The concept of cloud base seeding with hygroscopic salts flares for hail prevention and rain precipitation. An actualisation.

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Abstract: A new method of hail prevention using hygroscopic flares has been used since 1995 in the South-West of France. The hypothesis is to accelerate the precipitation process with the goal of reducing the mean altitude of the centre of gravity of the storm. It is safe for Environmental aspects as it uses only calcium or sodium chloride produced by flares carried by aircraft at the cloud base. The mass of salt is minuscule compared to the mass of water produced by a storm. This method includes the potential for precipitation enhancement, as it was first developed in South-Africa for that purpose.

1. Introduction

In 1992, the results of a South African project on rain augmentation by means of hygroscopic flares (Mather 1997) raised the possibility of modifying the early stages of storm formation and thereby accelerating the rain process. This suggested that seeding with such flares might reduce the average altitude of the zone of high radar reflectivity and thereby induce more cloud water to precipitate before it reaches the hail formation zone. This event was previously observed in natural storms in Lot-et-Garonne (France), with or without hail; 50 storms with hail had a gravity centre of the zone source of intense reflectivity at a higher altitude, therefore colder, than 100 storms with only rain; all storms are documented with radar and a dense network of 400 hailpads and rain gauges.

A new experiment to test this novel type of cloud base seeding was started in 1995, and running through 1999, in Moyenne-Garonne (South-West of France). This experiment used mostly methods and tools developed in South-Africa, including flares with a mean salt particle diameter of 0.3 microns. It now uses new flares with different chemical compositions designed to increase the mean size of the salt particle to 0.5 and now to 0.8 microns.

The present paper proposes to discuss the experiences realized since the test stopped in 1999. Seeding with different types of flares is still conducted on a 4 000 Km² zone of the south-west of France while hail nets have spread over more than 40% of the orchards that are profitable.

2. The hygroscopic seeding hypothesis for hail reduction.

Figure 1 shows a vertical cross section of a typical hailing storm of the region as produced by TITAN (Dixon 1993). Zone A is where there is new high reflectivity corresponding to a strong and almost vertical gradient of reflectivity varying from 0 to 40 dBz in less than 2 km of altitude. The hypothesis underlying seeding is that higher reflectivities would have appeared a few minutes later at almost the same level, similar to those that had already appeared in zone **B** and where hail was already present, as was confirmed a few minutes later on the ground.

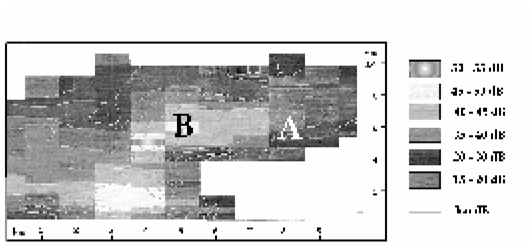


FIG 1 – Example of a VERTICAL CROSS SECTION

The concept underlying the present project is that cloud base seeding with hygroscopic salt particles (with a 0.5 micron average size) would favour the coalescence process and thereby modify the characteristics of the drop size distribution. As a result, the phenomena of zone **A** would be made to occur at a lower altitude, at which liquid water would not yet have reached hail formation conditions.

To be effective, this type of cloud base seeding has to be started at a very early stage of development of the storm.

In monocell storms, it has to start 10 to 15 mn before the appearance of 4O dBz reflectivity at altitudes where the temperatures are around or below 0°C. As in multicell storms, it has to continue for at least 15 min so as to affect most of the inflow of one new cell; it can continue for 30 to 40 min as would be done for a supercell storm, a rare phenomenon in this part of the world.

Conditions for seeding:

- adequate safety for the seeding crew and active radar recording to help the crew to find the best seeding zone,
- strong laminar inflow at the cloud base (more than 3 m/s vertical velocity) of a storm entering or already over the zone to protect, and having a high probability of hail
- cloud base temperature superior to -2°C.

Real time information regarding natural aerosols coming into the inflow would be very important but is not yet expected to be available in the near future.

3. Initial test: 1995/1999; First results

Experimental Design

Over an area of 8000 km² a ground network of 472 hailpads (3 km grid) and 114 rain gauges plus 10 weather stations has been installed. A 5 cm radar has been equipped with a South-African digitized system that can record a full volume scan every 3,5 min. The TITAN software (M. DIXON, 1993) processes the data and allows analysis of different variables such as storm identification, location, surface, volume, mass of precipitation, etc, as well as rates of variation of these parameters. Radar data are available since August 1995.

