The Rise and Fall of the Rainmakers:

a history of the CSIRO cloud-seeding experiments, 1947-1981

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Synopsis

Searching for activities to carry out in peace-time, in 1946 the Radiophysics Laboratory of the CSIR (which became CSIRO in 1949) seized on cloud-seeding, a rain-making technique discovered in America. The Laboratory gained an early lead in the field of cloud physics and rainmaking and by the 1950s it had established an international reputation. But in Australia it never managed to entirely overcome scepticism about cloud-seeding; nor did it succeed in entrenching the technique in agricultural practice. In the 1970s the program suffered a series of setbacks: the retirement of Radiophysics' leader, 'Taffy' Bowen, who had been the driving force behind the program; a shift in focus within the field of climatology; and new demands on the CSIRO from government. When in the early 1980s the cost of running a seeding aircraft rose steeply while returns to wheat farmers fell, cloud-seeding was deemed uneconomic and the program was abandoned.

Introduction

People of many times and cultures have developed techniques to 'make' rain fall. Both the USA and Australia had some vigorous proponents of artificial rainmaking in the 19th century; their techniques included lighting fires and setting off explosions, both on the ground and in the air[1]. In the twentieth century the more sophisticated attempts to make rain took the form of 'cloud-seeding' – artificially introducing into clouds substances that act as 'nuclei' around which water may condense and then fall as rain (or snow). In Australia, CSIRO investigated cloud-seeding over the period 1946 to 1981, at the same time conducting theoretical research in cloud physics. This study traces the history of the program's experimental side.

Cloud-seeding originated in America in 1946. Along with methods to ward off hail and disperse fog, it became known as 'weather modification' – a topic that attracted world-wide interest and became the subject of numerous conferences and a large volume of literature. As recently as 1977 the World Meteorological Organisation thought it worthwhile to issue guidelines on rainmaking.[2] Experiments still continue in some countries, as do conferences discussing their results.[3]

So the interesting point about the CSIRO experimental program is that it 'failed': experiments ceased in 1981 and cloud-seeding did not become an accepted part of the repertoire of agricultural techniques for any great length of time (although it was adopted as a routine technique by the Tasmanian Hydro-Electric Commission, for filling dams). Why did work stop in Australia while it continued in other countries? Technical and economic factors were important in cloud-seeding's demise, but they are not the whole story. The technique was cross-disciplinary, a physical-science technique applied to the domain of agriculture, and the barriers between scientific disciplines (and institutions) hindered its adoption. There was active opposition to it from some quarters. And, importantly, towards the end of the program there was a significant shift in the way Australian governments thought about drought, to which cloud-seeding had become closely linked.

The CSIRO cloud-seeding program evolved at the time that Australia was building its post-war political and economic relationship with USA. The cloud-seeding group too devoted much effort to creating links with its

American counterparts. It has often been claimed that this country's post-war relationship with the USA has been virtually colonial in nature: it seems obvious to look at how the political and scientific links between the two countries might be related. Overall it seems that the scientific relationship mirrored the political one (as has been claimed for the relationship between Australia and Britain in the colonial period[4]). Years ago Donald Fleming remarked that the natural history enterprise 'served a fundamental part of the quest for a national identity in societies where cultural differentiation ... was insecure, and the sense of the land correspondingly important for self-awareness'[5] – and in the case of post-war Australia one could take the 'cultural differentiation' to be differentiation from America. I expected to find evidence of this in the cloud-seeding program, and certainly the Australia group insisted vehemently on the location-specific nature of its research, and the primacy of local knowledge. But this seems to have been more to justify their activities within Australia than to differentiate themselves from their American counterparts – although they did assert their independence in other ways.

Fleming also wrote of how natural history 'coincided with the primary national purpose of mastering [the] environment and canvassing its economic potentialities'.[6] The cloud-seeding program seems to suggest that in the 1950s and '60s Australian science, despite its best endeavours, was still valued within Australia primarily as an adjunct to the productive system, remaining bound 'to an ethic of practicality and knowledge-for-use', which Fleming attributes to a continued identification with 'the pioneers'[7] Manning Clark, like Fleming, noted that in Australia this identification persisted long after the so-called pioneers had a firm, technological grasp of the country.[8]

Sources

My account of the cloud-seeding program is drawn almost entirely from archival material held at the CSIRO Radiophysics Laboratory in Sydney, material which to the best of my knowledge has never been used before. These files are mainly from the Division of Radiophysics. The archive also contains some files from the Division of Cloud Physics, a separate CSIRO

Division to which the cloud physics program was transferred in 1972, but other archival material was transferred to what is now the Division of Atmospheric Research in Melbourne and has been unavailable to me for this study. Because I have used a limited range of sources for this account it can only be a partial one at best, told mainly from the viewpoint of CSIRO. C. B. Schedvin too has written a brief, unpublished, history of the program from the same point of view, but based on archival material originating in the CSIRO central office and the CSIRO Executive in particular: this account I discuss below.

The history of cloud-seeding in the USA has been well documented but published accounts of the CSIRO program are few. The best one is probably that by E. J. Smith, a member of the CSIRO program, which was published in 1974.[9] This is a straightforward summary of the CSIRO's experiments which gives no consideration to the context in which they were carried out; I have not drawn upon it for this study. A similar but more technical account, concentrating on the experimental work of the 1980s, has been given by Warren King, another researcher in the program.[10] A slightly broader approach has been taken by Brian Ryan, yet another former member of the Division of Cloud Physics. His unpublished manuscript, 22 pages long, outlines CSIRO's work on cloud and rain physics in general; only a few pages are devoted to the practical program, and again this is a summary of the experiments, with the conclusions drawn from them.[11]

C. B. Schedvin's treatment of the cloud physics program is the fullest I have found (29 pages) . It is a section of a draft chapter, written around 1986, in the second (unpublished) volume of his history of CSIRO. Schedvin traces the development of the program from 1946 to 1984, giving much attention to rainmaking. He also comments on the general features of the program, noting that, like other attempts at artificial rainmaking made elsewhere, the CSIRO work had the pattern of initial caution followed by periods of over-optimism and premature claims of success.[12] In this manuscript Schedvin takes a largely 'internalist' view of the program, although he does note that rainmaking was chosen as a research program because it was 'an applied problem of major potential significance'[13]; that rainmaking was 'the public face of cloud physics'[14]; and that there was pressure as early as 1950-51 for 'practical rainmaking' to ease drought[15]. Although I cannot comment on the complete manuscript, in dealing with cloud-seeding Schedvin has not chosen to elaborate on the political or economic context of the work. His general conclusion is that there was relatively slow progress in understanding cloud behaviour and precipitation, and that if the theory had advanced more rapidly the rainmaking program would have closed sooner than it actually did[16] (because the theoretical work would have allowed the cloud-seeders to better understand the limitations of their technique).

Why the program persisted

If one question is: 'Why did the CSIRO program cease while similar work in other countries kept going?', another question is, paradoxically: 'Why did the Australian program keep going as long as it did?' The accounts of the program discussed above all suggest that an initial optimism about the prospects of rainmaking was whittled away by a growing understanding of the physical processes involved, dampened further by field trials that had negative or ambiguous results, and finally killed when the computed cost-benefit ratio of seeding deteriorated badly. All, except Schedvin's, consider these events in isolation. When I began this study I considered it likely that 'external' interests were at least partly responsible for the program's continuing as long as it did, even in the face of very early doubts about whether cloud-seeding could ever be useful under drought conditions. In at least one published CSIRO report it is admitted that eagerness to produce tangible results, especially under drought conditions, meant that a lot of cloud-seeding activity was not run as a well-designed experiment, and thus was considered to be of no use in gauging the effectiveness of the technique.[17] But a second look seemed to suggest that the cloud-seeding program might have persisted partly because of the *lack* of effective connection with such interests – what could be called the 'radical disconnection' of this part of CSIRO from the economic/productive system, and its orientation, instead, towards the international (and USA-dominated) scientific community. This disconnection is a well-recognised feature of the post-war CSIRO: Schedvin noted that research programs were inclined to take on a life of their own, and to take scientific criteria as their points of reference.[18] But it is a little surprising that such an apparently 'applied' research program as cloud-seeding should have showed this.

The problem that Schedvin identifies – the pure and applied parts of the program becoming uncoupled – seems to be the key one. Success in cloud-seeding depends strongly on local factors.[19] Writing in 1982, King formulated three questions that in 1948 were the ones that had to be answered to establish the long-term prospects for cloud-seeding: the most critical was, 'How often do suitable clouds occur?'[20] The answer varies from region to region. King claims that the question was not tackled until the mid-1960s, due to lack of suitable instrumentation.[21] Yet he has also privately admitted that the separation between the 'practical' cloud-seeding group and the 'theoretical' cloud physics group, within the same laboratory in CSIRO, led the cloud-seeding program to run for ten to fifteen years longer than it otherwise would have; the 'theoretical' group already possessed the instrumentation that the 'practical' group needed to determine the frequency of suitable clouds.[22] It seems that the two sides of the program may have developed different agendas: the practical side was the more valued within Australia, but the theoretical had more international esteem.

Notes

1 . Jeff Townsend, *Making Rain in America: A History* (Texas Tech University, Lubbock, Texas, 1975).

2. J. Maybank, The scientific planning and organization of precipitation enhancement experiments, with particular attention to agricultural needs, World Meteorological Organization Technical Note No. 154 (Secretariat of the World Meteorological Organization, Geneva, 1977).

3. E.g. South Africa has been running experiments for at least the past fifteen years. (G.K. Mather and D. Terblanche, 'Initial results from cloud seeding experiments using hygroscopic flares', paper presented at the World Meteorological Organisation Conference on Weather Modification, Paestum, Italy, 1994.

4. Roy MacLeod, 'On Visiting the "Moving Metropolis": Relections on the Architecture of Imperial Science', *Historical Records of Australian Science*, 5, 3 (1982), 1-16.

5. Donald Fleming, 'Science in Australia, Canada and the United States: Some Comparative Remarks', *Proceedings of the 10th International Congresss of the History of Science*, 1962 (1), 180-96, quoted in MacLeod, *ibid.*, p. 4.

6. *ibid.*, p. 4.

7. Fleming, *ibid.*, p. 183.

8. 'By 1960 and possibly earlier the material backwardness, the isolation and man's lack of power to subdue the ancient continent ceased to be the living present, although they lingered on as part of the dead hand of the past, weighing on the brain of the living.' Manning Clark, 'The Quest for an Australian Identity', in Manning Clark, *Occasional Writings and Speeches* (Fontana, Melbourne, 1980), p. 221.

9. E. J. Smith, 'Cloud Seeding in Australia', in W. N. Hess (ed.), *Weather and Climate Modification* (John Wiley, New York, 1974), 432-453.

10. W. D. King, *Cloud seeding in Australia: experiments 1948-1981 and prospects for future developments* (unpublished mimeograph, CSIRO Division of Cloud Physics, Sydney, 1982).

11. Brian F. Ryan, *Cloud Physics Research in Australia* (unpublished MS).

12. C. B. Schedvin, unpublished MS, from volume 2 of Schedvin's history of CSIRO (c. 1986), p. 60.

13. *ibid.*, p. 60.

14. *ibid.*, p. 65.

15. *ibid.*, p.72.

16. *ibid.*, pp. 70-71.

17. 'In the past, because of economic pressures such as those caused by drought, the tendency was to begin seeding a given area as soon as possible. This left minimal time for planning procedures such as examining alternative target areas, optimizing the use of controls, selecting the best season, or installing extra rain gauges.' (CSIRO Cloud Physics Division, *Research Activities* (July 1979), p. 26.)

18. C. B. Schedvin, 'CSIRO: What went right? What went wrong?', *Australian Physicist* 26, 9 (September 1989), 211-215, p. 213.

19. W. D. King, *Cloud seeding in Australia: experiments 1948-1981 and prospects for future developments* (unpublished mimeograph, CSIRO Division of Cloud Physics, Sydney, 1982), pp. 10-16.

20. *ibid.*, p. 1. The other two questions were, 'Would these clouds eventually produce their own ice crystals and rain if left untreated?' and 'What magnitude increases in rainfall could be expected from seeding?'

21. *ibid.*

22. W. D. King, personal communication

Chapter 1: Weapon of war, 1946-1952

... the condition [drought] keeps occurring and occurring again, when there is the possibility that by spending a bit of time and money the country's greatest enemy could be conquered.

R. W. Clay (private citizen) to CSIR, 6 December 1948.[1]

The Radiophysics Laboratory and its leaders

The early history of the Radiophysics Laboratory has been described many times.[2] Founded in 1939 to research the new 'weapon', radar, it ended the war as one of the largest divisions of CSIR, and one of the most prestigious. Along with the other physical science divisions of CSIR, which had been called into existence to serve the war effort, the Radiophysics Laboratory had no pre-existing peacetime role to return to.

In 1942 the Laboratory's newly appointed head was F. W. G. (Fred) White. In 1943, while touring radar establishments in the UK and USA, White came across Edward G. ('Taffy') Bowen, then working at the Radiation Laboratory of the Massachusetts Institute of Technology. White and Bowen had first met at King's College, London, when White was a lecturer and Bowen a research student. White invited Bowen to become Assistant Chief of Radiophysics, taking charge of its research activities, and Bowen duly arrived in Australia in 1944. In the following year White was elevated to the CSIR Executive and given special responsibility for the physical science divisions; in 1946 Bowen was formally appointed as the Chief of Radiophysics. He held the position until his retirement in 1971.[3]

Bowen was a Welshman who had gained his PhD under E. V. Appleton at the University of London in 1933, working on atmospheric physics. In 1935 he became one of the small group working under Robert Watson-Watt that developed the first British experimental air-warning radar, and went on to lead the team that developed the first British airborne radar. In 1940 he was the radar representative with the Tizard Mission, which transferred important aspects of radar technology from Britain to the USA. Bowen spent three years in the USA, first in Washington as a radar liaison officer and then at the MIT Radiation Laboratory developing airborne radar systems.[4]

For many years Bowen's right-hand man in Radiophysics was J. L. (Joe) Pawsey, who played a very important role in fostering the new science of radio astronomy at the Laboratory.[5] Pawsey had studied physics at the University of Melbourne and then obtained his PhD in 1934 under J. A. Ratcliffe at Cambridge, working on ionospheric studies. He then worked for five years at EMI, contributing to the technology that was to make television commercially viable. At the outbreak of war Pawsey returned to Australia, joining Radiophysics in 1940. By 1945, when Radiophysics began its postwar program of research, he was recognised as the leader of Radiophysics' investigations of 'fundamental science'.[6] According to his colleagues, Pawsey believed in the value of attempting the occasional 'long shot' – and was 'an arch-empiricist', whose favourite saying was 'suck it and see'.[7]

The post-war CSIR/CSIRO

Pawsey's attitude was in tune with the CSIR culture of the time. At the end of the war CSIR faced the future with a desire to reduce the amount of applied research it was doing in favour of the search for knowledge. Influential individuals, such as David Rivett, CSIR's Chief Executive Officer from 1926 to 1948, and Fred White, believed strongly in the 'classical' theory of the growth of scientific knowledge which emphasised rationality, autonomy and self-directed inquiry. This view was strengthened by the greater role of the physical sciences in CSIR during the war; in the physical sciences there seemed no doubt that the advancement of abstract knowledge came before its application.[8] At the war's end CSIR was about to enjoy more freedom to explore than it had ever had: in the 1930s it had frequently been under trial and expected to rescue particular industries, while during the war its role was to help with whatever problem came to hand.

To assist the pursuit of uncommitted enquiry CSIR wanted to separate scientists from consumers of science – not out of a lack of interest in practical matters, but to protect the researcher from day-to-day problems.[9] The post-war organisation was structured in a way that accorded with these principles of scientific autonomy and individualism, and was designed to maximise individual freedom. Although the Executive was formally responsible for allocating resources of the organisation, in practice the Chiefs of Divisions (the organisation's sub-units) were highly autonomous.[10] Research objectives were set from the bottom up: the Executive merely arbitrated on research programs recommended by the Chiefs. The promise of such freedom in directing research had swayed Bowen in his decision to head Radiophysics.[11]

Radiophysics' research program

In July 1945 Bowen presented to the CSIR Council, the organisation's governing body, a peacetime program for Radiophysics.[12] He wanted to strike a balance between applied and fundamental research, as the war had forced Radiophysics into giving 'too much' attention to practical problems and more fundamental research was needed to redress the balance. The main categories of work outlined in the program were studies of radio propagation, vacuum research (for the purpose of generating radio waves at very high frequencies), radar aids to navigation and surveying, and the radar study of the weather.[13] This last was included because during the war it had been found that storm clouds produced characteristic radar echoes.

Woodruff Sullivan has traced the rise and fall of Radiophysics' various research programs between 1946 and 1953. Vacuum physics work died away within two years and the application of radar to air navigation, although highly successful (i.e. adopted by the industry), ceased to be significant after the mid '50s.[14] The programs that flourished were radio astronomy ('radio propagation' at first) and rain and cloud physics. Between 1946 and 1949 these programs increased their share of the professional staff from 6% to 63%, while total staff grew by only 25%. In terms of publications coming from Radiophysics, radio astronomy and rain and cloud physics accounted for 71% of the papers – the radio astronomers, however, were more productive than the cloud physics group.[15] The radio astronomy group was led by Pawsey, while Bowen directed the rain and cloud physics work.

The cloud physics program, and especially its rainmaking component, flourished in those early years because it promised significant economic benefits to Australia, and because it balanced the more arcane radio astronomy research.[16] The growth of these areas was not due just to their own intrinsic strengths. Some of the research directions Radiophysics took in the early post-war period led to dead-ends, mainly because they did not match up with the needs, interests or capabilities of Australian industry. An enthusiastic Bowen, making use of his connections in the USA, had Radiophysics experimenting on the production of the new transistor technology soon after it was invented, but this came to nothing when Australian companies decided that they were interested in using transistors, not in making them. Between 1947 and 1949 Radiophysics also built one of the world's first-generation computers, but by 1954 the now CSIRO Executive had decided to abandon the field of computer design, perhaps partly to concentrate resources on fields of basic research such as the new radio astronomy and cloud physics.[17]

The invention of cloud-seeding

In the mid 1940s the most widely accepted theory of rain formation was that proposed by Tor Bergeron. This held that water vapour in the atmosphere, as it cools, condenses upon small particles to form a cloud. As the water vapour condenses it releases 'latent heat' which forces the cloud to higher altitudes, resulting in a progressive cooling. The cloud extends upwards until some of the water droplets freeze as small ice crystals. (Normally the water in the tops of clouds is supercooled – that is, the water freezes at well below 0°C.) The ice crystals act as 'nuclei', attracting water vapour and growing as droplets. Eventually they fall through the cloud, collecting more water droplets as they go. Depending on various conditions the precipitated water may fall as hailstones, snowflakes or raindrops. In the mid 1940s this 'Bergeron process' was widely believed to be the only mechanism of precipitation, although some literature existed on the formation of water droplets in warm (non-freezing) clouds by collision and coalescence.

In early 1947 the aim of Radiophysics' cloud physics program was simply to investigate how radio waves were reflected by water drops and ice particles in clouds. The object was to verify existing theories of radio scattering, make fundamental studies of cloud structure and water-drop formation, and see if this knowledge could be applied to short-term forecasting.[18] These plans were fundamentally altered by a serendipitous discovery made in Schenectady, New York, at the research laboratory of the General Electric Company.

World War II had stimulated research in a number of areas of both pure and applied meteorology. Among the many people led into war-related meteorological research was Irving Langmuir, Associate Director of the General Electric Company and a Nobel prize-winning physical chemist. Langmuir had begun to work in the area by studying the uses of smoke-screens, and then the nature of clouds in relation to their effects on the icing-up of aircraft. From there he branched out into more general studies of meteorology.[19]

Langmuir was assisted by a technician, Vincent Schaefer. In the summer of 1946 Schaefer was studying clouds in a laboratory setting, attempting to create ice-crystals in a freezing unit. On 12 July, having trouble keeping the chamber cold enough, Schaefer put a large piece of 'dry ice' (frozen carbon dioxide) into it. Upon contact with the chamber's atmosphere the dry ice seemed to produce millions of tiny ice crystals.[20] After more tests Schaefer concluded that the dry ice had produced natural 'condensation nuclei' – the ice crystals – by lowering the temperature of the cloud to about -40°C. Schaefer decided to try to recreate the effect in the field. On 13 November 1946 he scattered three pounds of dry ice into a stratified cloud and saw 'an avalanche' of ice crystals fall thousands of feet below the cloud before evaporating. Cloud-seeding was born.

CSIR enters the field

News of Schaefer's historic experiment reached the CSIR group by 19 November, through newspaper reports.[21] Bowen was in the USA and so

Pawsey, as acting Chief, wrote to N. A. Whiffen at the Australian Scientific Research Liaison Office within the Australian Embassy in Washington, asking him to find out more about the work at General Electric. The Radiophysics group had known about Schaefer's laboratory trials for several months, for one of Radiophysics' staff, E. B. Kraus, had visited the Schenectady laboratory in the middle of the year.[22] But until Schaefer's field trials, Radiophysics had not been interested in rain-making.[23]

On 5 December Pawsey wrote to Fred White, enclosing a report by Kraus and another of Radiophysics' staff, Pat Squires, on the technical background to the problem of artificially induced precipitation. The CSIR group had already reproduced Schaefer's laboratory experiments.[24] Now it planned to do more laboratory investigations in collaboration with the CSIR Division of Physics and also wanted to carry out research high in the atmosphere. For this, high-flying aircraft were needed, and for the more regular cloud physics work, they needed a lower-flying craft such as a Tiger Moth. Pawsey asked White to approach the RAAF to secure these.

Security issues

Getting further information about the experiments at General Electric was difficult. At first this was said to be because General Electric was trying to clarify its patent position, but later it became clear that the difficulty was because the technique was seen to have potential military value.[25] In February 1947 Whiffen in Washington reported that he was unable to obtain information from General Electric until he had obtained clearance from the defence services, for although the project was not yet classified, General Electric was trying to have it sponsored by a branch of the services.[26] By early March the project was to be highly classified, 'on account of its possible use in bombing targets under cloud'.[27] Indeed, the Australian Embassy advised Radiophysics that only an officer of the Australian Army would be permitted to discuss the work on artificial precipitation with General Electric.[28] The value to Radiophysics of General Electric's information was already diminishing, as in February 1947 the Australian group had successfully seeded clouds in the field. Nevertheless, Radiophysics continued to request the information. A frustrated Bowen wrote to the Australian branch of General Electric in March 1947, trying a backdoor approach. However, he emphasised that 'we do not regard any of this work in the military sense and would not agree to handle it as such'.[29] A final direct appeal by the Australian Embassy in Washington led to an Embassy officer being allowed to visit Langmuir and Schaefer. But Bowen cabled his regret that General Electric would not release the results except on a classified basis. 'We regard this work of great importance to primary industry in Australia', he wrote, 'and will therefore not agree to discuss it on a secret basis'.[30] By mid-May Whiffen had received clearance from the US War Department to discuss aspects of General Electric's work. The details, when released, were not particularly useful to Radiophysics.[31] Apparently the two programs had already diverged.

In the background of these developments was an increasing concern about the propriety of CSIR's undertaking secret research. Bowen's statement, rejecting secrecy, echoed similar statements by David Rivett in the same month: in a public address on 'Science and Responsibility' Rivett had stressed the necessity for complete freedom in the search for and exchange of knowledge, and had attacked the continuation of the security arrangements that had prevailed during the war. Secrecy, he pronounced, was futile: with regard to nuclear technology, the so-called 'secrets' of the atomic bomb were a set of engineering procedures which other nations were certain to develop within a few years.[32] The Australian defence forces felt vulnerable in their relation to science and technology. The Defence and Supply departments controlled no research establishments of their own but relied on the cooperation of CSIR and a few university and private groups. Australia was a marginal player in the defence networks of the western world and the flow of technical information from the UK and the USA could easily be stopped.[33] Rivett's position was therefore an embarrassment.

In practice Rivett accepted that security arrangements were necessary to cover the patches of defence work remaining in CSIR. (There was nothing of this kind, however, in Radiophysics.) But throughout 1947 and 1948 concerns over CSIR's 'lax' security arrangements surfaced repeatedly. As the Cold War intensified in 1948 the supply of 'sensitive' information from the UK was cut off, apparently as a result of pressure from the USA. In Australia these doubts culminated in a political attack by the Federal Opposition parties on the government and on CSIR. Following the attack the organisation was subjected to an external review and subsequently reconstituted as CSIRO (Commonwealth Scientific and Industrial Research Organisation) in 1949. Even before the review the Division of Aeronautics, the section of CSIR still most involved in defence work, had been transferred to the Department of Supply and Development. And even after the organisation was reconstituted security remained a sensitive issue.[34]

International liaison

In 1947 some aspects still remained of the close scientific liaison that the war had created between Britain, the US and Australia, especially in the field of radar.[35] Australia's Scientific Liaison Offices, particularly that in Washington, had played an important role in transferring technical information among the three countries. The ASLOs continued to provide such help to Radiophysics in its attempts to gather information about rain-making programs. They both acted as CSIR's agents in dealing with other countries and circulated information over a wider area (for instance, collecting from DSIR in the UK information on Russian cloud-seeding experiments); their officers made personal visits to sites and wrote reports on them, represented Radiophysics at meetings and even presented Radiophysics' papers at these meetings.[36] Radiophysics staff themselves put a great deal of effort into the same kinds of activities to maintain their overseas contacts.[37] This too was a legacy of the war for, particularly from 1942, there had been a great deal of interchange of scientists, especially physicists, among the three countries, and the value of these opportunities for interaction was not forgotten.[38] Overseas trips by Radiophysics staff – and there were a surprising number at a time when the passage by ship to Europe took four weeks – were for 'intelligence' gathering, education, publicity and making personal contacts.[39] In the field of radio astronomy and, apparently, in rain physics, Radiophysics was very concerned to avoid duplicating the efforts of others.[40] It could not afford to put scarce resources into areas in which, all else being equal, the Australians would be handicapped by distance-induced delays in having their work published in the major journals. Sullivan notes that after some radio astronomy work had been needlessly duplicated by Radiophysics as a result of poor communication, Pawsey tried to coordinate certain aspects of the research in Australia and the UK in 1946 and again in 1948-49.[41] Sullivan identifies the end of these attempts with the realisation that 'Australian science ... was becoming an independent entity, not just an extension of the mother country'.[42] (As 'the colonials' were attempting to organise 'the metropolitans', a certain amount of independence had obviously been achieved already!)

