P1.11 THE UNFORTUNATE ACADEMY REPORT ON WEATHER MODIFICATION

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1. INTRODUCTION

Like so many reports the recently published "Report on Critical Issues in Weather Modification" by the National Research Council of the US National Academy of Sciences starts with an Executive Summary, ES. The purpose of these ES is to inform the public, the news media, the political and administrative authorities and the scientific community about the essence of the document in plain but accurate language. The ES should stand alone. However, if interested about details, then the Report should be consulted.

Unfortunately, the ES of the *Report* is not up to these standards. It states that every single assessment since the National Academies' report in 1964 found ***"that scientific proof of the effectiveness of cloud seeding was lacking (with a few notable exceptions, such as the dispersion of cold fog).***" This implies that nothing has happened in the past forty years, basically implying that weather modification, WM, is dead.

This is a careless statement, it is a false statement. In 1975 the Congress of the World Meteorological Organization, WMO, stated in WMO (1976) on stimulation of precipitation: *"Of the many experiments conducted in this field, only a few have clearly demonstrated that seeding has increased the precipitation; in some cases, there is evidence of a decrease."* In 1994 WMO (WMO, 1994) states: *"A long standing programme to augment rainfall from winter time cumulus in the eastern Mediterranean is one of the most widely accepted examples of precipitation enhancement (13 to 15 % increases) associated with a seeding experiment."*

The American Meteorological Society (AMS) (1998) states: *"There is statistical evidence that precipitation from supercooled orographic clouds (cloud that develop over mountains) has been successfully increased by about 10%. The physical cause-and-effect relationships, however, have not been fully documented. Nevertheless, the potential for such increases is supported by field measurements and numerical model simulations."*

Obviously, the *Report* is using a different song book!

I also see no reason why warm fog is not automatically included under fog, considering that it has been used successfully during WWII (operation FIDO) and at Paris-Orly airport. Its effectiveness is well known. Stratus clouds (the Langmuir and Schaefer experiment, see Schaefer, 1953) and non-convective orographic clouds (Hobbs and Radke, 1973) seem to be part of the "few notable exceptions".

The *Report* perhaps implies, as I would find justified, that every modification of non-convective cloud is working, that the difficulties are with the convective clouds which are requiring randomized treatment. But why did it not say so? Let us have a look at the convective clouds, and restrict ourselves to rain enhancement.

2. THE CRITERIA FOR MODIFICATION OF CONVECTIVE CLOUDS

Let me spell out what the *Report* did not clearly say about the basis of the "new" judgement. It seems to be based (without reference) on the four WMO criteria of the early 1970ies which say that credible outcome of an experiment should satisfy the following criteria:

A) The modification experiments have to be randomized;
B) The increase in rain has to be judged on the basis of rain received at the ground;
C) The seeding effect has to be understood on physical grounds;
D) The seeding experiments have to be transferable to other areas.

In April 2003 I organized a roundtable discussion at the 8th WMO Scientific Conference on Weather Modification in Casablanca addressing the usefulness of these criteria. Based on the outcome of

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the discussion I proposed to Congress XIV of WMO in 2003 to have them overhauled. This was supported by the Italian delegation and accepted by CgXIV. The *Report*, not aware of these developments, elevates the criteria to bible status.

There is no question in my mind about the need of **A) and B)**. The reason for B) is that only rain at the ground is an economic benefit. B) may have to be reformulated if there is an acceptable way to extrapolate from radar measurements (this is really a loaded problem).

3. PHYSICAL UNDERSTANDING

To understand **C)** one has to consider the global situation in the early nineteen seventies when most nations were involved in some sort of WM based on the successful seeding of stratus cloud by Langmuir and Schaefer (Schaefer, 1953) and the detection of AgI as an artificial ice nucleus by Dr. B. Vonnegut to initiate the cold rain process at an earlier state of the cloud development. Vodoo science was rampant and exaggerated claims were common world-wide. WMO stepped in and formed an Executive Committee Panel to bring order into the field. [It contained names such as A.Alusa, Borovikov, Burtsev, R. Cunningham, A. Gagin, P. Goldsmith, Academician Krastanov, R. Lavoi, Y. Sedunov, J. Warner, etc. with R. List as chair. The many actions this committee took and the WM role of WMO have been discribed by List (2003)].

