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# The Fight Against Hailstorms in Italy, 1950–70: A Long History of Confirmation Bias

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This article analyzes the experiments for hail suppression by means of exploding rockets in Italy, where a remarkable national program of active defense was undertaken in the period 1950–70. The history of the trials of this technique is reconstructed in view of highlighting the methodological flaws of the entire experimental approach. A supplementary source of information is offered by about 1,600 "storm postcards": reports sent back by farmers after single weather events. An archive of these postcards, recently collected, digitized, and analyzed for the Trentino region (northern Italy), offers an interesting glimpse into the scientific and pseudoscientific approaches to a difficult to predict and volatile phenomenon, both for farmers and for appointed experts.

*Key words:* Hail suppression; Italy; Exploding rockets; History of meteorology; Confirmation bias.

## Introduction

The attempts to fight hail have a long history, often going back to folk beliefs that in some cases are still extant today.[1] Pagan beliefs, eventually integrated into the Christian practices, used to claim the presence of evil spirits in thunderstorm clouds:[2] this can explain the ancient custom of tolling bells in case of such clouds. Rituals connected with magical arts were recommended in antiquity, as for example reported by fifth century Irish bishop Palladius.[3] During the Middle Ages,

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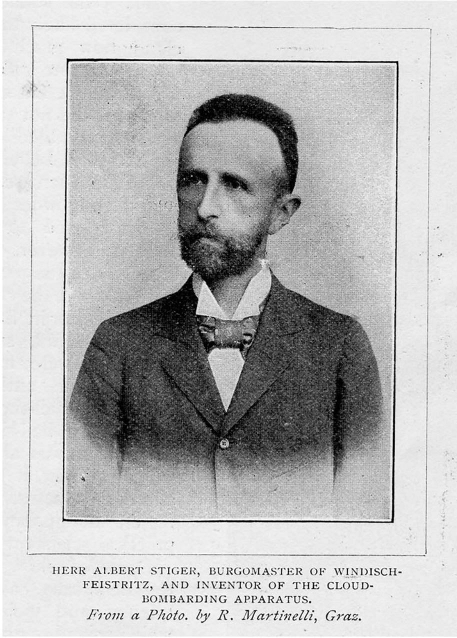
the connection between the most dangerous atmospheric phenomena and evil spirits was often condemned by the Church; however, in some cases, disbelievers were tolerated in their superstitions.[4] Pope Urban VIII (1568–1644) had authorized a prayer for the blessing of the bells: "Grant O Lord, that the sound of this bell may drive away harmful storms, hail and strong winds, and that the evil spirits that dwell in the air may by Thy Almighty power be struck to the ground."[5] Such practices were also condemned as an expression of pure superstition by German protestant theologians, such as Johann Michael Dilherr.[6] A recurring thought throughout the historical period in which every natural phenomenon could be justified by God's will, since the Middle Ages, was that hailstorms could be interpreted simply as an act of punishment for the sins of the communities hit by the damage.[7] In any case, the custom of ringing bells to dispel hail gradually disappeared, but remained popular in various parts of Europe until the nineteenth century; the case of France has been studied particularly by Alan Baker.[8]

As an example of a different attitude, the adventurous Renaissance artist Benvenuto Cellini (1500–1571), in his autobiography (1562), left a note of his successful cloud shootings in Florence: "I had pointed several large pieces of artillery in the direction where the clouds were thickest, and whence a deluge of water was already pouring; then, when I began to fire, the rain stopped, and at the fourth discharge the sun shone out."[9] The theory of the effect of acoustic waves (in this case, blast-generated sound waves) in hampering hail formation, or in destroying already formed hailstones, would be the natural evolution of that belief, already rather common in Europe in the fourteenth century;[10] the faint gap between superstition and science in the collective image of natural phenomena led to a reliance on physically aggressive actions against the threat, which was perceived as a consequence of evil forces.

A generic belief in the effects of the use of firearms on hail seems to have been present throughout history, and even in the 1970s there is evidence for the belief that hailstorms never occurred during military engagements that made use of heavy artillery.[11]

This approach became so popular in Austria and in Italy that severe accidents were often recorded among peasants. In 1750 Austrian empress Mary Therese banned hail cannons on those grounds, but also owing to the frequent protests, originating from the competing convictions that shootings might increase hailstorms or even diminish rainfall in the surrounding areas.[12] Following the technical development of agriculture in the late nineteenth century, the acoustic impact technique made ground. Bespoke anti-hail cannons were built in 1895 and tested by the burgomaster M. Albert Stiger (figure 1) in Styria (Southern Austria), based on an idea of Luigi Bombicci in Bologna (Italy),[13,14] who hoped for "a glimmer of chance to fight hail with healthy detonations." Cannons (figure 1) were to be operated when a hailstorm was already under way (a condition termed "beating hail").

This method was discredited after a two-year test at Windisch–Feistritz (southern Austria) and Castelfranco Veneto (Northern Italy) in 1898–99. In 1907



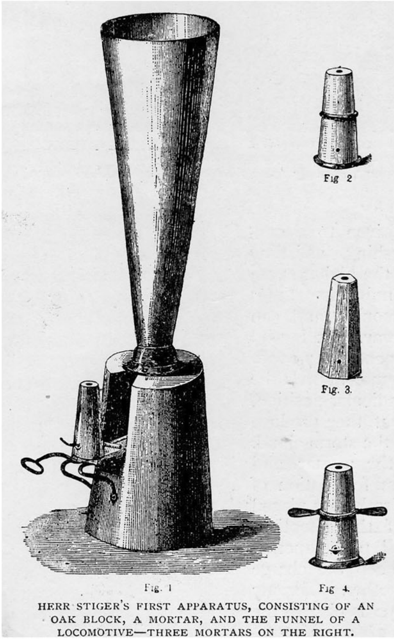




**Fig. 1.** Left: M. Albert Stiger, advocate of early hail cannons. Right: Stiger's prototype hail cannon. From "How Herr Stiger Fights the Hailstorms," *The Wide World Magazine*, New York (1900). *Credit*: Historical Archive "Pietro Laverda," Breganze (I)

the meteorological journal *Meteorologische Zeitschrift* published an interesting analysis concerning the factors that should have led to discontinuing the experimentation on explosive techniques to fight hail.[15] Nonetheless, anti-hail systems based on explosives continued to be proposed, with continual technological improvements in newly developed devices. Ultimately, in Jon Wieringa and Iwan Holleman's words: "the only beneficial effect of firing explosive rockets and grenades at hail clouds may be the emotional satisfaction of the gunners, who have fired at the enemy."[16] Nevertheless, to date hail cannons can still be found in the catalogues of several manufacturers around the world (e.g. for the Croatian market).[17]

In the period 1950–70 the Italian Ministry of Agriculture supported a huge national experiment to test the methods of active defence against hail, involving several regional players. This experimentation was based on a national network of local groups using exploding rockets (or other measures) and monitoring their effects by inviting observers to fill in and mail storm postcards. The latter had to be filled in at every storm event (at the observers' workplaces) from the late-nineteenth century till the early 1980s. This huge monitoring effort was probably unprecedented in the world, as far as weather phenomena are concerned. It can be framed in a pioneering "citizen science" approach to collecting widespread observations of natural phenomena. The development of such networks was connected with the wider establishment of observational networks and systems for archiving climatological datasets from weather observations which characterized that period (see the work by Edwards,[18] in particular chapter 10). A fuller account of the long-lasting effort made worldwide since the mid-nineteenth century to document weather data at increasingly numerous stations is reviewed in a comprehensive survey by Rob Allan et al.[19] Yet, this was not the only example in those years. For instance, in the USA, a storm-spotting network of volunteers, established in the early 1940s, operated as an integrated warning system which proved to be instrumental in decreasing the number of casualties of tornadoes.[20] Another similar example was the recruitment of artificial satellite spotters for *Moonwatch*, a program for amateur scientists initiated by the Smithsonian Astrophysical Observatory (SAO) in the USA in 1956.[21] In the same period, but in a completely different social and geographical context, a *citizen science* initiative for earthquake monitoring and defence was carried out in China during the Maoist period, involving several tens of thousands of lay participants.[22] It is worth mentioning two weather observational networks that emerged in Victorian England as early as in the mid-nineteenth century, overlapping with the institutional network of the Royal Meteorological Society: one by James Glashier, who established a voluntary network for meteorological observations of "about fifty zealous meteorologists," and another promoted by George James Symons, dedicated to precipitation, whose extent in 1887 can be estimated as over two thousand observers.[23]

In Italy, soon after the establishment of national unity under the Italian Kingdom in 1861, and the subsequent annexation of Rome and the surrounding territories in 1870, efforts were made to collect pre-existing weather observation activities into a unified service. In particular, on November 26, 1876, a government decree established a Royal Central Office of Meteorology (*Regio Ufficio Centrale di Meteorologia*), which represented the first attempt to set up a single national meteorological service, and a Board of Directors (*Ufficio Direttivo*) composed of meteorologists, chaired by Father Angelo Secchi (1818–1878). The Office began to function in May 1879 in the headquarters of the Roman College whose observatory, with the death of Father Secchi, had come under government control. Pietro Tacchini (1838–1905), a renowned astronomer, geophysicist and meteorologist, was appointed as its first director.