In the late '40s and early '50s Radiophysics was building its relationships in the field of cloud and rain physics with other researchers, particularly those in the US. It managed to get a toe-hold in the American system to the point of being invited to submit papers to US meetings concerned with weather modification: the second Radar-Weather Conference (October 1951) appears to have been an all-American affair with the exception of Bowen.[43] Such involvement was feasible because the field was a small one. Assessing cloud-seeding in the USA in 1951, Bowen thought that there was little real experimental work being done, and that 'one cannot help drawing the conclusion that they are lagging far behind our own efforts'.[44]

The CSIR cloud-seeding program takes shape

Radiophysics began field trials, seeding clouds with dry ice, in January 1947. On 5 February over Bathurst, NSW, the cornerstone of its future research was laid when a cumulus cloud was seeded and within minutes swelled into a towering anvil and began to drop rain. This event was later claimed as 'the first occasion in history in which a substantial rainstorm was deliberately caused by man' – strictly true, for Schaefer's historic experiment had produced snow![45] Within days Bowen claimed that 'it is practically certain that we can produce rain artificially, given the right meteorological conditions'.[46] The program for the next few months was to carry out further dry ice experiments and to test the usefulness of other materials for seeding. By late March the CSIR Division of Physics had confirmed US findings that silver iodide was an efficient seeding material. Radiophysics was apparently keen to begin using this material, but was slow to do so (apparently for technical reasons) and had not taken it up even by September 1948. Throughout 1947 and 1948 the focus of Radiophysics' work was on the physical processes occurring in seeded clouds; it had not yet begun to look at the problem of inducing rainfall over a wide area.[47] By the end of 1948 the Radiophysics researchers had made about 40 seeding tests (all with aircraft supplied by the RAAF). The results led them to believe that they could identify reasonably well clouds that would respond to being seeded with dry ice. By November 1948 Bowen had turned his attention to the relation between cloud conditions and rainfall, especially during droughts; however, he thought that the relation between cloud type and the effectiveness of seeding could be considered at a later stage.[48] By 1949 about eighteen people were connected with the rain and cloud physics program. The program was now dominated by theoretical studies, perhaps partly because of the increasing difficulty of finding 'suitable' clouds that were not already raining. In 1950 one of the cloud seeders, E. J. (Pat) Smith, estimated that the expectation of finding such clouds had declined from 50% in 1948 to 30% in 1949 and was tending to 0% in 1950![49]

This decline may have been due to long-term climatic variation for 1950 and 1951 were drought years in Australia's eastern States. Around the middle of 1951 the Radiophysics group began to be drawn into operational cloud-seeding – practical seeding to relieve drought – or at least took the first steps towards it. The now CSIRO group had had some contact with parties in Tasmania and when Bowen visited Tasmania in August 1950 he found 'intense' interest in rainmaking by the agricultural, forestry and hydro-electric power authorities. Following this visit Pat Smith was sent to Tasmania to start a series of experiments that would, in a year or two, indicate whether Tasmania was suitable for practical rainmaking. The experiments were hindered by a shortage of suitable clouds, and by May 1951 they were wound down and Radiophysics intended to retrieve its equipment from the field. But in June 1951 Radiophysics had to turn its attention back to practical cloud-seeding, following a visit from Ian Clunies Ross, who had joined Fred White as the second member of the new CSIRO Executive. Clunies Ross 'stressed his interest in such experiments [i.e. those reported to have been carried out in the US] in view of the fact that the Executive is continually embarrassed by inquir[i]es about rain-making.'[50]

As a result of this direct pressure Radiophysics decided to conduct experiments modelled on those that Langmuir was now carrying out in New Mexico, and for which he was claiming great success. These experiments used silver iodide, not dry ice, as a nucleating agent. Silver iodide worked as a seeding agent because its crystal structure is extremely similar to that of ice crystals; it also allowed clouds as warm as -4° C to be seeded. Its potential had been discovered by another researcher at the General Electric laboratory, Bernard Vonnegut, at almost exactly the same time that Schaefer had carried out his historic field trial. Vonnegut went on to devise a way of vaporising silver iodide so as to introduce it into clouds in a suitable form: this was to heat the material to 2500 °F to produce crystals of silver iodide 'smoke' and then to send these into the air on a heated updraft. The device for creating this updraft was called a 'ground generator'. Such generators became popular with commercial 'rainmakers' as they were cheaper to operate than an aircraft. Silver iodide was also much easier to handle than dry ice, which had to be kept cold.[51]

The experiments that Radiophysics now carried out with ground generators were modelled on those of Langmuir but did not replicate them exactly, for under Australian conditions reproducing Langmuir's set-up would have required a very large amount of the rather costly silver iodide.[52] Radiophysics' experiments differed significantly from Langmuir's in at least one respect: they were based on the assumption that a chain reaction in rain formation was possible. Working on this assumption, the researchers used far smaller quantities of seeding material than they would have if they had not assumed a chain reaction. These experiments had negative results, which the CSIRO group used to repudiate Langmuir's claims for the effectiveness of ground generators.

Even before these experiments Bowen had preferred aircraft seeding over the use of ground generators, arguing that an aircraft allowed a known quantity of material to be introduced into a cloud at a specific point and the growth of 'precipitation elements' traced.[53] (For most of its subsequent cloud-seeding experiments Radiophysics used aircraft fitted with burners that vaporised a solution of silver iodide to produce the tiny silver iodide crystals.) Radiophysics' field trials, in contrast to Langmuir's, were directed towards trying to determine the physics of the processes rather than 'merely' showing that cloud-seeding worked. It may be that Radiophysics' preference for airborne seeding was also part of an attempt to differentiate the Australian experiments from Langmuir's activities and claims. The relationship between Radiophysics and the General Electric researchers was faltering as early as 1948, and by 1951 Bowen was openly voicing his annoyance at Langmuir's 'highly irresponsible statements' in the popular press and the lack of 'properly authenticated scientific account[s] of the data from which the conclusions are drawn'.[54] Langmuir's pronouncements were having an adverse effect on CSIRO's work, both because 'there is a relatively small body of people who believe [them] and are correspondingly scornful of our own modest claims' and because 'there is a rather greater number of people who point out the absurdity of some of his claims and automatically put all rain-making activities into the same category'.[55]

Jeff Townsend, who has studied the history of rainmaking in the USA, describes Langmuir as one of the cloud-seeding researchers who wished to play 'the grand role of scientific revolutionaries', and who quickly took the position of a rebel against the scientific orthodoxy represented by the US Weather Bureau.[56] This polarisation of the debate in the USA was to lead to a lengthy investigation by a congressional committee (the Orville Committee) in the mid-1950s. Open controversy was finally quietened only in the late 1950s when the responsibility for coordinating research into 'weather modification' was handed to the National Science Foundation. In Australia, by contrast, at least until the early 1950s Bowen took considerable care to keep Radiophysics' rainmaking work positioned well inside the bounds of scientific orthodoxy. He was able to point to two staff, Kraus and Squires, who were *bona fide* meteorologists and who 'between them probably know as much as anyone about the physics of cloud and rain formation'.[57] Radiophysics' first public announcement of its cloud-seeding work appeared in *Nature* on 12 April 1947. Although Bowen seems to have enjoyed being able to point to newspaper reports of CSIRO's cloud-seeding work – including some in the New York Times[58] – he cautioned his staff about the fact that reports were appearing in the press before the scientific journals: 'I consider this to reflect badly on the standing of the Laboratory as a scientific institution and will do my utmost to see that it does not happen in future.'[59] By contrast, Langmuir and Schaefer were not publishing very much, if at all, in the scientific literature, but were communicating through the popular press.[60] Although Radiophysics apparently did not wish to practice 'popular science' in this way, press coverage of the American work influenced their own program by leading to calls for them to take on operational, i.e. applied, cloud-seeding.

Operational cloud-seeding

Bowen had sought to avoid any involvement in practical rainmaking. In February 1947, in a carefully worded letter to David Rivett, he commented that the experiments had been so successful that 'we must guard against the danger of allowing ourselves to be diverted from the scientific work to the more practical problem of making rain in the drought areas. I think that the best way of doing this is to make careful arrangements at an early stage for someone else to be responsible for the application of our results.' He went on to suggest that the subject might be important enough to warrant the creation of a special government department, and that he saw a role in operational rainmaking for the RAAF (flying), the Weather Bureau (determining favourable conditions for seeding), agriculturalists (establishing the need for rain) and CSIR (to advise on methods).[61] Rivett was in favour of the idea.[62] But although Bowen was still discussing this with White in 1948 – 'My main enthusiasm has been for getting work of this description done and I don't mind much how it is done' – nothing came of it.[63]

In the second half of 1951 the 'operational' side of Radiophysics' cloud and rain physics program continued to expand. CSIRO's Tasmanian State Committee decided to drop the dry ice experiments that had been started in 1950, because of their relatively high cost, but wanted to experiment with ground-based silver iodide burners. Langmuir's experiments with such burners had been reported in the Australian press as early as January 1950, and Radiophysics had started similar experiments at Hay, NSW[64]. Members of the local Pastures Protection Board (prominent graziers in the district) were asked to keep special records of the rainfall. The local people became convinced that the Hay experiment was producing rain: '[CSIRO] will certainly be called on if they ever have a drought'.[65] But CSIRO decided that the burners had not worked.[66]

By late 1951 the Minister for the Army had asked CSIRO to assist in ameliorating the drought then affecting Queensland. In his reply to Fred White on this question Bowen distinguished between controlled experiments, which took time and resources to arrange but which were scientifically useful, and uncontrolled experiments that would be useless in accounting for what occurred, whether there was rain or not. He was recalcitrant, 'more than ever convinced that a proper scientific investigation of the problem is the only way in which progress will be made ...'.[67] Bowen's reply to requests from drought-stricken regions that CSIRO carry out experiments for them was usually along the lines that 'our chief concern at the moment is to obtain a complete picture of the physical processes involved'.[68] A request from Broken Hill Water Board led to the formulation of policy: CSIRO would give practical assistance when relief was needed urgently, but the operation would have to be organised and financed by those requesting the help.[69]

While reluctant to get involved directly, Bowen was very encouraging to others, both individuals and organisations, that wanted to carry out their own cloud-seeding experiments. He seems to have looked upon experiments by other parties, even if uncontrolled, as possible sources of useful information. When the Zinc Corporation of Broken Hill requested advice on undertaking its own experiments, Bowen replied that '...we are not being secretive about our experiments on the physics of rain formation. We are, in fact, anxious to tell everyone all that we know, especially people like yourselves who might be able to help and perhaps co-operate by doing similar experiments.'[70] Similarly, in the course of a long correspondence with a Queensland grazier, W. H. Anning, he discussed experiments on non-freezing clouds. As Radiophysics was unlikely to do many experiments of this kind itself, he wrote, 'it would be an excellent thing ... if you could see your way to seeding warm clouds. ... [W]e would be terribly interested in the results.'[71]

Using outside resources

Bowen was certainly interested in recruiting resources from every other source available to him. He looked for advice to other CSIRO Divisions – those of Physics, Aeronautics, Industrial Chemistry, Tribophysics, and particularly the Meteorological Physics section in Melbourne – and to organisations such as the Ministry of Munitions, the Long Range Weapons Establishment in South Australia, and of course the Weather Bureau. Most of these requests were for technical advice. For data, Bowen enlisted the help of Australian National Airways, Qantas and Trans-Australian Airways to measure temperature as a function of altitude. For equipment, Bowen approached sources as diverse as Richard Woolley, the Commonwealth Astronomer (for a rain gauge), the South Australian Department of Mines (for a dust counter) and the NSW Department of Railways (for a coal crusher, in use at the Ultimo power station, with which to crush dry ice). And for places in which to experiment, he requested the use of sites as diverse as the Women's Hockey Grounds at the University of Sydney (Radiophysics was housed at the University until 1968) and the Sydney Harbour Bridge. This far-flung net of connections is typical of Bowen's entrepreneurial style but is also a sign of the continuing material shortages of the immediate post-war period. What is conspicuous, however, is the relatively small number of contacts made between Radiophysics and any agricultural advisers, even the agricultural sections of CSIRO itself, or any bodies concerned with water management.[72]

The major outside resource was, of course, the aircraft provided by the RAAF. For cloud-seeding with dry ice the material had to be dropped into clouds from above. This needed a high-flying aircraft and most light civilian 'planes were not up to the job.[73] (This was the greatest impediment to private cloud-seeding experiments.) The first move to obtain high-flying aircraft had been initiated by Pawsey, who in December 1946 had asked White to approach the RAAF about aircraft use; however, in November Kraus had already made the first (fairly informal) approach to the RAAF about the use of a lower-flying plane. As a radar research establishment Radiophysics had developed a strong working relationship with the RAAF during the war and so hoped to be able to continue to draw on its resources. Certainly, once the work was under way

Radiophysics made regular reports on its progress to the RAAF; it also continued to provide advice on subjects such as air navigation.[74]

Cloud-seeding as a weapon

The exact nature of the RAAF's interest in cloud-seeding is unclear. During the war the RAAF had had a great need for meteorological services: so great, in fact, that in 1940 the Commonwealth Bureau of Meteorology was attached to the RAAF as a directorate.[75] The kinds of information that interested the RAAF were forecasts of wind direction (for navigation), cloud cover and general visibility (for air strikes, landings and parachute drops), and general factors that affected aircraft safety, such as turbulence and icing. After the war, at the same time it was supporting Radiophysics' cloud physics research, it was receiving information about US research on weather through its own channels. In July 1948 H. A. Wills of the Division of Aeronautics passed on to Bowen reports pertaining to a US project, 'Thundercloud', which, he said, 'I have at last managed to pry out of the R.A.A.F.' – and these were unclassified reports.[76]

On their side, the US defense forces were interested enough in the Australian work to ask Radiophysics for information, both directly and through the Australian Meteorological Office.[77] Although it was reported in late 1948 that the US Air Force had proved to its own satisfaction that 'no useful results' could be achieved through seeding clouds with dry ice, military interest in cloud-seeding persisted. Military sponsorship of General Electric's work had ended fairly early but various sections of the US forces sponsored other programs: the US Signal Corps sponsored work at MIT, and in 1953 the Air Force established a tropical meteorology lab in Honolulu and began backing a cloud physics program at the University of Chicago.[78] The Defense Department was one of Langmuir's staunchest supporters: 'Project Cirrus', a project to test the efficacy of cloud-seeding which ran from 1947 to 1952 (and after which Langmuir went into semi-retirement[79]) was financed entirely by defence funds.[80] The military support fundamentally shaped the development of rainmaking research in the USA.[81]

The US Defense Department was undoubtedly interested in cloud-seeding as a weapon. Until 1972 at least, the Naval Weapons Center in California studied both cloud-seeding techniques and the effects of seeding over an extended area (and also in the early 1970s personnel of the Defense Department carried out a large seeding operation to alleviate droughts in the Philippines[82] – perhaps as a field test). The original interest in General Electric's work had been reported to be that of bombing under cloud cover; a 1968 report by geophysicist Gordon J. F. MacDonald, who had been connected with the defense establishment, also suggested that seeding could be used 'for local enhancement of precipitation to cover or impede various ground operations', or to remove moisture from the air, so as to prevent rain downwind, thus subjecting a specified stretch of territory to drought.[83] There seems to be good evidence that from 1967 the US used cloud-seeding in the Vietnam War to try to hinder the movement of supplies for the Vietcong: the aim was to increase rainfall at the beginning and end of the monsoon, to make travel through the jungle more difficult and to trigger landslides and wash away river crossings. (The results of these 'offensive' seeding operations, however, could not be quantified any more easily than those of civilian seeding programs.[84]) The seeding apparatus for this purpose was developed at the Naval Weapon Center and the techniques used were those of commercial cloud-seeders. The CSIRO group was in contact with the Naval Weapon Center as late as 1970, and provided it with information and instructions on cloud-seeding.[85]

Although hardly as reliable in its effects, cloud-seeding, like the atomic bomb, represented the harnessing of immense forces latent in the natural world, released by a small trigger. This view – that small changes in the atmosphere could bring about large effects – was held by cloud-seeders of all persuasions. Langmuir used to liken seeding a cloud to striking a match that could set a whole forest on fire. The countervailing view, that the forces of the atmosphere were vast and could be altered only by the imposition of equally vast forces, was the more orthodox position held by, for instance, the US Weather Bureau. Townsend notes that the Weather Bureau's opposition to the US cloud-seeders, particularly Langmuir, was partly based on this intellectual stance but also partly on its view of itself as a protector of the public interest.[86] It was also part of the Bureau's public role to defend against the idea that small, man-made triggers could indeed affect the weather, given the widespread concern in the late 1940s and early 1950s that the explosion of atomic bombs might be altering weather patterns. The Bureau would have backed the view (actually voiced by an army meteorologist) that 'it would take 10 atomic bombs per second to have an appreciable influence' on the atmosphere.[87] In Australia these concerns seem to have been muted. Here, insofar as cloud-seeding was popularly seen as a weapon, it was one to be used against the 'enemy' of drought.

Charting a course for the future

Radiophysics' first formulations of the cloud-seeding problem were technical ones. In 1947 Kraus recognised that the viability of cloud-seeding would depend on how frequently suitable clouds (ones above freezing level) occurred, and noted that 'for the time being this problem has been shelved'.[88] In 1951 Pat Smith identified four meteorological variables, not necessarily independent, that were important in determining when a cloud was suitable for seeding with dry ice.[89]

In January 1952, in an outline of the rain and cloud physics work planned for the future, Bowen presented the problem from an economic as well as a technical point of view. He distinguished clearly between ameliorating the effects of drought and increasing agricultural production overall; he also noted the difference between increasing total annual rainfall and increasing the rainfall in a crucial part of the growing season. Only this last possibility seemed to be economically feasible.[90] Bowen seems to have seen cloud-seeding as able to aid agriculture only in a specific and limited way (although he himself was interested in investigating a separate problem – whether drought periods were associated with a lack of cloud). Furthermore, he was extremely aware of the importance of location-specific factors that might affect the efficacy of cloud-seeding, noting that 'it is important to investigate this matter on an Australia-wide point of view to determine in which areas ... [to concentrate on] practical rain-making attempts'.[91] (In later years, Bowen sometimes presented a much less specific view of the possibilities of cloud-seeding; it is hard to decide whether he was doing so to achieve certain ends, or whether he had become carried away by the subject.) Given this appreciation of local factors, and the way that Smith had formulated the technical problems of cloud-seeding, it was logical that the major activity of the cloud-seeding program was to become attempts to establish how often suitable seeding conditions occurred in specific parts of Australia.

Comment

The cloud-seeding program was similar to Radiophysics' other major activity, radio astronomy, in that they were initially driven by radar technology and techniques. In both fields innovation had been brought about by 'marginal' participants, who had introduced techniques developed during the war into a different field – astronomy in one case and meteorology in the other.

The two programs also differed. The CSIRO cloud physics group had less of a problem than did the radio astronomers in establishing their standing with the pioneers in these fields in other countries.[92] This is probably partly because there was no colonial legacy to contend with – Britain was one of the other radio astronomy pioneers, and the one the Radiophysics group looked to most – and because in the USA the field of cloud-seeding seems to have broadened quickly, so that it was not dominated by any one group.[93] And with its promise of practical results, cloud-seeding, and cloud physics generally, was able to act as a smokescreen for the more arcane astronomy program.[94] As that program expanded, this function was to become more important, as the next chapter shows. And yet, for all the vaunted practicality of the program, it seems that by 1949 theoretical studies of rain and cloud physics were dominating the program at Radiophysics.[95] This may simply have been because the number of suitable occasions for cloud-seeding around Sydney was falling: in 1950 Pat Smith estimated that the number of such occasions per year had fallen from 70 in 1948 to 30 in 1949, and then to 5 in 1950.[96] And in 1952 there was a serious setback to the program's practical side, when an RAAF aircraft with its crew, two scientists, and their equipment, crashed into the sea off Cronulla.[97] But the larger role played by theory may simply represent an interest in basic research for its own sake.

Jeff Townsend has pointed out how the Langmuir camp, the cloud-seeders who positioned themselves as 'revolutionaries', preferred to justify their practices by 'experience', that is, practical attempts at rainmaking, rather than by detailed explanations of the physical processes involved. The CSIRO group was somewhat different. At this time CSIRO could be considered the embodiment of scientific orthodoxy in Australia, and the cloud-seeding group sought legitimacy by publishing in the scientific literature. Far from wishing to appeal to popular experience the CSIRO group did not want to take on practical cloud-seeding. Although Bowen seems to have shown a keen awareness of the economic rationale that must govern the use of cloud-seeding, perhaps to some extent this was, or later became, a guise under which the scientific problems could be pursued. In a letter to Bowen in January 1949, Ross Gunn, Director of Physical Research in the US Weather Bureau, virtually accused the Australians of being over-optimistic about the economic potential of the technique – indeed, accused them of lack of objectivity. Bowen's reply was, perhaps, disingenuous:

Here in Australia we have been lucky in our rainmaking work, more particularly in that we have been encouraged to investigate the physics of the process without worrying too much about the economics of the question. ... I was a bit surprised, therefore, to find you saying in your letter "your group feels that artificial seeding is likely to be of greater economic value than we do". I wonder where you have got that impression from?[98]

At the time, some research groups Radiophysics dealt with (the Canadians, for instance) were dubious about the prospects for cloud-seeding, and so Gunn's statement appears to have been correct. Bowen's reply was probably a defensive move aimed at keeping his group dissociated from the enthusiasts of the Langmuir camp and well into the 'scientific' camp. However, elsewhere Bowen admitted that the experiments had concentrated on the scientific aspects of the problem and that the economic problems and the practical application to agriculture were being left until 'a later date'.[99]

There is no doubt that Radiophysics had seized upon cloud-seeding because it genuinely seemed to offer huge economic returns. But the group also saw that

on the experimental side the field is wide open. Here is a major process of nature. No information is available that is worth a damn [sic] which will serve to confirm or re[f]ute.[100]

It may be that not only was cloud-seeding a 'practical' area that counterbalanced radio astronomy, but also that *within* cloud-seeding, in later years, the economic rationale became something of a smokescreen for the science – or the science lost touch with the economic rationale.

Notes for Chapter 1

1. Clay, from Mt Isa, was writing at a time when northern Queensland was drought-stricken. (R. W. Clay to CSIR, 6 December 1948, Radiophysics file A1/11/1.)

2. This description is taken from R. W. Home, 'Science on Service, 1939-1945', in R. W. Home (ed.), *Australian science in the making* (CUP, Melbourne, 1988) 220-251, p. 227 and pp. 232-3.

3. *ibid.*, p. 246.

4. W. T. Sullivan, 'Early years of Australian radio astronomy' in R. W. Home (ed.), *Australian science in the making* (CUP, Melbourne, 1988), 308-344, p. 310.

5. E.g. *ibid.*

6. *ibid.*, p. 313.

7. *ibid.*, p. 334 and p. 336.

8. C. B. Schedvin, *Shaping Science and Industry* (Allen & Unwin, Sydney, 1987),p. 314.

9. *ibid.*

10. Gillespie, D. T. C., 'Research Management in the Commonwealth Scientific and Industrial Research Organization, Australia', *Public Administration* **42** (1964), 11-31, p. 19.

11. Peter Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope* (CUP, Melbourne 1992), p. 30.

12. Sullivan, *op. cit.*, p. 341. The original reference is Radiophysics file D1/1.

13. *ibid.*, p. 310.

14. Robertson, *op. cit.*, p. 31.

15. Sullivan, *op. cit.*, p. 311.

16. The quote is from Sullivan, *op. cit.*, p. 310.

17. Trevor Pearcey, *A History of Australian Computing*, Chisholm Institute of Technology, p. 29 and p. 40.

18. Bowen to Sir Edward Appleton, 6 March 1947, Radiophysics file A1/1/11.

19. Jeff Townsend, *Making Rain in America: A History* (Texas Tech University, Lubbock, Texas, 1975), p. 41.

20. *ibid.*

21. Pawsey to Whiffen, 19 November 1946, Radiophysics file A1/11/1.

22. Pawsey to Whiffen, 19 November 1946; Kraus to Pawsey, 21 November 1946, Radiophysics file A1/11/1.

23. E g. in October 1946 Kraus's work for the immediate future looked like being a mathematical description of the convection processes in the atmosphere. (Bowen to White, 18 October 1946. Radiophysics file A1/11/1.)

24. Kraus to Schaefer, 3 December 1946, Radiophysics file A1/11/1.

25. Cablegram, 11 December 1946, from the Australian Embassy in Washington to Radiophysics; and transcript of article in the Sydney *Sun* newspaper, 23/1/47. Both in Radiophysics file A1/11/1.

26. Whiffen to Bowen, 11 February 1947, Radiophysics file A1/11/1.

27. Australian Embassy, Washington, to Radiophysics, 13 March 1947, Radiophysics file A1/11/1.

28.*ibid.*

29. Bowen to J. P. Tivey, Australian General Electric Pty Ltd, 24 March 1947, Radiophysics file A1/11/1.

30. Cablegram from Bowen to Australian Embassy, Washington, 25 March 1947. Radiophysics file A1/11/1.

31. By the end of the month Bowen noted that 'it is fairly clear that their [GE's] work does not bear very directly on our own efforts at practical rainmaking.' Bowen to Whiffen, 29 May 1947, Radiophysics file A1/11/1.

32. Schedvin, *Shaping Science and Industry, op. cit.*, p. 332.

33. Such information flows *were* cut off. For instance, Peter Morton has found that in 1948-49 America forced Britain to refuse entry to young Australian scientists who had formerly been placed in British institutions for training in advanced rocketry and electronics. Morton comments that this embargo was kept secret and 'has never been fully understood by Australian historians, yet it is a key ingredient in Australian-American relations just after the war'. Peter Morton, 'Engaging with Leviathan: A Historian's Perspective on Using the Scientific Archives of the Department of Defence', in Tim Sherratt, Lisa Jooste and Rosanne Clayton (eds), *Recovering Science: Strategies and Models for the Past, Present and Future* (Australian Science Archives Project, Canberra 1995), 51-56, p. 55.

34. E.g. Schedvin, *Shaping Science and Industry, op. cit.*

35. D. P. Mellor, *The role of science and industry* (Australian War Memorial, Canberra, 1958), p. 439.

36. E.g. T. C. Bell to Bowen, 11 July 1949, Radiophysics file A1/11/1.

37. Sullivan, *op. cit.*, has documented this in the case of radio astronomy.

38. Mellor, *op. cit.*, p. 439.

39. Sullivan, *op. cit.*, p. 327.

40. For example, Bowen to R. A. Smith, 19 April 1950, Radiophysics file A1/11/1. Bowen requested advance copies of papers from the Physics Department of the Telecommunications Research Establishment in the UK, as 'we would not ... like to repeat matter which might have already appeared in your papers'.

41. Sullivan, *op. cit.*, p. 327.

42. *ibid.*

43. Memo from C. E. Stout, Chairman, 1951 Radar-Weather Conference, 30 July 1951, Radiophysics file A1/11/1.

44, Bowen to White, 18 December 1951, Radiophysics file A1/11/1.

45. Pawsey to David. C. Wigglesworth, 20 April 1951, Radiophysics file A1/11/1.

46. Bowen to Wing-Commander Perrin, Director of Operations, RAAF, 10 February 1947, Radiophysics file A1/11/1.

47. Bowen to Irving P. Krick, 1 October 1948, Radiophysics file A1/11/1.

48. Bowen to H. N. Warren, Director of Meteorological Services, Department of the Interior, 17 November 1948, Radiophysics file A1/11/1.

49. Australian Archives, RP file B2/3(a) part I. Minutes of meeting of the RP radio meteorology committee, 17 April 1950.

50. Australian Archives, RP file B2/3(a) part I. Minutes of meeting of the RP radio meteorology committee, 15 June 1951.

51. Bowen to Gresford (CSIRO), 27 March 1947, RP file A1/11/1.

52. Taking into account the quantities of silver iodide that Langmuir had used, Vonnegut's results on the effectiveness of AgI, cloud chamber experiments, and the different temperattures of clouds in Australia and New Mexico, the Radiophysics group concluded that, *assuming that no chain reaction took place in rain formation,* it would be necessary to use 50 lb of silver iodide per hour. At a cost of £7 per pound, this was too expensive. The group decided to do a different experiment, burning a smaller quantity of AgI and *assuming that a chain reaction was possible.* (Australian Archives, RP file B2/3(a) part I. Minutes of meeting of the RP radio meteorology committee, 15 June 1951.)

53. Bowen to Sir Geoffrey Taylor (Cambridge), 10 August 1950, Radiophysics file A1/11/1.

54. Bowen to T. C. Bell, 26 January 1951, Radiophysics file A1/11/1.

55. Bowen to T.C. Bell, 26 January 1951, Radiophysics file A1/11/1.

56. Townsend, *op. cit.*, p. 69 Langmuir's group was not the only one in the US. Bowen and Pawsey began to correspond with, for instance, Michael Ference, the meteorologist in charge of the US

Signal Corps' work on forced precipitation, and Irving P. Krick, an ex-Caltech private meteorological consultant, both of whom were 'moderates'. (Bowen to T.C. Bell, 26 January 1951; Krick to CSIR, 14 June 1948; Krick to Bowen, 18 October 1948; and subsequent correspondence. All Radiophysics file A1/11/1.)

57. Bowen to Sir Edward Appleton, 6 March 1947, RP file A1/11/1. During the war Squires had been attached to the Meteorological Directorate and had contributed to forecasting through the analysis of weather fronts. (Mellor, *op. cit.*, pp. 518-520.)

58. *New York Times*, 9 and 13 July, 1947, Radiophysics file A1/11/1.

59. Memorandum from Bowen to Kraus and Squires, 8 April 1947, Radiophysics file A1/11/1.

60. Harry Wexler, Chief, Special Scientific Services Division, US Weather Bureau, to Bowen, 8 April 1947, Radiophysics file A1/11/1.

61. Bowen to Rivett, 11 February 1947, Radiophysics file A1/11/1.

62. Rivett to Bowen, 20 February 1947, Radiophysics file A1/11/1.

63. Bowen to White, 25 March 1948, Radiophysics file A1/11/1.

The post-war CSIRO was well aware of the problem of the 'development gap' – the development that had to be done to turn basic research into new products and processes. But the problem was partly one of resources: in general CSIRO was not funded to a level that would have allowed it develop techniques and processes to the point where they could be easily adopted by industry. (See Gillespie, D. T. C., 'Research Management in the Commonwealth Scientific and Industrial Research Organization, Australia', *Public Administration* **42** (1964), 11-31,p. 15 and Shelton, J. P., 'CSIRO Patents and Research for Industry', *Australian Physicist* **2**, 1 (January 1965), 3-6, p. 6.) And with few exceptions Australian industries could not afford the cost of development either. It is not surprising, therefore, that in the absence of a specific directive to do otherwise, Radiophysics (and other areas of CSIRO) would have considered that the best use of its scientific talent was to move from problem to problem, generating fundamental knowledge that was then available for use – at least in theory. Indeed in agriculture, where state government bodies developed and disseminated research, this may have been a satisfactory use of resources. (Agriculture satisfied the classic conditions of 'market failure' which justified R&D being done by a centralised institution: that is, CSIRO served the interests of many small producers who as individuals would be unable to undertake large-scale R&D and/or to appropriate the benefits flowing from it.) But another factor worked against a Division moving on 'from problem to problem': the investment that it made in equipping itself to solve problems in a specific area.

