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Charles Henry Brian Priestley 1915–1998

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Charles Henry Brian Priestley (known as Bill) was born and educated in England. After completing the Mathematical Tripos at the University of Cambridge, he joined the Meteorological Office in 1939. In 1946, aged 31 years, he took up an Australian appointment with the Council for Scientific and Industrial Research (CSIR, later to become CSIRO) to establish and develop a group to undertake research in meteorological physics. Thereafter he was based in Melbourne, Australia. The group earned world recognition, particularly for its investigations of turbulent transfer in the lower atmosphere, and evolved to become the CSIRO Division of Atmospheric Research. Priestley's own early research focused on large-scale atmospheric systems, including substantial work on global-scale transport, and later on small-scale atmospheric convection and heat transfer, in which he established some significant results. He had a leading role in the development of the atmospheric sciences in Australia, and was strongly involved in international meteorology. His career with CSIRO extended to 1977, and he finally retired from all professional commitments in the mid-1980s. After several years of declining health, he died on 18 May 1998, seven weeks before he turned 83.

Family Background

Bill Priestley was born in the north-west London suburb of Highgate on 8 July 1915, the third of four children and the second son of Thomas Gordon Priestley and Muriel, née Brown. Named Charles Henry Brian, he acquired the nickname 'Bill' while a small child, through his father's observation that, when wearing his summer sunhat, he looked like the cowboy film star Bronco Bill.

Bill's paternal grandfather, Henry William Priestley, rose from clerk to a partnership with Joshua James in a London mantle (cloak) manufacturing firm. In June 1882, he married Joshua James's eldest daughter, Mary Sophia (called in the family Minnie). Of their eight children, only four reached adulthood: Henry James (known as Harry), born in April 1883, Bill's father Thomas Gordon (known as Gordon), born in December 1884, and their sisters, Hildegarde and Greta. The Priestley sons were educated at Mill Hill School, established in 1807 at Hendon (then on London's north-eastern outskirts) as a grammar school for sons of dissenters from the established

[1] Mrs Susan McCarthy (née Priestley) is the granddaughter of Bill's uncle, H. J. Priestley.
[2] This memoir will also appear in *Biographical Memoirs of Fellows of the Royal Society of London*, 2011.

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church. Henry James Priestley progressed from Mill Hill to the University of Cambridge, then left with his wife for Australia early in 1911 to take up an appointment as foundation professor of mathematics and physics at the newly established University of Queensland. Thomas Gordon Priestley joined the family business in 1902, becoming a partner about the time of his marriage in March 1909 to Muriel, second daughter in a family of seven born to Charles Brown, a leading Baptist minister from 1890 to 1925, and his wife Florence, née Harding. Brown was an inspiring minister, who continued to play a leading role in the Baptist church during his retirement at Chorley Wood, Buckinghamshire. Bill's deep admiration for his grandfather, not least his ability to engage an audience, was undiminished although attachment to his religious inheritance faded after childhood into agnosticism.

The children of Gordon and Muriel Priestley were David Gordon, born in January 1910; Muriel Joan (Joan) born in January 1912; Charles Henry Brian (Bill) born in July 1915; and Winifred Greta (Greta) born in 1919. Bill was given the forenames of both his grandfathers before the intended personal name of Brian. When he was aged two, the family moved from Highgate to a house built for them at Chorley Wood, then a large village on the edge of the beautiful Chiltern Hills. An extensive garden incorporating a tennis court, cricket pitch and putting green was the venue for socializing. Bill was very close to his father, enjoying his introduction to outdoor activities, and while feeling that his mother favoured his older siblings, he nevertheless remembered her as 'a lovely person, very gifted'.[3] An accomplished pianist, she would lead singing evenings for the family and friends. Bill's own capability with musical instruments was not high but he greatly enjoyed singing, an enjoyment expanded during his schooldays at Mill Hill where he laid claim to singing all four solo parts in Handel's *Messiah.* In later life, he was keen to sing at any opportunity and had lifelong pleasure in listening to music, whether at live concerts or from his own large collection of recordings.

When the Priestley grandparents retired to Frinton-on-Sea on the Essex coast, Minnie continued to host extended family gatherings, alternating at Christmas with the Browns at Chorley Wood. Bill recalled the sad death in 1928 of his beloved grandmother Minnie during an afternoon nap, when he happened to be staying at Frinton. To him, she was a tiny person with 'a colossal sense of humour and kindliness', the one who 'bound the family together'. By contrast, grandfather Henry William was cold, humourless and aloof, only redeemed by sympathetic consideration towards his wife. Serious business downturns during the great depression forced Gordon's family to sell the Chorley Wood property in 1930 and move to a 'very ordinary house' in the same district. Grandfather Priestley showed 'the kind of man he was' by blaming Gordon for the business losses and disinheriting him, despite protests from the James family that the downturn was no fault of Gordon's. This exacerbated Gordon's declining health and he died in July 1933, leaving his family dependent on support from relatives, including Bill's maternal grandfather Charles Brown. Bill felt the loss of his father deeply, but drew comfort and support from Norman Lloyd who had married his aunt Greta Priestley in 1920. Lloyd was one of his uncle Harry's former Queensland students who had been given introductions to English relatives when the students enlisted with Australia's First World War contingents. Three met their wives through the introductions.

After some years in Queensland the Lloyds had settled back in rural Derbyshire where Norman, an engineering graduate, managed a large firebrick company. To Bill he was 'a most understanding man and could see my problems better than my father ever had', while Greta Lloyd took over her mother's hospitable role by making the Derbyshire home a focus for family gatherings. Bill was to spend at least a month of each long university vacation with the Lloyds. This, and sympathetic interest from the Brisbane Priestleys, who had suffered their own trauma in the premature death of Bill's uncle Harry in February 1932, disposed him favourably towards Australia. Bill resembled his grandfather Charles Brown in his tall, lean physique, and his uncle Harry in facial features, including the high

[3] This and similar quotations, in this section and elsewhere, where no source is indicated, are taken from the record of an interview with Susan McCarthy, July 1985, held privately.

forehead. In social traits he inherited his father's friendliness, love of sport and impish sense of humour.

Education

As a four-year-old, Bill started at a small kindergarten catering for the local church community in Chorley Wood, but before then he had acquired an unusual calendar ability. His father would call on him to demonstrate it as a 'parlour trick' for friends. Someone would pick a date—any date in the nineteenth or twentieth century—and he would respond within a few seconds naming which day of the week it was. And he 'was *never* wrong', he claimed, although he 'lost the art' at preparatory school while retaining a strong memory of it: 'I can remember doing it without hesitation—no one taught me a formula, I wasn't capable of understanding what formulae were—and after I lost it I tried to rationalise how I did it and was never able to do so!' From 1922 to 1928 he was a weekly boarder at Beaumont House preparatory school in Heronsgate, joining some London cousins there, and did well in both lessons and games. Following an emergency appendix operation and subsequent pneumonia in 1928, he spent a year at home with lessons three mornings a week from the local Baptist minister H. J. Flowers, a brilliant teacher and a major influence on Bill's development. The lessons included calculus. H. J. Flowers' son was to become the physicist Baron Flowers, FRS.

In 1929, Bill succeeded in gaining a full scholarship to Mill Hill School. As a boarder from 1929 to 1934, he learned what he considered a most valuable lesson in how to carry life's burdens equably. There were taunts about being a 'brain', teasing about his rugby ability, a somewhat spartan physical regime, and the school's 'stratified but not vicious' discipline. Always keen on sports, he relished opportunities for honing his skills at cricket and other ball games. Bill spent four years in sixth form, with mathematics as the main subject and physics during the last three years. He acknowledged the brilliance of the senior mathematics master, Herbert Coates, who imparted an appreciation of the power and beauty of mathematics and of method and elegance in science generally. Well prepared for the Cambridge entrance examination, Bill won the open (Baylis) major scholarship to St John's College in 1934, as well as a supplementary county scholarship and a bursary from Mill Hill. This support was vital if his education was to continue, given the family's straitened circumstances.

At Cambridge he had G. I. (later Sir Geoffrey) Taylor as his tutor in second year, and was awarded the Adams Memorial Essay Prize for an undergraduate research essay on 'Tides'. He read for parts 1 and 2 of the Mathematical Tripos (hydrodynamics and thermodynamics), finishing with first-class honours in both parts to gain the BA and the University (Mayhew) Prize for applied mathematics in 1937. Wishing to remain for a further year 'for sporting reasons', he chose economics as his additional subject because it included the study of mathematical statistics. The statistical interest never waned. It flowed over into later leisure pursuits where he analyzed poker and bridge sessions and the times taken by fellow club members to complete golf rounds. On the St John's College hockey field he met an Australian, Rutherford Robertson, who was studying plant physiology, and they became friends. Priestley went on to represent St John's College at cricket and to captain its hockey team. Sir Rutherford ('Bob') Robertson recalled, in a letter to Connie Priestley written one month after Bill died: 'I had played hockey in Australia ... whereas Bill was taking it up for the first time. I found myself instructing this tall Londoner in the rudiments of the game, but I should record that he went on to distinction in the College team, whereas I was lucky if I got a game in the Seconds.'

At the Meteorological Office

As a young man, recently graduated from Cambridge with a double first, and with a strong interest in thermodynamics, hydrodynamics and mathematical statistics, Bill Priestley looked around for a job, with a preference for one in commerce or industry (this was 1938). It is not clear why he did not pursue a career in academia since he was bright enough. Maybe the threat of war was a factor, or perhaps there were financial constraints. In any case, with nothing on offer, and after a few months of 'hand-to-mouth' existence, he finally spotted two newspaper advertisements. The first was for a technical officer at the Meteorological Office, which was recruiting to meet the demands of the expanding Royal Air Force, and the second was for a technical assistant at a marine laboratory. After interviews he was offered both, but went for the fancier title with the lower pay. It was a first 'lucky accident' so far as his future career and life were concerned. Priestley was appointed to the Meteorological Office as a Technical Officer in April 1939, and spent over seven years, including all of the war years, with the Office. He was not called up and did not volunteer for military service, since Meteorological Office scientists were considered to be working in a reserved occupation, vital to the war effort. Almost coinciding with his appointment, a second lucky accident occurred. When about to begin a forecaster training course, he was chosen to join a small research group in micrometeorology led by O. G. (later Sir Oswald) Sutton at the Chemical Defence Experimental Station at Porton Down in Wiltshire. A position had become vacant through the appointment of P. A. Sheppard, from the Porton Down team, to a senior lectureship in the Department of Meteorology at Imperial College, London, under Professor D. (later Sir David) Brunt. In seeking Sheppard's replacement, O. G. Sutton asked to see the details of the most recent recruits to the Meteorological Office, and chose Bill Priestley.

During his two years at Porton, Priestley came to work closely with two men in particular, F. A. Pasquill, who during his lifelong career at the Meteorological Office became a world expert on turbulent diffusion, and E. L. Deacon, who would follow Bill to Melbourne in 1946 and forge his career in CSIRO. At Porton, Sheppard had developed a drag-plate instrument for measuring the frictional force of the wind on the ground, from which, in conjunction with wind measurements, aerodynamic properties of both the flow and the surface could be evaluated. Priestley took over this work, but soon he concentrated on turbulent diffusion in the lower atmosphere. Then, in mid-1941, all three men were transferred to Canada with responsibilities for establishing a major joint UK/Canada facility for wartime gas and smoke experiments at Suffield, Alberta, a location satisfying a requirement for a much larger site than was available at Porton. Bill's part was to organize the meteorological section of the complex. During his two years at Suffield, his main scientific contribution was to demonstrate that gas spreading is affected not only by environmental air turbulence, but also by a heavy gas effect; that is, the self-spreading of a dense gas cloud. The prevailing opinion at Porton was that there would be no heavy gas effect, an opinion strongly held by Sutton's predecessor in charge of the Porton meteorology group, who was now the Chief Superintendent at Suffield. Priestley was somewhat sceptical, and his experiment confirmed that 'the heavy gas effect could, under certain conditions, be not merely significant but totally dominant'. He submitted his report on the experiment, but received no response and concluded that the Chief Superintendent had regarded it with disfavour. However, outside Suffield the work came to be held in high regard, and the validity of the heavy gas effect, when the wind is not too strong, is now universally accepted (e.g. Britter 1989). There seems to be no published information on the pioneering experiment, however, except Bill's brief mention of it in his interview with B. R. Morton in August 1988 (Morton 1998).