Under the guidance of Tacchini, the Office was organized into five sections: the first for the calibration of the instruments, the second for the study of climatology, the third for weather forecasts, the fourth for seismology and finally the fifth for agricultural meteorology.

As part of a major project for monitoring hail events, a dense network of observers was established in 1879. The network recorded virtually all major storms. During the period of this experimentation, storm postcard forms were expanded with further questions and spaces to be filled after hailstorm observations, including not only the impact, but also the presumed effects of exploding rockets or other hail-suppression techniques eventually adopted.

In this case, involving a large network of volunteers (often, however, driven by direct economic interests), especially in the early decades after World War II, leaned on enthusiasm for the "new" field of weather modification, in turn benefitting from the optimistic idea that modifying the weather could be easier and more convenient than adapting to it. The context of the postwar period meant the research effort was still militarily-oriented, and naturally inclined toward a possible strategic exploitation of the results. In the United States, the wide availability of funding to support technological innovation for military purposes further favored this process.[24] Moreover, those techniques, applied to fields other than hail-fighting, fitted well with the general purpose of incorporating weather modification into the arsenal of weapons potentially usable at a larger scale in the Cold War context.[25] In this regard, the words pronounced in 1953 by General George Churchill Kenney of the Strategic Air Command are lapidary: "the nation which first learns to plot the paths of air masses accurately and learns to control the time and place of precipitation, will dominate the world."[26] Perhaps it is not entirely by chance that, in the context of Italian anti-hail campaigns, the vocabulary in use for describing the tools and activities carried out by the personnel often involved concepts (like "fighting" and "defending") borrowed from military jargon.[27]

In addition to other past reviews of hail suppression in the twentieth century (such as the work by Stanley Changnon et al.[28]) this article aims to illustrate and discuss the birth, development and end of the fight against hail in Italy, in its technical and—above all—monitoring aspects. In particular, the story of the fight against hail by means of exploding rockets is analysed through the available technical reports and documents, including the archives of storm postcards. In hindsight, results of that experiment were influenced by confirmation bias and by an ill-posed survey, which led to results that apparently have never really been questioned.

## Documentary Sources

The archival research required for the present work was carried out in the frame of two projects, namely ASTRO and ASTRO2 (2012–17),* coordinated by CREA–AA (*Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria*, or Research Unit on Agriculture and Environment, Rome) and *Fondazione Edmund Mach* (in San Michele all'Adige, Trento, Italy). The two projects aimed to enhance meteorological data collection in the Province of Trento and create an integrated digital weather-climate archive. The projects allowed the extension and

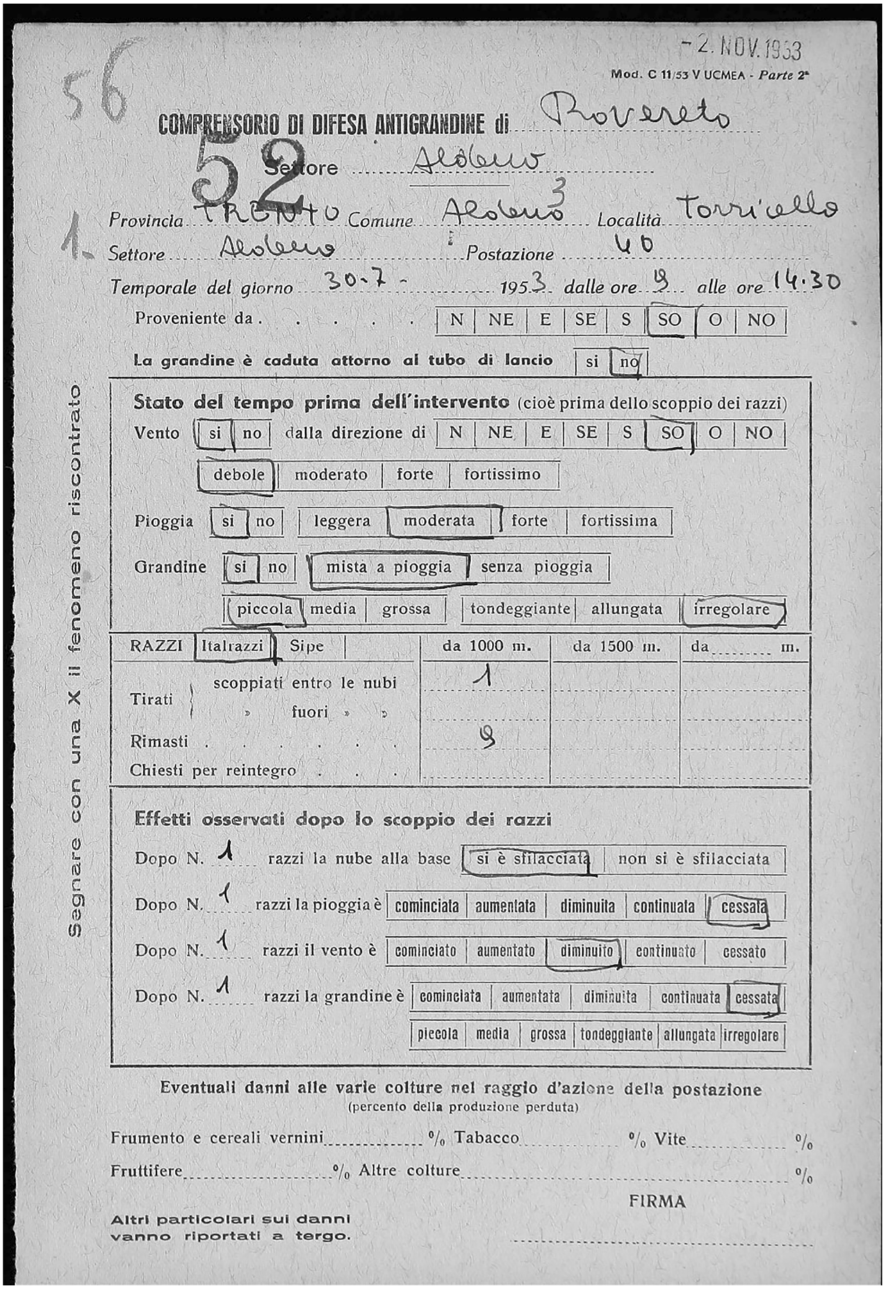
* Project ASTRO2, CREA-AA, report by Rocco Scolozzi et al. Available at CREA-AA archives. Note: all quotations originally in Italian were translated by the authors of this paper, except for Benvenuto Cellini's *Autobiography*.[9]

enrichment of the historical climate series, retrieved from original documents stored in public libraries and other institutions, for the scientific purpose of climatic characterization, but also to recall and appreciate the work carried out in the survey stations by those who worked there. This article focuses on the archive of "storm postcards," event record sheets named in the original Italian *cartoline dei temporali*, related to the investigation of anti-hail campaigns. These event registration cards were filled in for a number of sites all over Italy from the late-nineteenth century until 1981 (examples in figure 2). For Trento Province, these documents were recovered from collections held in historical libraries and Franciscan convents,* such as Trento Municipal Library and the Library of the Franciscan Convent of San Bernardino, Trento.

A total of 1,618 storm postcards from 105 sites in Trentino were recovered, scanned and read. Their format changed over time, following changes in information requirements. A national public office named *Servizio dei temporali* (Storm Service), part of the Central Office of Meteorology (*Ufficio Centrale di Meteorologia*), was in charge for editing, printing, and distributing, while the compilation was left to voluntary farmers, coordinated by local farmer organizations (such as agricultural consortia).

The collection of information on thunderstorm events detected over national territory was part of the institutional activity of the Central Office of Meteorology, as mentioned, from the beginning of its operation in 1879 until the 1980s. This extended period of activity led to the counting and documenting of about 50,000 storm events. Postcards were distributed to all stations in the government network which had a correspondence with the Office (thermo-pluviometric stations, private citizens, astronomical observatories, weather stations of educational and religious establishments, harbourmasters' offices and the signallers of the Italian Royal Navy). The postcard forms were to be signed by chief officers: the mayors, in case the postcards were collected by the respective municipalities, or the directors, in case the report was written by observatory staff. Templates were designated by a code and, eventually, by the last two digits of the year of printing; they were modified and updated with each reprint. In total thirty-four different formats were found, which differed not only in their graphic layout, but also in the quantity and type of information requested. Since 1951, the postcard formats in use (e.g. model C5) included specific information concerning hail-related damages, referring to a variety of different crops, affected areas and any documented hail suppression activity. Some formats explicitly referred to the exploding rockets. The format most useful for the purposes of this work was C11, containing specific information about hail, type of rockets in use and their effects on wind, rainfall and hail.