64. Australian Associated Press report, typescript copy dated 26 January 1950, Radiophysics file A1/11/1.

65. Australian Archives RP file B2/3(a) part I. Minutes of meeting of RP radio meteorology committee, 17 August 1951.

66. Australian Archives RP file B2/3(a) part I. Minutes of meeting of RP radio meteorology committee, 14 December 1951.

67. Bowen to White, 18 December 1951, Radiophysics file A1/11/1.

68. Bowen to Ellis Gulliver, 14 May 1947, Radiophysics file A1/11/1.

69. C. B. Schedvin (unpublished MS, from volume 2 of Schedvin's history of CSIRO (c. 1986)). I did not find any corroborating evidence.

70. Bowen to G. R. Fisher, General Manager, Zinc Corporation Ltd, 5 February 1947, Radiophysics file A1/11/1.

71. Bowen to W. H. Anning, 21 March 1949, Radiophysics file A1/11/1.

72. The first sign of contact between Radiophysics and the state water management system appears to be a letter to the NSW Water Conservation and Irrigation Commission in August 1949.

(J. O'Brien, Secretary, [NSW] Water Conservation and Irrigation Commission, to Bowen, 12 August 1949, Radiophysics file A1/11/1. This appears to have been a reply to an earlier letter from Bowen.)

73. Radiophysics experimented with a number of other methods for inducing clouds to form rain, apart from seeding them with dry ice and silver iodide. As early as April 1947 it considered spraying clouds with calcium chloride, to induce large hygroscopic nuclei to form. Around 1950-51 it tried spraying water onto clouds. And in 1955-56 it tried to charge cloud droplets artificially to induce coalescence. (Bowen to Gresford, 17 April 1947, Radiophysics file A1/11/1; CSIRO annual report 1950-51, p. 126; CSIRO annual report 1955-56, p. 131.) Radiophysics also considered using rockets to deliver seeding material to cloud and in pursuing this idea it contacted both the Australian Munitions Supply Laboratories and the Long Range Weapons Research Establishment in South Australia. (Bowen to Flight-Lieutenant J. Lynch, 2 June 1950, Radiophysics file A1/11/1.)

74. Robertson, *op. cit.*, p. 69.

75. Mellor, *op. cit.*, p. 517.

76. H. A. Wills, CSIR Division of Aeronautics, to Bowen, 27 July 1948, Radiophysics file A1/11/1.

77. There were many requests, from various quarters. A typical request is that from F. W. Gillespie of the Office of the [US] Air Attache, dated 1 November 1951. (Radiophysics file A1/11/1) He noted that the US Air Force had 'expressed an interest' in the CSIRO program, and asked for information on just about every conceivable aspect of it.

78. Interestingly, Bowen reported that the Chicago program was 'clearly based upon that of the Radiophysics Laboratory'.

79. Townsend, *op. cit.*, p. 61.

80. Georg Breuer, *Weather Modification: Prospects and Problems* (CUP, Cambridge, 1980 ed.), p. 70.

81. *ibid.*, p. 35. The RAF also began rainmaking experiments in 1949 (although its interest was not sustained for long); again, Bowen was happy to make information available to them. (Bowen to J. E. Cummins, ASRLO, London, 19 August 1949, Radiophysics file A1/11/1).

82. Breuer, *op. cit.*, p. 70.

83. *ibid.*, p. 71.

84. *ibid.*, p. 72.

85. For instance, E. J. (Pat) Smith to Pierre St Amand, Naval Weapons Center, China Lake, California, 30 April 1970, Radiophysics file A1/11/34 (c) 3/1970/GEN. In this letter Smith thanks St Amand for his (Smith's) recent visit to China Lake and says that he is sending notes from Radiophysics most recent training course in cloud-seeding. In a later letter (St Amand to Bowen, 1 September 1970, Radiophysics' file A1/11/34 (c) 3/1970/GEN) St Amand writes (how sincerely I do not know) that 'for many years now I have been watching your impressive program with deepest interest and feel that I could learn a lot from you and your colleagues, as indeed I already have.'

86. Townsend, *op. cit.*, p. 22.

87. *ibid.*, p. 67

88. Kraus to Pawsey, 1 December 1947, Radiophysics file A1/11/1.

In 1949 Tor Bergeron, whose theory of rain production had held sway in the 1940s, identified as the core problem of rainmaking, 'whether such a release can produce an appreciable amount of rainfall, and when and where this could be done'. (Bergeron, quoted in Breuer, *op. cit.*, p. 35.) Bergeron's basic idea was that cloud-seeding could be successful only in those situations where there is an adequate supply of supercooled droplets but at the same time an insufficient amount of the ice crystals that trigger precipitation: that is, in cases where the available water in the cloud is not fully 'used'. Bergeron pointed out that this condition could occur only within a certain temperature range. He also forecast the suitability of different types of cloud formation for seeding – forecasts which apparently have been vindicated. Bowen saw this paper, but considered it disappointing – 'it doesn't contribute much to the subject' – and thus these predictions seem to have played no part in shaping Radiophysics' research program. (Bowen to Priestley, 16 and 22 November 1949, Radiophysics file A1/11/1.)

89. Australian Archives, RP file B 2/3 (a) part I. Minutes of meeting of the RP radio meteorology commitee, 2 February 1951. The four important conditions were: the synoptic situation (namely, a low pressure trough); clouds with greater than average water content; an unusually low freezing level for the time of year; an unstable lapse rate of temperature between 0°C and 10°C. Using these parameters, Smith estimated that the number of suitable occasions for cloud seeding around Sydney had been 70 in 1948, 30 in 1949 and 5 in 1950.

90. Bowen seems to have drawn on relatively few sources of advice about the value of rainfall to agriculture. One of them, however, was S. M. Wadham, Professor of Agriculture at the University of Melbourne. Wadham had a particular interest in marginal wheat-growing regions and believed that for them, 'the amount of precipitation required to tip the scale of crop against no crop is small'. (Wadham to Bowen, 27 January 1949, Radiophysics file A1/11/1.) In one document Bowen argued – from what information I do not know – that in the Mallee district wheat yield was correlated with, not the annual rainfall, but with the rainfall during a crucial three-week period in the early growth of the wheat. (Australian Archives, RP file B 2/3 (a) part I. Minutes of meeting of the RP radio meteorology commitee, 11 January 1952.)

91. Australian Archives, RP file B 2/3 (a) part I. Minutes of meeting of the RP radio meteorology commitee, 11 January 1952.

92. The CSIRO radio astronomy group had to fight constantly in its early days to assert the veracity of its observations against the claims of the Cambridge radio astronomy group in particular. (Robertson, *op. cit.*, pp. 94-95.)

93. C. B. Schedvin has noted the same advantage in the field of entomology: at the time when Australian researchers were establishing their claims, 'there were no obvious centres of concentrated knowledge'. (Schedvin, 'Environment, Economy and Australian Biology, 1890-1939', *Historical Studies* **21**, 82 (April 1984), 11-28, p. 24.) Krick and Ference were two of the 'moderate' cloud seeders that Radiophysics began to correspond with. (Note 56, above)

94. Sullivan, *op. cit.*, p. 311, and S. Atkinson, pers. comm. Sally Atkinson was Bowen's private secretary for many years.

95. Minutes of the meeting of the Radiophysics radio meteorology committee, 16 August 1949. Australian Archives RP file, B2/3(a), part I.

96. Minutes of meetings of the Radiophysics radio meteorology committee, 8 September 1950 and 2 February 1951. Australian Archives RP file, B2/3(a), part I.

97. There were no survivors.

98. Gunn to Bowen, 24 January 1949, and Bowen to Gunn, 1 March 1949, Radiophysics file A1/11/1.

99. Bowen to Shire Engineer, Shire of Marong, Victoria, 5 October 1949, Radiophysics file A1/11/1.

100. Pawsey to Bowen, 20 December 1947, Radiophysics file A1/11/1.

Chapter 2: Turning points, 1957-1963

But there is no doubt that the art of rain making is control. This aspect has been developed to its utmost in Australia and even the rain makers are controlled ...

Albert Norman, '"We made it Rain": Letters from the South Seas', *Christian Science Monitor*, 27 January 1958.

In the period 1957-1963 the CSIRO rainmaking program reached two turning points. One was a disturbing deterioration in experimental results; the other, a failed attempt to get the Commonwealth government to legitimise the technique by establishing an organisation to carry it out as a routine practice. It is worth looking first at some of the background to these events.

The beginning of wide-area experiments, 1953-1956

In the early 1950s the CSIRO cloud physics group was one of the few in the world that had the use of an airborne research facility.[1] This gave it a definite lead in the field. By the mid 1950s the CSIRO cloud-seeders were confident, claiming that

[w]hile related work has also been proceeding in other countries of the world, it is largely as a result of investigations carried out in Australia that the basic problems are now more clearly understood.[2]

The program expanded. Satisfied that it could induce rain from individual clouds, Radiophysics turned its attention to trials of seeding over wide areas (of the order of 1,000 square miles). In these the fundamental problem was to distinguish any effect caused by cloud-seeding from the natural variability of the rainfall, and so each experiment had to run for a couple of years. For these experiments Radiophysics managed to find the funds to buy a light aircraft of its own. (Seeding with dry ice had required a high-flying aircraft that could carry a thousand pounds of dry ice per cloud seeded; seeding with silver iodide was less demanding.) In September 1954 Radiophysics started experiments with the Victorian State Electricity Commission and in December that year it seeded clouds near Cloncurry in Queensland. These were essentially preliminaries to the main experiment of this period, started in 1955 in the Snowy Mountains region, in conjunction with the Snowy Mountains Hydro-Electric Authority (SMHEA).

The other notable event of this period occurred in October and November 1954, when Radiophysics staff took part in a project in the Hawaiian islands to study the physics of rainfall from warm clouds. This experiment, 'Project Shower', was funded by the US Office of Naval Research; the other participating institution was the US Weather Bureau.[3] Once again, the Australian group made its measurements of cloud parameters from an RAAF aircraft, flown to Hawaii for the purpose. Project Shower was Radiophysics' first international collaboration in cloud physics, and it shows how the group was becoming more closely connected with the 'mainstream' US research in the field. Radiophysics' relations with the US Weather Bureau were quite good, in contrast to those of the Langmuir camp.

Background developments in radio astronomy

At the same time that the cloud-seeding program was expanding and becoming more closely linked to the American scientific institutions, so too was Radiophysics' radio astronomy program. By the early 1950s that program was in full swing and the main question was what kind of new instruments should be developed for it. By coincidence, in 1951 Lee DuBridge, President of CALTECH (California Institute of Technology), asked Bowen to advise on how radio astronomy might be developed in the USA, which until that time had been lagging in the field. Bowen, apparently impressed by Bernard Lovell's plans for the large telescope at Jodrell Bank (UK), the first of its kind, drew up a proposal for a similar large telescope. But rather than simply accepting an offer to head this new facility in the US, with Fred White's encouragement he began to explore the possibility of building a large telescope in Australia.

Bowen's proposal had competitors both inside and outside Radiophysics. Nevertheless, after a complicated sequence of events it was eventually realised as the Parkes radio telescope, opened in 1961.[4]

As the Commonwealth Government seemed unlikely to meet the cost of this proposed telescope it was necessary to look elsewhere for funds. In 1954 the US Carnegie Corporation contributed $US 250, 000 towards the telescope from its British Dominion and Colonies Fund. In April 1955 the Commonwealth Government too agreed to finance the project, but only as far as matching, pound for pound, private contributions. CSIRO mounted a popular appeal for funds but raised little in Australia, and so in 1955 Bowen began to do the rounds of other American philanthropic organisations. He succeeded with the Rockefeller Foundation, which pledged another $US 250,000. This was enough to get the project started; other money was raised later from other sources. In discussing this episode in his history of the Parkes radio telescope, Peter Robertson points out that the large American philanthropies recognised that science funding could strengthen America's cultural and political influence in the post-war world, 'particularly in countries such as Australia where a power vacuum had developed as a result of Britain's declining influence'.[5] Shortly after the Carnegie Corporation made its award in 1954, Vannevar Bush, the president of the sister Carnegie Institution, proclaimed the desirability of strengthening those ties. He wrote:

Nothing, I am sure, would bring our two counties closer together more effectively than for Australia to lead the way in an important area of fundamental research. ... Also I feel sure that this accomplishment on your part would lead the Australians to view this country [America] as a place where good fellowship is found in the discussion of mutual interests.[6]

Robertson also comments on the different attitudes to science shown by the contributing parties. The Australian Government was cautious to the point of seeming to need 'reassurance from the Americans that the idea was worth supporting'.[7] As for private Australian donors, not only was there a lower level of available resources, and little tradition of private philanthropy, but most of the private support for science that did exist was directed to 'more utilitarian research in fields such as medicine, biology and agriculture'.[8] The public appeal for funds for the radio telescope raised a negligible amount over a period of years, but when in the late 1950s CSIRO set up a trust to raise money for a special laboratory for plant industry research, £30, 000 was donated within a month. R. G. Casey, Minister for CSIRO, lobbied the Government for this project, arguing that it would provide substantial economic benefits for Australia, and the government 'had little hesitation' in agreeing to meet the full amount of half a million pounds.

Funds *could* be raised in Australia for the physical sciences. Mark Oliphant at the newly created Australian National University obtained half a million pounds, for what initially was to be a proton accelerator (finally abandoned in 1961). And in 1952 Harry Messel at the University of Sydney established the Nuclear Research Foundation, which in its first eight years raised more than three million pounds to support research using cosmic rays to investigate the fundamental structure of matter. (Admittedly, two-thirds came from overseas, but raising even a million pounds in Australia was a considerable achievement.) But nuclear physics and the search for fundamental laws of nature were supported because nuclear physics and its applications were seen as central to the nation's defence planning, and because these fields carried international prestige.[9] Radio astronomy, by comparison, was an arcane science with little practical value. The question of which areas of science Australia could successfully compete in does not seem to have mattered: after all, Australia was a leader in radio astronomy but not likely to become one in the expensive field of nuclear physics.

Bowen did not attempt to justify radio astronomy in terms of its immediate practical value but argued that benefits would flow in the long term.[10] The more pragmatic players, such as White and Casey, went to some lengths when supporting the proposed telescope to stress the practical benefits of radio astronomy, such as a better understanding of radio communications or plasma physics. Underlying the attempts to justify the telescope by its practical 'spinoffs' was a concern about the effect that it would have on the existing balance between pure and applied research in CSIRO – in terms of its public profile, if not in terms of its running cost.[11] White had actively supported the radio astronomy program and Clunies Ross and Casey had at least approved of it, but by announcing plans for a giant radio telescope CSIRO laid itself open to the charge that radio astronomy fell outside its charter.

Radio astronomy had come to dominate Radiophysics' budget, growing from 38% in 1952 to 51% in 1956 – which meant, by that latter year, about £150, 000 per year. (The cloud and rain physics group accounted for a third of the budget in 1956, i.e. about £100, 000 annually.[12]) In defending this level of funding to White, Bowen was bold enough to claim that the CSIRO outlay on radio astronomy was ten times that of the research groups at Cambridge or Manchester in the UK, and far greater than that of any individual group in the USA, and yet despite this the Australian group was 'trailing the field badly in many respects'. Presumably Bowen meant to imply that the Radiophysics group could not hope to compete at all at a lower level of funding. Nevertheless, in October 1956 senior Radiophysics staff and the CSIRO Executive decided that support for the giant radio telescope would be met, not by cutting Radiophysics' other work, but by pruning the existing radio astronomy program.[13]

Even before the telescope was commissioned until October 1961 it acquired a political significance, by becoming bound up with the American side of the space race. By 1957 the USA had established several military facilities at Woomera in South Australia, which was now a well-equipped rocket range. In 1958 the space race erupted and NASA was born. The new organisation found itself embarrassed by a complete lack of satellite tracking dishes – indeed, up to 1959 the most competent instrument anywhere for this purpose was the new telescope at Jodrell Bank. The American use of Woomera was formalised in 1960 with the signing of a US-Australia agreement relating to space tracking and communication, and part of that agreement was a proposed deep-space tracking station with a 26-m diameter dish, which would have made Woomera one of three stations world-wide that NASA could use for satellite tracking. Meanwhile NASA had already discussed with Bowen the use of the Parkes telescope. That was in early 1959: by June of that year Casey, who was also Minister for External Affairs, was impressing upon Cabinet that the Parkes telescope was likely to strengthen Australia's hand in negotiations with the USA. A formal agreement on the way NASA would use Parkes was reached in 1960. Although it turned out that NASA used Parkes little until 1966 (depriving the telescope of some of the political kudos that Jodrell Bank had accrued from satellite tracking), the 1960 agreement had secured greater political justification for the telescope. It seems likely, therefore, that cloud-seeding, as a very visible and 'applied' research program, became more politically important for Radiophysics in the second half of the 1950s while the astronomy program was politically 'exposed' – but that this added importance probably only lasted for a few years.

The wide-area experiments

In the early to mid-1950s the emphasis in the Radiophysics cloud-seeding program was on understanding what happened to silver iodide after it was released into the atmosphere. By 1955 the researchers had determined that silver iodide decayed rapidly after being released from ground generators, and that ultraviolet radiation was the culprit. This pretty much put paid to claims (such as Langmuir's) for the effectiveness of ground generators. The group now developed silver iodide burners that would operate on light aircraft, so that the 'smoke' of silver iodide crystals could be introduced directly into clouds. Optimism surged, and in early 1955 Bowen began to suggest that the Government should introduce weather control legislation. But it was still not known if rainfall could be increased over a wide area, and if so, whether this could be done economically. The first of the major wide-area experiments carried out in the next decade was run between 1955 and 1959 in the area administered by the Snowy Mountains Hydro Electric Authority (SMHEA).[14] Radiophysics started several other experiments along similar lines in this period, in various climatic regions: in the Mt Lofty Range north of Adelaide (beginning in 1957), the New England area of NSW (1958), Sydney's Warragamba catchment area (1959) and the Darling Downs area of Queensland (1960).[15]

The Snowy Mountains Experiment

This experiment seems to have resulted from an approach by Radiophysics to the SMHEA but it was funded by the SMHEA.[16] It was done by choosing a target area for seeding and a control area that was not to be seeded, and seeding clouds over the target area on a proportion of the days suitable for seeding, the actual days being chosen at random. After the first two years of seeding, Radiophysics claimed increases in the precipitation in the seeded areas of around 20%. But the SMHEA was sceptical. It employed P.A.P. Moran of the Australian National University as a statistical consultant and in 1957, only two years into the experiment, he privately advised Clunies Ross that 'the experiment must be continued for another two years before we shall have any idea of what is really happening.'[17] Although the SMHEA agreed that the experiment should be extended for a further two years, it not agree with Radiophysics on the interpretation of the results. Roscoe Braham, a meteorologist at the University of Chicago, was asked to independently assess the experimental design. In November 1959 he did so, and judged some aspects of the experiment, such as the randomisation and the seeding technique, to be excellent. But he also found that the experimental design was flawed in that, because of difficulties in measuring precipitation quickly and accurately, snowfall sometimes had to be estimated rather than measured, and those making the estimates knew on which days the seeding was done.[18] As well, while agreeing that the seeding probably had increased precipitation, Braham thought that the 20% figure which CSIRO put on the increase was probably 'substantially larger' than the real increase.[19]

The researchers had thought it reasonable to assume that if seeding caused any extra rain or snow, this precipitation would occur within a few hours of seeding. But five years into the experiment the SMHEA decided that, on the basis of its own measurements (disputed by Radiophysics[20]), there was no evidence that this occurred. As a result it disagreed with Radiophysics' claim that the substantial overall increase in precipitation which Radiophysics had recorded had anything to do with the seeding, and insisted that if the work were to be published, the results would have to be described as 'inconclusive'[21]. In the end CSIRO and the SMHEA could not even agree about the issuing of a joint ministerial statement announcing the results of the experiment.[22] The whole episode led to a great deal of ill-feeling between Radiophysics and the SMHEA. [23] It may be a sign of the sensitivities attached to this experiment that the Radiophysics files on it, seemingly alone of the cloud-seeding experiment files, were destroyed.[24]

Drought relief operations

Two years into the Snowy Mountains experiment, however, Bowen's optimism was still high. This optimism was picked up by the Sydney press in January 1957 and given some journalistic embellishment.[25] 1957 was a dry year in the eastern States; dry enough to be classified as a drought. Even before the dry conditions became alarming, the rural community was well aware of the rainmaking experiments,[26] and as early as February 1957 Radiophysics received requests for operational cloud-seeding. These requests were turned down on the grounds that Radiophysics lacked the funds to meet them (or, more specifically, the aircraft and personnel). By May, CSIRO had applied to the Federal Treasury to buy a new aircraft for rainmaking – although for experiments, rather than drought relief – and this was heartily endorsed by Arthur Fadden, Deputy Prime Minister in the Menzies coalition government.[27] Soon after this a push began at a political level for Radiophysics to carry out 'emergency drought relief' cloud-seeding. This urging may have come from Casey, possibly after discussions with White. It was certainly Casey who asked the Minister for Air, F. M. Osborne, to arrange for the RAAF to lend Radiophysics a couple of aircraft for this purpose. The loan was agreed to, but the Department of Air refused to bear the cost. CSIRO had no funds available either, but Casey obtained an assurance from Treasury that the project could go ahead, up to a cost of £10, 000. With these arrangements in place Casey told White to go ahead with the work. In agreeing to the loan of the aircraft Osborne seems to have required that the work would be described as 'experimental' and not as 'relief'. 'We will have to be careful about publicity', wrote Casey, 'as we are liable to be bombarded with similar requests if the impression is given that we can do this sort of thing over a wide area.'[28]

The operations were to cover New South Wales, Queensland and Victoria. The State Departments of Agriculture were to advise where rain was most needed, and the Weather Bureaux were to indicate in which of those areas suitable clouds were likely to occur. The choice of a seeding site was a compromise between these two, with desperation being considered the more weighty factor.[29] These arrangements minimised CSIRO's responsibility for the outcome of the seeding. Casey's announcement of the plans for drought-relief attempts appeared in the press on 5 June. By 12 June an RAAF Dakota that had previously been used for rainmaking experiments was stationed at Amberley, Queensland; a second was ready at Richmond air base by 16 June and a third began flights from Nhill in Victoria soon after. By 21 June substantial rain had fallen in Victoria and the Victorian Department of Agriculture asked for the seeding to be halted; the 'plane involved was soon redeployed to Queensland. Radiophysics diverted its resources to these operations only with great reluctance. Its overriding concern was that its two controlled experiments under way in South Australia and the Snowy Mountains would not be disrupted in any way.[30]

Although these emergency operations were of no use in determining the effectiveness of cloud-seeding (as Bowen continually emphasised), the general understanding was that the seeding in northern New South Wales and Queensland had been quite successful. Letters of thanks began to stream in. The State Departments of Agriculture 'frankly admitted' that the program had assisted in New South Wales and Queensland.[31] Casey was happy for CSIRO to take public credit for the rain that had fallen and even Arthur Fadden received his share of thanks for CSIRO's work.[32] Then in July, in the face of this apparent success, the question arose as to how to end the program. It was a sensitive issue, for there were still parts of both NSW and Queensland that needed rain. But as White wrote to Casey, 'I think we must face the fact that there is always likely to be some area of Australia which, in the opinion of the agriculturalists and primary producers, needs rain'. It was decided to end the emergency program on 26 July and return the borrowed aircraft to the RAAF. In White's view, the interest that had been aroused in the States in cloud-seeding had 'created a favourable opportunity for a discussion of the responsibilities, both financial and operational, for similar measures in the future.'[33] He proposed to Casey that discussions should be held with the States about forming a special commission, 'jointly between the States and the Commonwealth, to control this situation'.

When the emergency seeding was ended in late July there was a flurry of protests, both to the government and to CSIRO. In one case CSIRO succumbed to the pressure, agreeing to carry out more seeding in the Warren-Trangie-Nyngan region of NSW, home to several merino studs. ('They are the mainstay of the pastoral industry, which in turn is one of the principal factors in our economy', pleaded (Sir) W. N. Kater, a prominent landowner, urging yet another extension of the work from the end of August.[34]) CSIRO asked the landowners in this region to keep quiet about this exercise, not wanting to stir up more requests. But requests kept coming. In August the NSW Department of Agriculture wrote directly to Bowen, indicating that rain was again needed in some parts of the State. Rural bodies were also pressuring their State representatives, who were appealing directly to the Commonwealth. By September CSIRO was desperate for the Commonwealth government to decide whether it would continue to fund operational cloud-seeding or would require State governments to carry the cost.[35]

Emergency seeding, again funded by the Commonwealth, was restarted in September 1957 by H. Holt, acting minister for CSIRO. Even more pressure was now applied, especially from Queensland, where Premier Nicklin appealed directly to the Prime Minister for rainmaking aircraft to be sent to south-east Queensland. The reply was non-committal. Within a fortnight the Queensland State Minister for Agriculture telegrammed the same request to Holt and an aircraft left for Queensland the next day. A similar request from New South Wales soon after caused White to cable Holt, concerned that it was 'too easy for state governments to make such requests', and suggesting that the States be required to bear the cost of operating the aircraft.

The presumed success of the emergency seeding unleashed an apparently insatiable demand for rainmaking services, both from individuals and from the States. It also resulted in closer links between the Radiophysics cloud seeders and the State Departments of Agriculture. Nevertheless, it seems that cloud-seeding did not really become incorporated into the discussions of what one might call the 'drought establishment' – those who were to shape government policies on drought. In 1958 Keith Campbell, Professor of Agricultural Economics at the University of Sydney, commented that

Spectacular though rainmaking experiments have been, we would be foolish to place too much reliance on the potentialities of this technique, especially if it diverts attention from alternative measures. After all, production instability will still be with us as a major problem whatever success the rainmakers ultimately achieve.[36]

This view of drought – as one risk factor among many affecting agricultural producers – did not become incorporated into government policy until thirty years later, but its slow ascendancy may have been one factor underlying the eventual demise of the cloud seeding program.

A Rainmaking Commission?

As early as 1955 Bowen, buoyed by the apparent success of the experiments, had suggested to Casey that the Government should start to think about drawing up legislation on 'weather control'. Bowen and the CSIRO Executive had consistently presented CSIRO as defending the farmer's interests, working to establish the efficacy of rainmaking techniques and to prevent farmers from being cheated by ineffective commercial operators. 'We consider that we have an inescapable responsibility to develop rainmaking methods specially suited for Australian conditions and to ensure that they are adequately tested and verified before being recommended for general use', wrote Bowen. [37] This role, as protector of public interests, was comparable to the one taken by the US Bureau of Meteorology. The rainmaking legislation that Bowen began to discuss in 1955 was an extension of this, its object being 'to prevent abuse of weather control techniques and to give the Commonwealth some form of control over the operations in this field'. Again, the issue of control was presented as a question of protecting the public interest. For one thing, it was thought that techniques of successful rainmaking were likely to become widely known and operations by unskilled people might lead to floods that would threaten life and property. For another, the effect of weather control experiments could not be confined inside State boundaries: while state instrumentalities might advise on the need for water, weather should be modified only by a body with Commonwealth-wide authority.[38] It was suggested that in the preliminary stages, while Radiophysics was still checking its experimental results, a Weather Control Commission might be set up, which would issue licences to persons properly qualified to do experiments. At a later stage further legislation might be needed to give the Commonwealth 'complete control of actual weather modification operations'[39], although it was envisaged that the actual seeding operations would be carried out by the private sector.[40]

Bowen and White were deeply concerned to prevent the 'quite chaotic state' that they thought would follow if people learned how to seed clouds successfully but no controls were in place.[41] In the USA, up until late 1957 (when Casey discussed the matter with the Director of the National Science Foundation) only piecemeal legislation had been enacted with regard to weather modification, State by State. Although the US Federal Government had the power to enact such legislation Congress had chosen not to do so. Partly as a result, rainmaking in the USA developed up until 1958 in a way that Bowen considered to be 'rather chaotic'.[42] Why was there such concern in Australia about order and control? One reason was that CSIRO had adopted the role of 'public protector'; another, that it hoped for legislation 'to encourage and also safeguard from interference the continued experimental work of responsible groups' – i.e., CSIRO.[43] It is also possible that other general, political fears (such as of communism or even the atomic bomb) might have been projected onto weather modification. As well, Australia carried a strong tradition, stronger than that in the US, of expecting government to authorise science and technology, and to bear the risks of using it.

