State of Washington
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CASCADES ATMOSPHERIC WATER RESOURCES PROGRAM

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INTRODUCTION

Overall Purpose

The overall purpose of the State of Washington, Department of Water Resources, Cascade Atmospheric Water Resource Program is to research the feasibility for developing a dependable technique to intervene upon the micro and meso-physical components of precipitating systems in order to accomplish a beneficial redistribution of precipitation across the Cascade Mountains.

It is believed that the predominant growth mechanism for the development of precipitation from winter storms over the Cascades is the collection of supercooled droplets by ice crystals (i.e., riming). Therefore, it should be possible to reduce the rate of growth of precipitation particles due to riming by seeding these storms with artificial ice nuclei. If growth by riming can be inhibited, some of the precipitation which, under natural conditions, falls on the West side of the Cascade Divide would be artifically diverted to the drier Eastern slopes.

Work Performed

Pursuant to the above stated overall purpose the FY 1969 activities were primarily directed toward a more thorough understanding of the natural mechanisms that produce precipitation over the Cascade Mountains during the winter.

In order to realize this immediate objective, a program was initiated to examine in detail the vertical structure of the lower atmosphere when winter storms were occurring over the Cascade Mountains.

The components of this program were:

(i) Two 3 CM radars, - one located on the east side, the other on the west side of the Cascade crest - were operated to obtain information on the structure of precipitating clouds and hopefully to provide preliminary data on the trajectories of precipitated particles. Both radars were operated continually from December 1 through March 31.

(ii) During the same period rawinsondes were released from the above mentioned radar sites at three or six hour intervals during storm periods. These soundings provided information of the vertical structure of the storms and of the way in which storms are modified as they move across the Cascades.

(iii) An instrumented Queenaire plane was based at Moses Lake in the Columbia Basin - well to the east of the Cascades from February 1 through March 6. Fourteen flights, totaling forty-six hours, were conducted in attempts to obtain measurements in the storms that occurred over the Cascades during the period.

These flights provided information on the microstructure of storms including cloud particle types, sizes and concentrations, liquid water content and ice nuclei concentrations.

(iv) Ground observations were made of the spatial and temporal distribution of precipitation using a dense network of sensors. In addition, the size and structure of precipitated solids were investigated in more detail at Snoqualmie Pass using an automatic photographic technique.

(v) Throughout the winter months continual measurements of concentrations of natural ice nuclei in the air were observed with the aid of a NCAR counter at Quillayute on the Pacific Coast, in Seattle and at Stampede Pass, on the Cascade Crest. Moreover, measurements were made of the concentrations of natural ice nuclei in precipitation at Snoqualmie Pass using a "drop freezing" technique.

(vi) A theoretical model is being developed to describe the growth and fallout of precipitation from the relatively warm, moist winter storms that frequent the Pacific Northwest. This includes a study of the airflow over a large mountain barrier, the development of clouds within the airmass, and the microphysics associated with the growth and development of precipitation in the clouds. The purpose of this model is (a) to predict the distribution of precipitation over the Cascade Mountains under natural conditions, (b) to delineate the conditions where artificial seeding in storms should be most effective.

(vii) Detailed measurements have been made of the concentrations of cloud condensation nuclei from industrial sources in Washington. The effects of these particles on clouds and precipitation have also been investigated.

(viii) During the course of the FY 1969 a number of new instruments for weather modification research underwent further development. These include an automatic cloud condensation nucleus counter, an electrical counter for measuring the concentration and size of sodium containing particles in the air, two devices for determining the concentration of cloud particles (ice and water), and a cloud droplet spectrometer. In addition, a device for automatically photographing precipitation particles was constructed and operated throughout the winter at Snoqualmie Pass.

(ix) Historical records of monthly precipitation data having continuous records during the period 1929 through

1966 have been prepared for computer analysis for one hundred and ninety stations in Washington, Oregon, Idaho and British Columbia. Similarily, records of water year runoff for fifty-nine streamgages have been assembled. All data are being analyzed in a manner directed toward accounting for the explicable portion of the areal and temporal variability.

Particular attention is being devoted to the distribution of precipitation across the Cascades and over the inter-mountain plateau.