Quite suddenly, however, in October 1943, Priestley was recalled to England to join the newly formed Upper Air Analysis and Forecast Section (the Upper Air Unit) at the Meteorological Office at Dunstable in Bedfordshire, some 50 km north-west of London. The Section was headed by Dr S. Petterssen, the eminent dynamic meteorologist, and its urgent function was to provide better information in the form of improved forecasts for aircraft navigation, particularly for the increased bombing raids over Western Europe. There, as a forecaster, Priestley collaborated in the development of a more robust technique of upper air analysis using thickness (temperature) patterns to produce isobaric contour charts at successively lower pressure levels (greater heights), and participated in the successful D-Day weather forecast. In September 1944, he was promoted to Senior Meteorologist and officer-in-charge of the Synoptics Section of the Upper Air Unit, with responsibility for administration of the Section and all upper air forecasting and research. He had become deputy to Petterssen at 29 years of age. At the end of the war, in 1945, he succeeded Petterssen as head of the Section when Petterssen returned to Norway. With an Upper Air Unit colleague, W. C. Swinbank, Bill Priestley shared a side interest in turbulent transfer in the lower atmosphere and in mid-1946 they produced a manuscript arguing the importance of buoyancy in enhancing the upward turbulent transfer of heat. Sir Nelson Johnson, then Director-General of the Meteorological Office, sent this to the Advisory Committee for Meteorological Office Research, as procedure required. Soon after, the Committee sent a revised version to the Royal Society for publication ([4] – see later). During his seven years with the Meteorological Office, Priestley gained comprehensive experience of atmospheric systems over a wide range of scales, from the microscale up to global.[4] He took on some organizing and management responsibilities in Suffield and then in England and handled these well. Later in his career, he looked back on it as two pieces of good fortune: that he had joined the Meteorological Office, and that he had been assigned to the Porton position when it became vacant at just the right time.

At Dunstable he met Constance (‘Connie’) Tweedy, a Northumberland woman who was one of the first female meteorological assistants appointed by the Air Ministry. She was the daughter of police constable Henry Tweedy and Sarah, née Gair. Connie worked in the Upper Air Unit and became a supervisor of the mainly female staff who decoded and plotted meteorological observations for the analysts. She attained the rank of flight lieutenant by the time she left. Sometime during 1944 she had become engaged to an airman in the Fleet Air Arm who was later killed in action. Shortly afterwards, at a local dance, she met Bill who, it seems, had been aware of Connie’s engagement but knew nothing of its tragic ending. Connie knew Bill from their professional work, being aware that ‘he was very tall and sort of gentle. He had very nice eyes and beautiful hands, which you would notice when he was drawing a map…. He had a great sense of humour in those days’.[5] Some six months after their first night out they became engaged, and were married six months later on 26 April 1946, fully aware of their likely emigration to Australia. The wedding took place at her village church of Seghill near Newcastle, after Bill had gone through an Anglican baptism at the insistence of the vicar at Harpenden where they had found a flat. Bill felt that it was ‘the happiest of marriages …. I owe her much for the strong support … throughout my Australian career’ (Morton 1998).

Getting Established in Australia

In Australia, CSIR had decided to form a new Section to undertake research in meteorological physics, and to focus on what was perceived to be a major constraint on Australia’s growth—the lack of water. This was in response to a need for more fundamental studies of atmospheric processes, as recognized by F. W. G. (later Sir Frederick) White, a member of the CSIR Executive, and E. G. Bowen, Chief of the CSIR Division of Radiophysics. Establishment of the new Section had the full agreement of H. N. Warren, Director of the (Australian) Commonwealth Meteorological Bureau. CSIR sought advice from Sir David Brunt (Imperial College, London) as to suitable people for the position of Officer-in-Charge of the new Section. He proposed Priestley, ‘whom I regard as quite the brightest young man who has come into meteorology within the last ten years’.[6] In early 1946, Brunt approached Bill and offered the strongest support for his nomination. For Bill, the challenge and prospects of greater freedom were attractive, as was Australia itself, particularly as he had family connections who were loud in its praise. Two concerns momentarily unsettled him. First, he was perturbed at the prospect of giving up an established position in the UK with excellent career prospects, to transfer to a position in Australia with prospects less clearly defined. Second, the promised independence of his Section from the Bureau of Meteorology would set an unprecedented pattern in government-financed meteorology: could it flourish under such bureaucratic conditions? Over the next few months, his doubts were progressively allayed through talks with several key visitors to London. Sir David Rivett, then chairman of the CSIR Council, described the organization and its philosophy; E. G. Bowen, who had started a study

[4] Microscale or small-scale refers to horizontal space scales of 1 m to 10 km; mesoscale (see later) to scales of 10 km to several 100 km; large-scale or global scale to scales of 1000 to 10,000 km.

[5] Quoted from ‘Constance Priestley: A Life Story’, interview with the University of Melbourne, February 1999, held privately [‘Connie interview’].

[6] Letter to CSIR Executive, April 1946.

of radar echoes from clouds that required meteorological support, extolled the CSIR from the viewpoint of a Chief; and H. N. Warren gave assurances that he fully approved the venture and promised all possible support. Encouraged and persuaded, Priestley applied for the position with CSIR as Officer-in-Charge of the new Section. In addition to Brunt's strong recommendation, other senior people provided highly favourable reports as to his suitability for the position. These included Sir Nelson Johnson, Dr S. Petterssen and Dr O. Maass, Director of Chemical Warfare at the Canadian Department of National Defence (in relation to the work at Suffield). These recommendations give an early indication of Bill Priestley's scientific abilities, his standing with his mentors, and his potential as a leader. Brunt wrote: 'The most suitable man whom I have been able to find is a young man of 30 [Priestley], whom I can recommend without reservation. He was a pupil of G. I. Taylor at Cambridge, is an extremely capable mathematician with a sound grasp of the physical aspects of meteorology…'. Sir Nelson Johnson stated: 'He is an exceptionally able officer of outstanding scientific ability and strong personality', while Petterssen wrote: '[Priestley] has showed great promise and has become one of my most valued collaborators'.[7] By May 1946 the CSIR Executive had produced a shortlist of six candidates, including Bill Priestley, the youngest and 'by far the outstanding candidate'. He was offered the position but, before he accepted, he had a long meeting in London with Mr L. Lewis of the CSIR Executive, at which several issues were resolved. He formally accepted the offer with duty to commence on 23 September 1946. Priestley started by making visits to relevant laboratories in the UK, after which he and Connie departed on board the passenger ship *Dominion Monarch* on 24 November, arriving in Melbourne on 23 December 1946. They had Christmas Day lunch with Fred White's family in Brighton.

The initial question was whether the new section should be based in Melbourne, where the Bureau of Meteorology had its headquarters, or in Sydney, where Bowen's CSIR Division of Radiophysics was located. Radiophysics included a meteorologically orientated cloud physics group that used instrumented aircraft to conduct measurements in and around clouds, with associated laboratory experiments and cloud seeding investigations. These activities drew on the Division's expertise in radar observations of cloud liquid water content, and in developing instrumentation for the various measurements required. In early 1947, Priestley spent some weeks in Sydney becoming acquainted with the cloud physics staff and their work. However, in view of the much wider range of meteorological interests within the Bureau of Meteorology, he decided to establish his group in Melbourne.

At first, he shared an office with another CSIR group occupying a disused warehouse in Flinders Lane, Melbourne. Then the Executive approved the initial recruitment of four more scientists. At that time, his choice of research areas depended on the availability of people of sufficient quality and the research would then be built around these staff (today it is usually the reverse). Two impressive young men from the Bureau of Meteorology approached him, and Priestley expressed strong interest, since their skills would have allowed the Section-to-be suitable diversity, quicker development and acceptance across Australia. The Bureau's Director refused to countenance this possibility—an action that took Priestley aback, since it imposed a different pattern on their relationship from the one he had expected following their meeting the year before in London. Indeed, the partition of responsibilities between the laboratories and the Bureau of Meteorology created competition and rivalry between the organizations that continued until recently. In 2005, the Centre for Australian Weather and Climate Research was formed to combine the efforts of the two organizations, particularly in weather and climate observations and predictions.

Priestley recruited the four scientists from elsewhere (see later) and, late in 1948, the embryonic group moved to temporary huts on a CSIR site at Highett, 16 km south-south-east of Melbourne. The group also established a station for micrometeorological measurements on flat grassland at Edithvale, 12 km further to the south-east. In early 1949 CSIR became independent of the government public service system and was renamed Commonwealth Scientific and Industrial Research Organization (CSIRO). Bill

[7] All quoted from the minutes of the CSIR Executive meeting, 20 May 1946.

Priestley's group became the CSIRO Section of Meteorological Physics.

Development of the CSIR-CSIRO Group

Initial Plan

Before he had left England bound for Australia, Bill had set out his thoughts for a research programme in a letter to Fred White dated 26 August 1946. We quote extracts here because they reveal his early appreciation of problems in meteorology that awaited a long-term solution, and that he felt were capable of assault by his new Section. His views reflect just seven years of experience in meteorology, a new field for him—experience gained in the most extreme of circumstances.

> To start with, meteorology is a difficult and inexact subject. Its main difficulty is that the theorist cannot solve his complete equations, and the experimentalist cannot control his experiment. To make progress the meteorologist often has to resort to greatly simplifying assumptions … in research as well as forecasting one is forced to follow hunches: and it is largely a knack of having the right hunch, or of selecting the right assumptions, which distinguishes the good meteorologist.
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> I consider it is most important to allow the programme to emerge gradually, and not to force it with undue haste. As to scope of the work, any detailed consideration of the programme must await a thorough survey of the problems and possibilities in Australia. It would be unwise to try to anticipate this, but certain preconceived ideas are inevitable.
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> The most pressing problems of meteorology are those of motion, heat and water phase, which contain fundamental problems of which much is still not known. In these is included the micrometeorology of the surface layer, with its vital bearings on agriculture, soil problems, etc. Oceanography is also included, and this should be most important in Australia. I put this class of problems first in importance to meteorology, both in its local and world-wide applications. Second comes climatology and the statistical side. Despite my personal interest in this field, the Council may consider such work to be more appropriate to the work of the Bureau of Meteorology, [in which case] close liaison will be necessary.

So, in mid-1946 Priestley had identified micrometeorology, with its strong focus on the vertical transfer of heat, mass and momentum, as a critical area of research. He must surely have had Swinbank and Deacon in mind as future members of his team.

In early March 1947, he put forward his 'Proposed initial programme of work'[8] for the nascent CSIR Section of Meteorological Physics. His objective was initially to assemble a dedicated research team to examine the factors that controlled evaporation, ranging from synoptic meteorology to agricultural practices. Characteristically, he thought mainly of the processes involved, and argued that significant progress could be made here, rather than in the then-embryonic field of numerical modelling. Nevertheless, he was satisfied with specifying one of the goals of the proposed research programmes: observations to permit better simulation of the atmosphere. Major research efforts would be directed to the small-scale end of the size range—to micrometeorology and turbulent transfer in the atmospheric surface layer (heights up to a few tens of metres). This would be a fundamental study involving the measurements of mean vertical profiles, and of the turbulent fluctuations and hence the vertical eddy fluxes of heat, water vapour and horizontal momentum, followed by critical consideration of the related theories of turbulent transfer. Weather forecasting experience had convinced Bill Priestley and Bill Swinbank that all three eddy fluxes would, in time, become a synoptic prerequisite for forecasting work. Not much research had been done on this subject, and none at all in Australia. No direct measurements of the turbulent fluxes in the atmosphere had ever been made. Priestley recognized that the results of such research would lead to 'a wide variety of applications covering the whole range of meteorological problems'. It would be of importance to Australia, with particular direct applications in agriculture and water conservation [83, 89]. He pointed out the great advantages to Australia of conducting such a study that would cover the vast country with its wide ranges of temperature, humidity and wind conditions.

Priestley also proposed a secondary line of research, more loosely defined, that would deal with large-scale atmospheric systems. Two

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[8] Copy available in the library, CSIRO Marine and Atmospheric Research, Aspendale, Victoria.

complementary programmes could be developed: one on the theoretical problems of dynamical meteorology, the other on the investigation of general and local circulations and the nature of the seasonal variations from year to year. His plan showed sound judgment and foresight by proposing work that would fill recognized gaps in knowledge, was feasible, and would lead to important applications. It endured as the foundation of the group's major activities for two decades.

