An Experiment on Artificial Stimulation of Precipitation in the Snowy Mountains Region of Australia

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Abstract

A long-term experiment on the artificial stimulation of rain over an area has been in progress in the Snowy Mountains region of south-east Australia. The form of the experiment is described, and preliminary results from the first six months' operation are presented.

1. Introduction

This paper presents an interim report on a long-term experiment in the artificial stimulation of precipitation which was initiated in Australia, jointly by the Snowy Mountains Hydroelectric Authority and the Commonwealth Scientific and Industrial Research Organization, in June 1955. The objective is to determine whether cloud seeding with silver iodide nuclei can produce an economically significant increase in precipitation over the Snowy Mountains region. Aerial seeding is employed exclusively to reduce the doubt present in some previous experiments as to whether the seeding material actually entered the cloud systems involved.

The tests will need to be continued for several years before reliable conclusions can be drawn but since they incorporate some novel features in the general design of the experiment, a description of the procedures adopted may be of interest to other workers in this field. Few actual experiments of this kind have been adequately reported in the literature.

2. Design of the experiment

(a) *Method of control*

A basic factor in all attempts to arrive at a quantitative assessment of the changes in precipitation induced by cloud seeding is the reliability with which the precipitation that would have occurred in the absence of seeding can be inferred.

A method frequently used in the past to provide this essential comparison is to locate a "control" area adjacent to the seeded area, the natural rainfall of which is closely correlated in time and amount with that for the seeded or "target" area. Even if such a correlation can be established between two adjacent areas following a careful analysis of data for a sufficient period, and over an adequate network of stations within the areas, any relationship so established is necessarily an historical one and there must be inherent uncertainties in its extrapolation to the present or future. An alternative approach relies on seeding being confined to random periods, so that the intervening unseeded periods are available to provide the essential control data.

This avoids some of the disadvantages of the historical method. It is not dependent upon the existence of long series of records from a closely spaced network of stations, and has the merit, in fact, that any desired cover of gauge stations may be specially installed for the purpose of the tests. This is the method that has been adopted in the present experiments.

(b) *Length of period*

The length of period selected for »on-off» seeding should clearly not be so short as to introduce high variability, and not so long as to prolong unduly the duration of the tests.

In south-east Australia there is for most of the year a fairly regular procession of pressure systems from west to east, with an average period of six to seven days. The frontal surfaces which are the main source of cloud and rain in the Snowy Mountains area are generally located approximately midway between the anticyclone centres.

It was pointed out by Mr. E. B. Pender of the Snowy Mountains Hydroelectric Authority that the selection of a natural period corresponding to the passage across the area of the anticyclone centres would provide a twofold advantage: the measurements of precipitation could be made more expeditiously in the favourable weather usually accompanying anticyclones, and also making the measurements at "null points" would be the next best thing to reading all gauges simultaneously. This convenient natural period has therefore been adopted.

For the purposes of these experiments a period is defined as the interval between the passage of successive anticyclone centres across the 150° E meridian of longitude. During the winter of 1955, however, some periods were as short as three days, and also the raingauge and other readings at the end of some periods had to be made in most unfavourable weather conditions. It seems therefore desirable to further specify that each period shall not be less than 8 days and also that those anticyclones should be excluded which (e.g. by reason of their centres passing a long distance north or south of the Snowy Mountains area) are not accompanied by reasonably fine weather in the catchment area. The division into seeded "on" and unseeded "off" periods is made on the basis of a set of random numbers (FISHER and YATES, 1948). This series is unknown to the individual who decides the end of each period and the beginning of the next.[1]

The regular procession of high pressure and frontal systems across south-east Australia, described above, normally holds from March to December, but breaks down during the summer months (December—February), due to frequent incursions of easterly air and penetrations of monsoonal air from the tropics.

The decision was therefore taken to treat the summer months from December 1st separately for the purpose of analysis. The present paper deals with results from the commencement of operations up to December 1st 1955.

(c) *Estimation of precipitation*

The variability which occurs in the precipitation records of a particular area is a compound one. The total rainfall is itself subject to variations due to natural causes, but there is a further variability as a result of sampling errors. A raingauge measures only a minute sample of the total precipitation over an area, and any increase in the number of raingauges reduces, to some extent, the variability which makes the assessment of cloud seeding experiments difficult. The raingauge cover in the Snowy Mountains area has been greatly increased since the beginning of this experiment. The locations of the raingauges are shown in Figure 2. The precipitation measured at these locations is the total precipitation, both rain and snow. At the conclusion of each period isohyetal patterns are drawn for that period by the Hydrology Section of the Snowy Mountains Hydroelectric Authority, and the total precipitation in acre feet calculated by integration of the isohyets. The precipitation estimated in this way furnishes a better estimate of the true total than that given by individual gauges.

