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Rain-making and its possibilities in India*

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ABSTRACT. The article gives a brief account, in non-technical language, of the present position of 'rain-making' and its applicability under conditions as normally prevail in India. After an introduction to Bergeron's theory of rain formation, which provides the main basis for the present day experiments on rain-making by seeding 'cold' clouds with 'dry ice' or other suitable germs, the essential meteorological conditions as are required to be satisfied for the success of such trials are discussed briefly. An examination is then made, in some detail, of the characteristics of clouds and other meteorological features over India, with particular reference to conditions in Madras area during the northeast monsoon season and in northwest India, during the southwest monsoon months with a view to finding out how far the method could be applied in this country to solve practical problems, such as, scarcity of rainfall due to monsoon failures. The use of 'seeding agents' other than dry ice for purposes of rain-making has been discussed. The possibility of applying the rain-making technique to control the weather associated with a cyclone by altering its track has been commented upon.

While, on the basis of information as is available at present, it is felt that the scope of rain-making in India from the practical point of view is likely to be strictly limited, it is considered most desirable that further and more intensive researches in the laboratory and extensive field experiments should be carried out before a final verdict is given.

1. Introduction

No investigation in the field of meteorology has ever attracted so much notice and evoked such keen interest of the general public as the trial experiments which have been made in some countries in recent years on the production of rain from clouds by giving them an artificial stimulus. Brief reports of success of these trials, commonly described for the sake of brevity as experiments on 'rain-making' or 'artificial rain', as have appeared from time to time in newspapers and other journals, seem to have led some people to think that the day has at last come when the long cherished dream of mankind, *viz.*, 'Weather to order' has

*The reports on rain-making by the seeding of clouds which have appeared in the press in recent years have evoked much interest among the public in India. Eager enquiries are received from time to time in the India Meteorological Department regarding the feasibility of Artificial Rain-making in this country. This department has followed the reports that appear in the press and has kept abreast of the developments on the subject as discussed in the foreign scientific journals. I had asked Mr. A.K. Roy to review the position as it stands today and write an article in non-technical language for the purpose of communicating this position to a wider public in the country. It is hoped that the above article will fulfil this purpose, and that it will help all readers, technical and non-technical, to see a balanced view of the problem of rain-making, with special reference to meteorological conditions in India.

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become a reality. In India, a country whose economic structure depends chiefly on her agriculture and whose annual budget is said to be controlled largely by the monsoon rainfall, the possibility of a successful application of any such man-made method of causing rainfall to help solve the problems that are brought about by the vagaries of weather, naturally arouses the keenest interest in the minds of all sections of the people. It is, therefore, no wonder that numerous and frequent questions are being put to the meteorologists in this country enquiring whether they have made a study of these rain-making methods, and whether they propose to carry out similar trials in India, and if so, when. Under the prevailing conditions of food shortage in India, which has been further aggravated by repeated failures of northeast monsoon in Madras and by prolonged droughts in some areas during the last southwest monsoon season, the eagerness of the public generally and of the agriculturists and financial experts in particular, to know more about the practical possibilities of these rain-making experiments is only most natural. In this article it is, therefore, proposed to make a brief review, in as simple terms as possible, of the principles underlying the trials that have till now been made on the 'making of rain', and the extent to which our present knowledge in this regard can be applied to solve our practical problems, with particular reference to the meteorological features as normally prevail in this country. A general survey as above of the scope of the present technique of inducing clouds to yield rain is considered desirable, so that we make a proper and correct appreciation of this new venture of science to control Nature to the best advantage of mankind.

