TOWARDS A NEW PARADIGM FOR WEATHER MODIFICATION SCIENCE AND TECHNOLOGY*

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ABSTRACT

Weather modification science and technology development and implementation program plans have been created since 1946, and have collectively led to modern weather modification technologies. These modern weather modification technologies have helped the community at large for over 60 years. Recent technological and scientific advances, scientific community recommendations, and contemporary socioeconomic problems form the basis for constructing a new plan that facilitates the development and applications of modern weather modification technologies for more effectively benefiting society. Pending Congressional legislation adds urgency to a new approach for developing weather modification science and technology. This paper describes this new approach.

The proposed approach encompasses a comprehensive agenda of fundamental and applied research and development efforts directed toward optimizing existing technologies used to manage "treatable" atmospheric processes and conditions, and to allow the development of select relevant innovative technologies. It will require a permanent, national program that administers its resources and oversees its activities. High-level implementation guidelines are also provided.

1. Introduction

The scientific and operational communities generally agree that the recent advances in the relevant, general physical processes and technologies (e.g. Orville 2001; NRC 2003) need to be capitalized upon in the form of a concerted and sustained national program to carry out basic and applied research in weather modification (e.g. Garstang et al. 2005). They have not laid out the details describing such a program. Pending Congressional Legislation (e.g. Hutchison Bill in the Senate, S517 – 109th congress, and companion bill by Udall) adds a new urgency to establishing a new program. This paper describes such a weather modification program. Weather modification science and technology development plans have been constructed (e.g. Schaefer 1969, 1976; Juisto 1974) and subsequently implemented. Each implementation has yielded improved weather modification technologies and understanding of the hydrologic cycle, and has helped the community at large meet water resource requirements.

Weather modification technologies may be effectively applied to facilitate the water and energy cycles (e.g. Reinking & Martner, 1995; Smith et al., 1997; Silverman et al. 2001a,b; Woodley et al., 2003a,b). Nonetheless these results are tempered by a long-running issue concerning whether operational cloud seeding activities, especially associated with convective clouds, achieved the intended results claimed. Additional evaluations are required to address the aforementioned issue and before answering the question," are weather modification technologies ready to increase water resources and alleviate, or possibly prevent, drought."

Additional evaluations are planned as part of the Next Weather Modification Program (NWMP), partially since weather modification technologies are viewed as key to dealing with many present and potential future scientific, environmental, and socioeconomic issues, such as steadily increasing human suffering and property damage caused by hazardous weather (e.g., severe weather; supercooled fog, freezing rain), fire, and other environmental problems related to toxic wastes, ozone hole, "acid rain", biological or chemical warfare (CDC 2000). A socioeconomic issue relates to the effect from impending drought, predicted by modeling simulations to affect more than 40% of the world's population by the 2020's. A United Nations Water Development report (UN/WWAP 2003) notes that over the next 20 years the average global supply of water per person is expected to drop by one-third. This report also notes that by 2050, 2 billion to 7 billion people will be severely short of water. Precipitation accounts for roughly 1% (by volume) of the total global water budget, and its only input. Water usage is presently about 8% (by volume) of the total water budget and is projected to reach 12% by 2025 (Shiklomanov In Press). Anthropogenic air pollution, for example, may compound the water shortage (e.g. Givati and Rosenfeld, 2004). This emphasizes the need to develop cloud seeding technologies designed to enhance the efficiency of the hydrologic cycle.

The proposed Next Weather Modification Program (NWMP) would be built from current scientific base and implemented according to standard engineering practices. Modern weather modification technologies are effectively applied to disperse supercooled fog, augment the ice crystal process in cloud systems, especially orographic clouds. Thus implementing program objectives on such systems, especially winter orographic systems, would help maximize programmatic success. We agree with many of the suggestions and concepts for a weather modification scenario for the future recently promulgated by List (2004). He urged that "the study of the precipitation processes in all their forms is of greatest importance to the evolution of weather modification." Some technologies show great progress toward enhancing warm and cold cloud precipitation process efficiencies and even suppressing hail damage. However, they need to be further developed for successful application to mitigate hurricane and tornado damage, minimize the negative affects of anthropogenic air pollution on precipitation efficiency, or to neutralize negative effects from pollutant deposition. The near impossibility of obtaining statistical significance in random seeding trials, especially with respect to glaciogenic seeding of convective clouds complicates seeding evaluation confidence for these events. We also agree with List's (2004) assessment of the four WMO criteria for rain enchancement, i.e., that the criteria need to be overhauled and reformulated, and extended to hail.

