing cumulus and firing of rockets.

Release of seeding material within appropriate temperature range in atmosphere will ensure efficient seeding results and flying back at top speed from the seeding site is essential to evade the downdraft vis-a-vis ensure flight safety measure. Air Traffic Control(ATC) has to ensure top priority to facilitate landing of the returning Quick Reaction Helicopter (QRH). Schematic in Figure 8 shows the same.

Figure 8: Schematic of recovery of Quick Reaction Helicopter returning after firing the rockets.

3. Seeding Agents Delivery in Cloud

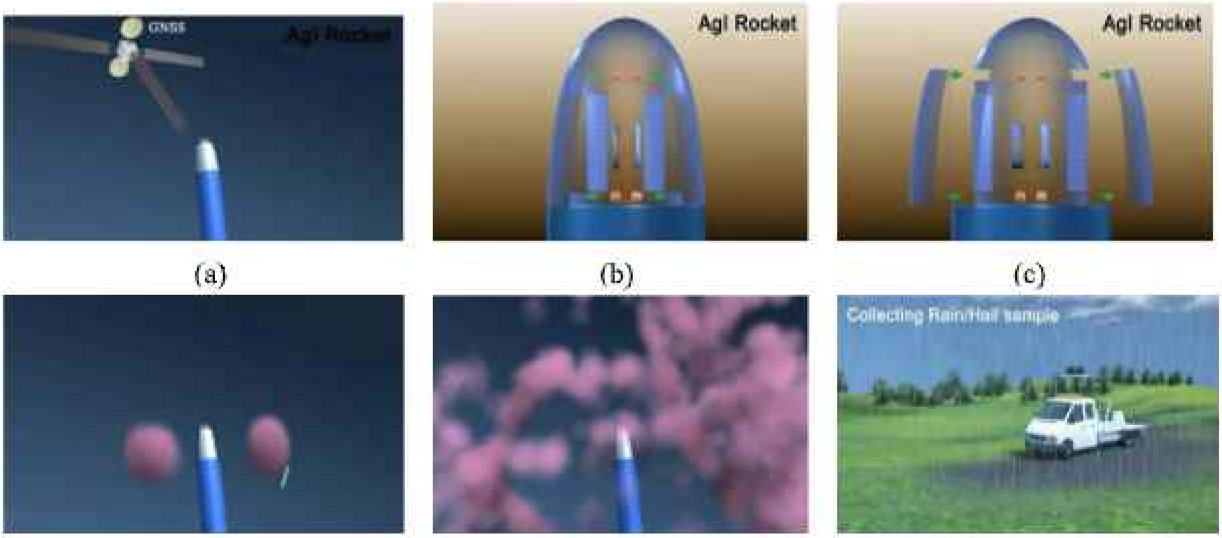
Conceptual design of AgI and NaCl rockets are shown in Figure 9. Rocket nose has GPS receiver which receives a current from the satellite after the rocket attains the pre-programmed height.

Below the GPS receiver is the servo motor which is triggered by the GPS receiver. Below the server motor is the AgI pyrotechnic cartridges (for AgI rocket shown in Figure 9(a)) and NaCl finely ground powder(for NaCl rocket shown in Figure 9(b)). Rocket body carries rocket fuel and fins provide the aerodynamic stability during flight. After servo-motor is triggered it releases the spring lock. Spring expands and throws out the pyrotechnic cartridges or NaCl powder tray. Two springs are symmetrically placed to expand in 180^0 opposite direction so that their reverse reactions are mutually nullified. Figure 10(a-e) shows the sequence of the activities in the cloud during seeding, process for AgI rocket which ejects pyrotechnic cartridges for cold cloud seeding. All set and done efficient seeding is possible only when overseeding is done in appropriate temperature range in the cloud.

Figure 10 (f) shows the sample collecting van below the seeded cloud after the hail-mitigation operation.

(a) (b)

Figure 9: (a) AgI and (b) NaCl Rockets



(a) (b) (c)

(d) (e) (f)

Figure 10: (a) Rocket gets signal from satellite after it reaches preprogrammed level (b) Servo motor is activated (c) Servo motor releases the springs lock which releases the pyrotechnic cartridges and throws them out into cloud (d) Pyrotechnic cartridges burn while falling (e) Seeding particles rapidly spreads in the cloud initiating nucleation and precipitation (f) Test van may be used to collect the samples of precipitation for further study

4. Conclusions

For achieving safe and efficient hail-mitigation operation, the suggested ordered sequence of actions are broadly listed below:

(i) Identification of the growing cumulus cells which may grow into hailstorms as early as possible on the radar scope.

