ON THE CONTRASTIVE NATURE OF WEATHER MODIFICATION KNOWLEDGE: COMMONSENSE REASONING AND COMMONSENSE KNOWLEDGE

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Abstract. Weather Modification specialists constantly face a difficult problem in their operation and research tasks. The explanation of events on the basis of data is neither completely deductive nor completely inductive. The reason is clear since it is very difficult to isolate the weather objects from their environment and their complex interactions; therefore any attempt of methodological isolation tends to destroy vital elements of their dynamics. Here I present a discussion about the role abductive inference plays in applied weather modification knowledge due to its contrastive nature, and how these general considerations are applied in Texas.

1. INTRODUCTION

Weather Modification activities should be conducted with some interests in research since they confront tasks that are almost always pallidly represented in the laboratory. Experiments at lab scale can lead to important discoveries about chamber clouds; however, these clouds are missing important features related to the meteorological and geographical dimensions of real weather. Early in time meteorologists, hydrologists, and climatologists made these same complaints against lab results that were then extremely celebrated by physicists and chemists.

The problem is really complex. Physicists look for general statements about the nature of observed phenomena and are very capable when they describe closed systems and reversible processes. However, weather objects and processes are neither closed nor reversible. For instance, storms need a strong interaction with the environment to import mass and energy, and to export entropy. Only in this way, storms can live in stages far from equilibrium. On the other hand, chemists approach their subjects with more concern for special features, are able to describe very well the particular processes called "chemical reactions", and have pinpointed the catalytic nature of weather modification actions. They have given a plethora of important results for Weather Modification (WM), though the most important features of weather are very difficult if not impossible to create in a laboratory. Once again, complexity asks for field realizations. Physics and chemistry form the basis around which we build powerful instruments to take measurements, constitute a precise language to describe objects and phenomena, and provide a beautiful set of mathematical equations that help this language to make models and predictions. Nevertheless, we don't know with enough detail the initial conditions for these equations, and the weather is easily influenced by variations in its early stage because it is chaotic and unstable.

Richard P. Feynman (1918-1988), Nobel Prize in Physics in 1965, once wrote:

> "Physicists always have a habit of taking the simplest example of any phenomenon and calling it 'physics', leaving the more complicated example to become the concern of other fields--say of applied mathematics, electrical engineering, chemistry or crystallography…"
> (Feynman et al, 1964; see also National Science Foundation, 1965)

Theses quotes probably point out why physics has become a paradigmatic science for epistemologists, but also indicate the clue for a methodology for the sciences that deal with open objects and irreversible processes: **Engineering.**

Weather Modification is applied science, but its applications are engineering. As an applied science **WM** enhances its connections with fundamental research in Meteorology, Cloud Physics, and Cloud Chemistry, whereas as engineering **WM** puts scientific knowledge into practice, applies its knowledge with judgment and attempts to develop ways to economically utilize that scientific knowledge.

