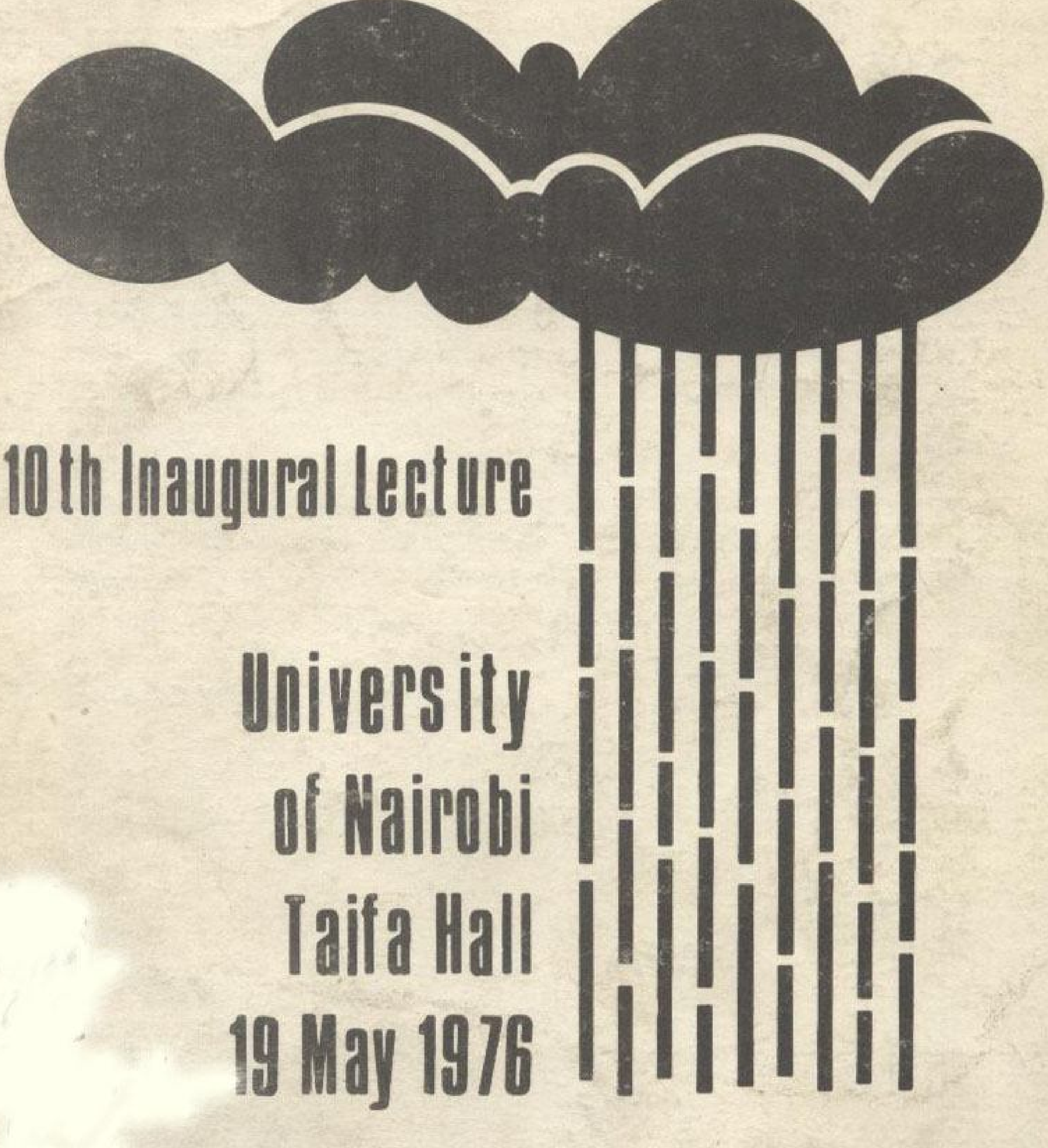
THE ART OF RAINMAKERS



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THE INAUGURAL LECTURE SERIES were started in the days of the University of East Africa, when it was the practice of the then University College Nairobi, to have its newly appointed Professors deliver their first public lectures in Nairobi. The current series under the University of Nairobi are supported by funds from the University Deans' Committee, and copies of the lectures are on sale at bookstores.

