"REVIEWED"

THE THEMATIC DIMENSION IN WEATHER MODIFICATION, PAST AND FUTURE

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ABSTRACT

Weather modification research is considered as taking place on the contingency plane defined by a theoretic axis on which mathematical and logical operations take place, and a phenomic or empirical axis on which experimental operations (including observations) on natural phenomena take place. The manner in which these operations are organized and combined in the framing and testing of hypotheses is strongly influenced by a third dimension called thematic by Holton, in which premises or postulates operate that are not directly either verifiable or falsifiable. The thematic premise that has most strongly influenced weather modification research for almost 30 years is that physical understanding of each step in the precipitation process, natural and modified, is a prerequisite for an effective technology.

This premise will be examined in the light of alternative themas operating in other sciences and of Nelson's principle of insulation. This admits of empiric parameters at one level of understanding that may later be theoretically deduced from a deeper level. It is suggested that a different thema is emerging in weather modification research related to interpretations of empirical evidence, which may insulate a portion of this field from what has been described as its great complexity and difficulty.

1. THE THEMATIC DIMENSION

1.1 *Characteristics*

The thematic dimension in science complements theoretic and empiric (phenomic) dimensions. Theoretic hypotheses invite experimental verification; empiric hypotheses invite theoretic explanation. Together they define what Holton (1973) calls the contingency plane, where theory and empiricism interact. He points out that activities in this plane are greatly influenced by thematic premises, along a third axis, that by their nature can be neither verified nor falsified but which inspire and organize the work of individuals and groups in a scientific endeavor.

Even given a common body of theory and experience, different people will go different ways under the influence of different thematic premises. Einstein sought a grand unification of theories that would reveal new laws (Davies, 1980); Langmuir "challenged himself to explain basic phenomena in terms of the known laws of science" (Suits, 1962). Other themas that have worked within the contingency plane in entirely different ways include treatments of historic relationships among ideas, artistic and creative aspects, relationship to social circumstances, amd many others.

A fundamental difference between the theoretic and empiric axes may be pointed out by analogy from the observation by Whitehead (Price, 1954) that "Literature must in some sense be believable, whereas the experiences of human beings in fact develop beyond all powers of conjecture." Theory, like literature, must in some sense be believable. The theoretic axis is the creation of human thought and conjecture under the rules of logic derived from Aristotle. Empirics, being the experiences of human beings in their exploration of the universe, each day discovers things not conjectured in yesterday's system of beliefs. Theories are often proven wrong and abandoned (e.g. phlogiston and the geocentric universe). Empirical discoveries, once well substantiated, are more stubborn.

As background, two sciences may be contrasted in the thematic dimension. For high-energy physics, Figure 1 shows how an empiric thema, once it had established the observable characteristics of the physical world, gave way in the mid-19th century to a theoretic thema which still leads the way. Early scientists spoke of and exploited the "electric fluid", assuming it to be continuous. Theoretical physicists postulated the electron and subsequent particles long before they were observed in experiments that have characteristically been indirect, by methods not accessible to ordinary experience.

In medicine, on the other hand, pressing needs to treat diseases and injuries placed the focus immediately under the hand and eye. The thematic orientation has emphasized empiric investigations of diseases and their remedies such as surgical and chemical treatments of cancer, while theoretic studies have played mainly an ancillary role. The direct empiric experience of patients and symptoms remains essential even when complemented by indirect inputs. Discoveries such as AIDS resulted from observation, not from previous conjectures.

