美國對天水的利用

Project Skywater in United States

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中 文 摘 要

據統計世界上的水量十分充沛，足够供給全部人類應用。其所以缺水之原因大致可分爲三種：分佈不均，取水不便及水質不良，自有史以來，人類即爲缺水而奮鬪不懈，對於水文循環中之每一因子歷來均曾深加研究，諸如築壩以儲逕流，佈藥以減蒸發，芟草以損蒸散等等，均以增加可利用之水源爲目標。近五年來美國政府鑒於許多地區地下水及地面水之不足，乃又動念於天空之水源，由美國墾務局領導研究與規劃，如何使天水下降成爲適效及時之有用水源，作者今暑在美國參與教授講習會中，對此印象殊深，且覺饒有興趣，趁此大會機會，爰特介紹彼邦對於天水利用方面之進展情形與諸位。

The United States Bureau of Reclamation began development of its program of atmospheric water resources research late in 1961 with a little fund of US$ 100,000 and only 3 contractors. The program was generally called Project Skywater, a precipitation management program concerned with altering the precipition processes. the project was expanded to 26 contractors and the fund was increased to US$ 3,750,000 at FY 1967. The direction and overall planning for Project Skywater comes from the Office of Atmospheric Water Resources (OAWR) in the Bureau's Denver Center. Outside contractors account for about 90 percent of the program, most of them are universities and individual research centers and lawyers.

Experimentation is the heart of project. The activities eneompass six areas: experimental seeding, air mass characteristics, cloud characteristics, seeding agent characteristics, agent delivery ang side effects.

Experimental Seeding

Experimental seeding programs employ current techniques and equipments to specify existing capabilitjes and to find out what needs to be done to increase the effects and evaluate the results properly. It also helps to define logistical factors and generally points the way to the operational use of precipitation management techniques. University of Nevada has been conducting a long-term winter project requiring 75 seeding trials of proper evaluation. Analysis of the data has not been completed. A new seeding program, also using ground-based silver iodide generators, was established in western Montana in FY 1967. The program depends on streamflow and snow course data to evaluate results. As a rough conclusion, seeding on days with positive vorticity advection and northwasterly flow produced decreased precipitation while seeding on days without positive vorticity advection and with southwesterly flow produced increased rainfall. Vorticity is related to the upward movement of air. However, there were not enough cases to provide statistically significant results.

Air Mass Characteristics

The bulk of experimentation is directed at studying specific facets of the precipitation management problem. A climatological study of an area discloses the weather patterns associated with natural precipitation. The temperature and moisture profiles give further information about when and where cloud treatment is likely to be effective. The natural condensation nuclei and ice nuclei concentrations are reference points in determining the amount of treatment material to add to the clouds. Precipitation data were stratified by upper air wind and temperature and analyzed in a trans-sky diversion program. The analysis showed (1) no clear cut relationship between precipitation pattern and wind direction was evident, (2) the ratio of precipitation on the two sides of a ridge was low for periods of light precipitation, and (3) about 80% of the seasonal precipitation fell when the 700-millibar (10,000 feet) temperature was −10°C or higher and the heaviest rates occured at −4°C to −8°C. Montana State University studied the natural precipitation characteristics of the central Montana and found (1) moist Pacific air overrunning a cold surface layer retreating northeastward; this is frequently associated with an advancing cold front, (2) maritime polar air, gen erally from teh west, overrunning a stationary front, caused by an outbreak of very cold airfrom the north, (3) influx of moist Pacifice air into the area, often accompanied by a surface cold front, in the absence of cold artic air at the surface; in this case a combination of orographic and dynamic lifting is involved.

Studies of the natural concentration of condensation and ice nuclei are not yet on a systematic nationwide basis. A number of contractors make nuclei counts quasi-routinely. Natural counts reach a maximum during the early afternoon and are typically about four nuclei per liter, taken at −20°C.