In this lecture, Professor Godwin Olu Patrick Obasi, Professor of Meteorology, gives examples of recent occurrences of drought, and the misery accompanying them in various parts of the world. In particular, he stresses the need for the perfection in the art of rainmakers to help in alleviating world drought. He then examines the art of "Gods of rain" quoting biblical examples and those of the African "rain-doctors". He suggests that although the art of the latter remains somewhat obscure, it could still be categorized in the realm of science although it strictly belongs to the field of metaphysics. The lecture concludes by examining both the art of rain formation by nature and those practised by meteorologists.

Professor Obasi was born in Ogori, Kwara State of Nigeria. He started formal schooling at Okene and attended Government Secondary School Zaria, 1950 – 1953. He attended the Nigerian College of Arts, Science and Technology between 1954 – 1956. His earlier career interest had been in Mechanical Engineering. Because of the withdrawal of his scholarship by the then Northern Nigerian Government, he took up employment with the Nigerian Meteorological Services. While there, he was initially trained as a class IV meteorologist (observer) before winning the Federal Government Scholarship to study Mathematics and Physics at McGill University, Montreal, Canada. At the University, he graduated with Upper Second Class Honours degree in 1959. He then proceeded to the Massachussetts Institute of Technology, Cambridge, U.S.A. In 1960 he completed the Master of Science Degree in Meteorology with distinction. By October 1962 he completed all the academic requirements for the degree of Doctor of Science in Meteorology. In addition, his doctoral thesis won him the Carl Rossby Award, the first recipient of the Award at the Massachussetts Institute of Technology. Professor Obasi was the first African South of the Sahara to earn a doctorate degree in meteorology.

Early in 1963, Professor Obasi returned to his home country in Nigeria and was charged with the responsibility of Research and Training in the National Meteorological Services.

In 1967 he was appointed a United Nations Technical Assistant W.M.O. Expert attached to the Department of Meteorology of this university. The post was held against a Senior Lectureship. He helped in the development of the Department initially from a staffing of two to the present strength of eight. In addition, the student population has since increased from 2 in 1968/69 session to over 60 during this academic year. In July 1974 he was appointed full Professor and Head of the Department both by W.M.O. and the University of Nairobi. In July 1975 he became the Dean of the Faculty of Science.

Professor Obasi has served in many capacities in the world forum of meteorology. In 1965 he became the first Chairman of the World Meteorological Organisation Working Group in Tropical Meteorology. The work of the group resulted in what is now popularly known as the Global Atmospheric Research Programme Atlantic Tropical Experiment (GATE). In addition he is one of the 14 members of the

International Commission on Dynamic Meteorology. He is the representative of the International Association of Meteorology and Atmospheric Physics on the JOC panel on GATE. In East Africa, he is member of the East African Joint Council on Meteorological Training and Research, and a member of the Kenya Research Sub-committee on Hydrology.

He is a Fellow of Royal Meteorological Society, and a member of the American Meteorological Society. Professor Obasi also takes interest in statistics. He is a member of the British Institute of Statisticians, having acquired the Membership by examinations specialising in Agricultural Statistics. He is also a Fellow of the Royal Statistical Society. Professor Obasi takes interest in soccer, hockey, boxing and wrestling.

THE ART OF RAINMAKERS

INTRODUCTION

Over three quarters of the earth's surface is covered by water. The water volume in the world oceans is estimated at 1350 million cubic kilometers. The global average annual rainfall on our earth is 2210 thousand cubic kilometers.

Rain water is both a friend and foe of mankind. Harnessed and properly used, it is one of his greatest allies. In excess, flood can result and thus become a terrifying enemy, destroying life, natural resources and structures in its path.

In recent times, rainfall failure for prolonged periods of time often referred to as drought has received a lot of publicity. I will here quote few examples of the effects of drought on socio-economic activities of mankind and thus clearly emphasising the need for the perfection of the art of rainmakers.

Perhaps the most well known case is the recent Sahelian drought which affected countries on the borders of the Sahara desert. On 11th May 1973, the Food and Agriculture Organization in Rome issued the following abbreviated communique: "An appeal for airlifts and for immediate additional aid . . . for six drought stricken West African countries was made today by the Food and Agriculture Organization of the United Nations, F.A.O." In making the appeal, FAO Director General Addeke H. Boerma stated:

> "In some areas there now appears serious risk of imminent human famine and virtual extinction of herds vital to nomad population." Dr. Boerma stated that his special representative for problems of the Sahelian Zone . . . had reported that . . . "the situation is still deteriorating".

Within the Sahelian zone which had rainfall deficit since 1968, millions of cattle and other domesticated animals had perished. In 1973 an FAO official for African affairs estimated that out of a population of 30 millions in the six Sahelian countries, "about one third are now weakened by hunger and malnutrition and some people are dying." According to the Newsweek of 4th June, 1973, Mortada Diallo, a regional director of the United Nations Economic Commission for Africa said "If the problem is not solved in two months, nearly six million people may die."

