DESIGN CONSIDERATIONS OF A WINTER OROGRAPHIC
CLOUD-SEEDING PROGRAM IN THE
ALBORZ MOUNTAINS OF IRAN

A. E. Dabiri *
G. Nemat †
J. A. Warburton ‡

*Mechanical Engineering Department, Arya Mehr University
  of Technology, Teheran, Iran
†Iranian Meteorological Department, Teheran, Iran
‡Desert Research Institute, University of Nevada System, U.S.A.

1. INTRODUCTION

Like many nations in the world, Iran has limited availability of useful
water for hydroelectric power generation and for agricultural and industrial
needs. The development of water resources is thus important to the overall
economic progress of the nation. One of the possibilities for improving the
availability of water is the more efficient use of atmospheric water through
a program of precipitation management.

An investigation has been conducted of the synoptic and mesoscale cli-
mates of the Alborz Mountains region in northern Iran from the viewpoint of
weather modification potential. This paper presents a scientific plan for the
implementation of a winter orographic cloud seeding program, based upon the
results of these climatic investigations. The encouraging overview by Sax,
et al. (1975) for winter orographic seeding programs suggests that the poten-
tial for success in this type of program may be good.

2. LOCATION AND CLIMATE

(a) Geography

The Alborz Mountains, located at a latitude of 36°N, rise from the
Ghazvin Plain (elevation 1300 m) to about 3500 m with a few higher peaks. The
experimental design is centered on an area of approximately 4000 km² of very
rugged mountainous terrain (see Fig. 1). The difficulties of accessibility
for ground based activities will pose problems in both the operation of a
weather modification project and its evaluation. The mountain range lies
along a WNW-ESE line and presents an orographic barrier to storm systems which
move across Iran from the south and southwest. Forested areas occur only along
rivers, the mountains being generally devoid of vegetation. Accessibility is
by a small number of unpaved roads and the needs for helicopter support and
over-snow vehicles in winter are evident.

Figure 1 shows that the weather modification program could be conducted
FIGURE 1

PROPOSED RADIOSONDE STATIONS
in one, two or more areas, allowing for a choice of statistical design if a randomized seeding design is used. Each of the two "target" areas delineated is 2,000 km² in size. They are separated by a very rugged inaccessible "buffer" zone approximately 70 km in width. The elevation of the two "target" areas ranges from 2000 meters at the southern boundaries to 4000 meters in the north. The western (Shahroud) catchment is generally lower in elevation (2500 m average) than the eastern catchment of Karadj-Jajrud (3300 m average).

The Shahroud river system drainage flows westward and north to the Caspian Sea. The Karadj and Jajrud system flows west and south to Teheran.

(b) Climatology

(i) Precipitation

The precipitation which falls in the Alborz Mountains is principally snow and occurs from November through April. Most of the precipitation falls when cyclonic winter storms move from southeast to northeast across the region. Analysis of twelve (12) years (1963-1974) of data from five recording precipitation gauges has shown that the daily precipitation amount is altitude-dependent, being 3 to 4 mm/day at 1300 m elevation, 6 mm/day at 1500 m, and 18-20 mm/day at 2800 m elevation on precipitation days. The data for the 12 years also showed that there was an average of 75 days with precipitation for the November through April period. Evidence of the orographic effect up to approximately 2300 m in elevation is shown in Figure 2 which presents the mean accumulated precipitation for January through April in the Karadj-Jajrud catchment, for 15 sites with elevations ranging from 1300 m to 2800 m.

(ii) Winds

Winter precipitation in this region of Iran normally begins in conjunction with southerly winds. These winds gradually swing to the southwest and west, usually within the first 24 hours of the storm period. As the storm passage proceeds, the wind directions continue to shift to northwesterly, at which stage precipitation usually stops.

A study of two years of data from the region shows that wind speeds at 700 mb, range from 23 to 70 km/hr. Six hundred mb winds can reach 100 km/hr. during winter storm periods.

(iii) Temperatures

For cold cloud-seeding programs, cloud top temperatures are proving to be useful in some cases as indicators of seedability (see e.g. Bethwaite, et al., 1966, and Mielke, et al., 1971). Radiosonde data from Teheran airport show that the 500 mb temperatures during storms in November and December are around -25°C. In January, the temperature at this level is typically -30°C, -27°C in February and -22°C in March and April. The 700 mb temperatures range from -1°C in November to -9°C in January and warm up to 0°C in April. These temperature ranges suggest that cloud systems normally considered seedable will occur frequently throughout this 7 month period.
January-April Accumulated Precipitation

Elevation of Observation Stations (m)

2800
2600
2400
2200
2000
1800
1600
1400
1300

KARADJ-JAJRUD CATCHMENT AREA
3. PROJECT DESIGN--PHASE I

Because there have been only limited scientific investigations of this geographical region pertaining to atmospheric characteristics of clouds and weather systems, there is a paucity of information needed to develop, at the outset, a sound scientifically based weather modification project design. The design being considered, therefore, begins with an exploratory Phase I, which is expected to require 3 years to complete.