Results

The data obtained from all the projects listed above have been reduced and are now in the process of being analyzed. At the present time the following tentative conclusions can be drawn:

(i) Radar observations at the Enumclaw site, near the western foothills of the Cascades, showed that precipitation did not occur at Enumclaw unless the "radar cloud tops" were above 10,000 feet. Moreover, that portion of the clouds that extended above 16,000 feet (mean temperature of clouds at this altitude was -23°C) appeared on radar to consist mainly of ice. It was observed that over the Cascades precipitation could develop in rather thin layered clouds which did not extend above about 15,000 feet.

It was not found possible to obtain quantitative information on precipitation particle trajectories with the use of the radar which was available.

(ii) With the aircraft used in FY 1969 (Queenaire A-80), it was found to be advantageous to fly into approaching storms from the east side of the Cascades. A total of fourteen flights were made during the two month period in which ten yielded information on the microstructure of clouds.

Natural ice nucleus counts aloft at -21°C were found to be so low (generally less than one per 300 liters) that usually none were recorded during the flights. However, particles collected in the clouds showed that appreciable concentrations of ice were present even at temperatures as warm as -5C. In many cases the ice crystals were irregular in shape and showed evidence of riming.

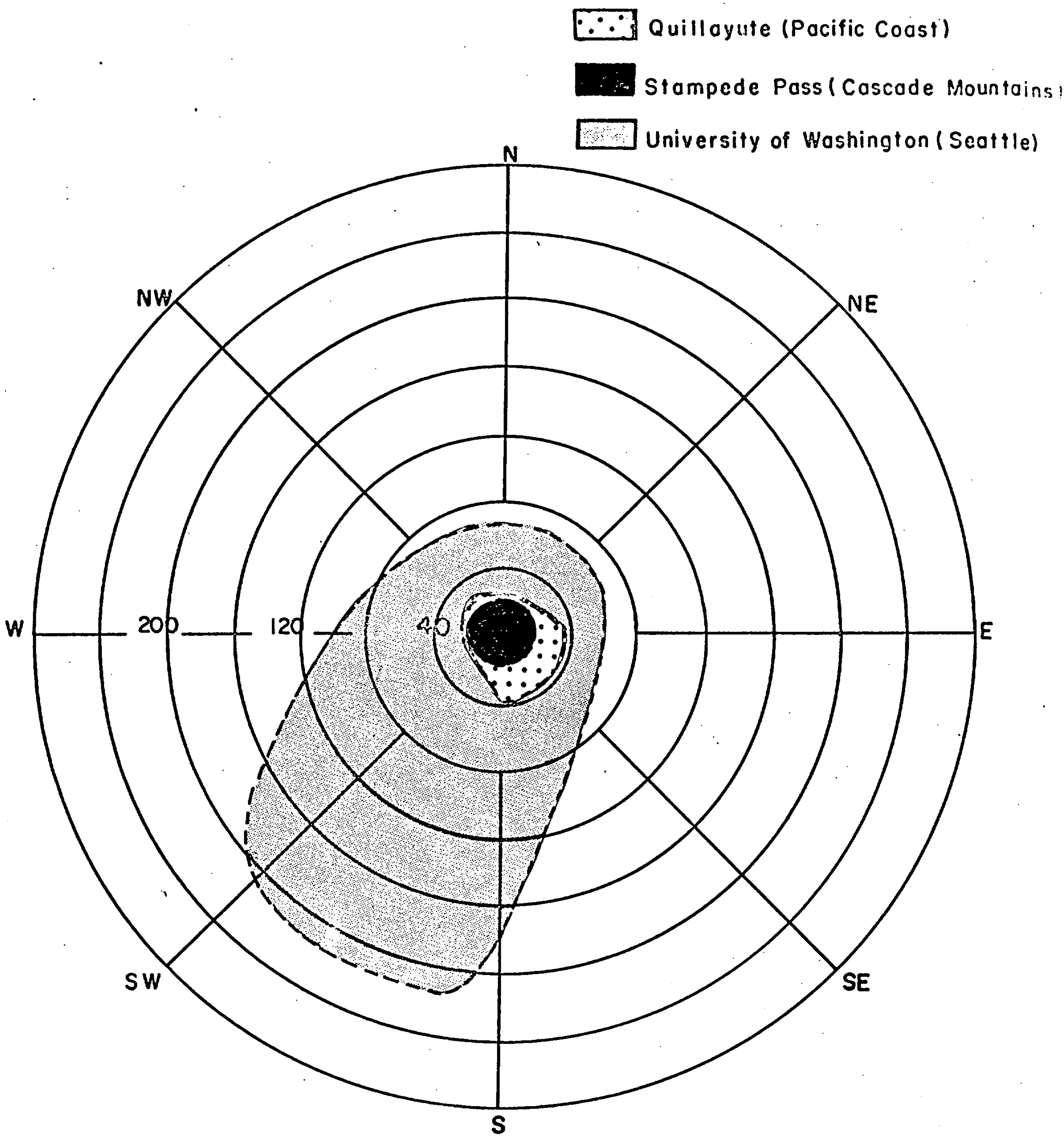
The new electrical cloud particle counter under development in this program functioned successfully during many flights.