The Micrometeorology Programme

One of Priestley's most lasting benefits from his time at Porton in the UK and in the Upper Air Unit of the UK Meteorological Office was that three colleagues were to join him in Australia shortly after the Section began work—E. L. Deacon from Porton and F. A. Berson and W. C. Swinbank from the Upper Air Unit. He first appointed Deacon and Swinbank, followed a short time after by R. J. Taylor, who had worked with Pasquill in wartime micrometeorology in Queensland (Pasquill was sent from Suffield in Canada to Queensland in late 1943). Taylor was theoretically orientated while Deacon and Swinbank were expert in experimental science; these two would take leading roles in developing the micrometeorology programme, with Swinbank in overall charge. The observational programme was conducted at the Edithvale site, with instruments mounted at several heights on a 30-m tower of open steel-pipe construction. The tower provided measurements of the mean profiles of wind speed, temperature and humidity together with net radiation and the vertical heat flux in the ground just below the surface.

At the heart of the enterprise was a major new venture: fast-response measurement and recording of turbulent fluctuations, and from these the evaluation of vertical fluxes of heat, water vapour and horizontal momentum. The fast-response measurements of temperature and humidity were made with fine-wire resistance thermometers, dry and moist; and the horizontal and vertical components of wind velocity with hot-wire sensors. The electrical signals from all these were recorded as traces on a photographic chart, by thin light beams from a bank of mirror galvanometers. To evaluate the fluxes and the mean-square fluctuation magnitudes, the covariances and variances were calculated from the output of a mechanical computer (a differential analyzer) built from army disposals anti-aircraft gunnery predictor components. After initial trials beginning in 1949, a comprehensive series of measurements was conducted, with twenty-three observation days from March 1951 to February 1953. The concerted results gave early information on the relationship of fluxes to mean vertical gradients, with its dependence on the atmospheric stability condition—unstable with a daytime upward heat flux, stable with a night-time downward heat flux, or close to neutral with heavy overcast skies and very small heat flux, and/or strong winds. The Edithvale developments brought to reality the primary focus of Priestley's initial proposals. He took a close interest in the results, especially in connection with his own ideas about convection in the lower atmosphere.

Larger-scale Meteorology and Upper Atmosphere Studies

Bill Priestley had a particular interest in the general circulation of the atmosphere, and by 1951 synoptic meteorology was bolstered by the appointments of A. J. Troup and F. A. Berson, and a few years later of R. H. Clarke. All were instrumental in developing major studies, both theoretical and observational, of summertime cold fronts and sea breezes in southern Australia, leading to several major field expeditions in the period 1955–59. The work emphasized the important role of differential heating between land and sea. The observations overall revealed the structure of dry cold fronts over featureless terrain, with evidence linking the strong circulations at the leading edge of such fronts to frontal squalls and atmospheric pressure jumps. At about this time (the early 1960s), Priestley was thinking of how small-scale motions feed energy into the general circulation, particularly about the mesoscale contributions to vertical momentum transfer in the westerlies of the middle latitudes. Clarke's dynamic and kinematic analyses of fronts indicated that these could be important agents in this transfer. Priestley suggested a new expedition objective—the measurement of the mesoscale vertical velocity and associated momentum and heat transfer—and Clarke expanded the objective to a full field study of the planetary boundary layer in the westerlies.

The Wangara expedition to Hay in southern New South Wales (July and August 1967) was the definitive study in its field; the huge dataset was published in 1971 and has formed the material for scores of articles in international journals by Australian and overseas scientists. The fact that the expedition totally failed to confirm the expectation that had prompted it is a quirk typical of the research process.

Another research direction was prompted by the absence of an ozone observational programme in the Southern Hemisphere, of which Priestley and Swinbank had been aware before they left England. Acquisition of three Dobson spectrophotometers enabled total ozone and the vertical profiles of ozone concentration to be measured at several locations from 1955 onwards, eventually providing an extensive body of knowledge of the structure and circulations of the stratosphere. Other notable activities, which led to significant future developments, were instituted: in the 1950s, measurements and studies of solar and terrestrial radiation; in the 1960s, studies of the global-scale Southern Oscillation, which influences rainfall in eastern Australia; in 1970, establishment of a geophysical fluid dynamics laboratory; and from the early 1970s, measurements of carbon dioxide concentration and other atmospheric constituents from aircraft and from the ground.

Priestley as Chief

At the start, the objective of Priestley's Section was to carry out basic research in the deliberate, unhurried and English scientific tradition. Permanent accommodation for the Section's laboratories was required as activities and staff expanded. At Priestley's suggestion, CSIRO purchased a very suitable site at Aspendale, a bayside suburb in south-east Melbourne. The Section moved from Highett to Aspendale in November 1953, and so, after an unsettled first eight years, the Meteorological Physics Section was finally in its permanent quarters. In 1955, it became the Division of Meteorological Physics, with Bill Priestley as its first Chief. Throughout these early years, both as Section Head and then Chief, Priestley found a permanent counsellor and supporter in Sir Frederick White, then a member of the CSIR Executive and after 1949 Chief Executive Officer of CSIRO. Indeed, in 1959, after White became Chairman of CSIRO, in pushing for increased membership of the CSIRO Executive he invited Priestley to fill one of the vacancies (Morton 1998). Bill, still working to achieve more for Australian meteorology and being unsure of his ability to make solid judgments across the whole front of applied science, declined.

The initial and continuing success of the Division in its early years was surely due to Priestley's leadership and scientific qualities, and to the then CSIRO policy of appointing Chiefs and then allowing them to structure their Divisions more or less as they wished. Such liberal lines of structure gave plenty of freedom to the Chiefs and to individual scientists. Therein lay one of Bill Priestley's main strengths—identifying and appointing the best persons for jobs, then allowing them to get on with the work. His philosophy on the success of research scientists, leadership and research institutions was expounded succinctly in a confidential document, later declassified [90]. He observed that

> the first principle determining the quality of a research institute is that the people are more important than the structure. This is particularly true in research. The second principle is that, while the best people will do good research in a poor structure, by and large it will not hold them. Attainment of excellence in an institutional sense may require more than a decade of resolve and effort. Of the people, the leadership is paramount. The prime responsibility of the leader is to generate and perpetuate a favourable atmosphere, and he must demand the best from his staff and know when he is getting it. It is desirable that he should lead by example, doing or having done his own research at a quality level that in itself gives him authority. At all lower levels, the best research leaders are those who lead by example. As to individuals, writing up is an inherent part of research. Early on, training at writing should be intense for a scientist's first few papers. After that, if he cannot write well he is not a very good research worker.

He strongly supported involvement in the writing of manuals, requiring an enquiring and critical mind and an ability to digest and regurgitate what is best in the literature. One of the best research meteorologists whom Priestley knew, R. C. Sutcliffe, had been charged early in his career with the task of writing a manual that became internationally known (Sutcliffe 1940).

Priestley himself, in collaboration with Petterssen in the 1940s, wrote a manual on the teaching of upper air isobaric analysis and forecasting, before he had published a single research article.

Early on, Priestley's appointment of Swinbank and Deacon allowed work on extending their near-surface methods to the measurement of the rate of loss of water from undisturbed landscapes. Appointing researchers such as Berson, Troup and Clarke allowed work on the precipitation and weather forecasting aspects of the problem. But he also hired several talented local people, some of whom had previous exposure to meteorology but others of whom (E. K. Webb, A. J. Dyer) had not. I. C. McIlroy and D. E. Angus had a more biological background. Recognizing that the surface heat exchange is driven by radiation, Priestley hired P. Funk and challenged him to develop methods to improve the measurement of net radiation. The main goal he gave to all of them was to study air-surface exchange so as to permit the evaporative loss of water to be determined and eventually predicted, and perhaps even controlled. Priestley encouraged work on all possible approaches: Swinbank, Taylor and Dyer worked on measuring eddy covariances, McIlroy and Angus developed gradient methods for apportioning incoming solar radiation. The last two also developed weighing lysimetry to a high level of technical sophistication. Among his other activities, Webb studied evaporative losses from water bodies, sometimes usefully employing water balance methods. In all these areas of specialization, Priestley maintained a strong interest and a level of contribution that defined his role in CSIRO—he was principally a scientist, and only secondarily a manager. He maintained his contact with the research programmes by direct participation as much as possible, and made a point of visiting, as often as he could, the numerous micrometeorological and boundary-layer field programmes that were pursued during the 1950s and 1960s.

As his Division expanded, albeit slowly from the later 1950s and through the 1960s, Priestley's contact with individual scientists inevitably varied, but he made a point of asking every scientist to his office for an annual discussion of their programme of work. This was usually done on an informal basis. At 9.30 in the morning, he would appear unannounced in a scientist's office or laboratory, and invite him or her to his office at 10.30, thus giving them an hour to prepare to defend their current work, to discuss results and plans for publication, and to set out plans for the next year. Bill enjoyed this one-to-one interaction and invariably had many suggestions to make on improvements to the individual's work and future plans. The meetings were of mutual benefit. He was exceedingly generous in his guidance to younger scientists, serving as a mentor to many. However, he was impatient with any evidence of poor quality in his team and did not draw back from confrontation, although such occasions were infrequent.

Through the 1960s, Priestley's views on the numerical modelling of the atmosphere began to change, through the influence of both his Australian colleagues and his international connections. The USA in particular was leading the field in its development, and Priestley was perceptive enough to see its potential in both numerical weather prediction and climate modelling, but realized that CSIRO lacked the resources to make progress in this field by itself. The need to involve and to encourage the Bureau of Meteorology in numerical modelling was apparent, because they had both the necessary skilled meteorologists and the modern computers that were essential. Priestley worked with the Director of the Bureau of Meteorology, W. J. Gibbs, to establish a new, joint research centre—the Commonwealth Meteorological Research Centre (CMRC)—which became operational in 1969. The importance of the 'development of appropriate models for Southern Hemisphere numerical prediction' was emphasized in their 1967 Prospectus for Meteorological Research in Australia [71]. Priestley expended much effort to ensure that this new Centre was successful, and for several years spent one day a week there. In parallel with the growth in numerical modelling of the atmosphere, there was a growing international emphasis on atmospheric composition and chemistry. Post-war industrial development had led to the deterioration of air quality in cities around the world and significant research efforts directed at understanding these changes followed. Priestley supported the growth of studies in air pollution and, in particular, engagement in the La Trobe Valley Air Shed Study (see later). Almost inevitably the work on regional changes to atmospheric chemistry led to questions about the potential for human influences on the composition of the global atmosphere. He both encouraged and fostered the redirection of Divisional efforts towards what was then an emerging field—the possibility of global warming related to increased concentrations of gases such as carbon dioxide. He oversaw the emergence of an atmospheric chemistry programme directed at the new topic of global biogeochemical cycles. There followed a programme of high-precision atmospheric carbon dioxide measurements that would lead G. I. Pearman, an appointee of Priestley's in 1971, to become Australia's pre-eminent expert and spokesman on many aspects of climate change and global warming. Pearman, a botanist by training, was just the person to respond to Bill Priestley's vision and encouragement in the early 1970s.

In 1971–73 a series of events determined the remainder of Priestley's career in CSIRO. In 1971, the Cloud Physics Section of the Division of Radiophysics was briefly moved into his jurisdiction when J. P. Wild became that Division's new Chief. Later that year, Priestley's Division was renamed the Division of Atmospheric Physics, with its work now covering a wide range of atmospheric physical processes. In 1972, CSIRO created a new Division of Environmental Mechanics with J. R. Philip as Chief. This announcement, discovered one morning 'in a press release', was a bombshell to Priestley since its terms of reference were close to what his own Division had been doing for twenty-five years. A hurried phone call to Canberra, and a visit soon after by the CSIRO Chairman, J. R. (later Sir James) Price, led to the decision that Priestley should oversee both Divisions. He then insisted that such an arrangement should be formalized and should include the CSIRO component in the CMRC. It was finally decided by CSIRO to create the Environmental Physics Research Laboratories (EPRL), with Priestley as Chairman, to comprise the Divisions of Atmospheric Physics, Cloud Physics (which had become a separate Division in 1972) and the new Division of Environmental Mechanics, together with the CSIRO component of CMRC. As a consequence, the position as Chief of the Division of Atmospheric Physics was advertised and in early 1973 Priestley retired to be succeeded by G. B. Tucker. Bill continued in CSIRO as Chairman of EPRL until his final retirement, being consulted by both the Executive and the individual Chiefs, and well pleased to have shed a large management role. He needed the time so gained for other matters that were to press themselves upon him throughout the early 1970s. He retired for health reasons from CSIRO in 1977, and the EPRL grouping was discontinued. To our knowledge, there was only one long period of absence that he permitted himself during his twenty-five years as Chief. He was at the University of Chicago for about six months in 1957, during which he wrote his book on turbulence in the lower atmosphere [91]. This sabbatical followed the publication of one of his most unusual contributions, 'On the Heat Balance of a Sheep Standing in the Sun' [42] that served as an introduction to a longstanding interest in the factors that control heat exchange.

