James R. Holton

1938–2004

BIOGRAPHICAL *Memoirs*

A Biographical Memoir by
John M. Wallace

NATIONAL ACADEMY OF SCIENCES

JAMES REED **HOLTON**

April 16, 1938–March 3, 2004

Elected to the NAS, 1994

By John M. Wallace

James Holton was one of the leading dynamic meteorologists of his generation, noted for his keen physical insight into the workings of the upper atmosphere and, in particular, for his lucid explanations of how atmospheric circulation arises and how it shapes the distribution of chemical tracers. He had a remarkable ability to recognize the basic building blocks that impart structure to complex atmospheric flow patterns and to envision the simplest and often the most important applications of complex mathematical relationships.

In his vibrant personal life, he was instrumental in building a community between his family, his neighbors, his far-flung network of research colleagues, and his running, hiking, and biking buddies. He and his wife, Margaret, also made important contributions to society in their role as parents of a child with disabilities. As an outdoorsman and as an academician, Jim thrived on competition and camaraderie; he enjoyed being challenged, both physically and mentally. He was equally at home lecturing, running a meeting, cramped in a tent with the wind roaring outside, or sipping wine in front of the fireplace in a posh English inn.

Family and Childhood

James Reed (Jim) Holton was born and raised in Pullman, Washington, in the heart of wheat-growing country. He was the eldest of three children. His father, C. Stewart Holton, earned his bachelor of science degree from Louisiana State University and his PhD from the University of Minnesota. Soon after graduating, Stewart took a position in the Division of Cereal and Crop Diseases in the US Department of Agriculture (USDA), which was housed in the Department of Plant Pathology at Washington State University. Stewart and workers in the laboratory that he directed made major advances in the control of smut in cereal grains, particularly in wheat and oats, which resulted in increased yields. Although Stewart was employed by the USDA, his duties were similar to those of a university faculty member: He supervised graduate students, attended faculty meetings, and authored or co-authored more than one hundred publications, including two books. Jim's mother, née Helen Treptow, was born in Iowa and moved to Seattle when her parents died to work as a servant and attend high school. She later earned a bachelor of arts degree at Washington State University and worked there as a secretary.

Jim attended the public schools in Pullman and graduated in 1956 as senior class president and valedictorian. His boyhood was typical of a child growing up in a rural setting at that time. He had the freedom to roam far and wide on his bicycle, sharing many adventures with friends. Among his boyhood friends was James G. Anderson, who later gained distinction as an atmospheric chemist at Harvard. Although they went to different universities, Holton and Anderson kept in touch because their mothers were good friends, and they enjoyed a strong professional camaraderie later in their careers. Another of Jim's companions was Bounce, a cocker spaniel, whose life was prolonged by the attentions of the WSU veterinary school, where he was treated for even such minor annoyances as spiky cheatgrass seeds caught in his ears.

The obligatory piano lessons that Jim took as a boy did not instill a lifelong a love of classical music. However, his experiences in the Boy Scouts while hiking, camping, and skiing left lasting impressions. During high school he took part in student government and in the class play, and he worked summers at the WSU agricultural school helping with tasks such as pollinating experimental varieties of hybrid plants. During college, he graduated to driving a truck to help with the university's wheat harvest.

University and Postdoc Years 1956–1965

Jim earned an undergraduate degree in physics at Harvard in 1960. He was introduced to meteorology during his senior year. The following year he entered the graduate program in meteorology at MIT with support from a Ford Foundation Fellowship. Jim's doctoral thesis research was conducted under the supervision of Jule Charney. After briefly considering a suggestion of Charney's that didn't work out,[1] Jim conducted a series of laboratory experiments and theoretical analysis of the "spin-down" of a rotating fluid in a cylindrical tank where the rotation is impulsively reduced. Greenspan and Howard had already discovered the spin-down of a homogeneous (constant density) fluid (Greenspan and Howard 1963). Frictional drag along the bottom of the tank induces a large-scale circulation cell with intense radial, boundary-layer inflow along the bottom of the tank and more diffuse ascent and radial outflow extending throughout the interior. Conservation of angular momentum within the radial outflow slows the rotation in the interior of the tank orders of magnitude faster than would occur under the influence of boundary-layer friction alone. Jim dealt with the more complicated case of a stably stratified fluid. He showed that as the static stability is increased, the friction-induced circulation cell tends to be increasingly confined to near the boundaries, and under its influence, the tangential flow rapidly spins down, much as it does in a homogeneous fluid. However, in a stratified fluid the adjusted flow exhibits vertical shear, which is subsequently "spun down" much more slowly by laminar diffusion. Jim's laboratory experiments on these matters guided subsequent theoretical work on the spin-down problem.