(a) Working Models

Phase I would involve the development of a working model for seeding of cold orographic storms. It is intended that this model should provide for the inclusion of a convective component, which appears to be important in orographic winter storms in other mountainous mid-latitude regions such as the Sierra Nevada, U.S.A. (Project Skywater, 1974). In order to develop and test these models adequately, it will be necessary to obtain more frequent and more closely spaced upper air sounding data than is presently available. This can be achieved by installation of a small number of radiosonde stations and by more frequent releases from Mehrahabad airport (Teheran). The design calls for radiosonde installations at Karadj town and Ghazvin (see Fig. 1).

The working model is to include the ice phase, and in order that real data can be employed to develop predictions of precipitation and effects of seeding, a suitably instrumented cloud physics aircraft would be used in Phase I to gather such data. This would include measurements of ice and water in cloud, ice crystal types and populations, the incidence of accretional ice growth, the cloud liquid water content and information about the atmospheric aerosol. The airborne program would be augmented by ground-based mountain laboratory observations of precipitation types, intensities and chemical composition.

(b) Inadvertent Modification

In forming an assessment of the weather modification potential for the Alborz Mountains project areas, it will be necessary to investigate two major aspects of possible inadvertent modification. The first is the effect on the weather systems moving into the eastern section of the proposed study region of gaseous and particles emissions from the city of Teheran (see Fig. 1). This very large city produces quite significant emissions and it will be necessary not only to look at the effects of these on the cloud microstructure, but also to investigate the possibility of a 'non-uniform' input to the overall region, if a two-area project design is used.

The second is the effect on the cloud microstructure of extensive dust clouds which are produced over the Ghazvin plain in westerly wind conditions (see Fig. 1). The density of these dust clouds is sufficient to reduce visibility to a few kilometers in the lower 1000 meters. The absence of significant vegetative ground cover in these regions to the south of the Alborz Mountains, suggests that this latter problem would not depend on season but be significant at most times during the year. Investigations would include the measurement of CCN and cloud droplet concentrations in the lower cloud layers under various potentially inadvertent modification conditions. In addition, radar systems located in the foothills area of the Alborz Mountains will be used to measure
location and elevation of first echoes and maximum echo height. These measure-
ments will be made during Phase I to determine whether these dust clouds are
having an impact on the precipitation growth processes. Comparisons will be
made between these results and the model predictions.

(c) Predictor and Response Variables

Phase I will include an attempt to develop reliable predictors for the
Phase II seeding program. Predictor variables are expected to include the
following: (i) Storm duration; some evidence exists (e.g. Mielke at all., 1971)
that seeding may have an effect on storm duration. A randomized seeding design
might effectively use predicted storm duration as a meaningful variable. (ii)
Precipitable water; this quantity, deduced from radiosonde data will be investi-
gated as a predictor. Potential condensate is an alternative yet similar quantity
for consideration (Chappell et al., 1974). (iii) Cloud top temperature; as
mentioned earlier, this parameter has been suggested as an indicator of seed-
ability. Partitioning and stratification of winter storms into groups by
temperature, would be investigated. All available historical and newly generated
data pertaining to precipitation as a function of cloud-top. 500 mb and 700 mb
temperatures, will be studied to determine the feasibility of using these
parameters for prediction purposes.

Response variables for use in the evaluation phases of the program would
include precipitation amount and duration. The proposed project areas are not
well instrumented with rain or snow gauges. However, the number of gauges in
the two regions shown in Figure 1 has been increased recently to 60. Gauge
density is expected to be one per 50 km². Gauges are not hourly recording types;
hence, if precipitation duration is to be developed as a response variable, it
will be necessary first to develop adequate procedures for measurement of times
of precipitation occurrence.

Trace chemical analyses for measurement of the seeding and other chemicals
in the precipitation, are being considered also as response variables. The
transport of submicron sized particles of seeding agents over mountainous
terrain is a complex issue. The use of chemistry and particle nuclei analyses
have potential for resolving questions related to non-uniform dispersion of
seeding materials over the project areas.

Radar is also being investigated as a tool for both prediction and response
aspects of the program. Recent work in establishing usable Z-R relationships
for determining snowfall rates from radar reflectivity, may open the way for
useful radar assessment of seeding effects (see e.g. Sekhon and Srivastave, 1970).
Qualitative radar reflectivity data will certainly be usable for comparisons of
seeded and non-seeded cases.

Altitude dependence of precipitation is expected to be significant in this
mountainous region of Iran. If orography is playing a role in the determination
of precipitation amount (and this appears at this time to be true at elevations
up to 2300 meters), project areas could be chosen to distinguish these features,
particularly in the event of a randomized cross-over design, since the two areas
under consideration do not have similar elevation cross sections (north to south).
Suitable choices of area then could enable the use of altitude dependence of
precipitation as a response variable particularly if coupled with measurements

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of seeding chemical content.

(d) Data Management

One of the most significant areas of development needed in Phase I is that of Data Management. In an experiment of the dimensions planned, a large quantity of data will be generated requiring management. Appropriate digital data acquisition and storage systems are to be designed and implemented such that rapid data processing can be achieved.

