RESEARCH AND DEVELOPMENT TECHNIQUE FOR ESTIMATING AIRFLOW AND DIFFUSION PARAMETERS IN CONNECTION WITH THE ATMOSPHERIC WATER RESOURCES PROGRAM

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ABSTRACT

This report presents a summary of the research and tentative results concerning the problem of using scaled topographic models and laboratory techniques to study the transport and dispersion of cloud seeding material over mountainous terrain. Three mountainous areas along the continental divide have been selected by the Bureau of Reclamation for such studies. Each area has field cloud seeding programs in progress.

Results from the field and model for the Eagle River Valley-Climax area showed the following similarities between field and model:

1. The principal valley was filled with tracer material.
2. The angle of inclination at which the tracer material leaves the generator sites was between 60-80 degrees with respect to the terrain.
3. The direction of the tracer plume was approximately the same.
4. Partial similarity was achieved for the horizontal and vertical dispersion of the tracer material with the model airflow consisting of a vertical temperature distribution approximately similar to the field.

Keywords: Weather modification, cloud seeding, model studies, dispersion, boundary layers.

TABLE OF CONTENTS

TABLE OF CONTENTS - Continued

FIGURES

Figure

I. INTRODUCTION

Purpose of Research Program

Several weather modification field programs are now in progress to augment water resources in the western states by artificially seeding wintertime orographic cloud systems. Artificial ice nuclei, in the form of silver iodide smoke from ground-based and air-borne generators, are released in the natural airstream where turbulence and convection currents are expected to carry the material into supercooled water clouds, and thus initiate precipitation by the Bergeron ice crystal process.

The physical basis for treating cold orographic clouds by seeding has been discussed by Bergeron [Ref. 1] Ludlam [Ref. 9] and Grant and colleagues [Ref. 7]. The orographic clouds which form along and windward of the mountain ranges over the western United States are frequently composed of supercooled liquid droplets. The temperature activation spectrum of natural nuclei is such that the number of effective natural ice nuclei does not meet cloud requirements, under some conditions, for converting the cloud water to ice form at the warmer cloud temperatures and higher condensation rates. In such cases snow may not develop, or the precipitation process may be inefficient.

If artificial ice nuclei can be activated in the saturated orographic stream far enough upwind of the mountain barrier, a more efficient conversion of cloud water to ice crystals should result in increased snowfall. Otherwise, the unconverted cloud water evaporates to the lee of the mountain barrier.

Successful cloud seeding depends upon the introduction of sufficient artificial nuclei (e.g., silver iodide) into supercooled clouds to obtain optimum crystal concentrations. If the concentration of crystals in the cloud should be less than the optimum concentration, then not all of the vapor provided by the orographic updraft can be readily condensed upon the snow crystals. When the concentration of crystals is above the optimum number overseeding may occur and the resultant precipitation may be less than would have occurred naturally.

Grant and colleagues [Ref. 7] have developed a simple model for showing the variation of optimum ice nuclei concentration as a function of cloud system temperatures. The optimum ice nuclei concentration was defined as that which enabled the cloud system to grow ice by diffusion at a given condensation rate. In the Climax, Colorado area, the optimum concentration of crystals needed to insure an efficient precipitation process was estimated between 100 to 5 per liter depending on the range of temperatures (-13°C to -35°C) and vertical velocities (1.5 to 0.1 m/s) that occur at this location. A more refined and improved model has been derived by Chappell [Ref. 6] that was tailored for existing cloud conditions at Climax and Wolf Creek Pass, Colorado.

The realization of the delivery of the optimal distribution of seeding material to orographic cloud systems presents a complex theoretical and operational problem. In order to help solve this complex problem several questions need to be answered in a quantitative manner. Such questions are:

1. Under given storm conditions will artificial freezing nuclei reach the target area?

2. How much of the target volume will be covered (i.e., horizontal and vertical dimensions of seeding plume) and in what concentrations?

3. What are the effects of stability, wind shear, orographic features and other natural factors on dispersion of the seeding material?

The overall purpose of this research is to help provide some answers for the above questions by utilizing the wind tunnel as a tool to model the atmospheric planetary boundary layer over mountainous terrain and the transport-dispersion of a passive tracer material simulating the silver iodide seeding material. A second phase of the research involves obtaining limited field data that will assist in enlarging our understanding of the transport-diffusion process in the field and also providing relevant data to check on the laboratory simulation results. Essentially, the field program is limited to the Climax-Eagle River Valley area; the remainder of the field data for other areas will be provided by private contractors.

Research Goals

The wind tunnel or laboratory method consists of making concentration measurements of a dispersing tracer material over a scale model of selected terrain placed in a simulated atmospheric flow. Field measurements of tracer concentration for selected meteorological conditions are used to confirm and/or correct the laboratory results. The general objectives for the research are as follows:

1. Determine the full capability for laboratory simulation of airflow over complex roughness features.

2. Investigate the similarity for atmospheric transport and dispersion of particulate material such as silver iodide over complex terrain with a wind tunnel model.

3. Evaluate the use of wind-tunnel simulation of airflow and transport in various types of orographic terrain as related to weather modification operations.

4. Obtain field information on the relative dispersion and transport characteristics of tracers with particle sizes ranging from meter to molecular sizes.

5. Establish modeling criteria for future operational programs in weather modification.

The more specific and intermediate objectives are described in the following sections. The objectives have been altered somewhat to include and place emphasis on the acquisition of information on plume characteristics for the San Juan mountain areas during winter storms. This is in direct support of the pilot seeding project planned for the Colorado River Basin.

This report summarizes the research and results obtained during the past year on three selected topographic regions where operational cloud seeding is in progress or is being planned.

Topographic Areas Under Investigation

1. Eagle River Valley-Climax Region - The first region of interest studied is situated in the central Colorado Rockies on the continental divide near Leadville. A Colorado State University weather-modification experiment [Ref. 8] has been active in this area for several years. Figure 1 shows the primary area of interest and the region which was modeled for the wind-tunnel study. Generally, the topography of this area consists of three types, blocking ridge (Red and White Mountain and Mosquito Range), valley (Eagle River Valley and others) and singular mountains (Chicago Ridge and Chalk Mountain).

2. Elk Mountain Region - The second region of interest is situated near Elk Mountain in southern Wyoming between Laramie and Rawlins. Wintertime studies, conducted at the University of Wyoming's Elk Mountain research facility [Ref. 10], are investigating precipitation augmentation, tracking of seeding material and cloud physics of cap clouds.

Elk Mountain is relatively isolated from other large terrain features and the geometry of its shape is relatively simple. It is classified as a singular mountain in contrast to the more complex terrain near Leadville and the Wolf Creek Pass area. Figure 2 shows the primary area of interest.

3. San Juan Region - The third region of interest is situated in the San Juan Mountains in southern Colorado. The area modeled is a 30 x 80 mile strip extending from the New Mexico border through Pagosa Springs and over Wolf Creek Pass to the Rio Grande River Valley.

The Wolf Creek Pass area is typical of a blocking ridge type but complicated by the presence of river valleys and a concave topographic entrance when approach from the south-southwest. Figure 3 shows the topographic relief which was modeled for the wind tunnel study.

II. EAGLE RIVER VALLEY-CLIMAX STUDY

Topographic Model

The first topographic model of this study simulated the Eagle River Valley area and topography surrounding Climax, Colorado (Fig. 1). The direction of the free stream (or geostrophic) wind is approximately 320° or northwest. The horizontal and vertical scale of the model is 1:9,600. Overall dimensions of the model is approximately 25 ft 6 in. x 5 ft 10 in. The lowest and reference elevation is 7,800 ft (2379 m) and the highest is Mt. Lincoln at 14,284 ft (4350 m) msl. The maximum height difference in the model is 8 in. Further details on the topographic model are found in References 4 and 5.

