# WORLD METEOROLOGICAL ORGANIZATION

***WMO DOCUMENTS ON WEATHER MODIFICATION APPROVED BY THE COMMISSION FOR ATMOSPHERIC SCIENCES MANAGEMENT GROUP, SECOND SESSION, OSLO, NORWAY, 24-26 SEPTEMBER 2007***

## EXECUTIVE SUMMARY OF THE WMO STATEMENT ON WEATHER MODIFICATION

- Purposeful augmentation of precipitation, reduction of hail damage, dispersion of fog and other types of cloud and storm modifications by cloud seeding are developing technologies which are still striving to achieve a sound scientific foundation and which have to be adapted to enormously varied natural conditions.
- Operational programmes in fog dispersion, rain and snow enhancement and hail suppression are taking place in many countries around the world. The primary aim of these projects is to obtain more water, reduce hail damage, eliminate fog, or other similar practical result in response to a recognized need. Accomplishment of the stated goals is often difficult to establish with sufficient confidence. Economic analyses show that rainfall enhancement and hail suppression operations, if successful, could have significant economic benefit, but uncertainties make investments in such efforts subject to considerable risks.
- Research programmes are currently less numerous and are undertaken in only a few countries. The main purposes of research projects are, in general, to elucidate weather modification concepts, to examine some link(s) in the overall modification hypothesis, to test the efficacy and impacts of some modification activity, or to establish proof for some proposed or previously tested methodology. The long-term practical aim of research is to provide a sound basis for the operational implementation of the research results.
- In order to identify and confirm the results of seeding experiments and operations, it is necessary to employ sophisticated statistical designs and analyses. Confidence intervals should be included in the statistical analyses to provide an estimate of the strength of the seeding effect so informed judgments can be made about its cost effectiveness and societal significance.
- Improvements in observational facilities and modelling capabilities now permit more detailed examination of the cloud and precipitation processes and offer new opportunities for advancing the science and practice of weather modification.
- While the outcomes of operational projects in hydrological, economic or other similar terms is usually difficult to ascertain with confidence, it has been shown to be possible under appropriate circumstances such as very long project duration and the existence of highly correlated control areas.  Much work is being done to explore additional ways of evaluation. Operational projects, in comparison with research projects, accept a higher degree of uncertainty in the outcome of the intervention and therefore a considerable burden in justifying the investment needed.

- Cloud structure can vary widely from region to region. Seeding results in one geographic area cannot be automatically assumed to apply to another area. Transferability should be carefully considered, since, in addition to meteorological factors, differences in aerosol and trace gas constituents, surface characteristics and other factors may also cause unexpected variations in cloud behaviour and cloud response to intervention.
- Unintended consequences of cloud seeding, such as downwind effects and environmental and ecological impacts, have not been demonstrated but cannot be ruled out.
- There is mounting evidence that human activities modify local and sometimes regional cloud properties and precipitation. Clarification of the existence and processes of such inadvertent weather modification may provide important insights into the possibilities and limitations of deliberate weather modification.
- The activities of the WMO in the area of weather modification are aimed at encouraging research projects, and at providing guidance about best practices for operational projects.

The status of different technologies, and the physical concepts underlying them, is summarized as follows:

**Fog dispersal**

- In principle, all types of fog can be dispersed by sufficient heating or mechanical mixing, though such methods are often impractical and expensive. It may be economically viable at airports where the cost of aircraft delays and cancellations are very high.
- Dispersal of supercooled fogs using glaciogenic materials or coolants is well established as feasible.
- Seeding with hygroscopic materials has been shown to increase visibility in some types of warm fogs. An environmentally acceptable technology has yet to be demonstrated.

**Precipitation enhancement**

- There is considerable evidence that cloud microstructure can be modified by seeding with glaciogenic or hygroscopic materials under appropriate conditions. The criteria for those conditions vary widely with cloud type. Evidence for significant and beneficial changes in precipitation on the ground as a result of seeding is controversial and in many cases cannot be established with confidence.
- In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically-viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e., the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that under certain conditions precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of streamflow records from some long-term projects indicate that cost-effective increases have been realized.
- The use of glaciogenic agents such as silver iodide to seed supercooled cumulus clouds has produced few results of general validity. Observed responses of clouds vary widely. There are competing explanations and the questions are not yet resolved.
- Seeding of convective clouds with hygroscopic materials has been shown to be adaptable to different cloud types and has produced encouraging results but is not yet an established technology.