The NWMP does not include less developed technologies (e.g. extraterrestrial mirrors-Muschinski 2001; ionization, chaos theory-related approaches; sonic initiation of precipitation, making hurricane disappear from conventional radar), based on insufficient scientific and engineering test results, which pose a significant risk to programmatic success. The existing technologies combined with lessons learned from the last 60 years, recent technological advances, science community recommendations, and societal need provide an impetus for developing systems and technologies that monitor and manage atmospheric events, as well as the creation of a new weather modification research program plan.

2. Program scope

The proposed NWMP would be a 10 to 20 year national program that would administer the resources and the activities for all research and development efforts directed toward optimizing the technologies used to manage atmospheric processes and their resultants (e.g., hurricanes, orographic and convective precipitation, frozen rain, drought). Its mission would be to develop the operational application of atmospheric modification (weather modification) technologies that help provide sustainable water supplies and reduce atmospheric hazards. This includes improving the understanding of the relevant processes and their simulations, as well as the evaluation methods (physical, chemical and statistical) for operational activities through cooperative multidisciplinary research and development arrangements and a well-designed outreach effort. Then to transfer these technologies to its customers, such as, farmers, crop insurance industry, water district managers, utility industry, relevant organizations (e.g., WMA), scientific community, and government agencies (e.g., National Oceanic and Atmospheric Administration-NOAA, Environmental Protection Agency-EPA, National Aeronautics & Space Administration-NASA, Department of Defense-DoD, Centers for Disease Control and Prevention-CDC).

The NWMP mission would concentrate on three areas; (1) monitoring atmospheric water resource management parameters, (2) fundamental and applied research (and development) of the science basis and seeding technologies, and (3) public outreach and professional development, fostering the cooperation between NOAA and other federal agencies, state agencies, relevant commercial organizations, private groups, as well as the general public. The latter follows List's (2004) urging that "the contributions of the engineers and operators to the science of weather modification also need to be acknowledged…Engineers, like the scientists, need to be on a learning curve; they have to be involved now, so that when we approach the next level of sophisticated experiments, they know how it is done."

There is a need to better simulate, and thereby identify and monitor atmospheric events, airborne pollutants, and select inadvertent weather modification signatures. This ability combined with improved seeding technologies will maximize the benefit and success of this program, since they contribute to the resolution of water-related issues (especially water scarcity). These improvements, when combined with improved scientific understanding, provide a more useful tool for determining when and where the atmosphere or cloud can most likely benefit from implementing the improved technologies.

There is a need to conduct research and development activities of our scientific understanding, operational seeding project evaluations, and seeding technologies. This includes documentation and mitigation of inadvertent effects of pollutants on hydrologic cycle efficiency, and physical, statistical, and chemical technology development, and the development of statistical analytical techniques. Statistical analytical techniques need to be improved, especially with respect to convective cloud seeding applications, in order that they may evolve into a statistical tool that is not data and/or process limited. The development of improved dispersion techniques and higher yield cloud seeding agents is needed for obvious reasons. Technologies to "treat" hazardous weather systems (e.g. freezing rain, hail formation, tornadoes, hurricanes) are more critically needed, and will benefit from past and ongoing research results, especially research using ground-, air-, and satellite-based remote sensing devices (radars including Doppler, lidars, radiometers). The aforementioned need is rather daunting, but necessary and attainable in time. Initial efforts to develop an understanding of how present day cloud seeding technologies can be applied and modified to lessen the socioeconomic impacts of hazardous weather events and materials might begin with the information gained from model perturbation experiments. Renewed emphasis on the modeling of seeding agent tracer study results would greatly improve seeding agent placement within cloud systems, and the models could form the basis for Homeland Security needs.

There is a need to develop state-of-the-art cloud seeding technologies for application toward mitigating the effects of freezing rain events. The knowledge base is not large enough to reliably and practically support tornado or hurricane reduction efforts. It may one day support these efforts *after* appropriately funded and directed cooperative research campaigns have been completed.

The existing cloud seeding technologies are operationally used to reduce hailstone size, and have the potential to reduce the intensity of rotational hurricane winds. The reductions in hurricane rotational wind speeds following cloud seeding ("Esther" in 1961, "Beulah" in 1963, and 30% for "Debbie" in 1969) were not statistically distinguishable from the range of natural variability, and thus not yet scientifically accepted. Consequently, initial activities must be directed toward adding seeding routines to the best physical and numerical models, and verifying its outputs, which should form the basis for transforming these models to operations and ultimate application.