Research Accomplished for this Period

1. Laboratory Experiments - Only one period of experimental study was undertaken during the year since the majority of data had been collected in five prior experimental periods. All the research work was accomplished in the Colorado State University low-speed recirculating wind tunnel.

Two types of atmospheric airflow were simulated in the wind tunnel: a) a neutral stability airflow and b) barostromatic or stably stratified airflow. Concentration measurements were made over the topographic model for both airflow types using radioactive krypton as a passive tracer gas. Tentative problems and results have been presented earlier in References 4 and 5. Detail results and comparisons with field data will be thoroughly explored in a technical report now nearing completion [Ref. 12].

2. Field Data - The primary objective of the field program is to collect sufficient information to check on the laboratory results. The

program is not large scale and therefore its objectives are quite limited. On occasion the field program of this study has benefited from other field programs active in the same area. These programs are the Rocky Mountain orographic cloud precipitation and modification program sponsored by National Science Foundation and the State of Colorado weather modification program.

The principal objectives of the field program are as follows:

a) Obtain sufficient radiosonde, pilot balloon and near surface data to define the vertical structure of the atmosphere in orographic terrain especially during conditions when cloud seeding would most likely be in operation.

b) Obtain data on the trajectory of air parcels by means of the superpressure balloon technique and also make estimates on the atmospheric dispersion from these same measurements.

c) Obtain surface samples of tracer material (e.g., silver iodide and sulfur hexaflouride) downwind from generator sites in order to determine the dimensions of the tracer plume.

d) Obtain upper-level samples of the tracer material using a kite system and aircraft. Primary emphasis is on obtaining measurements on the vertical depth of the tracer plume by using an aircraft as a sampling platform.

Five periods of field data collection have been implemented to attain the four objectives listed above. The dates of these were as follows:

December 16-20, 1968
December 8-16, 1969
January 13-16, 1970
March 12, 13, and 16, 1970
April 30 - May 1, 1970

During these periods especially those for 1969-70 the following tasks were at least partially completed:

a. Collection of simultaneous radiosonde data at Minturn, Camp Hale and Fairplay.

b. Simultaneous collection of pilot balloon data taken at four different locations from Minturn to Chalk Mountain. However, low cloud ceilings limited the vertical extent of the data.

c. Realization of dual and single super pressure balloon runs in the Camp Hale, Leadville and Redcliff areas. Six of the runs were tracked by a double-theodolite technique and four runs were tracked by a M-33 radar and transponder system. The six runs tracked by double-theodolite technique were done under general northwest wind conditions and have provided additional data on the local dispersion characteristics in the Camp Hale area.

d. Sampling of silver iodide tracer material near the surface was accomplished at Chalk Mountain and Tennessee Pass.

e. Sampling the silver-iodide seeding material in the Climax-Leadville, Eagle River Valley area by aircraft.

Results

1. Field Results - Figure 4 shows one example of a cross-sectional view of seeding material concentration as generated by the silver iodide generators at Minturn and Redcliff within the Eagle River Valley during northwest winds. Aircraft sampling began several hours after the generators were in operation hence, the concentration field was considered in a quasi-steady state.

The atmospheric stability in the valley was near neutral but stabilizing gradually with height above the mountain peaks (Fig. 5).

The wind direction was generally northwesterly but turning slightly to the west at the higher altitudes. Wind speed was approximately 7 m/s in the valley with little vertical wind shear. At altitudes above the surrounding mountains the wind speed increases with height. These wind and stability conditions are generally typical during snow events, with some exceptions.

The characteristics of the silver iodide plume can be summarized in the following way:

Mean characteristics of plume - The flights on March 16 as well as the other two sampling days indicated that the seeding material filled the main valley downstream from Minturn. The main axis of the plume was located between Chicago Ridge and the Tennessee Pass region. The material was transported some 40 km downwind toward Malta but for some unknown reason quickly dissipated or was lost in the Arkansas River Valley. However, it is very probable that the material was transported upward and horizontally toward the Chicago Ridge region.

Convective-orographic cells - Willis [Ref. 14] made the observation in the Park Range studies that the seeding material may appear in the form of three dimensional pillars inclined along the mean wind direction due to wind shear.

Figure 4 shows random small-scale features in the main plume which resemble the pillars as described by Willis. Many of these features were inclined in the approximate direction of the wind.

These transitory cells appear to be the result of topography and wind shear and also in some cases to convective cells. These convective-orographic cells enhance the vertical dispersion by transporting local concentration maximums of seeding material into the base of the cloud.

Vertical and horizontal dispersion - The dual constant volume balloon runs taken on December 12, 1969 showed that the horizontal and vertical dispersion can be very significant in this locale (Fig. 6). Vertical motions on the order of $\pm$ 2 m/s are not uncommon. The total dispersive rates were proportional to t^3 and t^4 as indicated by the total separation rates of the balloons [Ref. 12].

Calculations of the eddy diffusivities from the balloon data showed that on this particular day the vertical eddy diffusivity changed with height, from 10^4 cm^2 sec^{-1} within the valley to 10^6 cm^2 sec^{-1} near the surrounding mountain summits. This indicated a strong vertical eddy flux out of the valley due to a strong shear flow at ridge level. Lateral and longitudinal eddy diffusivities were on the order of 10^5-10^6 cm^2 sec^{-1}.

The aircraft sampling showed that for the three days flown that the vertical transport of the seeding material was adequate for getting the material into the clouds. However, we have yet to sample a day when the atmosphere is stable.

The aircraft sampling also yielded some information on the horizontal dispersion of seeding material. At approximately 12,000 ft the plume was found to be over 10 km wide at 30 km downstream from the first generator (Minturn).

2. Field and Model Comparisons - The following similarities between the field and model concentration distributions were found:

a) In both cases the principal valley was filled with the seeding material (Fig. 16, Ref. 5).

b) The angle of inclination at which the seeding material leaves the generator sites with respect to the terrain was found to be between 60 to 65 degrees for the model and 70-80 degrees for the field.

c) The direction of the principal plume was similar for model and field (Fig. 18, Ref. 5).

d) Partial similarity was achieved for the horizontal and vertical dispersion with the model airflow consisting of a vertical temperature distribution approximately similar to the field.

Generally, the model results were for a steady-state wind condition without significant free stream directional wind shear. Hence, it was found in the model that the horizontal dispersion of the tracer in the lateral direction was not quite as wide as suggested by aircraft field measurements.

Figure 7 shows a comparison between the dimensionless concentration parameter $\frac{\overline{C}\,\overline{U}\,h^2}{Q}$ for the field and models as plotted versus height. The neutral case for the model differs significantly from the field and was probably due to the difference in stability between model and field, conflict in similarity criteria, and inadequate simulation of turbulence and upstream boundary conditions. The problems of modeling are amendable and better results for a model neutral case are anticipated with additional experimental work.

The model flow with a stability more stable than neutral gives reasonable results especially if the accuracy of the flight sampling equipment and effects of depletion variables are taken into consideration. Further details on the comparisons between model and field results will be presented and discussed in Reference 12.

III. ELK MOUNTAIN STUDY

Topographic Model

Construction methods, materials (expanded Polystyrene beadboard) and scale (1:9600) were essentially the same as for the Eagle River Valley-Climax model. Discussion with the University of Wyoming research group revealed that the best operational direction of the free stream wind would be 250° or west-southwest. The dimensions of the model are 5 ft 9 in. x 12 ft. The lowest and reference elevation is 6,800 ft and the highest is Elk Mountain at 11,156 ft. The maximum height of the model is approximately 5½ in.

Generally, Elk Mountain is isolated but hills to the north and south complicate the topography. The windward side of the mountain rises gradually from a sagebrush plain while the leeward side descends abruptly from 11,156 ft to 8,000 ft within 3 km. The only major obstruction upstream from Elk Mountain is an extension of the Park Range located some 65 km to the west-southwest.