**Hail suppression**

- Well-developed glaciogenic seeding technologies have been used operationally in many parts of the world to reduce hail damage. Evaluation of the results has proved difficult and the effectiveness remains controversial.
- Attempts to seed hailstorms with hygroscopic nuclei have been made but have not given demonstrable results.
- Some methods, such as hail cannons or ionization devices, have no physical basis and are not recommended.

**Other phenomena**

- No confidence can be placed at this time in the use of cloud seeding to reduce the strength of typhoons and tropical storms.
- Attempts to reduce lightning by seeding have not been shown to be effective.

**General comments**

- The scientific status of weather modification, while steadily improving, still reflects limitations in the detailed understanding of cloud microphysics and precipitation formation, as well as inadequacies in accurate precipitation measurement. Governments and scientific institutions are urged to substantially increase their efforts in basic precipitation research and related programmes in weather modification. Further testing and evaluation of physical concepts and seeding strategies are critically important. The acceptance of weather modification can only be improved by increasing the numbers of well executed experiments and building the base of positive scientific results.
- Governments and other agencies involved in weather modification activities should invest in relevant education and training.
- Operational weather modification projects should be reviewed periodically (annually if possible) to assess whether the best practices are being used. Any new project should seek advice from experts regarding the benefits to be expected, the risks involved, the optimum techniques to be used, and the likely impacts. The advisors should be as detached as possible from the project, so their opinions can be viewed as being unbiased. It is recognized that most weather modification projects are motivated by well documented requirements, but they also have associated risks and the results may remain uncertain.

___

## WMO STATEMENT ON WEATHER MODIFICATION

### INTRODUCTION

For thousands of years people have sought to modify weather and climate so as to augment water resources and mitigate severe weather. The modern technology of weather modification was launched by the discovery in the late 1940s that supercooled cloud droplets could be converted to ice crystals by insertion of a cooling agent such as dry ice or an artificial ice nucleus such as silver iodide. Over 50 years of subsequent research have greatly enhanced our knowledge about the microphysics, dynamics and precipitation processes of natural clouds (rain, hail, snow) and the impacts of human interventions on those processes.

Weather modification generally involves two distinct activities. In the first activity, science research seeks to prove concepts and in so-doing make the effectiveness of their application certain to within given limits and with a given degree of confidence. In the second activity, operational programs seek to apply different modification methods to produce a desired outcome (more rain, less hail, fog cleared, etc.) based on their assessment of the best approaches to follow consistent with the current state of knowledge. Some operational programs also include an evaluation component, but generally only as a lower priority. Such evaluations, however, have the potential to add scientific insight.

In recent years there has been a decline in the support for weather modification research, and a tendency to move directly into operational projects. It is crucial to recognize that weather modification is still an emerging technology. Uncertainties inherent in the current technologies can only be addressed by programmes of focused research that lead to deeper understanding of the effects of cloud seeding on cloud and precipitation development.

Currently, there are dozens of nations operating hundreds of weather modification projects, particularly in arid and semi-arid regions all over the world, where the lack of sufficient water resources limits their ability to meet food, fibre, and energy demands. The purpose of this document is to present a review of the status of weather modification.

The energy involved in weather systems is so large that it is impossible to create artificially rainstorms or to alter wind patterns to bring water vapour into a region. The only credible approach to modifying weather is to take advantage of microphysical sensitivities wherein a relatively small human-induced disturbance in the system can substantially alter the natural evolution of atmospheric processes.

The ability to influence cloud microstructures has been demonstrated in the laboratory, simulated in numerical models, and verified through physical measurements in some natural systems such as fogs, layer clouds and cumulus clouds. However, direct physical evidence that precipitation, hail, lightning, or winds can be significantly modified by artificial means is limited.

