FRANK SHERWOOD ‘SHERRY’ ROWLAND
28 June 1927 — 10 March 2012
FRANK SHERWOOD ‘SHERRY’ ROWLAND

28 June 1927 — 10 March 2012

Elected ForMemRS 2004

BY NEIL R. P. HARRIS*

Centre for Environmental and Agricultural Informatics,
School of Water, Environment and Energy, Cranfield University, College Road,
Cranfield MK43 0AL, Bedfordshire, UK

Sherry Rowland was a chemist who made substantial contributions in the fields of radiochemistry and atmospheric science. He is best known for his research on the stratosphere as, with Mario Molina, he wrote the seminal paper describing how chlorofluorocarbons deplete the stratospheric ozone layer, noting that any ozone depletion would be accompanied by a consequent increase in ultraviolet radiation at the earth’s surface. In 1995 he, along with Paul Crutzen, was awarded the Nobel Prize for this ground-breaking work. Sherry’s career was much more rounded than this brief précis suggests. His various roles included: manager of a semi-professional baseball team while in graduate school; founding chairman of the Chemistry Department at the University of California at Irvine (UCI); tireless and effective advocate for the need to take action on chlorofluorocarbon emissions and climate change; Foreign Secretary of the National Academy of Sciences; and last, but certainly not least, devoted husband, father and grandfather.

EARLY LIFE AND EDUCATION

Frank Sherwood Rowland was born on 28 June 1927 in Delaware, Ohio. Known as ‘Sherry’ from a young age, he was the second of the three sons of Sidney and Margaret Rowland. His father was Professor of Mathematics and Chairman of the Mathematics Department at Ohio Wesleyan University. He was a precocious child and entered high school at the age of 12, graduating a few weeks before his 16th birthday in 1943. The age for the compulsory military draft was 18 and so he went straight to Ohio Wesleyan University as one of the few high school

* Neil.Harris@cranfield.ac.uk

© 2019 The Author(s)
graduates. After two years he joined the Navy as a trainee radar operator. World War II ended while he was in basic training near Chicago. The end of the military crisis meant that he was able to pursue his love of sports for a year in various Navy base teams. Once discharged, he went back to Ohio Wesleyan and graduated two years later with majors in Chemistry, Physics and Mathematics as well as being on the University basketball team.

Following in the footsteps of both parents, he moved on to the University of Chicago, where he was randomly assigned Willard Libby as a mentor. Libby, the inventor of the carbon-14 dating method, for which he was awarded the Nobel Prize for Chemistry in 1960, was to be a major influence on his life. Following its wartime work, Chicago was an exciting place to be, being particularly well endowed with nuclear scientists: his lecturers included four other Nobel Laureates (Enrico Fermi (ForMemRS 1950), Maria Goeppert Mayer, Henry Taube (ForMemRS 1988) and Harold Urey (ForMemRS 1947)). He was a prolific note-taker, filling many yellow pads over the course of his career, and his notes of the lectures he received from Nobel Prize winners at Chicago are in his archive cheek-by-jowl with notes from the talks of often unnerved graduate students at scientific meetings. While always emphasizing the need for intensive critical thought allied to hard work, Libby gave his graduate students unusual freedom in deciding how to spend their time. Sherry took full advantage of that, playing baseball and basketball for the university and being player–manager of a semi-professional baseball team in Ontario, Canada, in the summers. His athletic, 6’5” frame was put to good use, though it did cause Libby to question Sherry’s commitment to science (figure 1).

The final and most important piece of good fortune was meeting and then marrying Joan (pronounced Jo-Anne) Lundberg, a University of Chicago graduate, in June 1952. They were to be married nearly 60 years, with Joan being an extremely close, supportive and clear-eyed confidante for all that time. In the early days she even helped in the laboratory. Libby often
surveyed the laboratory at midnight. If Joan was there keeping an eye on Sherry’s experiment (and they were long experiments), he would say ‘Just you tonight, Sherry?’