Research Efforts for This Period

1. Laboratory experiments - Three sets of experimental data were taken during this time period. The Colorado State University low-speed recirculating wind tunnel was used for the first measurements. The second and third series of measurements were made in the 6 ft x 6 ft meteorological wind tunnel.

Two atmospheric airflow types were simulated in the wind tunnel 1) a neutral stability airflow and 2) a stably stratified airflow. Concentration, velocity profile and turbulence measurements were made for the neutral case but further measurements are needed for the stably stratified airflow. Tentative results have been presented earlier in Reference 13.

2. Field Data - Radiosonde, pilot balloon, and some ice nuclei concentration data have been supplied by the University of Wyoming research group. The data were taken at a field site some 10 m southwest of Elk Mountain and at the observatory on Elk Mountain.

Results

A brief summary of the work accomplished in the wind tunnel for the neutral stability airflow case is presented in the following paragraphs.

In the laboratory a free stream velocity of 9 m/s was chosen to assure that the airflow was turbulent over the model. The boundary-layer thickness was 30 to 40 cm. The surface streamline pattern for this type of airflow was determined previously and was shown in Reference 13. At the upstream slope of Elk Mountain, the upstream flow diverges due to the blocking effect of the mountain. On the leeside of the mountain separation of the flow occurs. Here wind directions fluctuate strongly and high turbulent intensities (40-60%) occur.

A field silver-iodide generator was simulated by a small source on the model and a radioactive gas tracer (Kr 85) was released over the model. The gas tracer in the model airflow was then sampled to determine the horizontal and vertical spread of the material over the model [Ref. 5].

Figure 8 shows the surface distribution of the tracer in terms of a dimensionless concentration parameter $\overline{C}UX^2/Q$. It is important to note that Fig. 8 is a mean distribution, i.e., a concentration distribution averaged over a long period of time as time is related to the actual field. In this case the lateral concentration distribution approaches a normal distribution except near Elk Mountain where the plume axis was deflected to the north. At the present time no field data are available to verify this behavior.

Figure 9 shows a vertical cross section of the plume along the horizontal axis of the maximum concentration. The development of the plume height shows a definite effect of Elk Mountain.

Field measurements under near neutral atmospheric conditions at the Elk Mountain site showed that mean ice nuclei concentrations vary from 100 to 400 particles per liter during periods when field generators were operating. If X represents the distance from source point to sampling point the dimensionless concentration parameter $\overline{CU}X^2/Q$ ranges from 30 to 80 for the field measurements. Computing the same parameter for the model data (Fig. 8) showed values ranging from 30 to 40, in fair agreement with the field.

Further field and model data are required before a more complete evaluation of the transport-diffusion problem can be accomplished for this site. A technical report on this problem will be published during the coming year.

IV. SAN JUAN STUDY

Topographic Model

This newest topographic model of the series was constructed during the last half of the year and was finished in July. The overall dimensions of the overall model are approximately 12 ft x 28½ ft. The model is divided into 14 sub-sections to facilitate placement into the wind tunnel. The model was constructed to simulate a south-southwest (220°) free stream or geostrophic wind. This wind direction was selected on the basis of information from Chappell* and the San Juan experimental design study [Ref. 7].

Since the large extent of the geographical area to be modeled required a large scale reduction it was decided to construct a distorted scale model with a horizontal scale of 1:14,000 and a vertical scale of 1:9600. The lowest elevation is 5,800 ft and the highest is Summit Peak at 13,272 ft. The maximum model height is estimated to be approximately 9¼ in.

The following procedures were employed in constructing the model:

1. U.S. Geological survey maps for the model area were selected. It was necessary to use three different map scales 1:24,000, 1:62,500 and 1:125,000 in order to cover the entire area.

2. A commercial photographic firm enlarged and reproduced the selected maps to the desired scale of 1:14,000. Ozalid copies were made of the photographic originals.

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*Associated with the Department of Soils and Meteorology, Utah State University as of September 1970.

3. All the ozalid maps were pieced together to form one large map. The map was then divided into fourteen sub-sections.

4. Selected topographic contours, usually 200 ft, were then traced on vinyl plastic overlays for all fourteen sub-sections.

5. These plastic overlays were then placed on top of strips of styrofoam FR and the topographic contour sections were cut out with the aid of a heated nichrome wire cutter.

6. The various styrofoam contour sections were then oriented and built up with the aid of the original ozalid maps. The contour sections were finally glued together and mounted on a 3/4-in. plywood base. The complete model at this stage is shown in Fig. 10.

7. The next phase of work consisted of smoothing off the terraces in order to make the topography more realistic. This was done by applying two types of permanent plastic modeling clay by hand. Care was taken to preserve as much detail as possible.

8. The model was then painted with three types of latex paint. This was done for the purpose of covering the clay sticky surface and delineating forest, timberline and valley areas. At this juncture no attempt was made to model the forest areas, however, the means do exist to approximate these areas if the need arises. Figure 11 shows the model in its completed form.

Research Efforts for this Period

1. Laboratory program - A number of exploratory tasks are usually performed before any serious experimental work can start. In this case, two tasks were performed: a) the engineering, construction and placement of the sources on the model and b) placement of the model in the environmental wind tunnel.

The engineering and construction of the sources will be described in detail in a later report. The locations of the model sources were based on information received from EG & G regarding the location of proposed field generator sites. At the present time twenty generators are proposed for future field operations and the twenty corresponding source sites have been installed on the model. Figure 3 shows the location of the sources.

The placement of the topographic model in the environmental wind tunnel consists of locating the fourteen sub-sections properly then sealing all cracks between sections with permanent plastic modeling clay.

The downstream and upstream ends of the model have been extended with transition sections which crudely approximate the terrain upstream and downstream from the principal model. This addition is necessary to provide a gradual vertical transition from the model base down to the wind-tunnel floor.

The next procedure was to adjust the wind tunnel roof so as to assure that the longitudinal pressure gradient along the model was approximately zero. Figure 12 shows the topographic model as presently arranged in the environmental wind tunnel.

Exploratory mean velocity profile and turbulence measurements are being taken at the present time in order to determine the proper upstream boundary conditions for the model. Diffusion experiments will start in October 1970.

2. Field data - Preliminary radiosonde and pilot-balloon data have been supplied by Western Scientific and EG & G. These data will be used to help determine the proper boundary conditions and velocity profiles in the wind tunnel.

V. PROBLEM AREAS AND FUTURE WORK

Similitude Criteria

A number of papers have been written on the subject of similarity between model and field studies. We will not consider the details of the problem in this report but will refer to other references on the subject.

Several investigators such as Bernstein [Ref. 2], Nemoto [Ref. 11], and Cermak and Arya [Ref. 3] have examined the similarity problem. A thorough examination of this problem for the Eagle River Valley-Climax area will be presented by Orgill [Ref. 12].

The San Juan model presents an additional similarity problem since the model topography was distorted by making the vertical scale approximately 1.4 times the horizontal scale. This aspect of similarity will be discussed in future technical reports.

Verification of Laboratory Results

The verification of the model results is based upon comparisons with corresponding parameters measured in the laboratory and in the atmosphere. In the model, velocity profiles, temperature profiles, turbulence data and concentration data from the grounds upwards, as well as other data, can be measured with reasonable expenditure of effort. However, to duplicate the same type of data in the field would be costly and would require special field programs with large expenditures of effort.

Aircraft sampling of the seeding material concentration has provided the best and most direct information for verification of model-prototype similarity. Field work for the coming year will focus on aircraft sampling of vertical distribution of silver-iodide concentrations in the Eagle River Valley-Climax area.