None of these distinctions between theoretic and empiric themas

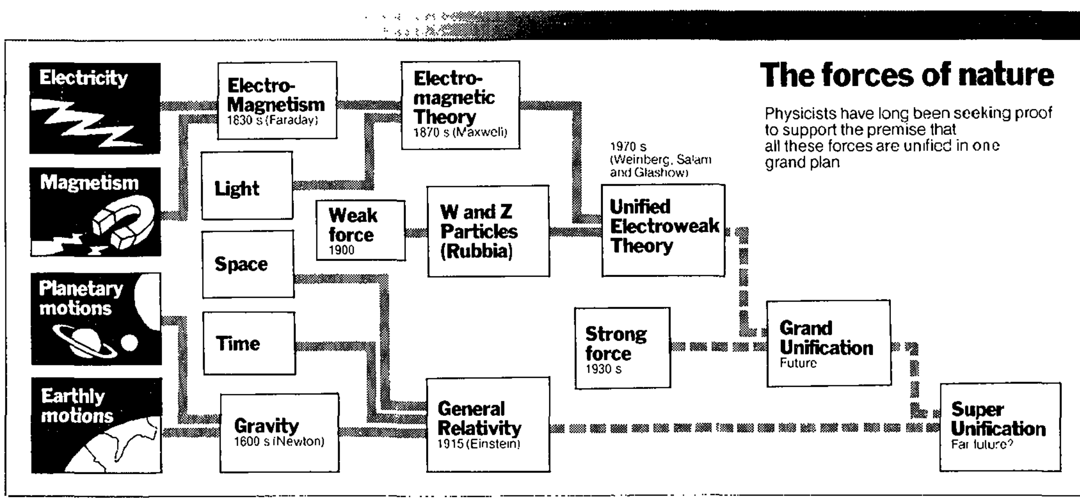

Fig. 1. The thema of direct experience of nature succeeded in mid-19th century by the thema of theoretical prediction of properties not directly experienceable, which became the inspiration for experimental verifications. Courtesy Christian Science Monitor.

sets one above the other in its power to seek the truth or extend the frontiers of science. The danger comes when either pretends to a dominance that impedes the other.

1.2 *In meteorology*

Meteorology apart from weather modification has been historically an almost entirely empiric science, and it remains so today. The rotation of storms was established empirically long before Buys-Ballot explained it theoretically. On the contingency plane of scientific weather forecasting, theoretical studies now being directed to such matters as the general circulation derive their inspiration from the need for better empirical performance and owe their selection to heuristic appraisal of their relevance to that purpose.

A recent review of the activities of the National Center for Atmospheric Research (Hess, 1985) illustrates this point. Its mission to "Initiate, plan, and conduct a broad-based research program in the atmospheric sciences that will contribute to increased knowledge and understanding within the atmospheric sciences" has been carried out principally by a series of large-scale "experiments". These were not experiments in the usual sense of controlled manipulation of selected variables, but rather programs of detailed observation directed to selected topics such as acid rain (APEX) and the properties of single, isolated cumulus clouds (CCOPE). Models developed in connection with these programs have been valued primarily for how they accorded with previously observed characteristics, and only secondarily for predicting as yet unconjectured properties.

2. PRINCIPAL THEMAS IN WEATHER MODIFICATION

2.1 *Theoretic thema*

Two contrasting thematic premises have dominated weather modification for almost 40 years. The first, which I shall call theoretic, has given dominance to the theoretic axis of the contingency plane. It has tended to seek first a theoretic foundation for expected effects, and to make laboratory studies and field experiments contingent on theoretical expectations. Lacking a comprehensive theory of precipitation processes, it has gone forward on a piecework basis, such as trying to calculate the optimum concentration of ice-forming nuclei to convert a cloud to precipitation, in effect taking an atomistic view of the phenomena.

A widely accepted corrolary is that no empiric finding of a statistical or probabilistic nature is acceptable until it is supported by a completely understood and verified chain of physical theory connecting the act of seeding with the consequence of altered precipitation. In the words of Hobbs (1975), "Effects should be attributed to artificial modification only if a logical sequence of changes, of a predictable type, are documented from the clouds to the ground during a predicted period of effect of seeding." The same attitude has been expressed repeatedly by other adherents to this thema (e.g., Advisory Committee on the Application etc., 1965; Public Law 85-510, 1958; National Academy of Science, 1962; Nickerson, 1981; Braham, 1985).

Over the past two decades, the theoretic thema has become increasingly dominant in U.S. Government weather modification experiments: the National Hail Research Experiment (NHRE), the Florida Area Cumulus Experiment (FACE), the High Plains Experiment (HIPLEX), and the Sierra Cooperative Pilot Project (SCPP) are examples. It was also evident in the planning and conduct of the World Meteorological Organization's Precipitation Enhancement Project (PEP) and is strongly reflected in the official statements on weather modification by the National Science Foundation, the American Meteorological Society, and the World Meteorological Organization (WMO). It is epitomized in the statement by the Secretary General of WMO that "no operation to produce rain artificially should be attempted at this time" (Obasi, 1985).