He filled one of their cooking pans with layers of salt solutions with differing concentrations and placed it on the turntable of their hi fi.

Jim's wife, Margaret, recalls that he performed confirmatory experiments at home. He filled one of their cooking pans with layers of salt solutions with differing concentrations and placed it on the turntable of their hi fi. To mark the interfaces between layers of differing densities, he used floats constructed by mounting appropriately sized pieces of the bright red wax wrappers from Edam cheese blocks onto the pins that she used for sewing.

Jim's close friends and contemporaries at MIT included his office mates Joseph Pedlosky, James Mahoney, and John Young. "We enjoyed discussing problems in dynamics and we both had similar world views," Pedlosky recalls. "Jim was also the first to read the draft of my first thesis chapter, and his approval of its clarity made me believe I was on the right track. I also recall that we were both terrifically inspired by [adviser] Jule [Charney], and when Jim would come back from one of his discussion meetings with him, he would be glowing with excitement." Jim completed his doctorate in the spring of 1964.

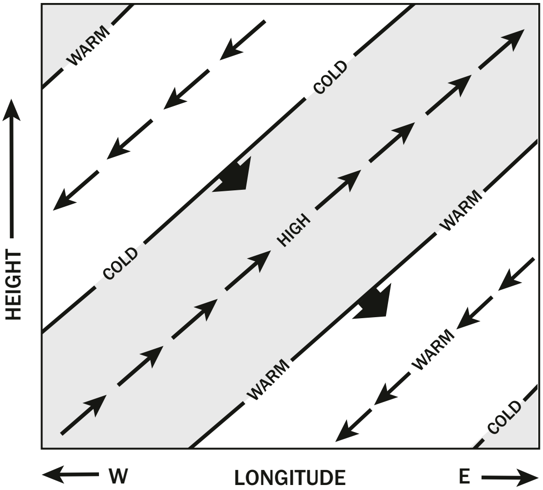
Around the time that he completed his PhD, Jim was selected from a slate of strong candidates to fill a faculty position in dynamic meteorology at what was then called the Department of Meteorology and Climatology at the University of Washington (UW), in Seattle. Charney's recommendation was highly influential in persuading department chair Phil Church and other department faculty members that Jim was the best choice for the position. Before taking up his duties at UW, Jim spent a year at Stockholm University as a postdoc, supported by the National Science Foundation and hosted by Bert Bolin. He maintained strong ties with Stockholm University and its faculty throughout his career.

Research 1965–1979

Jim was one of a series of new faculty hired by UW during the 1960s and early 1970s who substantially increased the size of the department and raised its stature. When he arrived in the autumn quarter of 1965, he was assigned the task of teaching dynamic meteorology classes to undergraduate students, including aspiring weather forecasters, and teaching the department's growing numbers of graduate students. His teaching evaluations were excellent, and some of the best entering graduate students sought him as a mentor for their research. Based on the enthusiastic recommendations of the department's senior faculty, he was promoted to associate professor in 1969 and to full professor in 1973.

Jim's graduate research at MIT had been largely in the realm of theoretical geophysical fluid dynamics. Upon completing his doctoral thesis, he became interested in the dynamical interpretation of atmospheric phenomena. While in Stockholm, he began work on the dynamics of the nocturnal low-level, southerly jet that is often observed during summer over the US Great Plains. By resolving the horizontal pressure gradient force into components parallel and perpendicular to the sloping terrain, he showed how the diurnal temperature cycle in the boundary layer drives a diurnal oscillation in the boundary layer wind, effectively coupling the viscous (Ekman) boundary layer and the thermal boundary layer. He noted that in order to duplicate in detail the vertical structure and phase of the observed jet, it would probably also be necessary to include time and height variations in the eddy viscosity and the eddy heat diffusion coefficients.[2]

Interacting during his first year at UW with synoptic meteorologist Richard J. Reed, a co-discoverer of the quasi-biennial oscillation (QBO) in zonal wind in the equatorial stratosphere, Jim's interest in the dynamics of planetary-scale phenomena was stimulated. When I joined the faculty in September 1966, he dropped by my office to get acquainted. During his visit he proposed that we collaborate on a modeling project to test the hypothesis I had put forward in my PhD thesis: that the downward propagation of successive easterly and westerly wind regimes in the QBO is due to vertical advection of angular momentum. The model that Jim proposed that we use was based in the equations that govern the evolution of a zonally symmetric vortex in response to prescribed sources of zonal momentum and heat, as formulated by Eliassen (Eliassen 1952). After scores of numerical experiments with various prescribed momentum sources and thermal damping, Jim and I became convinced that there was no way that we could realistically simulate the observations. Our working hypothesis was falsified; the downward propagation of successive wind regimes in the QBO must be due to some process