The problem of model-prototype verification is an important step in any complex modeling problem. Close cooperation between the laboratory and field programs under this contract will not only lead to acceptance with confidence of data obtained from the existing models but will enable new situations to be studied in the laboratory for which little field data are available.

VI. PAPERS PRESENTED IN CONNECTION WITH THIS CONTRACT

On April 6, J. E. Cermak and L. O. Grant presented a paper based on measurements by M. M. Orgill at the Second National Conference on Weather Modification, Santa Barbara, California entitled, "Laboratory Simulation of Atmospheric Motion and Dispersion over Complex Topography as Related to Cloud Seeding Operations".

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K. Kitabayashi was responsible for the wind tunnel measurements obtained for the Elk Mountain model. F. Chaudhry and J. Garrison assisted with the laboratory program. L. Hjermstad, D. Adams, S. Snook and Western Scientific, Inc. assisted with the field work and aircraft sampling. G. Wooldridge, Utah State University assisted with the numerical analysis and interpretation of the constant-volume balloon flights.

D. Dirks, University of Wyoming has helped by providing field data for Elk Mountain. Western Scientific and EG and G have assisted by providing information and data for the Wolf Creek Pass-Pagosa Springs area.

W. Tully, J. Dyer, S. Marsh, B. Blinderman, C. Carlson, B. Tamlin, and J. Buckley assisted in constructing the San Juan topographic model.

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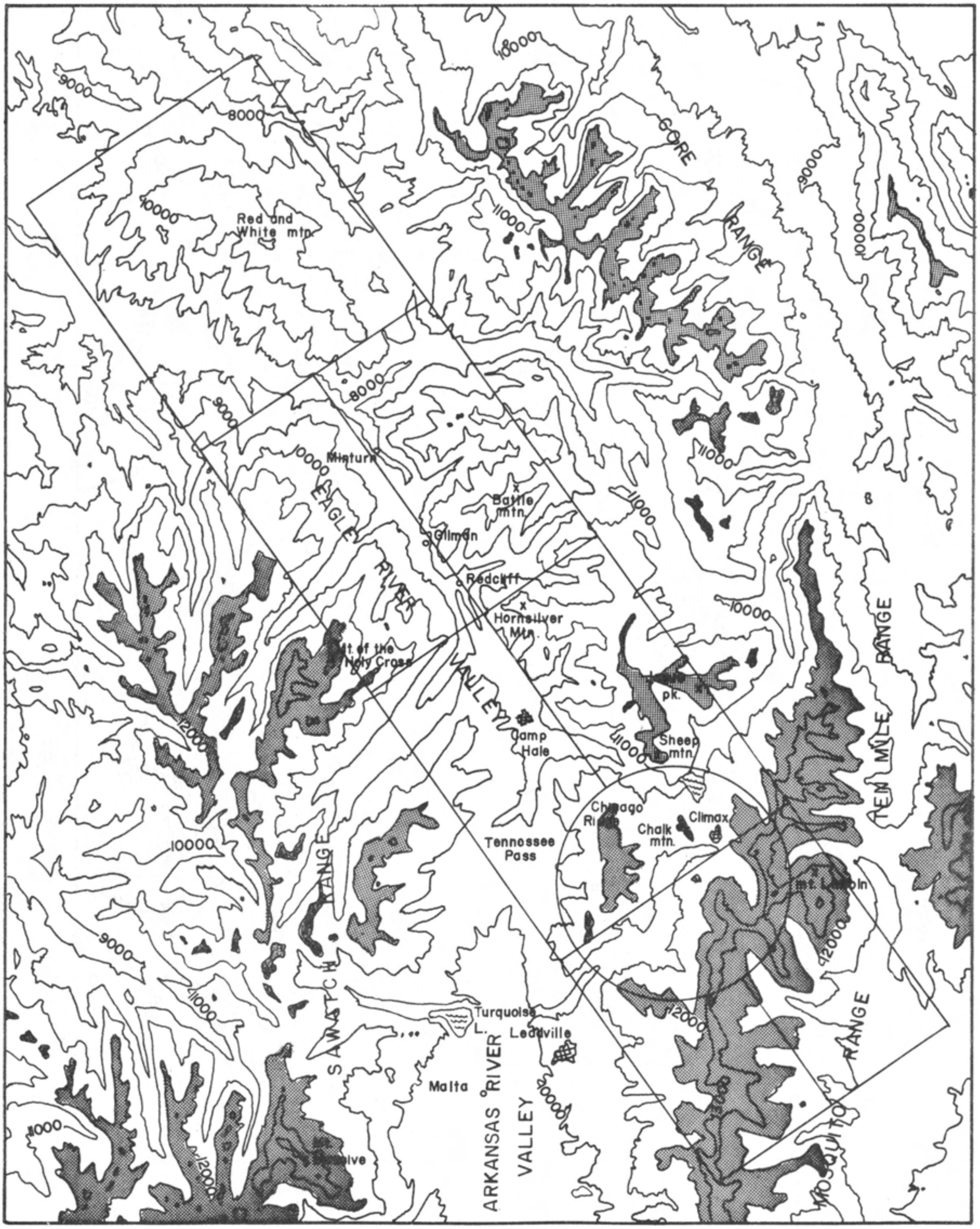

Fig. 1 Eagle River Valley and Climax topography modeled in wind tunnel.