(ii) Finding its Reaction Time, Cloud Motion speed and Location coordinates.

(iii) Mounting of Quick Reaction Helicopter (QRH) by rockets for firing in cold and warm regions of cloud.

(iv) Quantification of seeding agents to ensure over-seeding in cloud.

(v) Quickness of the pilot of the helicopter to be adequate enough to complete the operation of seeding within the reaction time.

(vi) Immediate clearance of the cloud area by pilot after firing of rockets for evading any downdraft from the cloud.

Hence, the systems approach to safe and efficient hail-mitigation operation consists of well coordinated and ordered network of activities which includes now-casting, satellite communication, Quick Reaction Helicopter, AgI & NaCl rockets, Navigation systems and Human Machine Interface (HMI) system of firing controls.

References

Baecker, D., Hutter, M., Romano, G., and Stichweh,R. (2007) Zehn Jahre danach. Niklas Luhmanns ‚Die Gesellschaft der Gesellschaft‘. Stuttgart: Lucius & Lucius.

Bertalanffy, L.v. (1969). General System Theory. New York: George Brazillier.

Byers H.R. and Braham R.R. Thunderstorm Structure and Circulation, 1948, J. Met., 3, 71-86.

Dennis, AS., Hail: A review of Hail Science and Hail Suppression, Edited by G. Brant Foote and Charles A. Knight, AMS, Vol.16, No. 38 Dec., 1977, pp181-193.

Detwiler Andrew, 2015, A case study of cloud seeding to reduce hail damage, Journal Of Weather Modification, April, Volume 47, pp 26-41.

Hand, W.H. and Cappellutib, G.(2011), A global hail climatology using the UK Met Office convection diagnosis procedure(CDP) and model analyses, Meteorol. Appl., 18: 446-458.

Kauffmann, S. (1995). At Home in the Universe. The Search for the Laws of Self-Organization and Complexity. New York: Oxford U.P.

Kumar P, Jaykumar D and Pawar s. 2015, Anti-Hail AgI Rocket design; International Journal of Trend in Research and Development, Volume 3(5),pp 143-152, ISSN: 2394-9333

Kumar P, 2017, "Hailstorm: Prediction, Control and damage Assessment" is jointly published by BS Publications, Hyderabad and CRC press U.K. 2017, Taylor and Francis Group, pp 350.

Kumar P, 2018,Towards design and development of isothermal cloud chamber for seeding experiments in tropics and testing of pyrotechnic cartridge, J. of Atmos. and Solar-Terrestrial Phys., Volume 181, Part B, December 2018, Pages 79-93.

Kumar P and Pati Debprasad(a), 2019 Quadratic growth hypothesis for reaction time prediction and 'rate of growth' based classification of cumulus. SN Applied Sciences Volume 1, Issue 5, May 2019; ISSN: 2523-3963 (Print) 2523-3971

Kumar P and Pati Debprasad(b), 2019 Quadratic Growth Hypothesis, Classification of Cumulus Based On Rate of Growth, Concept of Reaction Time and Cumulus Motion Speed. J. of Weather Modification, Vol 51, No 1.

Luhmann, N. (1995). Social Systems. Stanford, Cal.: Stanford U.P.

Miller, J.H., and Page, S.E. (2007). Complex Adaptive Systems. An Introduction to Computational Models of Social Life. Princeton: Princeton U.P.

Mull and Rao- Origin of Downdraft in thunderstorm and circulation in full ledged thunder cell, IJMG, Vol. 1, No.2, 1950, pp. 171-173.

Parsons, T. (1977). Social Systems and the Evolution of Action Theory. New York: Free Press.

Singh H, Datta R K, Chand S, Mishra D, Kannan B "A study of hail storm of 19th April 2010 over Delhi using Doppler weather radar observations" , Mausam, Vol 62, Number 3, 2011, P 433-440.

Srivastava K, Lau S, Yeung HY, Bhardwaj R, Kannan A M, Singh H ,"Use of SWIRLS Nowcasting systems for quantitative precipitation forecasting using Indian DWR data" ,VOLUME 63, Number 1,Mausam, 2011,P 1-16.

Sulakvelidze G.K., 1969, Rainstorm and Hail, IPST Press, Jerusalam.

Vonnegut, B., 1949. Nucleation of supercooled water clouds by silver iodide smoke. Chem. Rev. 44, 277–289.

Witt, A., et al , An Enhanced Hail Detection Algorithm for the WSR-88D ,Mon. Weath. Rev., 1998, 13. 1998, pp 286-303.

Wiener, N. (1948). Cybernetics: or Control and Communication in the Animal and the Machine. Cambridge, Mass.: MIT-Press.