The complexity and variability of clouds result in great difficulties in understanding and detecting the effects of attempts to modify them artificially. As knowledge of cloud physics and statistics and their application to weather modification has increased, new assessment criteria have evolved for evaluating cloud-seeding experiments. The development of new equipment — such as aircraft platforms with microphysical and air-motion measuring systems, radar (including Doppler and polarization capability), satellites, microwave radiometers, wind profilers, automated raingauge networks, mesoscale network stations — has introduced a new dimension. Equally important are the advances in computer systems and new algorithms that permit large quantities of data to be processed and models with more detailed description of cloud processes to be run in relatively short time.

New datasets used in conjunction with increasingly sophisticated numerical cloud models help in testing various weather modification hypotheses. Chemical and chaff tracer studies help to identify airflow in and out of clouds and the source of ice or hygroscopic nucleation as the seeding agent. With some of these new facilities, a better climatology of clouds and precipitation can be prepared to test seeding hypotheses prior to the commencement of weather modification projects.

If it were possible to predict precisely the precipitation from a cloud system, it would be a simple matter to detect the effect of artificial cloud seeding on that system. The expected effects of seeding, however, are almost always within the large range of natural variability (low signal-to-noise ratio) and our ability to predict the natural behaviour is still limited.

Comparison of precipitation observed during seeded periods with that during historical periods presents problems because of climatic and other changes from one period to another. This situation has been made even more difficult with the potential inadvertent effects of mega-cities and of agricultural practices on cloud and rain formation. Furthermore, there is mounting evidence that climate change may lead to changes in global precipitation amounts as well as to spatial redistribution of precipitation. Consequently, the use of any evaluation technique must take into account and mitigate the bias introduced by these non-random effects on precipitation.

In currently accepted evaluation practice, randomization methods (target/control, crossover or single area) are considered most reliable for detecting cloud-seeding effects. Such randomized tests require a number of cases readily calculated on the basis of the natural variability of the precipitation and the magnitude of the expected effect. In the case of very low signal-to-noise ratios, experiment durations in the range of five to over ten years may be required. Confidence intervals that infer a range within which the true effect lies should be included in the statistical evaluation in order to obtain an estimate of the strength of the seeding effect. Whenever a statistical evaluation is required to establish that a significant change resulted from a given seeding activity, it must be accompanied by a physical evaluation to:

(a) Confirm that the statistically-observed change is likely due to the seeding; and
(b) Determine the capabilities of the seeding technique to produce the desired effects under various conditions. A physical evaluation is also important to gain insight into if and how the results might be transferable to another geographic area.

The effect of natural precipitation variability on the required length of an experiment can be reduced through the employment of physical predictors, which are effective in direct proportion to our understanding of the phenomenon. The search for physical predictors, therefore, holds a high priority in weather modification research. Physical predictors may consist of meteorological parameters (such as stability, wind directions, pressure gradients) or cloud quantities (such as liquid water content, updraught speeds, concentrations of large drops, ice-crystal concentration, radar reflectivity, cloud top height, and cloud horizontal extent).

Objective measurement techniques of precipitation quantities are to be preferred for testing weather modification methods. Each measurement technique having its own uncertainty, both direct ground measurements (e.g. raingauges and hail pads) and remote sensing techniques (e.g. radar, satellite) should be considered. Secondary sources such as insurance data introduce new sources of error and bias, and should not be used by themselves.

Operational programmes should be conducted in full recognition of the potential risks and benefits inherent in a technology which is not totally developed. For example, it should not be ignored that, under certain conditions, seeding may cause more hail or reduce precipitation. Properly designed and conducted operational projects seek to detect and minimize such adverse effects. Weather modification managers are encouraged to add scientifically-accepted evaluation methodologies to be undertaken by experts independent of the operators. Operational programmes should include physical measurements so the science of weather modification can benefit from the results. In spite of the cautionary notes mentioned above, it should be clear that the potential for increasing rainfall by cloud seeding exists, although the uncertainty of success is still large.

Brief summaries of the current status of weather modification are given in the following sections. These summaries are restricted to weather modification activities that are based on accepted scientific principles and have been tested in the field.