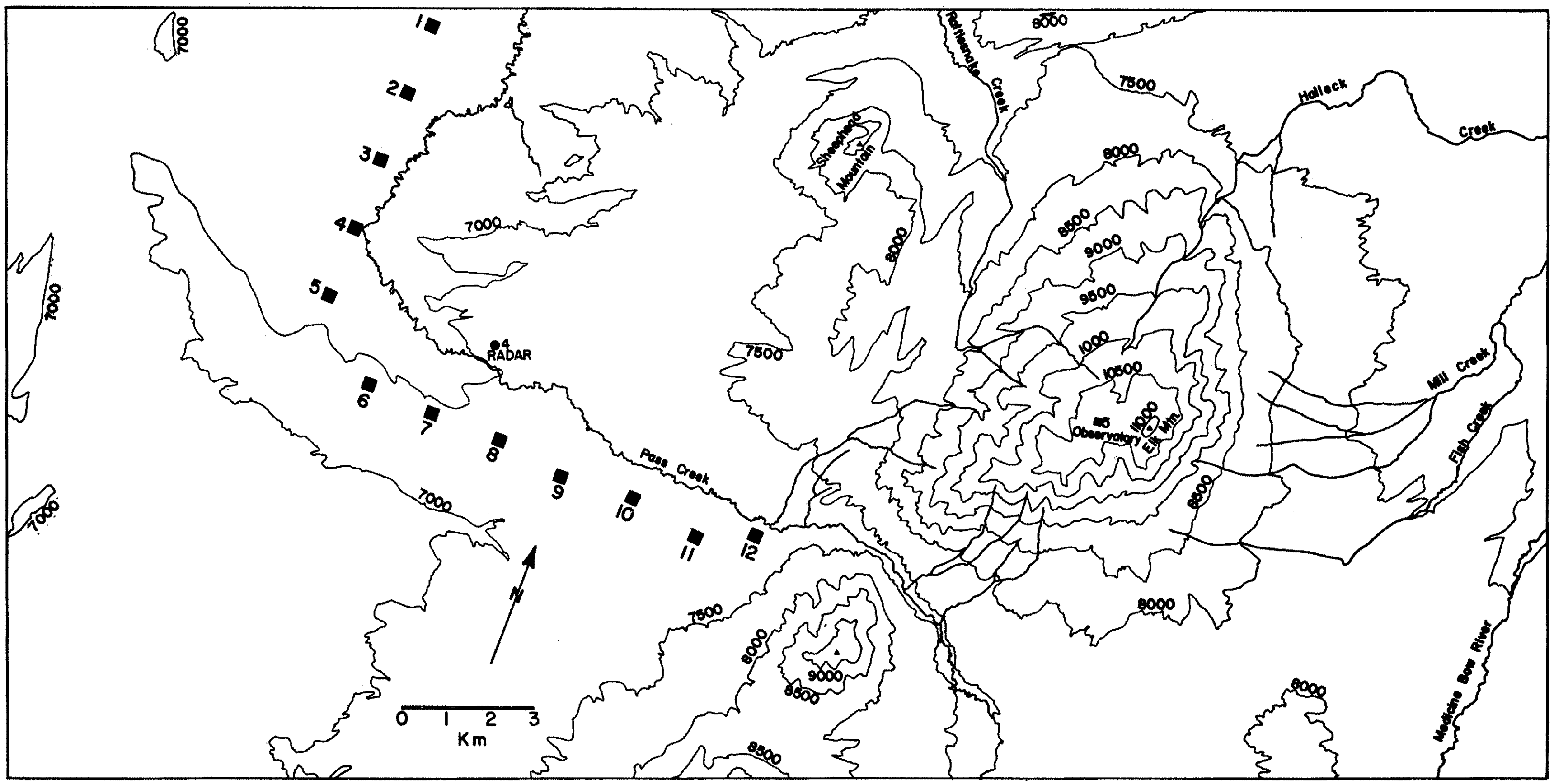

Fig. 2 Elk Mountain and surrounding topography modeled in wind tunnel.

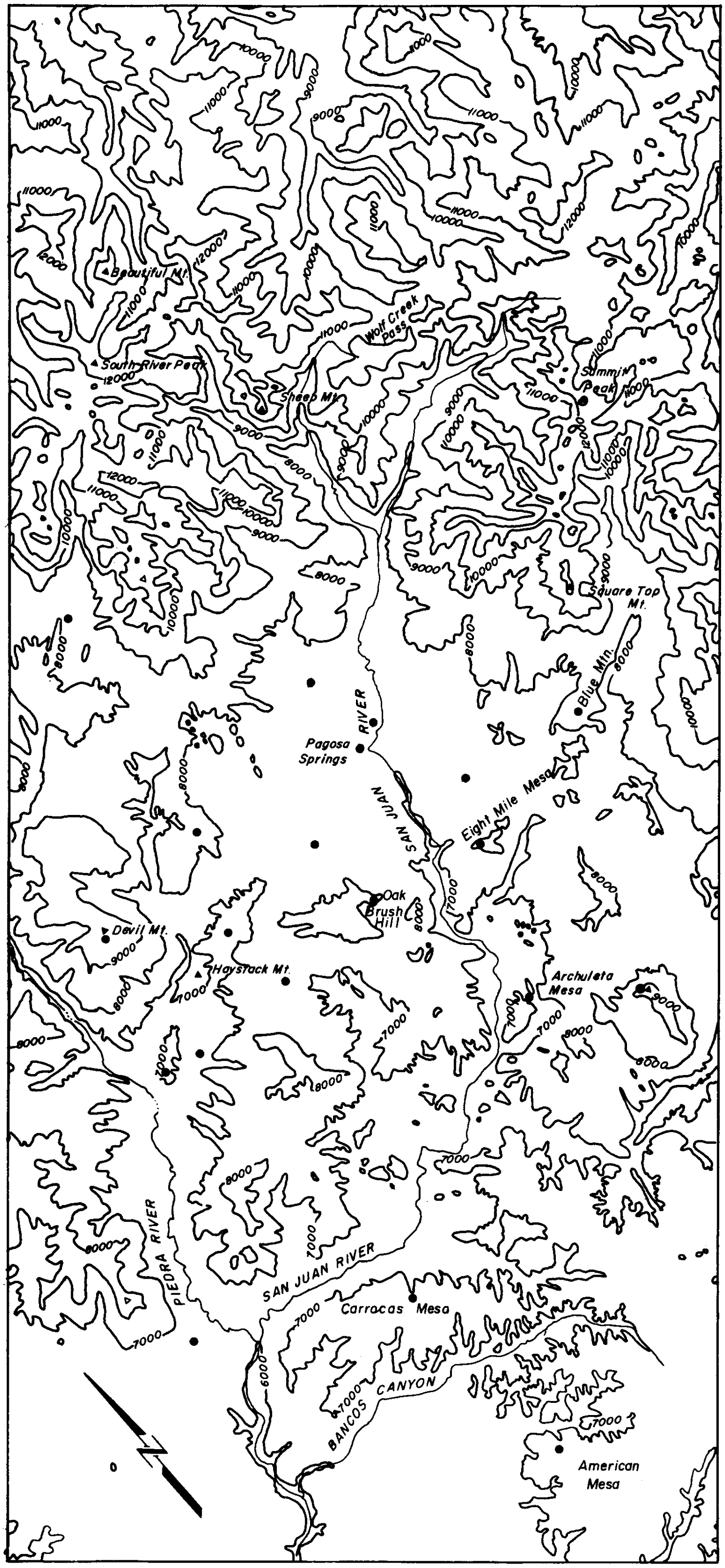

Fig. 3 San Juan River and Wolf Creek Pass area modeled in wind tunnel.

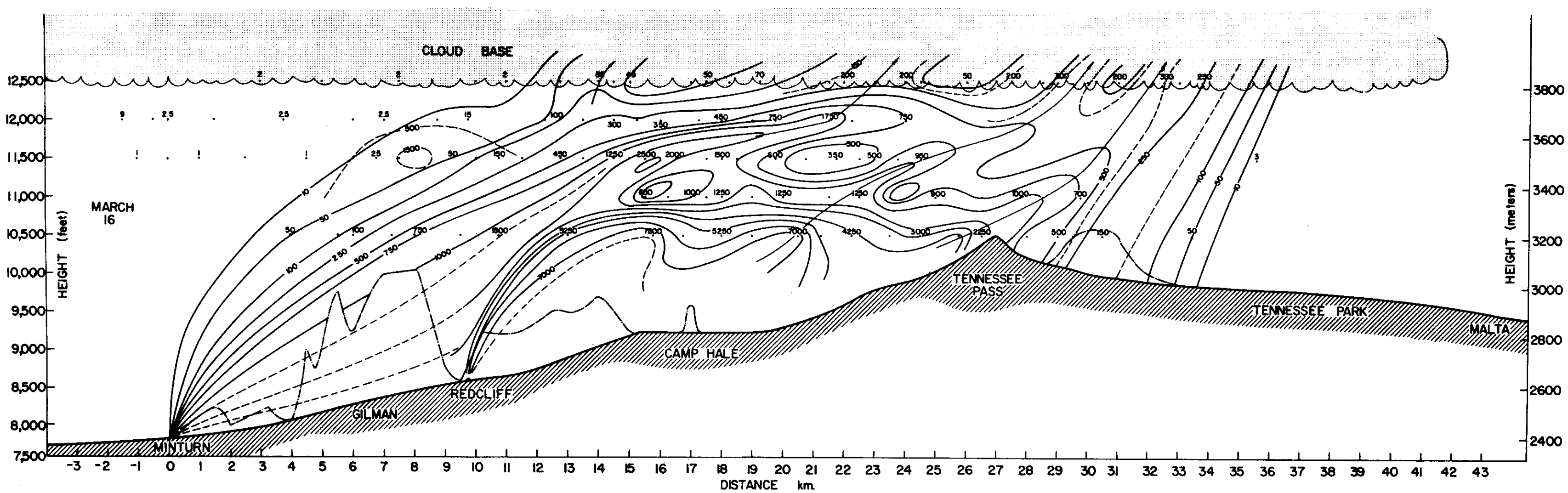

Fig. 4 Cross-sectional view of seeding material concentration (particles/liter) as generated by silver iodide generators at Minturn and Redcliff within the Eagle River Valley during northwest winds.

