A Plan for the next phase in Weather Modification Science and Technology Development

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Introduction

Weather modification science and technology development plans have been constructed (e.g. Schaefer, 1969, 1976; Juisto, 1974). Those plans have lead to modern weather modification technologies, which have been helping the community at large meet water resource requirements for over 50 years. Present-day cloud seeding technologies and the recognition of treatable clouds are scientifically based. The scientific community acknowledges that cloud seeding yields a 10% increase in the amount of precipitation (compared with normal precipitation) that reaches the ground when the seeding is prudently conducted under favorable atmospheric conditions (e.g. Weather Modification Association, 2005; American Meteorological Society, 1998; Elliott et al., 1995; Weather Modification Association, 1993; World Meteorological Organization, 1992). Apparently, some stakeholders benefit greatly from an order of magnitude less increase in the amount of rainfall (compared with normal rainfall).

Weather modification technologies may be affectively applied to facilitate the water and energy cycles, which are key to dealing with many present and potential future scientific, environmental, and socioeconomic issues. Contemporary socioeconomic problems mostly focus on drought. For example, there is a clear and pressing need for additional clean water, since it is predicted that more than 40% of the world's population will live in water-stressed areas by the decade of the 2020s. There is also steadily increasing property damage and human suffering caused by hazardous weather (e.g., freezing rain, severe weather), fire, and other environmental problems (related to toxic wastes, ozone hole, 'acid rain', biological or chemical warfare, CDC 2000, for example). Technological and scientific advances have recently yielded, new seeding material, polarimetric radar, Doppler radar and software, and enhanced computational resources (e.g. Orville et al., 2000; NRC, 2003). Hence, an impetus for developing systems that monitor and manage atmospheric events. The atmospheric events are treatable using proven and some new modern weather modification technologies, and they include hurricanes, tornadoes, and pollutant transport. Consequently, the next phase in weather modification science and technology development is to outline a high-level national program plan for developing modern weather modification science and technologies that takes advantage of lessons learned, recent science and technological advances for more effectively benefiting society.

The 'next phase' in weather modification science and technology development will encompass a comprehensive agenda of fundamental and applied research & 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 the resources and the activities to develop the operational application of atmospheric modification (weather modification) technologies, which help provide sustainable water supplies and mitigate the excessive effects from atmospheric hazards (frozen rain, hurricanes, tornadoes, other). This includes improving the understanding of the relevant processes and the evaluation methods for operational activities as suggested by Silverman (2001a), making use of cooperative multi-disciplinary research and development arrangements, and a well-designed outreach activity.

Discussion:

Lessons learned activities, as well as recent science and technological advances have identified many focal areas for initial efforts undertaken during the next phase in weather modification science and technology development.

There is a need to develop the ability 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 or new technologies.

Developing improved dispersion techniques and higher yield cloud seeding agents are needed for obvious reasons. The development of 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, and others). The aforementioned need is rather ominous, 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 simulating these systems, then with these models modify them to include the results from applying various seeding technologies. The modeling of seeding agent tracer study results would greatly improve seeding agent placement within cloud systems, and they could form the basis for Homeland Security needs (J. Golden, NOAA, FSL, Boulder Co., 2004, personal communication).

The state-of-the-art cloud seeding technologies might be ready for application toward mitigating the effects of freezing rain events. The knowledge base is not large enough to reliably support tornado 'zapping' or hurricane 'snuffing' 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 may possibly be used 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 is not yet scientifically accepted. Consequently, modeling studies should dominate these efforts, initially.

Simulation and modeling studies will require verification. This should be accomplished through carefully designed cooperative efforts. Cloud seeding program evaluations also need to be improved. Evaluations require 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 truly a primary standard for precipitation amount measurements? That is, does it represent the natural spatial and temporal precipitation amount field (e.g. DeFelice, 1998) under all conditions, or better than alternative measuring devices? The answer is crucial to evaluating the success of precipitation augmentation projects, for example. If not, could the Z(reflectivity) - L(precipitation water content) relationship be used to estimate rainfall amount? The Z-L would not require estimates of hydrometeor terminal velocity, and L can be verified using a dual wavelength microwave radiometer.

Inadvertant modification studies need to be increased, and not solely from a climate change point-of-view. For example, a land cover change from agricultural to urban over a modest area can introduce a climatic forcing similar in magnitude and direction to that from carbon dioxide (R. Pielke Sr., 2001, personal communication). Here initial efforts should at least focus on strategies for (a) minimizing the effect from inadvertent modifications to the atmosphere, and (b) neutralizing airborne pollutants within cloud systems or redirecting their air trajectories to settle on 'safe surfaces'.