When we introduced C) in WMO we cloud physicists did not want to loose control to the statisticians, who, in those days, wanted to use WM as a testbed for the evolution of the then rather simplistic statistics. We wanted to have the last say and wanted to be sure that the few cases could be caught where statistics could give wrong results (what optimism!).

Understanding of the physics was assumed to be the knowledge base of that time because there was no point to envisage physics developed at a later time. In those days the level of physical knowledge expected could best be expressed by the Weinstein 1-dimensional cloud model (with and without seeding)(1970).

At present we may have a general knowledge about how precipitation is formed. However, as I try to get it across to the cloud physics community, there is no "average" cloud, there is no understanding of an average cloud. It does not exist. The only thing we can try is to understand how a given single cloud works, subject to the availability of all the necessary information. I was brought up at a time of the Aitken and Pollack counters for the measurement of aerosol particles with their concentration rapidly changing over short space and time scales. The concept of the Cloud Condensation Nucleus, CCN, was not known then. Surprisingly, it is not generally understood now with all its ramifications. Neigburger and Chen (1960) showed that only a fraction of the aerosol particles of an initial spectrum and of known characteristics will be activated and that the activation will depend on the speed of the condensation process, i.e. the cloud formation. In other words, some particles will be activated as CCN in one case but not in other situations. This makes a definition of CCN by giving an upper limit of supersaturation pointless, unless CCN are specified as those aerosol particles which become weather active CCNs in a specific case.

Dr. Roelof Bruintjes (personal communication) has recently shown me satellite images taken for different aerosol species (SO_x, desert mineral dust, and carbonaceous particles from biomass burning) over the Arabian peninsula. The 12-hour variations of the individual components over space, time- and height was enormous, so was their relative contribution to the concentration.

These two points clearly indicate that one of the conditions to understand clouds forming in such a realistic and ever changing environment is to take account of the real constituents and their variability in the air ingested by developing clouds. These are tough conditions to be handled by numerical cloud models. The computing power for such complications is not available. [The variability of the aerosol was recently underlined also by Dr. R. Carbone (personal communication) who showed a movie of scanning the atmosphere with a prototype aerosol lidar with a spacial resolution of 3 m and an initial range of 5-10 km. The swirling motion of the aerosol down to that scale was very disturbing!

In summary, criterion C) needs complete rethinking, maybe by linking it to result from 3-dimensional models with detailed microphysics. As it stands it is of no use.

Point D) is also murky because it is not a concept which can be quantified as describing similarity of topography, synoptic weather patterns and rainfall. As List (2004) pointed out, this aspect was introduced on political grounds and addressed testing in other countries [see repetition of the USSR hail prevention experiments in NHRE by NCAR and in Grossversuch IV in Switzerland]. Saying that a concept should be tested and produce positive results in other experiments might be all of what we can do.

4. SCIENTIFIC "PROOF"

The only reliable statements made in randomized experiments are statistical in nature.

Statistics does not proof anything, it only gives a measure of the outcome, such as the confidence level. Considering point C) the word "proof" is completely out of place.

It is always very difficult in science and engineering to unscramble signals which are extremely week and buried in the noise of events like the variability of weather. As weaker the signals are, the longer the search for the signal will be. Is there anyone who thinks that we can do better in the atmospheric sciences and physically outguess the nature of such signals? Maybe we should accept what happens in medicine where relations are untangled by statistics alone, reenforced in time by other similar investigations.