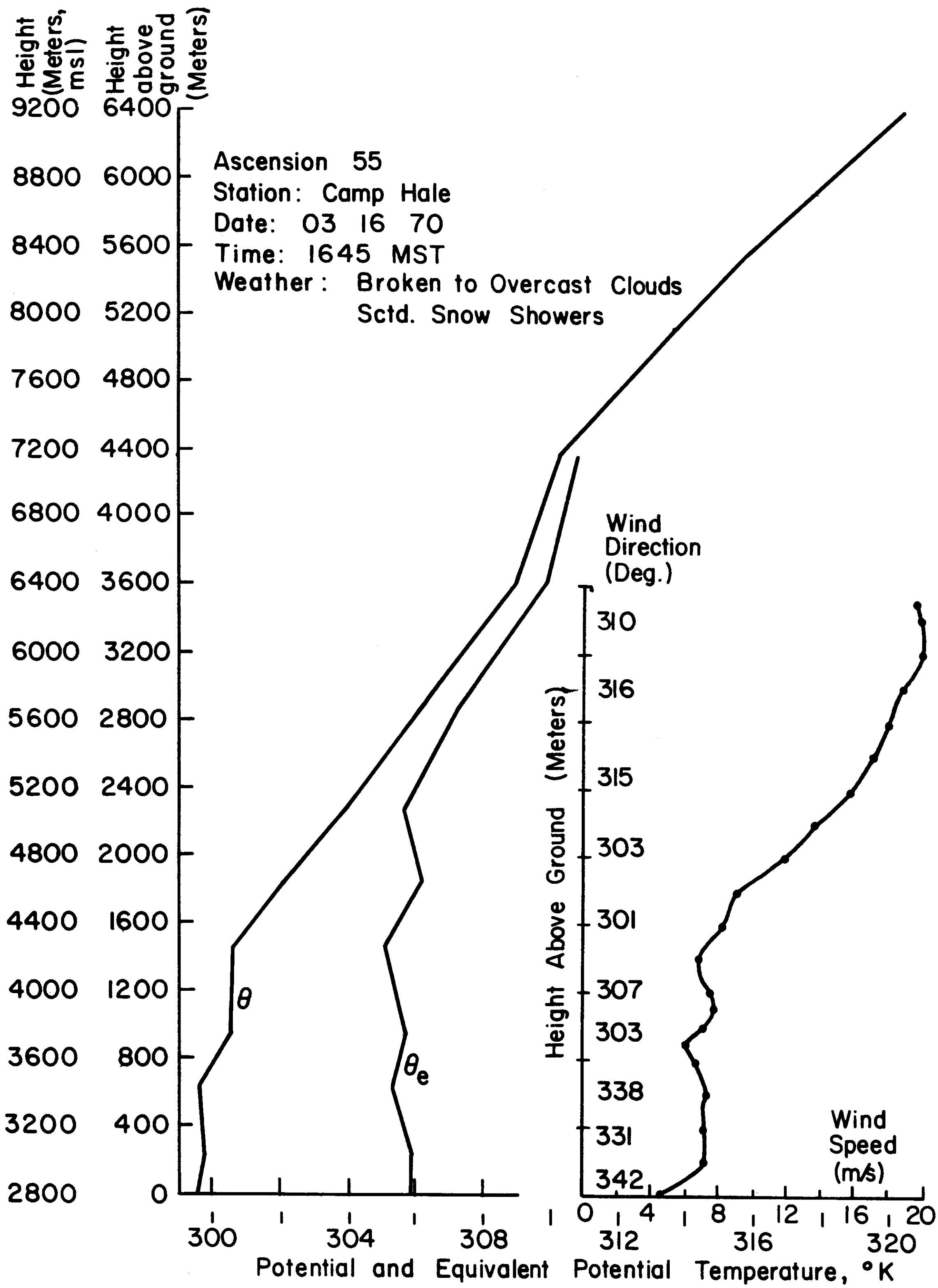

Fig. 5 Vertical temperature and wind variations during the afternoon of March 16, 1970.

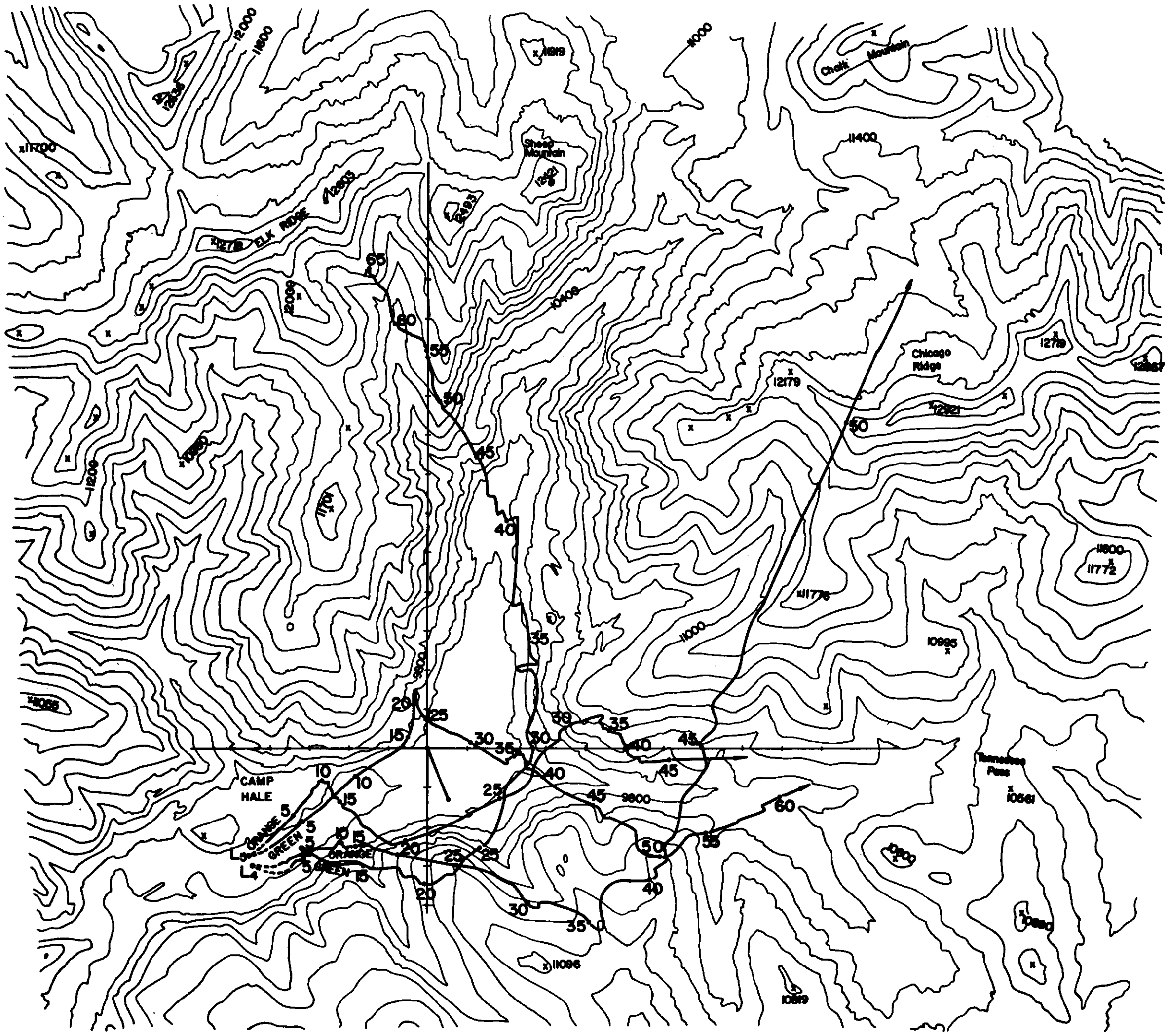

Fig. 6 Dual constant-volume balloon trajectories obtained on December 12, 1969.