Political rejection

In late 1957 White prepared a Cabinet submission to authorise the creation of a Commonwealth Rainmaking Commission. The Commission was intended to undertake practical rainmaking as a separate activity from CSIRO's controlled experiments. This would leave the experimental work undisrupted in times of drought. The legislation setting up the Commission would define the legal liability of the rainmakers, and license and train commercial cloud-seeding operators.[44]

The proposal, presented to Cabinet in February 1958, was rejected. According to Casey, Menzies was critical of the publicity that had been given to the cloud-seeding experiments, which he (Menzies) thought led people – especially the Queensland Premier? – to believe that they 'had only to demand a rainmaking aircraft in their district to counter the effects of drought.' Furthermore, he believed that acceptance of the cabinet submission 'would inevitably mean that we would be gradually drawn into taking full financial responsibility for coping with drought conditions in the States.'[45] The Commonwealth government had traditionally played only a minor role in drought relief, as after Federation matters pertaining to agriculture had remained the responsibility of the States. The Commonwealth had no constitutional power to deal with rainmaking, although CSIRO's activities were 'covered' as long as they were experimental. This last difficulty was not insuperable, however. The Attorney-General's Department had advised that it would be possible to create a Rainmaking Commission by Commonwealth legislation, which would be able to provide emergency rainmaking over Commonwealth Territories. If the States wished to make use of its services they could enact legislation to extend the cover of the Commonwealth Act to their own State.[46] Presumably, the payment for the Commission's services could also have been negotiated.

Menzies' stance was consistent with his position as the political representative of the urban middle class. Judith Brett, for instance, notes that despite Menzies' own rural background – he came from a marginal wheat-growing area of Victoria – 'he was frequently out of sympathy with the Country Party which did represent the sort of people among whom he grew up.'[47] Agriculture's contribution to the Australian economy had reached its post-war high in the early 1950s, with the percentage of the workforce in rural industries, rural contribution to GDP and contribution to exports all declining steadily thereafter.[48] The Country Party retained considerable political power within the coalition government but there is no sign that support for cloud-seeding by the 'grass roots' or industry bodies of the rural sector was translated into effective political support in Canberra. In any case, in the late 1950s the Government's agricultural policy did not provide a congenial climate for a technique such as cloud-seeding. In the late '40s and early '50s the Government had been concerned with expanding the volume of agricultural exports and import-substituting commodities. But by the late 1950s the emphasis had swung back to providing a secure income to the producer and uniform and stable prices to the consumer: while not absolutely inimical to techniques to increase extractive efficiency, this policy was less concerned with stabilising actual production than with price controls.[49] Still, against this should be set an undeniable concern about the effects of drought on the 'national interest'.

It seems that Menzies' personal lack of belief in cloud-seeding as a workable technique, rather than questions of policy, carried the day. According to Casey, Menzies held that the capacity to make rain was unproven, even despite the solid support that both Casey and CSIRO had given it. Menzies may have been influenced by, for example, John McEwen (Country Party), a significant force in the Coalition government, who also did not believe that rainmaking was effective[50]. Even more likely, he may have been influenced by the scepticism of the Snowy Mountains Hydro Electric Authority. Before the issue was presented to Cabinet CSIRO had insisted that

[t]he U.S.A. cannot be looked to for knowledge on rainmaking. ...[lack of organised effort in the USA has been] fortunate for Australia, as it has given this country an opportunity for world leadership which we now have[51]

but the press reports on cloud-seeding coming out of the USA at that time were fairly negative. On 5 February 1958, only a few days before the crucial cabinet meeting, the Australian press reported that the US Advisory Committee on Weather Control had advised President Eisenhower that US rainmakers had been successful only in mountainous areas and under certain conditions. Casey lamented to White, 'This is the sort of comment that Mr. Menzies is likely to get his teeth into – and quote in Cabinet'.[52] Later comments coming out of the USA were not much more encouraging. In May 1958, for instance, the American Meteorological Society issued a press statement – which, ironically, Bowen appears to have had a hand in – that gave little hope:

Present knowledge of atmospheric processes offers no real basis for the belief that the weather or climate of a large proportion of the country [the USA] can be significantly modified by cloud seeding.[53]

Even without invoking a 'cultural cringe' towards the Americans, it is entirely plausible that the Cabinet's decision-making was swayed by such negative statements.

The Cabinet's decision may also illustrate a generally greater aversion to risk in Australia, as compared to the US, which was probably due at least in part to a relative lack of resources. In 1959, in addition to the experimental groups, ten operational groups were at work in the USA. In summing up the value of cloud-seeding, Robert D. Elliott, a US practitioner, noted:

It is clear ... that the value [of cloud seeding] exceeds the cost by several orders of magnitude. This explains to a great degree the sustained interest and participation in many cloud seeding projects even though it is not possible, with present observational data and statistical techniques, to obtain scientifically definitive results in any given place even over a period of several years. It is a matter of taking a calculated risk.[54]

In the USA individuals were free to take this 'calculated risk'. In Australia a more paternalistic State wished to prevent them from doing so. But it was not willing to bear the risk itself.

The government's refusal to set up a rainmaking commission, or to take other steps towards operational cloud-seeding, put CSIRO in a difficult position, as it continued to receive requests for rainmaking assistance. A frustrated Bowen asked the Executive to clarify the terms in which future requests should be turned down, warning that the goodwill which had accrued to the organisation could easily be lost.[55] (The Executive, naturally enough, felt strongly that responsibility for the decision should be sheeted home to the Government.[56]) I do not know to what extent, if any, such goodwill was lost. There appear to have been few other *immediate* side effects; for instance, no alteration in the experimental rainmaking program and no immediate increased emphasis on fundamental cloud physics as opposed to empirical tests of cloud-seeding. Into the early 1960s at least Bowen remained hopeful of a legislated approach and it seems that he also sought some support, direct or indirect, from influential individuals, for an operational cloud-seeding practice.[57] Nevertheless the government's refusal to establish a rainmaking commission meant that if rainmaking was to gather any further degree of legitimacy this had to come from more convincing (Australian) experimental results.

Radiophysics' relationship with the USA

Despite the statements that Menzies 'got his teeth into', US views of cloud-seeding were not universally pessimistic. As a solution to the long political battle over rainmaking in that country, in July 1958 the National Science Foundation (NSF) was given the role of coordinating weather modification experiments. In March 1959 the NSF announced the grants for research in weather modification for the 1959 fiscal year: a total of $US 1, 130, 000. The aim of the program was a more intensive study of the scientific basis of weather modification, a change from the former 'scattered and unrelated investigations' to 'efforts soundly based on scientific knowledge'.[58] An important change was highlighted by one grant to the University of Chicago, for studying the physical effects of silver iodide seeding upon clouds, rather than trying to measure changes in precipitation. (There were also grants for two randomised cloud-seeding trials of the kind CSIRO was running.) It is probably fair to say that at this point the larger, better resourced and now more coherent US research program began to eclipse that of CSIRO, which had been funded to a level equivalent to roughly a sixth of the NSF's 1959 allocation. The discrepancy between the scale of effort in the two countries grew swiftly. In fiscal year 1961 the NSF's grants under its Atmospheric Sciences Program was $US 1.5 million, a third of it specifically for weather modification. The projections for 1962 and 1963 under the same program were $6.6 million and $17.4 million respectively.[59]

However, Radiophysics' work remained well regarded in the USA in the late 1950s and into the 1960s. The group seems to have become closely involved with its American counterparts. In 1958, three US groups, including the US Weather Bureau, were carrying out experiments with silver iodide burners that followed the design of the Australian ones; 'almost every [US] group' concerned with cloud-seeding at that time was using liquid-water-content meters designed and built by Radiophysics; and several groups were using nuclei-counting sets also borrowed from the Australians.[60] (And a decade later, in 1966-67, Radiophysics worked in Australia with the US Naval Research Laboratory on a series of experiments given the name of 'Project Whitetop'. [Unfortunately the archival material on this project was transferred out of the Radiophysics files in the 1970s, and I have found no further details on the project.[61]])

As in radio astronomy, there were some problems in having the Australian work recognised. In at least one case the CSIRO group was deprived of priority for a finding because a journal editor had delayed publication of the work until after the same finding was reported by an American group.[62] But this does not seem to have been common, and was not as much of a problem as it was for the radio astronomers. By the late 1950s Radiophysics had planned another step in establishing its position on the world stage – holding an international cloud physics conference. The conference, originally scheduled for 1959, seems to have taken place in August or September 1961.[63] [Again, unfortunately I have been unable to find any records of the conference itself, only references to it in letters. In one Bowen described it as 'a magnificent occasion'.[64]]

As early as 1952 Bowen had been invited to head a proposed US research centre for cloud and rain physics.[65] His personal involvement in the US system continued to grow, and in 1957 he was invited to contribute to the President's Advisory Committee on Weather Control. Following a public statement by the American Meteorological Society that year , White commented to Bowen,

This strikes me as being rather humorous, although satisfying in some ways to us. The great majority of the results quoted are, of course, Australian. It is very unusual to find an American authority such as this recognizing "foreign" work. However, I suppose it simply means that you are partly "Americanised"![66]

Bowen became further integrated into the American system to the extent of reviewing proposals for funding under the Atmospheric Sciences Program of the National Science Foundation.[67] Given this involvement, it is perhaps surprising that Bowen remained in Australia; this is discussed further in the last chapter.

Diminishing returns from seeding

In mid 1958 Radiophysics was still, in public at least, cautiously optimistic about cloud-seeding. It recognised that success was entirely dependent on the right meteorological conditions; whether economically significant rainfall could be achieved was still uncertain. Even in 1960 Bowen was expressing considerable hope for the technique's use, although only for certain parts of the country: the central arid lands and the coastal regions had both been ruled out as being unlikely to benefit from seeding. But by 1961 the experimental results were showing disturbing trends. The Darling Downs experiment (started in 1960), seemed to be showing a consistent *reduction* in rainfall in seeded areas (although the statistics were not conclusive.) So too were the Mt Lofty range experiments, which had been halted after only three years.[68] The seeding in the Warragamba Dam catchment area had started off well but after eighteen months was showing zero increase in rainfall. The New England experiments, which had also started off with promise, indicating rainfall increases of 15%, were now showing a serious reverse trend. And even the Snowy Mountains experiments were worrying. According to Radiophysics, the overall result at the end of five years was a 19% increase in precipitation in seeded areas, but while the seeding had been stepped up over those five years, the percentage increase in precipitation had gone steadily down.[69]

Radiophysics responded to these problems by checking for obvious factors, such as changes in seeding technique over time, and examining more closely the daily rainfall records of the experimental areas. So for a while it was business as usual – or almost as usual, for the Darling Downs experiment too had been suspended, 'in view of the possible reaction of the agricultural community' should anyone suspect that seeding decreased rainfall.[70] But by 1962 it appeared that the result of an average cloud-seeding experiment in Australia was 'compounded of positives and negatives'– that is, cloud-seeding sometimes promoted rainfall and sometimes inhibited it.[71] The conditions giving positive results were known: good towering cumulus clouds. The experimental program was now refashioned to concentrate on determining the conditions that might give negative seeding results. By 1963 the experimental results were still inconclusive, and fluctuating significantly from year to year. There was now doubt too about one of the researchers' fundamental assumptions: that the effects of silver iodide were *not* cumulative over time.[72] And so in 1964 the large-scale experiments were suspended. The Radiophysics group turned to analysing the data it had already gathered, and to making fundamental studies of how 'freezing nuclei' worked to produce rain, in the hope of giving large-scale experiments a sounder basis.[73]

Comment

In the late 1950s cloud-seeding missed its moment to become established as a routine practice and thus legitimised. CSIRO's claims for its effectiveness were offset by sceptical assessments from the USA, and what symbolic significance the field did have was less compelling (to government) than that of nuclear technology or the nascent space-age. Although the Menzies government refused to create a separate authority to carry out rainmaking, when CSIRO carried out emergency rainmaking it was acting very much as an executive arm of government. (Interestingly, Casey sometimes used the term 'we' in referring to CSIRO.)

Although the Radiophysics group had not attained credibility with the national government, it had established itself internationally in its field. In this period it strengthened its links with the American system, and it may be that just as the group was becoming self-assured, it was not only more closely linked to the USA, but also, as White remarked of Bowen, more 'Americanised'. Is it possible that the American scientific system did not just adopt the Australians' techniques, instruments and findings but in fact *appropriated* them?

Afterthought: was cloud-seeding linked to the atomic age?

In the first chapter I noted that cloud-seeding was similar to the atomic bomb in that both used a small trigger to release vast, latent, natural forces, and I suggested that in Australia in particular it could have been viewed as a weapon against a hostile Nature. It may be that in Australia cloud-seeding became a sort of 'poor man's nuclear technology', or at least received an analogous construction. The insistence on the State's control of the technology, and the fears about what might result if 'unauthorised persons' began to use it, seem to mirror, weakly, contemporary fears about atomic weapons.

Nuclear explosions were persistently linked to the weather, specifically the inducement of rain. In September 1956 the *Washington Post* published a report which claimed that unexpectedly heavy rain was falling over northern Queensland in the path of a 'fallout laden cloud' from an atomic test at Maralinga.[74] Harry Wexler, Director of Meteorological Research in the US Weather Bureau, sceptically asked Bowen if he knew of any connection between atomic tests and the weather; Bowen replied that in Australia, 'no significance' was attached to the Queensland rainfall. He added that 'under the right conditions, the dust thrown up by such an explosion might give rise to wide-spread rain for a day or two after the explosion', but that 'the chances of the conditions being just right are so remote that it would be next to impossible to distinguish it from a chance phenomenon.' But Bowen did not cite any evidence, experimental or theoretical, for this point of view; he did not even draw any connection between this and his own, controversial, idea that the arrival of meteoritic dust from space caused increased rainfall.[75]

Popular belief in a connection persisted. In June 1957, a day after public claims of success for the 'drought relief' cloud-seeding, an unnamed CSIRO weather scientist (not from Radiophysics) reported an overall change in Australia's weather patterns but stated firmly that 'H-bomb explosions have nothing to do with it'.[76] (The British atomic tests that were then being carried out on Christmas Island were in the news almost every day.) The same article in the Melbourne *Sun* in February 1958 that had damned the US cloud-seeding attempts noted that the Advisory Committee on Weather Control had told Eisenhower that 'weather might eventually be changed by setting off nuclear explosions high in the atmosphere'. In a note to Casey, White addressed this point specifically, noting that the 'official attitude' of the World Meteorological Office 'at present' was that nuclear explosions have no effect on the weather. 'However', he added, 'this attitude may be incorrect'.

The possibility that atomic explosions might indeed cause rain was presumably quite threatening to the cloud-seeding fraternity, as it could have opened the way to a 'stronger' technology ousting or subsuming their 'weaker' one. This is perhaps one reason for the seeming lack of concern about trying to establish or disprove the link empirically. In February 1962 Sir Mark Oliphant wrote to Bowen about such a hypothesised link. 'I have always held that those who say that nuclear weapons affect the weather are crazy', mused Oliphant, 'but now I wonder!' He went on to calculate the possible effect of ions in the atmosphere serving as condensation nuclei, adding, 'if your meteoritic dust acts as nuclei for condensation, ions should be even more effective ... an extraordinarily small use of the total ions available as nucleating centres, would serve to produce a lot of rain!'[77] Arthur Higgs, Radiophysics' Technical Secretary, replied on Bowen's behalf (apparently Higgs was often given the task of writing the more difficult letters[78]), rejecting the idea out of hand.[79]

Notes for chapter 2

1. Brian F. Ryan, *Cloud Physics Research in Australia* (unpublished MS), p. 4.

2. CSIRO annual report 1955-56, p. 129.

3. Ryan, *op. cit.*, p. 4.

4. See Peter Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope* (CUP, Melbourne 1992) and Haynes *et al.*, *Explorers of the Southern Sky: The History of Australian Astronomy* (CUP, in press). The differences of opinion inside the organisation led to the radio astronomy group splitting in the late 1950s and several members leaving for other institutions. The external competition came initially from the Commonwealth Observatory at Mt Stromlo, where in 1951 the Director, Richard Woolley, announced his intention to construct 'as soon as possible' a radio telescope of large resolving power. This prompted Fred White to warn that 'it would not be in the interests of collaboration for the Commonwealth Observatory to enter precisely the same field'. Woolley himself was ambivalent about radio astronomy: the bid may have been pushed primarily by Mark Oliphant, a distinguished nuclear physicist and Director of the Research School of Physical Sciences at the newly created Australian National University (ANU). Oliphant planned to introduce radio astronomy as an option for postgraduate students at the ANU and argued that there should be a national radio astronomy centre. This challenged Radiophysics' position in the field. It was already clear that government funding for one large radio telescope was uncertain: two such instruments were out of the question. After a year of negotiation, in May 1952 the Mount Stromlo Board of Visitors and the CSIRO Executive opted for a 'separation of interests', although according to Haynes *et al.*, 'Oliphant never relinquished his hopes for a national radio astronomy facility'. (Haynes *et al.*, pp. 262-263.)

5. Robertson, *Beyond Southern Skies, op. cit.*, p. 125.

6. Vannevar Bush to Bowen, 17 May 1954, CSA file KE 2/14, quoted in *ibid.*, p. 125.

7. *ibid.*

8. *ibid.*

9. *ibid.*, p. 129.

10. *ibid.*, p. 126.

11. *ibid.*, p. 129.

12. *ibid.*, p. 131.

13. *ibid.*

14. Unfortunately the Radiophysics files on the Snowy Mountains Experiment were destroyed.

15. Bowen to Harry Wexler, Director of Meteorological Services, US Weather Bureau, 5 March 1958; A. J. Higgs to G B Gresford, 30 January 1959; and E. J. Smith 'Cloud-seeding in Australia', Enclosure A to 'Notes on Cloud Seeding Programme', 28 May 1963. All in Radiophysics file A1/11/1.

16. Bowen to the Acting Research Secretary, Physical Sciences (CSIRO), 3 July 1957, Radiophysics file A1/11/1, and E. K. Bigg, personal communication. Keith Bigg was a member of the Radiophysics rain and cloud physics research program from 1954 until the program, transferred to a new Division of Cloud Physics, was abandoned and the Division closed in the early 1980s.

17. C. B. Schedvin, unpublished MS, note 75. The original reference is CSA, Series 3, file KC 31/5/7, Pt. I. P. A. P. Moran to Clunies Ross, 1 May 1957.

18. Schedvin MS. Original references are CSA Series 3, KC 31/4/1, *An assessment of the Snowy Mountains Cloud-Seeding Experiment* by Roscoe Braham Jr, Department of Meteorology, University of Chicago, 20 November 1959, p. 3, and *ibid.*, pp. 5-8. However, Keith Bigg asserts that the experiments were repeated by an independent contractor who obtained the same experimental results. (E. K. Bigg, personal communication.)

19. Schedvin MS, *op. cit.*, note 76. Original reference is Roscoe Braham, *ibid.*

20. Keith Bigg asserts that the SMHEA's measurements were completely inadequate, on a number of grounds. (E. K. Bigg, personal communication)

21. E. K. Bigg (personal communication)

22. Schedvin MS, *op. cit.*, p. 81.

23. This account of the Snowy Experiment comes from E. K. Bigg (personal communication).

24 These files are noted as destroyed on a schedule of Radiophysics files obtained from S. Atkinson. I do not know when, why or by whom they were destroyed.

25. Schedvin MS *op. cit.*, pp. 80-81. The quote is from the Sydney *Sun*, 12 January 1957.

26. E.g. in May 1956 the annual conference of the Graziers' Association of NSW passed a resolution in effect thanking CSIRO for its rainmaking experiments. (S. Ick-Hewins [sic], Graziers Association of NSW, to CSIRO, 10 May 1956, Radiophysics file A1/11/1.

27. Arthur Fadden to Goodes (Department of the Treasury), 20 May 1957, Radiophysics file A1/11/34. Fadden ends with the delightful comment, 'All this leads me to the conclusion that from every possible angle, except absolute certainty as to the value of the expenditure, that [sic] we should spend a few quid on the experiment, and consequently I approve of it.'

28. Casey to Quarmby, 24 May 1957, Radiophysics file A1/11/34.

29. Bowen to White, 'Interim report of cloud-seeding for drought alleviation programme', 9 July

1957, Radiophysics file A1/11/34.

30. E.g. Bowen to White, 28 June 1957, Interim report on the drought alleviation programme, Radiophysics file A1/11/34.

31. White to Casey, 11 July 1957, Radiophysics file A1/11/34.

32. Casey to Muir, Secretary of the Queensland Cane Growers' Council, 9 July 1957; H. Garside, Queensland Grain Growers' Association, 22 July 1957, both in Radiophysics file A1/11/34.

33. White to Casey, 11 July 1957, Radiophysics file A1/11/34.

34. N. W. Kater to Clunies Ross, 29 August 1957, Radiophysics file A1/11/34.

35. White to Holt (acting minister for CSIRO), 10 September 1957, Radiophysics file A1/11/34.

36. K. O. Campbell, 'The Challenge of Production Instability in Australian Agriculture', *Australian Journal of Agricultural Economics* 11, 1 (July 1958), 3-23, p. 8.

37. Bowen to Ian Allen, MHR, 7 March 1958, Radiophysics file A1/11/1.

38. Bowen, 'Weather Modification: Notes for Information of Minister', 26 January 1955, Radiophysics file A1/11/28.

39. Bowen, 'Weather Modification: Notes for Information of Minister', 26 January 1955, Radiophysics file A1/11/28.

40. Bowen to Casey, 3 February 1955, Radiophysics file A1/11/28.

41. White to Casey, 28 Jan 1955, Radiophysics file A1/11/28.

42. Bowen to J. W. Shand QC, 27 May 1958, Radiophysics file A1/11/28.

43. Bowen to J. W. Shand QC, 27 May 1958, Radiophysics file A1/11/28. It was probably this concern that led CSIRO to ask the Civil Aviation Authority to inform it of any applications to carry out cloud-seeding or modify an aircraft for doing so. In response, the CAA promised that no licence for the use of aircraft for rainmaking would be issued without prior consultation with CSIRO. (F. G. Nicholls, Secretary, General Administration (CSIRO) to the Director-General, Department of Civil Aviation, 17 February 1955 and C. S. Wiggins (CAA) to Nicholls, 4 March 1955, both in Radiophysics file A1/11/28.)

44. Schedvin MS, *op. cit.* Original reference is CSA, Series 476, CEP Agenda Item 3, 'Rainmaking Legislation', 16 October 1957.

45. Schedvin MS, *op. cit.* Original reference is CSA, Series 476, confidential memorandum by Casey to Clunies Ross, 30 February 1958.

46. F. G. Nicholls, notes from meeting of [CSIRO] Executive Committee, 16 October 1957, agenda item 3, 'Rainmaking Legislation', p. 2, Radiophysics file A1/11/28.

47. Judith Brett, *Robert Menzies' Forgotten People* (Pan MacMillan, Sydney, 1992), p. 156.

48. E.g. the rural population as a proportion of the whole population fell from 31.1% in 1947 to

13.9% in 1976, while the rural sector's contribution to GDP was 29% in 1950-51 but only 7% in 1978-9. (A. G. L. Shaw, 'History and Development of Australian Agriculture', p. 19, and A. Stoeckel and G. Miller, 'Agriculture in the Economy', p. 167, both in D. B. Williams (ed.), *Agriculture in the Australian Economy* (Sydney University Press, Sydney, 1982 ed.).

49. D. H. McKay, 'Stabilization in Australian Agriculture', *Australian Journal of Agricultural Economics* 9, 1 (June 1965), 34-35.

50. Perhaps Menzies' views were also influenced by Mark Oliphant, with whom he had a relatively close relationship. Oliphant had clashed with Bowen in the early 1950s over the question of the national radio astronomy institute (see note 4 above). There may also have been some rivalry stretching further back, for Bowen and Oliphant had first become acquainted when both were working on the British development of radar in the 1940s. But I have no evidence that there was any lasting ill-feeling between them in the late 1950s.

51. White to Bowen, 10 February 1958; a copy of a statement by White to Casey, which looks as if Bowen originated it. Radiophysics file A1/11/1.

52. Casey to White, 5 February 1958, Radiophysics file A1/11/1.

53. Statement by the American Meteorological Society, 10 May 1957, Radiophysics file A1/11/1. In a slightly later letter Bowen claimed to White that much of the information it was based on had come from him.

54. Robert D. Elliott, 'Seeding of West Coast Winter Storms', in *Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineer*, p. 54; a paper presented at the Weather Modification Conference in Denver, Colorado, August 1959. Elliott was the president of North American Weather Consultants.

55. Memorandum, Bowen to CSIRO Research Secretary (Physical Sciences), 27 February 1958, Radiophysics file A1/11/1.

56. Guy Gresford, CSIRO Research Secretary (Physical Sciences), to Bowen, 21 March 1958, Radiophysics file A1/11/1.

57. E.g. letters from Bowen to M. C. Buttfield, General Manager, AMP Society, 16 February 1960, and to Peter Baillieu, 8 November 1960; both in Radiophysics file A1/11/1.

58. US National Science Foundation, 'National Science Foundation Announces $1,130,000 Research Program on Weather Modification', 23 March 1959. Filed in Radiophysics file A1/11/1 with the correspondence of May 1959.

59. Earl G. Droessler, Program Director for Atmospheric Sciences, National Science Foundation, to Bowen, 21 July 1961, Radiophysics file A1/11/1.

60. Bowen to L. J. Dwyer, Director, Bureau of Meteorology, Melbourne, 14 January, 1958; Roscoe

R. Braham, Associate Professor, University of Chicago, to Robert M. Cunningham, Air Force Cambridge Research Center, 17 December 1958; both in Radiophysics file A1/11/1.

61. The original Radiophysics file was A1/11/66. A note on the file cover indicates that the material was transferred to the CSIRO Division of Cloud Physics, after that Division was created in 1972 to take over the cloud physics program. The material *may* be in Cloud Physics file A2/9.

62. H. Dessens to Bowen, 18 May 1960, Radiophysics file A1/11/1. The journal in question was the well-regarded *Tellus*. The Radiophysics paper (by Pat Squires, on the correlation between atmospheric pollution and cloud stability) had languished in the pigeonhole of *Tellus'* editor for two years and three months!

63. Bowen to Roscoe Braham, 8 January 1959 (mentions the plans for 1959); Pat Squires to Joanne Malkus, Woods Hole Oceanographic Institute, 30 July 1959 (on the revised date of August-September 1961); both in Radiophysics file A1/11/1.

64. Bowen to Robert D. Elliott, 1 June 1962, Radiophysics file A1/11/1. The Radiophysics group appears to have revised its cloud physics research program following the conference, but not its cloud-seeding. (Warner, Turner, Telford and Squires, 'Cloud Physics programme as viewed in the light of the conference on cloud physics', typed manuscript, 16 October 1961, filed at the back of Radiophysics file A1/11/1 (1960-63).)

65. CSA file PH/BOW/9, Bowen to White, 7/11/52, cited in Robertson, *op. cit.*, p. 207, note 16.

66. White to Bowen, 3 July 1957, Radiophysics file A1/11/1. The American Meteorological Society had 6, 500 members.

67. Bowen had reviewed programs for at least fiscal year 1961 and possibly for other years. Earl G. Droessler, Program Director for Atmospheric Sciences, National Science Foundation, to Bowen, 21 July 1961, Radiophysics file A1/11/1.

68. Mt Lofty experiments (1957-59 inclusive), E. K. Bigg, personal communication. Darling Downs experiments (1960-1961): 'Meeting on cloud-seeding experimental trends', attended by Bowen, Smith, Adderley and Bethwaite, 31 May 1961, Radiophysics file A1/11/1.

As early as May 1957 the US Weather Bureau had alleged that 'indiscriminate cloud seeding on a large scale ... could have caused the worst drought of recent times in the Midwest and Southwest [USA]'. The Bureau argued that the cleaner the air, the better the chance of rain from both warm and supercooled clouds. (Typescript of extract from *Science News*, 4 May 1957, Radiophysics file A1/11/1.) Perhaps this was little more than another salvo fired in the political battle between the Bureau and the followers of Langmuir. Radiophysics may have been concerned about these allegations but I have found no evidence that it was.

69. Bowen to Louis J. Battan, Associate Director, Institute of Atmospheric Physics, University of Arizona, 25 July 1961, Radiophysics file A1/11/1.

70. E. J. Smith, 'Cloud Seeding in Australia', Enclosure A to 'Notes on Cloud Seeding Programme', 28 May 1963, Radiophysics file A1/11/1.

