"REVIEWED"

THE PRECIPITATION ENHANCEMENT PROJECT OF THE WORLD METEOROLOGICAL ORGANIZATION, PROGRAM AND PROGRESS

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ABSTRACT. In the first half of 1981 the Precipitation Enhancement Project, PEP of WMO will be in the third year of its Site Selection Phase in the Duero River basin centered about Valladolid, Spain. The purpose of this field investigation is to establish if the clouds and cloud systems are suitable for seeding to enhance precipitation, and if they occur frequently enough. The basic goals of PEP are discussed and an up-to-date view is presented on the status of the operation.

1. INTRODUCTION

The Seventh World Meteorological Congress in 1975 agreed that the time had come to embark upon an internationally planned, executed and evaluated experiment in artificial precipitation augmentation, and approved the WMO Precipitation Enhancement Project (PEP). The Eighth Congress in 1979 endorsed the more detailed plans for PEP dealing with the continuation of the field measurement program of the Site Selection Phase 3 (SSP-3) and the preparation for the seeding experiment, should the site in Spain be found suitable. It allocated substantial funds for management, scientific planning and international coordination. Thereby, it has to be remembered, that WMO carries out large projects with the help of resources committed and scientists seconded by its Members, i.e. the different national weather services.

The objectives of PEP are listed in Appendix A. They were discussed by List (1976), who also gave background and progress in planning in the early stages of this international venture.

PEP consists of three phases. They are:

Site selection;
The seeding experiment;
Evaluation.

The selection of the site for conducting the main (seeding) experiment, the second part of PEP, has always been regarded as crucial to the whole project. It must take account of the major aim of PEP, which is to demonstrate at a statistically significant level whether precipitation at the ground can be increased or not over an area where it would also provide economic benefits.

After an initial selection of the more promising six sites (in Algeria, Australia, India, Spain, Tunisia and Turkey) from among 16 originally proposed, numerical simulation experiments were carried out on the basis of rainfall data. Their purpose was to establish if a hypothetical increase in rainfall of 10 to 20% would be detectable above the natural local precipitation variability, as evident from the records over the previous ten or more years. The Commonwealth Scientific and Industrial Research Organization of Australia performed these experiments.

In the light of the results, together with visits to proposed sites and climatological studies, WMO Executive Committee Panel of Experts on Weather Modification reached the conclusion that the sites in Australia and Spain best met the conditions required for the PEP experiment. Because no substantial resources could be made available for a study of the Australian site, SSP-3 was limited to Spain by the PEP Board. This led to the third stage in Spain of the site-selection phase which is aimed at establishing if the clouds over the proposed site are suitable for seeding and whether they occur frequently enough to warrant expectations of a detectable and significant precipitation increase. To do this requires an intensive on-site cloud and cloud microphysics investigation extending over two or three years. Such a study is now under way.

The Plan for PEP appeared as WMO PEP Report No. 3 in 1976, whereas the Operations Plan for SSP 3 appeared as No. 11 in 1978. The PEP Design Document is Report No. 9 (1978). These are the key planning documents which were laid out by the Panel, the Scientific Planning Group at the WMO Secretariat, together with seconded scientists from all over the world. Important detailed aspects of PEP were studied (and are continued to be studied) by groups of experts and led to other documents (see Appendix B) related to precipitation enhancement. (WMO's documentation of its programs and their progress is also important to its Members, because of the value of expert and technical advise).

2. THE SITE-SELECTION PHASE, STAGE 3.

The Spanish site is located in the northwestern part of the country in the Duero River basin. The city of Valladolid (population about 240,000) is near the center of the area; the field headquarters is installed at the local airport (Figure 1). The precipitation climatology can be summarized as follows for the period January to May (when precipitation enhancement is considered): Monthly average of precipitation 44mm, number of days with precipitation in Valladolid 10, in Salamanca 9; days per month with low or middle clouds 25, days with clouds of vertical development 6. For further details see PEP Report 10.