Cloud Characteristics

One of the major factors being studied is the stimulation of buoyancy due to the release of latent heat when artificial nuclei, i. e., seeding material, convert portions of a supercooled cloud to ice. Results from FY 1967 studies indicated that local cloud temperature increases can be 1° or 2°C which will often double the local cloud buoyancy. The resulting vertical accelerations should significantly alter the cloud evolution. A computer was used daily, in connection with Meteorology Researc Inc.'s summer cumulus field program, to run models of convection cell dynamics for the environmental sounding obtained each morning. The results of the single cell model were used to tailor the field operations to make best use of the natural conditions. The computer output indicated which size clouds would be most sensitive to seeding. The compurer predictions were compared with actual cloud observations, permitting empirical improvement of the model. Numerical models of cumulus clouds over a ridge were put into a computer. One model allows airflow down to the surface of the valley on either side of the ridge, and simulates a mountain wave quite well. A shear in the wind field permits clouds to form sooner than they would with no wind, but the growth of small clouds is inhibited. The model is being extended to include the effects of unequal heating on the two sides of the ridge, and the precipitation process is being introduced. No firm conclusion can be drawn yet, but the shady-slope model suggests that clouds form earlier when the shady slope is on the downwind side the ridge. In another study of cumulus clouds, South Dakota School of Mines and Technology photographically documented the changes in appearance of seeded clouds. Seeding with dry ice was followed by pronounced glaciation in the upper parts of the cloud in almost every case. Unseeded clouds rarely showed glaciation. Some clouds seeded with salt produced showers for up to 30 minutes before glaciation was evident at cloud top. A third summer study, Fresno State College Foundation's Sierra Cumulus Project, examined the behavior of pairs of clouds, one seeded with dry ice and one not. Analysis of the data indicated that (1) the precipitation mechanism was artificially triggered when cloud-top temperatures were as warm as −1°C, (2) precipitation reached the ground when the seeded cloud was only 6000 feet thick and (3) the higher the cloud base temperature, the better the chance of precipitation reaching the ground, provided the cloud top extends above the freezing level. A winter orogaphic study in Colorado found several cloud characteristics that seem to determine seedability. Seeding effects from silver iodide are indicated most often when (1) the moist layer is thin (less than 5000 ft thick), (2) the top of the layer is −20°C or warmer and (3) the temperature in the target area is −10°C or lower.

The University of Nevada is using the wave clouds that form over the valley immediately east of the Sierra Nevada as a natural outdoor laboratory. Studies are being made of coagulation of ice crystals and the formation and growth of cloud droplets and ice crystals in natural and seeded supercooled clouds. The studies require the use of two instrumented aircrafts and a sophisticated radar system for positioning the aircraft in the appropriate portion of the cloud. An air preparation box and a cloud chamber were used in combination with X-rays in a standard diffractimeter at South Dakota School of Mines and Technology to delineate the water vapor sublimation threshold at −65°C. A combination of photocells and X-ray diffraction permitted the determination of the settling rates of ice particles in clouds at low temperatures. Other projects under study involve condensation and sublimation phenomena in the temperature range 0° to −40°C and measurements of elastic moduli for silver iodide. These studies are too new to have produced results from which sound conclusions can be made.

Seeding Agsnt Characteristics

Thls project is interested in new and better treatment materials as well as understanding the behavior of the primary seeding agents. Major emphasis was placed on silver iodide.

T. G. Owe Berg Inc. is studying the behavior of silver iodide in several environments. Tests were conducted in a small cold chamber and with single water drops and single silver iodide particles suspended in anonuniform Ac field at various temperatures down to −23C and at various relative humidities. The results of the study suggested the following conclusions. There is no harmful interaction of silver iodide with its environment at the cloud base. Uncharged silver iodide particles do not interact with cloud droplets and the interaction with the water vapor does not impair the effectiveness of the silver iodide as a seeding agent. In general, the interaction between charged silver iodide and water vapor is harmless. However, when charges on the silver iodide and the cloud droplets are large, interaction between particles and droplets may occur and may then impair the effectiveness of the silver iodide as a seeding agent. Other works took place at Meteorology Research Inc. and in South Dakota. MRI made a study of the nucleating characteristics of two organic chemicals, metaldehyde and 1,5-dihydroxynaphthalene. Neither is subject to photolytic decay, as some researchers have observed with silver iodide, and high particle concentration can be produced from both by heating and condensation. While these organics look promising, considerable work is required before they will be ready for operational use. A South Dakota study revealed that the newly found Phase IV of silver iodide is probably metastable and would not occur in the quenched products of silver iodide generators.