In 1983, a further CSIRO reorganization led to the Division being augmented with sections of the Division of Cloud Physics and the CSIRO component of the Australian Numerical Meteorology Research Centre (ANMRC, which had succeeded the CMRC), both of which were being disbanded. Its name then became the Division of Atmospheric Research. In 2001, this Division incorporated atmospheric scientists from the former Division of Environmental Mechanics, and in a further change on 1 July 2005 the Division of Atmospheric Research merged into the new Division, CSIRO Marine and Atmospheric Research. The Division that Bill Priestley founded had grown from a total staff of approximately twenty in 1950 to more than eighty when he retired as Chief in 1973. This was the base for further development to a staff of 140 in the year 2002. The Division of Atmospheric Research as a sector of the new, merged Division has continued to occupy the Aspendale site, after several stages of extensive building operations. In 1995, the Division named its main lecture theatre, the Priestley lecture theatre, and instigated an annual Priestley Lecture to be held there. The inaugural lecture in October 1995 was given by A. M. Yaglom on a topic close to Bill's heart, 'Heat transfer laws in free convection'. Unfortunately, Bill was not well enough to attend. Preceding the inaugural lecture a painting of Priestley by Frances (Fay) Philip (wife of ex-CSIRO Chief J. R. Philip) was unveiled and hung in the lecture theatre. It reveals the tall, angular Bill Priestley, seated and in pensive mood, late in his career.

A comprehensive overview of the activities, achievements and people of the Division has been presented in Garratt *et al.* (1998). Bill has presented his own reminiscences detailing his experiences and views in the development of his CSIR-CSIRO group, and in his wider interactions in the Australian meteorological context [89].

Scientific Achievements

Bill Priestley was 23 years old when he graduated in 1938, and it is understandable, given the circumstances, that his work over the next six years or so left him little time for research and no time in which to publish new results, if any, from his mainly operational work. Yet he gained invaluable experience in two areas of meteorology that were to define his research career: (i) small-scale turbulence near the ground (in 1939–42, when England was fighting for survival), and (ii) large-scale dynamics (1943–45, when England was striving to defeat Germany). With the war years behind him and a career beginning in Australia, his publications finally burst forth. For fifteen years after 1945, maybe a little longer, he was at his most prolific, before the heavy responsibilities of Chief of Division and his national and international work slowed him down. Two significant pieces of work came after 1961 [69, 80], together with many reviews and published invited lectures. What is remarkable about his published work up to 1960–61 is the way that it falls into the two categories indicated above. From 1945 to 1951 his Upper Air Unit years finally bore fruit, and with approximately twenty published articles, most were concerned with large-scale dynamics [1–3, 6–15, 17–20]. From 1951 to 1960, the experience of his Porton work, his tea-time discussions with Swinbank in 1945, and the accumulation of observations at the Division's Edithvale site from 1949 onwards came to fruition. Of approximately thirty articles published, most were concerned with small-scale heat transfer and convection [24–26, 28, 29, 31–35, 37–44, 46–50, 53–55].

Large-scale Dynamics

In order to place in context Priestley's significant work on large-scale dynamics, we must first review briefly the state of knowledge as it existed in 1945, recalling that after the Second World War meteorologists were eager to revisit the fundamental problem of the maintenance of the general circulation of the atmosphere. The great English geophysicist, astronomer, and statistician Sir Harold Jeffreys, Fellow of St John's College, Cambridge had tackled this theoretically (Jeffreys 1926), but upper-air observations had been lacking with which to confirm his work. Up to 1940, little was known regarding winds and temperature throughout the troposphere, but the operational demands of the War gave impetus to the establishment of networks of stations from which to make upper-air observations. It was well known at the time that considerations of the annual earth–atmosphere radiation balance reveal that the earth and atmosphere as a whole receive a net radiation surplus in low latitudes and a deficit polewards of about latitude 35° . The receipt of solar energy drives the atmospheric circulation, and the mean pattern of surface winds reveals low-latitude (tropical) easterlies and mid-latitude (temperate) westerlies, separated by a semi-permanent high pressure region or belt at latitudes 30° –35° (the subtropics). By virtue of surface friction, this implies an upward flux of westerly angular momentum in the tropics and a downward flux at middle to high latitudes, with the maximum polewards (meridional) flux occurring across the high-pressure belt in both hemispheres. The above facts were well known when the War ended, and a description of the character of the meridional fluxes of angular momentum and energy was recognized as being of fundamental importance for a better understanding of the general circulation. Jeffries in 1926 had argued that, at least in the mid-latitudes with the prevailing surface westerlies, the main mechanism responsible would be a kind of 'eddy transport', the 'eddies' being the deep northerly and southerly winds of the large-scale pressure systems around these mid-latitude belts.[9] According to Priestley [22] the most fundamental issue, certainly the most controversial at the

[9] Herein we use eddy or turbulent fluxes to describe the small-scale vertical transfer or transport of momentum, heat and matter in the atmospheric boundary layer, and large-scale or global-scale eddy fluxes to describe the horizontal transport throughout the atmosphere from north to south (or vice versa), i.e. along a line of longitude (a meridian), hence meridional fluxes or transport.

time, related to the respective parts played by the mean meridional circulations and the large-scale quasi-horizontal disturbances (depressions and anticyclones) as agents in the poleward transport of heat, water vapour and momentum.

Priestley's time with the Upper Air Unit gave him three years of synoptic experience that later stood him in good stead as a research meteorologist. The piece of large-scale work that Priestley considered one of his best concerned the dynamical control of atmospheric pressure [7, 13], which led to his substantial work on global-scale transport. In these two publications he considered a longstanding paradox in large-scale dynamical meteorology and showed how this could be resolved. Through the atmosphere, generally the wind is close to geostrophic (the geostrophic wind results from the balance of the horizontal pressure gradient force and the Coriolis force), yet the vertically integrated horizontal divergence based on the geostrophic wind approximation gives grossly excessive surface pressure changes and speeds of translation of cyclones and anticyclones. Priestley showed that a closer approximation, using a wind that allowed for trajectory curvature, provided pressure changes comparable to those observed [7]. This was a precursor to his work on global-scale atmospheric transport, where his major focus was on evaluating the meridional (north–south) fluxes of heat, water vapour and angular momentum, at several levels throughout the troposphere. These fluxes could be evaluated directly from the upper-air data recorded at various stations where regular radio-soundings and upper-wind measurements were made. He perceived that knowledge of the meridional fluxes would give a more complete description of global-scale relationships. For example, the meridional transports should be consistent with the distributions of sources and sinks at the earth's surface. Comparison of the flux with the mean meridional gradient for each entity, at any level in the atmosphere, would show whether there is a recognizable flux-gradient relationship. More fundamentally, however, he recognized it as important to identify the mechanism of the transport [17, 20, 23]. In the high-pressure belts centred at 30° to 35°, Priestley suggested that mean meridional drift circulations with equatorward flow at low levels and poleward flow at high levels would play a significant part in the meridional transports. Such mean circulations occurring around the high-pressure belt would effectively be components in meridional planes of a toroidal circulation.

For the evaluation of these meridional fluxes from measurement, Priestley introduced an important principle. He emphasized that the directly measured upper-wind data should always be used, rather than estimated winds, such as from measured mean gradients or from the pressure pattern, with their likely pitfalls. In hindsight this can be seen as a major breakthrough, and it followed directly from his work on the dynamics of pressure changes. It enabled him to deduce for the first time contributions to the mean meridional transport of both the large-scale quasi-horizontal eddies and the mean meridional circulations. Thus, he made the first direct evaluations of the meridional fluxes at various levels. Initially [17], he based these on mid-latitude data from a station at Larkhill in southern England at latitude 51° North. Then [20] he took data from several stations in the high-pressure belts, at latitudes between 29° and 37° in both hemispheres. In the mid-latitude case, he found that the annual mean meridional eddy flux of heat (sensible plus latent), height-summed through the depth of the atmosphere, was indeed very close to the value required for long-term balance. This provided direct evidence that, in middle latitudes, the large-scale atmospheric eddy transport is a vital process in the meridional transfer of heat. For the mid-latitude momentum transfer, the conclusion was similar, though it could only be in broad approximation because use was made of only a limited coverage of surface-friction measurements. However, it could be concluded that the meridional eddy transport of angular momentum from the low latitudes was of the right magnitude to maintain the mid-latitude westerlies against surface friction [23]. This directly confirmed the essential part played by large-scale eddy transport in maintaining the atmospheric general circulation, as envisaged earlier by Jeffreys.

For the high-pressure belts at lower latitudes, the annual mean meridional eddy fluxes of heat (sensible plus latent) and of zonal momentum were each height-summed and averaged across the several upper-air stations. For both fluxes, it was found that the resulting mean eddy flux would make a significant contribution to, but would be well short of, in fact only half of, the value required for long-term balance. The latter value, for an adapted reference latitude of 35 $^\circ$, was, for the case of heat flux, evaluated by Priestley from published studies of the radia- tion balance. For the case of momentum flux, no comparable studies were available, so he carried through the full process to determine the required long-term balance flux, starting with detailed evaluations of the global distribution of surface frictional stress over the oceans, calculated from published global surface wind data [20, 22]. The results provided a first approximation to the total torque across the Earth's axis, on the atmosphere as a whole, in the various latitude belts. Further, he derived for the first time the distribution of the total northward flux of atmospheric angular momentum for the annual mean and for each of the four seasons. These and earlier results confirmed unambiguously the existence of a mean meridional circulation across the lower-latitude high-pressure belt, with the circulation stronger in winter than in summer.

Convection

It was probably through W. C. Swinbank that Bill Priestley's interest in atmospheric convection began. Swinbank's research on fog during the Second World War involved measuring temperature fluctuations well away from the ground, using instruments attached to the cables of barrage balloons. In the year following D-Day, the Upper Air Unit was under intense operational pressure to deliver reliable weather forecasts. On a few days during this period, Priestley and Swinbank found time to discuss turbulent transfer and the unusual nature of the temperature observations. They noted that the fine-scale structure of the fluctuations changed with synoptic situation and also showed the presence of sharp minima in temperature. Indeed they had noticed that the observed temperature fluctuations in sunny daytime conditions, both near the ground and at a height of some 1,000 m, were of an unusually large magnitude and structure. The observations implied a significant upward heat transfer but, given their knowledge of the prevailing near-zero vertical lapse rates on these occasions, these phenomena seemed at variance with the classical theory of vertical heat transfer in a turbulent medium. Inevitably, as it now seems in hindsight, their discussion soon turned to the relative roles of buoyancy and shear-induced (mechanical) turbulence.

In reviewing the revolutionary nature of their work, we must first revisit the classical theory of small-scale turbulent transfer in the lower atmosphere, propounded much earlier by, *inter alia*, G. I. Taylor. In this, eddies that scale to the height effect the vertical transfer of heat, momentum and mass, in analogy to molecular transfer; an eddy at rest at any level is assumed to have the temperature of the environment at that level. Necessarily, any flux is directed down the gradient. The occurrence of an upward-directed sensible heat flux when the lapse rate of potential temperature is neutral or slightly stable is not predicted by the simple mixing-length theory, so Priestley and Swinbank amended the theory to allow for the fact that a parcel of air (an eddy) not moving vertically at some instant may have a potential temperature differing from that of its environment at the same level, and may subsequently start to rise or sink because of buoyancy. They thus assumed that turbulent transfer would be enhanced in the presence of an upward heat flux, on account of the buoyancy fluctuations. This they called 'convective turbulence' to identify it as separate from 'mechanical turbulence'. A new term was then added to the mixing-length equation (or the flux-gradient equation) that could allow for a countergradient heat flux (see [4]). In this manner Priestley and Swinbank explained how the upward-directed heat flux could be passed from a superadiabatic layer near the ground to levels of several hundreds of metres where the mean lapse rate was zero or even positive. Indeed, Priestley's team's observations at the field site near Edithvale did later confirm a strong influence of this kind. Eventually, their work led to a joint paper published in *Proceedings of the Royal Society* in 1947 [4] that challenged the established views on vertical turbulent heat transfer and was the trigger for the turbulence work later taken up in CSIRO in Australia. This was one of the most productive papers of their two careers, at least as measured by the extent of subsequent work that ultimately stemmed from it. Priestley in particular published several articles over the next fifteen years that related the temperature fluctuations in convective conditions to the vertical heat flux [31, 49]. Another result of the 1947 paper lay dormant until 1966. In explaining the puzzle of countergradient heat transfer in convective conditions, Deardorff (1966) emphasized the importance of the concept developed by Priestley and Swinbank of non-local mixing above the surface layer. Today, non-local mixing is known to extend to the whole of the convective boundary layer, and also to occur in vegetation canopies and other complex flows near the ground. It has had numerous applications, including turbulence parametrizations in numerical weather prediction and pollution transport models.

