R. Alan Plumb: A brief biographical sketch, and personal tribute

Raymond Alan Plumb was born on March 30, 1948, in Ripon, Yorkshire, UK. He is not known for talking about his childhood, but we do know that he liked to sing, and was part of a group called the Avocets.

Alan did his undergraduate degree in Manchester, obtaining his BS Physics with I Honors in 1969. He was offered a fellowship to do his PhD at Cambridge, but had a negative reaction to a visit there and decided to stay at Manchester, where he pursued his studies in Astronomy, completing his PhD in 1972. With a highly disengaged thesis advisor, Alan was largely self-taught as a graduate student. He studied planetary atmospheres. Towards the end of his studies, Alan participated in a summer school organized by Steve Thorpe in Bangor, Wales, where he came into contact with the broader international community in geophysical fluid dynamics. Raymond Hide became particularly influential, and became Alan's mentor at the UK Meteorological Office, where Alan worked for four years after his PhD. Another key early influence whom Alan met then was Michael McIntyre. McIntyre's interest and encouragement were very important to Alan at that early time, and would continue to be so in later years, including after his move to Australia.

Alan's first peer-reviewed journal article, "Momentum transport by the thermal tide in the stratosphere of Venus" [*Plumb*, 1975] was based on his PhD thesis, though it came out several years after his degree. This first paper shows that even at this early point in his career Alan was a mature scientist, with an approach that has since remained remarkably constant. The young Dr. Plumb was already an expert practitioner of what we now know as classic geophysical fluid dynamics. His mathematics is elegant and sophisticated but never more complex than necessary, and is combined with great physical insight and clarity of exposition. Certain themes from this and his other earliest papers have stayed at the forefront of his work to the present: angular momentum; wave-mean flow interaction; the interplay of conservative and nonconservative processes (advective and diffusive transport, sources and sinks of tracers). Above all, one finds in these early papers an author seeking the most direct route from fundamental physical laws to observed behavior.

Alan's first position at the UKMO was Scientific Officer, then Senior Scientific Officer. As a member of Hide's group, Alan had great freedom to pursue his interests in fundamental GFD. UKMO policy at that time, however, commonly required anyone in Alan's position to switch groups after three years or so. In Alan's case, any other group he might have joined likely would have given him greater operational responsibilities, taking him away from basic research. Largely in response to this, Alan moved in 1976 to CSIRO in Aspendale, a suburb of Melbourne, Australia.

CSIRO was at that time hospitable to basic, curiosity-driven research. It was very strong in dynamical and physical meteorology with a roster of young scientists whose names are now familiar to many in our field (e.g., Webster, Stephens, Frederiksen, Baines). Alan's contributions in stratospheric dynamics drew international attention, and were proudly touted by the lab in annual reports at the time.

Alan's papers from the early CSIRO years cover a mix of explicitly middle-atmospheric topics (QBO, equatorial waves, meridional circulations, sudden warmings, mesospheric two-day waves) with theoretical GFD papers whose applicability was broader, though they may have been motivated by stratospheric problems. One of my favorites in the latter category is *Plumb* [1979]. In this paper, Alan shows that transport of a scalar by small-amplitude waves is diffusive in character if either the scalar is subject to damping (such as Newtonian cooling in the case of temperature, or in the case of a chemical species, reactions which can be represented as relaxation towards a chemical equilibrium state) or the waves are growing in time. At the same time, it also showed that the eddy fluxes often don't appear diffusive because when the waves are almost steady and conservative, the fluxes are dominated by the off-diagonal (i.e., advective) components of the diffusion tensor wherever the Stokes drift is nonzero, as it usually is. That was not realised at the time, and it showed how important it is to use the residual, not the Eulerian mean, velocity as the advecting velocity when trying to parameterize eddy transport. Though not one of Alan's most-cited papers — as of this writing, it is ranked sixteenth, with 93 citations — this one is a contribution of the most fundamental sort. Diffusion, in the sense of Fick or Fourier (in which the local time tendency of some scalar field is proportional to its Laplacian in space), is by far the simplest and best-understood transport process. It is of great value to know when nominally more complex processes lead to diffusive behavior. Einstein showed that Brownian motion leads to diffusive transport when viewed statistically on large scales, and Taylor showed that fluid turbulence, under some circumstances, does as well. Linear waves and turbulence are entirely different sorts of fluid flows, so Alan's explanation of the diffusive as well as advective character of linear waves deserves, in my view, to be mentioned in the same sentence as Einstein's and Taylor's papers in any historical discussion of tracer transport in fluids.

Another favorite of mine is *Plumb* [1986] in which Alan generalizes the quasi-geostrophic Eliassen-Palm flux to three dimensions. This was a great demonstration of technical mastery, but more importantly a work of fundamental significance, building the basic toolbox our field needs to understand cause and effect in the atmosphere. Few scientists are able both to recognize when problems like this need to be solved, and to solve them.