Education and training in cloud physics, cloud chemistry, and other associated sciences should be an essential component of weather modification projects. Where the necessary capacity does not exist, advantage should be taken of facilities of other Members;

Weather modification programmes are encouraged to utilize new observational tools and numerical modelling capabilities in the design, guidance and evaluations of field projects. While some Members may not have access or resources to implement these technologies, collaboration between Member States (e.g., multinational field programmes, independent expert evaluations, education, etc.) are encouraged that could provide the necessary resources for implementing these technologies.

## FOG DISPERSAL

Different techniques are being used to disperse warm (i.e., at temperatures greater than 0°C) and cold fogs. The relative occurrence of warm and cold fogs is geographically and seasonally dependent.

The thermal technique, which employs intense heat sources (such as jet engines) to warm the air directly and evaporate the fog, has been shown to be effective for short periods for dispersal of some types of warm fogs. These systems are expensive to install and to use. Another technique that has been used is to promote entrainment of dry air into the fog by the use of hovering helicopters or ground-based engines. These techniques are also expensive for routine use.

To clear warm fogs, seeding with hygroscopic materials has also been attempted. An increase in visibility is sometimes observed in such experiments, but the manner and location of the seeding and the size distribution of seeding material are critical and difficult to specify. In practice, the technique is seldom as effective as models suggest. Only hygroscopic agents should be used that pose no environmental and health problems.

Cold (supercooled) fog can be dissipated by growth and sedimentation of ice crystals. This may be induced with high reliability by seeding the fog with artificial ice nuclei from ground-based or airborne systems. This technique is in operational use at several airports and highways where there is a relatively high incidence of supercooled fog. Suitable techniques are dependent upon wind, temperature and other factors. Dry ice has commonly been used in airborne systems. Other systems employ rapid expansion of compressed gas to cool the air enough to form ice crystals. For example, at a few airports and highway locations, liquid nitrogen or carbon dioxide is being used in ground-based systems. A new technique, which has been demonstrated in limited trials, makes use of dry ice blasting to create ice crystals and promote rapid mixing within the fog. Because the effects of this type of seeding are easily measured and the results are highly predictable, randomized statistical verification generally has been considered unnecessary.

## PRECIPITATION (RAIN AND SNOW) ENHANCEMENT

This section deals with those precipitation enhancement techniques that have a scientific basis and that have been the subject of research. Other non-scientific and unproven techniques that are presented from time to time should be treated with the required suspicion and caution.

### Orographic mixed-phase cloud systems

In our present state of knowledge, it is considered that the glaciogenic seeding of clouds formed by air flowing over mountains offers the best prospects for increasing precipitation in an economically-viable manner. These types of clouds attracted great interest in their modification because of their potential in terms of water management, i.e., the possibility of storing water in reservoirs or in the snowpack at higher elevations. There is statistical evidence that under certain conditions precipitation from supercooled orographic clouds can be increased with existing techniques. Statistical analyses of streamflow records from some long-term projects indicate that cost-effective increases have been realized.

Physical studies using new observational tools and supported by numerical modelling indicate that supercooled liquid water exists in amounts sufficient to produce the observed precipitation increases and could be tapped if proper seeding technologies were applied. The processes culminating in increased precipitation have also been directly observed during seeding experiments conducted over limited spatial and temporal domains. While such observations further support the results of statistical analyses, they have, to date, been of limited scope. The cause and effect relationships have not been fully documented.

This does not imply that the problem of precipitation enhancement in such situations is solved. Much work remains to be done to strengthen the results and produce stronger statistical and physical evidence that the increases occurred over the target area and over a prolonged period of time, as well as to search for the existence of any extra-area effects. Existing methods should be improved in the identification of seeding opportunities, targeting of the seeding material, and the times and situations in which it is not advisable to seed, thus optimizing the technique and maximizing the cost effectiveness of the operations.

It should be recognized that the successful conduct of an experiment or operation is a difficult task that requires qualified scientists and operational personnel. It is difficult and expensive to fly aircraft safely in supercooled regions of clouds. It is also difficult to target the seeding agent from ground generators or from broad-scale seeding by aircraft upwind of an orographic cloud system.