[1] A more desirable procedure would be to seed the control area in the present "off" periods, the effects of seeding would then be twice as apparent and the time scale of the experiments shortened. At present, however, seeding of the control area is not desired by the Snowy Mountains Hydroelectric Authority because of their heavy construction programme in that area.

3. Area of operations

The experiments are taking place over the catchment area of the Snowy River in south-east Australia, an area in which major engineering construction is in progress, under the control of the Snowy Mountains Hydroelectric Authority, to provide water storage for both hydroelectric and irrigation purposes. This general area in relation to south-east Australia is shown in Fig. 1, and its subdivision into "control" and "target" areas in Fig. 2.

The subdivision into "control" and "target" areas was decided by the following a priori considerations: (i) the "control" area included areas to the north where major construction works are at present in progress; the Snowy Mountains Hydroelectric Authority desired that the experiments should have little likelihood of affecting the precipitation in this area; (ii) the "target" area was that part of the main catchment area south of the "control" area, and was of approximately equal area. It included the comparatively small Guthega catchment area in which precipitation is of immediate and direct economic value, as the run-off from this area is utilized by a hydroelectric power station already in operation. This area is enclosed by the broken line in Figure 2.

The orography and climatology of the region seem suitable for an operation of this kind. As the region is approached from the west, the terrain rises rapidly (6,000 feet in 20 miles). The crest of the main range roughly follows a line drawn through the centres of the "control" and "target" areas. Prevailing winds are from the northwest to southwest, and precipitation and deep clouds are most frequently associated with winds from that quadrant, usually in conjunction with frontal or post-frontal synoptic situations. To date, the clouds seeded have been cumuli or stratocumuli.

4. Equipment

A schematic drawing of the silver iodide smoke generator is reproduced in Fig. 3. A generator unit is suspended from each wing-tip of an Avro Anson aircraft; a pump within the cabin of the aircraft is used to pump a solution containing silver iodide from a tank in the fuselage to the wing-tip units. There

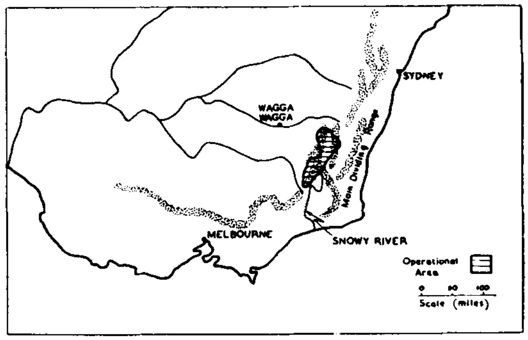


Fig. 1. Map showing Snowy Mountains area in relation to south-east Australia.

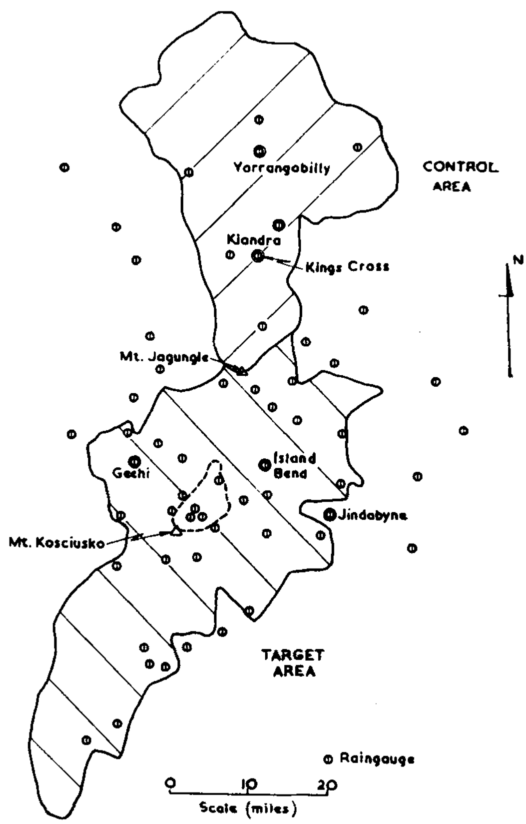


Fig. 2. Snowy Mountains catchment area, showing the target and control areas and other salient features.