Thus, from the outset, the main research effort at Aspendale was focused on the unstable (that is, daytime) side of neutral conditions, since this was when the fluxes were largest and geophysically most important. The expectation that the eddy transfer coefficient (ratio of vertical flux to vertical gradient) for heat would exceed that for momentum was confirmed against the opposite prediction of classical theory (e.g. Taylor 1917). However, Priestley and his small team were surprised, and their overseas colleagues at first incredulous, at the closeness to neutral at which this and associated buoyancy effects began to appear. It had long been known that the dampening of wind-shear turbulence under stable conditions occurred at Richardson numbers (Ri, a measure of thermal stability) of order 0.5. The surprising discovery was that on the unstable side, the vertical temperature gradient was found to follow a z^{-1} dependence on height (z) at small values of Ri, which is the well known law of 'forced convection', but a significant departure from neutrality was evident with Ri as low as -0.02. From Ri $= -0.03$, which could occur in moderate-to-strong winds, the heat flux was independent of wind speed and proportional to the 1.5 power of the temperature lapse rate. The potential temperature profile then obeys the law

$$\partial\theta/\partial z \sim z^{-4/3}$$

and the heat flux H is given by

$$H/\rho c_p = b(g/T)^{1/2}(\partial\theta/\partial z)^{3/2}z^2$$

so that in this regime the heat flux can be determined from the measured vertical temperature gradient alone [32, 40]. In the above, ρ is air density, c_p is the specific heat of air, g is the acceleration due to gravity and T is temperature; the constant b is known as the Priestley constant, with a value close to unity (Deardorff and Willis 1967). In his acknowledged classic analytical theory on convection from a large horizontal surface [32], Priestley showed these to be the relationships applying to effectively free convection. Unbeknown to him, L. Prandtl and A. M. Obukhov had made the same free-convection proposal for $\partial\theta/\partial z$ in the 1930s and 1940s by different means. The dual law was found to hold for at least a 20-fold range of heights and, under normal conditions of surface heating over most of the earth, these heights would be most accessible for measurements of the gradient. Thus the new law was both powerful and practical. The temperature fluctuation records were also surprising in showing that, even very close to the ground, the effect of instability was not to augment the temperature fluctuations due to wind shear but to create a new set of fluctuations of larger scale. These sustained their identity while penetrating deeply through the background of wind-shear turbulence. Accordingly the transfer coefficient for heat increased with height faster than did that for momentum. These interpretations followed naturally from the 1947 paper by Priestley and Swinbank [4].

Bill Priestley's work on convection throughout the 1950s began when he realized in 1951 that CSIRO Meteorological Physics and, particularly, Cloud Physics in Sydney could benefit from work on convection. With no obvious candidate for the work, Priestley started on it himself, from the viewpoint of both turbulence in and around convection, and convection within the atmospheric boundary layer. Much of his thinking on convection is summarized in Chapters 4 and 5 of his monograph, *Turbulent Transfer in the Lower Atmosphere* [91]. This, his only book, was based on a series of lectures that he gave as a visiting meteorologist at the University of Chicago in 1957. Two ex-colleagues from wartime Porton reviewed the book. O. G. Sutton described it as a 'progress report on micrometeorology during the last decade' and went on to say that 'Although there are many points of controversy … it can be said without hesitation that this is a balanced account, written by a leading authority' (Sutton 1960). P. A. Sheppard opened his review with: 'The scientific study of the vertical transfer of heat and water vapour in the lower atmosphere dates effectively from 1912 when the liner Titanic struck an iceberg in fog. The event led to the Scotia expedition to the Newfoundland Grand Banks in which G. I. Taylor participated. His observations laid the foundations of the theory of turbulent transfer in the atmosphere.' He went on to say that 'Priestley gives an admirable account of the [current] position and shows how theory and recent observations are leading to better understanding of the relevant mechanisms. If he implies greater penetration than is perhaps justified, that is excusable in one who has made so considerable an impression on the subject' (Sheppard 1960).

Priestley's initial thinking on turbulence and free convection led naturally to the role of large convective elements, either thermals or plumes, within the boundary layer, and therefore to the energetics of these elements within a turbulent environment, with and without vertical wind shear. So far as turbulence around convective elements is concerned, Priestley's fundamental contributions included: (i) the fact that cellular convection in the atmosphere would have different aspect ratios from the classical Benard theory because eddy viscosity and conductivity would be non-isotropic [54], and (ii) the fact that parcel convection in a constant lapse rate would not have just the two modes of infinite rise or simple ascent to an equilibrium level, but a third—namely penetration of that level and subsequent damped oscillations [33] (see Turner 1973). Other major contributions are his work with F. K. Ball in 1954–56 on the formal treatment of vertical plume rise through an ambient temperature gradient, and his own work on a plume bent over by the wind. He and Ball [34] showed that, in calm conditions, the plume rise should be proportional to source strength to the 1/4 power times inversion strength to the power $-3/8$. Their approach employed an assumption of plume stress dependent on the square of the plume velocity. This plume-rise result is usually credited to Morton *et al*. (1956), though this appeared a year after the Priestley and Ball article. The two works were quite independent (Morton 1998), though G. I. Taylor had produced many of the results much earlier.[10] It was to take some twenty years for the data to become available to confirm the plume rise predictions: the law holds over at least five orders of magnitude, from laboratory salt water plumes to volcanic eruptions. Priestley extended the approach to a bent over plume in a turbulent environment [38], and considered the rise as occurring in two stages: the first when internal turbulence dominates, and the second when an abrupt transition occurs, to a state where the turbulence is everywhere the same as that in the environment (so that an 'open parcel' argument could be used—another earlier research contribution by Priestley).

[10] In a postscript to Morton *et al*. (1956), Sir Geoffrey Taylor notes how the two junior authors brought a draft for him to read. He then discovered that most of the theoretical part was almost identical with a treatment he had written some years before but had not published.

Small-scale Turbulent Transfer and Evaporation

Bill Priestley's involvement at the UK Meteorological Office with colleagues such as Pasquill, Sheppard, Sutton, Deacon and Swinbank—all micrometeorologists—was key to his life-long interest in the small-scale vertical transfer of momentum, heat and water vapour by turbulence in the atmospheric boundary layer. Indeed, this set the scene for a major component of the CSIRO Division's work throughout the 1950s and 1960s. In addition to his own research on large-scale dynamics and small-scale convection, a third main interest of his focused on the natural water cycle in the atmosphere, specifically evaporation from the land, and on Australian rainfall climatology. Both were intimately tied to his Division's work but it is probable that Priestley himself would never have identified this corpus of work as amongst his best. He certainly never did in any of his interviews, nor in his later reminiscences on the success or otherwise of the Division's research.

Throughout his career, one of Priestley's main objectives was the fostering of the more basic studies from which a problem-solving capacity is generated. Indeed, this was the main thrust of his initial research plan submitted to the CSIR Executive in 1947 and wholly endorsed by them. Early in his scientific career Priestley was fully aware of the value of numerical modelling of the atmosphere, particularly relating to weather forecasting. As we have said in an earlier section, the measurement or reliable estimation of evaporation from the Australian landscape was a high priority of his. The techniques developed by his own group of measuring the small-scale vertical fluxes of heat and momentum could be readily applied to the vertical flux of water vapour, which equates to the evaporation from a specified small area of land, regardless of the coverage of actively-transpiring vegetation. A consequence of this was Priestley's interest in the determination or parametrization of larger-scale values of surface heat flux and evaporation over land and sea, so as to match the requirement for grid-scale values in numerical models (the grids of which had horizontal scales of hundreds of kilometres in the 1960s). Results from his Division's work on small-scale transfer, and from other research groups around the world, could readily be applied to this problem over the ocean (via bulk transfer coefficients), but not so readily over large areas of land. Thus, we come to a scientific paper, published by Bill Priestley and R. J. Taylor, that has had outstanding practical success, particularly in the agricultural meteorology community, and is highly relevant to grid-scale calculations in numerical weather forecasting and climate models of the atmosphere. It is of interest to describe briefly how this article came to be written, based on the evidence at hand. We note, importantly, that Priestley was senior author.

Some time in 1970, Priestley suggested to Taylor that he follow up their mutual discussions on large-scale sensible and latent heat transfer with an observational analysis and underpinning theoretical framework. Whatever occurred in the interim, Taylor handed Bill a draft article in late 1970 or early 1971, with which, it must diplomatically be said, Priestley was far from happy. Part of the problem related to the proposition that the large-scale parametrization of the sensible heat and latent heat fluxes over a moist or well-watered land surface can be expressed in terms of energetic considerations, implicit in which is the close relationship between the Bowen ratio (sensible heat flux divided by the latent heat flux, or evaporation) and the ratio s/γ, where s is the slope of the curve of saturation humidity versus temperature at a specified temperature, and γ is the ratio of the specific heat of air at constant pressure and the latent heat of vaporization. Priestley was eventually convinced by Taylor and other more junior colleagues that this was the key to the approach, whereupon he immersed himself in a joint study with Taylor. The article has long since been recognized as a landmark [80]. The authors effectively took Penman's equation for evaporation (E) from a saturated soil surface to show that the evaporation is constrained by the available energy (net radiation (R) minus the soil heat flux (G); the ratio $E/(R - G)$ is termed the evaporative energy fraction), the limits being determined, *inter alia*, by s/γ. They further took the flux-gradient relations for heat and water vapour transfer above the surface, and derived a working hypothesis that could be tested using observations. Their key result stated that the evaporation (E) from a horizontal uniform moist or well-watered surface is given by

$$E = 1.26[s/(s + \gamma)](R - G),$$

where the constant 1.26 was determined from several datasets from land sites around the world, while the term $s/(s + \gamma)$ is a purely thermodynamically determined function of surface temperature. For some, their work provided new ideas on the involvement of the feedback from the boundary layer as a whole (e.g. McNaughton 1976) that in much later years provided the reasons why it worked as well as it did, and showed something of its limitations. By the 1980s and 1990s scientists had far more understanding of how the surface energy balance (SEB) is thermodynamically coupled to the growth of the convective boundary layer (CBL) over land surfaces. The energetics of terrestrial surfaces are therefore determined not only by the surface energy balance, but also by the properties of the coupled SEB-CBL system, including entrainment processes at the boundary-layer top. Such a linkage was proposed implicitly by Priestley and Taylor, who suggested that atmospheric processes (ill-defined at the time) cause the evaporative energy fraction under equilibrium moist surface conditions to take on a value of $1.26s/(s + \gamma)$.

The constant of 1.26 is nowadays referred to as the Priestley-Taylor ratio (Raupach 2001). This result was a stroke of prescient genius and subsequent work has confirmed its robustness and why it has worked. Their study allowed Priestley and Taylor to conclude: 'In the context of [the Global Atmospheric Research Programme], one of our basic aims must be the specification of heat flux and evaporation over all land surfaces, and what has been written indicates that an energy approach to the problem is both physically realistic and operationally practical.' In hindsight this was a fitting culmination to the 'practical contributions from a fundamentally oriented group', namely his Division [83]. For many in the scientific community, the above expression provided a simpler formula than Penman's or others that seemed to work as well or better in well-watered landscapes, and made their article one of the most-cited in the agricultural meteorology and hydrometeorology disciplines. Their approach involved a kind of thinking that ranged far beyond the narrow confines of other work on evaporation and the surface energy balance at the time. As a result, it led directly to further progress in our understanding of processes in the boundary layer and, in addition, it produced a practical result with enduring value to agricultural meteorologists and hydrologists.