* In Trentino Franciscan convents had a long tradition of hosting weather stations and appointing friars for daily observations and data recording since the early establishment of a Central Meteorological Service under the Austrian empire.



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– 2. NOV. 1953

Mod. C 11/53 V UCMEA - *Parte 2ª*

**COMPRENSORIO DI DIFESA ANTIGRANDINE di** Rovereto

52 Settore Ala

Provincia Trento Comune Ala 3 Località Torricello

1. Settore Ala Postazione 40

Temporale del giorno 30-7- 1953 dalle ore 13 alle ore 14.30

Proveniente da . . . . . . | N | NE | E | SE | S | SO | O | NO |

**La grandine è caduta attorno al tubo di lancio** | si | no |

Segnare con una X il fenomeno riscontrato

**Stato del tempo prima dell'intervento** (cioè prima dello scoppio dei razzi)

Vento | si | no | dalla direzione di | N | NE | E | SE | S | SO | O | NO |

| debole | moderato | forte | fortissimo |

Pioggia | si | no | | leggera | moderata | forte | fortissima |

Grandine | si | no | | mista a pioggia | senza pioggia |

| piccola | media | grossa | | tondeggiante | allungata | irregolare |

| RAZZI Italrazzi Sipe | da 1000 m. | da 1500 m. | da ...... m. |
|---|---|---|---|
| Tirati { scoppiati entro le nubi | 1 | | |
| Tirati { » fuori » » | | | |
| Rimasti | 9 | | |
| Chiesti per reintegro | | | |

**Effetti osservati dopo lo scoppio dei razzi**

Dopo N. 1 razzi la nube alla base | si è sfilacciata | non si è sfilacciata |

Dopo N. 1 razzi la pioggia è | cominciata | aumentata | diminuita | continuata | cessata |

Dopo N. 1 razzi il vento è | cominciato | aumentato | diminuito | continuato | cessato |

Dopo N. 1 razzi la grandine è | cominciata | aumentata | diminuita | continuata | cessata |

| piccola | media | grossa | tondeggiante | allungata | irregolare |

**Eventuali danni alle varie colture nel raggio d'azione della postazione**
(percento della produzione perduta)

Frumento e cereali vernini ...... % Tabacco ...... % Vite ...... %

Fruttifere ...... % Altre colture ...... %

FIRMA

**Altri particolari sui danni vanno riportati a tergo.**

**Fig. 2.** Model C11/53, the most complete form of storm postcards, which included detailed information on the operation and functioning of rockets. *Source*: project ASTRO2 archives, CREA, Rome

The documentary sources were supplemented by interviews with people who had worked on hail-fighting campaigns in Trentino since the 1950s. Some former operators, currently retired, provided interesting eye-witness accounts on operational protocols, as well as on the history of the organization and management of hail suppression in Trentino.[29]

## Functional Principles of Exploding Rockets

The need for formulating hypotheses about the mechanisms underlying the rocket defence method resulted in a heuristic approach: presuming the effectiveness of the method, scientific theories were then sought for explaining the causal relationship between the explosion and the disruption of hailstone formation. Accordingly, different physical mechanisms were invoked to explain the (presumed) working principles of exploding rockets by the effect of air pressure waves, on the basis of the theories briefly summarized below.

### *Hail Formation Suppression*

This mechanism was considered in connection with acoustic-wave devices (cannons), and dates back to the work by Luigi Bombicci, who proposed his explanation as early as 1890.[30] His theory proposes a disruption mechanism acting in the initial phase of hail formation, claiming that pressure waves prevent the growth of hailstones through air vortices generated by the blast.

### *Water Droplet Freezing*

Water is supercooled when its liquid state is thermodynamically unstable; under these conditions, a quick change of status to solid ice can be promoted by a small mechanical perturbation, such as a sudden pressure impulse. In the lower part of the cloud, independent freezing of supercooled water would occur following a pressure wave,[31] leading to a large number of ice particles, whose coalescence and growth would be hampered by the "competition" for the water supply in the cloud, due to their numerosity. This effect was already quoted by Bombicci as one of the possible mechanisms operating in the acoustic wave technique.[32]

### *Cavitation Effect*

This mechanism would act against already-formed hailstones that contained air bubbles embedded in the ice. The latter would be broken by the pressure wave generated by the blast, leading to the collapse of the hailstones; researchers often attributed this idea to the work by A. E. Crawford.[33]

Invoking several independent mechanisms to explain the phenomenon marks the weakness of scientific understanding: here a supposed physical explanation was invoked only for the sake of supporting a procedure, presumed to be effective before any validation.

Nevertheless, the most likely theoretical conceptual scheme, and the subject of scientific investigation, was, with just a few exceptions, the cavitation theory: laboratory experiments confirmed the phenomenon and a consequent hailstone softening, leading to a harmless fall, as postulated by O. Vittori[34] and G. Roncali.[35] However, just a few years after Vittori's paper, the practical applications of this theory were seriously contradicted by experiments,[36] showing that a blast of one kilogram of TNT was ineffective in damaging hailstones five meters away, in contrast to the claimed 150 m. On the other hand, an experimental confirmation of Roncali and Vittori's thesis came from the work of Roger Favreau and Guy Goyers.[37] Keith Browning[38] also presented observational evidence that the natural breakage in mid-air is not an uncommon phenomenon in hail-bearing clouds, and above all that broken hailstones have the ability to recover their size, easily resuming their growing stage.

The action of water spray seeding, consisting of injections of supercooled water droplets into clouds, was not contradicted by the scientific community, but nor did it receive the attention of a dedicated test, being probably considered too weak to modify the dynamics of the large volumes in question. However, regardless of the scientific grounds, the use of exploding rockets spontaneously spread as a bottom-up initiative, from the French experience started in 1936 from farmers' organizations,[39] and boosted by a contagious excitement. Since 1949, in Italy self-organized campaigns were initiated by local consortia, such as in Cenate (Lombardy)[40] and around Asti (Piedmont).[41] Reports on these attempts fully supported the use of rockets, with, as put in one such report, a "unanimous agreement of technicians, meteorologists, academics, farmers."[42] Interestingly, the physical principle invoked in the referenced report is the vortex disruption and dispersal of glaciogenic nuclei—particles naturally present within the cloud, and responsible for ice cluster formation—before the nuclei come into action.

In those years, one further explanation was proposed for the formation of hailstones, recalling an old theory[43] which claimed that electricity would be a necessary agent in hail formation. Accordingly, hail formation would be hampered if the static electric charge in the cloud could be decreased. This theory stimulated an experiment in an area near the city of Asti (Piedmont) based on new ionising oxides, of unspecified nature but made up of radioactive material, and promising "indisputable and positive" effects;[44] some more detail can be found in Paolo Desana's report on hail defence in Italy (1956).[45] However, that thesis had been already confuted by Bombicci (1956), on the basis of observational evidence.[46]

In the postwar period, Ezio Rosini was among the first, in Italy, who tried to explain the physical mechanisms of hail fighting techniques.[47]* According to his reports, the method of exploding rockets consisted of arranging a network of firing positions in the territory to be protected, a few kilometres upwind of the expected storm paths, namely, the most common paths according to experience. However, the theoretical bases were not clear and ascertained. In Rosini's words: "The method of the exploding rockets lacked the scientific preconditions; whereas silver iodide burners were introduced after initiatives of institutions and personalities of high scientific profile, rockets were promoted as bottom-up initiatives, motivated by the urgency of pursuing protection practices, and supported by empirical insight."

Still in 1949, in a work by Dino Rui,[48] director of the anti-hail service in Verona, the opinion that exploding rockets should be "retired" was opposed by the author, who expressed his confidence in their effectiveness. On the other hand, he welcomed experimentation with the "new'' seeding techniques, as a preventative action, to be employed in association with shooting. But from a review of the publications that appeared from the 1950s through the early 1980s, it is evident that scientific interest around hail suppression exclusively focused on the use of nucleants, neglecting the discussion on exploding rockets. Rosini[49] in his 1958 report (for Italian, non-specialist readers), considered two methodological approaches for the hail fight, both based on cloud seeding. By quoting the new 1958 anti-hail campaign in the Verona area, which could boast the supervision of the scientific design by an internationally recognized scientist like Frank Ludlam from Imperial College London, he states that "statistics no longer has a place in it, the thunderstorm being attacked using pure physical methods, on the score of a rational theory on hail formation." A theory that, according to Rosini's purposes, should have found a confirmation in the results of the experimentation as a matter of urgency. Rosini eventually returns to the topic of the decline of statistics in the experimentation, which, in his opinion, had, by then, become "a simple chapter," being outweighed by the possibilities offered by physical and synoptic meteorology. Thanks to the latter, in his concluding remarks, Rosini invokes the institution of a meteorological prediction service released from the national air force and oriented to agricultural use, namely for the prediction of thunderstorms, or precipitation in general.