2. Basic principles behind rain-making

To understand the subject of rain-making and the basis of the experiments so far made in this line, it is necessary first to consider briefly certain fundamental aspects of clouds and rain-formation. A brief discussion on this most intriguing feature of meteorology was made by the writer in a short article[1] in *Science and Culture* in 1948. Strange as it may seem, it will be readily admitted by meteorologists all over the world that although the physics of cloud development is fairly clear, the physical processes which lead to the growth of rain from the preceding stage of cloud formation are not yet completely understood, despite a very detailed study of the problem extending over a number of years by eminent physicists, physical chemists, and meteorologists. The first plausible and fairly comprehensive theory of rain-formation which received support of meteorologists generally, although with certain reservations, was the one which was propounded in 1933 by Bergeron[2]. According to him, rainfall of appreciable amount occurs from only those cloud masses which have water droplets and ice particles existing side by side, at temperatures below O°C. In other words, if Bergeron's theory were true universally, rain can be expected from only such clouds as extend beyond the freezing level and also contain ice crystals along with water droplets. The American and Australian rain-making experiments about which we have been usually reading in newspapers and journals in India are really attempts to supply these ice crystals artificially to the layers of clouds which, though at temperatures below O°C, contain no ice particles and are composed almost wholly of super-cooled waterdrops. The process by which this supply of ice crystals is made consists in the sprinkling, from an aircraft, of 'dry ice' (solid carbon dioxide) over clouds of the right type, that is, those that are known to have super-cooled water droplets at least in their top layers. The procedure followed is a simple and straightforward one and the material essentially needed for the experiment is some 25 to 30 pounds of dry ice, procurable in countries like Australia and USA at a small cost. The only arrangement to be made in this connection which entails prior planning and organisation and involves appreciable expenditure is the flight in an aircraft by the personnel who are to sprinkle the dry ice to act as the 'seeding agent', at the right time and over the right spot.

3. Limitations of the method with special reference to conditions in India

The relative simplicity of the arrangements required to be made for achieving results of such far-reaching importance has created a great impression in the minds of the public who, naturally, are curious to

know why we should any longer allow any part of a country to suffer from the consequences of scarcity of rainfall, now that a method appears to have been found to induce clouds to yield rain as and when desired. For an answer to this question it has to be observed that the rain-making method, as described above, depends for its success on a number of factors, the most essential amongst which is the existence of a suitable type of cloud, which is likely to respond to the dry ice treatment for yielding precipitation below. It is evident from what has been said already that the experiments under discussion are more correctly to be described as on 'inducing clouds to yield rain' rather than 'rain-making', and that we remain dependent still on the bounties of Nature for getting rain over a particular area. The results of systematic trials made in Australia during the last few years have shown that, while the planting of ice crystal 'germs' in certain types of clouds definitely facilitates the production of rain which we may not otherwise have, it is necessary for the success of such trials that the clouds must extend to a height where the temperature is 7° C to 15° C below freezing point and its thickness must be equal to or greater than the height of its base above ground. In the Australian areas where most of the experiments have hitherto been made, the required temperature of –7°C to –15° C at the top layer of the cloud occurs generally at elevations of some 8000 to 12,000 ft above ground[3].

In India, except during the winter season and in more northern parts, the freezing level is usually as high as 14,000 to 15,000 ft above ground, and the temperature of –7°C to –15°C in a cloud is rarely to be expected unless it extends to a height of some 16,000 to 20,000 ft. This means that, for making an experiment of this kind, the aircraft carrying the dry ice and the personnel to implant them in the clouds has to fly to a much greater height than in Australia or USA, necessitating the use of the right type of properly equipped aircraft, and involving a relatively higher expenditure. While this is a matter which should not present any insuperable difficulty, the real problem from the practical point of view is the spotting of the right type of cloud, which on being 'seeded' with dry ice would give us the desired rain on the ground, for, there is as yet no known simple method which enables us to tell from our observations on the ground if the low cloud that we see on a particular occasion extends to a height well above the freezing layer or not. Consequently, what will often happen is that the aircraft carrying the personnel and equipment for the rain-making experiments will have to make numerous reconnaissance flights in search of a suitable cloud before it is able to discover one which has the correct temperature at the top layers and is also of the right thickness.