Scientific Awards

Bill Priestley became a fellow of the Royal Meteorological Society in April 1942, serving as Vice-President in 1957 and 1958, and was made an honorary Life Fellow in 1978. With his CSIRO career flourishing, awards flowed at regular intervals: the 1949 Buchan prize of the Royal Meteorological Society for his series of articles in the Society's *Quarterly Journal*, 1945–49; a Doctorate of Science from the University of Cambridge in 1953 based solely on the two dozen or so papers published in the years after he left Cambridge; and election to the Australian Academy of Science (AAS) in 1955, one year after its foundation. In 1956, he won the University of Melbourne's David Syme Research prize for his early work on convection in turbulence, and in 1966 he was elected a Fellow of the Royal Society of London. In 1967, he was awarded the Symons Memorial Gold Medal, the senior award of the Royal Meteorological Society, for distinguished contributions to meteorology. Around 1964, his old colleague O. G. Sutton, Director-General of the UK Meteorological Office, invited him to spend a week at his home while Priestley was visiting the UK. In fact, Sutton was due to retire and looked to Priestley to succeed him, introducing Bill to two members of the Meteorological Committee over lunch. Next year, Priestley received a letter from the Permanent Under-Secretary at the Ministry of Defence, inviting him to a meeting in England with a view to his being considered as a candidate for Director-General. Another candidate on the short list was B. J. (later Sir John) Mason. Mason and Priestley conferred over lunch and Priestley subsequently withdrew, the chief reason being that he and his family were happy in Australia. In 1965, Mason became Director-General of the UK Meteorological Office, and Bill Priestley is quoted later as saying that he thought Mason 'did a superb job as Director-General'.

In 1973, Priestley received the highest honour conferred by the World Meteorological Organization (WMO), the IMO prize, but the award that gave him the greatest pleasure was the Rossby Research Medal, the American Meteorological Society's highest honour. He won the medal in 1974 'for his fundamental contributions to the understanding of turbulent processes and the links between small-scale and large-scale dynamics in the atmosphere'. In 1976, he was made an Officer of the Order of Australia and awarded the Flinders Medal, which is the highest award given by the Australian Academy of Science to a physical scientist. Finally, in 1983, the Australian Meteorological and Oceanographic Society introduced its most prestigious award with the Priestley Medal, awarded biennially in recognition of excellence in research.

Professional Activities

By the 1960s, Bill Priestley was heavily involved internationally. He was one of several eminent scientists entrusted with formulating and planning the WMO Global Atmospheric Research Programme (GARP), first as a member of the WMO Advisory Committee and subsequently as one of the founder members of the Joint Organising Committee for GARP. He also served on three commissions of the International Association of Meteorology and Atmospheric Physics. He served on the WMO Advisory Committee of GARP from 1963 to 1969, becoming chairman in his penultimate year. The committee was disbanded in 1969, ostensibly so as not to overlap with the new Joint Organising Committee for GARP, but Priestley saw this as a mistake—the Advisory Committee served a very useful purpose in encouraging education in meteorology, especially in developing countries, and acting as a bridge between meteorological services and the academic world. During this period, he first put forward the idea of a project to gather historical sea-surface temperature data, a project that eventually came to fruition. In 1967, Priestley was appointed with eleven others as a founder member of the Joint WMO/ICSU (International Council of Scientific Unions—now the International Council of Science) Organising Committee for GARP, and served on it for four years. Incidentally, he was one of only two members from the Southern Hemisphere on both the WMO Advisory Committee and the Joint Organising Committee for GARP. However, he found the long-haul travel very wearing, since he went to Europe and the USA up to four times a year—an Australian's lot that is not readily appreciated by our European and US colleagues. He retired from all WMO responsibilities in 1977.

Invited lectures given by him during the 1960s and 1970s reflected his broad range of scientific interests and increasing stature as a national and international leader in the atmospheric sciences. His 1968 Einstein Memorial Lecture, given in the Bragg Theatre at the University of Adelaide, dealt with the future of meteorology—the important roles likely to be played by numerical prediction using ever more powerful computers and satellites that are able to provide observations on a near-continuous, global basis. In contrast, his 1970 Pawsey Memorial Lecture dealt with the physical and micro-environment of life on Earth, reflecting his own interests in the heat balance of animals and emphasizing emerging problems of the environment. Priestley's 1976 Matthew Flinders Lecture revealed his longstanding interests in both atmosphere and ocean, and the often striking parallelism and manifold interplay between the two. Towards the end of his career in CSIRO, and while still actively involved in his WMO responsibilities, he took on several major tasks for the Australian Academy of Science. These tested to the limit his managerial skills and ability to cope with pressing scientific problems in the public arena.

In early 1971, world-wide concern arose when an American scientist, Harold Johnson, predicted that the advent of commercial supersonic aircraft in the stratosphere would drastically reduce ozone concentrations through interaction with the exhaust gases. In June 1971, M. F. C. Day introduced discussion on supersonic aircraft and their possible environmental effects to the Australian Academy of Science's Committee on the Environment. Various pressure groups had led to public confusion, and so the Academy commissioned a review and convened a working group to provide a balanced view, naming Priestley as its chairman. Their report, published in February 1972, concluded that adverse climatic effects from such aircraft appeared unlikely (AAS 1972). In June of that year, Bill himself made a supersonic flight in the prototype Concorde G-BSST and so became one of the earliest pioneers of supersonic travel (Captain B. Trubshaw, Director of Flight Tests, British Aircraft Corporation, signed a certificate to such effect). Though relatively reassuring, while admittedly based on incomplete knowledge, the AAS report was mercilessly and not altogether scrupulously attacked. Nevertheless, nowadays scientific opinion would demand no major revision of its main conclusions—a decrease in total ozone of 1% or so and minimal climate impact arising from a fleet of 500 supersonic aircraft flying in the lower stratosphere (e.g. IPCC 1999). Such was the scientific and public response that the ANZAAS journal *Search* devoted an entire issue to the subject. There were four papers ranging from technical criticisms to a general discussion of the role of scientists in the decision-making processes of government. Priestley, as was only fair, was allowed the right of reply. To avoid 'the inevitable mental leap-frogging intrinsic in such a situation', none of the papers was refereed or altered, providing him with the basis for his reply. The issue is not only a fascinating case history of the role of the scientist in society, but also provides a glimpse of Priestley's philosophy so far as his own staff were concerned. The only non-technical article accused the Committee of 'social irresponsibility' and Bill Priestley, as Chief of a CSIRO Division, of imposing a moratorium on public statements and debate by his scientific staff via a memorandum to staff. He responded, in part [82]:

> Premature public debate by reputable scientists can easily mislead the public into thinking that they have been presented with an expert, authoritative view. Another social responsibility of scientists is surely that, when talking publicly, they shall talk good science. The public disenchantment with science in some parts of the world … is due in no small measure to

> the fact that so many don't … It is my official responsibility to discourage this sort of thing, and I choose to regard it as part of my social responsibility also. The memorandum I directed to my staff contained an undertone of advice to this effect, which was aimed particularly at two or three young colleagues who were prone to go beyond their own expertise. In all other respects the memo was an information statement, not an instruction. Can [the author] really be serious in suggesting that it constituted a 'moratorium on public debate by scientists'? I agree that scientists should take part in public discussion of scientific issues. We seem to disagree on the question of the time at which responsible scientists should move to generate public discussion. I prefer not to do this until after some depth of thought has been invested, allowing if possible a reasoned thesis to be put forward.

These words were written at the end of his tenure as Chief, and for many of his staff it may have been the first time in twenty-five years that his thoughts on such matters had been so clearly enunciated. Priestley ran the Division in an authoritarian and paternalistic style and, as Chief, enjoyed a high level of autonomy. He did not hesitate to intervene in the conduct of his subordinates' research programmes, to offer pointed criticism or even to comment on the conduct of a staff member's private life. Although autocratic, opinionated and sometimes quick in his judgment of his staff and scientific acquaintances, he would have seen this as part of his role and was perceptive and generous in defence of his science and of the laboratories he had created.

During the following two years, extensive publicity was given internationally to suggestions by some European and American scientists that a new ice age was approaching and that droughts in the Sahel and India, and wheat failures in the Ukraine, were among the symptoms of this change. Following concern expressed at the World Food Conference in November 1974 about the possible effects of this predicted climate change on agricultural productivity and the global food supply, the Australian Government requested the Australian Academy of Science to report to it on these assertions. A committee on climate change was established by the Academy in March 1975 with Priestley as its Chairman; its report was handed down in March 1976 (AAS 1976). The main conclusion, that there was no convincing evidence of an imminent climatic change, either on a global scale or in Australia, must be set against the evidence then available in 1975. Another far-sighted conclusion stated that 'All past climate changes have been due to natural events on an astronomical or global scale. Human activities are now developing in ways that could have an appreciable effect on the climate within decades.' Two decades later, the Intergovernmental Panel on Climate Change (IPCC) was to take up this very issue in its first report on climate change. In 1976, the Committee's report was well received, both at home and abroad, with little adverse publicity given to it at the time. The report's main conclusions were in tune with studies elsewhere that global warming through an increase in atmospheric carbon dioxide may constitute a more serious cause for concern than the possibility of an ice age.

In between the 1972 and 1975 Academy committees that Priestley chaired, he sat on a third Academy committee, chaired by Rutherford Robertson. In February 1973, the Prime Minister, Gough Whitlam, asked the Academy, as a matter of urgency, to advise the government on the actual or potential harm to Australia of nuclear weapons testing on Mururoa Atoll in the Pacific Ocean. A draft of the report was sent from the Academy Committee to the Prime Minister on 30 March that year. While generally agreeing with the findings of an earlier report of the National Radiation Advisory Committee, Robertson's committee did draw attention to the remote possibility of a potential hazard not hitherto considered. This concerned fumigation, whereby the transport of pollution from aloft may produce a high concentration of that pollutant over a small area, which (a remote possibility) could be densely populated. It was unfortunate that this additional, albeit remote, possibility came to be exploited politically. It is also highly probable that Priestley, the only meteorologist on the Academy Committee, first drew attention to the fumigation process, thereby ensuring its controversial inclusion in the final report.

In the early 1970s, Priestley's professional commitments were many. These included his expanding CSIRO Division at a time when he was about to retire as Chief and hand over to G. B. Tucker, his WMO work, his chairmanship of the two Academy committees, and his membership of the nuclear weapons committee. Another ongoing commitment was also moving towards fruition. In 1969, WMO had recommended that member countries establish a global network of remote stations specifically to monitor changes in atmospheric composition that might affect climate. By this time relevant activities within the USA were well advanced, and there followed the United Nations Conference on the Human Environment held in Stockholm in June 1972, which called for an international commitment on stations to monitor background atmospheric composition. Encouraged, Priestley and the Director of the Bureau of Meteorology, W. J. Gibbs, approached the Australian Government for support of such a concept and, in 1973, the Government agreed to set up a station and an associated work programme. The Division found itself with primary roles in the specification of functions (through WMO committees), location of a suitable site and provision of key programmes. By the mid-1970s, co-ordination had been established within the Department of Science and Consumer Affairs through the appointment of L. Wainwright of the Space Projects Branch as project manager. The search for a site continued for several years, with a location in north-west Tasmania identified and ultimately chosen. Observations commenced at the Cape Grim observatory in Tasmania in 1976 and the facility was made official in 1978; at the time of writing it is still operating, one of a dozen or so key baseline stations around the world. It has been part of a small global network of such observatories that together have assisted in defining the global budgets of carbon dioxide, methane, nitrous oxide and other gases. Observations have also identified (i) the long lifetime of chlorofluorocarbon (CFC) gases in the atmosphere, and thus their potential importance in ozone depletion and, subsequent to international agreement on the phasing out of the production and use of these gases, the effectiveness of this intervention; and (ii) the roles of aerosols in background air. The observatory has helped provide answers to many scientific and policy-relevant questions through the combination of very high quality observations and theoretical modelling of atmospheric transport. The early vision and support from Bill Priestley was key to this highly successful research investment.

Final Years

Following Priestley's retirement from CSIRO and all WMO activities in 1977, he was offered and accepted a part-time professorship at Monash University in Melbourne. Giving a course of lectures each year was a new experience and this occupied his time for four years. In 1981, when he had reached the age of 65 and, according to the prevailing rules, could no longer be paid for his services, he resigned. In April 1981, he chaired an Academy symposium on the lower atmosphere at which some of the first findings of the Cape Grim observatory were reported. In late 1981, he began preparing for an invited lecture to be given at the Eighth Session (sessions were quadrennial) of the WMO Commission for Atmospheric Sciences. This was held in Melbourne in February 1982, where he gave an invited lecture entitled 'Commentary on five decades of meteorology: 1940–1990'. Professionally he was close to calling it a day, but two final tasks awaited him.