Other reports, for example by Ottavio Sarrica,[50] account for the available techniques and their diffusion not only in Italy, but also in France, Switzerland and the Soviet Union (USSR), but no analysis of their effectiveness. The "Sovietic"

* Ezio Rosini (Parma 1919–Roma 2002) was a physicist and mathematician, researcher in geophysics at the Italian National Research Council (CNR), officer of the Meteorological Service of the Air Force, from 1949 professor of meteorology and climatology at the University of Rome, delegate for Italy in the Commission of Climatology of the World Meteorological Organization and director of the Phytopathology Observatory of the Veneto Region.

method is given wide space in the work by Vento,[51] who reported in Italian the main contents discussed at the International Conference on weather modification held in Tashkent (USSR) in October 1973, attended by 268 participants from twenty-eight countries. Again, the only technique considered was cloud seeding.

Franco Prodi[52] provided a concise critical overview of the state of the art in hail suppression techniques in 1981. In France three groups were active. In particular, in southern France around 420 ground-based generators with silver iodide were arrayed over an area of about 70,000 km$^2$ and more in the regions of Beujolas and Bourgogne. In Garonne, initially aeroplanes were used to disperse nucleating agents, while at the same time, rockets conveying the nucleating substance were launched from mobile bases.

In the United States, a large-scale five-year hail-prevention program was performed by scientific units, with assessment of efficacy by comparison with non-inseminated reference areas.

In Yugoslavia, Hungary, Argentina and in nine USSR republics the so-called “Sovietic” method was applied. The nucleant substance was carried by high-altitude rockets from launching bases, regulating both the trajectory and the timing of injection of the nucleating substance into the cloud. Side effects were highlighted, because big fragments of the rockets, not provided with a parachute, could fall down and cause damage. The efficacy of these methods was verified on the basis of reported damage in the area before and after the operation.

In the same paper, an account is given on the most important European experiment on hail control, the Grossversucht IV, carried out in Switzerland by Swiss, French and Italian partners. On half of the potential hail days the insemination was performed, while on the remaining half no action was taken, as they were intentionally left as a control. The intensity of hail at ground level was monitored by means of a network of hail pads, whereas mobile platforms on vehicles observed spectra of droplet radii and collected hailstones. By the time of Prodi’s review article, this experiment was not yet finished.

A milestone in the awareness of scientific understanding about processes connected with suppression techniques was the “Meeting of Experts on Dynamics of Hailstorms and Related Uncertainties of Hail Suppression” held in Geneva in February 1981. Contents discussed therein are summarized in a WMO report[53] offering a review of the state of studies on the dynamics of hail formation. Admittedly, previous optimism in progress about understating hail formation processes, reflected in various operational suppression programs started world-wide, was diminishing due to recent rather inconclusive results of some projects. In particular, recent studies had highlighted that processes controlling hail formation were revealing more complex aspects than previously thought. A categorization of hail thunderstorms into three classes—namely single cell, multicell and supercell—seemed to be applicable in many parts of the world. However hail damage worldwide seemed to be determined by storms which did not fit these categories.

Also, the mechanisms of storm processes did not seem adequate to support adequate predictions of the effects of seeding. The inadequacy of the current classification schemes, the yet unresolved role of smaller scale motions (i.e. less than few kilometers) in the process of hail growth, the intrinsic difficulties of implementing seeding strategies based on the coalescence processes in regions where this mechanism did not seem to occur (i.e. where large droplets were not usually observed) were all aspects that clearly pointed out the need for further investigations and to reach a better understanding at a level required for a more reliable approach to effective hail suppression.

## Hail Suppression Campaigns in Italy with Exploding Rockets: The Early Years of Enthusiasm

The late 1940s were years in which meteorology was experiencing a real paradigm shift, moving towards supercomputers capable of performing operations hitherto unthinkable, and pursuing the idea of soon using computational models for weather modification actions, including for the benefit of agriculture. In the US, in the framework of the "Meteorology Project," officially started on July 1, 1946,[54]* the confidence in the practical consequences of advances in numerical weather prediction transpired from Von Neumann's words: "[the Meteorology Project would take] the first steps toward influencing the weather by rational, human intervention […] since the effects of any hypothetical intervention will have become calculable."** The quoted document, indeed, included weather control in his project aims. So high was the confidence in the opportunities of a human intervention on weather, the use of nuclear weapons was considered to reduce the threats of hurricanes.[55]

In Italy, apart from some self-organized and pioneering experimentations between late-nineteenth and early-twentieth century, carried out by acoustic wave cannons, the year 1949 marked the start of a series of official experimental campaigns which lasted until the early 1960s. These campaigns were supported by the Anti-hail Advisory Board—established by the Italian Ministry of Agriculture and Forests—under the coordination of the Phytopathology Observatory of Veneto, directed by Dino Rui, a key figure in Italian anti-hail experimentation at the time, and author of several important papers and reports.

* In January 1946, a New York Times article "announced "a" plan […] for development of a new electronic calculator" aimed at "solving the mysteries of long-range weather forecasting." The US Weather Bureau, with the Navy and the Air Force Weather Services, granted the funds necessary for a "Meteorology Project" at the Institute for Advanced Studies (IAS), aiming at developing computer forecast methods. This project started six years before the IAS computer would be completed.[18]

** Justification Memorandum, PD #ENI-22/00028, the Institute for Advanced Studies, 6 June 1946. Quotation from Harper.[55]

The first campaign was carried out in 1949 on 33,000 hectares, in 266 town districts. A variety of crops were cultivated in the farms where the experimental campaigns were carried out; however, the most valuable vineyards were always involved, particularly in Piedmont, Veneto, Trentino—Alto Adige. The very first report records that "if an even more gratifying judgement cannot be expressed, it is just because the interventions were not numerous [...]; some due reservations totally fell in front of the enthusiasm, or rather the euphoria coming over the farmers who saw anti-hail rockets at work."[56]

Since the second year of the experimentation (1950) the Ministry had established an Advisory Board for hail suppression, composed of field technicians, meteorologists and ballistic technicians. Experimental campaigns took place one year after another, with technical improvements, increases in the area under control and local hail-fighting consortia more and more involved in the assessment of results. The placement numbers and surface areas of the Italian consortia for the first five campaigns are shown in table 1.[57,58]

The local consortia that carried out the active defence operations were requested to answer a few questions concerning the effectiveness of the hail fight and their own willingness to continue the campaign in the following year. The opinions of local consortia were generally positive, advocating a wider use of rockets and the inclusion of surrounding territories. Positive judgements were generally expressed even when technical problems were recorded, as in 1953: "Premature blasts, head ejections, missed ignitions, bangs in the downward trajectory, vane breaks [...] always due to the non-compliance of the precise precautionary rules issued by the competent bodies and duly recalled by the firms, also owing to an excessive trust in the devices, in defiance of the fact that they are composed of explosive matter."[59] In that year, a second group of questions were directly asked to rocket operators, who had positively answered on the effectiveness of the method: under which conditions were rockets supposed to give a positive effect; what this positive effect was; what the presumed percentage of rocket effectiveness was; and a question about the possibility of improving hail defence, and how. In total, 131 districts agreed that the positive effect occurred in cases of a timely action with simultaneous firing, and when rockets exploded inside the clouds. No answer was received from another nineteen districts.* About the improvement, a widening of the equipped districts was suggested, invoking the compulsoriness of defence, as well as a higher number of placements and a greater

* Common answers on the effect of rockets were like the following: "hailstones turning into sleet, or their smashing on the ground," "stop of hailstorm," "cloud disappearance and wind cessation," "hail attenuation with removal or reduction of hail damages."