**ACADEMIC CAREER**

After completing his PhD on the chemical state of cyclotron-produced radioactive bromine atoms in August 1952 (1)*, Sherry and Joan moved to Princeton, where Sherry had been appointed Instructor in the Chemistry Department, an appointment facilitated by Libby. At a leaving party prior to going to Princeton, Libby took Joan aside and said ‘Sherry is very smart, but lazy. If he can make it at Princeton, he can make it anywhere. If he can’t, then the hell with him.’ Joan took that to heart and made sure he made it! Their two children, Ingrid and Jeffrey, were born during the following three years. Summers were spent at the Brookhaven National Laboratory developing the use of ‘hot atom chemistry’ in the synthesis of tritium-labelled organic compounds. This topic, and radiochemistry more broadly, formed the core of Sherry’s research for nearly 20 years, expanding over time to include studies of the mechanisms and rates of a broad range of chemical reactions. As importantly, he started receiving support from the Atomic Energy Commission (AEC) which was to continue in various guises for 40 years. He was always on the look-out for new topics to keep his group fresh. He achieved this by taking time out every five years to draw up a list of five interesting issues that his group was not working on.

In 1956 he moved to be Assistant Professor at the University of Kansas, where he ran a laboratory doing research in radiochemistry. The main focus of the research at Kansas was understanding the chemical reactions of energetic tritium atoms (e.g. 4, 6), with a few studies of reactions of bromine and chlorine radioisotopes (e.g. 5, 7). He rose through the ranks until his promotion to full Professor in 1963.

His research group was international from the start, including postdocs from Europe, Japan and South America. This partly resulted from a penchant for international travel and grand opera which had been strengthened by regular sabbaticals, especially to the International Atomic Energy Agency in Vienna. The fact that the Director had a permanent box at the Staatsoper that was often available presumably added to the attraction of such visits. His overseas travels were so extensive that his group combined to give him a gift of a book entitled *See the USA* at the 1963 Christmas party.

He was then offered the opportunity to be the first Chair of the Chemistry Department at the University of California at Irvine. The offer was facilitated by Libby, now a Professor at University of California at Los Angeles, who presumably thought that Sherry had worked hard enough. The opportunity to mould a new department in a new university with ambitious growth plans was irresistible, and Sherry set about building up a department with talented and collegial colleagues. His office for the first year was in a portacabin a mile from the campus building site. In September 1965, the new Department opened, consisting of seven faculty, five staff, three first-year graduate students and a handful of advanced students. Its smallness ensured a true team spirit with few of the entrenched rivalries that can characterize larger, well-established organizations. He stepped down as Chair in 1970 but always maintained a strong commitment to the Department’s well-being. Later, he was one of the driving forces

* Numbers in this form refer to the bibliography at the end of the text.
behind the formation of the Department of Earth Sciences in 1990 and helped bring in his friend and eminent colleague, Ralph Cicerone, as its founding Chair.

On retiring from the Chemistry Department chairmanship, the hunt was on for new avenues of research. Since coming to UC Irvine, Sherry’s own research had broadened to include reactions which were initiated by photolysis with ultraviolet (UV) light (8, 9). The increased awareness of the environment on the part of scientists and the general public led him to look for challenges in the field of atmospheric chemistry—and especially the use of radiochemistry in tackling atmospheric issues. His first environmental foray was into the measurement of mercury levels in museum specimens of swordfish and tuna, which provided valuable information on the background levels of mercury (10). In this case, the work provided reassurance that mercury had always been present, and so showed that not all the mercury had come from recent pollution. By this time, he had acquired a deep understanding of chemical reaction mechanisms including UV photolysis. He had earlier studied the levels of tritium in the atmosphere (2, 3). This, coupled to his increasing interest in the environment, meant that the building blocks were in place for the main scientific discovery of his life.

**Ozone depletion**

In January 1972 Sherry attended one of a series of chemistry–meteorology workshops aimed at encouraging collaborative work in the two disciplines. He was there because he had shared a train carriage from Vienna to Salzburg with an AEC programme officer who was looking for more chemists to join the meeting! During the workshop, James Lovelock (FRS 1974) presented the first measurements of the chlorofluorocarbon CCl₃F (chlorofluorocarbon-11 or CFC-11), made during a cruise of the RRS Shackleton from the UK to Antarctica (Lovelock et al. 1973). CCl₃F was thought to be inert in the atmosphere and so had the potential to be used as a tracer of atmospheric motions. Sherry wanted to find out what happened to these molecules and his photochemical background convinced him that CCl₃F molecules would be destroyed by sunlight at high altitudes if nothing removed them first. He added the idea to his annual proposal to the AEC along with the usual raft of radiochemical topics.