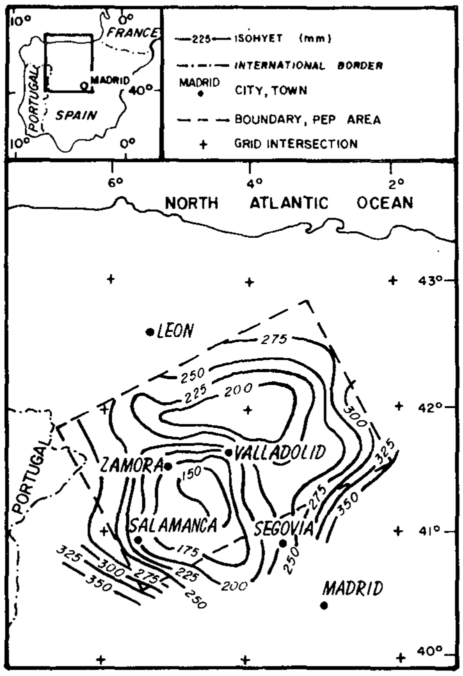

Fig. 1. Location of the SSP-3 site in Spain. Isohyets of rainfall (mm) for the period Feb. to June (from PEP Report No. 9)

The EC Panel on Weather Modification stated about the Spanish site:

a) The statistical simulation experiment on the detectability of a seeding effect within the variability of the natural rainfall met the requirements.

b) The terrain in the experimental area is uniform and suitable.

c) The available data base at the basic meteorological facilities, as well as the possible logistic arrangements are satisfactory.

SSP-3 is the preparatory, on-site study of microphysics and mesoscale structure of clouds and cloud systems by aircraft, radar, radiosondes, satellite and other measuring systems. It should tell, whether the Spanish site exhibits a good weather modification potential or not, considering that the best-known seeding technique by silver iodide dispersion is going to be used. The paper by Cunningham (1980) is giving an overview of this phase, which started in early 1979 and will continue until the end of the 1981 season.

The question of suitability is very difficult to answer if the advantages do not clearly show. Such a situation seems to develop at the Spanish site. The meteorological systems which have been investigated in 1979 and 1980 show cloud regions with low ice crystal concentration, but the latter are embedded in clouds with ample ice particles. More observations need to be made to prepare a basis for a decision.

3. THE PRECIPITATION ENHANCEMENT EXPERIMENT

The detailed operational plan for the statistical seeding experiment will be based on the outcome of SSP-3 with its information on cloud systems and cloud microphysics. Nevertheless, a few statements about the type can already be made:

1) The clouds considered for modification are those associated with cyclonic activity. The associated airmasses are modified maritime with cloud droplet concentrations generally less than $500 cm^{-3}$.

2) The direct target area is about $10{,}000\ km^2$, with a total area available for controls and the study of extended area effects of approximately $50{,}000\ km^2$.

3) Precipitation enhancement is to be achieved by increasing the ice crystal concentration in supercooled clouds by the release of AgI from aircraft, either from burners or droppable flares. The seeding is supposed to affect the collodidal stability of the clouds and may also have effects on their dynamics.

4) The basic evaluation of the seeding effect will be statistical in nature and based on the rainfall at the ground.

5) An experiment duration of five years is contemplated, assuming that a 10-20% change in seasonal precipitation will be detectable at an acceptable level of statistical significance.

6) The seeding success is to be judged on the basis of rainfall at the ground. A dense network of raingauges many of the recording type, will be required to obtain sufficient information on precipitation.

7) The experimental unit for randomization and the primary evaluation interval is, at the moment, considered to be a 24-h period.

It has been stated repeatedly, that any conclusions from the statistical experiment need to be backed-up by physical insight into the seeding effects through thorough cloud and cloud-microphysical studies during the seeding experiment. PEP should provide not only statistical results. The successful outcome of the project requires a strong program of meso- to microscale physical measurements, complemented by a substantial modelling effort.

The measurement parameters illustrate the extent of PEP. They are:

- precipitation amount, intensity, duration and spatial distribution at the ground;
- synoptic meteorological variables at several points over the experimental area;
- local radiosonde information;
- cloud systems characteristics, including mesoscale organization (with satellite input);
- cloud base and top heights and temperatures, cloud liquid and total water content, droplet and drop size distrubitions;
- ice particle type, concentration, size and distribution spectrum;
- ice nucleus and CCN concentration below cloud base and at ground;

- (radar) echo top heights;
- radar reflectivity (volume scan);
- raindrop size distribution at the ground at one or two sites;
- characteristics of the seeding plume.