71. Bowen to Robert D. Elliott, 1 June 1962, Radiophysics file A1/11/1.

72. CSIRO Division of Radiophysics, *The Radiophysics Laboratory, 1964*, p. 26.

73. E. J. Smith, Cloud Seeding Section: Programme for 1964, 12 December 1963.
The Australians were now treading the same road that the University of Chicago experimental group had followed a few years before, although they were led to it by the internal developments of their own program rather than by imitation.

74. 'Rain in Australia follows A-blast', *Washington Post–Times Herald*, 29 September 1956.

75. Bowen had a hypothesis that meteoritic dust in the atmosphere acted as freezing nuclei, increasing rainfall. He wrote a number of papers on the subject, but the idea was not widely accepted. In September 1956 he wrote to a colleague,

As you know, this whole question of the freezing nucleus content of the atmosphere and its possible connection with meteoritic dust is very controversial at present, but if you were to ask the average meteorologist what the freezing nucleus content was at 15,000 ft yesterday, he would probably reply with a blank stare. It is a pity that the meteorological profession insists on keeping themselves ignorant of one of the most important physical quantities leading to the formation of rain.

(Bowen to Charles E. Smiley, Department of Astronomy, Brown University, Rhode Island, 25 September 1956, Radiophysics file 'Outward Correspondence – U.S.A. – "S" General, Jan. 1947-Oct. 1969.') The issue illustrates the influence that astronomy had on the cloud physics program. Bowen was also in touch with Fred Hoyle for many years: was he influenced by Hoyle's idea of the Earth being seeded by life from space?

76. Sydney *Sun-Herald*, Sunday 23 June 1957, p. 1.

77. Oliphant to Bowen, 1 February 1962, Radiophysics file A1/11/1.

78. Haynes *et al.*, *Explorers of the Southern Sky*, *op. cit.*

79. A. J. Higgs to Oliphant, 8 February 1962, Radiophysics file A1/11/1. In another case, the Australian Atomic Energy Commission had great difficulty in enlisting the help of Radiophysics in a study of parcels of air tagged with radio isotopes, but the reasons for this are unclear.

Chapter 3: Persistence, and resistance, 1963-1971

...unequivocal answers to the question have not yet been found, but surely waiting for such answers, even if they are obtainable, is no single excuse for withholding use of techniques of cloud seeding, particularly in times of crisis. [The Director of the Bureau of Meteorology] would be considerably embarrassed if he were asked not to use techniques of forecasting unless they were based on unequivocal answers to meteorological questions.

E. E. (Otto) Adderley, a member of the CSIRO cloud-seeding group, responding to an attack by Bill Gibbs, Director of the Bureau of Meteorology, March 1968[1]

He [Bowen] had insight, intuition, and he worked on that basis rather than science. Of course that doesn't go down too well with most scientists.

E. K. (Keith) Bigg, former member of the Radiophysics cloud physics group[2]

The previous chapter described how in the early 1960s the cloud-seeders had reached a technical stalemate when the results from their wide-area experiments seemed to be deteriorating. In an effort to crack this problem they mounted one major experiment, of a new design, between 1964 and 1970. While this was running Bowen once again took the fight to have cloud-seeding accepted into the political system. Although by the '60s the CSIRO group had consolidated its position internationally, its status in Australia was not so secure.[3]

The persistence theory

The wide-area trials that the CSIRO group had run in the '50s were of two basic designs. In the first type, a 'control' area was left unseeded while a target area was seeded on a random basis – that is, the days on which seeding was done were selected randomly from the set of all days suitable for seeding. The ratio of the rainfall in the target area to that in the control area was used (after a little statistical massaging) as a measure of the effectiveness of seeding. The second type of experiment was called a 'two-area cross-over' trial. Again, two areas were selected. On some occasions the first area was seeded while the second was not; on other occasions the second area was seeded while the first was untouched. And again, the ratio of the rainfall in the seeded area to that in the unseeded area was taken as the measure of effectiveness. The Snowy Mountains experiment had been of the first type, subsequent experiments of the second.

The cloud-seeders had always assumed that when an area was seeded with silver iodide there were no long-lasting effects – certainly not effects that would remain after a few months. But early in the 1960s Bowen became convinced that an effect of this kind was playing havoc with the two-area cross-over tests, by causing the *difference* in the rainfall in the two areas to decrease over time. If the rainfall in the two areas was becoming more similar, the statistical analysis would greatly underestimate the effects of seeding. Bowen aired this idea in 1966 in the *Journal of Applied Meteorology*.[4] It was not an entirely new idea, as there had been American suggestions that some 'persistence effect' might occur, but this was its clearest formulation. Bowen later claimed that he had first suspected persistence effects during the Snowy Mountains experiment.[5] If the idea was right, then the statistical results of the previous experiments had underestimated the actual increase in rainfall due to seeding. To Fred White, Bowen wrote that

It would be fair to say that the increase [in rainfall] was at least that achieved during the first year of each experiment ... It may not be possible to use this argument in public, but we certainly have grounds for being much more optimistic than we have been for a long time.[6]

Bowen was so convinced of the correctness of this idea that, using his US contacts, he had it drawn to the attention of a committee of the US Academy of Sciences that was then investigating cloud-seeding.[7] But one thing was lacking: a physical explanation of the effect. Bowen directed Keith Bigg, a member of the cloud-seeding group, to 'go out and *find* these persistence effects'.[8] Bigg recalls that he, like 'everyone else', thought that 'this was just another one of Taffy's bright ideas'; it was not until twenty years later that he became convinced that Bowen had been right.[9]

At the time few people were persuaded that persistence effects existed. Indeed, the very statistical measures being used to established the effectiveness of seeding, and which would also demonstrate persistence effects, were attacked by a statistician working under Roscoe Braham, the meteorologist who had criticised the design of the Snowy Mountains experiment.[10] Years later support began to come from another quarter. When Bowen presented a paper in Washington on the subject in 1970 he noted that the physics of the persistence effect remained obscure, but that for an explanation 'one is almost invariably forced back to some form of interaction between weather systems and the environment.'[11] A climatologist, L. A. Joos, heard the talk, and later began to correspond with Bowen about what might produce such an effect.[12] Joos' suggestions may or may not have been correct. But by 1970 it had become easier to entertain the idea of persistence effects, as there had been a shift to looking at the weather as occurring within a total system within which the ground itself might be important.

The Tasmanian Experiment, 1964-1970

In the early 1960s this discussion of possible mechanisms was still a long way off. The first step was to run an experiment to establish that the effect was real. This experiment was carried out in conjunction with the Tasmanian Hydro-Electric Commission (HEC). The high central plateau of Tasmania was used as the target area and three control areas were chosen at different distances and directions from the target. Seeding was undertaken in 12-day periods, but only in every second year, and so the Tasmanian experiment ran for a long time, from 1964 to 1970. The final results seemed clear. Seeding had increased autumn rainfall was by 30%, at a 5% significance level (that is, the odds of obtaining this result by chance were one in twenty). Seeding also seemed to increase rainfall in winter in periods of light to moderate rain. For the first time in an Australian experiment there was no sign that seeding had lost its experiment over time. As early as 1966, preliminary results showed that in 1964 precipitation in the target area had been 25% higher than that in the control area, and that it remained high after seeding ceased in December 1964 and did not return to its normal value until August or September 1965. Naturally, Bowen took all this as support for his theory.[13] But not all members of the cloud-seeding group itself were convinced: the seasonal variations in the effect of seeding were put down to some kind of microphysical change in the clouds.

The first cloud-seeding 'school'

In 1965 Radiophysics was again pressed into operational seeding in Victoria, NSW and Queensland.[14] Towards the end of the 1964-1965 summer CSIRO was approached by the Forestry Commissions of NSW and Victoria to seed over areas that were threatened by bushfires[15], and in April and May it seeded drought-stricken regions of southern Queensland.[16] In May, Bowen, apparently trying to get out of the perennial round of such obligations, wrote to a number of State authorities, suggesting that they should take responsibility for any cloud-seeding operations which they might require during droughts and bushfires.[17] By June this proposal had been transformed into plans for Radiophysics to run a course of instruction in the techniques of cloud-seeding, to which State authorities would send representatives to be trained.[18] This plan was apparently well received and the first such course was held in August 1965. It was attended by representatives of State departments of agriculture and forestry, and assorted others from CSIRO, the Bureau of Meteorology and East-West Airlines. Following the 'school', the participants were invited to spend some time in the field, flying the Radiophysics' seeding aircraft. The 1965 cloud-seeding course was apparently a success for Radiophysics decided to run another in 1966. Meanwhile, Bowen intensified his campaign to have State governments take on the responsibility for cloud-seeding.

Political approaches in the mid 1960s

Bowen may have stepped up his initiatives at this time because he saw the threat of commercial cloud-seeders moving into the field.[19] Certainly he was keen to offload the cost of operational seeding. The time was ripe for handing over the responsibility for this work to the States as CSIRO had developed a good working relationship with most of the relevant State departments.[20] But getting *any* body, public or private, to take on cloud-seeding had proved surprisingly difficult up to this point, as is shown by the trials and tribulations of Donald M. Shand. Shand was the Chairman of East-West airlines and had keenly supported Radiophysics' cloud-seeding since the late 1950s. In 1963 or 1964 CSIRO enlisted him to drum up further support for seeding among the graziers.[21] In a 1966 letter, Shand outlined the farce of 'buckpassing' that he had met so far:

I approached the graziers [about cloud-seeding]. All graziers agreed that the right thing for me to do was to see the P.P. [pasture protection] Boards. This I did and they advised me that the right authority would be at the Federal level. I approached certain people at this level who informed me that these clouds belonged to the State of N.S.W. and therefore I again put the proposition up to State authorities, but they informed me that the water from this area would be going into Federal territory. I then approached the Water Foundation who informed me that their function was to conserve water and not to make it. I have called a meeting of the presidents of all the banks in Australia and suggested that an authority be set up. This type of approach has been made over the past 2 $^1/_2$ years.[22]

In 1966 Shand and Bowen made other approaches, for instance to the NSW parliament, where they arranged to have 'Dorothy Dix' questions raised in the parliament at question time on 25 October, followed by a screening of CSIRO's 1964 promotional film, 'The Rainmakers'. Somewhat anticlimactically, it was shown after a film of the 1962 Cup Final at Wembley (Tottenham Hotspur v. Burnley); nevertheless, it did arouse the interest of at least one member of Parliament.[23] But nothing much came of this effort. The political approaches begun around 1963 had still not borne fruit three years later.

Approaches to the Australian Agricultural Council

In January 1966 Bowen sent a statement on cloud-seeding to the Australian Agricultural Council, a peak agricultural body coordinated by the Commonwealth, to have it considered by the Council's subsidiary Standing Committee on Agriculture on which the States were represented. In taking this action he by-passed the member of the CSIRO Executive who would normally have been responsible for forwarding the information to the Agricultural Council.[24] The issue of cloud-seeding was first referred to the Standing Committee on Agriculture at its meeting on 2 February 1966, and was considered by both the Committee and the Council at various meetings until at least November 1966.

The Council, which by its own assessment was the only body with Australia-wide representation that was concerned with drought, considered cloud-seeding only as a drought relief measure – not, for instance, as a means of building up water resources ahead of a drought.[25] It gave far more time to considering other, preventative, steps to be taken against drought, principally the conservation of water and fodder. Cloud-seeding was not initially linked in the Council's collective mind with the growing issue of conservation, although Bowen was now tending to put a conservation 'spin' on the issue, pointing out that 'you cannot conserve what you have not got'.[26] The Council's statements have a familiar, contemporary, ring, emphasising as they did that it was up to individual farmers to provide for themselves against the 'emergency' of drought, and that the role of Governments was to give farmers incentives to do this.[27] Cloud-seeding, at least in the form of a government-controlled technique, did not fit too well with this philosophy.

Nevertheless, the Standing Committee on Agriculture did consider the issue. By this time a reasonable *modus operandi* for seeding had been worked out between CSIRO and the States. None of the State representatives on the Standing Committee expressed negative views of the technique; those of New South Wales, Tasmania and Victoria were very positive, while the South Australian representative emphasised the close cooperation that his department had had with CSIRO over cloud-seeding.[28]

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At a meeting of the Standing Committee in late 1966, the CSIRO representative, C S Christian, raised the idea that cloud-seeding might go hand in hand with water conservation, and at this meeting the Committee invited CSIRO to prepare a report on cloud-seeding in relation to both drought relief and water conservation. But the Committee's essential demand was for more information. The Chairman put it to the meeting that CSIRO should lead the States, because it had the 'definite information'. Christian responded that cloud-seeding was like other natural resource issues in which 'the initiative has [mostly] come from the States rather than from the Commonwealth'. But the Chairman was insistent: 'the C.S.I.R.O. should now put the facts before the people on which [a] judgement can be made.'[29] However, at this point there was probably very little information that CSIRO could add to that which it had already given the Agricultural Council.

The States accept cloud-seeding

The deliberations of the Agricultural Council and its Standing Committee were overtaken by other events. Bowen prepared a document on cloud-seeding for both the May and November 1966 meetings of the CSIRO Advisory Council, the organisation's guiding body. This document, moderate but positive in tone, stated that the seeding technique in use had reached a 'stable and efficient level' and that major changes in practice were unlikely in the near future. It presented seeding for droughts and bushfires as justified by the amount of water that could be extracted from supercooled clouds; emphasised that cloud-seeding was the only process known by which the 'maximum possible precipitation' could be 'extracted' from weather systems; and circumscribed the geographical regions suitable for cloud-seeding. Last but not least, it cited a change in attitude towards cloud-seeding that had occurred in the USA in the previous year, a change from an attitude of scepticism to one of faith – with concomitant projected increases in spending on the technique.[30]

Soon after this document was prepared in May, CSIRO presented a statement on cloud-seeding to Government: presumably the same document, or something like it. Following this, on 11 July the Acting Prime Minister, Jack

McEwen (Menzies had recently retired) sent a statement on cloud-seeding to the State Premiers, which suggested that they consider initiating cloud-seeding in their respective States. The statement voiced confidence in the technique, but its crucial point was that the Commonwealth was now willing to reimburse the States for the running costs (although not the capital costs) of cloud-seeding done to relieve drought.[31]

The effects of this statement cannot be quantified, as there was already quite a bit of State-sponsored seeding going on in 1965 and 1966, but the years 1967-1969 probably saw the most widespread cloud-seeding in Australia. In March 1967, for instance, seeding was under way in five States. Victoria was pursuing it the most vigorously. New South Wales had two aircraft seeding, and Queensland, one; Western Australia was set for two experiments to be run jointly by CSIRO and the State; and in Tasmania the CSIRO experiment was running well, with the Hydro-Electric Commission expected to take over practical seeding in due course (which it did).[32]

In issuing invitations to the 1966 Cloud Seeding School Bowen cast his net wider than in 1965, and also invoked the Prime Minister's statement to the Premiers. State departments were invited to nominate two types of people to attend: those who would carry out the work, and those 'senior officers who would like to hear about and assess the possibilities'.[33] As in 1965 a member of the Weather Bureau was invited to give talks in the course, but so too were two staff of the NSW Department of Agriculture. All this added up to a serious attempt to enlist as many people as possible in the cause. The participants were mainly from agricultural departments, but there were also representatives from forestry bodies, water conservation authorities, the WA Public Works Department and the University of Queensland.

The State representatives at the course had views on cloud-seeding which ranged from neutral at worst to very positive at best. G. Nicholson, an agronomist with the NSW Department of Agriculture, summed up what was probably a common position:

My association with C.S.I.R.O. cloud seeding experiments over the past six to eight years has aided the build up of good public relations between research and extension. An incentive was required for State authorities to accept cloud *seeding as an aid to production. Nature [fires and drought], plus public opinion, provided the incentive.*[34]

With the exception of 1969, the cloud-seeding schools continued yearly until 1970, the year before Bowen retired. By that time they had become international events, the last one attracting not only 23 Australian participants but also 5 from the Philippines, 2 from the USA, and one each from New Zealand, Peru and Korea.[35] (Participants had also been invited from Israel, Japan and Russia.) In their five years of operation these schools were attended by 126 people and the notes from them were widely distributed.[36]

By 1970, although a number of States were said to be considering legislation to govern cloud-seeding, only Victoria had actually enacted it, giving the Victorian government control of weather modification and prohibiting unauthorised operations.[37]. But even without specific legislation the other States were firmly in control of the activity. Private individuals and groups were discouraged from moving into the field and it would have been possible – although apparently it proved unnecessary – to exclude them by invoking regulations of the Department of Civil Aviation that prohibited the release of material from aircraft without prior authority.[38] The State operations were usually carried out by the Departments of Agriculture, who appointed cloud-seeding officers to supervise the activity; the actual work was done by private contractors. In Bowen's opinion, 'a happy and relatively trouble-free situation seems to result in which private companies have the pleasure and presumably the profit of participating, while the Department concerned remains firmly in control.'[39]

Conflict with the Bureau of Meteorology

In 1967, just as State governments began to accept cloud-seeding as a sanctioned technique, open conflict broke out between Radiophysics and the Bureau of Meteorology. The antagonism between them seems to have gone back a long way[40], well before 1957, but in that year real trouble had occurred when the Bureau's statistician, Gerry O'Mahoney, criticised the way the Snowy Mountains experiment was being conducted. O'Mahoney was supported by the Bureau's Director, Bill Gibbs; as a result, Bowen 'wrote Gibbs off'.[41] Radiophysics and the Bureau of Meteorology had also clashed over a seeding experiment in the mid '60s done by the Victorian Department of Agriculture, for which the CSIRO analysed the results: O'Mahoney attacked them again about the procedures being used. A few months after the Prime Minister's statement to the Premiers had supported cloud-seeding, Gibbs sent interested State authorities a counter-statement which argued that cloud-seeding had not been proven to be effective.[42] And by 1967 the Bureau may have had another reason to think that Radiophysics was encroaching on its territory: at some time in the 1960s Bowen had become interested in long-range weather forecasting – specifically, predicting droughts – and in 1967 he published the first of what were to be ten booklets predicting rainfall trends (the last came out in 1976).[43] The Bureau may well have been aware of this work, even if it had not yet been published. Although exacerbated by personal antagonism between Gibbs and Bowen, the underlying struggle was an institutional fight for superior authority.

According to the Bureau, on 18 July 1967 Fred White wrote to Gibbs seeking to get the Bureau 'more involved' with cloud-seeding, but also objecting to the proposed publication of a paper by Gerry O'Mahoney that argued against the effectiveness of cloud-seeding in a specific experiment.[44] On 21 July Gibbs wrote to Bowen. Ostensibly he was seeking greater involvement by the Bureau, in line with White's suggestion. But in the same letter he described the O'Mahoney paper as an example of an independent evaluation, adding, 'I know that you will not be in complete agreement with the contents...'.[45] Bowen was incensed. To Fred White he seethed that 'not for the first time, the Commonwealth Bureau of Meteorology is fiddling around in a disgraceful way in a matter which is of the utmost importance to this country'.[46]

White may have taken some action on this complaint. At any rate, the Bureau's story is that it was then gagged. In early August Gibbs sent the Minister for the Interior, Mr Anthony, a statement to the effect that cloud-seeding was not proven, specifically attacking the CSIRO statement distributed by McEwen in July. Later that month the Minister directed that the Bureau was to make no public statements on cloud-seeding. The order was reiterated by the Bureau's new Minister, Nixon, in October of the same year.[47]

Nevertheless, by September 1967 Radiophysics was convinced that the Bureau's opposition to its own views on cloud-seeding had been codified into policy; certainly the Bureau was still using public forums to push its case. Bowen found, while giving a public lecture in Cobar, that

...the local Meteorological Officer virtually denied everything that I had said. He was later quite apologetic about the whole thing and gave the impression that he was only doing what he had been told to do.[48]

A similar event occurred in Victoria, when a member of the Victorian Department of Agriculture was giving a lecture at a Water Resources conference: by pre-arrangement, Gerry O'Mahoney was given time to present the 'not proven' case. Other cases occurred, and the States complained to Radiophysics about them, being 'occasionally ... quite bitter about the behaviour of the Bureau in this matter'.[49]

The conflict erupted in public again in March 1968 while Bowen was overseas.[50] The Melbourne *Age* got hold of a 'confidential' statement from the Bureau in which Gibbs took the line that it was 'undesirable to have a single authority responsible for the design, operation and evaluation of the experiment'. The *Age* also noted that the Bureau had been gagged on the issue.[51] It appears that around this time Dick Kingsland, Secretary of the Department under which Meteorology fell, had (like White before him) urged the Bureau to get together with CSIRO to try to agree on a joint position. 'But', said Gibbs in writing to Bowen, 'I doubt that you and I could reach such a position'.[52]

He was right. As Bowen was overseas another member of the cloud-seeding group, Otto Adderley, prepared a detailed response of several pages to Gibbs' statements.[53] When Bowen finally replied to Gibbs, three months later, he did not attack the substance of Gibbs' statements but instead scathingly insisted on the Bureau's complete lack of international standing in the field, and indeed its complete lack of practical involvement:

You are certainly entitled to express your opinions and beliefs on cloud seeding but, with no specific work of your own going on in this field, no laboratory *work, no practical work and therefore no factual material of your own to draw on, you must not be surprised if people discount what you have to say.*[54]

The comparable conflict in the USA, between the 'fringe' advocates of cloud-seeding and the US Weather Bureau, had been resolved, or at least quieted, by putting the matter under the jurisdiction of the National Science Foundation. No such resolution was possible in Australia. The CSIRO itself was Australia's closest analogue to the NSF. Australian universities were carrying out little research related to cloud physics (and in any case, the Bureau of Meteorology claimed that many in the Australian universities shared its scepticism about cloud-seeding[55]). On what grounds were governments to choose between the arguments presented by the CSIRO and the Bureau? I cannot answer this for State governments as I have no information about their interest in cloud-seeding after 1970. But the silencing of the Bureau in 1967 probably reflects not so much the Commonwealth government's faith in CSIRO as the need to protect the public position it had taken in recommending cloud-seeding to the States. The general conflict between the two positions was officially ended fifteen years later when CSIRO abandoned its strong advocacy of cloud-seeding, in the circumstances described in the next chapter.

Lack of university involvement in the field

Why was there so little Australian university research in areas related to cloud-seeding, even straight cloud physics? After an initial burst of enthusiasm in the late 1940s from S. M. Wadham, Professor of Agriculture at the University of Melbourne (see note 90, chapter 1), there is no sign of any interaction between CSIRO and the agricultural departments of universities. But perhaps this is no more surprising than the fact that only in 1967 did the cloud-seeders make contact with the agricultural and land-use divisions of CSIRO. The lack of contact in both cases points to disciplinary barriers. As well, agriculturalists may have seen cloud-seeding as a possible boon for agriculture, but not as an activity that they could contribute to, evaluate or control.

Lack of contact with the physics departments of universities probably had other causes. In many fields relationships between the university sector and CSIRO were extremely cool as long as a vast discrepancy remained in their research funding.[56] Bowen is known to have opposed and attempted to undermine attempts by other Australian organisations to move into radio astronomy, and it would not be surprising if he had attempted to do the same in cloud physics.[57] There is only one exception. Between 1962 and 1966 Bowen agreed to support, from Divisional funds, a research program in cloud physics at the University of New England (Armidale) started by Neville Fletcher. This support, to the tune of five thousand pounds a year, was terminated in 1966 by the CSIRO Executive only when Commonwealth funding for university research became available for the first time. But almost certainly it was given solely because Fletcher had been a member of the Radiophysics cloud-seeding group, and 'one of the most outstanding men we have had'.[58] As well, Fletcher's research program was one of laboratory studies into silver iodide and ice crystal nucleation, and studies of natural rainfall: subjects that complemented, not competed with, Radiophysics' cloud-seeding.[59]

Comment

At the end of the 1960s cloud-seeding in Australia had reached its apogee. It had been accepted as an operational technique by a number of the State governments and the Tasmanian Hydro-Electric Commission, and Radiophysics had formed good links with these groups. The scientific reputation of the Radiophysics group appears to have been well established internationally, while Bowen's personal reputation was such that he was invited to act as a consultant in the USA. Although in Australia cloud-seeding had become strongly linked to drought relief only, Bowen thought that it should not be viewed as an emergency measure: 'the proper basis for the practical operations for which State Governments are now accepting responsibility, is continuing benefits to agriculture, water resources, etc.'. His overall position was still that 'the potential value of cloud-seeding is such that it is a good bet to carry on with seeding now without waiting until a fuller answer has been provided'.[60] But the physical effects of cloud-seeding were being unravelled very slowly. In 1971 the main problems of the field were still understanding the microphysical processes of cloud-seeding, measuring cloud characteristics, and understanding when and why seeding produced an increase or decrease in rainfall.[61] The greater acceptance of cloud-seeding in Australia in the late '60s was not due to changes in knowledge or technique: it was due to the way in which Bowen had exploited aspects of Australia's federal system.

Notes to Chapter 3

1. E. E. (Otto) Adderley, 'Notes on two statements by W. J. Gibbs, Director of Meteorology, forwarded with his letter of 20 March, 1968', Radiophysics file A1/11/68.

2. E. K. Bigg, personal communication.

3. The group's standing was certainly high in the USA. In a short history of weather modification Horace R. Byers, himself a former researcher in cloud-seeding at the University of Chicago, was lavish in his praise of the CSIRO group, which, he said,

... could probably be called the world's most outstanding scientific group dealing with cloud physics and weather modification. It is probably correct to say that no other organization contributed more to practical cloud physics during the period approximately 1950 to 1965.

(Horace R. Byers, 'History of Weather Modification', in W. N. Hess (ed.), *Weather and Climate Modification* (John Wiley, New York 1974),p. 23)

4. E. G. Bowen, 'The effect of persistence in cloud seeding experiments', *Journal of Applied Meteorology* 5, 2 (1966), 156-159. Bowen may have also aired the idea at the 1965 International Conference on Cloud Physics in Tokyo.

5. 'However', he wrote, 'our meteorological friends, as usual, chose to ignore the data and follow their preconceived ideas, namely that persistence could not possibly occur. So to preserve the peace we dropped the idea...'. (Bowen to James E. MacDonald, Institute of Atmospheric Physics, University of Arizona, 27 October 1965, Radiophysics file A1/11/61.)

6. Bowen to White, 22 September 1965, Radiophysics file A1/11/61.

7. Robert D. Elliott to Bowen, 15 October 1965, and Bowen to White, 22 September 1965; both Radiophysics file A1/11/61.

8. E. K. Bigg, personal communication.

9. E. K. Bigg, personal communication.

10. Roscoe R. Braham, Jr, Professor of Meteorology, University of Chicago, to Bowen, 13 December 1967, Radiophysics file A1/11/61.

11. Extract from a paper, 'Forthcoming Problems in the Modification of Rain and Fog', presented by Bowen at the AMS/ESSA Centenary Symposium, Washington, 14 February 1970.

12. L. A. Joos, Regional Climatologist, Weather Bureau Central Region, US Department of Commerce, to Bowen, 24 February 1970, and following correspondence. Radiophysics file A1/11/61.
13. 'Present Status of Cloud Seeding'; memo attached to letter from Bowen to B. McKeon, CSIRO Secretary, 6 January 1966, Radiophysics file A1/11/34 (1) part III.
14. 'Present status of cloud seeding', note with letter to the Secretary, CSIRO, from Bowen, 6 January 1966, Radiophysics file A1/11/34 (c) 1.
15. Bowen to A. R. Trist, Queensland Forestry Department, 28 June 1965, Radiophysics file A1/11/34 (c) 3.
16. *ibid.*, and Bowen to J. L.Hennessy, 28 June 1965, Radiophysics file A1/11/34 (c) 3.
17. E. K. Bigg, personal communication; Bowen to Gill, Forests Commission of Victoria, 25 June 1965, Radiophysics file A1/11/34 (c) 3.
18. *ibid.*
19. By 1966 at the latest, and possibly earlier, in Radiophysics' view the 'the stage could now be said to be set for it [cloud-seeding], in that many individual graziers and Local Government bodies were asking for seeding to be carried out, and at least one aero-engineering firm was in a position to manufacture and fit seeding equipment to aircraft.' A. J. Higgs, 'Report on Discussion on Cloud Seeding at a Meeting of the Standing Committee on Agriculture held at Parliament House, Sydney, 2nd February, 1966', 3 February 1966, Radiophysics file A1/11/34 (1) part III.
20. Relationships with the NSW Department of Agriculture were clearly very good: Bowen agreed to the Department's seeding in the New England region in May 1966, even though that rendered useless experimental data gained in the area in 1965. (Bowen to G. Edgar, NSW Department of Agriculture, 28 April 1966, Radiophysics file A1/11/34 (1) part III.)
21. In fact he had been asked by CSIRO 'to band the graziers together in an effort to raise funds for the commercial application of rainmaking on the western side of the [Great Dividing] Range'. D. M. Shand, Chairman of East-West Airlines, to R. G. Casey, 17 March 1966, Radiophysics file A1/11/34 (1) part III.
22. *ibid.*
23. File note, 25 October 1966, Radiophysics file A1/11/34 (c) (1) part III. ('Dorothy Dix' questions are those asked to allow a member of the government to publicise some piece of 'good news'.)
24. Bowen to C. S. Christian (member of the CSIRO Executive), 6 January 1966, file A1/11/34 (1) part III. Christian was the CSIRO representative on the Standing Committee for Agriculture. Bowen sent the statement to the Agricultural Council while Christian was absent, but it is not

clear whether he was deliberately by-passing Christian.