The Sahel zone was not the only part of Africa affected by drought. In Eastern Africa, Ethiopia, Somalia, Kenya and Tanzania were countries severely affected. Some of the wildlife of Kenya and Tanzania were threatened of extinction.

Across Asia the story was similar. The drought-prone regions of India had suffered a harvest estimated at nearly sixty per cent below normal in 1972. Bangladesh suffered a shortfall of two and a half million tons in its rice harvest (enough to just sustain about 10 million people!) In Sri Lanka, drought caused crop losses of thirty per cent of expected harvest. Chinese newspapers openly spoke of drought and famine.

In the Americas, drought ranged the Central America maize producing areas and Mexico lay in the throes of drought.

Back home in Kenya, the 7 o'clock Voice of Kenya evening news bulletin of 29th March, 1976 read as follows: "The Government of Kenya has given 400 bags of maize, 300 packets of milk and 100 tins of cooking fats to aid the drought stricken victims of Kalama location in Machakos district." The word to note here is drought.

About a week ago the Daily Nation produced an article entitled "Britons pray for rain as water crisis worsens" written by Donald M. McNicoll. Part of the article reads as follows: "A prayer mat from Botswana hangs in the offices of the Wessex water authority. It bears the word *pula* — meaning let there be rain.

But it would take a prolonged monsoon, experts agree, to overcome England's worst drought for 249 years. Yes, drought in England, where it is supposed to rain just about all the time!

Some reservoirs are nearly empty, some two-thirds empty, and great many half empty.

The Wessex Water Authority . . . has urged families to bathe together. A leaflet advises the two millions Wessex water consumers: Mum, dad and the kids bathing together is fun and saves water."

Similar experience may be quoted in other parts of the world. To my mind, the important question is — what perversity of nature had withheld the life-giving rains in areas infected with drought? What are the rainmakers doing about this or has their art not reached the perfection of alleviating rain failures? Ladies and gentlemen, these are the considerations that have led to the choice of the theme of this lecture.

Most of the western civilizations have discarded belief in the multiplicity of Gods who governed the world of the ancients, and the tendency has been to attribute weather control to the one God of the old-testament prophets. There are several accounts of biblical prophets calling up their God to change the weather. For example: the prophet Samuel called upon the Lord and "the Lord thundered with a great thunder on that day upon the Philistines and discomfited them; and they were smitten before Israel." In fact, Elijah succeeded in discrediting the competing prophets of Baal by calling upon the Lord to bring lighting from the sky where they had failed. Perhaps the most well known biblical rainmaking is that which resulted in Noah's flood. The story of the flood is covered in Genesis 6 — 9. Genesis 6: 13 — 15 states: God says to Noah, "A tremendous judgement is coming and here is the way to escape. Build a huge boat." Finally it comes time for Noah and his retinue to go into the ark, for God says, "For yet seven days, and I will cause it to rain upon the earth forty days and forty nights; and every living substance that I have made will I destroy from off the face of the earth" (Gen. 7:4). Gen. 7:11 says "..., the same day were all the fountains of the great deep broken up, and the windows of heaven were opened." The water involved in the flooding was more than forty days of rain.

There are many who have cast doubt on the occurrence of Noah's flood because of its catastrophic destruction and its universality. They claim that any event which does not fit the order of things as we know today gives difficulty. Yet about 10,000 B.C., a curious event of a great mystery happened in what is now known as the arctic. Here I refer to the frozen mammoths and other animals. Climatology indicates that for the past 12,000 years the area has been uniformly cold. Studies of the great mammoths and the other animals that have been found there, up to that time indicate that the climate had been warm. When the animals froze, they died so quickly that plants of a warmer climate were still in their mouths, neither spit out nor swallowed. According to an account, the meat of the great beasts was frozen so rapidly that it was still good to eat when it was found. Scientists who are familiar with deep-freezing have figured out that on the basis of the mass of these huge animals, the temperature would have had to drop within a few hours to -100°C. Nobody yet knew how or why this happened.

In Africa there have been several cases in which "rain doctors" have claimed to be able to make rains and/or stop them. In some societies, their art is used as a weapon against the opponents of their clients. You may wish to recall the case of the last general election in Kenya where the Luanda based "rainmakers" threatened to stop rain unless a particular candidate is voted for. During the drought that affected most parts of Kenya in 1974/75, an appeal was made to these rainmakers and were invited to Nairobi where they appeared on television. Aside from the Luanda group, the Kalenjins are also known to use magic in search of rain.