The reasons for taking these measurements are many fold:

a) The power of the statistics is to be increased by the use of precipitation covariates which will be sought in SSP-3. Possible examples are: synoptic situations, cloud top height, ice crystal concentration, 500 mb temperature, and droplet concentration.

b) The microphysical measurements will be necessary to document a direct causal relation between seeding and rainfall.

c) Extended area affects, as supported by large area rainfall measurements, may also be established through observed changes in the dynamics and microphysics of cloud systems. Tracer studies of seeding plumes are necessary for the same reason.

d) The transferability of PEP results to other parts of the globe is of great interest, because it could significantly influence the design of operations elesewhere. However, procedures and conclusions can only be transferred through conceptual models constructed from extensive measurements in the areas of concern, as well as in the PEP experimental site.

e) The measurement parameters listed above may also serve for the development of adequate numerical cloud models, which might be used in the prediction of weather modification effects.

f) The precipitation efficiency of cloud systems, combined with their total precipitation, needs to be assessed in order to provide insight into extra area effects and the question of optimizing seeding strategy.

No weather modification project would be complete without studies relating to the impact on the environment (ecological and societal). First environmental and hydrological studies have already been undertaken (PEP Reports 4 and 12) and an economic analysis of the value of the additional rainfall is presently under study.

4. ORGANIZATIONAL STRUCTURE

The overall management of PEP within WMO is under the control of the PEP Board. This body was formed in 1976 and is also responsible for resources for PEP. The scientific responsibility is with the EC Panel of Experts on Weather Modification, which acts in an advisory capacity. The Scientific Planning Group (SPG) at the WMO Secretariat in Geneva is the acting arm of the Board and is in charge of plan preparation for the different phases of PEP and the conduction and coordination of operations in the field. The SPG is also in charge of plan preparation for the different phases of PEP and the conduction and coordination of operations in the field. The SPG is also in charge of the overall evaluation. A member of the SPG acts as the Field Project Coordinator in Valladolid and is in charge of the daily operations. A Spanish liaison officer is assiting him. Last but not least there is an advisory group to the SPG, which consists of scientists actively participating in the field study. The countries participating SSP-3 are providing whole packages of contributions, consisting mostly of scientific and technical personnel and hardware for a specific aspect. They are also responsible for the basic evaluation of the data they collect. A major contribution is provided by the host country, because it is responsible also for basic facilities like hangar, field headquarters, communications, synoptic network, raingauge network, etc.

5. TIME SCHEDULE

Most weather modification experiments in the past have been conducted in two stages: exploratory and confirmatory. The results of a randomized exploratory experiment are often ambiguous until post hoc stratifications of meteorological conditions are carried out. These may reveal that a modified seeding strategy or a restriction of seedable events would produce significant statistical results. To test whether the results of this post hoc stratification were due to chance or not, a confirmation experiment needs to be designed.

Until sufficient knowledge has been accumulated about the PEP site and its meteorological characteristics, it is difficult to formulate a seeding strategy for PEP to become directly a confirmatory experiment. However, the Panel believes that building upon worldwide experience, by appropriate observations during SSP-3 and the design and setup phase, a sufficiently refined seeding strategy can be devised to avoid most or even all of the exploratory phase. SSP-3 really represents already a part of it. Studies of seeding plumes, which may be started also in a pre-seeding phase, may further help to lead more directly into the seeding experiment.

The question of "normality" of the three seasons of SSP-3 is another important problem. It is hoped that satellite data and synoptic studies will establish if the field measurements of this phase are representative in the average of what can be expected for a 5 year seeding experiment.

There is another point which needs to be taken into account in a time schedule of a WMO experiment: the budget cycle of the organization. The funding is provided by WMO Congress, which takes place every four years, with the next one coming up in spring of 1983. Further, the budget proposals need to be considered first by the WMO Executive Committee, which meets every year in spring.