Simulation and modeling studies will require verification through carefully designed cooperative efforts that will generate sufficient, adequate data for physical, chemical and statistical evaluation method developments. Cloud seeding program evaluations also need to be improved by revisiting whether measuring devices used for evaluations are primary standards; if not, does one exist, if so, is there a better device? For example, is the standard precipitation gauge, or the recent commercially introduced laser precipitation gauge, truly a primary standard for precipitation amount measurements? That is, could it provide the natural spatial and temporal precipitation amount field (e.g., DeFelice 1998) under all conditions at that point, versus alternative measuring devices? The answer is crucial to evaluating the success of precipitation enhancement projects, for example. Furthermore, if the existing precipitation gauges are not the best primary standards for precipitation amount measurements, then could the Z (reflectivity) – L (precipitation water content) relationship be used to estimate rainfall amount? The Z-L relationship would not require estimates of hydrometeor terminal velocity, and L could be verified using a dual wavelength microwave radiometer. It would require that the Z, L measurements are temporally and spatially concurrent, and 'normalized' to historical precipitation amount measuring devices.

Inadvertent modification studies need to be increased, and not solely from a climate change point of view. For example, an agricultural to urban land cover change over a modest area can introduce a climatic forcing similar in magnitude and direction to that from carbon dioxide (personal communication with R. Pielke Sr. 2001). Anthropogenic air pollutants have been reported to reduce precipitation process efficiency under some conditions (e.g. Givati and Rosenfeld, 2004). Here initial efforts should at least focus on strategies for minimizing the effect from such inadvertent modifications to the atmosphere, and neutralizing airborne pollutants within cloud systems or redirecting their air trajectories to settle on surfaces that have high buffering capability or which are less sensitive to environmental pollutant deposition.

3. Strategy

Recent technological and scientific advances, along with contemporary socioeconomic problems and lessons learned included in DeFelice (2002), make a case for seeking applications of modern weather modification technologies that could benefit society. This requires an organizational structure that optimizes the engineering and science disciplines that must work together to:

a) Develop and continually improve the ability to computationally identify and monitor all atmospheric environmental conditions that are good candidates for beneficial modification through its developed technologies.
b) Develop technologies to more efficiently execute traditional cold and warm cloud seeding applications, and targeting and delivery of seeding agents.
c) Develop computational simulations and strategies to mitigate atmospheric environmental hazards, including hazardous toxic clouds or plumes.
d) Improve evaluation protocols (includes verifying the models developed under a).
e) Develop strategies to minimize the effects from the inadvertent modification of atmospheric conditions (formerly termed inadvertent weather modification).
f) Create a proactive professional development and public outreach activity.

Any weather modification program plan, whether as described herein or otherwise, must pursue a comprehensive agenda of fundamental and applied research and development efforts directed toward the goal of optimizing the technologies used to manage atmospheric processes and conditions. It is also assumed that the resources stated below represent the amounts necessary to achieve stated deliverables, and that stated future needs are reasonable.

This plan addresses current and near future needs of the weather modification community and also outlines the high-level infrastructure that will address the recommendations from the parent science community (Table 1). Table 1 summarizes how the plan objectives align with recommendations from the National Research Council (NRC). This plan will benefit from using standard project management processes and updates from improvement exercises (e.g., DeFelice et al. 2005), and by having the depth and foresight to address the differences of perceptions between the science and operational communities as detailed in Garstang et al. (2005), i.e., 1) Interpretation of scientific proof, 2) Current status of cloud models as applied to weather modification, 3) Evidence of glaciogenic seeding in convective clouds, 4) Cold season orographic seeding, 5) Evidence for hail suppression, and 6) Support for specific purposes.

The cold season orographic seeding perceptual difference related to cold season orographic seeding (e.g. see Garstang et al., 2005 item 4) is not a significant difference in perspective, since the science community sees orographic cloud seeding as a particularly promising candidate for an intensive field program (Garstang et al. 2005). The sixth perceptual difference reflects differences between the individual cultures (i.e., scientific vs operational) than anything else. This program plan helps mitigate these perceptual differences by setting up an integrated team approach to its activities, and by insisting that the research and development component of this program be geared toward improving the effectiveness of operations.