A few months later, Mario Molina joined the group as a postdoctoral researcher and he chose the CCl₃F project because it was furthest from the topic of his PhD. Molina looked rigorously at all the possible removal processes for CCl₃F (uptake by land or oceans, rain-out, chemical reaction in lower atmosphere, etc.) and concluded that high-altitude photolysis was indeed the dominant removal process. In the process, chlorine atoms would be produced and these would catalytically destroy stratospheric ozone through reactions involving chlorine atoms and the chlorine monoxide radical. The ozone would be depleted primarily in the upper stratosphere at altitudes around 40 km. A direct result of reduced stratospheric ozone would be an increase in the amount of UV reaching the Earth’s surface, with potential consequences for plants, animals and materials.

This finding was published in *Nature* in 1974 (11). Despite the typo in the title, it produced a vigorous scientific and public response. The reaction, particularly from the chemical industry, was immediate and vicious, and it quickly became clear to him that his life would not be the same again. The president of one company using CFCs even claimed that criticisms of CFCs was ’orchestrated by the Ministry of Disinformation of the KGB’ (Waxman 2012). One evening Sherry came home and told Joan that she should come on his trips in future. She
said that they could not afford it; his prescient response was ‘I don’t think we can afford not to.’ As he predicted, life was very different. One mark of shame for academia is that he was not invited to give a seminar at a chemistry department in a US university for 10 years. The virulence of the early debate is all too easily forgotten now that the ozone depletion is seen as a solved problem.

The *Nature* paper provoked a great deal of research, with new measurements made in the laboratory and the atmosphere and a new generation of two-dimensional (latitude, longitude) models being developed that described the photochemistry and dynamics of the atmosphere. The focus was on where and when the ozone depletion would occur and what processes might ameliorate it. Sherry’s research group thus developed a second strand, with atmospheric chemistry added to radiochemistry, though even the radiochemistry side managed to study reactions of a number of halocarbons. More pertinently, the expertise in kinetics was expanded to investigate critical reactions of the halogen compounds involved in the photochemical cycles leading to ozone depletion cycles. This early work, with much done in collaboration with Mario Molina, investigated all aspects of the complicated processes involved (e.g. 12, 13, 16). Most notable was the study of the gas phase hydrolysis of chlorine nitrate, which acts as a ‘reservoir’ for chlorine in the stratosphere and reduces the amount available for ozone destruction (17). The new rate constant which they measured substantially reduced the computer model estimates of ozone loss in the upper stratosphere, where most of the ozone loss was thought to occur. Interest in ozone depletion was starting to wane: the issue seemed remote and far away, not requiring immediate action.

One of the challenges with laboratory studies of chlorine nitrate is that it is extremely difficult to distinguish the gas phase reactions from the hydrolysis which happened on the wall of the reaction vessel. Although highly frustrating at the time (17), this insight proved invaluable in understanding the processes leading to the Antarctic Ozone Hole, whose existence was announced in a bombshell paper published in *Nature* (Farman *et al.* 1985). This paper showed that October ozone values over Antarctica in the 1980s had inexplicably declined by more than 30% compared with the values seen in the 1960s. This finding provoked an immediate response, with major field expeditions to the Antarctic, renewed interest in laboratory and modelling studies, and a re-examination of existing atmospheric measurements. Large numbers of atmospheric scientists were working on the puzzle, and conflicting photochemical and meteorological mechanisms were invoked to explain it. Like many atmospheric chemists at the time, Sherry knew that any mechanism that could enhance the production of chlorine atoms over that of the inert chlorine nitrate would lead to faster ozone loss. His advantage was knowing the ease with which hydrolysis of chlorine nitrate could occur on usually inert laboratory surfaces. The problems were (a) whether there were suitable surfaces 18 km above the Earth’s surface and (b) whether these reactions could lead to such fast ozone destruction in just a few weeks each year? The realization of the existence of polar stratospheric clouds and informal discussions with colleagues during conferences provided a good deal of the answer (18).

Despite industry resistance, major progress on ozone depletion had been made in political and diplomatic circles. A number of countries, including the USA, Canada, Denmark, Norway and Sweden, had controlled the use of CFCs as propellants in spray cans in the mid-1970s. After that initial flurry of action, the main political effort had moved to the global level of the United Nations. This had led to the Vienna Convention for the Protection of the Ozone Layer in 1984, which provided a framework for international controls on the production of
CFCs and other ozone-depleting substances, though it relied on subsequent protocols to be agreed to produce real controls. The discovery of the Ozone Hole added a sense of urgency to these negotiations and prompted scientists to look more closely at whether ozone was being depleted elsewhere.