Jim created this schematic depicting the vertical structure of a Kelvin wave in the equatorial plane while Vernon Kousky and I were working on our observational paper showing that they are detectable in sounding data from equatorial stations, and he graciously allowed us to use it (Wallace and Kousky 1968). The HIGH, and LOW labels in the schematic mark the axes of the wave perturbations in the geopotential height field, the WARM and COLD labels refer to axes of the perturbations in the temperature field. The long thin arrows indicate the axes of the zonal and vertical components of the wind perturbations in the waves, and the short broad arrows indicate the direction of phase propagation.

other than vertical advection. I was afraid that our experiments had been a waste of time, but Jim found the results interesting and proposed that we write them up for publication.[3]

While our QBO paper was still in press, Jim became aware of a new paper published in the *Journal of the Meteorological Society of Japan* by Yanai and Maruyama reporting the existence of vertically propagating planetary waves in the equatorial stratosphere, forced from below (Yanai and Maruyama 1966). This "Yanai and Maruyama wave" corresponded with one of the modes in Matsuno's 1966 theoretical analysis of waves on an equatorial beta-plane, the so-called "mixed Rossby-gravity wave" (Matsuno 1966). Jim immediately recognized that this newly discovered wave might hold the key to explaining the downward phase propagation of the QBO. Around the same time, Jim visited our synoptic lab to review a series of time-height sections based on daily radiosonde ascents at equatorial stations. The smooth contours in these plots had been laboriously hand-drawn by graduate research assistant Vernon Kousky. Downward propagating waves were clearly apparent in Kousky's sections for zonal wind and temperature, and when Kousky's sections were overlain on the light table, it was apparent that the temperature perturbations led the zonal wind perturbations by one-quarter cycle. Jim asked to see the corresponding section for the meridional wind component, *v*. When he saw that that section was almost featureless, he immediately deduced that Kousky's waves corresponded with another of Matsuno's solutions, the one that he had referred to as the "equatorially-trapped Kelvin wave."

Jim was aware that in the recent theoretical analysis by Lindzen (Lindzen 1967), a wave mode similar to the one in Kousky's sections had emerged as a solution of the governing equations for planetary waves on an equatorial beta-plane, but this finding had gone unnoticed because the governing equations had been reduced to a single equation in the meridional wind component v without checking to see whether there was a solution for which v was equal to zero. Upon seeing Kousky's results, Jim immediately contacted Lindzen and they agreed to write a short note affirming the existence of the Kelvin wave in his solutions. Invoking the coexistence of Kelvin waves and mixed Rossby-gravity waves in the equatorial stratosphere, the former transporting westerly momentum upward and the latter transporting easterly momentum, they proposed a mechanism whereby the breaking of the waves as they approach their respective critical layers gives rise to alternating, downward-propagating easterly and westerly wind regimes like those in the QBO. The relevance of the Lindzen and Holton mechanism was subsequently confirmed in a series of elegant laboratory experiments by Alan Plumb and Angus McEwan (Plumb and McEwan 1979). State-of-the-art atmospheric general circulation models, with sufficient vertical resolution at stratospheric levels to capture the wave-mean flow interactions, are capable of simulating the QBO.