**Table 1.** Use of anti-hail rockets in Italy in the period 1949–1955

| | 1949 | 1950 | 1951 | 1952 | 1953 | 1954 | 1955 |
|---|---|---|---|---|---|---|---|
| Surface (ha) | 38,000 | 145,000 | 225,000 | 418,562 | 489,875 | 570,000 | 555,000 |
| Placements | 270 | 1,266 | 2,930 | 6,303 | 7,989 | 9,836 | 9,807 |
| Provinces | 2 | 8 | 16 | 22 | 22 | 24 | 24 |
| Active experiments | 2 | 12 | 35 | 61 | 81 | 113 | 140 |

"withering fire," the use of more powerful, elevation-adjustable rockets and, to a lesser extent, a lower price for rockets—or public financial support.*

In outlining the fortunes of the explosive rocket technique, it is worth mentioning another aspect, totally unrelated to scientific aspects: there was a general growing interest for the development of a new industry. The first Italian campaign (1949) had made use of French rockets by the Ruggieri firm, Montreau. In 1950, the Italian firm Terrazzo started its rocket production in Peschiera del Garda (Veneto region). Technological improvement on the rockets enabled them to carry the exploding charge over 2,000 m in altitude, instead of the 1,000 m of the models on the market at the time, increasing the expected efficiency. The feedback from farmers was very positive: as an example, near Bolzano, in south Tyrol, "the effect was evident, because after shootings had started (105 rockets) the storm had turned into rain, determining a favorable impression in farmers in the area of Appiano/Eppan."[60] The long-lived national campaign fostered the industrial development of national rocket production, which had a hard time in satisfying the domestic and international demand (figure 3). Two main companies emerged in the production of exploding rockets in Italy, namely Italrazzi (Sommacampagna, Veneto region) and SIPE (Milan). The latter, with several factories in different Italian regions, concentrated on the production of explosive products, also for military use. In the 1958 report on anti-hail campaigning,[61] one paragraph is dedicated to the development of a national industry of rockets, witnessing a growing demand from abroad. A new business was gaining strength and, clearly, the interest was considerable for its progression; in 1960 Italy was the foremost producer of anti-hail rockets in the world.

* Rockets in Trentino were used with different burst heights (1,500 to 2,000 m), according to the assessment of the height of the cloud base (communication by C. Furlani, interviewed by the authors, Trento, July 20, 2017).

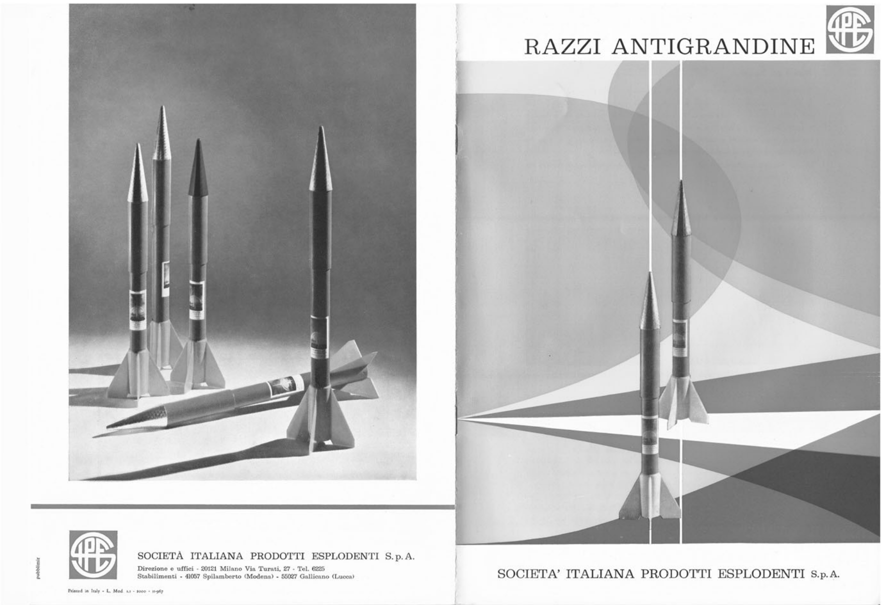


**Fig. 3.** Back and cover of an advertising leaflet for SIPE exploding rockets. *Credit*: Historical archive 'Pietro Laverda,' Breganze (I)

## Seeds of a Crisis in the Confidence in Exploding Rockets at the Turn of the Decade

The hail fighting campaigns, until then based on the exploding rocket technique, had witnessed the appearance of silver iodide rockets in 1955, which added a new agent of hail prevention, by joining the two mechanisms of shock waves and cloud seeding. A limited number of these rockets had been used also in 1956, and in that year in some areas of Piedmont even the use of some ionising oxides is recorded, making use of unspecified substances, neither authorized, nor recognized by the Ministry.[62] Interestingly, when commenting on the results of the 1955 campaign, the postulated incomplete effectiveness of exploding rockets was cautiously overshadowed by the idea that the protection assured by that technique could have reached its operational limit, calling for additional measures to attain a full protective result: "from the examination and the evaluation of the elements collected in the 1955 campaign, it is deduced that the defence has attained a saturation limit in most of the Po Plain. […] it is highly desired that a compromise is reached between the active defence and the insurance option against the damages of this meteorological agent […], to cover the hail risks that still remain in the areas protected by rockets to date."[63]

In 1958 and 1959, a campaign was planned by the National Anti-Hail Union according to a better-organized design with substantial support.[64,65] In the words of the anonymous compiler (perhaps its director, O. Romanelli), recalling Rosini's report of 1958: "Those who operated the defence upheld the belief in its effectiveness, but in practice they could not oppose those who denied it by such an evident, objective proof that could be accepted as a scientific demonstration. On the other hand, being the defence rather complex from the organizational point of view, farmers themselves urged a verdict from science, to ask for rules adequate to the needs and similar to the standard already ongoing in other fields of agriculture." The experience of 1958 had been claimed as very promising: for instance, in the province of Verona, important innovations were introduced, involving the use of a radar and physical measurements inside the clouds, with the use of aircraft and sounding rockets, to test both exploding rockets and nucleating agents, mainly silver iodide (AgI).[66] This was the very first test of this kind in Italy, carried out in collaboration with the University of London (Frank Ludlam), the Meteorological Service of the Italian Air Force (Ottavio Vittori) and the Central Office for Agricultural Ecology—UCEA (Ottavio Sarrica).

Starting from that experience, more intensive experimentation in the following year in eastern Lombardy and Veneto regions aimed at two ambitious goals:

- Increasing the theoretical knowledge on hail formation (particularly on the nucleation effect), as put forward by Ludlam.[67,68]
- Building a measurement and observational system enabling a straightforward probative value; this outcome was sought in order to "outdo the statistical method," which was too poor, according to the proposers.

The latter judgement on the statistical evaluation of results betrays the willingness to explain, perhaps, more the phenomenon of popularity of the method, rather than the results obtained. The impossibility to detect a positive effect would have been itself worth further statistical analyses. However, the increasing dismissal of the idea that the effectiveness of the method could have been quantitatively assessed, went hand in hand with the growing interest surrounding the experimentation on hail defence, and with scientific engagement in the campaigns. The two-year experimental campaign of 1961–62 was organized under the auspices of the Ministry of Agriculture and Forests, with the collaboration of the National Weather Service operated by the Air Force and of the National Anti-Hail Union. It boasted a wider vision, in comparison with the campaigns done until then, which had generally resulted from the sum of the initiatives of local partnerships. The campaign also gained advantage from results presented at the Congress of the International Geophysical Union, hosted in Verona by the Italian National Anti-Hail Union in 1960. The aims of this experimentation were twofold:

**Table 2.** Results of the two-year national campaign 1961–1962. Data as reported by Ufficio Tecnico Antigrandine[72]

| Year | Districts | | Evaluations | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Nr | ha | Excellent or good | | | Satisfactory or fair | | | Partially favorable or uncertain | | | Adverse or negative | | |
| | | | Nr | Percentage | | Nr | Percentage | | Nr | Percentage | | N° | Percentage | |
| | | | | Nr | ha | | Nr | ha | | Nr | ha | | Nr | ha |
| 1961 | 120 | 334 | 75 | 79.0 | 73.3 | 12 | 12.6 | 18.8 | 6 | 6.3 | 6.2 | 2 | 2.1 | 1.7 |
| 1962 | 134 | 339 | 78 | 72.2 | 70.8 | 20 | 18.6 | 21.4 | 9 | 8.3 | 7.0 | 1 | 0.9 | 0.8 |

- Testing the use of exploding rockets.
- Collecting observational data of hailstorms.

The scientific section of the experimentation, aimed at investigating the physics of cumulonimbus clouds during hailstorms, envisaged the use of rawinsondes, balloons and radar equipment. Over 3,000 emplacements in northern Italy were coordinated under the guidance of Ezio Rosini. In his introductory report, he stated that at that moment trust in the efficacy of nucleating salts was still low, suggesting to exclude this method from the experimentation: "Given the provisional conclusions attained by the experimentation officially carried out abroad in the last years, we find it questionable to insist on the tools presently available for the trials with ground-burned nucleating agents."[69] The results of the experiments (Table 2) were positively evaluated, but the final conclusion, by the National Anti-Hail Union, claimed that "the operation [with exploding rockets], presently carried out in beating hail conditions cannot be carried out but as a method of extreme defence." This was a confirmation that since the early 1960s, interest in exploding rockets was already fading, while attention was turning to other systems, in particular the nucleating agents.[70] The same people who at the beginning had been enthusiastic—or at least confident—about the rocket technique and had defended that technique against the emergent approach of nucleating salts, now distanced themselves, criticising the supportive statistics. In Rosini's technical paper of 1965[71] the following words can be read:

> The problem existed for farmers who found rockets effective and multiplied their use and, by extension, for the national institutions responsible for the coordination and development of agriculture; for the sake of economic engagement and due to their designated roles, the latter were urged to take a position. Simply for such reasons, the above-mentioned institutions promoted the "Italian scientific experimentation."