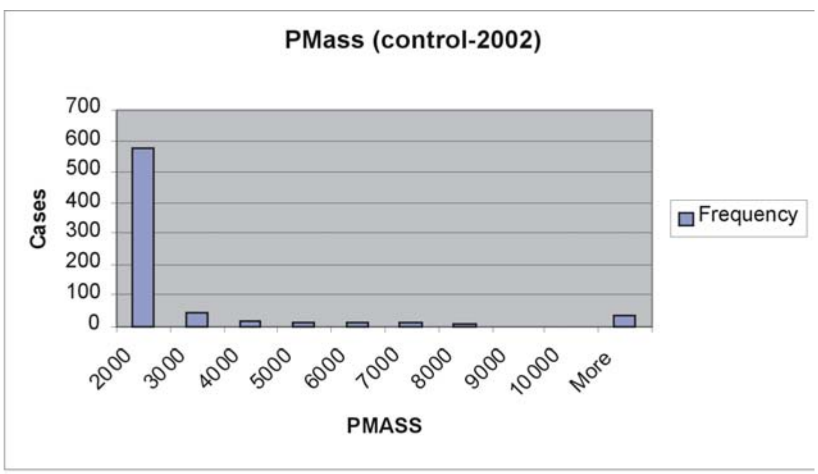
2. GALILEAN EPISTEMOLOGY

Galileo Galilei (1564-1642) founded a new epistemology with the statement that passive observation of ordinary events is not enough because these events are usually too complicated to reveal the underlying physical laws; therefore, **active experiments are needed** (Bolles, 1997). According to Galileo, the experiments should create events easy to understand where all the common complications are removed. In this direction he was able to ignore the friction and bouncy effect of air and any other additional accidents, and found the laws for inertia and free fall in vacuum. We know that frictionless surfaces and a perfect vacuum do not exist, but **scientists consider such laws more real than common experience due to the fact that these laws can show the dominant causes in place**.

In addition, Galileo was also a creative engineer, capable of designing and building pendulum clocks, thermoscopes, lenses and telescopes. **He was not a purist**. He did something even more creative, **he brought back mathematics**. As the reader will find later, only through mathematics **WM** experts can avoid excessive empiricism.

3. DATA MINING AND ENGINEERING

Can we follow similar steps when studying the weather? Yes and no. To some extent we already followed them in randomized cloud seeding experiments, but the complex nature of the subject did not allow us to simplify until all the complications were gone. If we bypassed these undesirable complications, we oversimplified the subjects and the results would be unusable. Therefore, **WM** experts should examine the complex phenomena of weather as precisely as possible in situations as natural and simple as possible to find meaningful "basic units" of behavior; thus avoiding oversimplifications that might lead to dissect meaningless units. The basic units could be used later in the analysis of more complex situations (Ruiz and Bates, 2003a). Experts in **WM** search for frequent and regular occurrences of phenomena within a geographical area without ignoring the rare events, but creating a special classification for them. Phenomena then are described by the attributes almost always present in each class. Classes distinguish each other by contrast. Doing this, **WM** experts accept the premise that phenomenological data are adequate to study weather modification actions, **emphasizes contingency**, and does not cease the search for universal statements and stable modes into the classes. This approach could be named "data mining" and is commonly utilized in engineering. Engineers like to say "there is gold in the mountains of data" (Pyle, 1999).



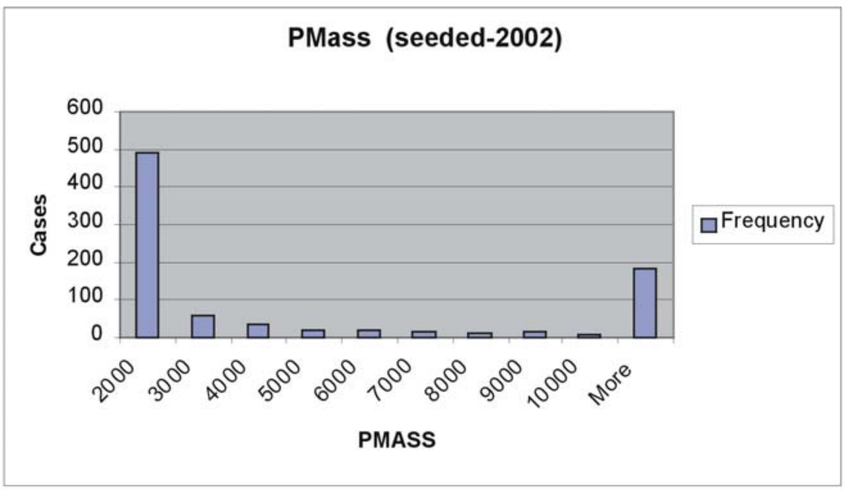
$$r = -0.96, \qquad N = 6.31 \times 10^{12} / PMass^{3.13}$$

Figure 1: Control Cases distributed by precipitation mass
r is the correlation coefficient

Convective processes deserve close attention since they usually behave as individuals and present a very high variability in their behavior. Here the aforementioned contrast among classes may be illustrated mathematically as a phenomenon of self-organizing criticality (Hergarten, 2002). Figure 1 shows the control cases (n = 841 unseeded control storms) in Texas during the 2002 season distributed according to their radar precipitation mass (PMass in kton, N is the number of cases in a particular interval). The distribution followed a potential law obtained by the method of least squares.

