THE SERIOUS FLAWS OF THE ACADEMIES' REPORT ON WEATHER MODIFICATION RESEARCH

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Abstract. The Report "Critical Issues in Weather Modification Research" by the National Research Council of the National Academies (the Report, in short) stresses lack of physical understanding as the reason for rejecting all success claims in modification (involving convective clouds). This conclusion is reached without realizing that statistics provides the only scientific tool to link the physics of clouds to the interference of seeding; it weighs the quality of the basic physical hypotheses underlying the seeding. Yet statistics, the cornerstone in the assessment of weather modification experiments, is not even discussed in the bulk of the Report.

The faults in the Executive Summary are easily spotted. The main body of the Report, however, is well written and its even bigger flaws are hidden in beautiful prose. The main failings of the Report will be described below.

1. ANDOMIZATION OF SEEDING EXPERIMENTS

The basic criticism of the Report is directed at the lack of recognition of the role of statistics and the purpose of a randomized experiment. The latter can be formulated as assigning a degree of significance to the testing of the hypothesis of how precipitation is formed and how it is to be altered by seeding.

For a weather modification (WM) experiment to be acceptable, the results have to be established in a randomized experiment. The seeding units can be days or single clouds/storms. Randomization will give an idea about how trustworthy the physical hypothesis is. The results are expressed in statistical terms such as confidence level, p-value, etc. Statistics can not provide new physics because the issues are much too complex, it can only attach variable degrees of credibility to hypotheses.

A statistical description is necessary because the individual units of a randomized experiment are highly variable. No cloud is a copy of another cloud. It is the opinion of this author that this variability is more important than the still unknown details of the precipitation physics of a single cloud. An example has been made for the hail case where only high resolution radar measurements and numerical models, down to the 100 m scale and lower, allow observations of packages of hailstones in the form of sheets (Thomson and List, 1999) or tongues (Farley and Orville, 1999). They are generally not detected and missed. It is obvious that such clouds, actually any type of cloud with highly variable internal structures, can not be "averaged" in the physical sense because of their non-linear behavior. That is the reason for using a carefully designed statistical approach to extract physical statements. No other method can do any better.

There is an even better example: the dependence of cloud evolution on cloud condensation nuclei (CCN) characteristics and concentration, as has been modeled by Neiburger & Chen (1960). Fifty years ago, when the concept of CCN was not established yet, it was known that the Aitken nuclei (aerosol particles) varied considerably with time and space. With the advent of space-borne soundings, it can now be shown that four major categories of CCN and their relative concentrations vary greatly. Bruintjes et al. (2005) demonstrated this temporal and special variability over Arabia. It is obvious that the evolution of clouds and precipitation is, to a large extent, determined by the characteristics of the air ingested. Does any one suggest that this influx has the same characteristics for every cloud of an ensemble or of any cloud in a whole seeding experiment? Does any one suggest that the physical processes are the same in a group of clouds? We may better understand with time how each single cloud works, but that does not address the group behavior. We will always need statistical measures to characterize ensemble properties. Even once the physics of the precipitation processes is fully understood will we not be able to "prove" that weather modification works. Thus, the word "proof" in the Report and the Executive Summary is not appropriate and shows insufficient understanding of the issues.

That statistical findings can not be expressed in absolute terms is reflected in the Statements by the World Meteorological Organization, WMO, (WMO, 1976, 2001) and the American Meteorological Society, AMS, (AMS, 1998a and b). These documents do not talk about proof because they imply through their wording the statistical nature of the findings. To deduce that nothing has been demonstrated to work is false. WM experiments in different parts of the world have shown that positive results have been obtained with adequate, i.e. acceptable significance. This applies to Israel I, the Australian experiment in Tasmania, the South African experiment involving single cloud seeding and maybe others as well. Statistical significance has also been reached in the Thai experiment, but the time delay of the seeding effect is, at present, not physically understood. Is the result caused by the luck of the draw? For an excellent, fine-combed assessment the reader is referred to Silverman (2001)

The reader may remember that many statistical findings are often given as reliable in 98 of 100 cases (typical for large studies involving tens of thousands of patients in medicine) or 92 out of 100 in political polls (involving 1000-2000 selected citizens). In WM the figure can be as low as 60 out of 100.and typically involve ~100-150 seeding units. These WM figures have been chosen to have experiment durations which are ”within reason” and are tolerable for political authorities.

2. EARCH ON STATISTICAL ASPECTS OF WM

The Report is entitled “Critical Issues in Weather Modification Research”. Yet not a single word is said about the recent achievements in statistics and the need for further research on aspects of statistics. Indeed major developments have occurred.; A ratio statiostics has been produced to assess WM experiments (Gabriel, 1999), pooling of different experiments has been propsed (Gabriel, 2002), and suggestion by List (2004) have been made that substantial increases of precipitation in individual seeding units may be traced to the actual case, thus providing a link between statistics and physics. The pooling possibility of different experiments is of great importance because parallel experiments can be processed as one. The parts may be undertaken in different regions of a country or on different continents. In such cases the experiment durations could be drastically cut. That might make it easier to carry out randomized experiments because the interference with a seeding operation would be reduced. In multi-national experiments the financial burden could be shared without having funds, equipment and people passing through national boundaries.