2.2 *Empiric thema*

The second thematic premise, which I shall call empiric, has given dominance to the empiric axis, with theoretic investigations contingent on questions raised by experience. It has tended to take a holistic view of clouds and precipitation, focusing attention first on replicable phenomena associated with cloud seeding that are broadly open to direct observation, and tending to defer the hunt for theoretical explanation until after some major empiric conclusions have been reached about the phenomena.

Project Cirrus (Schaefer, 1950) was characteristic of the empiric thema. Its thrust was to expand the phenomic indications of cloud modification that had been demonstrated on a small scale in the cold box. It relied on phenomic identification of colloidally stable supercooled clouds as experimental units, that is by seeing them remain supercooled rather than by measuring ice-crystal concentrations within them. It assessed the results from phenomic evidence of the destruction of the colloidal stability, such as temporary, local convection followed by subsidence of the cloud top and appearance of optical ice-crystal phenomena, rather than by measurement of ice-crystal and water-drop concentrations. Mostly, it avoided any need for randomization by producing effects so distinctive that uncertainty was eliminated, such as the figure-4 and gamma patterns drawn on a cloud "blackboard". In retrospect one may argue about the links and nodes, whether the ice seeds grew principally by sublimation or by collection; but pragmatically this did not matter: the colloidal stability of the clouds was destroyed, and they dissipated.

Some people, adherents of the empiric thema, moved from confirmation of the experience toward its explanation rather than expecting theory to lead the way. As Langmuir (1950) put it, "After the statistical proof of the significance of the 7-day periodicities, then and only then is it profitable to discuss the mechanism underlying the periodicities."

This thema dominated the work of the Advisory Committee on Weather Control in the early 1950's, leading to its finding (1957) that seeding influences were real. It is evident in many programs carried out abroad, notably in Russia, Australia, Israel, France, and India. Many examples are to be found in a recently published atlas and catalog of worldwide weather modification projects (Howell and Todd, 1985), which also contains references to the projects mentioned subsequently in this work.

3. THE THEORETIC THEMA — ACTIVITIES AND ACCOMPLISHMENTS

One of the major activities inspired and organized by the theoretic thema has been development of two classes of computational models of clouds and precipitation and calculation of the expected effect of seeding on them. The first class is microphysical, corresponding to the "static seeding" concept (Silverman, 1984a), and describes how droplets and ice crystals form and grow and are eventually transformed into precipitation. The second class comprises dynamic models (Orville *et al.*, 1984), concerned with the air motions within clouds that result from the redistributions of heat and mass by the microphysical processes (including the fall of precipitation through the cloud) and by external processes such as exchange of air between the cloud and its environment. Some attention has been given recently to combining them, but the resulting complexity has made a generalized exploration slow and difficult (e.g. Orville *et al.*, 1985).

Investigations with models have led to many insightful conjectures not likely to have arisen otherwise, such as that dynamic heat release within a stratiform cloud may lead to stronger vertical currents and more supercooled water than previously supposed. Many model results have been used to specify numerous elements of experimental design, such as the seeding aim of 100 cm-3 ice-forming nuclei in a convective cloud, and in structuring the design of evaluations for major experiments.

The theoretic thema has led also to important developments in instrumentation to measure cloud and precipitation states along the cause-and-effect chain predicted by models. These include doppler radars, microwave radiometers, and aircraft equipped for inertial navigation and a wide variety of cloud-microphysical observations.

The combination of extensive modeling, of hypotheses and experimental designs based on them, and of advanced technical equipment has tended to make flagship experiments in the theoretic thema increasingly complex, time-consuming, and expensive, and in some instances narrowly focused. Eight years of HIPLEX culminated in three months of field experiments, with 12 seed and 8 control events. They showed great skill in successfully coordinating many activities. However, the results did not follow the chain far enough to reach any conclusion concerning events more than five minutes after the time of seeding. Even so, a leading cloud physicist has declared it "an outstanding success" (Braham, 1985).