At about this time, the new Director of Meteorology, J. W. Zillman, asked Priestley to undertake a confidential critical review of research in the Bureau of Meteorology. He gladly accepted, and his final report was submitted to the Director in August 1982; it was declassified in 1992 [90]. In due course, many of his recommendations were acted upon when the Bureau's new Research Centre was established in 1985. He used this report, amongst other things, to set out long-held thoughts on the factors that underpin a successful leader and a successful research scientist (see earlier). He also summarized his thinking on past CSIRO-Bureau research policy and relations, going back as far as his early experiences with H. N. Warren. In his view there was, from the outset, broad understanding of the respective research roles in CSIRO and the Bureau, as embodied in the earlier prospectus [71]. Notwithstanding this broad agreement, certain restraints were later imposed on CSIRO that were not imposed on the Bureau, which Priestley illustrated by using the 1982 Review of Atmospheric Science in CSIRO.[11] He concluded that, while there had always been a general mutual understanding as to the respective research roles

[11] *Review of Atmospheric Science in CSIRO: Report of the review committee and statement of executive decisions*. CSIRO, September 1982, 109 pp.

and objectives, the same did not apply to research policy. During his early years in Australia his attempts to discover Bureau research policy, so that his own could be attuned to it, were unsuccessful, and he remained disillusioned in this respect to the end of his career. He was also disappointed that he had been unable to convince those who drew up the CMRC and ANMRC agreements, that the Officer-in-Charge could be equally well appointed as a Bureau of Meteorology or as a CSIRO officer. He believed that many of the early troubles and some of the aftermaths might have been avoided if this had been agreed, rather than allowing certain administrative considerations to prevail. From this basis, Priestley expounded his philosophy, alluded to throughout this memoir, which remains very relevant to the business of science today. We quote:

> The principle that administration in science be designed to help the scientist was given position of primacy by Rivett of CSIR. It has been sad to observe its decline together with the enormously increased share of the cake now gobbled up in non-productive activities. I can claim to be one who resisted to the last. But the Chiefs, by number and nature, were never fitted to form a united front on any issue. Just before he retired, Rivett had written to a colleague: 'Like you I am unhappy about the future. The main danger as I see it is that people will knuckle down to the bureaucratic regime and, by avoiding fight and seeking comfort, they will gradually reach a condition of tolerant acquiescence in what they formerly knew to be wrong. A generation will arise that knows not freedom and will be content to do without it. Then some day an old battle will be fought over again.'

This and his insistence on good writing by aspiring scientists may nowadays seem outdated—to the detriment, Bill would have argued, of good science and its communication.

During 1982, Priestley was also invited to replace W. J. Gibbs as part-time chairman of the Latrobe Valley Airshed Study, a major Victorian state government project to assess the environmental limits to power-station development. Such was the enormous size of the Study that, after two years, Priestley informed the Steering Committee that a full-time director was required, but his recommendation was rejected. With an increasing workload and his own part-time salary falling behind this and inflation, he resigned in mid-1985. By 1987, his concentration and memory had deteriorated significantly, as he admitted in his Morton interview. From the early 1990s, he was rarely sighted in public, as ill health took its toll. Whilst still active, he continued to play golf, bridge and poker. At golf he had had a single-figure handicap in his earlier years and had been a long-term member of the Metropolitan Golf Club in south-east Melbourne's sand belt. He also enjoyed watching sport on television: to quote from his interview, 'the slower ones can provide the best watching. In my experience as a research leader, the same was sometimes true of scientists'. He loved reading and with his wife regularly joined friends at the theatre and at concerts. He enjoyed setting himself the goal of listening to all his music records and tapes, which took him about six months. Then he was ready to start again.

Bill Priestley was possessed of a dignified manner, made measured pronouncements and had obvious outstanding scientific ability—assessments of him that were as valid in 1940 as in 1980. He could be autocratic, sometimes emphatically so during his time as Chief; his pronouncement during the review of supersonic aircraft is a good example, as was his confrontation with R. J. Taylor in 1971 over a scientific study. One story relates to pre-Christmas drinks in the Division where it was traditional for Priestley to join staff and celebrate the year's achievements. But on one occasion he proceeded to lambast scientists for their poor showing that year, and stormed out leaving his audience to reflect on his words. Such instances tended to mask a reserved, private individual who was intensely proud of his English background but equally proud of his contribution to Australia. Retirement from CSIRO meant handing in his government passport. He had considered Australian citizenship and, for a planned overseas trip with Connie, applied for an Australian passport, only to be foiled by a series of stubborn bureaucrats who insisted that the process would take six months when the trip was just three months away. As he would relate with a mixture of amusement and chagrin, he thereafter travelled on his English passport, which explains the inclusion of the Gilbert and Sullivan ballad 'For he remains an Englishman' in his memorial service (Connie transcript). Notwithstanding his years in Australia, he retained many of his

English characteristics and, as with many of us over the years, there was always a battle of loyalties when England played Australia at cricket in an Ashes series.

After several years of declining health, Bill Priestley died on 18 May 1998, seven weeks before he turned 83. His wife Connie died in April 2009. They are survived by their two daughters and a son, and six grandchildren. Behind his dignity and reserve, Bill possessed a delightful sense of humour, rarely seen other than by family and close friends. Bill Priestley was a man of great academic ability, integrity and leadership skills, a beautiful writer of the English language who made a notable contribution to the science of meteorology. Few men of science go to their final resting place with their name attached to two scientific constants or laws—the Priestley constant in free convection and the Priestley-Taylor ratio for evaporation in well-watered landscapes.

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References

1. AAS (1972). Atmospheric effects of supersonic aircraft. Australian Academy of Science, Report No. 15 [C.H.B. Priestley chairman], 48 pp.
2. AAS (1976). Report of a committee on climate change. Australian Academy of Science, Report No. 21 [C.H.B. Priestley chairman], 92 pp.
3. Britter, R. E. (1989). Atmospheric dispersion of dense gases. *Annual Reviews in Fluid Mechanics* **21**, 317–344.
4. Deardorff, J. W. (1966). The counter-gradient heat flux in the lower atmosphere and in the laboratory. *Journal of the Atmospheric Sciences* **23**, 503–506.
5. Deardorff, J. W., and Willis, J. E. (1967). The free-convection temperature profile. *Quarterly Journal of the Royal Meteorological Society* **93**, 166–175.
6. Garratt, J. R., Angus, D., and Holper, P. N. (1988). Winds of Change: Fifty years of achievements in the CSIRO Division of Atmospheric Research 1946–1996, 136 pp.
7. IPCC (1999). Aviation and the global atmosphere. Cambridge University Press, UK, Chap. 4, Sec.4.3, 136–152.
8. Jeffreys, H. (1926). On the dynamics of geostrophic winds. *Quarterly Journal of the Royal Meteorological Society* **52**, 85–101.
9. McNaughton, K. G. (1976). Evaporation and advection I: evaporation from extensive homogeneous surfaces. *Quarterly Journal of the Royal Meteorological Society* **102**, 181–191.
10. Morton, B. R. (1998). Dr C.H.B. Priestley: Chief CSIRO Division of Meteorological Physics, 1946–1973. [Interview] *AMOS Bulletin* **11**(4), 83–94.
11. Morton, B. R., Taylor, G. I., and Turner, J. S. (1956). Turbulent gravitational convection from maintained and instantaneous sources. *Proceedings of the Royal Society, A* **234**, 1–23.
12. Raupach, M. R. (2001). Combination theory and equilibrium evaporation. *Quarterly Journal of the Royal Meteorological Society* **127**, 1149–1181.
13. Sutton, O. G. (1960). Review of ‘Turbulent transfer in the lower atmosphere’ by C.H.B. Priestley (University of Chicago Press, 1959, 130 pp.).
14. Sheppard, P. A. (1960). Review of ‘Turbulent transfer in the lower atmosphere’ by C.H.B. Priestley (Univ. of Chicago Press, 1959, 130 pp.). *J. Fluid Mech.* **8**, 636–638.
15. Sutcliffe, R. C. (1940). Meteorology for aviators. H.M.S.O., London, 274 pp.
16. Taylor, G. I. (1917). Phenomena connected with turbulence in the lower atmosphere. *Proceedings of the Royal Society, A* **94**, 137–155.
17. Turner, J. S. (1973). Buoyancy effects in fluids. Cambridge University Press, UK, 367 pp.

Obituaries

Garratt, J. R. (1998). Obituary: C.H.B. (Bill) Priestley. *Bulletin of the Australian Meteorological and Oceanographic Society* **11**(4), 95–96.

Garratt, J. R., and Galbally, I. E. (1998). Obituary: C. H. B. Priestley – atmospheric scientist. *The Age* (Fri., June 19), A22.

Garratt, J. R., Manins, P. C., and Webb, E. K. (1998). [Obituary] C.H.B. (Bill) Priestley. *Clean Air* **32**(3), 9–10.

Garratt, J. R. (1999). [Necrologies] Charles H. B. Priestley. *Bulletin of the American Meteorological Society* **80**(2), 314, 316.

Gibbs, W. J. (1998). Obituary: C.H.B. (Bill) Priestley. *Australian Meteorological Magazine* **47**, 179–181.

Webb, E. K., and Garratt, J. R. (1999). Obituary: Charles Henry Brian Priestley. *Quarterly Journal of the Royal Meteorological Society* **125**(559A), 2791–2792.

Bibliography

Articles, Published Lectures and Conference Proceedings, 1945–1982

1. Priestley, C. H. B. (1945). The phase-lag between pressure tendencies at high levels and at the surface. *Quarterly Journal of the Royal Meteorological Society* **71**(309–310), 385–387.
2. Priestley, C. H. B. (1946). On the frictional influence of horizontal wind shear on vertical motion. *Quarterly Journal of the Royal Meteorological Society* **72**(314), 284–289.
3. Priestley, C. H. B. (1946). Atmospheric pressure changes. *Nature* **158**, 914–916.
4. Priestley, C. H. B., and Swinbank, W. C. (1947). Vertical transport of heat by turbulence in the atmosphere. *Proceedings of the Royal Society. Series A* **189**, 543–559.
5. Priestley, C. H. B., and Swinbank, W. C. (1947). Transport of heat and other properties by atmospheric turbulence. *Nature* (January 11).
6. Priestley, C. H. B. (1947). Inclined flow – synoptic and single station data. *Quarterly Journal of the Royal Meteorological Society* **73**(315–316), 186–188.
7. Priestley, C. H. B. (1947). Dynamical control of atmospheric pressure. *Quarterly Journal of the Royal Meteorological Society* **73**(315–316), 65–84.
8. Petterssen, S., Sheppard, P. A., Priestley, C. H. B., and Johannessen, K. R. (1947). An investigation of subsidence in the free atmosphere. *Quarterly Journal of the Royal Meteorological Society* **73**(315–316), 186–197.
9. Priestley, C. H. B., and James, R. W. (1948). Attributes of pressure changes. *Weather* **3**(9), 284–285.
10. Priestley, C. H. B. (1948). Heat transport and zonal stress between latitudes. In: IUGG. General Assembly. Proces-verbaux des seances de l'association de meteorologie, Oslo, Norway. pp. 148–151.
11. Priestley, C. H. B. (1948). Wind and pressure changes. *Weather* (3), 66–72.
12. Priestley, C. H. B. (1948). Horizontal curvature on a spherical earth. *Quarterly Journal of the Royal Meteorological Society* **74**(320), 200–201.
13. Priestley, C. H. B. (1948). Dynamical control of atmospheric pressure. II. The size of pressure systems. *Quarterly Journal of the Royal Meteorological Society* **74**(319), 67–72.
14. Priestley, C. H. B. (1948). Atmospheric pressure changes: the importance of deviations from the balanced (gradient) wind. *Australian Journal of Scientific Research. Series A. Physical Sciences* **1**(1), 41–47.
15. Priestley, C. H. B. (1948). Air circulation and the Antarctic. *Australian Journal of Science* **10**(5), 129–131.
16. Priestley, C. H. B. (1949). Meteorological aspects of soil and crop evaporation. In: Specialist conference in agriculture. Session A. Review – climatic factors. Proceedings, Canberra; Adelaide. p. Paper Aa.
17. Priestley, C. H. B. (1949). Heat transport and zonal stress between latitudes. *Quarterly Journal of the Royal Meteorological Society* **75**(323), 28–40.
18. Priestley, C. H. B. (1949). An experiment on the analysis of horizontal divergence. *Weather Development and Research Bulletin* (14), 22–29.
19. Priestley, C. H. B. (1950). On the dynamics of the general atmospheric circulation. *Australian Journal of Scientific Research. Series A. Physical Sciences* **3**(1), 1–19.
20. Priestley, C. H. B. (1950). Flow of momentum and mass across the high-pressure belt of the earth's atmosphere. *Nature* **165**(4204), 855–856.
21. Priestley, C. H. B. (1951). Atmospheric turbulence in the boundary layer – an appraisal of the present position. In: International symposium on atmospheric turbulence in the boundary layer, M.I.T. 33–48.
22. Priestley, C. H. B. (1951). A survey of the stress between the ocean and atmosphere. *Australian Journal of Scientific Research. Series A. Physical Sciences* **4**(3), 315–328.
23. Priestley, C. H. B. (1951). Physical interactions between tropical and temperate latitudes. *Quarterly Journal of the Royal Meteorological Society* **78**(332), 200–214.
24. Priestley, C. H. B., and Sheppard, P. A. (1952). Turbulence and transfer processes in the atmosphere. *Quarterly Journal of the Royal Meteorological Society* **78**(338), 488–529.
25. Priestley, C. H. B. (1952). Turbulent-transfer coefficients near the ground. *Quarterly Journal of the Royal Meteorological Society* **78**(335), 107.
26. Priestley, C. H. B. (1952). Atmospheric turbulence in the boundary layer – an appraisal of the present position. U.S. Air Force. *Geophysical Research Paper* (19), 33–48.
27. Priestley, C. H. B. (1953). Contribution to the discussion of the paper by P. A. Sheppard and M. H. Omar on the wind stress over the ocean from observations in the Trades. *Quarterly Journal of the Royal Meteorological Society* **70**(340), 303–304.
28. Priestley, C. H. B. (1953). Buoyant motion in a turbulent environment. *Australian Journal of Physics* **6**(3), 279–290.
29. Priestley, C. H. B., and Troup, A. J. (1954). Further studies of the physical interactions between tropical and temperate latitudes. Melbourne: CSIRO. (CSIRO Section of Meteorological Physics technical paper, No. 1). 22 pp.
30. Priestley, C. H. B., and James, R. W. (1954). Large scale transport studies from individual station data. In: International Association for Meteorology.