4. PROJECT DESIGN--PHASE II

At this time, Phase II design is planned to be composed of two parts: Statistical and Treatment Design.

(a) Statistical Design

The number of experimental units will depend upon the precipitation measurement procedure adopted. As already mentioned, gauges presently in use are of the accumulation type, not hourly recording. The measurements are made by non-technical people living in the project areas. From an analysis of several years of available data, it has been determined that an average of 30 "storms" affect the region in the period October through April. During this same period, there is an average of 75 precipitation days. A "storm" was identified as a synoptic feature leading to precipitation in the region having a duration in excess of 6 hours and with a maximum of 84 hours.

It has been possible to measure precipitation (including snowfall) daily but not in sub-units of one day. Hence, the 'day' appears attractive as an experimental unit since that would provide up to 75 units per year compared with only 30 "storm" units.

The choices of a single area target for seed and no-seed randomization; two areas for a target-control experiment; or two areas for a two-target, randomized cross-over design, are all available.

The single target area design has the advantages of avoiding extra-area effects and maximizing on available instrumentation, particularly in view of the rugged terrain and accessibility problems. The disadvantage is that only one half of the experimental units are seeded which will have the usual effect of lengthening the duration of the experiment. However, an additional advantage is that it is not necessary to have historical precipitation data for comparison purposes, although it would be useful in establishing the reliability of individual rain gauges and effects of elevation on precipitation.

The target-control, two-area experiment has the problem of extra-area effects or contamination. Since the two regions are well separated (70 km west to east), this problem might be minimal. However, the two areas are sufficiently different topographically, that their precipitation amounts are different, as are their areal distributions of precipitation. There are very few historical records of precipitation with the detail required to establish comparative isohyetal
patterns, and, unless sufficient additional data can be generated in Phase I of the program, it is doubtful if a target-control design would provide the best statistical approach.

The two target, randomized cross-over design has the advantage of maximizing the use of experimental units for seeding purposes provided the precipitation in the two areas is well correlated. Additionally, the cross-over design avoids the use of historical data which, as already stated, is very limited. However, some historical data is obviously needed to determine whether the precipitation in the two areas is well correlated. By using data from 13 existing gauges, all located in the three catchment areas, and which had several years of available data, correlation tests were performed. The 13 stations used are shown in Figures 3 and 4. Table 1 shows the results of these correlation tests. More than 90% of the coefficients are greater than or equal to 0.6. The tests were based upon the average precipitation over 3-day intervals. The good correlations suggest that it may be possible to use a randomized cross-over design. However, the final decision will await analysis from all available gauges in the project areas at the conclusion of Phase I of the program. The principal disadvantage with the cross-over design is, of course, that related to extra-area effects of seeding.

(b) Treatment Design

Seeding can be carried out either by airborne or ground-based aerosol generators in this region of northern Iran. Tests have been completed for the use of remote telemetry controlled AgI aerosol generators operated from a small number of control centers located within ratio-telemetry range of the generator sites.

A tentative network of 8 to 10 generators has been developed for each of the two project areas. Locations have been chosen considering accessibility, communications, power availability, wind velocities and proximity to the project area, taking into account growth rates and anticipated trajectories of ice crystals. The chosen locations for these ground-based units are shown in Figures 3 and 4. The elevation of the sites ranges from 1200 to 2200 meters. Locations were chosen so that ground-based seeding could be conducted when winds were in the sector 120° to 300° and with speeds from 10 to 140 km per hour. By investigating the frequency of occurrence of winds in different sectors, sites have been chosen so that more than 70 percent of these generators can be used more than 75 percent of the time.

4. SUMMARY

The results of this preliminary investigation and design have shown that all of the elements for a winter orographic cloud-seeding program are present in this mountainous region of northern Iran.

The measurement of the snowfall appears to present a somewhat greater than normal problem, since accessibility to the project regions is poor. Few, if any trained personnel are located in the project areas, and there is, therefore, a strong need for training of people to perform these tasks.
SHAHROUD RIVER

PROPOSED GROUND GENERATOR SITES

PROPOSED WESTERN PROJECT AREA (=2000 Km$^2$)

FIGURE 3
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**Oct-May Precipitation, 1972-1975**
Station to Station (A-M)
Correlation Coefficients
(3 day running means)

**TABLE I**
Due to the close proximity of one large city, Teheran (population 5 million people), and a large unvegetated plain (Ghazvin) to the south of the mountains, the possibility of inadvertent modification by these large sources of airborne particulates is considerable.

In order to formulate a well-designed randomized seeding program, the database on which this could be done needs to be built on and improved. This is now being done. When completed, the seeding technology and assessment systems can be determined and the project implemented when desired.

REFERENCES


FIGURE CAPTIONS

Fig. 1. Proposed project areas in Alborz Mountains, Iran, for orographic cloud-seeding program.

Fig. 2. Seasonal accumulated precipitation amounts in Alborz Mountains, Iran, for January-April -- shown as a function of elevation of observation stations.

Fig. 3. Proposed western project area, Shahroud Catchment, Alborz Mountains, Iran.

Fig. 4. Proposed eastern project area, Karadj and Jadjroud Catchments, Alborz Mountains, Iran.