In particular, NASA and the World Meteorological Organization (WMO) set up the International Ozone Trends Panel in 1986 to examine existing measurement records to see whether there was evidence for ozone depletion above populated areas. Sherry was selected to lead the chapter on ‘Trends in total column ozone measurements’ (19). This had two main areas of focus: (i) to examine if a recent analysis of satellite measurements showing a rapid decline in ozone above the Northern Hemisphere was correct; and (ii) to undertake a major reassessment of the historic measurements of the ozone column made at ground stations. Detailed analysis of the historical data sets and their calibration records was combined with the development of new statistical approaches looking at the seasonal differences in the trends. It led to the finding that changes of a few per cent had indeed happened over the northern mid-latitudes in winter and spring (20). However, the larger trends previously reported using the satellite measurements were partly caused by an inaccurate calibration record.

This work effectively provided a scientific conclusion to Sherry’s active research on stratospheric ozone depletion, though he continued to work tirelessly in the national and international policy arena. In 1987, the Montreal Protocol was agreed to limit the production of ozone-depleting substances. The originally agreed limits on production would not have stopped large-scale ozone loss. However, the provisions included the requirement for regular scientific and technical updates to be prepared for the Parties to the Montreal Protocol. Sherry continued to give evidence to Congress on the topic and stayed involved in the international assessments of ozone depletion organized under the auspices of the WMO and the United Nations Environment Programme. He wrote the first set of ‘Twenty questions and answers about the ozone layer’ to complement the main assessment produced for the Montreal Protocol process: its successors continue to provide a valuable source of information for the general public.

Over time, successive amendments and adjustments to the Montreal Protocol have led to a complete phase-out of CFCs and other major ozone-depleting substances as well as agreement to phase out their less harmful replacements. In all, 197 countries have ratified the Montreal Protocol, the most for any international agreement. Kofi Annan, the former Secretary General of the United Nations, declared ‘perhaps the single most successful international agreement to date has been the Montreal Protocol’. Its success has avoided increased skin cancer rates, reduced agricultural yields and material damage (United Nations Environmental Programme 2015).

In 1995, Sherry Rowland, Mario Molina and Paul Crutzen (ForMemRS 2006) were awarded the Nobel Prize for Chemistry for their work on the destruction of the ozone layer by CFCs. Curiously for a 30-year-old university, his colleague in the Physics Department, Fred Reines, received the Nobel Prize for Physics (for his detection of neutrinos) on the same day. This led to some confusion in the department. On hearing the news from Stockholm, Sherry rang his long-time friend and Chair of the Chemistry Department, Hal Moore, and asked if he had heard the news. Hal said he certainly had and started gushing on about how great and deserved it was for Fred. Sherry agreed and kept on trying to give him more information. Finally he calmly said ‘Hal, take a deep breath, relax and slow down. That’s not the whole story. I got a call too.’ That finally silenced him.
Despite being somewhat overshadowed by the importance and high public profile of the work on ozone depletion, Sherry’s later work on atmospheric chemistry is substantial in its own right. In 1978 he started a global measurement programme to track decadal changes in trace gases such as methane, CFCs, carbon monoxide and an array of hydrocarbons. The idea was to measure at many locations across a wide range of latitudes every three months and so get close to global coverage. This programme continues to this day and complements the networks in which a relatively small number of stations make continuous measurements. This work was done in conjunction with Don Blake (his then graduate student, now Distinguished Professor at UCI) and it led to pioneering work characterizing and understanding trends in methane and ethane. This programme was one of the first to detect the increasing methane concentrations. It could have been the first, as, when Don Blake went to see Sherry with a few years’ data to suggest that methane might be increasing, Sherry replied that ‘Everyone knows that methane is constant in the atmosphere.’ And so they waited a bit before publishing (14, 15).

A major spin-off from this work was the group’s continuing involvement in countless NASA aircraft campaigns in which hundreds of stainless steel canisters were filled and measured for a wide range of trace gases. Many topics were studied including emissions from biomass burning (21, 25), liquified petroleum gas (22) and transportation, as well as broader issues such as the long-range transport of polluted air (23–25).