Table 1. Next Weather Modification Program (NWMP) plan versus NRC (2003) recommendations

NWMP Plan	NRC Recommendations
1). *Assumes* a permanent, national (if not international) program that would administer the resources and the activities for all research and development efforts directed toward optimizing the technologies used to manage the efficiency of atmospheric hydrological processes.	1). "Because weather modification could potentially contribute to alleviating water resource stresses and severe weather hazards, … A renewed commitment to advancing our knowledge of fundamental atmospheric processes central to the issues of intentional and inadvertent weather modification ...."
2). Outlines a comprehensive agenda of fundamental and applied research and development efforts directed toward optimizing the technologies used to operationally manage the efficiency of atmospheric hydrological processes to help provide sustainable water supplies. See Resource Requirements	2). "Coordinated research program includes … Carry out exploratory and confirmatory experiments … Hygroscopic seeding … Orographic Seeding … Studies of specific seeding effects …". "Capitalizing on existing field facilities and developing partnerships among research groups and select operational programs."
3). Calls for developing: - better better monitoring capabilities for all atmospheric events, including frozen rain, hurricanes & tornadoes, airborne pollutants. - more effective dispersion techniques - higher yield seeding agents for warm and cold clouds - improved evaluation protocols. - strategies to minimize inadvertent weather modification.	3). "… coordinated national program be developed to conduct a sustained research effort in the areas of cloud and precipitation microphysics, cloud dynamics, cloud dynamics, cloud modeling, laboratory studies and field measurements designed to reduce key uncertainties…"

4. Organization

The proposed program would be organized into five functional areas as shown in Fig. 1, and their initial goals, based on lessons learned and recent scientific and technological advances, would be similar to the following:

- Weather Modification Event Monitoring/Analysis Prediction System Development Goals: (i) High resolution monitoring/analysis prototype systems able to identify the atmospheric conditions conducive to beneficial precipitation augmentation (e.g. orographic), hail suppression and other hazardous storm suppression (freezing rain, hurricanes, tornadoes, other). (ii) Transfer information to the Public Outreach/ Professional Development activity.
- Glaciogenic and Nonglaciogenic Seeding Technology Research/Development Goals: (i) Better nucleation efficiency of possible warm cloud, cold cloud, and other "cloud" seeding materials. (ii) More efficient delivery (dispersion) systems for a given application as identified under (i). (iii) Transfer results to Public Outreach/Professional Development activity.
- Applications Research/Development Goals: (i) Improved evaluation methodologies. (ii) Operational atmospheric management monitoring/analysis prediction systems. (iiia). Verified high resolution models with more sophisticated microphysics routines for understanding hazardous storms, inadvertent modification of atmospheric conditions (e.g. due to land cover

changes, air pollution, biomass burning) and other associated phenomenon (e.g. bioterrorist agent cloud transport). (iiib) Implement (iiia) with seeding material introduced. (iv) Improved targeting systems. (v) Improved applicability of evaluation technologies (e.g., dual, polarized, Doppler radars, tracer techniques). (vi) Transfer systems and results to public outreach/professional development activity for feedback on operational usefulness, and fine-tune them based on users' input.

- Public Outreach, Professional Development Goals: (i) Develop and present educational materials, demonstrations, workshops, and colloquia that emphasize the relevant appli-cations derived from this program's activities and related technologies. (ii) Coordinate the technology transfer to program customers. (iii) Conduct interactive open houses.

Plan Management Support Goals: (i) Provide an environment that facilitates the successful completion of all area goals and hence objectives. (ii) Provide overall programmatic metrics, guidance, and support during the life of the program. (iii) Participate in defining and developing future and related technology investigations. (iv) Administer seed grants for innovative or new applied research and applications.

The triangle in Fig. 1 symbolizes the interdependence of these functional plan areas. A core group consisting of the necessary skill mix to comprehensively address the underlying issue and a representative from the end user should be assigned to each objective.

