HOW MUCH WEATHER CONTROL?

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Not "Can man control his weather?" but rather "How much can man control his weather?" is the subject of this essay. After a summary of the extent to which man already controls his immediate environment, the possibility and desirability of controls on a much larger scale will be discussed.

SUCCESSES

Man already controls his weather to a much greater extent than many of us realize. In three ways he has learned to modify the weather very appreciably: by his clothing, by his structures, and by artificial lighting of various kinds.

Clothing, of course, is a very efficient control of the weather over most of the body. Its primary function is to reduce the rate at which heat is lost by the body. Each of us produces heat, a minimum of 1500 large calories per day. A seated person produces heat at the rate of about 100 large calories per hour. This is slightly more than 100 watts, to use the electrical equivalent.

Were it not for our clothing, this heat might be lost by radiation and by conduction to the air. The very great differences between the climatic conditions outdoors and those within the layers of clothing show that, at least as far as our bodies are concerned, we do exercise a large control over climate.

Likewise, structures of all sorts erected by man modify the climate of the spaces that they enclose. Thanks to heating and its more modern antithesis, cooling or air conditioning, we can maintain an atmosphere far different in temperature and in moisture content than that provided by nature.

Both inside and outside our structures we can change markedly the illumination of our surroundings and illumination is also a climatological element. Certainly, the illumination climate in the baseball stadium has been altered drastically.

On a larger scale, particularly in semi-arid regions such as California, irrigation has modified climatic conditions over vast areas. By adding water to otherwise dry soil, the heat capacity has been increased. The resulting crops alter the proportion of solar energy that is absorbed and not reflected upward. In turn, evaporation of the water from the ground and from plants increases the moisture content of the air, thus modifying another climatic aspect.

In each of these examples only a few of the basic climatic elements are involved: temperature, illumination, moisture, air movement or winds, water supply, and the reflectivity of radiation, called technically albedo. These are, after all, the primary climatic elements. When weather control is discussed, modification of one or more of these usually is considered; in most cases, the discussion is restricted to the moisture balance. But other elements have also been subjects of modification attempts.

Windbreaks have been used for centuries to protect habitations and fields. Rows of eucalyptus trees around citrus orchards are common in California. During the 1930's the federal government sponsored shelter belt planting on the Great Plains. Both these plantings are intended to prevent strong winds from reaching either valuable crops or dry erosible soil.

Even such a minor climatic element as lightning has been the subject of serious efforts at modification. Fog dispersal has been shown to be feasible by either of two methods, heating and nucleation.

But weather control in general usually means not the control of the weather over our bodies, or in our houses, or on our streets, or even over our airports, or our agricultural fields. It means the alteration of the basic weather phenomena, the storms that bring our rain and snow and gales. These are manifestations of the gigantic heat exchange system of our atmosphere. It continuously receives heat from the sun in the tropical areas and carries this heat poleward until it can be lost by radiation to space.

When man first tamed the horse and sought to guide a beast outweighing him ten-fold, he found a tender point where pressure of his puny muscles could direct the larger animal. Likewise, if man is to control an atmosphere which daily expends vast amounts of energy, he must find one or more tender spots where the slight pressure that he can bring to bear will be greatly magnified. So far we know of two such points: one is in the process leading to precipitation — rain and snow; the other is in the albedo of the earth's surface.

Precipitation

Precipitation is one step in the hydrological cycle. This is the sequence of evaporation of water chiefly from the oceans, its transport through the atmosphere as vapor, the condensation of the vapor into clouds, the gathering of cloud drops into raindrops, the disposition of the rainfall by evaporation and by flow on the surface and beneath it and back to the ocean.

For the past half-century the exact process by which cloud drops become raindrops has been the subject of much speculation, investigation and argumentation. Water vapor is invisible. When the air containing water vapor cools sufficiently some of the vapor condenses to form drops. Dew is one example; so is the water on the outside of glasses filled with a cool liquid.