Further, there is one more important consideration to be satisfied for the success of such a trial, and this is that the 'seeding' should be done when the cloud is in an active stage of development as, otherwise, coagulation of the cloud droplets following the dry ice treatment may result in no more than a few drops of rain reaching the ground, and at times may only help a premature dissolution of the cloud. Obviously, therefore, for any practical application of our present knowledge of rain-making to meet situations such as prolonged drought in any part of the country, or to solve the water problem of an area from the point of view of agriculture, what is required is that aircraft with the required personnel and equipment should be kept ready for 'sorties' at all times of the day, so that favourable occasions of cloud development which provide scope for the rain-making trials are not missed generally. To ensure this, it will often be necessary to arrange for flights which may not ultimately lead to any practical results. In India, the number of such fruitless sorties that may have to be made are likely to be quite large, because the freezing level being very high, many of the clouds that may seem to be rain-bearing, when observed from the ground, may during actual flight be found not to have reached the height where the temperature is between –7°C and –15°C. The most important information that has, therefore, to be gathered in connection with any scheme of systematic rain-making trials in India is how frequently do situations actually arise in this country, especially over the parts which are rather dry, when low or medium clouds of sufficient depth grow upto a height of 16,000 to 20,000 ft, and yet fail to cause precipitation on the ground.

While no completely reliable and definite information in this regard based on actual observations, is available till now, some indirect evidence exists which lends support to the view that relatively few cases occur in India when clouds of appreciable depth extend beyond the freezing level without yielding rain in the natural course. A tentative conclusion, as above, was arrived at by the writer on the basis of his examination a few years ago of the vertical distribution of relative humidity in the upper air, as furnished by soundings at a few stations in India on days of cloudy weather. Assuming for the purpose of this study that, on days on which low clouds of sufficient amount existed over the station, the top of the cloud column extended to that height upto which the relative humidity continued to be 95% or more, it was found that on most of the days when the cloud extended beyond the freezing level rain was actually falling at the station at the time of sounding or commenced shortly thereafter. Although the evidence, as above, may not be fully convincing, this having been based on relative humidity measurements which are not completely reliable especially at higher levels, the conclusion reached is in agreement with the general impression that we have formed from observations of cloud tops, as are sometimes possible to make from the ground, and also from the reports received from pilots on their cross-country flights. However, this is a point on which further and more definite information has to be gathered, for, on this would depend the practical possibilities in India of rain-making experiments being carried out by seeding 'cold' clouds with dry ice or other suitable seeding agent, such as, silver iodide. The organisation needed for the purpose is the provision of a few suitable aircraft for making regular reconnaissance flights on cloudy days at heights of 18,000 to 20,000 ft to see when and where they meet with low clouds with tops reaching the freezing layer and beyond, and then to make an immediate descent to find out if the area below is having any rain or not.

4. Northeast monsoon rains in Madras and rain-making

Dealing with the meteorological features of northeast monsoon rains in Madras, where the monsoon has had repeated failures in recent years, it is well-known that the air mass which normally prevails over the area is the rather dry air of continental origin which, after traversing northern India as a westerly to northwesterly stream, turns round anticyclonically and reaches Madras coast as northeasterlies, after a slight addition of moisture in the surface layers following a short sea travel. The thermal and thermodynamic structure of the atmosphere over the area is such that the shallow layer of humidified air in the first one or two thousand feet has little chance to rise high enough to form clouds of any significance. Even when, in certain favourable situations, the humidification of the air extends to a height of some three to five thousand feet, and turbulence in the lower layers helps the development of an extended belt of low clouds over the area, adequate vertical growth of the cloud is prevented as a rule by the markedly stable stratification of the air just above the lower humid layer, and the top of the cloud is usually thousands of feet below the freezing level.

The conditions which favour development of cloud of appropriate thickness, leading to appreciable rain over the area, are associated principally with the passage westwards of low pressure waves across the south Bay of Bengal. These lows cause to bring periodically into the Indian area truly maritime air of tropical origin and thereby help the development of extensive clouds and rain, principally over the zone extending from the central region of the low to where the tropical maritime air stream meets and interacts with the relatively dry northeasterlies or the northeast monsoon winds proper. While the passage of these low pressure waves, and consequent accentuation of the seasonal trough over the south Bay helps to strengthen the winds in the northeast monsoon sector—the incidence of rainfall on such occasions is often said to be due to the strengthening of the northeast monsoon —the precipitation is really the result of the convergence in the field of the tropical maritime air which gets into the Indian seas from the east. The westward moving lows in this season usually follow a track south of Lat.10° N, and the associated rain more frequently falls in Ceylon and in the extreme south of the Peninsula. Occasionally, however, the influence of these lows extends further to the north, and over the region of