The plan, derived from past lessons learned, including DeFelice (2002), must address the current and near future needs of the WMA community and also provide the high-level infrastructure to 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 project management process improvement exercises currently underway by the author.

It is important to make clear that the implementation of this plan calls for tackling tasks, issues within components (i), (ii), and (iii) in a multi-disciplinary, cross-component environment that exists throughout the entire life cycle of the plan. This is accomplished by

(i) specifying well-defined plan member roles and responsibilities at all levels within the plan at the plan's kickoff meeting.

(ii) 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 WMA community. This has economic benefits to the program as well.

Furthermore, the plan must have somebody, i.e., functional area lead, chartered to ensure that matured plan technologies are transferred to stakeholders and end users in a timely fashion.

The alternative could repeat historical performance.

Table 1. This plan versus NRC 2003 plan recommendations

1. This plan <u>assumes</u> 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 inadvertant weather modification ...."*
2. This plan 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. This plan calls for developing: -better monitoring capabilities for all atmospheric events, including frozen rain, hurricanes & tornadoes, airborne pollutants. -more effective dispersion techniques -higher yield seeding agents for warm & 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 modeling, laboratory studies and field measurements designed to reduce key uncertainties…"*

Program Organization:

The plan program would be organized into five functional areas as shown in Figure 1, and would have initial goals, based on lessons-learned and recent scientific - technological advances, that are 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, hail suppression, and other hazardous storm suppression (freezing rain, hurricanes, tornadoes, other). (ii) Transfer information to the Professional Development/Public Outreach 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 Professional Development/Public Outreach activity.

Applications Research/Development
Goals- (i) Improved evaluation methodologies. (ii) Operational atmospheric management monitoring/analysis prediction systems. (iii) (a). Verified high resolution models with explicit microphysics for understanding Hazardous storms, inadvertent modification of atmospheric conditions, and other associated phenomenon (environmental and as directed). (b) Implement (iii, a) 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 professional development/public outreach activity for feedback on operational usefulness, and fine-tune them based on users' input.

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

Plan Management and Support
Goals- (i) Provide overall programmatic metrics, guidance, and support during the life of this program. (ii) Participate in the definition and development of future and related technology investigations. (iii) Administer seed grants for innovative or new applied research and applications.

The triangle in Figure 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.

Program Objectives:

The initial program-wide objectives are:

1. Develop a system to identify and monitor all atmospheric environmental

conditions that are good candidates for beneficial modification through its developed technologies.

2. Develop technologies to more efficiently treat
    a. traditional cold and warm cloud systems
    b. weather and environmental hazards
3. Validate/verify the operational and computational aspects of weather modification technologies and systems developed under this program.
4. Develop strategies to minimize the effects from the inadvertent modification of atmospheric conditions (formerly termed inadvertent weather modification).
5. Create a proactive professional development and public outreach activity.