At this juncture it is of interest to recall the outcome of an interview I once had with a group of rainmakers in Nigeria during 1963. During that year, the Nigerian Meteorological Services was very keen in the development of research aimed at alleviating drought. As we were determined not to leave any stone unturned, we were keen to exploit the art of the "rain doctors". As Head of the research division of the service, the "raindoctors" were invited to my office and had exchange of views on the possibility of their making rain at a place and time of *my* choice. They flatly rejected this and requested that they would have to choose the timing. At that stage it was clear to me that they were probably banking on using their experience of the local weather. There are several others in Nigeria whom I have not been fortunate enough to meet. Therefore the one sample might not be representative of the school of "raindoctors". For this reason, it would be premature to rule out the credibility of this category of "rainmakers" simply because their art remains obscure. If it is accepted that the African "medicinemen" have made important contribution to medicine, I do not see much reason why we should be skeptical of the ability of the African "raindoctors".

Forecasting the Occurrence of Rain:

I would wish to treat this topic under the heading of the "Gods of Rain". Some of the "raindoctors" bank on their ability of being able to give accurate forecast usually in the time scale of a few hours to days, using animals or plants or other signs as sensors. In his Book of Signs, Theophrastus (373 — 286 B.C.) listed some two hundred maxims, including almost all those familiar to us today, namely "red sky in the morning..." and "... when flies bite vigorously it is a sign of rain".

In China, meteorologists attached to Weather posts in Commune are well grounded in folk meteorology. Typical of the proverbs are: "When dragonflies hover low and in concentration, a moderate amount of rain will follow". Or, "when crabs crawl on the road, a large amount of rain will fall within a day or two." In Ping Chou Commune near Canton grew a grass called "rain and wind flower." When the grass blossoms after a dry period, rain is in store. When a team of American Meteorological Society visited this post in 1974, the yellow and white flowers of the grass were wide open. The next day it rained. Although it was the beginning of the rainy season, the team decided to respect the "rain and wind flower". Here at home in Kenya, some plants such as coffee are alleged to be sensitive to the approach of rain.

The Akamba people of Kenya are known to have "Gods of rain" *Ngai ya mbua,* and *Athani ma mbua* — rain prophets. The *Mwathani* (rain prophet) bears no blame for any prediction which fails since he does not promise, he only reports what has been passed to him or acts as a media. It is not normal practice of the Akamba to control rain i.e. to bring or stop it at request. (Kavyu, 1973). Kavyu states that two sacrifices are made for rain, the first one has a long history, the other is done annually in a ceremony. During severe droughts in some areas the Akamba buried a child alive in a ceremony. This form of sacrifice has continued up to date, but these days it is only practised at Mutitu by the rain prophet of *Mbaa Mbua.*

At this stage I would not wish to dwell in detail on the meteorologists' art of rain forecasting. It suffices here to state that the principles involved are both dynamical and thermodynamical. Firstly the observed distribution of weather circulation systems have to be well mapped. Their mode of behaviour — intensification or weakening and their motions — are studied. Based on availability of moisture source, it is then possible to predict for a particular time when rainfall would take place at a particular area.

Coming back to the question of the art of "Gods of rain" it would appear that the methods used by the biblical God and those of the African "raindoctors" remain a mystery. Based on the premise that only through science can nature's secret of rainmaking emerge, it is useful to consider whether science has metaphysical presupposition. If this is so, then their art might qualify as scientific.

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Science can flourish only in a climate which accepts the concepts of order and regularity, and believes that the universe is not arbitrary but governed. This is the concept of natural law.

There is a series of orderly events that impress themselves on the minds of men — the recurrence of the seasons, the cycles of day and night. Life itself has an orderly regularity — the cycle of life and death. All men had faith in the orderliness and reproducibility of nature.

But side by side with this faith in order, man also had an equal faith in the underlying chaos: the drought, lightning, floods, all appeared as expressions of the essentially chaotic nature of experience.

The world of nature and events, the world of experience, appears in many aspects to be formless and aimless, and against this chaos man strives for meaning, for order and regularity.

We can define science therefore as the pursuit of systematic knowledge by the application of reason to empirical observations, and the philosophical justification for this process is concerned with the application of reason. This has two aspects; first the logical validity of the processes of reasoning; secondly the truth of any axioms (i.e. statements which are taken as the fundamental starting point of the structure of the knowledge) which may have been made, explicitly or implicitly.