The main limitations in the airborne measurement program was the lack of sufficient operational range in the aircraft. This deficiency severly restricted the necessary margin of safety by precluding a reasonable alternate landing capability. In addition, on several occasions turbulence and aircraft icing forced the plane to return to the base before the flight plan was completed.

(iii) Ground observations at Snoqualmie Pass indicated that simultaneous measurements with the optical snow rate sensor and a weighing bucket precipitation gage could be used to determine the average mass of precipitated particles. The intensity of precipitation was found to be related more to the mean mass than to the number density.

Snow crystals were observed to be rimed to some degree in all storms and in many cases very heavy riming occurred. There appeared to be a direct relationship between the extent of riming and the intensity of precipitation.

(iv) During the winter of 1968-69 the concentrations of ice nuclei active at -21°C were measured continuously at Stampede Pass (Cascade Mountains), University of Washington (Seattle) and Quillayute (Olympic Peninsula). A summary of the results of these measurements is shown in Fig. 1, from which the following facts emerge:



Quillayute (Pacific Coast)
Stampede Pass (Cascade Mountains)
University of Washington (Seattle)
N
NW
NE
W
200
120
40
E
SW
SE
S

Figure 1

1. The average concentrations of ice nuclei (active at -21°C) are much greater at the University of Washington than at the other two (non-city) sites. In particular, when the winds were such as to bring air to the University of Washington from the downtown and south Seattle industrial area (i.e. winds from S through SW to W), the ice nucleus counts were much higher than for other wind directions. These results demonstrate that ice nuclei from anthrophomorphic sources are significant in Seattle.

2. The ice nucleus counts at Quillayute show that with winds from the continent the ice nucleus counts are much greater than with winds from the Pacific Ocean.

3. The ice nucleus counts at Stampede Pass are much smaller than those at either the University of Washington or Quillayute, and the counts are approximately the same for all wind directions.

4. The effects of snyoptic and local weather conditions on ice nucleus counts were also investigated. Arctic air masses which were unmodified by local conditions appeared to give low ice nucleus counts. In snow and fog the counts were about one-third

those in clear air. In some cases the ice nucleus count increased sharply in rain showers and also when fogs dissipated.

(v) Simultaneous measurements of the number of ice nuclei per gram of precipitation and the average mass per precipitation particle made at Snoqualmie Pass revealed the presence of many more ice particles than ice nuclei. At estimated cloud top temperatures of -8°C there were 3,000 more ice crystals than ice nuclei. But at estimated cloud top temperatures of -24°C this same ratio was unity.

This result demonstrates that the concentration of ice particles in the Cascades is not simply determined by the concentration of ice nuclei.

(vi) A detailed theoretical model of airflow over the Cascades has been developed. This model allows consideration of dry airflow, most airflow or a montage of cloudy and dry air. It also includes the release of latent heat. First steps have been taken to include, in a parameterized form, the growth and fallout of precipitation.