25. W. D. Hardy, Secretary, Australian Agricultural Council, to the Secretary, CSIRO, 3 March 1966, Radiophysics file A1/11/34 (1) part III.

26. Bowen to E. D. Darby, 17 November 1966, Radiophysics file A1/11/34 (c) (1) part III.

27. Notes appended to notes on the 64th meeting of the Australian Agricultural Council [February 1966?], Radiophysics file A1/11/34 (1) part III.

28. A. J. Higgs, 'Report on Discussion on Cloud Seeding at a Meeting of the Standing Committee on Agriculture held at Parliament House, Sydney, 2nd February, 1966', 3 February 1966, Radiophysics file A1/11/34 (1) part III.

29. Notes sent by P. F. Butler, Assistant Secretary, Agricultural and Biological Sciences, to A. J. Higgs, 18 November 1966, Radiophysics file A1/11/34 (c) (1) part III.

30. Statement on cloud-seeding submitted to the CSIRO Advisory Committee in May 1966, Radiophysics file A1/11/76.

31. Letter to the premiers of Victoria, South Australia, Tasmania and Western Australia [Statement on cloud seeding] from J. McEwen, Acting Prime Minister, 11 July 1966; McEwen to Askin, Premier of NSW, 11 July 1966. Radiophysics file A1/11/34 (c) 14.

32. Bowen to White, 14 March 1967, Radiophysics file A1/11/34 (c) 1.

33. Bowen to A. W. Knight, Commissioner, Hydro-Electric Commission of Tasmania, Radiophysics file A1/11/34 (c) 3/1966.

34. G. Nicholson, NSW Department of Agriculture, 'Organisation of cloud seeding within a state government department' [no date], Radiophysics file A1/11/34 (c) 3/1966.

During the cloud-seeding course the participants discussed the attitudes of the State departments and the States as a whole. The water conservation bodies were the least interested in cloud seeding; the forestry bodies were only interested in emergency (bushfire) seeding; the agricultural departments were the most interested. Queensland was the only State that reported a clear shift in its position, thanks to positive recent statements by CSIRO and the 'declared policy' of the Commonwealth Government on seeding. (Previously it had had a 'wait and see' policy, based on the negative results of the Darling Downs experiment and statements on rainmaking by the Bureau of Meteorology.) ('Course of Instruction in Cloud-Seeding Techniques: Discussion on the Attitude of State Representatives 16/8/66', Radiophysics file A1/11/34 (c) 3/1966.)

35. 'Fifth course of instruction in cloud-seeding technique, September 21-30, 1970: Attendance', Radiophysics file A1/11/34 (c) 3/1970 PAR.

36. E.g. Archie M. Kahan, Chief, Office of Atmospheric Water Resources, Bureau of Reclamation, US Department of the Interior, to Bowen, 30 July 1968, Radiophysics file A1/11/61. Kahan thanked Bowen for the text for the third course of instruction in cloud-seeding. Kahan had also been invited to participate in a future course. The total attendance figures are from a submission by the Division of Cloud Physics to a 1977 review of CSIRO's Environmental Physics Research Laboratories, p. 15, Cloud Physics file A1.

37. Bowen to Louis J. Battan, University of Arizona, 3 July 1969, Radiophysics file A1/11/28.

38. Bowen to J. F. Gabites, New Zealand Meteorological Service, 8 April 1970, Radiophysics file A1/11/28.

39. *ibid.*

40. Radiophysics' cloud-seeding work was criticised before 1956 too, but it is not clear by whom, although the Bureau of Meteorology is a likely candidate. In 1956 Bowen wrote of 'the belligerence, the innuendo and the befuddlement with which the meteorologist has reacted to this subject', and noted that

[a] great deal could be said on this subject, but the truth is that I have been much better treated in the U.S.A. than elsewhere. Here in Australia there is not much criticism at present, but at one time I was subject to vicious attacks and pressure was applied to get me to drop the work.

Bowen to John Lear, Science Editor, The [New York] Saturday Review, 5 October 1956, Radiophysics file Outwards Correspondence – U.S.A. - "S" General [sic].

41. E. K. Bigg, personal communication.

42. R. B. Crowder, Acting Director, Bureau of Meteorology, to M. J. Manton, Acting Chief, Division of Cloud Physics, 24 March 1982, Cloud Physics file A4.2 no. 2.

43. Robin Strathdee, 'Drought was predicted, but no action taken', Brisbane *Sunday Mail*, 8 January 1978. Press clipping in Cloud Physics file D5 (Publicity - General)44. R. B. Crowder, Acting Director of Meteorology, Bureau of Meteorology, to M. J. Manton, Acting Chief, Division of Cloud Physics, 24 March 1982, Cloud Physics file A4.2 no. 2.

45. Gibbs wrote:

Some time ago Fred White suggested that the Bureau should participate more closely in cloud seeding work. I have always been keen on the idea that a project of the importance of cloud seeding should involve the Bureau both in the planning and evaluation stages. In the meantime we could do our part by providing an independent assessment of cloud seeding results.

(W. J. Gibbs, Director of Meteorology, to Bowen, 21 July, 1967, Radiophysics file A1/11/68.)

46. Bowen to White, 27 July 1967, Radiophysics file A1/11/68.

47. R. B. Crowder, Acting Director, Bureau of Meteorology, to M. J. Manton, Acting Chief, Division of Cloud Physics, 24 March 1982, Cloud Physics file A4.2 no. 2.

48. Bowen to White, 7 September 1967, Radiophysics file A1/11/34 (c) 1.

49. *ibid.*

50. A. J. Higgs to Bowen, 26 March, 1968, Radiophysics file A1/11/68.

51. Statement by Gibbs [no date], Radiophysics file A1/11/68; R. B. Crowder, Acting Director, Bureau of Meteorology, to M. J. Manton, Acting Chief, Division of Cloud Physics, 24 March 1982, Cloud Physics file A4.2 no. 2.

52. Gibbs to Bowen, 20 March, 1968, Radiophysics file A1/11/68.

53. The interesting points in this vigorous rebuttal are (i) an insistence on the importance of location in cloud-seeding ('results in one geographical and meteorological context are not transferable to other contexts') and (ii) a much less cautious approach to operational seeding than Radiophysics had taken before. Adderley also strongly objected to the suggestion that it was wrong for a single organisation to be responsible for design, operation and evaluation, correctly pointing out that what was important (and what had been highlighted by Braham in the Snowy Experiment) was that the agency making the measurements of the rainfall upon which the evaluation rested should not know the actual details of the seeding. In the past it had been the Weather Bureau that had supplied these rainfall figures. This, therefore, was an argument for keeping the Weather Bureau completely out of the picture! (E. E. (Otto) Adderley, 'Notes on two statements by W. J. Gibbs, Director of Meteorology, forwarded with his letter of 20 March, 1968', Radiophysics file A1/11/68.)

54. Bowen to W. J. Gibbs, 8 July 1968, Radiophysics file A1/11/68. CSIRO by contrast had delivered the opening paper at a recent conference on weather modification by the American Meteorological Society, and had been invited to give another lead paper at an international cloud physics conference the following year.

55. 'My attitude is one of considerable enthusiasm for cloud-seeding experiments and associated research; but I am sceptical about what I believe to be over-optimistic claims of success. This view is shared by many scientific colleagues within the Bureau, in Universities and elsewhere in Australia.' G. B. Tucker, Commonwealth Bureau of Meteorology, 'Statement on Cloud Seeding', 1 August 1968, Radiophysics file A1/11/68.

56. Sullivan, *op. cit.*, p. 310, notes that in the immediate post-war period research funding for CSIR was thirty times that of the universities. The situation did not improve greatly until 1966

when the universities gained Commonwealth funding.

57. The incident regarding Mark Oliphant has been cited earlier (see note 4 , chapter 2), and Bowen's antipathy to Harry Messel at the University of Sydney has been outlined elsewhere, e.g. in Robertson, *Beyond Southern Skies, op. cit.* and Haynes *et al., History of Australian Astronomy, op. cit.*

58. Bowen to White, 19 October 1961, Cloud Physics file A2 (Rain and Cloud Physics – Collaboration with Physics Dept, UNE [University of New England, Armidale]).

59. Cloud Physics file A2 (Rain and Cloud Physics – Collaboration with Physics Dept, UNE [University of New England, Armidale]).

60. Bowen to H. P. Black, 3 April 1968, Radiophysics file A1/11/72.

61. Committee on Atmospheric Sciences, National Research Council, *The Atmospheric Sciences and Man's Needs: Priorities for the Future* (National Academy of Sciences, Washington D.C., 1971), pp. 47-48.

Chapter 4: Endgame, 1971-1981

I have read your draft News Feature "Can Science Control Rain" and would like to suggest some amendments. ... I have omitted your comment about Australia being a thirsty country – the parallel with its beer consumption is a little too obvious.

Jack Warner, Chief of the CSIRO Division of Cloud Physics[1]

The new Division of Cloud Physics

Bowen retired in 1971, after twenty-five years as Chief of Radiophysics. The cloud-seeding program had lost its greatest champion. Bowen was succeeded as Chief by Paul Wild, a radio astronomer, who now had to decide the future of the cloud physics research. Wild initially thought that the program would continue as before, perhaps even expand slightly, and that cloud-seeding would continue to be one of the group's major activities.[2] But he had no reason, political or scientific, to keep the cloud physics group within Radiophysics, and in July 1972 it was hived off to become a separate entity, the Division of Cloud Physics, under the leadership of Jack Warner, a long-time member of the cloud-seeding group. The new Division remained at the Radiophysics laboratory in Sydney but formally became part of the Environmental Physics Research Laboratories, an umbrella grouping headed by C. B. H. Priestley. The EPRL also embraced the Division of Atmospheric Physics (formerly Meteorological Physics) in Melbourne, the Division of Environmental Mechanics and, after its creation in 1974, the Australian Numerical Meteorology Research Centre, which was jointly operated with the Bureau of Meteorology.

It was at first assumed that weather modification would remain the new Division's major interest. Indeed, 'without the incentive of an active cloud seeding program much cloud physics [undertaken by the Division] would be an academic exercise and thus largely unwarranted', wrote Jack Warner.[3] This is an interesting comment in the light of King's suggestion, mentioned in the

Introduction, that the two programs had become uncoupled: perhaps Warner was conscious of this and sought to bring them back together. Certainly in the final cloud-seeding experiment (discussed below) considerable emphasis was placed on measuring the physical parameters of clouds. As well, the group was no longer as confident about its results as it (or Bowen) had been; apparently there was some doubt as to whether the 'true facts' had yet been distilled from the existing cloud-seeding data. The group felt vulnerable to attack and sought to ensure that their procedures were 'acceptable in the professional world of statisticians'.[4]

Throughout the 1970s Cloud Physics ran four major activities: cloud-seeding experiments; studies of convective processes in clouds, and of coalescence; investigations of the nature and distribution of 'nuclei' in the atmosphere; and research on stratospheric aerosols.[5] At the end of the 1970s the cloud physics activities still accounted for 84% of the Division's budget; the studies of atmospheric pollutants only 16%.[6] But throughout the decade, although popular support for the former continued, the latter rose to eclipse it in political importance.[7] As early as 1976 Warner considered that if (due to certain eventualities discussed later) the Division should have to abandon cloud-seeding, its future activities should centre around 'inadvertent' weather modification due to aerosols and particulates in the atmosphere.[8]

'Inadvertent' weather modification

In the USA cloud-seeding was now sometimes seen as unwarranted interference with the natural environment, a form of pollution. As early as 1966 the National Science Foundation had warned that

Anything that has a general and significant effect upon plants and animals, making some more abundant, others less so, is of primary concern to mankind, for it strikes at the very basis of human existence. Changes in weather and climate may be expected to have such effects.[9]

Such sentiments were aired more often in the 1970s. The US Committee on Atmospheric Sciences acknowledged that even if a capacity to modify the weather were developed, it should not automatically be used.[10] Elsewhere

cloud-seeding was described as 'a controversial government activity with unpredictable and possibly disastrous long-range consequences', including increased sediment in lakes and dams resulting from increased water inflow, the increased likelihood of avalanches and floods, and possible increased precipitation downwind of a seeded area.[11] And in 1978 a former associate administrator of the Environmental Protection Agency linked weather modification with pollutants, suggesting that both should fall under a new Department of the Environment, so that their effects on weather and climate could be assessed and regulated.[12]

These American criticisms were based on the belief that cloud-seeding actually worked. In Australia, by contrast, there seems to have been little or no concern about the effects of increased rainfall from cloud-seeding on the natural environment, either because cloud-seeding was not generally believed to be effective or because it was not seen to be practised on a wide enough scale to significantly alter the environment.[13] Australian concern focused instead on inadvertent weather modification – the effects of industrial pollution on rainfall. In about 1978 a press report (undated) attributed to Cloud Physics the statement that industrial air pollution might be retarding the chance of rain from individual clouds. It was reported that Cloud Physics had found that most nuclei in clouds around which water had condensed were man-made rather than natural, and that their characteristics altered the likelihood of rain; that industrial pollution would change the whole character of Australia's rainfall. The pollution angle seems to have become a popular one with the press. The same story was picked up by the *National Times* in 1978 and by the Melbourne *Age* in 1980.[14]

By 1977 the Division of Cloud Physics was thinking about redirecting its efforts. Although the need to increase rain through cloud-seeding was still an important consideration, there was

a growing emphasis upon the need to understand to what degree man's everyday activities could have deleterious side-effects upon the weather on a long-term as well as short-term basis. The potential social and economic effect of results from this work may well in the future overshadow that from cloud seeding activities.[15]

But this shift in direction was blurring the distinction between the Division of Cloud Physics and the Melbourne-based Division of Atmospheric Physics, which in 1977 was running programs in atmospheric chemistry and regional-scale meteorology, among others.[16] And the Chief of Atmospheric Physics, G.B. (Brian) Tucker, was very public in his opposition to cloud-seeding, which probably undermined Cloud Physics' position.[17] Tucker was an old opponent of cloud-seeding: a decade earlier he had been decrying it from within the Bureau of Meteorology.[18]

A change of focus in climatology

Cloud-seeding was also threatened by a related intellectual shift of the 1970s, which saw climatologists begin to pay more attention to the large-scale, even global, aspects of weather and climate. This shift seems to have taken place throughout the Western world and to have been prompted by concerns about air pollution, particularly the level of carbon dioxide in the atmosphere. In the late 1970s and early 1980s, scientists studying the Australian climate began to focus on the El Nino–Southern Ocean Oscillation (ENSO) and started to debate the issues of global warming and long-term trends in rainfall. The 1982-83 drought in particular focused interest on ENSO. In 1983 at a major meeting about ENSO it was claimed that the phenomenon

is one of the most important processes determining rainfall over much of eastern Australia. At best it accounts for about 40% of the variance of annual totals in some localities. It provides a good general measure of widespread seasonal rainfall deficiencies and surpluses.[19]

Later researchers suggested that Australian crop production in general was strongly related to ENSO, and that for some crops the trend in, for instance, air pressure, could be used to predict final yields even before the crop was planted.[20]. (R. L. Heathcote has commented that at a time of shrinking funds for research, scientists from both CSIRO and the Bureau of Meteorology saw this 'applied' side of meteorology as giving them the chance to survive. 'Nothing like the chance of forecasting a drought to get the research funds rolling?', he quips.[21]) It seems that as climatologists shifted *en masse* to studying large-scale aspects of climate, the small-scale studies, such as cloud physics, became unfashionable, and were left on the margins of the profession's activities.

The changing political and economic context

The conservative governments in power between 1949 and 1972 had pursued a *laissez faire* policy with CSIRO, but under the Whitlam government political attitudes hardened noticeably. CSIRO was thought to be too big, with too many self-perpetuating programs that stemmed from the self-indulgence of individual scientists unwilling to recognise the 'larger priorities'.[22] These 'larger priorities' had changed too: with a government of a new political complexion came an explicit recognition that the agricultural sector had declined in relative economic importance (accounting for only about 10% of GDP in the early '70s).[23] Not surprisingly there was a political move against CSIRO's concentration on rural research which, in the early 1970s, accounted for at least half of its overall activities. In 1974 the Industries Assistance Commission was directed to inquire into rural research in Australia. Jack Warner, in discussing how far cloud-seeding should be categorised as rural research for the purposes of this inquiry, commented that 'in view of the Government's attitude towards support for the rural community' it was not in CSIRO's best interests to classify as rural research any program that *could* in any way be so described, but only those that unquestionably *were* so.[24] [emphasis added] While wanting CSIRO to cut back on rural research the Government also urged it to give more attention to environmental problems and the management of natural resources.[25]

These political shifts were coupled with economic pressures. There was a world-wide recession from 1973 and by the mid 1970s the Commonwealth Government was faced with an economic downturn, high inflation and rising unemployment. From 1975 to 1983 Commonwealth expenditure on science, as a percentage of all expenditure, remained essentially flat.[26] CSIRO's appropriation funding flattened off too. Only near the end of the 1970s did the organisation decide that after several years of budgetary restraint, it would have to look again at which programs should be sacrificed for the common good. The cloud-seeding program, which had no well-defined end point and involved the expense of running a research aircraft, was an obvious target. And no-one could point to any figures showing hard economic benefits from cloud-seeding, other than a rough cost-benefit estimate that had been made by the Tasmanian Hydro-Electric Commission in 1973.[27] This was favourable – the benefits were thought to be from four to ten times the cost of the experiments – but there were no comparable calculations for agriculture, which was a more difficult area to deal with as the effects of 'extra' rain depended upon both volume and timing.

The economic pressures triggered a number of reviews of CSIRO. The Fraser government, concerned about the efficient use of public funds, established the Independent Inquiry into the CSIRO ('the Birch Report'), which reported in 1977. The Inquiry was the first external review of CSIRO since its creation in 1949. Although its recommendations were essentially conservative they did push CSIRO to start changing the sectoral balance of its research between 1978 and 1983. Internal reviews also became common as CSIRO began to accommodate itself to the new economic conditions, and between 1972 and 1982 the Division of Cloud Physics was reviewed at least four times.

The final experiment

Meanwhile the Division went on with its seeding experiments, although with more planning and forethought than in earlier decades. After the success of the 1964-1979 Tasmanian experiment, various Queensland authorities were invited to nominate areas in their State where extra water was required, and the catchment of the Fairbairn dam, inland from Rockhampton, was a popular choice. Cloud Physics made a three-year survey of the area, to establish if the clouds here were suitable for a full-blown experiment. In the end the area was abandoned after a statistical simulation showed that the natural rainfall was so variable that no cloud-seeding experiment could hope to show conclusive results in five years or less.[28]

Cloud Physics then decided to turn to western Victoria, where the Victorian Department of Agriculture had carried out a five-year seeding operation some years before. This area was chosen because it was a wheat-growing region in which extra rain would be welcomed, and a reasonable amount of its rainfall was associated with the passage of cold fronts, which also dominated the weather patterns of a large part of southern Australia. The researchers spent three years (1975-78) examining the suitability of the clouds in the area for seeding. These preliminary investigations showed that the clouds associated with cold fronts were not suitable for seeding, but that those found in rain depressions – 'closed lows' – were. The suitability of the clouds for seeding was determined by measuring the clouds' liquid water content and ice crystal concentrations: it was the use of a single criterion, that liquid water content exceed 0.1 gm^{-3}, which most differentiated this experiment from all those conducted previously in Australia.[29] The experiment that followed the preliminary investigations was designed very carefully. Considerable emphasis was placed on assessing the physical effects of seeding. The target and control areas were placed in such a way that, going on past records, even a modest increase in rainfall could be detected, at a reasonable significance level, after five years. (There was no consideration, however, of 'persistence effects'.) This experiment was always intended as the 'make or break' one: the one that would determine the future of cloud-seeding in Australia, at least as far as agriculture was concerned.

Before the experiment began, its economic impact was estimated by establishing wheat yield in the region and rainfall in the growing season. From these measures it was calculated that a 10% seasonal increase in rainfall would yield an increase of $1 million (1978 dollars), five times the cost of the experiment. But by the end of the first year of operation aircraft costs had risen steeply and farm prices only modestly, casting doubt on whether seeding would be economically viable even if found to be technically effective. The costs of cloud-seeding could be cut if remotely-sensed data could be used to assess the suitability of clouds for seeding and if seeding material could be released from the ground instead of the air. Warner suggested that adopting these techniques should become the main aim of the cloud-seeding program after the completion of the experiment in Victoria.[30] But it was not to be. By the end of the second year of the Victorian experiment there had been no statistically acceptable increase in rainfall. In fact there had been only three occasions in the whole two years that had qualified as 'suitable for seeding', even though the general rainfall in the seeded areas had not been unusually low. The experiment was abandoned.

In the same year, 1980, the Division of Cloud Physics was to be reviewed yet again. According to Warner,

Stripped of verbiage the terms of reference ask the Committee to determine whether the Fokker [aircraft] is worth keeping, whether cloud seeding is worth doing and what would be the best way of disposing of the Division.[31]

Warner, who was to retire within a year or so, was getting tired of it all. He recognised that if cloud-seeding were abandoned there would be little reason for the Division of Cloud Physics to be maintained as a separate entity, even if it took on an expanded program of research in inadvertent weather modification. And so the end came in August 1981 when, under the direction of Mike Manton as Acting Chief of the Division, the cloud-seeding program was quietly dropped.[32] Formally, this was on the grounds that 'recent work by the Division of Cloud Physics and overseas groups suggests that precipitation enhancement is not feasible, except perhaps in special locations ... Our present ability to predict the occurrence of such circumstances is not sufficient to permit operational cloud-seeding experiments that are economically feasible.'[33] A press release announcing the end of cloud-seeding in rural areas was released by the CSIRO Executive in October 1981.

There was yet another review in 1982: this time of atmospheric research in CSIRO as a whole. It recommended that Cloud Physics be closed. The Division was disbanded in 1985.

Comment

On the face of it, cloud-seeding folded after the objective demonstration in the western Victoria experiment that the technique was unlikely to be economically viable in parts of Australia with similar synoptic patterns. However, underlying factors played a role. In the USA too cloud-seeding had suffered a downturn in the late 1970s. The National Science Foundation's activities had declined; the government agency most active in the field was the Bureau of Reclamation, but the scientific return on its activities was held to be low.[34] Both countries had seen the rise of 'ecological consciousness', a growing aversion to manipulating the natural environment, deliberately or inadvertently, and a declining belief in the ability of science to control the world, or the desirability of its doing so. But these were probably not significant factors in the demise of cloud-seeding in Australia. More important was the falling political significance of rural issues, as the agricultural sector became relatively less important to the economy. Cloud-seeding in Australia had become most closely identified with agriculture and drought relief (as against filling catchment areas, for instance). In the early 1980s it was recognised, as it had been in the late 1940s, that 'if cloud-seeding is not economic in good or average seasons, then it is even less likely to be so if practised only in drought years'[35] – but this time there was no political will to alleviate drought at any cost.

The economic contraction of the early 1970s led directly to the fiscal squeeze on CSIRO and its attention to cost cutting; it also led to the task of government's being seen primarily, perhaps almost solely, as that of managing of the economy. There was an increased emphasis on efficiency. This emphasis was even apparent in the Western Victoria experiment. The criteria determining whether or not clouds were 'suitable' for seeding were related to the idea of whether or not cloud-seeding was an efficient process for extracting the maximum amount of water from the clouds: the idea was that the clouds had to contain abundant liquid water, but too few ice crystals to make them likely to release that water by themselves. These criteria had in fact been identified as early as 1949.[36] And so concern with efficiency was not new. Even in the '60s Bowen had stressed that cloud-seeding was a technique for efficiently extracting a natural resource. But it is interesting that the Western Victorian experiment was the first Australian experiment in which the liquid water content of clouds was measured, even though this had been recognised as an important parameter in the earliest years of cloud-seeding. The instrument used in the Victorian experiment was designed by CSIRO, but the limits set for liquid water content were within the measurement range of other liquid water meters.[37]

According to Warren King, a former member of the Division of Cloud Physics, such measurements could have been made some years before they actually were.[38] Perhaps measuring physical parameters of clouds had been so difficult for some decades that the cloud-seeding group's attention had become fixed on proving the effectiveness of seeding through statistics, rather than through trying to demonstrate its physical effects. Or perhaps in Bowen's time, his faith in cloud-seeding had meant that precise measurements of parameters such as liquid water had not received the attention that they might have – but this is pure speculation. However, it was not instrumental measurements that finally killed faith in cloud-seeding; rather, the faith died first.

The CSIRO program had an interesting afterlife, which featured vitriolic debate between parties in CSIRO, Bowen in retirement, and others, and attempts by Keith Bigg to revive the idea of persistence effects.[39] CSIRO re-entered the field in 1987 when it devised a seeding experiment for Melbourne Water (the Melbourne water supply authority) to carry out over the Thomson River Dam in Victoria. Cloud-seeding was also 'preserved' by the Tasmanian Hydro-Electric Commission (HEC), who used it as a routine technique for filling its dams. One of the HEC's cloud seeders, Ian Searle (who was trained at one of Radiophysics' courses on cloud-seeding), in 1994 appeared in the media, urging that cloud-seeding be tried in the current drought.[40] And cloud-seeding was tried.[41] The great hope, the great dream that CSIRO pursued for decades, has not quite faded away.

Notes for Chapter 4

1. Jack Warner to Natalie Provis, Central Communication Unit, CSIRO Head Office, 20 December 1978, Cloud Physics file D5 (publicity – general).

2. J. P. Wild, Chief, Division of Radiophysics, to E. A. Cornish, Chief, Division of Mathematical Statistics, 19 February 1971, Radiophysics file A1/11/60.

3. Paper by Jack Warner, 'Research Program of the Cloud Physics Section of the Division of Atmospheric Physics', forwarded by C. H. B. Priestley, Chief , Division of Atmospheric Physics, to Victor D. Burgman, CSIRO, 10 February 1972. Cloud Physics file A1 (Research Activities – General).

4. J. P. Wild to E. A. Cornish, *op. cit.*, note 3.

5. Jack Warner to Patricia Paylore, Office of Arid Lands Studies, University of Arizona, 9 March 1973, Cloud Physics file D5 (publicity – general).

6. Cloud Physics entry in 'CSIRO Research Programs 1979-80'; sent by J. Warner to R. Lehane, CSIRO Science Communication Unit, 6 August 1979. Cloud Physics file A 1.2.

7. For instance, a 1977 review of the Division's work commended the atmospheric pollutants program as 'a study appropriate to Australia and world science in this field'. (*Review of the Environmental Physics Research Laboratories: Report of the Review Committee*, p. 30. Sent by H. R. Webb, Secretary, EPRL Review Committee, to J. Warner, 21 June 1977. Cloud Physics file A1.) And there was a furore in the early months of 1977 when newspaper reports misinterpreted some of the Division's work and suggested that emissions from Mt Isa Mines were polluting almost the whole continent. (Letters and articles in March 1977, Cloud Physics file D5 (publicity – general).)

8. J. Warner, 'Memo to Research Staff: Review of cloud seeding activities and future Divisional programs', 5 January 1976.

9. *ibid.*, p. 16.

10. *ibid.*

11. Isabelle Lynn, 'Whither Weather?', *The Environmental Journal* (the US National Parks and Conservation Magazine), February 1974, pp. 14-17. Cloud Physics File D5 (newspaper publicity).

12. Fitzhugh Green, 'Weather-Modification's Future', *New York Times*, 13 January 1978. (Apparently sent to Cloud Physics by Bowen in his new role as Counsellor (Scientific) at the Australian Embassy!] Cloud Physics file D5 (publicity–general).

13. However, in the mid 1980s, when attempts were made to run new experiments over the Snowy Mountains area, they were rejected on 'environmental' grounds by Dr John Whitehouse, Director

of the NSW National Parks and Wildlife Service which administered the Snowy Mountains National Park. (I. Sim, personal communication)

14. David Hickie, 'Pollution may be changing the weather', *The National Times*, Week ending 23 September, 1978, Cloud Physics File D5 (newspaper publicity). Only towards the end of this article was it mentioned that 'in recent years, research in other countries has shown that cloud nuclei are possible agents of global climatic change': global climate change had not yet become the dominant issue. Also, Peter Roberts, 'Dirty air a threat to rain: expert', *The Age*, 11 August 1980, Cloud Physics File D5 (newspaper publicity).