Many modern philosophers would confine the role of philosophy to this logical analysis, i.e. they regard philosophy as the search for general truths. Others would extend this role to include immediate experience, arguing that this is the ultimate test.

However, this is a very confined interpretation of philosophy compared with the interpretation placed on it by philosophers down the ages. If we take their broad definition of philosophy as the pursuit of wisdom and of the knowledge of the right way of life, the achievements of understanding of how we ought to live and what kind of knowledge is useful and attainable, then we have extended the definition far beyond what is generally acceptable today, so as to include not only philosophy but also ethics and metaphysics.

Metaphysics may be understood as the attempt to explain the universe as a whole, and man's place within the universe, by means of thoughts alone. This has been developed by the union and conflict of two very different human impulses, the one urging man towards mysticism (e.g.

Blake) and the other urging man towards science (e.g. Hume) — with the whole range of intermediate areas of study from magic (e.g. vodoo) through the pseudo-science (e.g. astrology) to the near sciences (e.g. extra-sensory perception).

Let us therefore draw a line between philosophy and metaphysics at the point which separates thought whose validity can be established from thought whose validity cannot be established. This then helps us to rephrase the question in the form "Does science have any axioms whose validity cannot be established?"

This immediately focusses our attention on the underlying assumptions of scientific methods; that there is a natural law, of universal regularity, which gives us a blind faith that a solution can ultimately be found. On this axiom is built the scientific belief in causality and induction.

If we emphasise the fact that this belief is irrational, we must infer that we do not know science to be true; but if on the other hand we admit the claim of scientific method, then we must accept that this belief is justified.

The art of rainmaking by the biblical God of the old testament and those of some of the African "raindoctors" would therefore qualify as science, although they would appropriately be categorized in the realm of metaphysics.

NATURE'S ART OF RAINMAKING AS REVEALED BY SCIENCE

It is a common experience that all rain fall from clouds. The clouds are composed of water droplets or ice crystals or a combination of both. The appearance of clouds varies. Some are layered, others are cumuliform and these are generally referred to as convective. The vertical motions in the convective types of clouds are larger than those of the layered types.

To understand the physical mechanisms responsible for rain formation, we must start with the processes leading to cloud formation, before further developments into rain. This consideration brings us into the realm of Cloud Physics.

Water substance occurs in our earth's atmosphere in vapour form, liquid or water and solid or ice. In a cloud free atmosphere, water exists in its vapour form consisting of water molecules. As a result of random motion of the molecules, collisions will inevitably result. Because of intermolecular forces a certain number of these collisions will be inelastic, that is, the colliding molecules will stick together and form an aggregate of two or more molecules. This aggregate form an elementary particle of water. If the aggregate is large enough it will persist and grow. It has been shown that for such aggregates to grow into cloud drop sizes, there would be a requirement of relative humidity of the order of 800 per cent.

Similar considerations apply to the formation of ice in water which has been cooled below 0° Centigrade. Here we use the term supercooled water. In this case, for pure water to spontaneously become ice, the temperature would have to be cooled to –40°C. For the change of water vapour to ice, the temperature would have to be lower than –70°C. These changes are referred to as Homogeneous.

All natural atmospheric condensation occurs on foreign particles referred to as nuclei of condensation. The most important of these are composed of sea salt, sulphates, nitrous acid, salts of ammonia, ashes and particles resulting from domestic and bush fires. Although subject to large variations in space and times, the atmosphere normally contains a wide spectrum of these nuclei. They range from about 100 to 1000 per cubic cm in country areas and from 100,000 to several millions per cubic cm in industrial areas. These are approximate and subject to large variations in individual cases.

The formation of water droplets that make up clouds is often initiated on a hygroscopic nuclei at less than 100 per cent relative humidity.

For nuclei having very small masses the relative humidity would have to exceed 100 per cent if they are to grow into cloud drop sizes. Once a nucleus has been subjected to a relative humidity equal to that appropriate to its size, it grows at a rate which is dependent on the moisture supply. Such nucleus is then said to have been activated.

As the humidity is increased as a result of a lifting process in the atmosphere, condensation will begin on all nuclei. The largest are activated first. As soon as some nuclei are activated, there will be a tendency for the humidity to fall. If the rate of air lift is large, the humidity will continue to rise until enough of the smaller nuclei are activated to bring the rise of relative humidity to a halt. It is then extremely unlikely that any nuclei not activated at the initiation of the condensation process will be activated later. In practically all cases of natural condensation, only a small fraction of the total nuclei is activated. These then are the processes that take place leading to the formation of water droplets that make up clouds.