Considering the different boundary conditions and also assuming efficient field studies (and their evaluation), the following time plan of (past and future) activities can be set:

First proposal of PEP by EC Panel:	Nov. 1974;
PEP approval by WMO 7th Congress:	Spring 1975;
Site Selection Phases 1 and 2:	1975-1978;
PEP design:	April 1978;
Operations plan for SSP-3:	September, 1978;
Start of field program SSP-3:	March, 1979;
Completion of SSP-3 field program:	May, 1981;
First evaluation and decision on the suitability of the Spanish PEP site:	Dec., 1981;
Operations plan for the PEP seeding experiment and supplmentary measuring program at PEP site, if found necessary:	1981-1982;

Review of PEP concept and approval of operations plan: Early 1982;
Start of randomized experiment: 1983;
Completion of randomized experiment: 1987;
Completion of major program and evaluation: 1988/1989.

6. SUMMARY AND COMMENTS

Initiated in 1974, the WMO Precipitation Enhancement Project is now reaching the half-time point of the field measurements of the Site-Selection Phase 3. This stage is now carried out on the only considered site (area of Valladolid in Spain) with substantial resources from a series of countries. No conclusions can be made at this point about the suitability of this site for a precipitation enhancement experiment - except that it is not a clear cut positive situation. The problem is twofold: It is not known yet if the deep cloud systems, which consist mostly of glaciated nimbostratus and produce about 70% of the total precipitation, do contain zones with supercooled water (susceptible to seeding) often enough and over sufficient time spans to make their seeding worthwhile. The other systems seem to be suitable for seeding, with the exception of the cumulo nimbi. However, preliminary statistical experiments show that the precipitation from the remaining shallow systems alone need to be nearly doubled to be detectable. Thus it will be up to some simplistic models to show if this is a reasonable expectation or not. The field season of 1981 should help to provide answers to these questions.

The detailed planning of the PEP seeding experiment needs to be carried out parallel to the evaluation of SSP-3 in order to be able to propose a sound project to WMO Congress 1983. Other avenues of attack of weather modification problems by WMO need also be developed in case the Site-Selection Phase applied to the Spanish site gives a negative result. There is also a possibility that another type of evaluation may be proposed in case the areal increase of precipitation at the ground is an unsatisfactory measure of seeding success. This could be the case if the rain increase is linked to convective situations which are normally associated with high precipitation variability.

If the Spanish site is found to be promising for a seeding experiment, it should be possible to start with the main PEP operation, the seeding experiment, in the 1983 season. This however, may require some initial plume dispersion and other preliminary studies.

The duration of a precipitation enhancement experiment is normally of the order of 10 years or longer. PEP is no exception. Like all the other ventures in weather modification, it will be judged not according to the standards acceptable when it was conceived, but at the standards acceptable to the scientific community when it is finished. This means that the planners have to be able to look into the future and make innovations in their planning that make PEP survive the test of time. This is not impossible. It requires, above all, a solid physical basis.

For example, it is suggested that radar volume scan is used to find relationships describing the evolution of radar echoes (as it has been done by Prof. Austin at McGill) in "regular" precipitation, and then look for the same in seeded situations. The difference would then represent a measure of the seeding effect, a seeding signature, i.e. a physical measure of the modification attempt. Not only that, it would also show where the seeding effect had taken place.

Beside the regular investigations the 1981 season will also be concerned about radar patterns and signatures which may or may not be associated with seedable cloud regions. For convection the recent meeting of the principal investigators of SSP-3/1981 in Montreal, December 15-18, 1980, suggested wind inhomogeneities (indicating updrafts or downdrafts) as measured with the MRL-5 radar, VAD (Velocity Azimuth Display) divergence measurements with Doppler radars, and radar signal ratios between the normal bright band level and a level below it.

At the suggestion of a WMO meeting held in Toronto, December 8-12, 1980, on the application of cloud models to seeding experiments, a closed box model will be used to indicate the degree and time evolution of a co-existence of high liquid water contents (higher than $0.2 g/m^3$) and high ice particle concentrations (bigger than 1 per liter) --as was observed during SSP-3/1979-1980. A 1-dimensional cloud model should also be applied to test its use for the prediction of the height of convective clouds.

The interesting aspect of PEP is the search for a promising site and the establishment of suitability (for seeding) criteria. This is quite new ground and new concepts need to be developed without resorting to a full fledged statistical seeding experiment - which is the only way to obtain a "firm" final answer. Perhaps the "Austin" method could be extrapolated to a suitability criterion.