15. Submission by Cloud Physics to the Review of the Environmental Physics Research Laboratories, 1977, p. 4. This document is missing its title page, but its identity is clear from both its content and its placement with the submissions by other Divisions to the EPRL review. It may be a draft, rather than the final version. Cloud Physics file A1.

16. Division of Atmospheric Physics Research Programme documentation, submitted to the Environmental Physics Research Laboratories Programme Review Committee (1977). Sent by G. B. Tucker, Chief of the Division of Atmospheric Physics, to Jack Warner, 1 April 1977. Cloud Physics file A1 (Research Activities – General).

17. J. Warner, Chief, Division of Cloud Physics, to G. B. Tucker, 2 November 1977, Cloud Physics file A4 (Research Activities – Weather Modification – General). Tucker believed that cloud seeding was not economically viable.

18. G. B. Tucker, Bureau of Meteorology, 'Statement on Cloud Seeding', 1 August 1968, Radiophysics file A1/11/68.

19. M. Coughlan, 'Australian drought and the southern oscillation', in *Colloquium on the significance of the Southern Oscillation – El Nino Phenomena and the need for a comprehensive ocean monitoring system in Australia* (Australian Marine Science and Technologies Advisory Committee, Canberra 1983), cited in R. L. Heathcote, 'Drought in Australia: Still a Problem of Perception?', *GeoJournal* [sic] **16.4** (1988), 387-397, p. 395.

20. *ibid.*

21. Heathcote, *op. cit.*, note 18, p. 395

22. J. R. Price, Chairman of CSIRO, to J. Warner, Chief, Division of Cloud Physics, 3 May 1974, Cloud Physics file A1 (Research Activities – General). Price wrote:

On a number of occasions, the Minister has expressed the view that CSIRO is too large and, more importantly, that its programmes include too many that are self-perpetuating and on which the so-called law of diminishing returns is operative. ...

The Minister has also expressed the view that such 'self perpetuating programmes' stem from the personal interest of scientists working in a particular field who are unwilling to change that field of activity, regardless of its overall priority.'

23. E.g. J. Ronayne, 'Further thoughts on diversity and adaptability in Australian science policy', *Minerva* XVII, 3, p. 456; and R. Castle, 'The protection of Australian industry: Intervention or Laissez-Faire?', *Current Affairs Bulletin*, October 1991, p. 22.
24. Jack Warner, Chief, Division of Cloud Physics, to Dr J. A. Allen, CSIRO Executive Officer, 22 July 1974, Cloud Physics file D5 (publicity – general).
25. E.g. media release, 27 September 1973, by W. L. Morrison, Minister for Science, Cloud Physics file D5 (publicity – general).
26. National Science and Technology Analysis Group, *The Nature and Role of Innovation in the Economy* (The Institution of Engineers Australia, Barton ACT, 1988), p. 19.
27. Submission by the Division of Cloud Physics to the Review of the Environmental Physics Research Laboratories, p. 8, Cloud Physics file A1.
28. 'The future of cloud seeding and associated research in the Division of Cloud Physics', [no author given: probably Jack Warner], 7 March 1980, Cloud Physics file A1.2.
29 W. D. King, *Cloud seeding in Australia: experiments 1948-1981 and prospects for future developments* (unpublished mimeograph, CSIRO Division of Cloud Physics, Sydney, 1982), p. 8.
30. 'The future of cloud seeding and associated research in the Division of Cloud Physics', 7 March 1980. Typescript, no author given (presumably Warner). Cloud Physics file A1.2.
31. J. Warner to T. Cocks, 29 April 1980, Cloud Physics file A1.2.
32. M. J. Manton, Acting Chief, Division of Cloud Physics, to P. Ford, CSIRO Institute of Physical Sciences, 27 August 1981, Cloud Physics file A1.2.
33. M. J. Manton, Acting Chief, Division of Cloud Physics, to J. W. Zillman, Director, Bureau of Meteorology, 27 August 1981: 'Research Programs for the Division of Cloud Physics'. Cloud Physics file A1.2.
34. William R. Cotton, Associate Professor, Department of Atmospheric Science, Colorado State University, to Jack Warner, 16 June 1978, Cloud Physics file A4.
35. W. D. King, *op. cit.*, p. 15.
36. By Tor Bergeron. See note 88, Chapter 1.
37. *ibid.*, p. 9.
38. W. D. King, personal communication

39. Ryan, *op. cit.*, cites three recent studies as verifying the existence of persistence effects: E. K. Bigg and E. Turton, 'Persistent effects of cloud seeding with silver iodide', *Journal of Applied Meteorology* 27 (1988), 505-514; G. K. Mather, E. K. Bigg and S. Renton, 'Apparent persistent effects in the Nelspruit area from silver iodide seeding for hail suppression', *Journal of Applied Meteorology* 29 (1990), 806-811; and Y. I. Potapov, Y. I. Zotov, N. O. Plaude and G. V. Utkina, 'Study of ice nuclei in the area of hail suppression operations in Moldavia', in N. Fukuta and P. E. Wagner (eds), *Nucleation and Atmospheric Aerosols* (A. Deepak Publishing, 1992).

40. E.g. 'Cloudbusters', *The Bulletin*, 27 September 1994, pp. 37-38.

41. E.g. 'Souris launches cloud seeding plan to fight dry', *Sydney Morning Herald*, 8 October 1994, and 'Where the Rainmaker flies, every cloud has a silver lining', *The Australian*, 26 November 1994.

Discussion: cloud-seeding in context

This study could be extended in several ways. Weather modification in Australia has a history that stretches beyond the borders of this account: rainmaking was practised in nineteenth-century Australia while hail prevention techniques were used well into the twentieth, and these must have affected how CSIRO's cloud-seeding was received. The grounds on which some groups opposed cloud-seeding, and the ways evidence was marshalled on both sides (particularly how statistics were used), also deserve a closer look. An intriguing point is the influence that Radiophysics' astronomy program may have had on its cloud physics program. Some influences seem obvious – for instance, Bowen's theory about meteoritic dust. Others may be more subtle, such as the concept of a 'signal-to-noise' ratio, a commonplace in radio astronomy, which may have affected the way the Radiophysics group interpreted its statistical measures. (There are hints of this in the Radiophysics correspondence.) The influence of astronomy may have extended to shaping the cloud-seeders' 'world view': as Townsend has noted, there was a considerable difference in the 'world views' of the maverick American rainmakers and the orthodox American meteorologists. And of course the interaction between the cloud physics program's practical and theoretical sides needs to be made clear.

However, I will round off the present account by considering only something of the political, social and economic context in which cloud-seeding was embedded. Three aspects of that context stand out: Australian practices and policies related to drought; the fragmentation of the Australian science system; and Australia's post-war relationship with the United States.

Australia's inconsistent view of drought

Whereas in the USA cloud-seeding was used for a variety of purposes, such as filling water catchments, in Australia it became overwhelmingly linked to the idea of drought relief. Although Bowen later tried to draw attention to other uses for cloud-seeding, drought was from the beginning the public *raison d'etre* for the Australian experiments. As in the USA, any

private doubts about the feasibility of using cloud-seeding for drought relief were not aired in public.[1]

Drought can be defined in several ways. But however we define it, 'drought' is a way we characterise one kind of extreme deviance from Eurocentric conceptions of climatic normality.[2] Studies of drought in Australia frequently use the concept of 'meteorological drought', which takes place when annual rainfall in a given area is in the lowest 10% of rainfall figures ever recorded. When meteorological drought occurs over at least 10% of the continent at any one time it is very likely to produce 'agricultural drought' – a shortfall of moisture that causes economically significant losses to crops and livestock.[3] If we apply this definition – meteorological drought occurring over at least 10% of the country – then drought is in fact a *normal* feature of the Australian climate, for a drought of this kind occurs somewhere in the country in three out of every four years.[4] Cloud-seeding was thought of as an emergency technical procedure for 'treating' drought.[5] As such, it may have appealed to governments because it did not require them to think about the frequency of droughts or to reassess their drought policies.

For decades the policies and practices of Australian governments failed to deal with drought in a systematic, long-term way, even though it was realised quite early in the history of European settlement that prolonged dry spells are normal in many parts of the country. In 1865 Surveyor General Goyder, faced with that year's drought in South Australia, created a regional resource management policy that is still relevant today.[6] In 1901 a NSW Royal Commission into the conditions in the State's Western Division noted that 'drought is the predominant characteristic of the west [of NSW], and not merely an enemy to be occasionally encountered.'[7] And in 1937, after drought had contributed to the miseries of the Depression, the Commonwealth government stated that 'drought is not abnormal in Australia and the economy of any State is, or should be, organised to meet such a contingency.'[8] Yet in many ways practices flew in the face of these perceptions. As late as 1990 each State had its own set of procedures for invoking a drought declaration, and in some areas producer groups were responsible for declaring drought. Claims for drought relief were more frequent in the marginal semi-arid country than in the higher rainfall areas. At face value, this is not surprising. But drought relief represented a subsidy to producers in those areas, and was generally provided whether or not they were managing the land in accordance with the constraints of the environment. In other words, a farmer could try to grow a crop in an area unsuited to that crop, fail, and then call for drought relief.

Drought and the settlement imperative

One reason for this inconsistent behaviour seems to have been a deep need to deny that drought was a permanent feature of Australia.[9] 'So powerful was this sentiment that, when Franklin Barrett was filming drought-stricken areas in western NSW in 1919, a local member of parliament prevailed upon the Government to ensure that Barrett's *Breaking of the Drought* was "subject to the strictest censorship"', writes Tim Bonyhardy.[10] And in 1921 the West Australian government banned a textbook by T. Griffith Taylor, founder of the geography department at the University of Sydney, because of its emphasis on aridity in Australia.[11] The need to deny that drought was normal sprang primarily from a desire to people the country. Bonyhardy argues that in general Australians were unwilling to accept that much of the continent might be unsuitable for settlement, and that this popular sentiment influenced government.[12] Governments themselves had incentives to act as if each drought were an isolated crisis. In the early decades of this century, up to at least the 1930s, national and imperial interests required people to be kept on the land and the greatest possible area to be put under crop, and this overrode the question of whether drought relief was justified by 'business considerations'.[13]

According to Powell, before the First World War 'a consuming passion for "closer settlement" was indulged by every Australian and New Zealand government'.[14] The landscapes this produced reflected social and economic goals, especially welfare-state notions regarding the distribution of national resources, efficiency and increased productivity. This last, as a national aim, was inseparable from an imperial aim. Between the First and Second World Wars the 'settlement imperative' revived strongly, partly due to nationalist and imperialist ambitions. The soldier-settlement scheme instituted after the First World War was designed to create this pattern of 'close settlement'.[15] But, in placing people on parcels of land too small to sustain them, it was doomed to fail. By the end of the 1920s ideas of close settlement were being condemned on economic and social grounds. Griffith Taylor insisted that the contemporary margins of settlement already approximated the limits set by an implacable Nature, and his ideas, initially rejected at the popular level, won some acceptance by the end of the 1930s.[16]

However, interest in settlement was revived in many countries in the 1930s and 1940s, due to the waves of people displaced from various countries in Europe.[17] In Australia in the early post-war period, 'there was still a latent belief in the existence of an intermediary region, an undetermined but very wide marginal zone that might be made over to more useful purposes by the introduction of irrigation, new crop or livestock strains, and a more numerous and more enterprising population.'[18] The cloud-seeding experiments were predicated on the existence of such a zone: indeed they were aimed at defining and mapping it. As late as the 1950s it was widely believed that the northern parts of Australia had to be populated to ward off the threat of invading hordes from Asia. Reliable rainfall (or at least, a reliable water supply) was the key to such settlement. The point was made by at least two of Bowen's correspondents: a rice grower from the Northern Territory and the indefatigable W. H. Anning from Queensland.[19]

Drought and the federal system

A second reason for the poor way in which drought was handled was the way responsibility for drought was divided up between different levels of government. After Federation the States had retained the responsibility for dealing with drought. But they lacked the ultimate financial incentive to do so, because drought relief was reimbursed by the Commonwealth. (The promise of such reimbursement was the crucial point in the 1966 letter that the Acting Prime Minister sent to the State Premiers about cloud-seeding, referred to in Chapter 3.)[20] The Federal government had no formal constitutional power to deal with drought, but it might have been able to acquire it if it had wished to do so: the 1950s and '60s saw State powers over many areas transferred to the Commonwealth. But, as Chapter 2 shows, the Commonwealth simply did not want to take on further responsibility for dealing with drought. This was natural, given that the responsibility was seen to be mainly financial (that is, the cost of repair and compensation for the damage and loss caused by drought) and potentially open ended.[21] Partly as a result, drought relief remained poorly coordinated between the States and the Commonwealth for decades. Only in the mid 1960s, for instance, was a select committee of the NSW Legislative Assembly charged with looking at ways to achieve such coordination.[22]

The Australian political system has been a stumbling block in other ways to dealing with environmental problems such as drought. In 1976 Randall Baker, a geographer with experience of the Sahel in Africa, suggested that the severe impact of the droughts in that region during 1968-73 was the result of a fragmented approach to dealing with drought by the governments of the region. In 1980 R.L. Heathcote, who has written extensively on drought in Australia, suggested that the same problem was found in Australia. Baker had argued that the structure of an administration largely determined how well that administration would deal with interdisciplinary problems, regardless of the talent or goodwill of its staff.[23] Both Baker and Heathcote stressed that it is easy, but less than just, to point to 'buck passing' within an administration as a sign of government inefficiency. Rather, it is a sign of a poor fit between the regional character of natural hazards and the generally non-regional boundaries of administrative areas. Such buck-passing was a significant feature of the attempts to have cloud-seeding adopted in Australia; witness the efforts of Donald Shand, described in Chapter 3.[24]

Technical means of alleviating drought

Yet a third problem in dealing with drought was simply the technical difficulty of transporting fodder, water or starving livestock around the country to relieve drought-stricken areas. This was overcome only in the 1960s, by better road transport. A 1965 study by the Rural Liaison Service of the Reserve Bank found that although the drought that began in 1964 (and continued into 1966) was severe in many areas, graziers suffered less than they had in previous droughts, and one important reason for this was that they could now move livestock around the country more quickly.[25] Chapter 3 notes some discussion in this period by the Australian Agricultural Council on drought prevention and alleviation. The Council's deliberations suggest that at this point, the late '60s, cloud-seeding was seen as an interesting possibility but not even potentially one of the most important drought-management practices.[26]

Re-thinking drought in the 1980s

By the 1970s the 'populate or perish' thinking had died away, improved transport made it easier to cope with drought and, as Chapter 4 notes, climatologists had shifted their attention to the ENSO phenomenon and possible ways to predict drought. All this made it feasible for governments to rethink their drought strategies. A further incentive to do so was given by the drought of 1982-83 which, coming after a number of good years, was seen as a national disaster. And a review of Australia's water resources, completed in 1983, pointed out (yet again!) that drought was inevitable in Australia. Although the impediments of the federal system remained, by 1983 the country had a new Labor government – traditionally less of a respecter of States' rights than the conservative parties.

In 1984 the Government set up the National Drought Consultative Committee, whose members were State and Federal bureaucrats and primary producers. This committee formulated the first national drought policy – a policy which for the first time linked drought relief measures with policies on rural restructuring. Earlier policies had been aimed at maintaining the rural population but now primary producers who were considered 'non-viable' in the long term would be expected to leave the industry. As the relative importance of the rural sector to the economy has declined – from about 29% of national economic output in 1950-51 to about 4% in 1990 – and as the political power of the rural sector has also fallen, so too have governments become less interested in promoting the welfare of the rural community.[27] Douglas and Wildavsky have argued that 'attribution of responsibility for natural disasters is a normal strategy for protecting a particular set of values belonging to a particular way of life', and that 'risk taking and risk aversion, shared confidence and shared fears, are part of the dialogue on how best to organize social relations'.[28] The re-assignment of the responsibility for drought to individuals marks a significant shift in social relations. In the late 1980s Heathcote commented on the general loss of sympathy for farmers affected by drought, predicting that if forecasts of drought became more reliable there would be 'even less public sympathy for any future victims of drought who had disregarded the warnings.'[29]

The new policy was the beginning of the end of the strategy, used in marginal areas, of gambling on either a good crop or drought relief. Its emphasis on self-reliance was the same emphasis that the Agricultural Council had given to the subject in the 1960s, as I noted in Chapter 3, which even then had been described as the 'traditional' view.[30] But now the policy was in line with the economic fetish of the day – 'governments should not intervene to distort market prices or outputs', proclaimed the Drought Task Force Review.[31] Government policy on drought is now such that it is hard to see any chance of a large-scale revival of cloud-seeding – even despite its recent resurrections, noted in the last chapter.

New organisations, old economic pressures

Under the new drought policy primary producers had to be responsible not only for the commercial performance of their 'enterprises' but also for ensuring that agricultural activity was 'environmentally responsible'. The call for 'environmental responsibility' was becoming commonplace in discussions of Australian agriculture; the movement that arose to answer it was Landcare. Landcare is an umbrella term covering many organisations across the country; a decentralised, self-help scheme. The Landcare movement did not originate in the ecological consciousness of the urban middle-class, which has fuelled most of Australia's formal Green groups. Rather (according to its national facilitator) the first groups were born in the early 1980s (just when cloud-seeding died) out of landholders' frustration with government inaction on land management problems – that is, the inadequacy of centralised government services (perhaps becoming increasingly inadequate as governments sought to wind back their spending). On the face of it Landcare and cloud-seeding would seem to be polar opposites: the one decentralised and 'environmentally friendly', the other centralised, 'hi-tech' and interventionist. But they are both responses to the same set of economic pressures. It has been suggested that the formalisation of Landcare in the late 1980s was propelled by the woes of the farm sector: for instance, farm business and profit declined by 350% between 1989/90 and 1990/91, with the figures expected to worsen.[32] According to a Victorian Landcare consultant, John Marriott,

tough economic times are causing people to bite the bullet and say: 'Well, hell, if we're going to get out of this we'd better do something about it now.' If things were still good they'd be saying: 'What's the worry? I'm making a quid ...'[33]

And the same sentiments are heard from CSIRO. In September 1994, Dr John Williams of CSIRO's Division of Soils addressed a conference on the changes that had to be made if Australia's rural industries were to become sustainable by 2020: the thrust of his talk was that with better management systems and technology, grain and pasture production could be increased from its present level of 30% of real potential to 50% – and that even if only a quarter of farms achieved this rise, farm export earnings would increase by half a billion dollars a year.[34] The switch from centralised state science to decentralised groups has been driven not by a change in ideology but by the economic concerns that have always driven Australian agriculture – a drive for efficiency and productivity – and by the withdrawal (or at least re-deployment) of government services to the rural sector.

The fragmentation of the Australian research system

A striking characteristic of the cloud-seeding program was its isolation from research groups in other fields. Geographical isolation may have played a part in this but structural barriers seem to have been more important. Radiophysics' lack of contact with (Australian) universities was discussed in Chapter 3. Even for its highly successful program in radio astronomy, a new field which won international acceptance, CSIRO's research was transferred to the university system most effectively by the movement of individuals – Bernie Mills and Chris Christiansen, who migrated from Radiophysics to the University of Sydney in the 1950s. As CSIRO did not have teaching functions it could not reproduce its research programs directly; in fields where it dominated the Australian research system, but was unwilling or unable to transfer its research to the universities, it may have handicapped the growth of those fields in Australia. (But the problem also lay with universities, where they were too starved of funds to absorb such transfers.)

The cloud-seeding group was isolated not only from the universities but also from other parts of CSIRO. Not until the late 1960s does it seem to have made contact with the Division of Land Research which, in the 1950s and '60s, had set out to determine if northern Australia were suitable for intensive agricultural and pastoral activities. From its research, that Division concluded that the nature of the soils in the area, plus extreme climatic variability, meant that 'there was essentially no future for rain-fed agriculture' in northern Australia.[35] This study surely bore on the interests of the cloud-seeding group, but I have found no sign that the two groups had any contact before the late 1960s, and even that contact seems to have been only a meeting or two.[36] They did not meet earlier largely because they were from different disciplines, and CSIRO's structure deliberately isolated disciplinary groups from one another.[37] Not only that, but the organisation's philosophy explicitly favoured small groups of twenty to thirty researchers whose programs could be controlled by a single leader, resulting in poor coordination across fields.[38] A general reason for the fragmentation of Australian agricultural research (which may also apply in other fields[39]) has been pointed out by John Williams:

the pursuit of unsuitable agricultural practices necessitated the parallel evolution of a scientific network geared to solv[ing] "one-off" production problems as they arose. This fragmented focus led to Australia's rural research effort becoming compartmentalised into separate disciplines and institutions.[40]

The policy vacuum

This fragmentation went unremedied in the Menzies period, when there was no science policy *per se*. Menzies thought that the idea of planning and directing science smacked of socialism, and the conservative governments that followed him after 1966 did not revise that view.[41] CSIRO was viewed as a substitute for a science policy, and was left to go its own way. As a result, the organisation was still allocating its resources in the 1960s in much the same pattern that it had in the immediate post-war period, with the dominant areas being agricultural production and rural-based manufacturing.[42] As Chapter 4 showed, only in the 1970s did CSIRO begin to redefine its role, in the face of competition from the universities in the field of basic research and increased government demands for demonstrated relevance.

Ann Moyal has pointed out that Australia has traditionally relied on institutions to provide the science necessary to attain national goals, rather than developing strategies that focus on economic and social objectives and encourage the necessary science to help achieve those objectives.[43] This is partly an inherited pattern, a result of the relationship between science and the state in Britain. But mainly it has been because, to a large extent, science has not been seen as relevant to national goals. The creation of CSIR would seem to be an exception, but in fact the organisation was created to meet the goal of 'economic self-sufficiency' within the Empire.[44] Although science has always been seen to be relevant to, say, agriculture, in a narrowly utilitarian sense, it has not been viewed as a means of developing the Australia economy. In the mid 1920s Australia was faced with a choice of economic directions, and it opted to try to increase its population and foster industrialisation through high tariff barriers, and put little emphasis upon fostering industry through science.[45] In the years immediately after the Second World War the government of the day did not see science as relevant to any of Australia's immediate goals of stabilising the economy, maintaining full employment and creating an adequate system of social security.[46] Neither CSIR nor any other scientific body was seen to play a central role in developing manufacturing industries. Technology development was seen as less important to the Australian economy than the continuation of a sufficiently high level of world and domestic demand.[47] It appears that the very trade protection used since the 1920s to achieve the national goals of employment creation, industrialisation, and population growth ('the familiar trio', as Schedvin calls them[48]) had the long-term effect of instilling into Australia an isolationist attitude, an aversion to manufacturing and a marked disinclination to export[49] – all conditions that would work against the growth of research and development in the private sector. This in turn was to make CSIRO's task of transferring its results to industry that much harder – or even impossible.[50]

Australia's relationship with the USA

To pursue its goal of industrialising, the Menzies government looked abroad, mainly to America. The US-Australia relationship also dominated Australia's political horizon in the first few decades after the war. A prominent theme, indeed *the* prominent theme, of studies of Australian science in the colonial period has been Australia's relationship to the European 'centre': post-war Australian science cries out to be considered in the light of the Australia-US relationship. (Where CSIRO research is concerned the question is given added piquancy by the fact that R. G. Casey was not only the Minister responsible for CSIRO between 1950 and 1960, but also Minister for External Affairs over almost the same period, 1951 to 1960.)

In the early 1940s America began consciously to shape a new international economic order for its own benefit. American officials of the period were keen to promote 'a series of multilateral arrangements based on the ideal of the "open-door" that would ensure non-discriminatory trade, currency convertibility, and unrestricted access to materials and markets everywhere', which was advanced as a formula for global development.[51] US efforts to support capitalism conflicted with the plans of the Curtin and Chifley Labor governments to help Australia recover from the war. These plans included nationalising the banks, protecting local manufacturing to help it diversify, and fostering heavy industry. Australian officials argued that America's policies threatened national sovereignty and were little more than a smokescreen for 'economic imperialism'.[52]

Australia resisted US initiatives in a number of ways[53] until 1946-47, when it bowed to US pressure, abandoning commitment to full employment, accepting a limited trade and tariff agreement, and ratifying US-sponsored multilateral agreements. It did not totally capitulate, however: from March 1947 the Australian Labor government refused to sign one of the 'Treaties of Friendship, Navigation and Commerce', which the US State department later described as being 'designed to stimulate foreign investment as a means of promoting economic development'. The Australian government was apparently disturbed by the threat of such a treaty to Australian authority over foreign investment and exchange controls. But in 1949 Labor was defeated at the ballot box. The new conservative government was assessed by the US State Department as being, 'to a much greater degree than its predecessor ... interested in encouraging the flow of American capital investment to Australia', as indeed it proved to be. After 1950 Australia signed a series of agreements which led it to be 'an open and hospitable region for American-based economic activities and multinational businesses.' As early as 1955 annual American investment in Australia rivalled that of British investment; by the late 1960s the total value of America's investments in Australia had outstripped that of Britain's.[54]

Military collaboration had begun with the war. The ANZUS treaty was negotiated in 1950-51; in 1952 Australia began buying substantial military equipment from the US; and in 1953 the two countries signed a Military Standardization Agreement, which replaced a long-established arms link between Australia as a Dominion and the UK. In 1955 a secret agreement anticipated the establishment of a 'joint' defence-intelligence facility near Alice Springs: Australia was to have no responsibility, even in a consultative sense, for operating this facility. Soon after this, Australia offered America use of the Woomera rocket range and the two countries collaborated on tracking rockets and satellites. During 1963-1970 a series of 'joint facilities', over which Australia gave up all sovereign rights, were established on Australian soil. The most visible sign of Australian support for the US was its decision to send troops to Vietnam. Australia viewed the American alliance as 'like an insurance policy' and 'every now and then you have got to pay your dues'.[55] Ed Clark, the US Ambassador to Australia in the '60s, described the country as 'a perfect place to do business – no leaks, no problems, no undercutting, no resistance'.[56]

These are the bare bones of the Australia-US relationship. How should it be viewed? In a recent study of the subject, Philip and Roger Bell discuss five 'models' of the relationship, ranging from 'ideological hegemony' to 'modernisation'. These views differ mainly in describing the mechanism by which Australia became dependent on America; they differ less on the degree of dependency so created. Bell and Bell themselves find none of these models to be entirely satisfactory: they themselves interpret the relationship mainly as the story of 'the smaller nation's continuing search for security or well-being in a competitive international system'.[57] In contrast to Ed Clark, however, Bell and Bell point to 'cultural resistance', arguing that as Australia became increasingly integrated into the world economy, and its authority over domestic political, economic and cultural issues was diminishing, these processes 'provoked intense efforts by government, as well as community groups and individuals, to resist any further erosion of their nation's power and cultural identity'.[58] Did science represent any such 'cultural resistance'? Or did it mirror the larger political relationship? Australia's scientific relationship with Britain in the colonial period showed tension and ambiguity: it would be surprising if the post-war relationship was much less complex.

Integration and independence

The CSIRO cloud-seeding group certainly sought to integrate itself with the US system. Graph 1 (CSIRO papers on cloud-seeding and cloud physics grouped by the origins of the journals in which they were published) gives a rough idea of how closely the Australian effort in this field became bound to the American one. Annual reports and popular articles have been excluded from the data but articles in non-specialist journals have not, and as these are over-represented in the 'Australian' category even fewer standard scientific papers were published in Australia than might be inferred from the graph. By the 1960s the number of papers appearing in US journals is striking; this was a period when the general political and cultural relationship between Australia and the USA was also becoming closer.

The turning to America was propelled by at least three, quite obvious, reasons. First, the cloud-seeding group lacked Australian peers – there was no community of 'critical mass'. The outward orientation that this produced is said to be common to all small countries, and to lead to researchers in such countries concentrating on abstract and theoretical ideas – the common currency of international exchanges.[59] At the beginning of Chapter 3 it was noted that the CSIRO group became more secure in its international standing at the same time that it was still battling for recognition in Australia. The criteria for recognition were different: in the wider arena, theoretical advances in cloud physics; domestically, undisputable practical success. It would not be surprising if these different reward schemes worked to uncouple the theoretical and practical strands of the program, as I have earlier suggested might be the case.