Agent Delivery

Some of the meteorological and logistical problems of agent delivery can be seen in the results of the Washington State Program. It indicated that material released from valley sites had little likelihood of reaching the effective level in the clouds. Further studies used airborne dispensers that could be positioned at the effective level. However, the icing conditions associated with seedable storms in the Cascades cause dangerous flying condition, aerial seeding was considered unfeasible. Additional analysis of both the terrain and the stability conditions indicated that placing generators on peaks that extend up through or near the usual cloud base would allow the nuclei to reach the effective level. The three-dimensional airflow can be determined by tracking, with a specially modified radar, chaff dropped from an aircraft.

The experimenter must face the question of the real effect of the seeding material on the precipitation process. The answer can be approached by analyzing the precipitation for traces of the seeding material. This does not prove that the material took part in the process, but it does show whether or not the material is present. The University of Nevade developed a procedure that uses neutron activation. The silver is first removed from a precipitation sample ion exchange. The material is then placed in a nuclear reactor where a radioactive isotope of silver is produced. The gamma rays emitted are counted and related to the mass of silver. Under favorable circumstances a mass of about one-billionth of a gram can be determined. Chemists at Utah State University are evaluating the use of atomic absorption spectrometry in silver detection. A slightly modified atomic absorption spectrometer equipped with a digital readout is being tested in the laboratory, and concentrations as low as 10^{-15} gram per milliliter have been detected. Colorimetric techniques are also being investigated but nothing conclusive was found in 1967.

Side Effects

The obvious goal of cloud seeding is an increase in precipitation over some specified target area. However, it is possible that activities in one area may have an effect elsewhere. Aerometric scientists are analyzing the spatial distribution of existing precipitation data in extended regions in, around, and downwind from a number of long-term cloud seeding programs in the western states. The program proceeded in four steps. The first step was to determine the areas and dates of cloud seeding activity to avoid confusion of the precipitation patterns by other seeding programs downwind from the long-term projects being studied. The second step was to select the appropriate long-term projects. Three were chosen, one in the Rogue River drainage basin of southwestern Oregon (9 years of operation), one in the Coeur d'Alene Lake watershed in northern Idaho (9 years), and one in the Southern Sierras of California (17 years). The third step was to select comparable storm periods during the seeded and unseeded years. Seeded/unseeded precipitation ratios were computed, plotted on base maps, and analyzed to detect patterns of high and low values. The fourth step was to stratify both seeded and unseeded storms by various meteorological variables.

The precipitati on patterns sometimes had certain similarities with the "hydraulic jump" and "wake" phenomena observed when the flow of a stream of water is obstructed by a rock. The rock in this case was the target area, and the jump line and wake were areas of increased precipitation. With this analogy in mind, we may stratify the storms in terms of an aerodynamic index number which might be called a "meteorological Mach number".

The author, at this time, would like to suggest the following eleven research topics for universities and research units:

(1) What are the atmospheric conditions best suited to artificial nucleation?
(2) How does silver iodide behave inside a real cloud?
(3) How much treatment material is need?
(4) Where should treatment material be placed in cloud and how should it be released?
(5) How does a seeding agent really work?
(6) How do we measure the important variables?
(7) What are the natural nuclei concentrations?
(8) What really comes out of the various nuclei generators?
(9) How can we tell what the real effect of seeding is?
(10) What are the meteorological side effects?
(11) What are the implications of precipitation management? This includes legal, social, biological, economical, hydrological and pollution problems.

The science of artificial precipitation is yet a new budding branch of knowledge, combined with physics, chemistry, agriculture, engineering eonomics and laws. This should be a very promising study and a very important contribution to human life.