Natural Precipitation (Rain or Snow) Processes

The process of cloudy condensation leads to a large concentration of liquid droplets (100 to 500 per cubic centimeter of air). It is impossible for rain drops to be formed by the process of condensation alone. If we take 20×10^{-4} centimeters as a typical cloud drop diameter and 1 mm as a typical rain drop diameter, it is clear that 125,000 typical cloud drops must be combined to form one rain drop. This is the role of the precipitation process and it is immediately evident that no mechanism that is able only to cause occasional combinations of drop pairs, is adequate to explain the formation of precipitation.

It is now agreed that there are only two basic mechanisms whereby a water cloud can release precipitation. The first of these is the ice crystal process often called the Bergeron-Findeisen mechanism. This is based on the fact that the equilibrium vapour density over supercooled water is greater than that over ice at the same temperature. If a few ice crystals appear in a supercooled cloud, for example, as a result of the freezing of a few drops, the ice crystals will grow rapidly at the expense of the supercooled water. It is important that the concentration of the ice crystals be small compared to that of the supercooled cloud drops so that the available water will be concentrated on a few ice crystals and will thus form precipitation elements.

The second basic precipitation mechanism is the collision and coalescence of drops in the gravitational field. The spectrum of drop sizes present in natural clouds is relatively broad. The larger drops fall with respect to the smaller drops and collide with them. Collisions increase the drop size resulting in a large collision cross section and a greater velocity of fall. This is evidently an avalanche-type process. This mechanism is referred to as the "accretion" process.

The ice crystal process can occur only in a supercooled cloud and only when a suitable number of ice crystals are introduced. The accretion process may proceed at any temperature but its efficient operation is dependent on the presence of relatively large cloud elements, a deep cloud, a large concentration of cloud drops and perhaps on other factors affecting the effectiveness of the collisions. There is ample evidence that both processes operate in the atmosphere. Rain from clouds that are everywhere warmer than 0°C. can result only from accretion process. Aircraft observations in middle latitudes indicate that most cyclonic rain originates as ice crystals.

There are a number of unsolved problems in connection with the accretion process. In particular there is inadequate knowledge of the conditions requisite for the merging of two small drops when they collide in the gravitational field. It appears that small drops often "bounce" without coalescing and it may be that an electrical field is required to promote coalescence. There are also aerodynamic forces that cause some drops to be deflected from the path of the overtaking drops. When the large drop has a diameter say ten times or more of that of the smaller drops these uncertainties largely disappear. The conditions for the initiation of the accretion process depend critically on "bounce-off" effects.

THE ART OF RAINMAKING AS PRACTISED BY METEOROLOGISTS

The art of rainmaking as practised by meteorologists is based on three main assumptions:

(i) That either the presence of ice crystals in a supercooled cloud is necessary to release snow or rain by the Bergeron-Findeisen process or the presence of comparatively large water droplets is necessary to initiate the coalescence process.

(ii) That some clouds precipitate inefficiently or not at all because condensation or ice nuclei are naturally deficient.

(iii) That this deficiency can be remedied by seeding clouds artificially with either solid carbon dioxide (dry ice) or silver iodide to produce ice crystals, or by introducing water droplets or large hygroscopic nuclei.

The possibility of producing rain from supercooled clouds by the introduction of artificial ice nuclei was foreseen by the German cloud physicit Findeisen in 1938. Earlier in 1931, Veraart in Holland dropped dry ice into supercooled clouds. It is quite possible that he produced slight amount of rain on several occasions, but because of his too sweeping claims, all his attempts were discredited.

On November 13th, 1946, Schaefer in the United States made the first field trial when 3 lb of crushed dry ice were dropped along a line about 5 kilometers long into an altocumulus cloud deck whose temperature was about -20°C. Snow fell from the seeded cloud for a distance of about 620 meters before evaporating in the dry air.

The seeding of large supercooled cumulus clouds with dry ice was first reported in 1947 by Kraus and Squires working in Australia. They observed that four out of eight seeded clouds gave heavy rains. Other countries that later carried-out experiments using dry ice included Canada, England, South Africa and the United States. In general the results showed that there was a high probability of inducing precipitation with dry ice if the cloud summit was colder than -7° centigrade and when depth of the supercooled region exceeds about 1250 meters.

From results of over 100 experiments carried out in Australia, it was concluded that with cloud summit temperatures warmer than -7° centigrade the chances of success fall off, tending to zero at 0° centigrade. At temperatures of –15° centigrade and below, the results lose their significance because the clouds have a high probability of raining naturally.