One of Alan's more dramatic achievements at CSIRO was the tank experiment demonstrating in the laboratory the mechanism for the quasi-biennial oscillation [QBO; *Plumb and McEwan*, 1978]. *Holton and Lindzen* [1968] had proposed that upward propagating gravity waves, with time scales of days or less, interacted systematically with the mean flow to generate an oscillation in the stratospheric winds with a period of over two years. The mechanism was inherently multiscale and nonlinear, with the amplitude of the waves determining the frequency of the QBO. While this idea must have seemed exotic at the time, its essential elements were familiar to Alan from his thesis work on wave-mean flow interaction in the Venusian atmosphere. Characteristic of Alan's later work both in research and education, his essential contribution was not only in understanding the physics better than most others (as demonstrated by several classic papers from the early CSIRO period [*Plumb*, 1977; *Plumb and Bell*, 1982a, b] in which Alan fleshed out the skeleton of the Holton-Lindzen theory, painting a physical picture of the QBO in three dimensions which in many respects stands unchanged today), but in recognizing what made it difficult for others to understand, and how to make it easier for them.

Alan's colleagues from the CSIRO period describe him as one of the leading lights of the field in Australia at the time, and as an unselfish collaborator. Robert Vincent, of Adelaide University, recounted to me regular trips Alan made to Adelaide, a relative backwater compared to Melbourne. Alan brought with him all the latest theoretical developments, but was also profoundly interested in and knowledgeable about observations. With Vincent's group, Alan played an instrumental role in developing a technique to estimate mesospheric eddy momentum fluxes from radar measurements. Robert Bell (CSIRO) was employed as a computer programmer working with different investigators, and wrote the code used to obtain the results in *Plumb and Bell* [1982]; Bell recounted the pleasure and satisfaction of working with Alan on this project, and also how it helped to establish his (Bell's) career, bringing him recognition and subsequent collaborations with other scientists.

Alan's colleagues from his Australian period also describe him with much fondness as a good friend with an active social life. He served as stage manager for a local musical theatre company (though he claims that he did not sing any roles), played volleyball, and brewed a strong beer. In hearing these recollections and others, one gets hints of certain non-scientific anecdotes whose existence is acknowledged, but whose details are not divulged, at least not to Alan's students (i.e., me). It seems that Alan's reputation as the most reserved of Englishmen has been earned partly through occasional departures from that role, though the details are likely to remain unknown to those who were not near him in Melbourne at that time.

Later in Alan's time at CSIRO, during the mid- and late 1980s, his scientific interests evolved towards transport problems of more direct relevance to stratospheric chemistry, more direct interaction with the comprehensive numerical models of the time, and more collaboration with American scientists. The latter may have been in part a consequence of an extended visit to NOAA's Geophysical Fluid Dynamics Laboratory in 1982.

After 1985, the discovery of the ozone hole drove excitement and growth in the study of the stratosphere. Despite the ozone holes location in the southern hemisphere, much of the activity was in the USA, where Sherwood and Rowland had made the original predictions of ozone loss due to chlorofluorocarbons (CFCs). In the late 1980s, NASA began a series of aircraft experiments to better assess the chemistry and transport of ozone and the key species influencing it. Alan would play an important role in these experiments after his move to the USA in 1988, and perhaps this move was partly motivated by a desire to be closer to the center of things.

Also, however, CSIRO was changing to favor more applied work funded by short-term contracts, which made it more difficult for Alan (and other basic researchers, many of whom left around this time) to pursue his interests. Alan's international reputation earned him an offer of a faculty position at MIT, in the great department that had been home to Jule Charney, Ed Lorenz, Victor Starr and others, and still was arguably the leading department in GFD. In 1988 Alan moved to the USA for reasons similar to those which had brought him to Australia: at MIT he could better pursue his interest in the basic physics controlling the circulation of the earth's atmosphere.

At MIT, Alan's interests continued to broaden. One new direction, motivated by his participation in the NASA aircraft experiments, was in nonlinear polar vortex dynamics and transport. With Darryn Waugh, Alan used the contour advection with surgery approach to diagnosing (and even forecasting, during field experiments) the generation of fine-scale filaments of polar vortex air in the midlatitude surf zone due to Rossby wave breaking events [*Waugh and Plumb*, 1994; *Waugh et al.*, 1994; *Plumb et al.*, 1994]. The discovery that the formation of such fine-scale features could be accurately predicted using only low-resolution meteorological data was a remarkable breakthrough which spawned a huge number of follow-on studies, theoretical and applied, by many other researchers.

Another new thread in Alan's portfolio was tropical tropospheric dynamics, particularly the dynamics of the Hadley circulation and monsoons [*Plumb and Hou*, 1992; *Hsu and Plumb*, 2000; *Plumb*, 2007b; *Prive and Plumb*, 2007a, b; *Clift and Plumb*, 2008]. At first glance, this topic may seem disconnected from Alan's work on the stratosphere. Once one recognizes the central role played by angular momentum in this work, the connection is clear; one of the central results in the now-classical axisymmetric theory developed by Schneider and Lindzen, Held and Hou, and then Alan, is known as Hide's theorem, due to Alan's former mentor.