Models created under the theoretic thema have greatly increased the specificity with which expectations are expressed as to the sequence of events within natural and seeded clouds. These expectations have been translated into hypotheses governing the design of experiments, and to the conduct of the experiments themselves. In the example of HIPLEX I, microphysical models led experimenters to expect that small isolated supercooled cumulus seeded with a specified dosage of dry ice would produce a certain density of ice crystals which would subsequently grow by riming and become graupel more quickly than in natural clouds. Observations showed that ice crystals formed in greater numbers than expected and grew by accretion rather than by riming.

This example illustrates an important limitation of these models. They typically follow a single Hobbsian chain of processes linking a sequence of nodes (states) from an initial to a final state. In reality, however, there is no unique chain, only a network with multiple loops. Identification of a "chain" is a conceptual venture based on mental images of nature, not nature itself. There are of course good reasons for seeking event chains. There is also good reason not to be chained to them.

Mastering this network has been conservatively described as an extremely complex task (e.g., Silverman, 1984b). Furthermore, for now, description of each node and each process can be only approximated by computer models, using arbitrary simplifications. The unavoidable consequence is a substantial uncertainty in the output of each process and in the description of each node. In general, items such as electrical forces between particles (obviously present in thunderstorms) have been neglected and the models have been parameterized or otherwise forced into agreement with selected laboratory or field data. Thus the models tend to become incestuously related to, and may become confused with, observations of the things modeled.

4. THE EMPIRIC THEMA — ACTIVITIES AND ACCOMPLISHMENTS

Many early weather-modification experiments in the U.S. were based on expectations sufficiently broad to be called empirical. The principal new feature of Whitetop, Santa Catalina, CLIMAX, Wolf Creek Pass, CRBPP, and RAPID projects was application of randomization to the evaluation rather than experimental design dictated by a particular theoretical expectation more elaborate than simply that average precipitation in the target area would be affected. Elsewhere in the world, the great majority of research projects has followed predominantly empiric designs, including those in Australia, Israel, Tasmania, South Africa, Bulgaria, Russia, and India. The overwhelming majority of these have reported strongly positive results (Todd and Howell, 1985).

Several of the experimental projects designed for evaluation according to strict pre-established statistical designs have been re-evaluated post hoc under the empirical thema. One of the more successful empiric re-evaluations applied synoptic analysis to the CLIMAX randomized experiment (Grant *et al.*, 1972). Events sorted by wind directions and temperatures aloft differentiated sharply between reported increases and decreases in precipitation. The Atlas and Catalog of reported weather modification results (Todd and Howell, 1985) and summaries of results grouped according to selected weather conditions (Todd and Howell, 1984; Howell and Todd 1985a, 1985b) illustrate other kinds of explorations that can be conducted under the empiric thema. They confirm the existence of effects at the end point of the seeding effects chain, which have led in turn to new conjectures proposing theoretic explanations (e.g. Howell and Todd, 1985b). From these and other evaluations, there has evolved a body of ad hoc but nevertheless useful explanation for a variety of cloud-seeding effects.

A major contribution of the empiric thema has been the experience accumulated from more than 400 project-years of practical weather modification applications for which specific results have been reported. The vitality of these actions was sustained by business judgements comparing the risk of pursuing perhaps ineffective means versus the cost of foregoing a reasonably expectable and often quite valuable benefit. Some of the conclusions derived from this body of data were reported at the First European Conference of the WMA (Todd, 1985).

There is as yet no serviceable theory respecting long-term or wide-area effects of cloud seeding. From the earliest experiments in 1949 by Langmuir (1962) to current questions by Bigg (1985), these matters have remained exclusively in the domain of the empiric thema.

5. DISCUSSION

Thematic premises, as described in the opening paragraph, can by their nature be neither verified nor falsified. Many themas may live within a single science. In some sciences, much synergistic interaction among themas has emerged, certainly desirable. Computer science (almost the same age as weather modification) has engendered themas of pure mathematics coexisting with others of human psychology and such concepts as artificial intelligence. The cooperative interaction among them has promoted rapid development of the science.

The obstacles to the application of innovations that Morison (1966) pointed out apply to weather modification: sources of the practical technology lacking in authority; disbelief in the magnitude of reported effects; reflection on the competence of those supposed to be in charge of developing the technology; the effects of personalities; and lack of a fundamental definition of the effectiveness of the institutions involved. The Weather Bureau's mission was to forecast the weather, not to modify it.