Another possibility could be to use the other six upper air sounding stations around Valladolid to link the cloud systems evolution to the large scale flow and see in which way it was affected by a seeding operation (Cho and List, 1980). This would require roughtly 90 min. sequences of sonde releases, but it could be limited to a restricted number of interesting days. Maybe there are other ideas forthcoming which are also worth consideration.

Finally, it must be stressed that PEP was never intended to answer once and for all, whether precipitation enhancement as an operational concept is feasible or not. The results will at best be conclusive only for the area in which the main experiment is conducted. However, if the PEP results are positive and the physics is well understood, there is a good chance that rainmaking will be possible under similar conditions elsewhere.

ACKNOWLEDGEMENTS

The source material for this personal view of PEP is found in decisions and reports of the WMO Congress, its Executive Committee, the PEP Board, the EC Panel/CAS Working Group on Cloud Physics and Weather Modification, the Scientific Planning Group at the WMO Secretariat, the series of the Weather Modification Program reports and in Technical Note No. 154, "The scientific planning and organization of precipitation enhancement experiments, with particular attention to agricultural needs" by Dr. J. Maybank.

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APPENDIX A: OBJECTIVES OF PEP

The WMO Executive Committee, at its twenty-eighth session in 1976, defined the scientific objectives of the Precipitation Enhancement Project as follows:

(a) To provide Members with reliable information about the probabilities of successful artificial intervention in meteorological processes with the object of increasing the amount of precipitation over an area of the order of 10,000 km^2. The size of the area for the proposed project (i.e. the target and nearby control areas) should be somewhere around 50,000 km^2, a scale large enough to provide adequate evaluation of scientific feasibility and economic benefit, but small enough to permit the use of adequate methods for seeding and observations;

(b) To demonstrate at a satisfactory statistical significance level over a relatively short experimental period (five years), that any increase observed is not a chance event but is associated with the seeding. The principal evaluation of this experiment will be in terms of precipitation at the ground;

(c) To obtain sufficient understanding of the meteorology and cloud physics in the area of the experiment to ensure that the statistical association of seeding, and any increase in precipitation, will be generally acceptable as a cause-and-effect relationship;

(d) To make an examination outside the target area in order to determine whether any benefits of seeding extend over areas greater than the target area, or wyether there has merely been a comparatively local redistribution of precipitation;

(e) To make systematic measurements, varying from mesoscale to cloud micro-structure, in order to develop additional co-variates to strengthen the power of the statistical analysis;

(f) To obtain well-documented scientific evidence that may lead to the optimization of the effects of seeding. For this purpose, a series of systematic cloud physics measurements should be taken on a routine basis. This would allow the application of statistical techniques to relevant physical parameters and could shed more light on the quantitative aspects of seeding techniques;

(g) To be able to make some recommendations about the applicability of the PEP procedures to other areas of the world;

(h) To assess the environmental impact of precipitation-enhancement activities, both within and outside the experiment target area.

APPENDIX B: REPORTS WMO PRECIPITATION ENHANCEMENT PROGRAMME

Report No. 1: Report of the First Session of the Interim Precipitation Enhancement Project Board, Geneva, November 1976;

Report No. 2: Position Papers used in the Preparation of the Plan for PEP:

Report No. 3: Plan for Precipitation Enhancement Project;

Report No. 4: A Review of the Hydrological Aspect of Evaluation of Precipitation Enhancement;

Report No. 5: Cloud Seeding Reagents;

Report No. 6: Areal Extent of Seeding Effects in Relation to the Precipitation Enhancement Project;

Report No. 7: Aircraft Instrumentation for Cloud Physics Research Weather Modification Programs;

Report No. 8: Report of the Second Session of the Interim Precipitation Enhancement Project Board, Geneva, April 1978;

Report No. 9: PEP Design Document;

Report No. 10: Survey of the Climatology and Synoptic Weather Patterns at the Proposed PEP Site in Spain;

Report No. 11: Operations Plan for Site-Selection Phase 3;

Report No. 12: Preliminary Environmental Impact Study of the Site Proposed for PEP:

Report No. 13: WMO Training Workshop on Weather Modification for Meteorologist - Lecutre Notes;

Report No. 14: The Dispersion of Cloud Seeding Reagents;