Two seeder aircraft were equipped with flare racks behind the engines and were able to carry 24 flares (the Aztec) and 40 flares (the Baron 55). A GPS with a PC recorded the flight track and the location and time of seeding.

There were two alternative seeding treatments. Treatment A used flares developed in South-Africa which contain mainly potassium and sodium chloride. Treatment B used flares made in France with calcium chloride. No placebo treatment was used and no suitable storms were allowed to be left untreated intentionally.

Allocation of treatment A or B to any one storm was randomized in order to allow unbiased comparison of the relative effectiveness of the two treatments. If a difference were to be found it would point, with some certainty, to the advantage of one of the treatments over the other. If no difference were found, it would leave open the question of whether both treatments were ineffective or equally effective. For a conclusive answer to that question one would have had to assign some storms not to be seeded, or to be seeded by placebo, an option that was unfortunately precluded by the organizational and financial constraints of the present operation. (For a discussion of this kind of experiment "piggybacked" on a seeding operation, see Gabriel and Changnon, 1982).

The program started in May of each year and terminated on October 10th. During the first two seasons, 1995 and 1996, both treatments were used successively, sometimes on the same seeded storm when the seeding lasted more than 24 min. The racks were loaded with equal numbers of A and B flares and a random choice was made which type to be used first, the other type being used when the flares of the first type were exhausted. Since 1997, only one type of flare is used on each day, the allocation being random. The method of randomization was changed in 1998 to an Efron procedure which ensures more balance (A. Koudou).

Statistical Analysis

A simple initial analysis encouraged the farmers to continue funding the experiment until now. This analysis had shown that of the 95 storms seeded over the network, **1)** 55 did not produce hail before, during and after the treatment, **2)** 27 stopped hailing after the treatment, **3)** 13 continued to produce hail during and after the treatment, **4)** No seeded storms started to produce hail during the expected seeding time effect.

More objective and precise analyses were initiated in 1998 when independent funding became available.

In June 1998 decisions were taken to compare the effect of the two flares. In order to minimize subjective decisions, it was decided to limit the analysis to hailpads within each seeded storm's tracks.

These tracks were to be delineated by means of TITAN software. However, that software was not yet accurate enough to distinguish the different cells that have been seeded. Instead, TITAN has produced storm cell mergers and divisions which have prevented the construction of a continuous record of data associated with each seeded cell.

Lacks of funding for research since 1999 obliged us to stop this analyse but we continue to record all seeding events with the radar and the ground network.

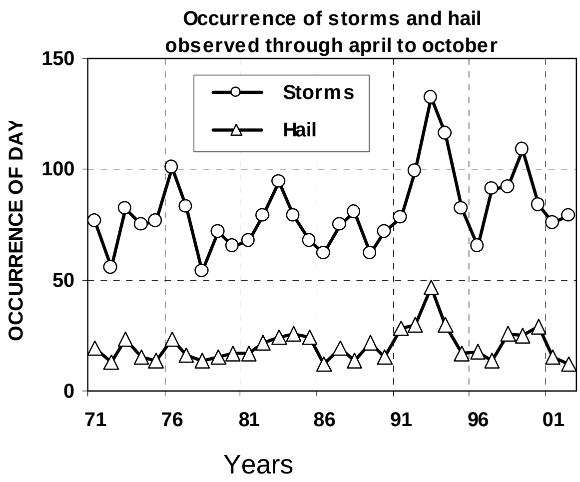
3. New results since 1999.

The funding for this research stopped in 1999 and as the farmers were very satisfied by the results they decided to fund themselves a prevention project over a 4 000 Km² area in Tarn-et-Garonne.

The Aztec has been assigned to this work from mid April until the beginning of October. Radar observation with TITAN is helping to operate the seeding program. A reduced ground network of 45 hailpads, 6 automatic and 13 manual weather stations, is able to describe every storm situation and to look at the results.

One of the most difficult tasks in weather modification remains the possibility to eliminate the natural variability hence to be certain that the supposed effect is really due to the seeding.

The following graph shows the variation of total daily storm and hail occurrence over our entire network (25 000 Km²) from April to October since 1971. Each time that at least one station observed a storm or hail in its vicinity, the occurrence was entered as 1.