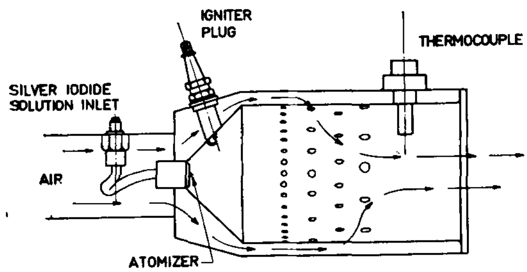


Fig. 3. Silver iodide burner.

the inflammable solution is atomized to a fine spray which is ignited by a "glow-type" spark plug. Thermocouples measure the temperature of each burner, and serve to indicate whether the burners are operating correctly. For reasons of safety, the incandescent vapour is cooled by radial introduction of air, so that the flames are confined to the interior of the burner tube. The solution employed contains silver iodide and sodium iodide in acetone; it is burned at the rate of 500 gm to 800 gm of silver iodide per hour.

The aircraft is equipped with complete navigational aids so that accurate position finding is possible in almost all circumstances —a very necessary requirement for the satisfactory execution of cloud seeding operations of this kind.

5. Operational procedure

In earlier experiments carried out by C.S.I.R.O. convective clouds were seeded with silver iodide nuclei released from an aircraft either within cloud or immediately below cloud base. These experiments indicated that seeding was likely to induce precipitation, providing that (i) the temperature of the top of the cloud was $-6°$ C or colder; (ii) the cloud was compact and at least several thousand feet in vertical extent. Following a successful seeding at cloud base, precipitation was usually observed below cloud base 20—30 minutes after seeding. Less information was available concerning the seeding of stratocumulus layers, but the observed intervals between successful seedings and the appearance of precipitation ranged from 20 to 50 minutes.

With the above considerations in mind, routine seedings are carried out as follows: (i) when visual inspection, or the prevailing meteorological situation, indicates that suitable cloud conditions may be found in the vicinity of the Snowy Mountains region, the aircraft takes off from its base at Wagga Wagga (about 90 miles NNW of the catchment area). At present, daytime operations only are conducted. (ii) As the aircraft approaches the target, wind and temperature measurements are made to augment information provided by the Meteorological Office at Wagga Wagga and an appraisal made of the cloud conditions prevailing. (iii) If conditions are considered favourable, the most suitable level for seeding is decided. The track of the seeding flight is then plotted by laying off a line equal and parallel to a line joining Mt. Jagungle and a point 10 miles south of Mt. Kosciusko. The distance upwind of the seeding track from the latter line, in the direction of the wind at the seeding level, is designed to allow for the expected time interval between a successful seeding and the arrival of precipitation at the ground. Naturally an exact determination is not possible but it is felt that the method used gives the best estimate than can be arrived at by using available data. The distance referred to is obtained by multiplying the wind velocity at the seeding level by 30 minutes in the case of cumulus clouds with bases at or below 6,000 ft, or by 60 minutes in the case of layer-type clouds; when the cloud base exceeds 6,000 ft, $1\frac{1}{2}$ minutes is added for each 1,000 ft by which the base exceeds that height. The best seeding level is considered to be the $-6°$ C isotherm; it is often impracticable to fly at this level, and seeding is usually carried out at cloud base. (iv) A number of passes is then made, following the predetermined track. If weather conditions prevent complete passes being made, the accessible part of the track is traversed. (v) Following the seeding, an attempt is made to assess visually the effects, if any, produced. Precipitation has often been observed over the target following seeding, but it is well known that such observations are of limited value. However, a marked lowering of the cloud base is very frequently observed.

The type of aircraft being used at present curtails the duration of individual seeding flights and also limits the extent to which advantage may be taken of suitable weather conditions. Extension of the seeding time and fuller use of available opportunities, particularly at night, is clearly desirable. It is planned to increase the duration of seeding during the daylight hours and to introduce night seeding at some date in the future.

6. Results

The precipitation results for periods No 1 to No 27 are given in Table I for both the target area (T) and the control area (C).

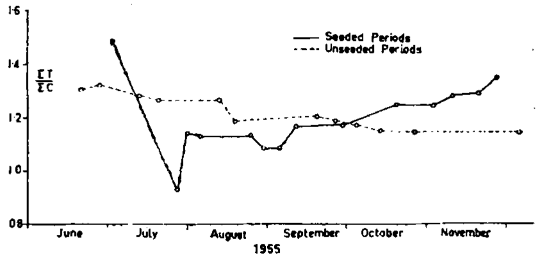
The ratios of the cumulative sums of the precipitations in the target and control areas are presented graphically in Figure 4 and in Figure 5 a plot is given of the ratios of target and control area precipitations for each period.