Seeded cases followed a similar distribution but with different parameters (regression coefficients) and a slightly smaller correlation coefficient (Figure 2).

What does self-organizing criticality mean in these cases? First, these graphics show the global structure of two ensembles that appear to organize into systems that do not have explicit concern with the outside environment. The constraints in organization in both systems seem to be internal. Second, both histograms are very similar but there are smaller cases in Graphic 1 than in Graphic 2 and greater cases in the later with an apparent increase in intermediate cases at expense of the smaller ones. For the control cases, doubling the precipitation mass implies a reduction in a factor near nine in the amount of cases, whereas for the seeded cases, the reduction factor is near five (use the equations to figure these factors). Self-organizing criticality might be a new way to detect significant seeding signals. It is certainly a way to develop a systemic study of weather modification actions.



r= - 0.94, N = 8.32x 10^9 / PMass^2.29

Figure 2: Seeded cases distributed by precipitation mass, **r** is the correlation coefficient

4. THREE-COMPONENT KNOWLEDGE

Engineering is not excessive empiricism since mathematical considerations allow engineers to always have a theory about experience. Then the theory leads to new scientific experiments, which may or may not corroborate the premises. The scientific experiment is guided by the theory, which asks questions and interprets results. Furthermore, engineering does not underestimate daily experience but uses it to make its creative realizations. As the readers can feel, engineering is a dialectic game, which searches for a balanced correlation between the empirical basis and the theoretical constructions. In this game the explorer must use his/her scientific background together with commonsense reasoning. A question now arises: **What is the logic behind commonsense reasoning?**

Deductive reasoning, which is the process of demonstrating conclusions from general statements, is usually identifies as prime logical reasoning.

However, in science, inductive reasoning (from cases to general statements) plays a major role since concrete data are always particular manifestations of patterns to be recognized through generalization. The so- called hypothetico-deductive method combines both types of reasoning to test hypotheses by the confirmation of their conclusions. Nevertheless, there exists a different type of reasoning called **abductive reasoning,** defined as the inference to the best explanation, which has gained space lately in diagnostic tasks (Josephson and Josephson, 1994). **Abduction** is considered by epistemologists as a third alternative which allows the creation of new hypotheses and the selection of the best one by comparison of explanations. It is obvious that in this kind of reasoning the background knowledge plays a prominent role. Abductive reasoning is the basis of commonsense knowledge, and for scientific purposes its principal feature is the capability to lead to new information. Science is mainly an abductive-inductive enterprise.

The structure of abductive reasoning could be expressed as follows:

Premise 1: **If A then B**
Premise 2: **B**

Abductive conclusion: **Probably A**

In this case it is clear that deduction cannot say a word since we have **B** in premise 2, which is a necessary condition for **A** but not a sufficient one. Notice that the abductive conclusion is only probable since we only have the conclusion of premise 1.

This situation is very common in scientific tasks and even more common in **WM** where decision-making is usually done without enough information and under the pressure of time. Later, during the evaluation of cases, experts should consider this to fairly evaluate the decisions made.

Abductive reasoning brings an interpretive component since selecting the best explanation implies the rejection of other alternatives, which are not logically excluded. This interpretive component has a contrastive essence that adjusts perfectly with the contrastive nature of **WM** knowledge. In **WM** we usually compare target units versus control units, looking for signals of modification that do not follow totally random patterns. However, our **WM** knowledge certainly uses deductive and inductive reasoning. **Rational knowledge,** expressed by conceptual and physical-mathematical models, is directly related to deductive reasoning and can help us in decision making although it is usually not sufficient on its own. **Behavioral knowledge,** expressed by the analysis of particular cases, is related to inductive reasoning and can help us in the identification of patterns. It can also trigger abductive reasoning, which at the end offers **interpretive (or abductive) knowledge** (Fontrodona, 2000).