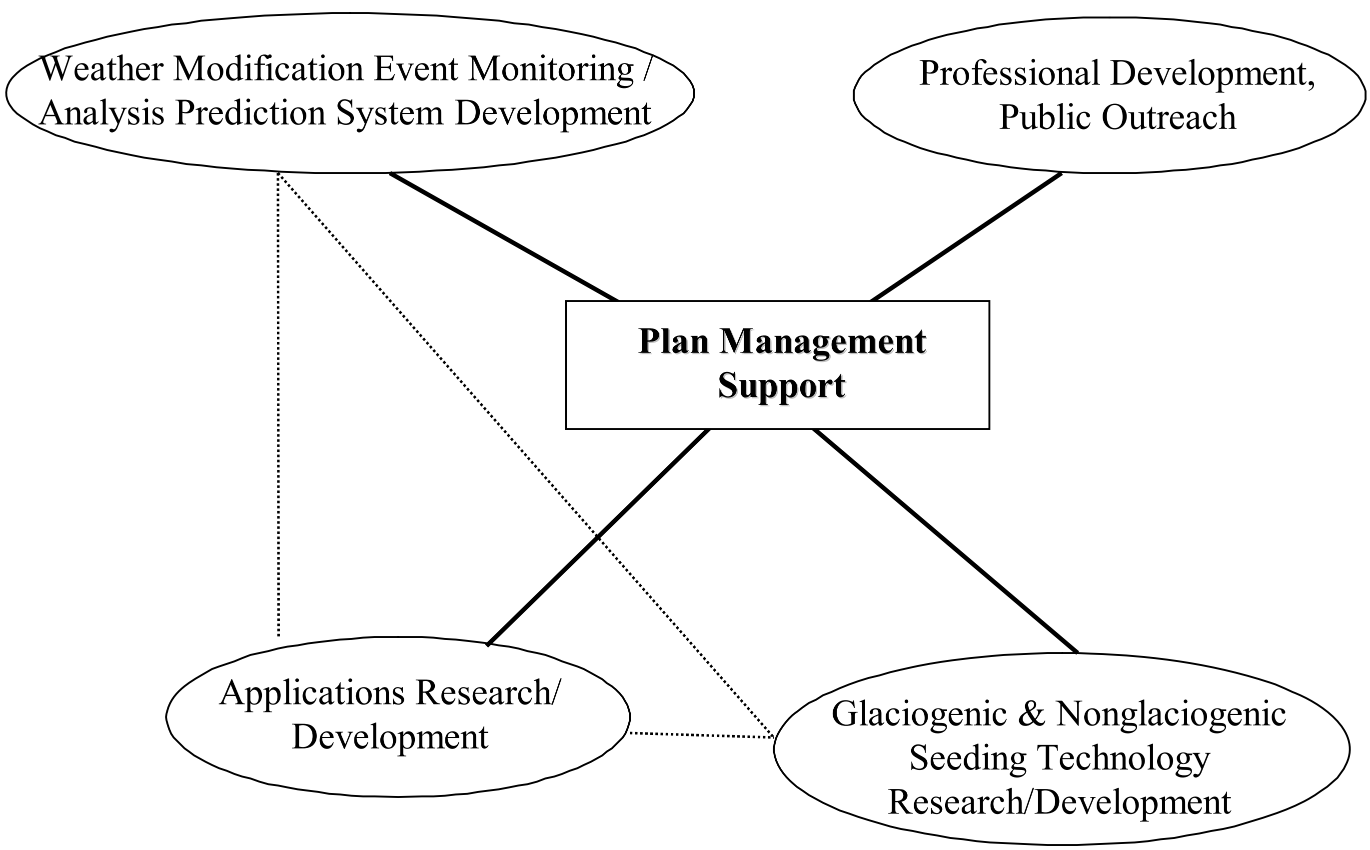

Figure 1. Program Organizational Chart.

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 participate by running an appropriate 'simulator', or by setting up volunteer 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.

program customers. A strong outreach activity can alleviate public misconceptions, especially a proactive one that provides interested individuals an opportunity to

Work Breakdown Structure (WBS):

The Program Manager would use standard project management tools to track task schedule and cost metrics for the plan tasks presented in the high-level tasking of work to be performed under this plan (or work breakdown structure-WBS). Table 2 summarizes the WBS.

Table 2. A suggested high-level tasking of work (WBS)

1. Atmospheric Modification Monitor/Analysis Prediction System Development
    a. Real-time monitoring component
        i. Precipitation augmentation (all systems-orographic, etc)
        ii. Hail suppression
        iii. Other hazardous storms
    a. Analytical component
2. Glaciogenic and Non-glaciogenic Seeding Technology Research/Development
    a. Seeding material nucleation ability optimization
        i. Warm cloud
        ii. Cold cloud
    a. Seeding material delivery system development
        i. Warm cloud
        ii. Cold cloud
3. Applications Research/Development
    a. Evaluation methodologies
    b. Model and prediction system development and verification
    c. Targeting system
    d. Evaluation technologies (dual polarized Doppler radar, tracer techniques, other)
    e. Inadvertent weather modification/global climate change
4. Atmospheric Modification Professional Development, Public Outreach
5. Program Management and Support

Resource Requirements (anticipated): This program would require a budget adequate for successful fulfillment of its objectives. Precedent is set by successful medical and other science programs, wherein substantial, long-term, committed funding has lead to positive results. Making such an investment for this plan very soon and continuing it through the decade of the 2040's, will most probably ensure that significantly less than 40% of the world's population will reside in water-stressed areas, for example.