Hence, one can infer the questionability of the judgements on rocket effectiveness collected by the forms filled by rocket operators. Similarly, data from the storm postcards, analysed years later, were not able to supply further information to the campaign planners, nor to provide any validation of the method. The questions asked by the Anti-Hail Advisory Board were formulated in a way that the statistics on the judgements, inferred from the subjective answers of the operators, would have easily led decision-makers to continue the experimentation, or even to implement a campaign, resting on a genuine experimental design. Despite the request for comments on the goodness of the method, field operators were apparently under little or no supervision by the scientific community. On the other hand, the decade-long campaign had totally relied upon the presumed validity of the method, whose evaluation had never been able to rest on an objective, quantitative assessment of its results.

In any case, the endorsement of the exploding rockets method would be soon withdrawn by the proposers themselves. Particularly, the enthusiasm of the most widely-recognized scientist in Italy for the study of hail, Ezio Rosini, would fade, faced with the lack of experimental evidence. After several years spent investigating protection methods, Rosini wrote: "We cannot experiment, sustained by the mere and generic hope to get some good result, without the guidance of a well-defined theory or at least of a working hypothesis."[73] This somewhat bitter statement, expressed in a comment on the national experimentation started in 1961, summarizes a need which had finally led to an ambitious project, where organizational difficulties had, in Rosini's opinion, partly undermined the expected results. This project had found its way after years of experimentation on a seasonal basis, confirmed year by year, with obvious difficulties in planning and in ensuring operational continuity. The results, summarized in table 2 for the campaign of 1961–62, confirm, once more, the highly favorable evaluation of the effects of rockets as perceived by observers.

Being one of the committed sponsors of the active fight against hail, Rosini could not be expected to distance himself from the defence consortia; their assessments were reflected in those expressed in the storm postcards by voluntary observers (including many rocket operators), which had contributed to the enthusiastic evaluation of the success of exploding rockets. Nevertheless, Rosini, as a scientist, could not help but remark on the methodological faults in the protocols of both implementation of the method and assessment of its results.

The same mood can be found in Rui's words about the objective difficulties in defining a rigorous experimental design—a necessary premise for a proper statistical analysis—the lack of which had hampered any attempt to give a scientific demonstration of the effectiveness of the method:

> To reach the goal of producing the compelling documentation about the […] real effectiveness of rockets, in which farmers had believed from the very start […], at the beginning it was decided to statistically investigate the results; however, the latter method did not prove the most suitable for the aims to be pursued and was replaced by other techniques, particularly when professors

> Rosini, Vittori and Sarrica were entrusted the above mentioned scientific experimentation, with adequate experimental equipment at their disposal.[74]

Hence, the new front for legitimising the continuation of the experiments with exploding rockets had turned into an attempt to explain the physics beyond the technique, especially the validity of the mechanism of cavitation.

On the contrary, within a few years, the completion of the *Grossversucht* experiments, carried out by a French-Italian-Swiss team,[75] particularly the fourth (1977–81), would enshrine the randomized method* as the one capable of attaining a judgement on the validity of the "Soviet method" of cloud seeding. This experiment received a preliminary negative opinion from Soviet scientists, who objected that those approaches were not identical to the ones they had used on their own territory, and suggested an aversion to the application of an independent experimental design.[76] The randomized method allowed the total decoupling of the results from the subjectivity of the decision maker, avoiding a bias of the outcomes. Yet, the latter approach would have required a long-term designed experiment, given the relatively low frequency of hailstorms as weather events, whereas the Italian investigators had striven to infer results from the operational activity against hail; far from being a true scientific experimentation, the latter had reflected many farmers' expectancies for years.

## The Abandonment of Exploding Rockets and the Short-Lived Hopes of a New Technique

After the national campaign of 1961–62, no reports can be found concerning hail suppression experiments. During the period from the 1960s to the early 1970s, exploding rockets were discontinued in most Italian consortia, gradually substituted by other approaches based on different principles, such as cloud seeding with ground burners, balloons, or aircraft. Seeding was thought of as the true cutting-edge frontier to counteract hail, whereas exploding rockets, used in beating hail conditions, began to be considered only as an extreme remedy—probably with the idea that the method was ineffective even if not detrimental.

It may be speculated that this action was discontinued for practical reasons rather than for a lack of scientific validation. The evidence of the effectiveness or ineffectiveness of explosive rockets was difficult to show from a statistical point of view, although attempts to reach a definitive assessment were many. The procedures used were rarely replicable, partly due to the relatively low frequency of hail, highly changeable from year to year, leading to conclusions that were never statistically significant.

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* Whenever a group of meteorologists, based on objective analysis of the weather state, identified the possibility that a hail event might occur, a decision was made whether to intervene or not on a purely random basis.

In any case, the decision whether to continue the fight or not was taken locally, at the consortium level. According to the people interviewed in Trentino,* there was a general trust in shooting, even if the shortcomings of this technique were mostly perceived in its very short duration after blasts and in its limited space extent. Among the main reasons for the gradual abandonment of rockets, in the opinion of the operators interviewed, safety came first, while costs seemed a secondary issue. Safety concerns increased due to some accidents, including severe ones. Already in the 1955 report, an agreement was hoped for to insure workers from the risks from rocket operations. The worst accident occurred in 1971 at Ala (province of Trento), when three men died from an explosion. Eventually, new regulations were issued to hinder free storage and use of rockets, also to counter terrorist groups in that period; this might have played an important role in the abandonment of rockets.

Concerning costs, in 1954 and 1955 the reports give notice of economic troubles due to the absence of a law which defined the sharing of the economic burden. An economic assessment of 1956 illustrates the extent of resources dedicated to fighting hail and their costs: 113 rockets used for every storm, on average 10.6 for each placement, 0.2 rockets per protected hectare, a general expense of ITL372,000,000, corresponding to an average cost of ITL756 per ha, corresponding to a present (2022) total value of about €6,192,000 and about €12.6 per ha, respectively: all things considered, a modest burden. Nonetheless, an old law (Nr. 211/1901) was invoked by some consortia in economic difficulty; it set forth the obligation of cooperation in hail defence, to induce farmers within their boundaries to subscribe.

Although the success of the hail fight with exploding rockets had never been officially acknowledged, during the 1960s the confidence in the effectiveness of weather modification was higher than ever. Until a couple of decades before, the chance of a human control of weather was hampered by an insufficient knowledge of the meteorological phenomena and, above all, by the still too elementary skill of numerical weather prediction, a prerequisite for wide-range projects of weather control.

In Lorenz's words: "the '60 s were the decade when thoughts of weather modification other than simple cloud seeding, passed from bizarre to respectable."[77] And indeed, by the early 1970s, the more recent technique of nucleating salts was becoming the most encouraging method, as an alternative to exploding rockets; in Trentino, this technique was the subject of experimentation during the period 1973–75. Nevertheless, three storm postcards sent from Rovereto (southern Trentino) in summer 1979 reported "anti-hail defence at work," in a period when

* Carlo Marchesi, Anselmo Guerrieri Gonzaga, Luigino Tinelli (director of Tenuta San Leonardo), Flavio Marchetti and Pietro Ferrari, formerly researchers at FEM; Sergio Panizza and Celestino Furlani, anti-hail operators of the consortia of Volano and Trento Nord, respectively.

no campaign against hail was officially ongoing: indeed, in those years, single farmers continued spot interventions with exploding rockets, still available on the market.

The proceedings of a conference held in Trento on the 29 November 1975[78] report interesting opinions, bringing to account how the experimentation with both exploding rockets and nucleating agents was declining. Indeed, its effectiveness, officially and repeatedly declared, in the long run had proven illusory. H. Oberhofer was directing the advice centre for fruit and grapevine growing of the Province of Bolzano. His speech was eloquent: 1967 had been a breakthrough year, due to great damages despite the strong efforts done for the rocket protection; the latter, in his words, "belongs to history." On the other hand, the experimentation carried out by nucleant powder injection was not considered mature and its results not trustable yet, leading the syndicate to prefer passive defence, namely insurance policies, as the most promising strategy. This approach, especially if facilitated by regional funds, would move the policy toward the "socialization" of hazard, in the wake of the well-established Swiss experience.[79] Similar conclusions had been put forward by G. Ferrari, president of the Farmers' Union of the Province of Trento. A negative assessment of the first three-year experimentation with nucleants in Trentino was also expressed by Pietro Ferrari ("The results obtained to-date, with both rockets and silver iodide, have deeply disappointed us").[80] This judgement was quite relevant, since the institute he represented was appointed by the regional administration for agrometeorological issues.