Perhaps the most broadly influential of all the work from Alan's first decade at MIT is a remarkable series of papers that grew out of Alan's study of tracer-tracer correlations in aircraft data. The series really begins with *Plumb and McConalogue* [1988], but the central ideas were established in the mind of the community by *Plumb and Ko* [1992]. This study clarified the conditions under which compact relations between simultaneous measurements of different tracers would be expected and the further conditions under which those relations would be linear, and generally clarified the roles of transport and chemistry in creating or breaking these compact relations. It continues with *Hall and Plumb* [1994], which clearly defined the concept of age of air; continues further with *Plumb* [1996], which broadened the theory of *Plumb and Ko* [1992] to include an isolated tropics, or tropical pipe, and then has continued since with further developments [*Waugh et al.*, 1997; *Neu and Plumb*, 1999; *Plumb*, 2007a].

It is difficult to overstate the impact this work had on the field at the time. I had the good fortune to be Alan's student during this period, and he gave me the opportunity to attend a number of conferences and workshops. The roughly decade-long wave of excitement and rapid progress (and funding) in stratospheric chemistry and transport that followed the discovery of the ozone hole had not yet passed, and avalanches of results from new field experiments, satellite measurements, and numerical models of stratospheric trace gases were still pouring in at these meetings. Alan was unquestionably the most important theorist in this scene. He cast a long shadow over each meeting, even if he wasn't there, and even though he didn't say much (apart from his own presentations) when he was. As soon as each new Plumb paper became available (often before publication) other scientists from many institutions would scramble to re-orient their research, doing their best to make use of Alan's new insights or to use their own tools to try to address the new questions Alan's new conceptual framework raised.

In more recent years, Alan's work has evolved in new directions again. One of these is stratosphere-troposphere interaction, where Alan has turned his attention to the physics of annular modes and the mechanisms by which stratospheric dynamics may influence tropospheric weather. Another is physical oceanography. Here, many of the ideas that evolved through the work of Alan and others in the context of the stratosphere are relevant, directly or indirectly, to the ocean; the ocean is, as is often said, more like the stratosphere than it is like the troposphere, due to the relative weakness of vertical mixing processes and internal heating and resulting strong control exerted by stratification. Since his move to MIT, Alan has been an educator as well as a research scientist. His record as a teacher and mentor is perhaps less widely known than his research record, but is no less stellar. Here I can speak from my own personal experience as well as that of all the other alumni I have come to know who worked with Alan or took his courses before, during and after my time as Alan’s student at MIT.

Alan’s classroom courses are models of clarity. The experience of taking one of them is basically a semester-long, much more in-depth version of the experience of reading one of Alan’s journal articles. One feels that one has been taken from a point of ignorance to a point of deep understanding by the shortest route. This is a very rare experience, not at all common to all classroom teachers, even those few whose research records are comparable to Alan’s. His lecture notes on Middle Atmosphere Dynamics are, in my view, better than any textbook on the subject, though it is the field’s loss that he has never published them. He has, more recently, co-authored with John Marshall an outstanding textbook [*Marshall and Plumb*, 2008] based on their undergraduate course.

As a mentor (speaking again from my own experience), Alan was hands-off while still providing critical insightful guidance. Due to the many demands on Alan’s time, I couldn’t necessarily get to see him very frequently or on short notice. When I did, the dynamic range of his reactions to the results I showed him was narrow; it took me a year or two to learn that a furrowed brow and mildly perplexed look was a pretty negative reaction even if not accompanied by any harsh words, while the phrase ”ẗhat’s good”ẅas the highest praise. Once I understood that, Alan was the best of mentors. If I was doing well, he let me go my own way, allowing me to develop as a scientist without micromanagement. If I started to drift in an unproductive direction, I was redirected in a way that left me feeling wiser rather than chastised. In a discussion with Alan, no words were wasted — at least none of his. Whatever the source of my confusion, Alan grasped it quickly and saw how to move me past it.

Alan's former graduate students, postdocs, and junior collaborators on whom his influence has been formative have gone on to positions of prominence at a wide range of scientific institutions around the world ; on the faculty of Columbia University alone, where the PlumbFest was held, three of us (Lorenzo Polvani, Tim Hall and myself) consider ourselves Alan's proteges.

Alan is famous among all who have encountered him, either at MIT or in the broader scientific sphere, for the kind respect with which he treats everyone. Alan never makes one feel stupid, even when one is. This trait stands out because it is far from universal among scientists of Alan's caliber (or even much lesser ones).

At the present time, Alan continues down the path he has been on since the start of his career in Manchester; finding elegant solutions to difficult and important scientific problems and explaining them in the most effective and clear way to students and colleagues. On the occasion of his 60th birthday, some of us gathered in New York City to mark the occasion, and to discuss the science of the stratosphere, to which he has contributed so much. On behalf of those of us who were present there, and those who were not but shared our feelings, I wish Alan health, happiness, and many more years in which to keep doing what he does.

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Figure 1. Alan Plumb shows his QBO water tank experiment to Bill Priestley and other dignitaries at CSIRO. From *Garratt et al.* [1998], copyright CSIRO.