5. ACCURACY OF EXPERIMENTS

Progress in WM is slow because the progress in the supporting sciences is slow and because we deal with extremely difficult problems. There is no science of WM, supportive science comes from cloud physics and cloud chemistry, cloud dynamics, weather forecasting, *in situ* and remote sensing, etc. It is not "us" and "them" the modifiers, it is "we" we have to blame - if there is any blame.

Let me make a point which did not enter the *Report* and, thus, stamps it as applying a "double standard". In rain enhancement we try do demonstrate an increase of rain of 10 -20 %. We do this with a significance which requires accuracies of fractions of these values. My question: Is there any other field in the atmospheric sciences where this type of accuracy is demanded and reached? Not in my experiments, not in your theories and models. ***If the standard of accuracy underlying weather modification experiments would be required for all papers in Meteorology and Atmospheric Physics then all the world's journals in the field could be reduced to one thin issue.***

This is also amazing when we look into how we measure precipitation. Raingages are within ± 10 - 12 % for wide-spread rain. For convective rain - the object of most rain enhancement - they will be out by more than 50 % [annual rainfall rates drop by as much as 40 % at the border of some highly developed European countries]. Don't think that radar is any better. Electrical calibration of radars alone is within a few decibels. Add beam filling, beam averaging, elevation and distance dependent errors and the assumption of an average fictional raindrop size distribution and particle phase (ice or water) at larger distance and you will be amazed by the errors obtained. The surprising thing is that it all may still work well enough for comparisons by being consistently wrong.

6 THE SUCCESSFUL RAIN ENHANCEMENT EXPERIMENTS

As stated in the Introduction statements on the art of weather modification are periodically issued both by the WMO (1976, 1996, 2001) and the AMS (1998). The text of the *Report* is quite different from these releases. What I do not understand is that those references have not been given so that the reader can judge. What all the statements miss is clear indication about what experiments are considered to have worked [such as Israel I, Tasmania, South Africa, and others]. That makes Silverman's (2001) work so important. Personally, I consider enhancement experiments to have been successful in at least three and one half continents. That to me is sufficient indication that glaciogenic seeding works and CCN seeding is just about there.

Why does the *Report* have so much problems to accept that seeding works if the conditions are right, when it is so easy going on inadvertent weather modification and accepts it without even discussing the validity? Another "double standard". I fully support the tough stand on WM experimentation, but it should be appreciated and compared with other ventures in atmospheric science.

Then there are long-duration seeding operations in California. With ~50 years of activity they fall into a different category, probably allowing assessment without randomizing. Results of this special and exciting work should be forthcoming soon.

Present day seeding intends to produce more rain when the rain process is already underway (see general assumption that seeding is to start when the radar reflectivity at a given level exceeds 30 db). No word has been said in the *Report* about seeding for rain when there is no rain. This is a scenario which may soon become important when rain is prohibited by an abundance of small CCN, with no larger particles present. For such situations precipitation may be inhibited by pollution (Rosenfeld. 2003).

7. WEATHER MODIFICATION STATISTICS

The *Report* includes a Section (Appendix) B entitled "Modern Statistical Methods and Weather Modification Research". I do not envy the author's task, seeing no references that he has published on WM or that he is familiar with the specific field. Further, he does not seem to be familiar with the extensive work of Prof. Ruben Gabriel and Dr. Bernie Silverman (no references).

R. Gabriel has been leading WM statistics up to his death in 2003. He has evaluated and re-

evaluated Israel I and II, has written beautiful papers explaining the process. In recent years he has further developed a new ratio statistics (1999) which allows the user to set his own goals for acceptance [an insurance company may have boundary conditions different from a power company, different from a farming community]. There is no need anymore to deal with a confidence level and a p-value. This major development was not mentioned in the *Report*. Gabriel (2002) also published his revolutionary idea of pooling data from different experiments. This is a proposal which can not be overestimated. It means that, under certain conditions, the results of different experiments can be evaluated as one experiment. This has far reaching consequences considering the reluctance in operational seeding programs to have the operations interspersed with non-seeded cases - and this for durations of 5 or more years. A scenario of pooling can be envisaged with great benefits in two instances:

1) Operational projects might be transformed into pooled experiments for much shorter periods of time. This might be desirable, for example, to the many Texas operations. The pooling could considerably shorten the experiment duration from 5-7 to ~2 years with 4 experiments in parallel. This could include restriction of seeding to only 2/3 of the seedable events and, thus, reducing the pain [to be checked by statisticians] (the 2/3 is applied in a Blue Mountain "operational" project in Australia).