Tenth General Assembly. Scientific proceedings, Rome. 443.
31. Priestley, C. H. B. (1954). Vertical heat transfer from impressed temperature fluctuations. *Australian Journal of Physics* **7**(1), 202–209.
32. Priestley, C. H. B. (1954). Convection from a large horizontal surface. *Australian Journal of Physics* **7**(1), 176–201.
33. Priestley, C. H. B. (1954). Buoyant motion and the open parcel. *Meteorological Magazine* **83**(982), 107–114.
34. Priestley, C. H. B., and Ball, F. K. (1955). Continuous convection from an isolated source of heat. *Quarterly Journal of the Royal Meteorological Society* **81**(348), 144–157.
35. Priestley, C. H. B. (1955). Plumes from tall chimneys. *Weather* **10**(10), 356–357.
36. Priestley, C. H. B. (1955). The physics of rainclouds [Correspondence]. *Quarterly Journal of the Royal Meteorological Society* **81**(347), 97.
37. Priestley, C. H. B. (1955). Free and forced convection in the atmosphere near the ground. *Quarterly Journal of the Royal Meteorological Society* **81**(348), 139–143.
38. Priestley, C. H. B. (1956). A working theory of the bent-over plumes of hot gas. *Quarterly Journal of the Royal Meteorological Society* **82**(352), 165–176.
39. Priestley, C. H. B. (1956). Heat convection from the earth's surface. *Nature* **177**, 435–436.
40. Priestley, C. H. B. (1956). Convection from the earth's surface. *Proceedings of the Royal Society. Series A* **238**, 287–304.
41. Priestley, C. H. B. (1957). The evolution of energy gain by the atmosphere through contact with the ground or ocean. Contract no, AF 19(604)-2179. Chicago: Chicago University. Department of Meteorology (Scientific report; 2). 56 pp.
42. Priestley, C. H. B. (1957). The heat balance of sheep standing in the sun. *Australian Journal of Agricultural Research* **8**(3), 271–280.
43. Priestley, C. H. B., McCormick, R. A., and Pasquill, F. (1958). Turbulent diffusions in the atmosphere [report of a working group of the Commission for Aerology]. Geneva: WMO (WMO technical note; 24). 68 pp.
44. Priestley, C. H. B. (1958). Sensible heat transfer from ground to air. In: Climatology and microclimatology: proceedings of the Canberra Symposium, Canberra (Arid Zone Research, 11). Paris: UNESCO. pp. 106–108.
45. Deacon, E. L., Priestley, C. H. B., and Swinbank, W. C. (1958). Evaporation and the water balance. In: Climatology: reviews of research. (Arid Zone Research; 10) Paris: UNESCO. pp. 9–34.
46. Priestley, C. H. B. (1959). The isotropic limit and microscale of turbulence. In: Atmospheric diffusion and air pollution: proceedings of a symposium, Oxford, F. N. Frenkiel, and P. A. Sheppard (editors) (Advances in Geophysics, 6). New York: Academic Press. pp. 97–100.
47. Priestley, C. H. B. (1959). Heat conduction and temperature profiles in air and soil. *Journal of the Australian Institute of Agricultural Science* **25**(2), 94–107.
48. Priestley, C. H. B. (1959). Estimation of surface stress and heat flux from profile data. *Quarterly Journal of the Royal Meteorological Society* **85**(366), 415–418.
49. Priestley, C. H. B. (1960). Temperature fluctuations in the atmospheric boundary layer. *Journal of Fluid Mechanics* **7**(3), 375–384.
50. Priestley, C. H. B. (1960). A determinant hypothesis for the superadiabatic wind and temperature profiles. *Quarterly Journal of the Royal Meteorological Society* **86**(368), 232–236.
51. Priestley, C. H. B. (1961). An alternative derivation of the diabatic wind profiles. *Quarterly Journal of the Royal Meteorological Society* **87**(373), 437.
52. Priestley, C. H. B. (1962). Some lag associations in Darwin Pressure and rainfall. *Australian Meteorological Magazine* (38), 32–42.
53. Priestley, C. H. B. (1962). Free convection in a wind. *Quarterly Journal of the Royal Meteorological Society* **88**(375), 100.
54. Priestley, C. H. B. (1962). The width-height ratio of large convection cells. *Tellus* **14**(1), 123–124.
55. Kraus, E. B., and Priestley, C. H. B. (1962). A discussion of the cell and parcel formulations of the convection problem. *Geofisica Pura e Applicata* **51**, 199–204.
56. Priestley, C. H. B. (1963). Some associations in Australian monthly rainfalls. *Australian Meteorological Magazine* (41), 12–21.
57. Priestley, C. H. B. (1963). Eddy diffusion in shear zones. *Quarterly Journal of the Royal Meteorological Society* **89**, 287–288.
58. Priestley, C. H. B., and Troup, A. J. (1964). Strong winds in the global transport momentum. *Journal of the Atmospheric Sciences* **21**(4), 459–460.
59. Priestley, C. H. B. (1964). Rainfall-sea surface temperature associations on the New South Wales coast. *Australian Meteorological Magazine* (47), 15–25.
60. Priestley, C. H. B. (1965). Effects of new instrumentation on network planning for evaporation. In: Proceedings of Symposium on the Design of Hydrometeorological Networks, Quebec. pp. 539–546.
61. Priestley, C. H. B. (1965). Air-earth interchange processes. Text of two lectures delivered: Institute of Tropical Meteorology, Poona, India. Poona, India: Institute of Tropical Meteorology. 28 p.

62. Priestley, C. H. B. (1965). Prospect of a breakthrough in scientific weather forecasting. *Australian Physicist* **2**(7), 111–114.
63. Priestley, C. H. B., and Troup, A. J. (1966). Droughts and wet periods and their association with sea surface temperature. *Australian Journal of Science* **29**(2), 56–57.
64. Priestley, C. H. B. (1966). The limitation of temperature by evaporation in hot climates. *Agricultural Meteorology* **3**, 241–246.
65. Priestley, C. H. B. (1967). On the link between micrometeorology and larger-scale dynamics. In: Second international symposium on dynamics of large-scale atmospheric processes, Moscow, A. S. Monin (editor). Nauka. pp. 228–229.
66. Priestley, C. H. B. (1967). On the importance of variability in the planetary boundary layer. In: Report of Study Conference on the Global Atmospheric Research Programme, StockholmICSU/IUGG; WMO. p. App. VI: 1–5.
67. Priestley, C. H. B. (1967). The problems of the lower atmosphere. *Australian Journal of Science* **30**(4), 117–126.
68. Priestley, C. H. B. (1967). Microclimates of life. *Science Journal* **3**(3), 67–73.
69. Priestley, C. H. B. (1967). Handover in scale of the fluxes of momentum, heat, etc. in the atmospheric boundary layer. *Physics of Fluids* **10**(9), S38–S46.
70. Leeper, G. W., Priestley, C. H. B., and Troup, A. J. (1967). Sequences of dry and wet months. *Australian Journal of Science* **29**(10), 375–376.
71. Gibbs, W. J., Priestley, C. H. B., and White, F. (1967). Prospectus for meteorological research in Australia. Interim report. Australia. Bureau of Meteorology. 16 pp.
72. Priestley, C. H. B. (1968). Modern outlooks in world meteorology. Part 1. Coresearch.
73. Priestley, C. H. B. (1968). Modern outlooks in world meteorology. Part 2. Coresearch (December).
74. Priestley, C. H. B. (1968). The future of meteorology. *Australian Physicist* **5**(12), 177–182.
75. Priestley, C. H. B. (1970). Interaction between oceans and atmosphere. *Report of the Australian Academy of Science* (12), 25–42.
76. Clarke, R. H., and Priestley, C. H. B. (1970). The asymmetry of Australian desert sand ridges. *Search* **1**(2), 77.
77. Priestley, C. H. B. (1971). The physical and microenvironment of life on earth. *Australian Physicist* **8**(1), 9–15.
78. Priestley, C. H. B. (1971). The physical and microenvironment of life on earth [Pawsey Memorial Lecture – 1970]. *Australian Physicist* **8**(1), 5–9.
79. Priestley, C. H. B. (1971). The global atmosphere: a memorial to H. C. Russell. *Search* **2**(8), 273–279.
80. Priestley, C. H. B., and Taylor, R. J. (1972). On the assessment of surface heat flux and evaporation using large-scale parameters. *Monthly Weather Review* **100**(2), 81–92.
81. Priestley, C. H. B. (1972). The scientific attitude. Sydney Water Board Journal (October), 26–27, 32.
82. Priestley, C. H. B. (1972). Reply to four criticisms of the Academy report 'Atmospheric effects of supersonic aircraft'. *Search* **3**(8), 298–301.
83. Priestley, C. H. B. (1972). Environmental research: practical contributions from a fundamentally oriented group. Melbourne: CSIRO. 23 pp.
84. Priestley, C. H. B. (1974). Microclimates. In: Encyclopaedia Britannica. 14th ed. pp. 114–122.
85. Priestley, C. H. B. (1975). William Christopher Swinbank: biographical memoirs. *Records of the Australian Academy of Science* **3**(1), 77–92.
86. Priestley, C. H. B., and Pittock, A. B. (1977). Inhomogeneity of satellite-derived climatological data. *Bulletin of the American Meteorological Society* **58**(3), 258.
87. Priestley, C. H. B. (1977). Flinders Lecture 1976 on 'Winds and Currents'. *Records of the Australian Academy of Science* **3**(3/4), 143–165.
88. Taba, H., and Priestley, C. H. B. (1982). The bulletin interviews: Dr. C. H. B. Priestley. *WMO Bulletin* **31**(4), 301–312.
89. Priestley, C. H. B. (1982). Reminiscences of 30 years of meteorologicalresearch in Australia. *Australian Meteorological Magazine* **30**, 19–30.
90. Morton, B. R., and Priestley, C. H. B. (1998). The Morton interview: Dr C. H. B. Priestley. *Australian Meteorological & Oceanographic Society Bulletin* **11**, 83–94.

Book

91. Priestley, C. H. B. (1959). Turbulent transfer in the lower atmosphere. University of Chicago Press, Chicago. 130 pp.