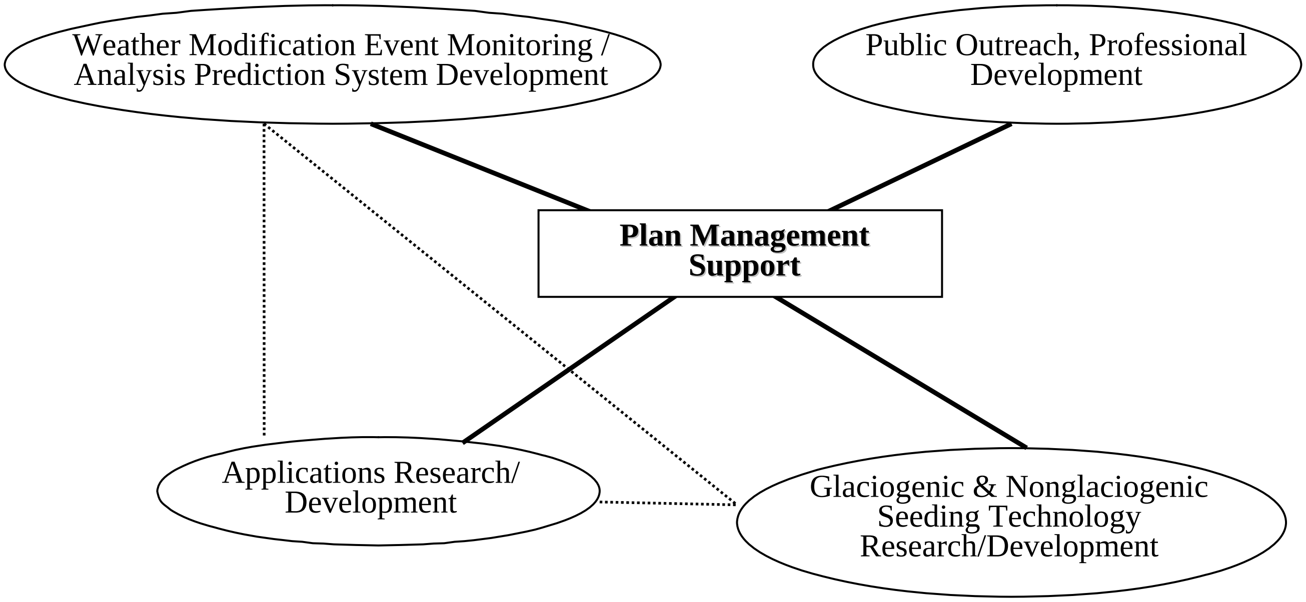

Figure 1. Next Weather Modification Program (NWMP) Organizational Chart. The triangle symbolizes the interdependence of these functional plan areas.

5. Resource Requirements (anticipated):

Resources are people, office and lab space, instrumentation, computers, money (herein budget). The Program Manager would use standard project management tools to track task schedules and cost metrics presented in the high-level tasking (i.e., primary activity) of work to be performed under this plan as summarized in Table 2.

Table 2. Suggested high-level tasking of work.

1. Weather Modification Event Monitor/Analysis Activity
   Prediction System Development
   a. Real-time monitoring component
      i. Orographic (winter)
      ii. Convective Systems (Summer)
      iii. Hailstorms
      iv. Other non-hazardous cloud systems (e.g freezing rain, etc)
      v. Hazardous 'cloud' systems
   b. Analytical component
2. Glaciogenic and Nonglaciogenic Seeding Technology Research/Development Activity
   a. Seeding material nucleation ability optimization
      i. Warm and Cold clouds
   b. Seeding material delivery system development
      Warm and Cold Clouds
3. Applications Research/Development Activity
   a. Evaluation methodologies
   b. Evaluation technologies (e.g. dual polarized Doppler radar, tracer techniques, Integrated Earth Observing Systems-IEOS)
   c. Model and prediction system development and verification
   d. Inadvertent weather modification/global climate change
   e. Targeting system development
   f. Extra-area and downwind effects
4. Public Outreach, Professional Development Activity
5. Program Management and Support Activity

Office and some laboratory space will be required, and should be capable of housing up to 500 employees. An east coast location would maximize the benefit of interaction with NOAA, DoD, DOE, DOI, NASA, other government centers and laboratories, and other relevant organizations. There should never be less than 70 to 80 FTEs for support and technical staff, 5 to 10 FTEs for student interns, and 15 to 20 FTEs for all program administrative staff. DeFelice (2002) provided a breakdown between FTEs and high-level activity (i.e., titles in Fig. 1 objects). The laboratory space could be used for archiving and processing large volumes (i.e., mega terabytes) of multi-disciplinary data, running multiple algorithms in near real time experimental cloud studies to develop modeling algorithms, nucleation experimentation with ice, water, and perhaps other substances, instrumentation development and storage, instrument calibration, sample prep for chemical analysis. This could include the development of 3 state-of-the-art cloud chambers to study ice, water and other species nucleation.

Budget *(anticipated based on fiscal year 2002 dollars, as exemplified in Table 3):* This program would require a budget adequate for successful fulfillment of its objectives, e.g., $20+ M/yr. Precedent is set by successful medical and other science programs, wherein substantial, long-term, committed funding has led to overwhelming positive results after multiple decades. For example, making such an investment for this plan very soon and continuing it through the 2040s will most probably ensure that significantly less than 40% of the world's population will reside in water-stressed areas.