In the same conference, opinions at least partially favorable to the effectiveness of exploding rockets were not missing (e.g. E. Barbero, speaking on behalf of the Chamber of Commerce of the Asti province, Piedmont). In the meeting the most recent techniques were also reported, especially nucleants, whose evaluation had aroused inhomogeneous judgments. Di Cocco, from the University of Bologna, in his concluding remarks (p. 93) stated—with a thinly veiled polemic—that "the convergence of views might be the consequence of a convergence of interests, rather than of a positive appreciation of the effectiveness—if only partial—of active defence. As long as its cost is not supported by any of the different players [insurance brokers, farmers, ministries] […], such opinions are meaningless." Finally, at the conclusion of the conference, a resolution of the Chamber of Commerce of Trento (hosting the conference) aimed to carry out hail fighting with a joint action of protective hail nets and insurance policies, benefitting from regional grants; the regional administration was asked not to dismantle the research on hail protection, even if under the guidance of a national programme, led by the National Research Council.

## The Storm Postcards: Adequate for Hail Suppression Monitoring?

The operators in charge noted on the postcards, using shared and parameterized criteria, information on the characteristics of thunderstorm precipitation (air pressure and temperature before and after the event, rainfall amount, the form of precipitation—rain or hail, the event duration, the direction of movement of the disturbance, the presence of electrical phenomena, news about any damage to crops, people and property, etc.). Some details on the reported impact of hailstorms included the type of crop and the extent of the damage. However, the information on hail damage from the postcards was neither accurate nor verified, neither quantitatively nor qualitatively. The description of thunderstorms, although essentially qualitative, would have allowed an unambiguous interpretation of the phenomena, making it comparable with what was observed at other sites, in order to better understand its genesis and evolution and define more accurately its main direction of motion.

A more general purpose of studying the frequency and distribution of thunderstorms and the damage caused to crops, but also with reference to floods, landslides, collapses, etc., was later complemented by reports on the effectiveness of anti-hail interventions. In 1951, with the launch, by the Central Office of Meteorology, of experimental campaigns to test the effectiveness of interventions, specific postcards appeared to report the use of rockets and the observed effects. From 1953 onwards,* C11 models appeared, consisting of two identical sections (part one and part two) in which information concerning the trajectory of the thunderstorm, the presence of wind and hail, and information on the use and effectiveness of explosive rockets and damage to crops was requested. The postcards were filled in by the personnel working in facilities that housed the hail stations and the first part was sent to the Experimental Scientific Meteorological Observatory in Verona, the coordinating centre of the experimental survey network.**

* Already in the early years of the twentieth century, the Office had installed two stations to study the effectiveness of hail cannons, choosing two important wine-growing areas: Casale Monferrato (Piedmont) and Conegliano Veneto (Veneto). The two stations were equipped with instruments to study thunderstorms and electrical phenomena, and a network was organized to collect information on thunderstorms and hailstorms, using special postcards. The campaign lasted for two summers (1901–02) and then the Castelfranco Veneto area was studied for five years, until 1906, with the use of cannons, rockets and hail bombs: the results of these anti-hail campaigns were however fully negative.

** The Scientific Experimental Meteorological Observatory in Verona was also equipped with a meteorological radar, the first of its kind built in Italy, with advanced features for the time. The Observatory, which depended directly on the Central Office of Meteorology and Agricultural Ecology, was equipped for radar-meteorology, operational meteorological assistance services, weather analysis and forecasting services, microphysical research and observations in the countryside.

During the years of testing the effectiveness of hail protection systems, data were only used for study and research purposes. The information provided by the postcards was mainly intended to enable the Office's scholars and technicians to verify the effectiveness of the methods used. Results were published mainly in ministerial and consortium technical reports, journals with local distribution and conference proceedings. Nevertheless, the systematic collection of information on thunderstorms enabled the publication, in the *Annals of the Office*,[81] of a number of studies on the distribution of thunderstorms in different geographical areas of Italy. In the "Notices" it is stated that "only the postcards received directly [from the Office] and those from the Agents of the Assicurazioni Generali in Venice* contain complete observations; those […] obtained in the work of sifting through the various materials mentioned above are partly approximate observations, so that they do not contain all the data required for in the postcard." All those observations that lacked details come from three other sources: observatory records, third-order weather stations, and the *Rivista Meteorico-Agraria*.**

The differences in time and place, the heterogeneity among different formats, the subjectivity of narrative answers and the non-standardized protocol of post-card filling, hampered a sound statistical analysis as well as an assessment of the effectiveness of hail suppression by exploding rockets. Among the several formats of the storm postcards, model C11 (figure 2) distinguished occurrence of hail and rainfall after shooting (table 3). Examining the questions in the C11 postcards, and in the absence of any explanatory documents on their interpretation, they appear to be affected by more than one flaw, if the purpose was a rigorous detection of the effects of rocket launching. Indeed, only hail giving way to rain might point out an effect of rockets, rather than a natural storm depletion. However, even in this case, the effect would not be proven, since hailstorms are known to be short-lived, compared to rainfall. Under these conditions, the useful data is poor and the apparently effective shooting cases (in table 3: ceased hail with continued rain) have a questionable reliability, due to the absence of any intervention protocol. For example, it is impossible to understand the distinction between "ceasing" and "diminishing," without a time reference for the duration of the phenomenon before rating it as "ceasing." The coding of the intervention execution was ambiguous, too: with dozens of shootings registered at a station, without any time

* The Office had the cooperation of the Agents of the *Compagnia delle Assicurazioni Generali* in Venice.

** The Agro-Meteorological Service (run by the Central Office of Meteorology) consisted of the systematic collection of monthly decadal average weather data, to which was added the news about the state of development of the main crops and the progress of agricultural work. Data were sent to the Office from a large number of stations spread throughout the country by means of special postcards and then processed and published in the *Rivista Meteorico-Agraria*. In addition, reports on disturbances and the damage they caused were used to improve the spatial and temporal definition of such events and were published in the *Annals*.

**Table 3.** Success rates of the anti-hail interventions; observations after shooting (mod. C11 only)

| | | Hail | |
|---|---|---|---|
| | | Ceased | Diminished |
| Rain | Ceased | 1 | 0 |
| | Diminished | 2 | 6 |
| | Continued | 25 | 3 |
| | Begun | 0 | 0 |
| | Not occurred | 0 | 0 |
| | Not declared | 0 | 1 |
| TOTAL | | 28 | 10 |

**Table 4.** Success rates for anti-hail interventions, enlarged sample

| | Ceased | Diminished | Continued | Begun | Not occurred | Non-interpretable |
|---|---|---|---|---|---|---|
| TOTAL | 29 | 10 | 4 | 0 | 89 | 25 |

measurement. It is difficult to understand when the intervention could be considered over.

Unfortunately, it was not possible to retrieve any accessory documents, useful for a better interpretation of the questions in the postcards, and the authors did not find any mention of the "storm postcards" use in the reports of the yearly campaigns, so that the true usefulness of the postcards in the assessment of the results of the campaigns remains undetermined.

For the sake of completeness of the data set, a second analysis considered non-C11 postcards with data or "notes" about anti-hail interventions (table 4).*

This larger sample includes several deficient postcards, reporting about hail but not distinguishing between before and after the shooting.