The second reason for the Australians to turn to the USA was simply the level of resources that the latter could provide: as the quote from Vannevar Bush in Chapter 2 makes clear, these resources were consciously used to bind other countries to the US. I have no evidence that CSIRO ever received any direct US funding for its cloud-seeding work, but it did take part in US-sponsored joint experiments. Even Neville Fletcher's modest research program on cloud physics at the University of New England was funded by the US National Science Foundation. And of course in the 1950s and '60s Radiophysics was taking a considerable amount of American money for the Parkes telescope, not only for its construction but also its use by NASA. With regard to this latter funding, Bowen wrote in 1960:

On the question of NASA and their possible use of the telescope, I agree that life would be quieter without them. However, the possible financial gains are too good to miss – always provided they go into the research activities of Radiophysics. ... [NASA is building a dish at Woomera] ... the total cost is firmly stated as being £A2 000 000, of which £900 000 is a contribution to Woomera for their part of the construction program. With this kind of money going around, we cannot afford to be stand-offish.[60]

The third reason for turning outwards, to America, was the idea of scientific 'maturity', where maturity was equated with international acceptance.

The discourse of development and modernisation

This concept of scientific maturity, held by many in CSIRO just after the war, was the same as that which Basalla voiced twenty years later.[61] As Roy MacLeod has pointed out, Basalla's diffusionist view of the development of science is closely akin to the model of the development of economies posited by W.W. Rostow, a neo-classical economist for whom 'development' was a set of stages through which each country passed in the same sequence.[62] In Rostow's theory differences between countries' historical and cultural conditions were merely 'noise' in the system.[63] Both Basalla's and Rostow's schemes assume a linear progression, a set of necessary conditions or tasks to be accomplished, the irrelevance of cultural and historical conditions of particular countries; both assume that the condition of the USA represents the ideal final state. Both views are part of the post-war American-generated 'discourse of development and modernisation', which Edward Said has described as

a truly amazing conceptual arsenal – theories of economic phases, social types, traditional societies, systems transfers, pacification, social mobilization, and so on – [that] was deployed throughout the world ...[64]

Wolfgang Sachs has considered the way in which this view of development became linked to the role of the newly created United Nations. Sachs emphasises that this view is place-less, a-historical, a story in which 'the histories of the world were seen as converging into one history, hav[ing] one direction, and the UN was seen as a motor propelling less advanced countries to move ahead.'[65] According to Sachs, the concept of 'one world' was to be achieved by stimulating progress everywhere, absorbing the differences in the world into an a-historical and delocalized universalism of European origin. The view he describes is similar both to the idea of assimilation that European Australians applied for a long time to Aboriginal people, and to the European colonists' wish to modify the Australian environment. Cloud-seeding is an attempt to 'rectify' or at least modify characteristics of a particular location, as were so many of the activities of Australia's European colonists. It may also be pertinent that cloud-seeding was a technology for agricultural development that more interested the 'new nations' of Australia, the USA, Israel, India, South Africa, and some other African countries than it did the 'old nations' of Europe. It may not be too far-fetched to see cloud-seeding as a forerunner of the 'green revolution' and akin to other 'development technologies'.

While attempting to modify the characteristics of the Australian climate the CSIRO cloud-seeders also insisted that the success of the technique was highly location-specific; that it had to be tested 'on the ground' and that results obtained in the USA could not be automatically applied to Australia. In doing this they were emphasising particular characteristics of place (Australia) and their own right to determine techniques appropriate to that place.[66] But this hardly seems to amount to the 'cultural resistance' that Bell and Bell refer to; it challenged no aspect of the American-dominated field but rather was an argument to use in Australia to justify its activities.[67] In any case, weather is markedly less 'local' in character than flora, fauna or geology, the fields in which 'peripheral' regions such as Australia have mounted their guerilla attacks on 'metropolitan' scientific theories. Even those attacks have tended to be accommodated, sooner or later, into a body of theory that seemed to have no overt place 'markers'. Only recently have Australian writers (such as George Seddon and Tim Flannery) turned Eurocentric biology, for example, on its head, pointing out that in world terms it is the biota of Europe which is unusual.[68]

Intellectual orientations

Covertly the CSIRO group was extremely dependent upon the mere existence of its US counterparts to legitimise its activity, but overtly it chose to assert its independence – even if this independence had little national accent. In its early days the CSIRO cloud-seeding group was keen to establish itself as a distinct entity, identified with neither the extreme enthusiasm of Langmuir and his supporters nor the scepticism of the US meteorological agencies. (A home-grown research effort was also seen by Bowen, among others, as a way to forestall an 'invasion' by American commercial 'weather modifiers'.) The CSIRO group frequently emphasised the difference and superiority of its techniques and the precedence of its claims, and on some occasions it was able to lend American groups superior equipment. The strongest sign of independence was the way, shown in Chapter 2, that the CSIRO group chose to highlight or downplay American developments in the field, insisting on their relevance or irrelevance according to how useful they were to it at the time. Bell and Bell too emphasise how Australia actively excercised choice in its general political relationship with the USA, rather than being a passive victim of political and cultural hegemony.

Ian Inkster has drawn attention to what is presumably a less voluntary aspect of the relationship: the 'mental maps' or intellectual/psychological orientations of the scientists.[69] The evidence on the cloud-seeders is mixed. One of the early experimentalists of the group, Eric [?] Kraus, who had made the original contact with the General Electric researchers, moved to the USA after only a short time with CSIRO. Another important member of the cloud-seeding group, Sean Twomey, also moved to the USA when the opportunity arose. (A third, Otto Adderley, moved to Japan upon his retirement). The cloud-seeders were almost as mobile as their counterparts in the Radiophysics radio astronomy program, who circulated between England, America, Australia and the Netherlands.[70] Bowen himself moved to the USA after his retirement from CSIRO, but eventually returned to Australia. In writing to an acquaintance in Cambridge in 1949 he referred to Australia as 'this distant outpost' and clearly felt the effects of isolation.[71] As Judith Brett has claimed of Menzies, Bowen appears to have been one of the 'highly ambitious, mobile people' for whom

the desire to be central may be as important in understanding their motivation as the will to power ... drawing closer to the centre may more nearly fit the way such people experience their own progress through life than, for example, climbing a ladder. [72].

And yet, as I noted in Chapters 2 and 3, Bowen turned down an offer to head a cloud physics institute in the USA and, with Fred White's encouragement, managed to have a large radio telescope built in Australia rather than accept an offer to direct one in the USA.[73] (Apparently this decision went against the tide; at the time there was a significant 'brain drain' of Australian scientific talent.[74]) The strength of the Radiophysics astronomy group was probably the most important factor keeping Bowen in Australia: in the 1940s and '50s, despite its nominal isolation, it outshone its European counterparts in size, diversity and resources.[75] And, paradoxically, Bowen may have been not only well resourced in Australia but also closer to the centre of national political power, having the ear of both Fred White and Richard Casey, than he would ever have been in America. In other words Australia (or rather CSIRO) provided enough of the resources usually associated with a 'centre' to have some attraction.

Australia and America seen as parallel systems

Bell and Bell point out that at least until the mid 1960s, Protestant Australians possessed a 'dual identity', in which national and imperial patriotism were complementary, not contradictory.[76] In the post-war period many Australians are said to have started viewing themselves as 'slightly different sorts of Americans'[77]; the dual identity had been stretched to include a third. This was made easier by a popular view of Australia and America as countries with similar origins that had undergone separate but similar development. Well before the 'discourse of development and modernisation' came along, faith in Australia's unlimited potential for development was often expressed in terms of the country following in the footsteps of the USA.[78] Bell and Bell point out that some formal studies of the US-Australia relationship written in the '50s and 60s deny causal linkages between the two societies, instead comparing them, highlighting their parallels and explaining cross-cultural similarities or 'national character' as expressions of broadly similar, but separate, domestic forces.'[79] (Fleming's well-known paper on the development of science in Australia, Canada and the USA, written in 1962, does just that, although Fleming also takes careful note of the differences between the countries.[80]) Some Australian historians, including Fred Alexander and Russell Ward, incorporated American themes and explanations in their attempts to define Australian experience.[81] One such theme was the 'frontier', appealing in both countries to a nostalgia for a rural past. Cloud-seeding may have incorporated the idea of the frontier (certainly Bowen used the term 'pioneer' quite often). More generally, the idea of the USA and Australia being countries developing 'in parallel' probably also led the cloud-seeders to consider their work as being done independently to, but in parallel with, that in the USA. The scientific relationship and the political relationship were governed by the same metaphor – which is not far from suggesting that the one acted as a metaphor for, or mirrored, the other, as Roy MacLeod has suggested for the colonial period.[82]

Cooperation or co-option?

MacLeod has also pointed out how an imperial power can co-opt the efforts of its empire, even in the most subtle ways.[83] There is great scope for examining whether America's informal sway over Australia had this effect on Australian science. In the field of cloud-seeding and cloud physics we can see some evidence of it in that, just as Bowen was happy to use the resources that amateur cloud-seeders represented, at least one important party of the US system – the military – was interested in the information the Australians might provide. This interest was shown by the requests for information in the

1940s, collaborative research sponsored by the US Naval Research Laboratory (Project Shower and Project Whitetop) in the 1950s and '60s, and the continued exchanges of information with the Naval Weapons Research group up to the 1970s.

For the Australians there was no conflict between these kinds of 'cooperative' efforts and their own efforts to solve local problems. How, then can we summarise the relationship from the Australian side? My guess is that the Australian government saw at least some, if not all, areas of Australian science in the same way that Prime Minister Stanley Bruce had seen CSIR: as playing a role in an imperial and cultural partnership. It may be that the Menzies government did see that science could contribute to its national goals, but to political rather than economic ones.

Notes

1. Jeff Townsend, *Making Rain in America: A History* (Texas Tech University, Lubbock, Texas, 1975), p. 45.

2. The Drought Policy Review Task Force of the 1980s created a new definition of drought: 'drought represents the risk that existing agricultural activity may not be sustainable, given spatial and temporal variations in rainfall and other climatic conditions'. Drought Policy Review Task Force, *Final Report of the Drought Policy Review Task Force, Volume 2*, (AGPS, Canberra, 1990), p. 19.

3. R. L. Heathcote, 'Managing the droughts? Perception of resource management in the face of drought hazard in Australia', *Vegetatio* **91** (1991), 219-230, p. 220.

4. *ibid.*, p. 223.

5. It can be argued that other means of dealing with a variable water supply, such as dams and irrigation networks, are also 'technical' in that they alter the land's natural patterns of drainage. No sharp line divides these from other 'drought-proofing measures', such as the storage of fodder, which in turn is not so different from a careful management of stocking rates; measures to reduce the effects of variable rainfall can be thought of existing on a continuum, running from those which involve a high degree of deliberate alteration to the environment to those which involve little or no alteration, such as drought insurance.

6. *ibid.*, p. 219

7. NSW Parliament, *Report of Royal Commission to Enquire into the Conditions of the Crown Tenants, Western Division of New South Wales* (Government Printer, Sydney 1901) Part I, p. vi., quoted in K. O. Campbell, 'The Challenge of Production Instability in Australian Agriculture', *Australian Journal of Agricultural Economics* **11**, 1 (July 1958), 3-23, p. 9.

8. *Commonwealth Grants Commission, Fourth Report (1937)* (Government Printer, Canberra 1937), p. 90.

9. R. L. Heathcote, 'Drought Perception', in J. V. Lovett (ed.), *The environmental, economic and social significance of drought* (Angus and Robertson, Sydney, 1973), 17- 40, p. 37.

10. Tim Bonyhardy, 'Drawings from the scorched heart', *Sydney Morning Herald*, 24 December 1994.

11. *ibid.*

12. *ibid.*

13. Comment by the Commissioner of Crown Lands, South Australia, 1917. Quoted in the *Final Report of the Drought Policy Review Task Force, op. cit.* note 3, p. 62.

14. J. M. Powell, 'Protracted Reconciliation: Society and the Environment' in R. MacLeod (ed.), *The Commonwealth of Science: ANZAAS and the Scientific Enterprise in Australasia 1888-1988* (OUP, Melbourne, 1988), 249-271, p. 252. The passion for closer settlement is also apparent in the history of irrigation, another technical approach to the problems of the environment. Already well developed in the nineteenth century, irrigation received further bursts of enthusiastic support from the governments of NSW and Victoria in the mid 1920s and mid 1950s. The States could not expect a return on their investment but this was accepted as the price to be paid for rural development. B. R. Davidson has argued that, after 1920 especially, irrigation's appeal was political rather than economic, for it appeared to permit closer settlement, that 'perennially attractive goal'. (B. R. Davidson, cited in K. J. Walker, *The political economy of environmental policy: an Australian introduction* (UNSW Press, Sydney, 1994), p. 99 and Walker, *ibid.*, p. 100.)

15. Schedvin points out that at the same time as CSIR was created to promote Imperial economic self-sufficiency (1926), so too was the Development and Migration Commission, whose role was to investigate options for closer settlement. (C. B. Schedvin, 'Environment, Economy and Australian Biology, 1890-1939', *Historical Studies* 21, 82 (April 1984), 11-28, p.12.)

16. Taylor classified 42% of Australia as arid, 34% as good pastoral country and only 21% as 'temperate' farming land suitable for close settlement. Taylor considered that the limits of European settlement in Australia were those lands occupied by 1865. He also prophesied that, when developed to the level of the United States, Australia would support a population of 20 million. (T. G. Taylor, *Australia, a study of warm environments* (London 1940),p. 444, cited in I. Bowman, 'Settlement by the modern pioneer', in T. G. Taylor (ed.), *Geography in the Twentieth Century*, pp. 253-254.)

17. *ibid.*, p. 254.

18 J. M. Powell, *op. cit.*, pp. 253 and 260.

19. P.A. Cullen to Bowen, c. 18 March 1957, Radiophysics file A1/11/1.

20. For drought, as for all other natural disasters, a State had to bear the initial costs, with the Commonwealth providing further support for costs above a threshold based on the State's population. This arrangement led to drought relief becoming the largest category of disaster relief paid out by the Commonwealth: between 1962-63 and 1987-88 it accounted for almost 57% of Commonwealth disaster payments. The money went towards transport for starving livestock, fodder or water; the slaughter of unviable stock; replacement seed; and loans at below market rates. (R. L. Heathcote, *op. cit.* note 3, and Heathcote, 'Drought in Australia: Still a Problem of Perception?', *GeoJournal* 16.4 (1988), 387-397.)

21. And of course by encouraging the settlement of marginal areas, and promoting practices such as land clearing, governments of all persuasions were ensuring that the demand for drought relief would grow.

22. D. Campbell, *Drought* (F. W. Cheshire, Melbourne, 1968), p. 1

23. R. Baker, 'The Administrative Trap', *Ecologist* 6, 247-251, p. 248, cited in R. L. Heathcote, 'An administrative trap? Natural hazards in Australia: a personal view', *Australian Geographical Studies* 18, 2 (1980), 194-200.

24. In contrast to Heathcote, Powell claims that the concept of an administrative 'region' found favour in Australia as early as the Second World War, and that in the immediate post-war era there was 'earnest implementation of the regional approach in the management of the built and natural environments.' (J. M. Powell, 'Protracted Reconciliation: Society and the Environment', in R. MacLeod (ed.), *The Commonwealth of Science: ANZAAS and the Scientific Enterprise in Australasia 1888-1988* (OUP, Melbourne, 1988), 249-271, p. 259.) Perhaps this was true in some respects. However, there were certainly significant regional problems – those of the Murray-Darling system come to mind – that did not fall under 'regional' administrations until decades later. Certainly it does not seem that drought was treated on a regional basis.

25. 'Drought effects in northern NSW', [no author], *Farm Policy* 6, 2 (Sept. 1966), 47-53.

26. However, it appears that farmers were not taking all the steps that they could have taken to drought-proof their properties. As early as the 1950s one of Bowen's correspondents, W. H. Anning, a Queensland farmer, wrote that

I'm most keen to learn about this business of rain precipitation, as our whole livelihood depends on rain, and this district is notorious for the uncertainty of the seasons.

Meanwhile, pending the day when we can whistle up a cloud and arrange to dump the contents over selected paddocks, I'm attacking this drought problem from another angle. That is to grow and store fodder in good seasons for use in drought. There is nothing new about the principle, but there is in its application in this district. No one has done so before partly because of lack of capital, partly because modern machinery has not been available, and partly because no one, including our State Agricultural Dept. has known enough about it. I planted 500 acres this year with sweet sorghums and some Sudan Grass ... and if I can get another crop next year, I'll feel that we are well on the way to eliminating drought as a major problem.

(W. H. Anning to Bowen, 2 June 1954, Radiophysics file A1/11/1.)

27. The first figure, 29%, is for agriculture, forestry and fishing, and is taken from Table 8-1, A. Stoeckel and G. Miller, 'Agriculture in the Economy', D. B. Williams (ed.), *Agriculture in the Australian Economy* (Sydney University Press, Sydney 1982), 166-185, p. 168. The second figure, 4%, is for agriculture alone, and is given in the *Final Report of the Drought Policy Review Task Force, Vol. 2, op. cit.*, p. 58.

28 M. Douglas and A. Wildavsky, *Risk and Culture* (University of California Press, Berkeley, 1982), p. 8.

29. R. L. Heathcote, 'Drought in Australia: Still a Problem of Perception?', *op. cit.*, p. 396.

30. *Final Report of the Drought Policy Review Task Force, Volume* 2, (AGPS, Canberra, 1990), p. 75. On the face of it, this review redirected drought policy quite sharply. But even in 1966 K. O. Campbell, Professor of Agricultural Economics at the University of Sydney, was able to claim that 'the overwhelming tendency' of governments was 'to place the onus on the individual grazier to take measures to keep his business afloat during periods of drought' and 'not expect the community to bail [him] out when conditions get tough'. This Campbell described as the 'traditional' view. He further claimed that when government agencies departed from it, it was generally to question whether the land was being managed sustainably. (K. O. Campbell, 'Problems of adaptation of pastoral businesses in the arid zone', *Australian Journal of Agricultural Economics* 10, 1 (June 1966),14-26.) But if this was the stated line of policy, it was simply not consistently put into practice, as the demand for drought-relief cloud-seeding in the 1950s shows. Perhaps such policies were implemented 'flexibly', with regard to the ebb and flow of political pressures from the rural sector.

31. *Final Report of the Drought Policy Review Task Force, Volume* 2, (AGPS, Canberra 1990), p. 75.

32. Figures from the Australian Bureau of Agricultural and Resource Economics, quoted by D. Smith, 'Landcare: who owns the revolution?', *Ecos 82* (1994-95), 16-19, p. 17.

33. *ibid.*

34. Bryony Bennett, 'Science ignored at Landcare's peril', *Ecos 82*, p. 19.

35. Ralph Slatyer, quoted in Ann Moyal (ed.), *Portraits in science* (National Library of Australia, Canberra, 1994), pp. 138-139.

36. A possible exception is a paper on the possibilities of artificial modification of precipitation, presented by Radiophysics' E. J. Smith at a 1963 National Symposium on Water Resources, Use and Management, hosted by the Australian Academy of Science in Canberra.

37. C. B. Schedvin, 'CSIRO: What went right? What went wrong?', *Australian Physicist* 26, 9 (September 1989), 211-215, p. 213. This occurred when new laboratories and groups were established and old ones reconstituted. For instance, the wool research bodies were established

not as an overall industry-based grouping but as one industry-oriented group (the division of textile industry) and two discipline-based groups (protein chemistry and textile physics).

38 C. B. Schedvin, *Shaping Science and Industry* (Allen & Unwin, Sydney, 1987), pp. 315-316.

39. Jan Todd, in describing how in the 19th century a variety of institutions played roles in choosing, transferring and adapting technologies for Australian conditions, is pointing to much the same kind of 'one-off' problem solving in a wider range of fields. Could this have contributed in any way to the later fragmentation in Australia's research system? (Jan Todd, 'Science at the Periphery: An Interpretation of Australian Scientific and Technological Dependency and Development Prior to 1914', *Annals of Science* 50 (1993), 33-58.)

40. John Williams, Assistant Chief, CSIRO Division of Soils, address to 1994 ANZAAS Conference, quoted in: Bryony Bennett, 'Science ignored at Landcare's peril', *Ecos* 82, p. 19.

41. James Davenport, 'The Impulse of Science in Public Affairs, 1945-1986', in MacLeod *op. cit.* note 13, 73-96, pp. 80-81.

42. Schedvin, 'CSIRO: What went right? What went wrong?' *op. cit.* note 45, p 212. The CSIRO 1963-64 annual report – chosen at random as an example – describes some 91 pieces of research: of those, 51 were in the area of agricultural production and 15 in rural-based manufacturing.

43. Ann Moyal, cited in Davenport, *op. cit.* note 40, p. 74.

44. Schedvin, Shaping Science and Industry, op. cit., pp. 17-18.

45. C. B. Schedvin, 'Environment, Economy and Australian Biology, 1890-1939', *Historical Studies* 21, 82 (April 1984), 11-28, p. 12

46. Schedvin, *Shaping Science and Industry, op. cit.*, p. 310.

47. *ibid.*, p. 311.

48. C.B. Schedvin, quoted by T. Wheelwright and G. Crough, 'The Political Economy of Technology', in MacLeod, *Commonwealth of Science, op. cit.*, 326-342, p. 331.

49. Ian Inkster, *The Clever City: Japan, Australia and the Multifunction Polis* (Sydney University Press, Sydney 1991), p. 97.

50. In the 1970s the Birch review of CSIRO, while putting the onus on CSIRO to transfer its results, noted that

The Committee is of the opinion that the problem arises from within the manufacturing sector itself, and that alterations to CSIRO alone will not solve the problem.

Independent Inquiry into the Commonwealth Scientific and Industrial Research Organisation, *Report* (AGPS, Canberra 1977), pp. 120-121.

51. Philip Bell and Roger Bell, *Implicated: the United States in Australia* (OUP, Melbourne, 1993), p. 114.

52. In 1944 Frederic Eggleston, the Australian Minister in Washington, warned Canberra that

When Great Britain secured complete industrial supremacy she went into free trade and thereby assisted in clamping her economic empire over the world in the Nineteenth Century. America is in the same position as Great Britain was then, and the same urge is showing itself. It cannot be sufficiently realised that in a situation where one power is immensely superior to all others, economically free trade is the short way to economic imperialism.

(Bell and Bell, *ibid.*, p. 115.)

53. At the UN, in 1946-47, Australia led efforts by small powers to head off American moves to make the new body principally a battleground for great-power politics. According to Bell and Bell, it also contested multilateralism from as early as 1941. 'Australia initially refused to reduce tariffs if this action threatened to endanger protected industries; it resisted strong US pressure to abandon plans for a locally produced automobile; and it collaborated with other Dominions in a strategy to avoid relaxation of British Empire preferences at the proposed international conferences, "except on a *quid pro quo* basis".' (Bell and Bell *op. cit.*, p. 116.) (This early preference for collaborating with the Dominions also appears in the cloud-seeding correspondence; presumably it was a remnant of the inter-war emphasis on 'Imperial self-sufficiency'.)

54. *ibid.*, pp. 118 and 119.

55. *ibid.*, p 146.

56. *ibid.*

But although Australia seems to have been keen to consummate these political and economic arrangements, its relationship with the US was somewhat ambivalent. Australia was late in achieving independence: for instance, it was slower than any of the other dominions except New Zealand to see that it might have a place of its own in the world apart from that as a member of the British Commonwealth. It was not until 1940 that Australia sent R.G. Casey to Washington and so joined Canada, South Africa and Ireland in having accredited diplomatic representatives in countries outside the Empire. (W. G. McMinn, *Nationalism and Federalism in Australia* (OUP, Melbourne, 1994), p. 291) Bell and Bell point out that although the Menzies government built its foreign policies around an alliance with America, conservative leaders such as Menzies himself, Casey, and the Country Party's John McEwen were privately disturbed by the growth of the cultural commerce between Australia and the USA. (Bell and Bell *op. cit.*, p. 137.). They comment that the realignment of Australia's interests, away from Britain and towards the US, 'was much slower than most historians have assumed'.

57. Bell and Bell *op. cit.*, p. 13.

58. *ibid.*, p. 112.

59. V. Walsh, 'Technology and the Competitiveness of Small Countries: Review', in C. Freeman and B. A. Lundvall (eds.), *Small Countries Facing the Technological Revolution* (Pinter, London, 1988), 37-66, p. 44. Walsh also points out that a consequence of limited resources in some small countries – and Australia is an example – is that an unusually high proportion of science funding goes to basic science, which is cheaper to conduct than applied research and development.

60. Bowen to White, 29 July 1960 (RPA file Z1/7), quoted by Peter Robertson, *Beyond Southern Skies: Radio Astronomy and the Parkes Telescope* (CUP, Melbourne 1992), p. 257.

61. George Basalla, 'The Spread of Western Science', *Science* 156 (1967), 611-622.

62. Roy MacLeod, 'The Contradictions of Progress: Reflections on the History of Science and the Discourse of Development', *Prometheus* 10, 2 (December 1992), 260-284, p. 271.

63. N. Clark, *The Political Economy of Science and Technology* (Basil Blackwell, Oxford 1985), p. 165.

64. Edward W. Said, *Culture and Imperialism* (Vintage, London, 1993), p. 351.

65. Wolfgang Sachs, 'One World', in Wolfgang Sachs (ed.), *The Development Dictionary: A Guide to Knowledge as Power* (Zed Books, London, 1992), p. 103.

66. For the period 1890 to 1939, Schedvin has concluded that science was accepted as legitimate and worthy of public support as applied science and technology were incorporated into the productive system, and that once science had become 'utilitarian' (he is speaking here of agricultural and biological science in particular), the centre-periphery relationship in science was weakened in some respects, in that foreign experts did not know local conditions. (C. B. Schedvin, 'Environment, economy and Australian biology, 1890-1939', *op. cit.*, pp. 11-28.)

67. Ryan, *op. cit.*, pp. 4-5, notes two theoretical advances made by the Australians: (1) the realisation in the 1950s that rain formation in warm clouds by coalescence of droplets was a stochastic rather than a continuous, steady-state process (J. W. Telford, 'A new aspect of coalescence theory', *Journal of Meteorology* 12, 436 ff.) and (2) Neville Fletcher's development of theories of nucleation (N. H. Fletcher, 'Size effect in heterogeneous nucleation', *Journal of Chemical Physics* 29, 572-576.).

68. E.g. George Seddon, 'Eurocentrism and Australian Science: Some Examples', *Search* 12, 12 (Dec. 1981- Jan. 1982), 446-450, and Tim Flannery, *The Future Eaters* (Reed Books, Melbourne, 1994).

69. 'Scientific Enterprise and the Colonial "Model": Observations on Australian Experience in Historical Context', *Social Studies of Science* **15** (1985), 677-704.

70. Described in, e.g., Robertson op. *cit.*

71. Bowen to M. W. Ovenden (Cambridge), 13 October 1949, Radiophysics file A1/1/1. Cited in Robertson *op. cit.*, p. 95.

72. Judith Brett, *Robert Menzies' Forgotten People* (Pan MacMillan, Sydney, 1992), pp. 154-155.

73. In Robertson's view, Bowen 'had reservations' about the idea of heading a telescope at Caltech, for '[a]lthough it would fulfil a growing ambition to build and take charge of possibly the world's finest radio telescope, it would of course be built on American soil'. (Robertson, *op. cit.*, p. 118.) Robertson also notes that Fred White 'did not welcome this American raid on the most successful of Australia's postwar research programs [i.e. radio astronomy]. The "brain drain" of Australian scientific talent was developing into an issue of national concern.' (*ibid.*)

74. Robertson, op. cit., p. 118.

75. *ibid.*, p. 95.

76. Bell and Bell *op. cit.*, p. 138.

77. Geoffrey Serle, quoted in *ibid.*, p.12.

78. Leopold Emery, Under Secretary for Colonies, exemplified this in 1923 when he wrote:

If the United States has grown in the last century from five millions to a hundred millions, there is no reason why, in the coming century, we should not grow to a population of two hundred or three hundred millions of white people in the Empire

(Quoted in T. Flannery *op. cit.*, p. 359.)

79. Bell and Bell *op. cit.*,p. 12.

80. D. Fleming, 'Science in Australia, Canada and the United States: Some Comparative Remarks', *Proceedings of the Tenth International Congress of the History of Science* 1 (1962), 179-196.

81. Bell and Bell *op. cit.*, p. 12.

Australian nationalism has been linked to America in a paradoxical way. As Castles *et al.* note, in post-war Australia economic prosperity played the role of a unifying ideology – a role played in other countries by events such as a war of independence, or an assumed origin in the remote past, or a divinely inspired mission. (Stephen Castles, Mary Kalantzis, Bill Cope, and Michael Morrissey, *Mistaken Identity: Multiculturalism and the Demise of Nationalism in Australia* (Pluto Press, Sydney, 1988).) In Australia the post-war boom, the 'Australian way', was defined in terms of consumerism, and the symbols of this consumerism became symbols of Australian-ness. But as Australia looked to America as the source and model of prosperity, pursuing the