These results indicate that the ratios of target area to control area precipitations are greater during the seeded periods but the number of observations are far too inadequate to determine whether this can be expected

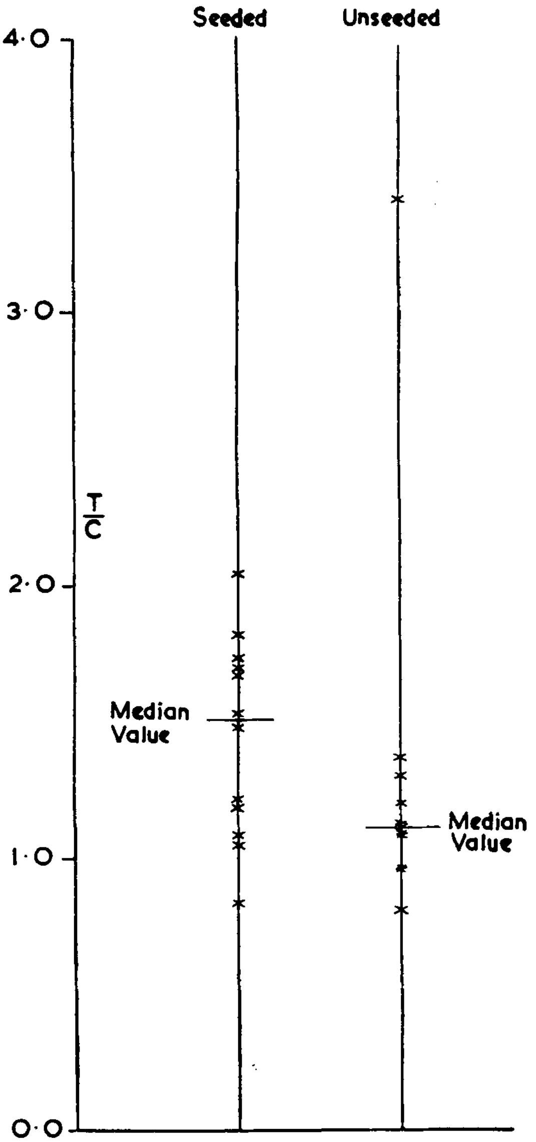
Table 1. Precipitation in target and control areas for periods 1 to 27 (8 June 1955 to 5 December 1955)

Period No.		*T*	*C*
Seeded	Unseeded	Thousands of acre feet	
	1	249,1	190,9
	2	128,7	94,2
3		5,5	3,7
	4	17,1	21,3
	5	105,8	88,1
6		19,1	22,6
7		117,7	98,3
8		22,5	20,5
	9	0	0
	10	333,8	305,3
11		0	0
12		217,7	206,3
13		0	0
14		81,5	46,7
	15	10,9	3,2
	16	132,1	118,0
17		14,1	7,7
	18	74,9	76,9
	19	97,8	100,8
20		105,8	61,9
	21	200,9	179,1
22		102,9	84,0
23		82,6	48,7
24		58,2	37,8
26		99,8	48,5
	27	78,9	71,3

In the number of the periods, No 25 was omitted due to a clerical error. Period No 26 follows immediately after Period No 24.



4. Ratios of cumulative sums of precipitation in the target and control areas.



5. Ratios of precipitation in the target and control areas.

naturally or whether there is an effect due to the seeding programme. It is proposed to continue the experiment until a significant answer to this question, one way or the other, is obtained.

7. Discussion

From an operational point of view the dissemination of silver iodide by an aircraft for the purposes of modifying the rainfall in a given area has proved to be quite successful. The procedure adopted is simple and unequivocal in use.

The use of aircraft in this type of experiment reduces the uncertainty as to whether the silver iodide reaches its operating region before becoming inactive and because of its freedom of movement gives greater accuracy in «aiming» the seeding operation.

The design of the experiment would appear to give the following advantages:

(i) The use of random »on-off» seeding allows the use of recently installed precipitation gauge coverage and extrapolation of historical data is unnecessary.

(ii) The integration of an isohyetal map to give an estimate of precipitation is not dependant upon all precipitation gauges being read, and does take some account of the spatial relationships of the recording gauges.

(iii) With the use of periods determined by the passage of high pressure systems there is greater probability that the precipitation gauge readings can be made in fine weather and a delay in reading any particular gauge or gauges is unimportant.

8. Acknowledgements

The onerous task of collecting and collating the precipitation data has been undertaken by Mr. E. B. Pender and his staff of the Hydrology Section of the Snowy Mountains Hydroelectric Authority without whose liberal cooperation this experiment could not have been undertaken. Acknowledgements are especially due to Mr. T. E. Bisits, who was responsible for drawing the isohyetal maps for each period and computing the total precipitations therefrom.

The smooth operation of the experiment owes much to Messrs. A. A. Tapp and J. S. Aitken who are responsible for the navigation and flying of the Anson aircraft and to Butler Air Transport Pty. Ltd. who are responsible for its maintenance and servicing.

Thanks are also due to the Meteorological Office at Wagga Wagga airport for providing synoptic information and forecasts, and to the Commanding Officer of the Royal Australian Air Force establishment at Wagga Wagga, for hospitality afforded to the flying personnel.

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