Cloud droplets do not form out of thin air. They form *on* something: dust particles, plant spores, or other atmospheric impurities, generally less than one micron in diameter. (A micron is one millionth of a meter or about 4/100,000ths of an inch.) The cloud droplets themselves are one to ten or more microns in diameter.

Clouds do not really float in the atmosphere. They settle slowly, but so slowly that in still air they would require more than two months to fall a mile. The larger the water drop, the faster it falls. Only drops half a millimeter or more in diameter fall fast enough to survive evaporation, and the vagaries of the wind, to become rain. A drop one millimeter in diameter falls at the rate of four meters per second, or a mile in about seven minutes — compared to the two months for a ten-micron cloud droplet.

The average drop size in rainfall is about one millimeter or four thousandths of an inch. But one millimeter is a thousand microns and cloud droplets are only about ten microns in diameter. Hence, the diameter of a raindrop is about a hundred times that of a cloud droplet and its volume a million times. So a million cloud droplets must in some way combine to make one raindrop.

Processes

Just how this combination occurs is a basic problem in cloud physics. Until about thirty years ago, meteorologists assumed that the cloud drops just kept on bumping together until they formed raindrops. Then the late Irving Langmuir presented mathematical arguments to show that such continuous bumping would take several days rather than several minutes or few hours that are observed. So a different theory, due originally to a German meteorologist, Wegener, was revived, almost simultaneously by a Swede, Bergeron, and another German, Findeisen. It is called the Bergeron-Findeisen, or freezing nucleus, theory.

Because the vapor pressure over ice is slightly less than over water at the same temperature, a mixture of ice crystals and water drops is unstable. The ice crystals grow and the water drops diminish. A few ice crystals introduced into a cloud of water droplets grow very rapidly, and soon attain a size large enough to fall through the atmosphere. Eventually, they may melt and reach the ground as rain.

For more than a decade this was the accepted process by which precipitation forms. Then high-flying airplanes brought back evidence of rain from clouds whose tops were warmer than freezing, and hence could not have any ice crystals. This led to a re-examination of Langmuir's computations and the conclusion that under certain conditions the collision of cloud droplets can be sufficiently rapid to cause rain. Today we consider that precipitation in the colder parts of the world results from the ice crystal process, whereas that in the warmer regions arises through the collision process.

Nuclei

A major question in the ice crystal mechanism is the origin of the first few ice crystals. Cloud droplets do not freeze when they are cooled below 0°C or 32°F. In fact, they can remain liquid or super-cooled down to about —40°, at which temperature they suddenly turn to ice. But at temperatures between 0°C and —40° a cloud drop may freeze if it encounters certain tiny particles present in the air. These particles are called freezing nuclei, or crystalization nuclei. As yet, not enough is known about them. Apparently, they are hydrophobic, that is, non-wettable.

The entire field of rain making, which is a major activity in California, is founded on the premise that the atmosphere is somewhat deficient in freezing nuclei. It presumes that suitable artificial nuclei can hasten the transformation of the water droplet cloud into ice crystals, which then will fall as snow and eventually as rain. As yet, no method has been found for determining on what kind of a nucleus a given snowflake or raindrop formed. The larger nuclei can be identified by electron microscopy, but most nuclei are too small for any measurement.

The only known means for detecting freezing nuclei is by the crystals that form on them in a cold box. Quite a few investigations have been conducted of the concentrations of freezing nuclei in the atmosphere. The results are widely divergent. Some people find that natural nuclei are always present in sufficient numbers to transform water droplet clouds into ice crystals. Others insist that natural concentrations vary widely from day to day and place to place, and in many cases are too slight to provide maximum efficiency.

At any rate, when nuclei, usually crystals of silver iodide, are introduced into clouds, effects frequently are visible. Clouds can be made to grow or to dissipate according to the exact method of nucleus introduction. But whether wide-spread addition of nuclei to clouds causes any significant change in the total amount of precipitation is another matter. Here the analysis is severely complicated by the great natural variability of rainfall.