discontinuity between the northeast monsoon winds and the tropical maritime air an extensive rain belt develops parallel to the east coast of Madras upto the latitude of 15 to 18° N. With the movement further westwards of the low pressure wave, this zone of discontinuity also shifts progressively to the west, causing precipitation over the greater part of Madras State. In these situations the associated weather over the area well within the northeast monsoon wind sector may be typified at times by a more or less continuous deck of low clouds, but these are usually of the stratocumulus type with tops reaching a height no greater than 7000 or 8000 ft, and are usually unproductive from the point of view of rain.

In Fig. 1 is shown a typical chart indicating a well-marked discontinuity in the nature of the cloud fields over the two sectors, one of which had widespread rain during the next twentyfour hours, and the other was practically rainless. If, during certain years, the field of activity of these low pressure waves remains generally restricted to latitudes below 10° N and, in consequence, the greater part of Madras State remains chiefly under the sway of the relatively dry northeasterly stream, the result as explained above will be a failure of winter rains in Madras. Artificial stimulation of clouds in the sector of northeast monsoon winds proper would in such circumstances yield little results, so long as the rain-making trials are restricted to cold clouds only.

5. Southwest monsoon rain in northeast India and rain-making

The position is found to be somewhat similar when we consider the meteorological features of the southwest monsoon season over West Rajasthan, the adjoining districts of East Punjab, Kutch, the northern parts of Saurashtra and the neighbouring districts of Bombay State, which suffer during some years from failure of monsoon rains. These areas, which lie at the southwestern edge of the monsoon trough, have normally only a shallow layer of monsoon air, or of a mixture of this air and the dry westerlies of continental origin, with tropical continental air from the north spreading anticyclonically at higher levels. As a result, ordinarily, even when considerable low clouds develop over the area, the clouds are often of limited