These three components are always present in **WM** knowledge. To some extension **WM** could become a paradigm for epistemologists because of the necessary interpenetration of the three aforementioned approaches. In WM the comprehension of what is singular is as much an aim as the explanation of general uniformities. It is precisely this focus in contingency what makes this discipline a special case.

5. TEXAS WEATHER MODIFICATION PROGRAM

The previous general considerations support the operations in the current Texas Weather Modification Program. The operations in this program are done on seedable convective clouds, whereas the volume-scan radar data are handled through a set of software utilities called TITAN, which also has an evaluation software package that matches seeded clouds with similar unseeded clouds (Bates and Ruiz, 2002; Mittermaier and Dixon, 2000). The Texas Program could be classified as a well controlled operational program which approaches with its structure the style of previous experimental approaches (Ruiz-Columbié et al, 2003b). Those randomized experiments created a methodology based precisely on the comparison between target and control samples. The resulting conclusions had a contrastive nature with a clear interpretive component.

The intrinsic complexity of the weather objects and their interactions does not permit opportunities for reductionism; hence, ideal laboratory conditions are never reached. The point is clear: **uncertainties are inevitable when dealing with clouds and precipitation since the processes are never clear-cut and without undesirable noise.** Additionally, uncertainties come from non-ideal information sources and from limitations and ambiguities in our rational knowledge. Overcoming this noise becomes a “titanic” task.

However, it is possible to create tools that help to detect improvements within the three-component knowledge model. For instance, since year 2001 in Texas the managing system, based in a scientific approach, has been able to assess the operational performances by using the comparisons between seeded and unseeded control clouds. Apparent increases in different variables, specifically precipitation leaving the clouds, have been reported. Now the system is capable of monitoring different factors that describe accurately the quality of performance and is seen as **a quality control tool** (Ruiz-Columbié et al, 2003a, 2003b; Ruiz-Columbié, 2004). The main factors under control are:

i) Positions where the seeding material is delivered;
ii) Amount of material;
iii) Cloud portions affected by the operations;
iv) Seeding times;
v) Missed opportunities.

Knowing these factors allow us to determine for every seeded case whether or not the seeding material is delivered at the right time and position, and with the appropriate dose. A high correlation between performance and apparent target responses has been detected, and after three years of scientific management we are convinced that **the greater the performance in cloud seeding operations the greater the responses**. This conclusion supports the idea that the seeding material acts as a **contributory cause** for the production of additional increases in the process of precipitation formation. The current critics (NAS, 2003), about the lack of scientific proofs of cause-and-effect relationships in **WM** results, should consider that the phenomenon of causation may present different nuances when dealing with complex events. The concept of contributory cause (Riegelman, 1981) is one example that needs to fulfill only two main criteria:

1) The condition referred as the cause must be shown to precede the effect;

2) Altering only the cause must be shown to alter the effect.

These two conditions seem to be fulfilled in well done **WM** operations in Texas.

We are now in a process to improve our management with the introduction and use of a new software system called "**N**owcast **D**ecision **S**upport **S**ystem" (**NDSS**), which comprises TITAN in its structure and utilizes NEXRAD level II data from multiple Doppler weather radars and other weather data streams. These weather data streams include sounding, rain gauge, wind profile and lightning data, (Weather Decision Technologies, 2003). During the operations the new system will give us more precise information than ever before. Later **NDSS** will allow us to improve the evaluations. On the other hand it is true that we still do not know the details of the chain of physical events that take place in a seeded cloud, but the results seem to indicate that **when the seeding operations are properly performed the dynamics of seeded units appear to improve in comparison with the control units** (Finnegan and Chai, 2003; see also Woodley and Rosenfeld, 1993).

The reader could now understand the insistence here on the rational-behavioral-interpretive character of **WM** knowledge since there is always a comparison between seeded and control cases. Sometimes the control cases are real units, sometimes they are mere models, but the conclusions are always reached through a contrastive method.

We hope that the introduction of the new technology and engineering will help us to enhance the results, ameliorate our interpretations and in time, demonstrate that our weather modification actions produce the expected effects on the ground.

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