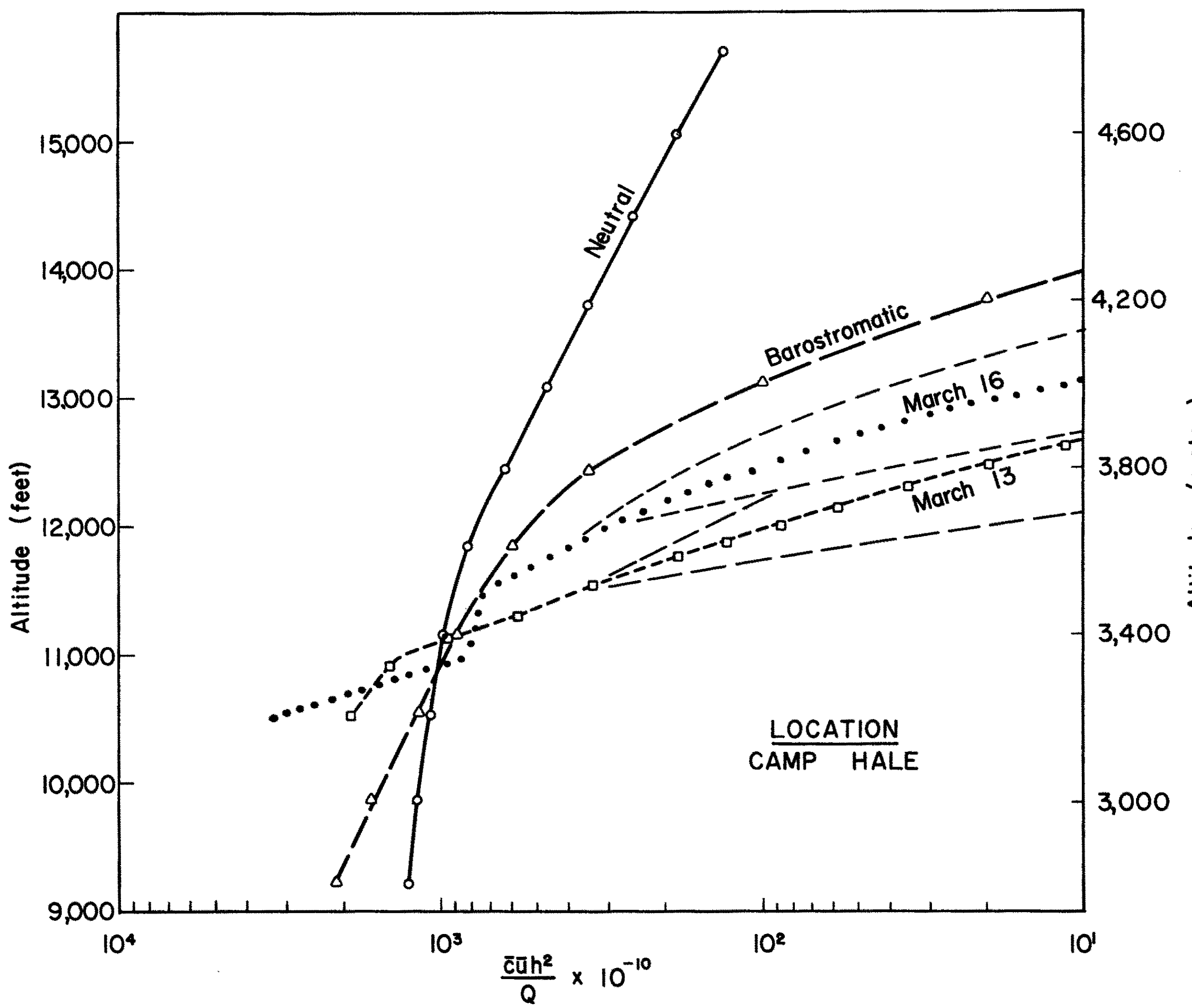

Fig. 7 Comparison between dimensionless concentration parameter $\overline{C}\ \overline{U}\ h^2/Q$ for the field and model versus height.

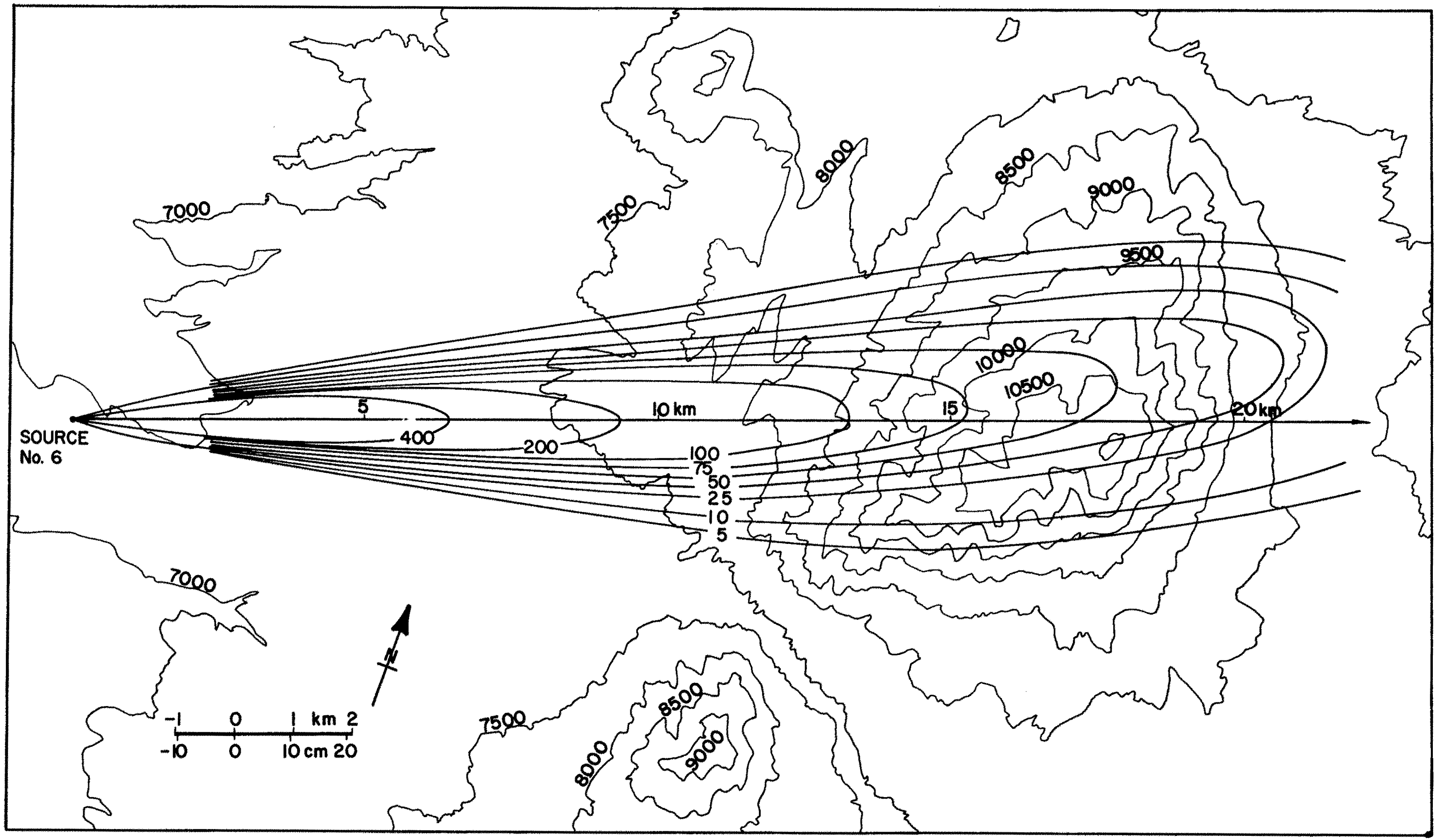

Fig. 8 Surface distribution of $\overline{C}\,\overline{U}\,X^2/Q$ over the Elk Mountain model. X is a horizontal length scale.