2) Different countries could also pool their national projects in an international experiment, save money for operating in their own land and obtaining answers quicker - without the hassle of transferring funds across borders.

If Prof. Gabriel would still be alive he may also have pooled all the past WM experiments of the world!

In 2004 one of my papers addressed the future of WM (List, 2004). In there I floated an idea about how to connect statistics with physics. From listening to old timers in WM I got the impression that interference by seeding often did not seem to have any effect, but that on occasion the rain would be doubled. If such cases could be isolated, they could then be related to the meteorological conditions which produce the largest effects by studying the detailed clouds on those days - bingo! Three weeks before his death Professor Gabriel told me that my arguments might work. The methods would involve the concept of a series of "one man out" studies or the application of a bootstrap method. I understand that the answers would be coached in statistical terms. It could be applied during an experiment (what heresy!) or applied retroactively to past experiments - if the data sets were still available.

The author's personal opinion is that a randomized experiment based on the rain received at the ground is sufficient for acceptance, if a body of other experiments confirms the results. This would be similar to what happens in medicine. Why not adapt their procedures?

In other words, tremendous advances have been made in statistics, but the *Report* does not report them, has not registered them.

8. MY ALIBI

My membership to the Group behind the *Report* was temporary, as properly listed. I participated in the first Academy Committee (NRC, 2000) on the same topic under the leadership of Prof. H. Orville. I remember being briefed by the Administrator of NOAA, Dr. Baker, who felt that another look at weather modification was timely. The first committee's findings was to provide the basis for a possible second step with a look into the WM future. Of note is Dr. Baker's comment that he was considering the possibility of a substantial program of order $200 million per year on the topic of WM, a program in need of support by Congress.

After a series of meetings of looking into the past and no sentence written down for the *Report*, I was personally looking for the contents of a big plan and its justification. I felt a need for discussion of the key issues, the key recommendations. Thus I wrote an "straw man" Executive Summary (see Appendix) of the then non-existing *Report*. Thereby, it became clear that spending $200 million/year could be justified if linked to the study of the precipitation process. This idea was attractive because rain formation is the big stumbling block also for weather forecasting during the convective season and climate change modeling, which does not have any skill in terms of precipitation. [And in my own simple picture of the world it is the precipitation which determines the climate.] Having produced the still raw Summary, I sent it to the members of the Academy committee. After not receiving any comment or feedback from my colleagues I felt that I was out of step with the group and its chair and resigned. Thus, I put more effort into a manuscript which had been in the works since the nineties. The resulting paper (List, 2004) contains many of my ideas. However, I did not conceive the paper as a "parallel" to the Academy *Report* out of respect for the Academy Committee members who's scientific achievements and personalities I admire.

It should be added that the List (2004) paper better recognizes the large contributions of the "operators" who have not only improved seeding procedures, seeding materials, radar procedures (TITAN!) and cloud observations, they also hav substantially contributed to the advancement of our understanding of clouds and precipitation.

9. FINAL COMMENTS

In summary, I see the *Report* as flawed in its main parts. I am disturbed by the lack of specifics, the lack of highlighting the progress, achievements and successes in weather modification and the spirited work of its scientists, engineers and operators.

One of my conclusions in terms of assessment criteria is that the *Report* uses old, outdated and quite misleading criteria to assess rain enhancement experiments. The *Report* further lacks a discussion of front-line, weather modification related statistics.