The fiscal internal funding requirements and anticipated programmatic expenditures would be aggregated to the main WBS activity (e.g. Table 2, 1. Weather Modification Event Monitor/Analysis Activity, 3. Applications Research and Development Activity), and tracked weekly compared to a baseline established at the beginning of the program. The budget amount categories will include loaded salary and non-salary (e.g. travel, benefits, equipment, supplies) and anticipated reimbursables (could include internal NOAA grants, NASA, NSF, EPA grants). The Applications Research and Development Area should have a budget that is no less than 10 to 20% of the total budget with nearly equivalent salary and non-salary amounts.

Anticipated Sources of Funding: NOAA, Congress, farmer groups, insurance industry, utility industry, state governments, water districts, and through **Cooperative Agreements.** This plan must contain cooperative agreements (or equivalent, i.e., MOUs - memorandum of understanding) with NOAA divisions, the National Center for Atmospheric Research Research Applications Program already dedicated to atmospheric modification activities, and relevant organizations throughout the cloud physics and weather modification research and operational communities. We suggest 40 to 50% of the total funds be set aside for reimbursables and MOUs.

Table 3. Next Weather Modification Program (NWMP) Summary Budget (for a 10 yr program)

WBS Activity	Salary ($M)	Non-salary ($M)	Total ($M-10 yr prgm)
1. Atmospheric Management Monitoring/Analysis Prediction System Development	42.0	10.8	52.8
2. Glaciogenic and Nonglaciogenic Seeding Technology Research/Development	40.0	10.8	50.8
3. Applications Research/Development	21.0	32.0	53.0
4. Program Management and Support	20.0	11.0	31.0
5. Atmospheric Modification Public Outreach	17.0	5.4	22.4
Professional Development			
Program Total	***140.0***	***70.0***	***210.0***
Anticipated Reimbursable			10.0
Anticipated Internal Requirement			***200.0***

6. Programmatic Success:

The likelihood of success is high, because the program is starting with some proven technologies, many of which have had more than 60 years to mature. The success of this program will be gauged by the development and transfer of demonstrated technologies to the operational sector. It is expected that there will be improved products, processes, and field procedures resulting in scientific publications and conference presentations. Success does not require new tools, demonstration of significant seeding signatures, or creation of new scientific disciplines. Consequently, future applications of this technology have a higher potential for success, and less risk than that of previous weather modification programs.

7. Risk Identification and Management:

The primary risks are likely to be losses of key personnel, funding, required data and technology, and systems, as follows:

- Loss of key personnel will be anticipated by management through open communication with government staff, unless a contractor is hired to handle the services contract. If a contractor is hired, then loss of key personnel will be anticipated through open communications with government and contract staff. The contractor will fill vacancies as quickly as possible. The contractor could be a particular government agency, an intergovernmental committee, or a non-government organization. We assumed that a non-government organization will handle the services contract since this is the current trend.
- Loss of internal agency funding allocation will be mitigated by (1) identifying and taking on reimbursed research that concerns similar interests and applications, for example, or by (2) rescoping, postponing, or canceling the affected research endeavor.
- Loss of required data and systems will be anticipated in the planning process, and suitable proxy data or alternative systems will be identified for quick access if needed.
- Law Suits, while not likely, are possible and will be mitigated by (1) making sure the federal government does not conduct cloud seeding operations, (2) keeping the public informed about the activities associated with the NWMP.

8. Deliverables:

(Initial, anticipated programmatic, *not annual*, deliverables)

- ➢ Proven systems to monitor and analyze all atmospheric environmental conditions (e.g., frozen rain, hurricanes, tornadoes, air pollutants) that are favorable for the beneficial modification through technologies developed by its activities
- ➢ Improved evaluation protocols and technologies
- ➢ More effective weather modification technologies for traditional, weather and atmospheric environmental hazard applications. For example:
  - o Higher yield seeding agents for warm and cold cloud systems

    - More effective delivery techniques
    - Highly developed cloud and mesoscale numerical models
- An implementable strategy to minimize the possible negative effects resulting from the inadvertent modification of our atmosphere
- A proactive professional development, public outreach program.

9. High-level implementation plan

The aforementioned plan clearly contains scientific and engineering components. The engineering component is defined primarily by the monitoring system and its development as well as the seeding technology and sensor development. The organizational structure to address issues related to the integration of science and engineering disciplines features an integrated team that stays together throughout the life cycle of the project, and would include guidance with respect to project size, and the culture (science versus engineering) of the prime dependent.