PUBLIC ADOVOCACY OF SCIENCE

Early on, during the original work on the breakdown of CFCs, Sherry decided that in addition to his scientific research, it was his duty to become a public voice on the subject. He summarized his views in his rhetorical statement at a White House climate change roundtable in 1997: ‘Isn’t the responsibility of scientists, if you believe that you have found something that can affect the environment, isn’t it your responsibility to do something about it, enough so that action actually takes place? . . . If not us, who? If not now, when?’

Once decided, he never shrank from this view and from doing what he believed to be his duty. At times this led to a questioning response from other scientists, who tended to avoid going near the line of policy advice. However, Sherry had a rare ability to summarize complex issues in clear and graphic ways and he found ways to use it. He often testified to the California and US legislatures, went to the Bundestag, and wrote articles on ozone depletion and climate change in a wide range of non-specialist publications. His skill and his standing in this field was recognized in a posthumous tribute by Henry Waxman, an influential member of the US House of Representatives: ‘Sherry Rowland’s life stands as a testimony to the critical role of scientific discovery in the development of wise and effective government policy’ (Waxman 2012).

In 1994 he became Foreign Secretary of the National Academy of Sciences, a post he held until 2002. He had always valued international collaborations and worked for many years with colleagues from Germany, Japan and China, among other countries. This personal experience fed into his work for the National Academy of Sciences and led to him becoming a Foreign Member of the Royal Society in 2004. In 1995, he helped to create, with Professor Prakesh Tandon of India, the InterAcademy Panel, a global network of the world’s science academies, to provide advice and recommendations on issues of global importance to those organizations.
and governments formally requesting such input. It now represents more than 130 academies of science, medicine and engineering.

**FAMILY**

Sherry and Joan had a daughter, Ingrid, and a son, Jeff, and two grandchildren, Taylor and Lindsey, who formed an extremely close and tight-knit core, the rock for Sherry’s life. The closeness and respect of his relationship with Joan (figure 2) can be seen in his testimony to the subcommittee on environmental pollution of the committee on Environment and Public Works of the United States Senate:

Senator Chafee: I am going to ask you a question. Suppose . . . you were king and you had what you might call unlimited authority. What would you do about this problem?

Rowland: If I were king, the first thing I would do is consult with the queen who is sitting behind me and who has a very good view on what the sensible things to do in such cases are.

That summed it up in life as well.

**HONOURS AND AWARDS**

| Year | Award                                                                 |
|------|----------------------------------------------------------------------|
| 1976 | Tolman Medal, American Chemical Society                              |
| 1979 | Leo Szilard Award, American Physical Society (for physics in the public interest) |
1983 Environmental Science and Technology Award, American Chemical Society
1983 Tyler Prize for Environmental Achievement
1987 Charles A. Dana Award for Pioneering Achievement in Health
1987 Gustavus John Esselen Award, American Chemical Society
1988 Global 500 Role of Honour for Environmental Achievement, United Nations Environment Programme
1989 Japan Prize in Environmental Science and Technology
1989 LLD, Ohio Wesleyan University
1989 DSc, University of Chicago
1990 DSc, Princeton University
1991 Dickson Prize, Carnegie-Mellon University
1991–1993 (successively) President-Elect, President, and Chairman of the Board of the American Association for the Advancement of Science
1993 Peter Debye Award in Physical Chemistry, American Chemical Society
1993 Robertson Memorial Lecture, National Academy of Sciences
1994–2002 Foreign Secretary, US National Academy of Sciences
1994 Roger Revelle Medal, American Geophysical Union
1994 Albert Einstein World Award of Science, World Cultural Council
1995 Nobel Prize in Chemistry (with P. Crutzen and M. Molina) ‘for their work in atmospheric chemistry, particularly concerning the formation and decomposition of ozone’
1995–2000 Founding Co-Chair (with P. N. Tandon, India), Inter-Academy Panel (IAP) on International Issues
1996 Honorary Lifetime Member, Ozone Commission IAMAP
1997 Nevada Medal
1997 Alumni Medal, University of Chicago
2003 Gold Medal, Academy of Athens
2004 Foreign Member, Royal Society

ACKNOWLEDGEMENTS

I would like to thank Sherry’s colleagues George Miller (Kansas and UCI), Hal Moore and Don Blake (both UCI) for their help in preparing this memoir. Barbara Chisholm, Sherry’s secretary, was invaluable in helping to access the Rowland Archives in the UCI Special Collections and Archives and in tracking down photographs. Finally, and most importantly, it was a real pleasure to have extended discussions with Joan Rowland while collecting material, and getting a rounded view of Sherry's life and character.