(vii) The study of precipitation and streamflow data shows highly significant change in the hydroclimatological regime over the Pacific Northwest that occurred around the year 1946. Water year precipitation means increased as much as 30% in some areas during 1947-1966 over the 1929-1946 period, although a general increase in sample means of around 5 to 10% occurred over most of the region. The significant increases born out by both precipitation and runoff occurred mostly at the high elevations, however, a few anomolous areas in the lowlands appear to be directly associated with industrial sources of highly efficient cloud condensation nuclei.

Analyses now underway give strong indications that although the increase in precipitation seems to have occurred in the winter months, the resultant increase in streamflow is exhibited in summer runoff.

Analyses of the data collected in FY 1969 is continuing and a more detailed discussion of the results will be given in the final report.

Future objectives

Further detailed investigations are planned, both from the air and on the ground, to determine the principle mechanism by which precipitation develops during the winter over the Cascade Mountains within natural and artifically seeded storms.

In the case of unseeded precipitation events the role of ice nuclei in forming precipitation particles must be determined more precisely and the spatiel distribution of liquid water in typical storm situations must be determined.

The radar facilities on the ground must be developed to a point where they are capable of obtaining quantitative information on the trajectories of precipitated particles. This information would provide the opportunity for directly checking the effects of artificial seeding and the predictions of the theoretical model.

The effect of artificial seeding on both the microstructure of the clouds and the distribution of precipitation on the ground must be investigated. In particular, the quantity and positioning of artificial nuclei required to produce the maximum diversion of precipitation to the eastern slopes of the Cascades must be determined.

The theoretical model must be developed to the point where it can be used to predict the optimum conditions for cloud seeding and as a diagnostic tool for analyzing the results.

Problem areas

In order to achieve the above objectives the following specific problems must be overcome.

(i) The project must acquire, or have access to, an airplane suitable for penetrating the deeply supercooled water clouds which characterize the Cascade winter storms. This plane should have the capability to fly in clouds at altitudes to at least 20,000 feet, carrying a load of 3,000 pounds plus a crew of four, and have a range of 2,000 miles or more. Further, the plane should have adequate power and durable structure to cope with the violent weather conditions that are commonly experienced within winter storms over the Cascades. Also, the plane must be highly instrumented for taking in-cloud measurements (including radar) and equipped for dispensing pyrotechnic seeding materials. The plane must be exclusively available to the project throughout the six winter months operational period (October through April). Ideally, it would be desirable to have a second plane solely for the purpose of carrying out the seeding operation. The previously mentioned instrumented aircraft would thereby be relieved of this task for a more thorough surveillance of the downwind effect of the seeding.

(ii) In order to obtain qualitative information on trajectories of precipitation particles under natural and seeded conditions, Doppler radar will probably be required.

In principle, a complete three dimensional picture of the distribution and fallout of precipitation can be obtained by the use of three Dopplers radars. This, of course, would constitute the maximum utilization of this instrument for our purposes.

(iii) Ground observations and operations during the winter in the Cascade Mountains are severely restricted by the extremely rugged nature of the terrain. These restrictions can be mitigated by the use of telemetering equipment and long term automatic instrumentation.

Reports Published and Papers Presented

"Ice Nuclei From Natural Forest Fires" by P. V. Hobbs and J. D. Locatelli. (Accepted for publication in J. Applied Met.)

"Simultaneous Measurements of Cloud Condensation Nuclei and Sodium-Containing Particles in the Atmosphere" by L. F. Radke. (Accepted for presentation at the 7th International Conference on Condensation and Ice Nuclei, Prague, 1969)

"Ice Nucleus Measurements at Three Sites in Western Washington" by P. V. Hobbs and J. D. Locatelli. (Submitted to J. Atmos. Sci.)

"Cloud Condensation Nuclei from Industrial Source and their Apparent Influence on Precipitation in Washington State" by P. V. Hobbs, L. F. Radke and S. E. Shumway. (Submitted to J. Atmos. Sci.)

Comments on "Ice Multiplication in Clouds" by D. A. Burrows and C. E. Robertson. (Accepted for publication in J. Atmos. Sci.)

"Further Comments on Ice Multiplication in Clouds" by P. V. Hobbs. (Accepted for publication in J.Atmos.Sci.)