Applications

Proponents of cloud seeding claim that it increases precipitation by 10 or 15 or 20%. But skeptics feel that the natural variability is so great that no increase has as yet been demonstrated. Some consider that a quarter-century of continued experience may be required to indicate any increase with the confidence usually required by scientific investigation.

Nevertheless, cloud seeding continues, year after year, because it is considered a good investment by those who pay for it. These people are mostly electric utility managers. Their hydroelectric operations in the Sierra Nevada, the Cascades, the Wasatch, the Rockies, and elsewhere, are so efficient that only a slight increase in stream-flow will bring in more revenue than the cost of cloud seeding.

In many cases an increase of about one percent in streamflow is all that's needed. Such an increase is almost impossible to establish definitely. The Geological Survey claims only five percent accuracy for its stream gauges. No one, least of all the Weather Bureau, would consider an estimate of precipitation over a stream basin, derived from the catches of two or three raingauages, to be accurate within ten percent. So increases of a few percent, indicated for many cloud-seeding projects, are enough to make the utility manager renew the contract, but are within the errors of measurement as far as the scientist is concerned.

If introduction of artificial freezing nuclei does effectively hasten precipitation, then on a sufficiently grand scale it could cause major changes in the entire circulation of the atmosphere. When water freezes, heat is liberated. If many cubic miles of water drops can be turned into ice at will, a considerable amount of heat can be liberated in the atmosphere, thus changing its thermal balance. Perhaps this freezing nucleus bit can exert sufficient pressure on the tender thermal mouth of the atmospheric horse to guide it for the greater benefit of man. But as yet we have insufficient evidence.

Albedo

The other possible tender spot in the atmospheric horse is in the disposition that the earth makes of the energy received from the sun. Dark soils may absorb nine-tenths of the sunshine impinging on them and reflect only one-tenth, whereas snow may absorb only a tenth and reflect nine-tenths.

Relatively slight alterations of these surfaces can change the proportions drastically. Dispersal of large amounts of black powder on a snow field can cause it to melt rapidly in the spring or summer sun. Similarly, white powder or other treatment can increase the reflectivity of desert areas.

In principle, such alterations of the natural albedo over areas of many tens of thousands of square miles could change the distribution of heat absorbed by earth. Major changes in the circulation pattern of the atmosprere would result.

CONSEQUENCES

Just what would these possible changes do to the weather of San Francisco or London or Singapore? We are in no position to estimate with any degree of confidence. On the whole, meteorology today is still an explantatory science but not yet a predictive one. We can explain yesterday's weather with considerable assurance, but our estimates of tomorrow's have much less confidence.

Three-quarters of a century ago weather forecasters claimed an accuracy of 85%, or six out of seven. Despite all the knowledge acquired in the intervening years and the aids of radio, aircraft, and electronic computers, today's forecasts are still wrong about one time in seven. Some of us feel that this is an inherent characteristic of the atmosphere. We think it has an indeterminate or random component so that no matter how much we know about its physical state today, we can never predict its behavior tomorrow more than six times out of seven.

From this point of view, the consequences of any large scale modification of the precipitation process, or of the albedo, cannot be predicted with full confidence. Whether our present understanding and prediction abilities are sufficient to warrant the undertaking of any attempts at large-scale weather modification is a matter for serious consideration. The probable consequences may be desirable, but we will still have the gnawing fear that a disastrous outcome also is possible.

Then too, no specific change in weather will be considered by everyone as desirable. The resort operator wants sunshine but the farmer may want rain. The skier wants snow but the highway maintenance man does not. Should California's rainfall be increased at the expense of Nevada's? Should Alaska's winters be made warmer if Florida is thereby given more freezes or summer heat?

With aircraft, rockets, and nuclear power man conceivably can *alter* weather over substantial portions of his habitat. But whether he can *control* it in the same way that he controls his rivers and his vegetation is still uncertain.