Unfortunately, the influence of a strong thema can lead to distortions of reasoning. An example appeared in a recent chronicle of Project Stormfury (Willoughby *et al.*, 1985), which concluded that "Observational evidence indicates that seeding in hurricanes would be ineffective because they contain too little supercooled water and too much natural ice" for seeding to produce either microphysical or dynamic changes. This statement is sustainable only if the necessary conditions of supercooled water and natural ice content for effective modification had been accurately determined, and also how they had to be distributed in the storm. The same article makes clear that the statement depends, in this aspect, not on any demonstration but on untested and substantially uncertain model expectations. The infeasibility of hurricane modification was thus affirmed, not on the basis of experience as claimed, but on the basis of models. Foreclosure of further experimentation has been counseled on the basis of a misrepresented premise. Perhaps in the light of fuller knowledge the decision would be justified. Perhaps it is justified today by the need to conserve scarce resources available for experimentation. It is not justified in the manner stated.

The chronicle also stated that "none (or perhaps only one: dynamic feasibility) of the five conditions for development of an operation hurricane amelioration strategy could be met." The first was the willingness of Governments to accept the risk of a seeded hurricane devastating a coastal region. Doubt on this point has been overblown by the thema of public caution: a different attitude has been taken by other governments, and by the U.S. Government in other situations of risk. The second was the state of development of instrumentation and personnel to do the seeding and document the results: if only the end results were required to be documented, the technology is here today. The third was microphysical, the presence of enough supercooled water; and the fourth was dynamic, a vortex sufficiently labile for human intervention to affect it: both have already been commented upon. The fifth was statistical: the experiment had to be repeatable and the results distinguishable from natural behavior. In this regard, the key role of timing of the seeding event and the changes in hurricane structure was entirely passed over.

When the several policy statements approved by the Council of the American Meteorological Society are examined, that on weather modification stands out. It is not hortatory, like that favoring establishment of an independent Federal agency for the atmosphere and the oceans. It is not empiric and descriptive like most of the others, such as that on weather radar (Amer. Meteor. Soc., 1981, renewed in 1984). Unlike the statement on forecasting, it does not note support of efforts along the theoretic axis for empiric forecasting skill (without insisting on the necessity for a complete understanding of atmospheric motions before a forecast technology can be said to exist). The latest, on mobile homes and severe windstorms (ibid., 1985), does not insist that an adequate theoretical understanding of downbursts is essential for protecting mobile homes. This is in contrast to the thema of the statement on the atmospheric environment (ibid., 1984) that "On the other hand, in weather modification, despite the practical benefits of a reliabile capability for enhancing precipitation or suppressing hail, these benefits have remained elusive for more than 30 years due to insufficient understanding of precipitation processes." The key words here are "insufficient understanding", since sufficiency is only in the eye of the beholder and the elusiveness of practical results is arguable.

What constitutes sufficient understanding or adequate knowledge of a technology is explored by Philip Nelson (1985):

> Newton's law is perfectly correct within its range of validity, and we would no more discard it than we would hydrodynamics, even though we know that fluids are not really continuous. Underlying the success of the heirarchical scheme is an idea that we can call the principle of insulation: succeeding scales are insulated from one another, making it possible for us to understand one scale without understanding all the deeper ones. Instead, each level of our understanding can be described by theories containing a finite number of parameters, for example the mass density and viscosity of a fluid in hydrodynamics. These parameters appear arbitrary and are determined by experiment. When the next level of understanding is uncovered, however, in this case perhaps the kinetic theory of gasses, the previously given parameters become computable, usually in terms of a smaller set of new parameters describing a world of shorter distances (Avogadro's number, for instance). In other words, the details of the deeper theory are encapsulated in a small number of quantities; these become the arbitrary parameters of the 'effective' theory, which is thus insulated from the many other details of the underlying theory.

Some of the key parameters of weather modification still appear arbitrary. Although cloud-physics models suggest certain concentrations of ice-phase nuclei as ideal for rain stimulation, at least one recent empirical study (Howell and Todd, 1985) finds no difference in reported outcome between heavy and light seeding rates.