Professor Gabriel’s dream was always to find a way to assess (non-randomized) operations. This topic has recently been explored by Dr. B. Silverman, who is applying further developed methods and pooling (!) to the California seeding operations. A paper entitled “Independent evaluation of seven cloud seeding programs in the Sierra Nevada mountains of California” has been submitted (personal communication).

Encouragement of research into WM statistics by the Academies’ Report would have been welcome. Yet, the author of the Appendix on Statistics of the Report had not sufficient insight for such a proposal and did not seem to have a background in WM statistics anyhow. He did not quote any of his own papers addressing the issues, he also did not quote any papers by Prof. R. Gabriel and Dr. B. Silverman.

3. THE ASSESSMENT CRITERIA

It was suggested in discussions with a member of the Academy Panel that “proof” was based on adherence to the four criteria as developed by the WMO in the early seventies. The Report itself, however, does not state the basis of judging. The WMO criteria for acceptance of weather modification experiments can be described as

i) The seeding experiment has to be randomized;
ii) The assessment of success has to be based on the increase of rain at the ground;
iii) The results have to be physically understood;
iv) The experiments have to be transferable to other parts of the world.
[These criteria can be easily adapted to hail.]

The Report assumes that the physics of rain formation is far from being fully understood, thus weather modification can not been “proved”. While I fully agree with the point of insufficient understanding of the rain and hail growth mechanisms, I do not agree with the conclusion. That was never the point when the criteria were developed by the WMO Executive Panel on Weather Modification, which the author has chaired from 1972 -1984. The third criterion was there to get WM erxperiment leaders to learn cloud physics to the level of Weinstein’s (1970) 1-dimensional cloud

models with seeding. Further (we) cloud physicists did not want to loose control to the statisticians who, at that time, were ready to take over the whole field and use it as testing ground for new developments in statistics. Another reason was that we (wrongly) felt that we could easily detect bad draws.

The fourth criterion was added because in times of cold war we did not want to accept claims of success unless repeated in other regions of the world. This criterion is highly questionable because "transferability" is hard to define in physical terms. [These issues are also discussed by List (2003, 2004, 2005). Indeed, WMO Congress in 2003 [Cg XIV] decided, as proposed by the author, to have the criteria revisited and improved. Indeed, the first two criteria are essential; the other two are not. Having more and more randomized experiments supporting the cause is the only way to make WM more and more acceptable.

The Academies' Report is glossing over these issues and does not spell out and rethink the assessment criteria. It also does not address the issue of when "physical understanding" would be considered sufficient. Deplorable is also the lack of recommendations to revisit old concepts such as dynamic seeding, exploratory WM experiments, etc.

4. THE EXECUTIVE SUMMARY

An Executive Summary normally contains the condensed wisdom of a report by giving a balanced account of the main issues and answers because the standard purpose is to inform the public, the political authorities, the news media and the scientific community at large about the status of the field. As such, the Summary has failed. It states "Significantly, every assessment of weather modification dating from the National Academies' report in 1964 has 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 statement is a deadly blow to weather modification considering that the Report is an official document of an organization of highest repute. Trampled is the credibility of intricate, complex and well conducted randomized WM experiments as they have been carefully conducted in different parts of the world according to the best scientific ways known at their time

Showing unfamiliarity with the field, the Report excludes "cold fog" from the category "unproven", but not warm fog which has been successfully dissolved [i) project "Fido" during WW II in which runways in the UK were cleared, ii) fog dissolution by Dr. Robert Cunningham, who had C130s jets directed across runways to enable an emergency landing - which may have led to the operational fog clearance at Orly and Charles de Gaulle airports in Paris (Sauvalle,1976)], iii) ice fog had been tackled in the USSR with heating, and iv) supercooled fog by injection of liquid nitrogen (Vlasiuk et al., 1976). "Fog" would have been more appropriate than "cold fog".

5. CONCLUSIONS

The Academies' Report on Weather Modification Research did not recognize that the statistical method applied in the assessment of the success of seeding provides a judgment of the physical hypothesis to be tested. This is the only major contribution one can make to the physical understanding of how precipitation mechanisms and the interference with them really work. Not understanding this issue makes any statement on the lack of general "physical understanding" suspect.

The report makes no reference to the much more positive periodic assessments by the World Meteorological Organization, WMO, and the American Meteorological Society, AMS. It falsely states that all assessments have always been negative. This is contrary to the reported achievements. Lack of understanding of the basics of statistics and the appropriate language may be the reasons for this failure.

In summary, the foundation of the Report is so flawed that this document should be withdrawn. The community of scientists and engineers involved in weather modification also deserve better in view of their continuous efforts to improve all aspects of weather modification.

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