It is important to make clear that the implementation of the Next Weather Modification Program (NWMP) plan calls for tackling all tasks, issues in a multidisciplinary, cross-component team environment that exists throughout the entire life cycle of the project. This is accomplished by:

- Starting with an organizational structure that supports the processes within this program and their interactions
- Specifying teams with multi-disciplinary skills and well-defined member roles and responsibilities at all levels within the plan at the plan's kickoff meeting.
- Developing carefully designed cooperative research and development efforts whose purpose is to enhance the understanding of the inherent multi-disciplinary processes for the good of the operational weather modification community. This has economic benefits to the program as well.
- Having somebody, i.e., the lead of the appropriate WBS Activity as noted in Table 3, dedicated to ensuring that matured plan products are transferred to stakeholders and end users in a timely fashion.

The ASCE/EWRI AWM SC Standard Practice Documents for hail suppression (ASCE/EWRI Standard 39-03, 2003), precipitation augmentation (ASCE/EWRI Standard 42-04, 2004), and supercooled fog dispersal (ASCE/EWRI Standard 44-05, 2005) provide details for implementing this program. The ASCE documents provide insights into the operational aspects for implementing respective programs, which will be most helpful in fine-tuning the relevant level 3 team activities (Fig. 2) under this program. They do not provide insight, for example, on how to implement hurricane weather modification component of this program. Initially, transform the best hurricane model into a hurricane observing system algorithm, verify performance, develop and insert seeding effect algorithms. Following subsequent verification, the latter would demonstrate the circumstances that lead to non-beneficial impacts from seeding. It could also help determine when the most effective time to seed the hurricane relative to minimizing wind damage and flooding likelihood, while maximizing rainfall amount on the mainland. Then verify the observing system algorithm results, etcetera in the manner outlined earlier in this section and as generally follows.

The following describes the high-level implementation team structure, and working guidelines for implementing each of the NWMP areas.

High-Level Implementation Team Structure: Implementing this program requires communication between the management and those carrying out the activities while allowing for a comprehensive approach at all vertical levels throughout the entire program. This is best accomplished by forming multiple, multi-discipline teams, whose leader reports to a similarly multi-disciplined team that is closer to the program level team, which is the core team. A program level team would be responsible for the overall program success and sets the strategic direction for the overall project. This team contains the leaders from the Atmospheric Modification Monitor/Analysis Prediction System Development (Monitoring systems) team, Glaciogenic and Non-glaciogenic Seeding Technology Research/ Development (Seeding Technologies R& D) team, Applications Research & Development team, and Public Outreach/ Professional Development team, which collectively make up the second level (or tier) teams. The customer is also part of this team. The program level team defines relevant objectives and corresponding deliverables. These objectives and corresponding deliverables become the focus of a team (often termed "second tiered" or level 2) tied to the respective area leader within the program level team The second tier teams devise their objectives necessary to create said deliverables, and contain the leaders from the next lower tiered teams. This structure enhances vertical integration within the program because each higher-tier team can optimize its higher-level product rather than allowing "sub-optimizing" of a lower-level product. Vertical integration is as important to programmatic success as is meeting the goals of each "tier" team. This mapping of teams to activity areas allows for a clear assignment of budget to the individual teams. Table 4 highlights some features of the NWMP interdisciplinary teams.

Table 4. Next Weather Modification Program (NWMP) Plan Multidisciplinary Team Features

- Led by a Team Leader who is also a member of the next higher tier team throughout program
- Multidisciplinary skill mix represented by its team members
- Has early and periodic involvement of customers and suppliers throughout lifecycle of project
- Given resources to enable success throughout the entire project (i.e., has its own budget and is empowered to act within its charter by its next higher tier team)
- Balances task, process and team relationships throughout the entire project
- Plans, performs, tracks and manages tasks and associated risks
- Maintains open communication both within the team and with other teams
- Plans integration with other teams toward overall product goals

10. High-Level Implementation Plan per Program Area:

Atmospheric Modification Monitor/Analysis Prediction System Development: Implementing this activity necessitates creating and empowering one multidisciplinary team for frozen rain monitoring, one for hail, one for supercooled fog monitoring, one for hurricanes, etcetera. Each team should include an engineering process representative who acts as interface to engineering processes throughout the life cycle of the project (i.e., a software engineer), a science programmer (not a software engineer), a science integrator (could be an applied scientist) who leads the team and acts as liaison to science process and attends engineering process meetings, subject matter expert(s) or SME(s) if necessary, and the customer. Here it is presumed that the science integrator must be tied to this plan, which implies that this plan is the owner of the team/process, but this does not necessarily have to be the case. Once the teams are formed at program start or shortly thereafter, each should agree upon and then work toward its immediate and long-term goals.