The frontispiece portrait photograph was taken in 2004 by Prudence Cuming Associates and is copyright © The Royal Society.

AUTHOR PROFILE

Neil Harris is Professor of Atmospheric Informatics at Cranfield University. He gained his PhD (‘Trend analysis of total ozone data’) under the supervision of Sherry Rowland and worked with him from 1984 to 1990. He subsequently worked as an atmospheric scientist in the Department of Chemistry in Cambridge, first in the European Ozone Research Coordinating Unit and later as a NERC Advanced Research Fellow. In 2015, he and Professor John Pyle FRS won the inaugural NERC International Impact Award and the Overall Impact Award for their role in
successful development of the Montreal Protocol on Substances that Deplete the Ozone Layer. He is Co-Chair of SPARC (Stratosphere–troposphere Processes And their Role in Climate), a core project of the World Climate Research Programme. Sherry acted as a mentor throughout this time.

REFERENCES TO OTHER AUTHORS

Farman, J. C., Gardiner, B. G. & Shanklin, J. D. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO/NOx interaction. Nature 315, 207–210. (doi.org/10.1038/315207a0)

Lovelock, J. E., Maggs, R. J. & Wade, R. J. 1973 Halogenated hydrocarbons in and over the Atlantic. Nature 241, 194–196. (doi:10.1038/241194a0)

United Nations Environment Programme (UNEP) 2015 Synthesis of the 2014 Reports of the Scientific, Environmental Effects, and Technology & Economic Assessment Panels of the Montreal Protocol. Nairobi, Kenya: UNEP.

Waxman, H. A. 15 May 2012 Tribute to F. Sherwood Rowland, United States of America House of Representatives Congressional Record.

BIBLIOGRAPHY

The following publications are those referred to directly in the text. A full bibliography is available as electronic supplementary material at https://doi.org/10.6084/m9.figshare.c.4880151.

(1) 1955 (With R. Wolfgang & C. N. Turton) Production of radioactive organic compounds with recoil tritons. Science 121, 715–717. (doi:10.1126/science.121.3151.715)

(2) 1959 Ratio of HT/HTO in the atmosphere. J. Chem. Phys. 30, 1098–1099. (doi:10.1063/1.1730089)

(3) 1961 (With E. L. Fireman) An additional measurement of the tritium content of atmospheric hydrogen of 1949. J. Geophys. Res. 66, 4321. (doi:10.1029/JZ066i012p04321)

(4) 1963 (With E. K. C. Lee) Isotope effects in recoil tritium reactions with methyl fluoride. J. Am. Chem. Soc. 85, 2907–2912. (doi:10.1021/ja00902a010)

(5) 1964 (With C. M. Wai & C. T. Ting) The stereochemistry of the replacement of chlorine atoms in alkyl halides by chlorine-38 activated in the (n,γ) process. J. Am. Chem. Soc. 86, 2525–2526. (doi:10.1021/ja01066a050)

(6) 1965 (With E. K. C. Lee & G. Miller) Moderator effects on recoil tritium reactions with methyl and methyl-d3 fluorides. J. Am. Chem. Soc. 87, 190–199. (doi:10.1021/ja01080a011)

(7) 1966 (With C. M. Wai, C. T. Ting & G. Miller) The stereochemistry of the reactions of (n,γ) halogen atoms with alkyl halides in the liquid phase. Chemical effects of nuclear transformations (Proceedings Series), vol. 1, pp. 333–344. Vienna, Austria: International Atomic Energy Agency.

(8) 1970 (With R. L. Russell) Photochemically induced rearrangement of ketene via an oxirene intermediate. J. Am. Chem. Soc. 92, 7508–7510. (doi:10.1021/ja00728a066)

(9) 1971 (With C. C. Chou & P. Angelberger) Methylene reactions in photolytic systems involving methyl iodide. J. Phys. Chem. 75, 2536–2538. (doi:10.1021/j100679a020)

(10) 1972 (With G. E. Miller, P. Grant, R. Kishore, F. Steinkrugler & V. P. Guinn) Mercury concentrations in museum specimens of tuna and swordfish. Science 175, 1121–1122. (doi:10.1126/science.175.4026.1121)

(11) 1974 (With M. J. Molina) Stratospheric sink for chlorofluoromethanes: chlorine atom-catalysed destruction of ozone. Nature 249, 810–812. (doi:10.1038/249810a0)