Report No. 15: PEP Site Selection Phase-3, 1979 Field Programme - Overview and Data Catalogue;

Report No. 16: Report on the Third Session of the Precipitation Enhancement Board, Geneva, September, 1979;

Report No. 17: Statistical Design Considerations for Precipitation Enhancement Projects;

Report No. 18: PEP Site Selection Phase-3, 1979 Field Programme - General Weather Conditions and Rainfall Characteristics;

Report No. 19: PEP Site Selection Phase-3, 1979 Field Programme - Two Studies of Precipitation Patterns;

Report No. 20: Report of the Fourth Session of the Precipitation Enhancement Project Board, Villanubla, Spain, May 1980;

Report No. 21: PEP Site Selection Phase-3, 1980 Field Season - Overview and Data Catalogue.

HAIL SUPPRESSION ACTIVITIES IN THE SOVIET UNION

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Hailstorm modification activities to prevent hail damage have been carried out in the Soviet Union for more than 15 years. Great interest to the national economy and high benefit-to-cost ratio of the hail protection program have motivated a considerable increase in the volume of hail suppression operations in the USSR.

Ten hail suppression divisions are currently operating in the Soviet Union. They comprise 53 groups (detachments). In 1979, these detachments protected crops from hail damage over an area of 6.5 mln ha. Results of hail suppression projects during the period 1975 to 1979 are presented in Table 1. Analysis of the hail protection results show that on the average, crop losses due to hail in the protected area have been reduced by more than 70 percent as compared with the many years' average damage and the losses in the control areas. The cost of the crop being preserved amounts to the sum of tens of millions of roubles.

However, we are still far from completely solving the hail problem, in spite of the fact that considerable progress has been made towards the solution of it in the last few years, since in some cases damaging hail is observed over the protected area. Reliable hail protection is the most complex problem in case of the development of very severe hail clouds.

A special research and experimental site (polygon) instrumented with a modern radar and meteorological equipment has been set up in the North Caucasus to study meteorological and aero-synoptical conditions of the formation and development of very severe hail clouds, as well as investigate the process of hail formation and growth in clouds, and improve the existing techniques of artificial modification of hailstorms of various intensities.

Recent studies by the Soviet scientists (Abshaev M. T., Bibilashvili N. Sh., and others) made it possible to more accurately define the spacial structure of hail cores in a cloud, the location of hail initiation, and the area and structure of updrafts, as well as to measure the period of hail core formation and the velocity and direction of their motion. Experiments on hail cloud modification aimed at their suppression showed that seeding should be done in the early stage of hail formation (when conditions are formed for hail initiation) rather than in the hail growth stage as it was suggested earlier. At this stage, it is much easier to achieve positive results from seeding with crystallizing reagents, making the most use of the effect of unstable equilibrium of a supercooled waterdrop cloud and stimulating premature (prior to hail formation) rainfall. Injec-

TABLE 1

RESULTS OF ANTI-HAIL PROJECTS IN THE USSR (1972-1979)

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Region of project	1972		1973		1974		1975		1976		1977		1978		1979	
	TA	EC	TA	EC	TA	EC	TA	EC	TA	EC	TA	EC	TA	EC	TA	EC
Caucasus	446	44	435	99	441	66	490	66	484	46	631	60	600	84	600	92
Krasnodarsky region	520	82	540	61	540	83	542	67	458	87	575	50	625	59	635	73
Ukraine SSR	110	100	210	91	210	82	210	82	275	88	390	99	390	99	395	99
Uzbekistan	243	92	282	81	282	94	300	100	300	89	400	98	410	80	500	97
Georgia	250	95	250	97	250	87	350	99	350	95	350	98	380	97	400	94
Azerbaijan	320	100	447	86	447	92	570	99	737	89	737	97	752	99	822	97
Moldavia	360	96	490	88	500	86	600	95	730	89	810	91	910	73	1000	96
Tadjikestan	320	94	370	82	380	95	420	93	450	79	520	91	550	89	550	71
Armenian	721	70	720	73	750	80	720	70	911	95	911	99	920	99	920	99
Total	3290	86	3684	85	3800	81	4202	86	3695	84	5006	85	5537	86	5822	91

TA - total area protected (thousands of ha)
EC - efficiency coefficient (%)