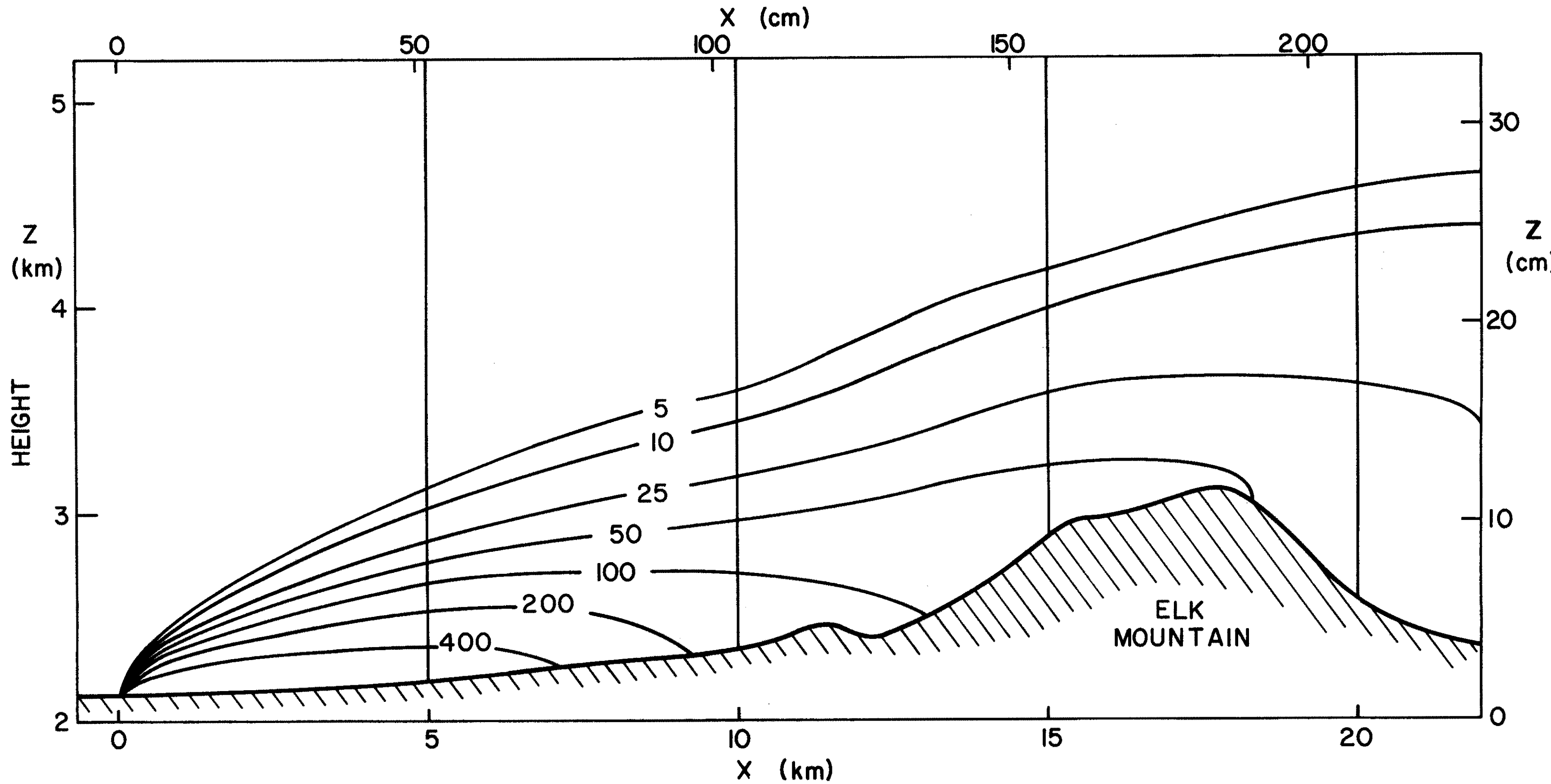

Fig. 9 Vertical cross-section of $\overline{C}\,\overline{U}\,X^2/Q$ along the horizontal axis of the maximum concentrations.

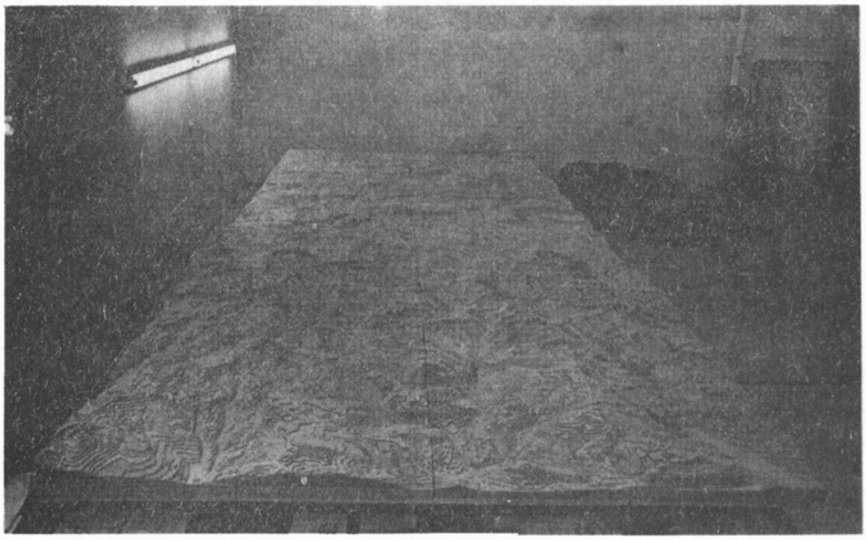

Fig. 10 San Juan topographic model before completion.

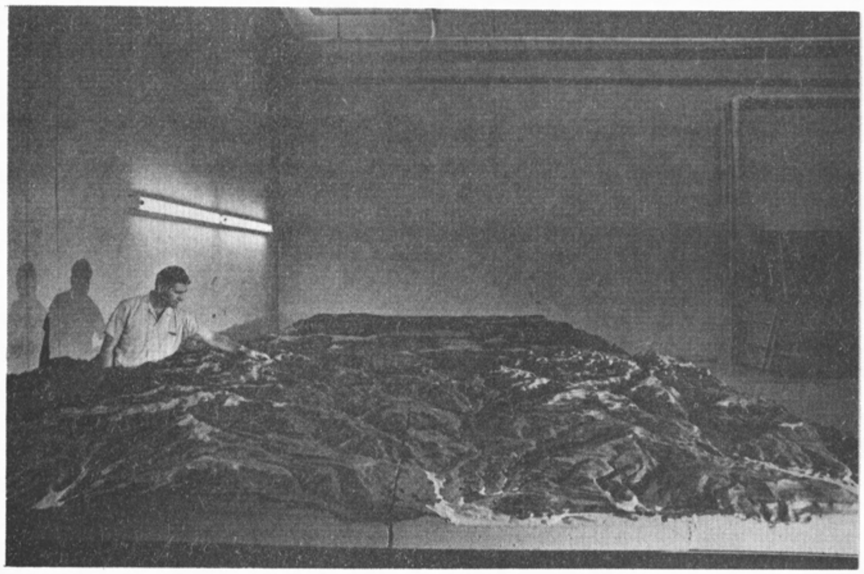

Fig. 11 San Juan topographic model in final construction phase.

Fig. 12 San Juan topographic model as presently arranged in the Colorado State University environmental wind tunnel.