(12) 1977 (With C. C. Chou, W. S. Smith, H. Vera Ruiz, K. Moe, G. Crescentini & M. Molina) The temperature dependences of the ultraviolet absorption cross sections of CCl2F2 and CCl3F, and their stratospheric significance. J. Phys. Chem. 81, 286–290. (doi:10.1021/j100519a002)

(13) 1978 (With J. E. Spencer) Bromine nitrate and its stratospheric significance. J. Phys. Chem. 83, 7–10. (doi:10.1021/j100490a002)

(14) 1982 (With E. W. Mayer, D. R. Blake, S. C. Tyler, Y. Makide & D. C. Montague) Methane: interhemispheric concentration gradient and atmospheric residence time. Proc. Natl Acad. Sci. USA 79, 1366–1370. (doi:10.1073/pnas.79.4.1366)
Frank Sherwood ‘Sherry’ Rowland

(15) (With D. R. Blake, E. W. Mayer, S. C. Tyler, Y. Makide & D. C. Montague) Global increase in atmospheric methane concentrations between 1978 and 1980. Geophys. Res. Lett. 9, 477–480. (doi:10.1029/GL009i004p00477)

(16) (With L. T. Molina & M. J. Molina) Ultraviolet absorption cross sections for several brominated methanes and ethanes of atmospheric interest. J. Phys. Chem. 86, 2672–2676. (doi:10.1021/j100211a023)

(17) 1986 (With H. Sato, H. Khwaja & S. M. Elliott) The hydrolysis of chlorine nitrate and its possible atmospheric significance. J. Phys. Chem. 90, 1985–1988. (doi:10.1021/j100401a001)

(18) (With S. Solomon, R. R. Garcia & D. J. Wuebbles) On the depletion of Antarctic ozone. Nature 321, 755–758. (doi:10.1038/321755a0)

(19) 1988 (With J. Angell, W. Attmannspacher, P. Bloomfield, R. Bojkov, N. Harris, W. Komhyr et al.) Trends in total column ozone measurements. In Report of the International Ozone Trends Panel - 1988 (World Meteorological Organization Global Ozone Research and Monitoring Project Report no. 18), vol. 1, ch. 4, pp. 179–382. Geneva, Switzerland: World Meteorological Organization.

(20) 1989 (With N. R. P. Harris, R. D. Bojkov & P. Bloomfield) Statistical error analysis of ozone trends—winter depletion in the Northern Hemisphere. In Ozone in the Atmosphere, Proceedings of the Quadrennial Ozone Symposium 1988 (ed. R. D. Bojkov & P. Fabian), pp. 71–75. Hampton, VA: Deepak Publishing.

(21) 1994 (With D. R. Blake, T. W. Smith Jr, T.-Y. Chen & W. J. Whipple)Effects of biomass burning on summertime nonmethane hydrocarbon concentrations in the Canadian wetlands. J. Geophys. Res. 99, 1699–1719. (doi:10.1029/93JD02598)

(22) 1995 (With D. R. Blake) Urban leakage of liquefied petroleum gas and its impact on Mexico City air quality. Science 269, 953–956. (doi:10.1126/science.269.5226.953)

(23) 1996 (With S. Smyth, J. Bradshaw, S. Sandholm, S. Liu, S. McKeen, G. Gregory et al.) Comparison of free tropospheric Western Pacific air mass classification schemes for the PEM–West A Experiment. J Geophys. Res. 101, 1743–1762. (doi:10.1029/95JD02861)

(24) (With D. R. Blake, T.-Y. Chen, T. W. Smith Jr, C. J.-L. Wang, O. W. Wingenter, N. J. Blake & E. W. Mayer) Three-dimensional distribution of nonmethane hydrocarbons and halocarbons over the northwestern Pacific during the 1991 Pacific Exploratory Mission (PEM–West A). J. Geophys. Res. 101, 1763–1778. (doi:10.1029/95JD02707)

(25) (With N. J. Blake, D. R. Blake, B. C. Sive, T.-Y. Chen, J. E. Collins, G. W. Sachse & B. E. Anderson) Biomass burning emissions and vertical distribution of atmospheric methyl halides and other reduced carbon gases in the South Atlantic region. J. Geophys. Res. 101, 24151–24164. (doi:10.1029/96JD00561)