We verify that the variation is erratic with periods when the occurrence becomes higher as in 1976, 1983, 1992/1994 and 1999. Hail occurrence follows well with $r^2= 0.54$.

On the average 48% of the hailing days are observed in April and May, leaving, from June till October, only one day with hail observed for five days with storms. The ratio is almost 0.75 in early April and goes down rapidly lower than 0.2 in May until October.
As already many times discussed, the problem is how to get a significant indicator of the effect of prevention when the natural phenomenon is already so variable and, in some cases, when the prevention starts when the risk is reduced naturally?

That is why, with the limited means we have now, we focus our observations on the behaviour of the field of reflectivity of the storm in the zone source (A zone in the Figure 1). Our indicator for a supposed successful seeding is when, 8 to 10 mn after the beginning of the seeding, we observe: 1) a radical fall of the average altitude of the maximum echo zone over the seeding zone, 2) an increase of the volume of maximum reflectivity (> 50dBz), 3) the altitude of max echo top increases or stays level and 3) only rain is observed on the ground.

As the three last years have been poor with storms and hail, the number of treated hailstorms is too low for a statistical analysis. For example in 2001 and 2003 only 12 storms were treated on the area. Our confidence is supported by the fact that all are showing the anticipated radar signatures.

4. Precipitation Enhancement and other developments.

Suggested by Mather (Cooper, 1997), we have been working on a new flare formulation using calcium chloride instead of potassium chloride. It is expected to have a better hygroscopic quality and a size distribution centred on 0.8 microns instead of the 0.5 of the first flares produced in South–Africa. We have also tested flares from USA which are still in development with NCAR.

Other projects in Europe and Africa have been in contact with us and are ready to prepare to use the new flare that is also useful for precipitation enhancement.

On this particular subject, the risk of a drought in our zone makes some farmers very suspicious about any weather modification project, fearing that it may reduce rain on their farm. The fact that we use for hail prevention a method originally elaborated for rain enhancement helps to convince these peoples on the seeding area, but not so easily those downstream. Information on the risks of hail and the time and location of the treatments are sent to more than 1200 persons twice a week allowing transparency and a possible dialogue.

5. Discussion

Our experience so far has taught us a number of things. First, it has become clear that every detail of the statistical design and protocol must be developed before the experiment is launched. That includes evaluation and choice of software for analysis. On the other hand, it also appears that these tools cannot be evaluated before consistent field results are available. That is why this first experience with the difficulties we have encountered leads us to the following conclusions.

1) Any project of weather modification has to be prepared well in advance with all the representatives from the people potentially concerned (for good or not) by the project. All social, economical and environmental aspects have to be discussed before, and the consequences accepted by all.

2) We must improve the performances of TITAN or any other tool so as to be able to follow each storm cell from an early stage until the dissipating stage, without confounding it with other cells. The new approach of recording lightning position inside the storms could be of help in obtaining direct indicators from the supposed seeded zone. This type of indicator should be able to reduce the difficulties for any analyses produced by the important natural variability of the hail phenomenon.

We hope that research in this field will be again possible to improve the Social, Environmental and Economical problems of areas regularly impacted by hail.

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References:

Cooper, W.A., R.T. Bruintjes and G.K Mather: Calculations pertaining to hygroscopic seeding with flares. *J. Applied. Meteor.,* **36**, 1449-1469. 1997

Dixon, M. and G. Wiener,: TITAN : Thunderstorm Identification, Tracking, Analysis, and Nowcasting- A Radar-based Methodology. *J. of Atmospheric and Oceanic Technology, Vol.* **10**, No. 6 785-797. 1993.

Gabriel, K.R. and S.A. Changnon ,jr.,:Piggyback weather experimentation : superimposing randomized treatment comparisons on commercial cloud seeding operations. *Weather Modification*, **14**, 7-10. 1982

Mather, G.K.,: Coalescence enhancement in large multicell storms caused by the emissions from kraft paper mill. *J. Applied Meteor.,* **25,** 1780-1784. 1991

Mather G.K., D.E. Terblanche, F.E. Steffens and L. Fletcher: Results of South African cloud seeding experiments using hygroscopic flares. *J. Applied Meteor.,* **36,** 1433-1447. 1997