Office and some laboratory space will be required, and should be capable of housing 120 employees. An east coast location would maximize the benefit from interacting with NOAA, DoD, DOE, DOI, NASA, other government centers and laboratories, and other relevant organizations. There should never be less than 70-80 FTEs for support and technical staff, 5-10 FTEs for student interns, and 15-20 FTEs for all program administrative staff. DeFelice (2002) provided a breakdown between FTEs and high-level activity (i.e., titles in Figure 1 objects). The laboratory space could be used for data analyses, experimental cloud studies to develop modeling algorithms, nucleation experimentation with ice, water, and perhaps other substances (such as polymers, etc.), as well as the development of instrumentation and information technology applications that are especially relevant to the data collected and analyzed through this program. This could include the development of 3 state-of-the art cloud chambers to study ice, water and other species nucleation. The laboratory should also house computers capable of archiving and processing large volumes (i.e., mega terabytes) of multi-disciplinary data in near real-time, instrumentation storage compartment(s), an area for instrument calibration, and other standard laboratory ware, as appropriate.

Cooperative Agreement Candidates (anticipated): This plan must contain cooperative agreements (or equivalent, i.e., MOUs- memorandums of understandings) with the National Center for Atmospheric Research, Research Applications Program, already dedicated to atmospheric modification activities, research aircraft and relevant resources at the South Dakota School of Mines and Technology Institute of Atmospheric Sciences, University of North Dakota, Weather Modification Inc., NOAA, and the University of Oklahoma MESONET to help with various aspects of model development/ validation efforts and other physical studies. The agreements should also be extended to Woodley Associates, North American Weather Consultants, Atmospherics Incorporated, as well as other relevant companies, organizations, universities, and government agencies (e.g., those in Texas, Nevada, and Kansas, Colorado State University, NOAA National Severe Storms laboratory, the USGS/U.S. Navy/U.S. Department of Agriculture/CDC research team-Bozeman, Montana, and the USGS/EDC teams for Land Use Dynamics, Applications Research, & Remote Sensing Systems).

Programmatic Success: The likelihood of success is high, because the program is starting with proven technologies, many of which have had more than 50 years to mature.

The success of this program will be gauged by determining whether or not its annual tasks have been met as planned and within cost; the ability of its outreach program to transfer program technologies to program customers. Surely, it is expected that there will be improved products, processes and field procedures; scientific publications and conference presentations. Success does not require new tools, demonstrations 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 (or atmospheric management) programs.

Risk Identification and Management: The primary risks are likely to be losses of key personnel, funding, required data and technology, and systems.

- 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 handles the services contract, then loss of key personnel will be anticipated through open communications with government and contract staff. The contractor's hiring capacity will be used to fill vacancies as quickly as possible. The contractor could be a particular government agency, an intergovernmental committee, or a non-government organization. Here it is 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, 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.

Program Customers: Program customers potentially come from the following entities: Farmers, crop insurance industry, water district managers, utility industry, relevant organizations (e.g., WMA, Environmental & Water Resources Institute-EWRI), scientific community, and government agencies (e.g., National Oceanic and Atmospheric Association-NOAA, Environmental Protection Agency-EPA, National Aeronautics Space Administration-NASA, Department of Defense-DoD, Centers for Disease Control and Prevention-CDC; foreign).

Anticipated Sources of Funding: Farmer groups, insurance industry, water districts, utility industry, State Governments, NOAA, Congress, and others, such as the Office of Federal Coordination for Meteorology (OFCM).

Deliverables: (Initial, anticipated programmatic, <u>not annual</u>**,** 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 atmospheric modification technologies for traditional, weather and atmospheric environmental hazard applications. For example:
    - Higher yield seeding agents for warm and cold cloud systems
    - More effective dispersion techniques

- A strategy to minimize the possible negative effects resulting from the inadvertent modification of our atmosphere
- A proactive professional development, public outreach program.

Closing Remarks:

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 and socioeconomic issues. It will encompass a comprehensive agenda of fundamental and applied research & 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.

Highlights of the proposed plan include:

- Based on many lessons learned during the past 50 years
- Five functional components
  - (i). Weather Modification Event Monitoring/Analysis Prediction System Development
  - (ii). Glaciogenic and Nonglaciogenic Seeding Technology Research/Development
  - (iii). Applications Research/Development including evaluation
  - (iv). Professional Development, Public Outreach
  - (v). Management Support
- It approaches tasks, issues within its components, especially (i), (ii), and (iii), in a multi-disciplinary, 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.
- The plan encompasses the recommendations of a NRC (2003) report, Silverman et al (2001a, b), & others, while addressing the near future needs of the WMA community.

Acknowledgments: The contents of this paper do not necessarily reflect the views of any government agency or Raytheon Company and its business units, especially Raytheon Technical Services Co, ITSS. The comments of Mr. Robert Black, Manager, Program Engineering Office, Contractor at EDC, two anonymous reviewers of a previous version of this paper are appreciated. The review of this paper by Dr. Joe Golden is greatly appreciated.

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