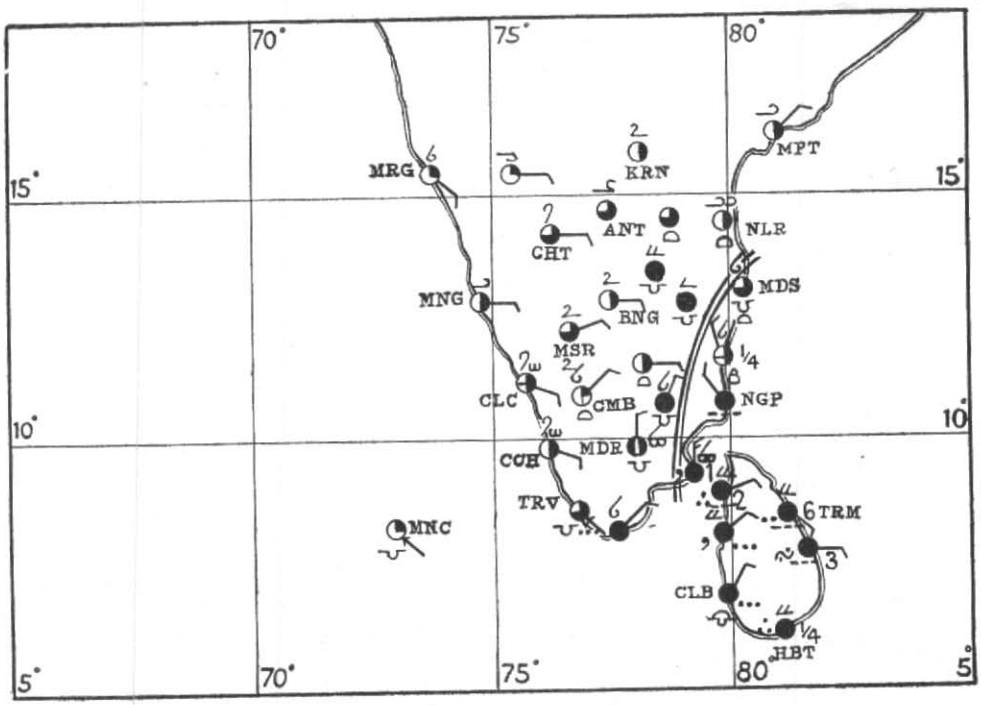

Fig. 1. Surface synoptic chart, 0830 IST, 26 December 1949

thickness with tops reaching no higher than 8000 or 10,000 ft, that is, far below the freezing level. The meteorological situations which favour the development of proper rain-bearing clouds and good precipitation over the area are those which cause an influx of the monsoon air in sufficient depth into this part of the country. This is facilitated most when, with the westward march of monsoon depressions or low pressure waves from the head of the Bay of Bengal across the central parts of the country, the westerly or the Arabian Sea Branch of the monsoon strengthens and dominates in a thicker layer than usual, and the prevailing air mass of continental origin at the upper levels is replaced by the easterlies of maritime character. There are years in which these monsoon depressions or lows forming over the head of the Bay of Bengal are less numerous than usual, and even if they form with their usual frequency, many of them after reaching Madhya Pradesh take a more northerly track than normally, with the result that while Uttar Pradesh, East Punjab and the Western Himalayas get abundant monsoon rains, the relatively dry zones of Rajasthan, Kutch and Saurashtra fail to get even their limited share of rain. Such northward shift of the track of monsoon depressions often causes the western end of the seasonal trough of low to be so oriented that over the areas under discussion the westerlies in the lower layers draw a greater share than usually of dry continental air from Sind and Baluchistan, inhibiting formation or at least persistence of even innocuous type of low clouds in sufficient amounts. In situations of this kind, cases sometimes arise in which widespread rain falls over the hills and plains of the greater part of the East Punjab, which is overrun by the moist easterlies and southeasterlies, while immediately to the west and southwest the northern parts of Rajasthan and even the adjoining districts of Hissar and Ferozepur in East Punjab, over which flow the continental westerlies, go practically dry, with little low clouds of any significance.

Fig. 2 shows a situation in illustration of rainfall distribution of this type. To the southwest of the zone of widespread rain, as demarcated by the partitioning line, lies an area where clouds are principally of the stratocumulus type. Considering the limited vertical growth of low clouds, if any, which form on the dry air side of the monsoon trough, one can hardly feel optimistic of fruitful results being achieved by any attempt on our part to augment the yield of rainfall over these relatively dry zones by the application of rain-making methods as are known to us at present. However, before we draw any final conclusion in this regard, it is most desirable that a thorough and systematic survey should be made of the low clouds over these areas, by arranging regular reconnaisance flights during one or two monsoon seasons to see if the clouds, even if these are generally of limited vertical extent, build themselves up locally to elevations where sub-freezing temperatures are reached.

6. Rain from 'warm clouds'. Use of agents other than dry ice in rain-making

As mentioned earlier, the theory of rain formation, enunciated originally by Bergeron and later developed into what is known as the 'Ice crystal theory of precipitation' by Bergeron and Findeisen, was accepted by meteorologists with certain reservations. While it was agreed generally that the coexistence of supercooled water drops and ice crystals in the top layers of clouds, with sub-freezing temperatures, constituted most favourable and perhaps also an essential condition in most cases for the development of rain and snow in extra-tropical latitudes, the non-fulfilment of such a condition did not preclude altogether precipitation in appreciable amounts falling over tropical and sub-tropical regions, and also in higher latitudes during spring and summer months. Indeed, in India, it has been felt all along that monsoon showers often occur from thick nimbostratus or large cumulus clouds, whose tops are several thousand feet below the freezing level, and this inference has received good support in recent years from observations made by pilots while flying above the monsoon cloud decks. Similar authentic reports[4] of rain falling from non-freezing clouds have also been received from other countries, principally in the tropics and sub-tropics, and ample evidence is now available to support the view that under certain favourable conditions rain of appreciable amount can be had from even such warm clouds as have their tops well below the freezing level. Thus, in a country like India where, it is believed, relatively few cases occur in which low clouds or thick