**Stratiform clouds**

The seeding of cold stratiform clouds began the modern era of weather modification. Shallow stratiform clouds can be under certain conditions made to precipitate, often resulting in clearing skies in the region of seeding. Deep stratiform cloud systems (but still with cloud tops warmer than –20°C) associated with cyclones and fronts produce significant amounts of precipitation. A number of field experiments and numerical simulations have shown the presence of supercooled water in some regions of these clouds and there is some evidence that precipitation can be increased.

**Cumuliform clouds**

In many regions of the world, cumuliform clouds are the main precipitation producers. These clouds are characterized by strong vertical velocities with high condensation rates. They hold the largest condensed water contents of all cloud types and can yield the highest precipitation rates. Seeding experiments with cumuliform clouds have produced variable results. This response variability is not fully understood.

Precipitation enhancement techniques by glaciogenic seeding are utilized to affect ice phase processes while hygroscopic seeding techniques are used to affect warm rain processes. Evaluation of these techniques has utilized direct measurements with surface precipitation gauges as well as indirect radar-derived precipitation estimates. Both methods have inherent advantages and disadvantages. For example, rainfall patterns produced by cumuliform clouds have complex spatial and temporal characteristics that are difficult to resolve with raingauge networks alone.

During the last ten years there have been extensive reviews of past experiments using glaciogenic seeding. The responses to seeding seem to vary depending on changes in natural cloud characteristics and in some experiments they appear to be inconsistent with the original seeding hypothesis. Experiments involving heavy glaciogenic seeding of warm-based convective clouds (bases about +10°C or warmer) have produced mixed results. They were intended to stimulate updraughts through added latent heat release which, in turn, was postulated to lead to an increase in precipitation. Some experiments have suggested a positive effect on individual convective cells. However, conclusive evidence that such seeding can increase rainfall from multicell convective storms has yet to be established. Many steps in the postulated physical chain of events have not been sufficiently documented with observations or simulated in numerical modelling experiments.

In recent years, the seeding of warm and cold convective clouds with hygroscopic chemicals to augment rainfall by enhancing warm rain processes (condensation/collision-coalescence/break-up mechanisms) has received renewed attention through model simulations and field experiments. Two methods of enhancing the warm rain process have been investigated. First, seeding with small particles (artificial CCN with mean sizes about 0.5 to 1.0 micrometers in diameter) is used to accelerate precipitation initiation by stimulating the condensation-coalescence process by favourably modifying the initial droplet spectrum at cloud base. Second, seeding with larger hygroscopic particles (about 30 micrometers in diameter) is used to accelerate precipitation development by stimulating the collision-coalescence processes. A recent experiment utilizing the latter technique indicated statistical evidence of radar estimated precipitation increases. However, the increases were not as contemplated in the conceptual model, but seemed to occur at later times (one to four hours after seeding). The cause of this apparent effect is not known.

Recent randomized seeding experiments with flares that produce small (0.5 to 1.0 micrometers in diameter) hygroscopic particles in the updraught regions of continental, mixed-phase convective clouds have provided statistical evidence of increases in radar-estimated rainfall. The experiments were conducted in different parts of the world and the important aspect of the results was the replication of the statistical results in a different geographical region. In addition, limited physical measurements were obtained suggesting that the seeding produced a broader droplet spectrum near cloud base that enhances the formation of large drops early in the lifetime of the cloud. These measurements were supported by numerical modelling studies. Although the results are encouraging and intriguing, the reasons for the duration of the observed effects obtained with the hygroscopic particle seeding are not understood and some fundamental questions remain. Measurements of the key steps in the chain of physical events associated with hygroscopic particle seeding are needed to confirm the seeding conceptual models and the range of effectiveness of these techniques in increasing precipitation from warm and mixed-phase convective clouds.

Despite the statistical evidence of radar estimated precipitation changes in individual storms in both glaciogenic and hygroscopic techniques, there is no evidence that such seeding can economically increase rainfall over significant areas.