Official U.S. policy on weather modification is ambiguous. One Department has stated it as to "help alleviate shortages of food, water, and energy" (U.S. Dept of Commerce, 1979). This was parapolicy, stated but not carried out. At the time, the policy of the Department of State was to discourage inquiries from abroad concerning weather modification by characterizing it as unproven, controversial, and unready for application. AID policy belongs to an empiric thema, making the best use of existing technology and "learning by doing", while NSF policy belongs to the theoretic thema of delaying application until the technology is "proven" by confirmatory experiments.

Further inconsistency comes from the unpublished minutes of a conference convened in 1963 to reconsider State Department policy on weather modification. "Any National Academy of Science review (it stated) --- will essentially confirm the Weather Modification Advisory Board conclusions regarding the technical status and operational use of weather modification ---. The passage of time and continued use of current seeding practices without natural disaster or adverse court judgements is important. *By continued acceptance, the degrees of freedom for decision-making have expanded* (emphasis added)." In other words, the *de facto* existence of a technology in being for more than 30 years is recognized without disparagement but seen as not available for incorporation into official policy.

6. THE FUTURE OF WEATHER MODIFICATION THEMAS

A clearly desirable objective for the future is of to replace the present pattern of interference, its conflicts, distortions, and ambiguities, with a pattern of cooperation and synergism that will enable weather modification to advance more strongly. To quote from the poem by W. H. Auden , "After Reading a Child's Guide to Modern Physics",

> This passion of our kind
> For the Process of finding out
> Is a fact one can scarcely doubt.
> But I would rejoice in it more
> If I knew more clearly what
> We wanted the knowledge for.

Do we want it for improving water supplies? For verifying models? For knitting the two together into a single discipline? What is the definition of effectiveness?

Cooperation and synergism will come about when there is frank acknowledgement by the leaders in each thema of the validity and accomplishments of the other and an end to unreasonable and logically unsupportable insistence on restrictive viewpoints. One can treat empiric experiments in weather modification with rigor equal or superior to that being devoted to chain-of-effects experimental designs. As to the role of proof, Vannevar Bush (1971) reminds us that "Unanimity of opinion has no status in this field of proof. The great majority of scientists have often been wrong."

A major step will the cross-thematic acceptance, examination, and organization of evidence. This means mainly empiric evidence, since there has been no bar to consideration of theoretic evidence. This corresponds to adding a lateral flow of information above Nelson's (1985) insulation level. There is a large amount of empiric data containing information, for example, about the relatioship between cloud types and cloud-seeding results, that is lying unused. Systematic exploitation of it has begun to yield results (Todd and Howell, 1985) and promises much more. An example of a timely empirical project is a follow-up of Bigg's (1985) report of unexpectedly persistent effects of silver iodide seeding, lasting apparently for days and perhaps for months. There exists a wealth of data in addition to that he has treated.

Discussing evaluation of practical operations, the Panel on Weather Modification of the National Academy of Science (1964) remarked that "The stratification analysis does suggest that stronger evaluation techniques than the simple target-control regression are possible, even when randomization is impractical. Specifically, climatological target-and-control relationships could be supplemented by synoptic-meteorological factors to increase the statistical probability of target-area precipitation." Examples of such analyses have been presented by Todd and Howell (1984).

An empiric orientation is likely also to sharpen the focus on weather applied weather modification as a distinct objective. Much of the research done in the name of weather modification has advanced career vectors with only weak weather-modification components. In its report on progress, the staff of the weather modification research project of RAND Corp (1969) said that, "left to his own desires, any individually funded competent researcher will spend most of his entire time carrying forward his own research program. Only rarely can such a person or group of such people afford the time or have the inclination to act as generalists and consider the problem of weather modification in its entirety."

In proportion as it is a world leader in weather modification research, the U.S. has received requests from foreign countries for technical assistance. These requests, whether from "developing" countries or more advanced ones, have almost all been concerned with practical matters of water supply or agricultural production. From the viewpoint of future effective assistance to a client state, the appropriate response will have to do with the probable benefits and costs of using weather modification in the present state of the technology. The policy question is one of decisionmaking under uncertainty. Apart from Olympian statements about "weather modification" there is a need to review and assess experience relevant to the particular situation of the client.

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