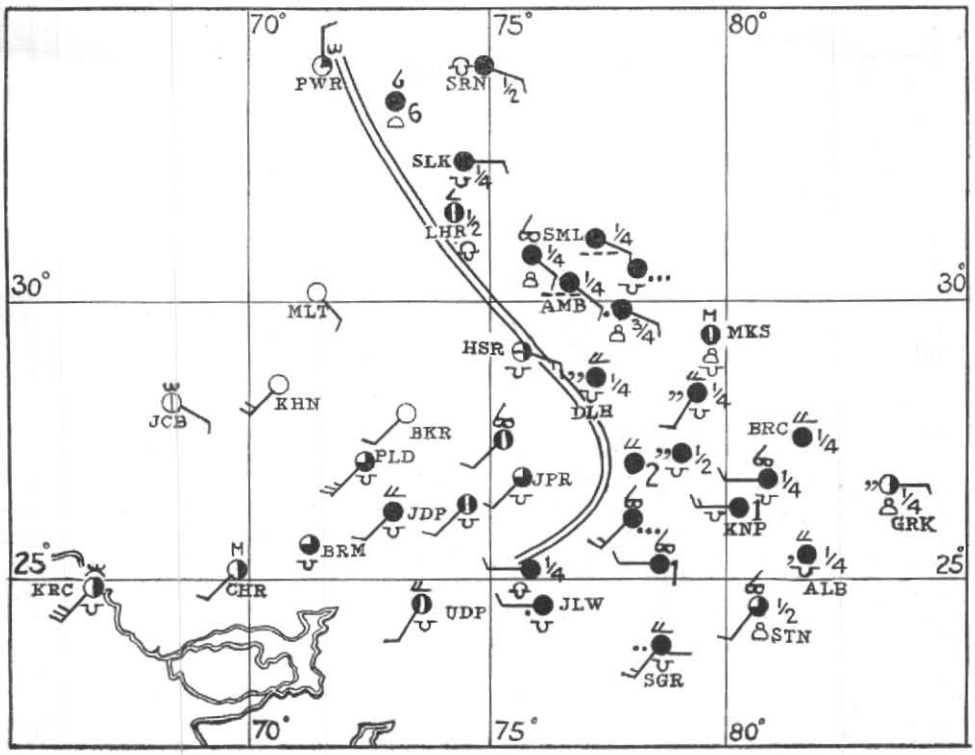

Fig. 2. Surface Synoptic chart, 0800 IST, 5 August 1948

medium clouds extend to heights with temperature between −7° C and −15° C and yet fail to yield rain, and where, on the other hand, low clouds in certain cases give ample rain even when the top is much below the freezing level, the technique of causing rain by seeding cold clouds with dry ice or silver iodide may ultimately be found to be of no more than limited practical utility. Even if in a relatively few cases we happen to find a cloud building up to a height with sub-freezing temperatures and yet giving no precipitation then and there, the dry ice treatment of the cloud to make it yield rain may not, it is feared, be of much practical value, as it is possible that the cloud in question might even in the ordinary course have given rain if we waited for some time longer. Further, in some of these cases, the process of causing precipitation rather prematurely from such a cloud might only mean disturbing the natural distribution of rain which would have fallen over the place and the areas adjacent to it. For, it is believed that the seeding, for instance, of a large cumulus cloud and causing it to release prematurely much of its water may sometimes prevent the cloud from developing into a full-fledged thunderstorm, and the latter from following a track as it would otherwise have done. The result may, therefore, well be that while the rain showers over the particular place may in consequence of the artificial stimulation of the cloud last somewhat longer, the total amount of rain received may not be substantially more and also the neighbouring places where the thunderstorm cell would have rolled down and caused showers eventually may not get any rain at all.