## HAIL SUPPRESSION

Hail causes substantial economic loss to crops and property. Many hypotheses have been proposed to suppress hail and operational seeding activities have been undertaken in many countries. Physical hypotheses include the concepts of beneficial competition (creating many additional hail embryos that effectively compete for the supercooled water), trajectory lowering (intended to reduce the size of hailstones) and premature rainout. Following these concepts, seeding methods concentrate on the peripheral regions of large storm systems and, in particular, the new growth zones located on the upwind forward flank, rather than on the main updraught.

While progress has been made, our understanding of storms is not yet sufficient to allow confident prediction of the effects of seeding on hail. The possibilities of increasing or decreasing hail and rain in some circumstances have been discussed in the scientific literature. Supercell storms have been recognized as a particular problem. Numerical cloud model simulations have provided insights into the complexity of the hail process and improved our ability to delineate favourable times, locations and seeding amounts for effective modification treatments, but the simulations are not yet accurate enough to provide final answers.

A few randomized trials have been conducted for hail suppression using such measures as hail mass, kinetic energy, hailstone number and area of hailfall. These randomized trails have not been conclusive. However, most attempts at evaluation have involved non-randomized operational programmes. In the latter, historical trends in crop hail damage have often been used, sometimes with target and upwind control areas, but such methods can be unreliable. Large reductions have been claimed by many groups. However, the weight of scientific evidence to date is inconclusive, neither affirming nor denying the efficacy of hail suppression activities. This situation is motivation for operational programmes to strengthen the physical and evaluation components of their efforts.

In recent years, anti-hail activities using cannons to produce loud noises have re-emerged. There is neither a scientific basis nor a credible hypothesis to support such activities.

Significant advances in technology during the last decade have opened new avenues to document and better understand the evolution of severe thunderstorms and hail. New experiments on storm organization and the evolution of precipitation including hail are needed.

**OTHER PHENOMENA**

Tropical cyclones contribute significantly to the annual rainfall of many areas, but they are also responsible for considerable damage to property and for a large loss of life. Hurricane modification experiments that aimed at reducing the maximum winds were conducted in the 1960s and early 1970s but without positive results. There is no generally accepted conceptual model suggesting that hurricanes can be modified.

While modification of tornadoes or of damaging winds from severe storms is desirable for safety and economic reasons, there is presently no accepted physical hypothesis to accomplish such a goal.

There has been some interest in the suppression of lightning. Motivation includes reducing occurrences of forest fires ignited by lightning and diminishing this hazard during the launching of space vehicles. The concept usually proposed involves reducing the electric fields within thunderstorms so that they do not become strong enough for lightning discharges to occur. To do this, chaff (metallized plastic fibres) or silver iodide has been introduced into thunderstorms. The chaff is postulated to provide points for corona discharge which reduces the electric field to values below those required for lightning, whereas augmenting the ice-crystal concentration is postulated to change the rate of charge build up and the charge distribution within the clouds. Field experiments have used these concepts and limited numerical modelling results have supported them. The results have no statistical significance.

**INADVERTENT WEATHER MODIFICATION**

There is ample evidence (as shown in the WMO-IUGG IAPSAG report) that widespread biomass burning and agricultural and industrial activities modify local and sometimes regional weather conditions. There are observations of natural hygroscopic seeding, making cloud drops become larger and accelerating the warm rain process.

Land-use changes (e.g., urbanization and deforestation) also modify local and regional weather. Air quality, visibility, surface and low-level wind, humidity and temperature, and cloud and precipitation processes are all affected by large urban areas. Documentation of the inadvertent effects of human activities on clouds and precipitation may provide additional insights into the theoretical basis for advertent (deliberate) attempts to modify the weather.

**ECONOMIC, SOCIAL AND ENVIRONMENTAL ASPECTS OF WEATHER MODIFICATION**

Weather modification is sometimes considered by countries when there is a need to improve the economy in a particular branch of activity (for example, increase in water supply for agriculture or power generation) or to reduce the risks that may be associated with dangerous events (frosts, fogs, hail, lightning, thunderstorms, etc.). Besides the present uncertainties associated with the capability to reach such goals, it is necessary to consider the impacts on other activities or population groups.

Economic, social, ecological and legal aspects should be taken into account. Thus, it is important to consider all the important complexity and recognize the variety of possible impacts, during the design stage of an operation.