Interesting cases are those where, even with damages documented by postcards, the anti-hail rockets were considered to mitigate the damages. From the analysis of reports on the effectiveness of shooting, evidence can be inferred on the habit of carrying out preventive actions (as confirmed by an interview to former operator Mr Furlani; and indeed, many postcards report comments in terms of "positive effects" matched to statements such as "not occurred," suggesting a hail-preventive

* Filled postcards often left the hail items blank: in these (numerous) cases, the absence of hail has been postulated. The cases of hail defined as "very small," "negligible," "beginning," or similar, have been grouped in the case of negligible solid precipitation.

effect of shooting). The consequent non-occurrence of hail was ascribed to the action of explosions, despite the exploding rockets theory implying their proper use in conditions of ongoing hailstorm ("beating hail"). Hence, the assessment of the success of the technique can be explained, often quoted in the postcards, even in absence of any hail occurrence during the storm event. Some examples of postcard notes account for the enthusiasm and the great confidence of many operators in their work, spontaneously resulting into a strong willingness to ascertain the good functioning of actions against hail.* The words echo a comment on the experience of the aforementioned popular engagement of people in the anti-seismic campaign in China, as reported by Fan.[82]

The set of entries reporting preventive shooting might affect the statistics of results. On the one hand this habit may have fostered the preventive use of rockets under conditions of scarce probability of hailstorm and, potentially, accounting the intervention as falsely successful; on the other hand, it may have masked the cases where the preventive shooting had not hampered the hailstorm, owing to the lack of a precise time recording of the events. In other words, in some cases, hail fading, which would have occurred even with no intervention, may have been ascribed to shooting, whereas a thorough information on the timing would have recorded, on the contrary, hail occurrence after shooting. Indeed, in the postcards, hailstorm duration is missing. Hail cessation could be detected without reporting the time elapsed from shooting. It is well known that hailstorms have limited durations compared to rainfall events. Hence indication of the end of the phenomenon remains a very ambiguous information. On the contrary, the pieces of information able to point out an effect would have been the exhaustion time, and not just the reporting of its generic end. Only referencing the exhaustion time to the mean natural one—however strongly changeable from case to case—could have ascribed the effect to the intervention.

The perception of success by form compilers—in many cases supposedly also shooting operators—remains an incontrovertible fact. Nevertheless, it must be stressed that the use of postcards was not widespread among all the operators. The two former operators interviewed, S. Panizza and C. Furlani, claimed they did not remember the existence of this pioneering citizen science network of storm postcards. This was a rather unexpected statement, considering that anti-hail

* An excerpt: "Many blows but with good results. Hail-bearing clouds, which had suddenly obscured the sky with an awful threat, were broken by shooting, so that the storm was transformed into a torrential rain." Another excerpt: "Thanks to the substantial intervention of the hail defence, the storm, beginning its ruinous work, was put to flight in time." Another: "The defence north of the valley started the attack against the black clouds, even if they might not have been hail-bearing. Further south, not to be outdone, as the storm went down, without realizing (?) the necessity, the offensive against clouds was started." Finally: "Given the dangerous and scary appearance of the large, dense, black, clouds, with thunders and flashes floodlighting the area, it can be thought that, with no defence, a fair hailstorm would have occurred, despite that one is not the usual storm track."

operators worked for farmers' associations and were asked to comment on the effectiveness of the method.

## Conclusions: A Case of Collective Confirmation Bias

Any objective assessment of scientific validity of the methods adopted in hail suppression practices seems to have had a minor role in the decision about adoption or abandonment of anti-hail exploding rockets. This conclusion is supported by many reports among those mentioned above. What is striking in this story is the quick transition from a sort of collective euphoria about the active defence, fully engaging the scientific actors of the experimentation, to a widespread mistrust, which led to a general abandonment of active defence in the span of a few years, and the more recent return of attempts with a technique—the hail cannons—fully discredited by both science and field practice. However, the most controversial aspect, common to all experimental campaigns carried out with different methods, is the contrast between the early-declared positive results of the experiments and their eventual scientific verification. J. Thomas Steiner compiled a comparative examination of seventeen experimental campaigns conducted worldwide in the period 1956–85. He uncovered evidence that in almost all of them the authors of the reports had certified the efficacy of hail reduction, with values estimated at up to eighty percent in the Soviet Union.[83] The high success rate reported for these experiments is also quoted in a paper by the US scientist J. D. Marwitz from the University of Wyoming:[84] he reported his scientific exchange experience in some atmospheric research centres in the former Soviet Union in 1972, concluding that he "detected no indication or reason to doubt the stated hail suppression results," assessed by the Soviet researchers as seventy to eighty percent. Similar results are those mentioned in another report from a US scientist, L. J. Battan, who was hosted for a scientific exchange program in the Soviet Union in 1976.[85] After stating that "There appear to be no scientific experiments on the efficacy of hail suppression going on in the U.S.S.R. at this time [1976]," Battan concluded that "For many years, hail suppression has been considered a demonstrated technology in the Soviet Union. Research is at a low level, whereas operations continue at a large and increasing rate." The subsequent gradual abandonment of these techniques again shows that evaluations of the effectiveness of the methods used could not show realistic results.

In the documentary sources available for this study, the opinions expressed by the different actors are clear, not so is the evidence that a change in the attitude had been determined by an objective analysis of the field results. It may be inferred that opinions had changed, leaving small documentary tracks in the gaps in information sent out, or officially published. It may be postulated that the assessments expressed in the early stage of active defence experimentation—or of its operational use—had been driven more by confidence in the goodness of the method, than by an objective analysis of results.

In the evaluation of the response to the experimentation results, which can explain the popular success of the methods (exploding rockets, but also acoustic cannons), a systematic error may be invoked, due to a normal human cognitive phenomenon, known as confirmation bias.[86] Like other biases, confirmation bias introduces a systematic error in terms of overconfidence in facts corresponding to beliefs and systematic denial of results that do not confirm the hypotheses. This would imply that people called to ascertain the validity of the method are prone to select the elements in favor of the preferred hypothesis and discredit the opposite hypothesis, attributing the failure to adverse conditions of different nature.[87]*

This explains the attitude of some farmers—or their consortia—who insisted on applying, or continuing, active defence, even against the advice of supervising technicians. The evidence was clear of an oversized enthusiasm of (potential) "weather modification" users on one side, and solution providers on the other—namely farmers and their associations, and service companies, respectively. Nevertheless, this is to be compared to a general scepticism by both scientific and political sponsors. This attitude can be traced back also in other settings. One major case was reported in the United States; the expectations of financial support for weather modification programmes and the complex response from the governmental agencies, driven by multi-faceted strategic policies, has been described, roughly for the same historical period, for example by Kristine Harper[88] and Stanley Changnon.[89] The latter work, particularly, reaches conclusions on the polarization of the attitudes toward weather modification, by the late 1960s, which closely resemble those outlined in the story of hail fighting in Italy. Here, on the scientific side of the controversy, the lack of a correct experimental design can be clearly tracked down in some comments from Rosini. Indeed, in his report on the experiments of 1958 and 1959, he questions the grounds of the statistical soundness of the experimentations carried out until then:

> None of the two Swiss [Grossversucht] and Italian experimentations were statistically based. […] The Swiss experimentation had such important initial faults [concerning type and use of rockets] to be devalued in the light of the empirical Italian experimentation. […] Moreover, the statistical evaluation was absolutely inadequate. […] As regards the Italian experimentation, led by the UCEA—Central Office of Agrarian Ecology—it was based on such unsteady statistical surveys—as are generic evaluations of damages by mayors—to hinder its compatibility with the needs of a scientific experimentation.[90]

His 1965 report is even more interesting:

> […] we claim that we have never been asked to find reasons to deny the effectiveness of rockets and to advise against them, but rather to look for

* One example of this approach is the commonly assumed statement that, in absence of the intervention, damages would have been even worse.


**Fig. 4.** A hail cannon in use in Pianezze, Veneto region. *Credit*: Historical archive "Pietro Laverda," Breganze (I)

> scientific grounds to explain their alleged effectiveness: even in science, as in many other fields of human activity, the diversity of the two attitudes and of the two working approaches is radical.[91]

Indeed, in the US, the Committee on the State of and Future Directions in US Weather Modification Research and Operations gave similar explanations to the arc of the sudden enthusiasm in hail fighting projects and their progressive abandonment in the world. They pointed out that "the number and volume of commercial projects […] in 1956–1957 had reached a level of about one-fourth of its peak."[92] The above-mentioned Committee stated that in 2003, despite the large number of operational activities, weather modification research programs conducted worldwide are very few. A report by the World Meteorological Organization[93] already marked the beginning of the decline in weather modification projects aimed at hail suppression, which had reached its climax in 1980 (thirteen projects over a total area of about 250 000 $km^2$). Nonetheless, operational weather modification programs continue worldwide, based on a simple probabilistic cost–benefit analyses, despite the clear lack of scientific proof.[94]

As said, still today the return of methods already officially discredited can be tracked. The case of acoustic cannons—nowadays mostly regarded as museum pieces, see figure 4—is a case-in-point; the story of this technique saw more than one scientific refutation of its effectiveness, demonstrated even from the theoretical point of view. Nevertheless, on several occasions during its 120-year-old story it was proposed to farmers and still today some arrays of cannons are confidently in place to "protect" sensitive areas.*

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* See e.g. the daily newspaper *Giornale di Vicenza,* February 14, 2013: "'Killing' hailstorms with seven cannons'. And, website "rete veneta", April 9, 2024: "Marostica, fighting hail—shock wawes to protect the land." https://reteveneta.medianordest.it/76237/marostica-lotta-alla-grandine-onde-choc-per-proteggere-il-territorio/ (titles translated from Italian).

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