In July 1946, Vonnegut discovered that minute crystals of silver iodide produced in the form of smoke, acted as efficient ice-forming nuclei at temperatures below –5° centigrade. The fact that enormous numbers of nuclei could be produced from 1 gm of silver iodide by vapourizing an acetone solution of silver iodide in a hot flame suggested the possibility of dispersing them in large quantities from the ground, since the minute particles could remain in the atmosphere for long periods until carried up by air currents into the supercooled regions of clouds.

Seeding of supercooled cumulus in Australia using silver iodide and aircraft as platforms showed that of those clouds which were colder than –5° centigrade at their summits, 72 per cent gave rain usually within 20 — 25 minutes of seeding.

Back home in East Africa, some experiments were performed in 1951 at Kongwa (Central Tanzania) in an attempt to increase rainfall from convective clouds. Small charges of gunpowder impregnated with about one fifth gm of silver iodide were fitted with a time fuse and carried up into the clouds by hydrogen-filled balloons. Having estimated the pattern of convection and the strength of the vertical air motion, the length of the time fuse and rate of ascent of the balloon were adjusted to enable the gunpower explode just above the 0°C isotherm. The results of the 15 experiments that were performed show that four cases gave rainfall downwind of the point of release of the balloons shortly after detonation of the charges, three cases were inconclusive and eight were unsuccessful.

Recently, it has become recognised that in order to obtain a meaningful statistical evaluation of cloud seeding experiments, it is necessary to eliminate bias introduced by the operator in choosing suitable seeding occasions and by unrepresentative periods of the weather situation. It has therefore become the practice to decide on the basis of the current meteorological situation whether, on a particular day, there will be cloud systems suitable for seeding, and then the actual decision to seed or not is made on the basis of an independent random choice. Such randomized experiments were carried out in Arizona in the United States where orographic cumulus clouds were seeded with airbone silver iodide generators.

The results obtained during the four years (1957 — 60), have failed to reveal any marked differences between the rainfall on the seeded and unseeded occasions.

Experiments in which water and aqueous solutions were sprayed in cumulus clouds had been made. The experiments introduce anything between 1 and 100 gallons of water in the form of fairly large drops into the tops of convective clouds but all produced no marked effects. The results are to be expected since the spraying of a few gallons of water into the top of a cloud cannot produce a shower unless a process of raindrop multiplication occurs. For such chain reaction to take place it would appear that the cloud would have to be very deep. In any case such deep clouds would have a high probability of precipitating naturally.

A more efficient method would be the introduction of small droplets or radius (30 — 40) x 10^{-4} centimeters into the base of growing cloud and to capitalize on their subsequent growth in the up and down drafts within the cloud. In 1952 eleven of such experiments were carried out in Australia in which water drops of medium radius 25 x 10^{-4} centimeters were sprayed at the rate of about 30 gallons per minute during flights made at about 300 meters above cloud base. On six of the seven occasions when cloud thickness was less than one and a half kilometers, light rain fell but, neighbouring untreated cloud did not precipitate. In the four cases where the cloud depth exceeded one and a half kilometers there was a considerable fall of rain or hail within a short time of seeding and on three of these occasions the neighbouring unseeded clouds did not rain. Similar experiments performed in the Caribbean showed that about a half of the treated clouds produced rain while only a quarter of the untreated cases produced rain. Those carried out in the United States gave inconclusive results. On the basis of these few experiments, it would appear that the method of spraying large drops into the top of convective clouds appears inefficient and too costly for large-scale application. Economically, the introduction of much smaller drops seems more promising but the technique requires much more careful investigations.

Considering the role played by giant hygroscopic nuclei in initiating the coalescence process, it would appear even more economical to use such nuclei rather than water droplets as seeding agents. Since dry salt crystals of diameter 10 x 10^{-4} centimeters will more than double their size while being carried up through the first few hundred meters of cloud, the dispersal of about 100 gm of salt would be equivalent to that of about a gallon of water in 50 x 10^{-4} centimeters diameter droplets. This method was tried here in East Africa where bombs containing gunpowder and sodium chloride were carried aloft by balloons with such arrangements that they exploded near cloud base and dispersed the salt particles. For the 38 days when salt was released, the total rainfall in an area 9 — 20 kilometers downward of the realease point was up to 150 mm in excess of that for intermediate unseeded days, but the rainfall over an area extending 7 kilometers upwind was also greater by about 60 mm. It appears that in these, as in other experiments carried out in Pakistan with salt dispersed from a ground generator, the number of salt particles reaching the clouds was insufficient to produce a detectable amount of rain even if each grew into a large raindrop. Accordingly there is no convincing evidence that salt seeding has produced positive results.