As was stated before, besides dry ice, silver iodide particles could be used as a seeding agent for stimulating cold clouds to give rain. The number of field experiments actually carried out so far with silver iodide particles have, however, been few, and according to workers in Australia their use has not proved as effective as dry ice pellets. Seeding by silver iodide parti-

cles, if this ultimately proves equally efficacious, would have one important advantage over the dry ice method, as in this case it might be possible to dispense with the use of aircraft flying at great heights for implanting ice-crystal 'germs' in the top layers of clouds. It is with this object in view that in the rain-making trials which are being organised in East Africa[5] by the Overseas Food Corporation in collaboration with the Meteorological Department, the seeding of clouds is proposed to be carried out by silver iodide particles to be produced by the explosion of small charges of gun powder, which have been previously impregnated with silver iodide. The arrangement proposed is that the charges will be carried into suitable clouds by hydrogen-filled balloons, and with the help of a time-fuse the explosion of the charges is to be so timed that the silver iodide particles are sprayed into the cloud at approximately the freezing level. It is, however, not known how far the method proposed will in actual practice, prove suitable or effective, especially in cases when the general level of the cloud top is below the layer of freezing and only at places it happens to reach a height with the desired temperature of about —10° C. For, unless the site for the release of balloon bomb is chosen correctly and it is found possible to effect the release from there at the right moment, the explosion may take place at a point where the cloud does not extend to the proper height. Further, the need for aircraft for a preliminary survey of the top layers of clouds will still remain, unless we are prepared to carry out the trials on a lavish scale and do not mind unnecessary use of silver iodide. However, the experimental method suggested is an interesting one, and the results of the experiments will be keenly awaited by all tropical countries, such as India, where the general structure of clouds, the height of freezing level, etc. are similar to those in East Africa.

So far, in this article, we have discussed in a general way the trial experiments on the production of rain from cold clouds alone. Langmuir and his collaborators in USA have, however, described in recent years some experiments in which the seeding was attempted in clouds which were wholly at temperatures above 0° C. Although the trials hitherto made on such warm clouds have in general not proved quite fruitful—measurable rain reached the ground and continued for some length of time in one of the cases reported so far—the ingenious theory which Langmuir has put forward to explain the formation of rain as a result of the seeding of warm clouds by dry ice or even by water only will, if substantiated, prove to be of great interest to countries like India, where the freezing level is high and, as such, non-raining clouds rarely reach sub-freezing temperatures.

7. Conclusion

From the brief review as above of the present day position of rain-making trials, it will be apparent that although the experiments made so far have demonstrated clearly that the use of only a few pounds of dry ice can, under certain favourable conditions, produce spectacular results in our attempts to control meteorological processes, and although the experience gained has been unique in as much as it has given us a valuable insight into the physics of clouds and rain formation, any statement to the effect that we have reached a stage when we can apply our knowledge to solve our practical problems by artificial control of rain would be over-optimistic.

It is still more premature to talk at present of any possible application of this rain-making technique to control the movement of a cyclone by altering its track.[6] The field of natural precipitation associated with a cyclone is a vast one, extending over thousands of square miles, and it is most unlikely that a process of cloud seeding, over certain limited areas in the non-raining sectors of the cyclone would produce such large scale effects as would affect appreciably the differential pressure changes in its field of activity and thereby cause it to deviate from its natural track. It is important to remember in this connection that the cloud seeding methods as have been applied till now mainly help the growth in size of the water droplets which have been formed already by the natural process of condensation, and that except in a few cases when clouds gain considerably in height as a result of seeding, the total amount of latent heat liberated in the cloud is unlikely to be augmented appreciably by our rain-making

trials. Further, the meteorological features which determine the path of a cyclone are complex and depend on numerous factors in a deep layer of the atmosphere from surface upto at least 30,000 ft above, and probably also on conditions obtaining in the stratosphere, and it is doubtful if a small variation in the amount of latent heat liberated near about the freezing level over certain restricted areas, even if this could be achieved by a process of cloud seeding, would materially influence the future track of a cyclone.

Although, a scientist should view with optimism the ultimate practical possibilities of the present results of rain-making experiments, it is most desirable that further and more intensive researches must be allowed to proceed, unhampered by any undue publicity, before he ventures to give an opinion if the high hopes of weather control, as have been raised in the minds of the public by reports appearing in the popular press, will one day be realised. It is important that, in line with other advanced countries which have taken up investigations on this subject, a well co-ordinated research organisation should be set up in this country soon to carry out full-scale experimentation and detailed studies on cloud physics, both in the laboratory as well as in the natural environment of the free atmosphere.

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