Legal aspects may be particularly important when weather modification activities are performed in the proximity of borders between different countries. However, any legal system aimed at promoting or regulating weather modification must recognize that scientific knowledge is still incomplete.

The implications of any projected long-term weather modification operation on ecosystems need to be assessed. Such studies could reveal changes that need to be taken into account. During the operational period, monitoring of possible environmental effects should be undertaken as a check against anticipated impacts.

---

## GUIDELINES FOR THE PLANNING OF WEATHER MODIFICATION ACTIVITIES

1. These guidelines are addressed to Members requesting advice or assistance on weather modification activities. They include recommendations for research experiments that are based on present knowledge gained through the results of worldwide theoretical studies as well as laboratory and field experiments. A synthesis of the main basic concepts and main results obtained in the weather modification programmes is given in the WMO Statement on the Status of Weather Modification. Guidelines for research experiments – as was well as recommendations for operational programs are provided. This Statement was revised under a review process requested by CAS IV and approved September 2007.

2. Members wishing to develop activities in the field of weather modification should be aware of the uncertainties outlined in the WMO Statement on the Status of Weather Modification.

3. Experimental programmes should be planned on a long-term basis because the precipitation variability is generally much greater than the increases or decreases claimed for artificial weather modification. Care should be taken to engage qualified operators. It is strongly recommended that an objective evaluation be performed by a group independent of the operational one. The use of appropriate numerical models may help in reducing the time required to evaluate the project.

4. Acceptance of the results of a weather modification program depends on the degree of the scientific objectivity and the consistency with which the experiment was carried out and the degree to which this is demonstrated. Also important are the physical plausibility of the experiment, the degree to which bias is excluded from the conduct and analysis of the experiment, and the degree of statistical significance achieved. There have been few weather modification experiments that have met the requirements of the scientific community with respect to these general criteria. However, there are exciting possibilities now for making progress in our understanding of weather modification issues using modern research tools, including advanced radar, new aircraft instruments, powerful numerical models, and sophisticated statistical techniques.

5. WMO recommends that a detailed examination of the suitability of the site for cloud seeding should be conducted similar to that done in the Precipitation Enhancement Project, for which WMO reports are available. To increase the chances of success in a specific situation, it should be verified through preliminary studies that:

(a) The climatology of clouds and precipitation at the site indicates the possibility of favourable conditions for weather modification;
(b) Conditions are suitable for the available modification techniques;
(c) Modelling studies support the proposed weather modification hypothesis;
(d) For the frequency with which suitable conditions occur, the changes resulting from the modification technique can be detected at an acceptable level of statistical significance;
(e) An operational activity can be carried out at a cost acceptably lower than the socio-economic benefit that is likely to result. All prospective studies require expert judgment and the results are expected to depend on the site chosen and on the season.

6. Weather modification should be viewed as a part of an integrated water resources management strategy. Instant drought relief is difficult to achieve. In particular, if there are no clouds, precipitation cannot be artificially stimulated. It is likely that the opportunities for precipitation enhancement will be greater during periods of normal or above normal rainfall than during dry periods.

7. WMO recommends that operational cloud seeding projects for precipitation modification be designed to allow statistical and physical evaluation of the results of seeding. If a rigorous evaluation is desired, then some randomization of the seed/control cases should be incorporated (for example, by seeding one in three cases). The physical measurements should include characterization of the seeding material. Operational weather modification projects should be reviewed periodically (annually if possible) to assess whether the best practices are being used. Any new project should seek advice from experts regarding the benefits to be expected, the risks involved, the optimum techniques to be used, and the likely impacts. The advisors should be as detached as possible from the project, so their opinions can be viewed as being unbiased.

8. The Members should be aware that the scope of efforts involved in the design, conduct or evaluation of a weather modification programme precludes the WMO Secretariat from giving detailed advice. However, if requested, the Secretary-General may assist (by obtaining advice from scientists on other weather modification projects or with special expertise) on the understanding that:

(a) Costs will be met by the requesting country;
(b) The Organization can take no responsibility for the consequences of the advice given by any invited scientist or expert;
(c) The Organization accepts no legal responsibility in any dispute that may arise.