Glaciogenic and Non-glaciogenic Seeding Technology Research/Development:

Implementing this activity necessitates creating and empowering one multi-disciplinary team for research and development of hygroscopic seeding agents, glaciogenic seeding agents, and potentially fabricating better dispensing units. This team is primarily science driven, but does have an interface with customers, some of whom are engineers and possibly computer scientists, and personnel with appropriate skill mixes (i.e., a machinist instead of a lab technician). Each team should include a customer representative, scientist (from the plan), technician (from the plan), customer technician, a subject matter expert as necessary, quality assurance person. The scientist (from the program) leads the team and acts as liaison to management, Quality Assurance (QA), and customer. In this case, the scientist (from the plan) is responsible for ensuring that there is a team member from QA involved in this effort, and that the results exceed program standards.

Interaction of the Next Weather Modification Program with Commercial Partners: The contractual and program management aspects of this interaction are well established, but the implementation could make use of the following guidance:

➢ Implementation team must be set up to include representatives from the science team (scientist, technician, possibly other depending on application), and the commercial team (science point of contact-POC, technician, other depending on application)

➢ Science team does not direct the commercial operation

➢ The commercial team must go through a training session set up through the Next Weather Modification plan Public Outreach/Professional Development group.

➢ Science team directs the post commercial operation analysis, with priority given to the analysis required by the commercial team. Then subsequently to in-depth analyses and joint publications

➢ The science team installs and is responsible for maintaining instrumentation on commercial property, and sampling platforms

➢ Science Team and Commercial Team set up an operations friendly real-time display to guide commercial operations and a periodic direct-broadcast data download and archive system backup. This removes the burden on commercial priorities to use and provide information for optimal results required by its client(s).

Applications Research and Development: Implementing this activity necessitates creating and empowering one multi-disciplinary team for developing new and existing technologies and applications, and even to creating new technologies and products. The primary customer is probably the program activities themselves, which is not the case in the other program areas, except possibly for Outreach and Professional Development.

These activities might involve field sampling campaigns, which should be conducted as set forth in their plans. However, the program level team would have a representative of (a) this program (as person in charge), (b) customer, (c) ground instrumentation group, (d) airborne instrumentation group, (e) other instrumentation (satellite special instruments) group, and (f) the modelers. Once the teams are formed at program start or shortly thereafter, each team should work toward its immediate and long-term goals.

Outreach & Professional Development Program: An effective outreach activity should not only feed the scientific and engineering communities through publications and presentations, but also provide the public with a better understanding of its mission through the number of activities it sponsors or coordinates and the access it provides. It will coordinate the technology transfer to program customers. It is strongly recommended that this be done in a multi-discipline, vertically integrated programmatic team framework, and that no multi-disciplinary team should be lead by a person or entity that exists outside of the Program.

A strong outreach activity can *alleviate public misconceptions*, especially a proactive one that provides interested individuals an opportunity to participate by running an appropriate “simulator”, or by setting up volunteer observation programs that allow them to help collect data needed for model verification and development. The outreach activity could also help concentrate the overwhelming collection of scientific, engineering, and technological knowledge gained since the 1940s.

11. Closing Remarks

The increasing need for water and the cost to society inflicted by severe weather further require that the intellectual, technical, and administrative resources of the nation be combined to resolve whether and to what degree humans can influence the weather (Garstang et al. 2005).

This paper describes a high-level plan for the “next phase” in weather modification science and technology development, made in response to recent technological and scientific advances, socioeconomic issues, and the findings expressed through Garstang et al. (2005). The program we propose will encompass a comprehensive agenda of fundamental and applied research and development efforts directed toward optimizing existing technologies used to manage “treatable” atmospheric processes and conditions, and to allow the development of relevant innovative technologies. It will require a permanent, national program that administers its resources and oversees its activities.

The proposed plan:

- is based on many lessons learned during the past 60 years
- has five functional components
  - Weather Modification Event Monitoring/Analysis Prediction System Development
  - Glaciogenic and Nonglaciogenic Seeding Technology Research/Development
  - Applications Research/Development including evaluation
  - Professional Development, Public Outreach
  - Management Support
- encompasses the recommendations of Garstang et al. (2005), an NRC (2003) report, Silverman et al. (2001a, b), Woodley et al. (2003a,b), Givati and Rosenfeld, (2004) and the near-term needs of the weather modification community.
- provides guidelines for implementation
- approaches tasks, issues within its components in a multidisciplinary, cross-component environment that exists throughout the entire life cycle of the plan. This is partially accomplished by specifying all plan member roles and responsibilities at the plan’s kickoff meeting, cooperative agreements, and a well designed technology transfer activity.

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