The seeding of layer clouds has often been carried out on supercooled stratiform clouds from aircraft using dry ice. Many experiments carried out in England, United States of America, Canada and Australia indicated that the effect is to produce a "hole" in the layer cloud and no precipitation occurred that reached the ground.

Large Scale Cloud Seeding Operations

Here we consider the possibility of modification of rainfall from widespread cloud systems extending over thousands of square kilometers. For operations on this scale, it is the general practice to release silver iodide in the form of smoke from ground generators producing about 10^{13} nuclei per second, relying on the air currents to carry it up into the supercooled regions of the cloud. Trials of this type have been carried out in the United States of America, Canada, South America, Israel, Australia, India, Senegal and Upper Volta.

For such large scale operations, generators are switched on when the arrival of suitable storms in the target area is imminent and kept burning during their passage, the working hypothesis being that seeding may cause an increase in precipitation over that which would fall naturally. These experiments are conducted under the auspices of ranchers, farmers, power companies and public utilities. At this stage I would like to mention a spectacular experiment carried out in Upper

Volta during 1969. The problem that concerned the Government was exceptional — namely a matter of filling up dams which supplied the capital Ouagadougau with water. Sodium Chloride (common salt) was sprayed in the clouds, in the direction of the wind and the experiment was reported successful since it rained enough to have the dams filled with water. Nonetheless it cannot be claimed with certainty that the prevailing clouds at the dam sites could not have developed naturally to give as much rain as was recorded. In any case the contractors were paid their charges.

In evaluating the results of such large scale rainmaking experiments, the vital question is: Is it probable that the rainfall pattern which appeared immediately following seeding would have appeared even if no seeding had taken place? The difficulty in answering this question lies in the inherent variability of natural rainfall and the meteorologists present inability to predict with sufficient accuracy what would have occurred in the absence of treatment. In areas having a fairly large annual rainfall exceeding say 100 cm, the rainfall in anyone year may easily deviate from the average over a thirty year period by ten or fifteen percent, while in marginal and dry regions the variations may be as much as fifty percent. Unfortunately it is in these latter areas where rainmaking is most in demand, that it is most difficult to assess the efficiency of cloud seeding because of the large annual natural rainfall variability. The fact that we are still far from being able to form an accurate estimate on purely physical basis of how much rain will fall naturally in a given area, leaves the effects of seeding to be assessed statistically. It appears therefore that the meteorologist art of rainmaking is still in its embryonic stage. Galileo once said "I can foretell the way of the celestial bodies, but can say nothing of the movement of a small drop of water." Meteorologists would appropriately state that they can predict the large scale motion of the earth's atmosphere to an accuracy that shows reasonable skill but their knowledge of the small scale processes that go into the physics and dynamics of rain formation is still quite rudimentary. Although in the USSR much claim of success in weather modification has been made, the rest of the world are more modest in their claims.

In a recent WMO/IAMP Scientific Conference on weather modification, Warner (1973) reviewed rain enhancement programmes that have been carried out in tropical areas. In his presentation, he described those features which make for an experiment whose result are most likely to be accepted outside, as well as inside the ranks of the cloud-seeding fraternity. These are:

(i) "Good statistical design and analysis of the experiment.

(ii) Long-term continuity.

(iii) Uniformity in cloud characteristics throughout the term of the experiment, or at least means of separating them.

(iv) A preponderance of clouds expected to be susceptible to the seeding technique employed.

(v) Sufficient background knowledge of the microphysics of clouds in areas to enable the experimeter to accept or reject the statistical results."

No doubt, meteorologists need to put in more work in the understanding of the dynamics of elements of cloud systems to enable important advancement in their art of rainmaking. In recent times two important new developments which will improve our understanding of the meteorologists art are in progress. The first is the use of numerical simulation experiments using actual rainfall figures to form an estimate of how real experiments should be conducted. The second concerns the use of numerical models of clouds which aim at predicting the rainfall which will occur in both natural and seeded conditions. Progress has been universally slow but the road is rough. Meteorologists cannot hope for a magic carpet which would carry them directly from Kepler to Einstein without undergoing the growing pains of Newtonian mechanics. The economic benefits of any important breakthrough in the art of rainmakers are obvious. With the same token, if the art is inadvertently used, it could have a catastrophic effect and an important repercussion on the hydrological balance of our planet. This in effect would change the climate. To ensure that our planet is not plunged into unpredictable consequences of large scale climatic changes, universally accepted weather modification laws should be worked out. The United States of America is showing some lead in this direction.

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