The *Report* does not provide a strong, specific vision for the future. I do not expect that the Academy *Report* with its unfortunate Executive Summary and the very weak parts of the main body will produce any substantial new funding. It does not present any new ideas and new insights. Do we have to wait for another 40 years for a better document?

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APPENDIX

Academy Committee on the Status and Future Directions in U.S. Weather Modification Research and Operations

PROPOSAL FOR AN EXECUTIVE SUMMARY

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Weather modification is as old as mankind. About 1500 BC the hittites used bows and arrows to kill he bad spirits behind the thunderclouds and Leonardo da Vinci told the city of Verona to use mortars to blow the hailstorms apart. Sound played another role be it through the ringing of church bells or the blasts of hail canons. The big revolution in weather modification came in 1947 when Langmuir and Schaefer used pebbles of dry ice [solid CO_2 at -67C *[check*]] to clear an oval out of a stratiform cloud and produced snow. Parallel to this Vonnegut, also of the GE Laboratory in Schenectady, discovered the properties of silver Iodide, AgI, to act as a catalyst for the formation of ice at temperatures between -4 and -10^{o}C.[1] These findings instilled new vigor into weather modification and nearly all countries of the world got involved in this art. The Kenian weather service, for example, sent hot air floats into thunderstorms with fuses timed to explode charges when reaching the hailstorm clouds. This enthusiasm came also through in JF Kennedy's speech to the UN in 1963 or 64 when he described weather control as a beneficial future technology *[ACADEMY, GET THAT QUOTE]*.

Well, since these days only warm fog can be mastered in restricted locations (heating by jet engines across the runways of Orly airport to evaporate the fog, or by the use of very corroding Sodium Cloride particles. At airports in the Northern States of the US, supercooled fog is operationally transformed into falling snow by dropping of dry ice pebbles or the application of AgI. Snow and rain however have been produced only in a handful of scientifically evaluated experiments all over the world. No proven success has been achieved in the treatment of hailstorms, tornadoes, hurricanes, ice storms or flash floods.

This lack of success, coupled with a large demand for more water in droughts, have lead to a disillusion about the methods and opened the doors for charlatans. Thus, the reputation of weather modification is at an all-time low.

We all believed that the search for full scientific understanding could be avoided. However, nobody hit the jackpot.

It has to be realized that the failure of weather modification is mainly based on inadequate support by the more basic sciences of cloud physics and cloud dynamics, numerical modeling (cloud to synoptic scale) and forecasting. They have not been developed to a degree where they can support advances in weather modification technology.

The basic scientific problem is the formation of precipitation. Precipitation is part of all violent weather events [with the exception of wind storms] and its interactions with the dynamic driving forces leads to the different manifestations found in the formation of snow, rain, graupel[2] and hail in simple snow and rain producing clouds to the more frightening hailstorms, tornadoes and hurricanes. Unfortunately, the formation of "simple" rain or"simple"snow is not well understood. Bits and pieces are known, but we need hand waiving to put the parts together into a consistent picture which is reflected in nature's events. This integration of knowledge is achieved by numerical cloud models. But the present ones do not have any predictive value of what is happening in nature.

The understanding of the formation of precipitation is not only required for better weather modification, it is at the basis of weather forecasting and its input into climate models is essential to overcome the zero skill these models have in assessing future climates in terms of precipitation. Climate models use clouds with diameters of 150 km! *[check grid size of GCMs].*

Before going into a proposal of research and operational activities it is necessary to point out that tremendous advances have been made in the past which justify new hopes for success.

1 It has been recognized that because of the high variability of weather events, only carefully

1Water does not normally freeze at the freezing point. It is normally supercooled to the temperatures at which ice nuclei, IN, present induce ice formation. This is also true for the formation of cloud droplets, and cloud condensation nuclei, CCN, are required to induce the liquid phase. IN and CCN are part of the natural aerosol.

2Graupel are lumpy particles with sizes up to 5 mm, and mostly consisting of collections of frozen water droplets. Melting leads to rain, while further growth leads to hailstones.

planned random experiments can answer the question about the success of operations. A few such experiments have been executed and fewer have produced positive results. In other words, the methodologies for execution and evaluation are available;

2 The scientific community has recognized that markers have to be set in the form of statements on the art of weather modification, as issued by the World Meteorological Organization, the American Meteorological Society and the >>Engineering Society *[check]*. These are approved statements for governments and individuals about where the field is and what is acceptable knowledge;

3 The weather modification community has organized itself into an organization to provide fora for interchange of results and experiences. It has a journal of its own and has an educational function;

4 Both the WMO and the AMS organize in coordinated fashion international conferences on weather modification every four years, spaced two years apart;

5 There has been a steady improvement in our understanding of precipitation as gained in big field projects, smaller field studies, numerical cloud and mesoscale models and in laboratory and theoretical studies;

6 Most importantly, there has been revolutionary technological advance in the form of new generations of polarized Doppler radars, the rotating aircraft-mounted Eldora radar systems, a variety of sounders, new high resolution satellite remote sensing;

7 Last but not least assimilation models are now being developed to integrate all these new data (particularly radar) into running mesoscale cloud models.

What is proposed for a big program is

SCIENCE

8 A concentrated attack in the form of comprehensive theoretical, laboratory and field studies on the formation of precipitation as occurring in stratiform and convective clouds, hailstorms and tornadoes, hurricanes, flash floods, snow storms. Studies of conditions causing droughts;

9 Development of sophisticated mesoscale and synoptic scale cloud models containing microphysics-scale processes;

10 Improvement of the limits for forecasting of severe weather events;

11 Applications of new advances into climate models, thereby substantially improving their credibility and predictive powers in terms of precipitation;

12 The execution of field experiments on the basis of what is known at present with the best available facilities, from high resolution satellites, to complex radar and other remote measuring systems, fully equipped cloud and storm penetrating aircraft, mesoscale meteorological measuring systems, etc.

13 Three field experiments to be established in geographical areas with consistent weather patterns and needs for additional water resources [rain enhancement in Texas and a Northern State, snow pack enhancement in the Rockies];

14 Development of the statistical methods to evaluate weather modification experiments [effects of single time units, isolation of single extreme cases such as very heavy hailstorms, seeded or unseeded];

15 Upgrading of weather modification experiments according to the advances in the research program, extensions from rain to hail to hurricanes.

TECHNOLOGY

15 Development of technology and approaches to modify the different weather events, starting with “simple” precipitating clouds;

16 Doubling every five years of the national computer system capability as presently available in the National Center for Atmospheric Research.

ENVIRONMENT

17 Modeling of the extra area effects of weather modification (Peter robbing Paul);

18 Continent-wide modeling of adding the to the numbers of water cycles [more recycling of rain water];

19 Extension of studies on the effects by weather modification on the social and economic fabric of society;

20 Extension of studies of the environmental effects of seeding materials;

21 Study of legal aspects of weather modification.

MANPOWER

22 Provision of training of top scientists and engineers in the respective sub-fields;

23 Provision of open workshops and conferences for all aspects of the program;

24 Full involvement of the political, public and private sectors;

25 It is obvious that such a program needs full participation of the private companies with their substantial facilities and knowhow.

ORGANIZATION & FUNDING

26 It is proposed that a Precipitation Research and Weather Modification Laboratory be formed, administered by the University Corporation for Atmospheric Research;

27 The source of funding should be through Congress;

28 The financial requirements are in the range of $200 million per annum.

FINAL COMMENT

A program of this magnitude can only be successful in a stable financial environment. Otherwise no young or established scientists and organizations will commit their futures for such a venture. The direct and indirect benefits will be substantial in terms of passive and active reductions of weather-related damages. Of great importance will also be the new skills of climate models in assessing precipitation.

Toronto, 3 September 2002

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