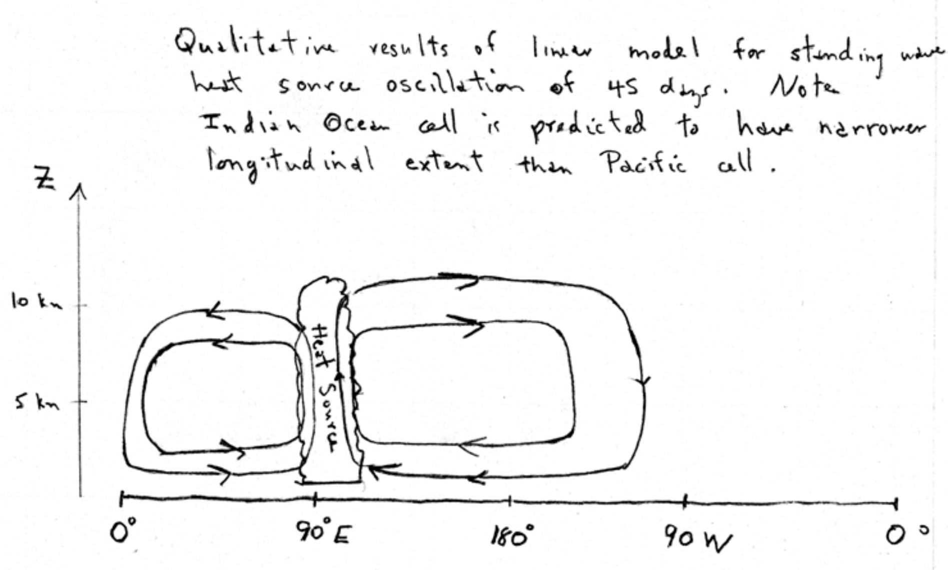
Not everyone agreed that that the QBO could originate from spontaneously occurring wave-mean flow interactions. I recall having lunch with Jim and the world famous climatologist Helmut Landsberg at the UW Faculty Club. Jim listened politely and respectfully as our guest dismissed the Lindzen and Holton theory as a fantasy of theoreticians and touted the QBO as evidence of the pervasive influence of the sunspot cycle and its higher harmonics on the atmospheric general circulation. Jim did not always show such forbearance. When Nobel Laureate Willard Libby gave a seminar at UW in which he argued that there must be ice caps on the surface of Venus, Jim challenged him during the question and answer period afterwards. He and UW faculty colleague Joost Businger followed up with a letter to Philip Abelson, the editor of *Science*, which had published an article by Libby on that topic. Quoting from the text of their original letter, "The report by W. F. Libby, 'Ice Caps on Venus,' (March 8, 1968) at first sight has the promise of containing a challenging and provocative new idea and has been treated as such by the press…However, after reading the paper there is nothing left of that promise; the reader feels merely the victim of a bad joke." They continued, "Libby's model inevitably implies either an absurdly large horizontal pressure gradient, or an untenable vertical temperature structure." The main thrust of their letter is well captured by the excerpt from its concluding paragraph, "We do not blame Libby for playing games with his imagination, but we do object to the editor of *Science* irresponsibly accepting such fantasies as worthwhile scientific material." A toned-down version of their letter was published in *Science*.

Taroh Matsuno spent a year at UW while on sabbatical from Tokyo University during the 1968–1969 academic year. Matsuno and his wife, Masako, and their two young children were the first of many foreign visitors whom Jim and Margaret hosted on behalf of the department. During that year, Matsuno developed a numerical model that was capable of simulating stratospheric sudden warming, which weakens and sometimes even temporarily reverses the direction of the strong westerly jet that encircles the polar region of the winter hemisphere. This warming occurs in response to planetary wave forcing from the troposphere directly below the polar night jet. Jim was not directly involved in this work, but he was highly supportive of it. He wrote to Matsuno the following year, while Matsuno was visiting the Geophysical Fluid Dynamics Laboratory in Princeton:

> *I have read your lecture on the sudden warming which you sent to Dick Reed. It is a very beautiful piece of work and I feel sure that you have essentially solved the problem. I hope that you will write it up for publication soon. I described your ideas briefly to Charney...and he agreed that they sounded quite plausible. He is anxious to see your paper, so that should be added inducement to write it up.*

The paper was published the following year (Matsuno 1971).

Jim also recognized the significance of the discovery of a new kind of wave disturbance in the tropical troposphere by Roland Madden and Paul Julian at the National Center for Atmospheric Research: an eastward-propagating, planetary-scale wave with a period ranging from thirty to sixty days. While their second paper on this topic was still in preparation, Jim wrote Madden a long letter with a sketch, offering his idea of how the waves that they discovered could be interpreted in terms of the superposition of two of the modes that emerge in Matsuno's analysis of waves on an equatorial beta-plane: the Kelvin wave and the gravest symmetric Rossby wave. Jim included a hand-drawn sketch that bears a remarkable resemblance to graphics in contemporary papers relating to the so-called "Madden-Julian Oscillation." Jim wrote several papers relating to the dynamics of tropical tropospheric wave disturbances during this period.



This sketch was included in a letter that Jim sent to Roland Madden on September 24, 1971, soon after the publication of Madden's paper with Paul Julian that reported the existence of a pronounced 40-50 day spectral peak in zonal winds in the tropical Pacific. In the letter, Jim suggested that linear wave dynamics might provide some insight into this phenomenon and he cited a recent paper that he had written on the subject. The theoretical interpretation embodied in his sketch has withstood the test of time. The overturning circulation to the right of the idealized heat source represents an equatorial Kelvin wave and the cell to the west represents a Rossby wave.

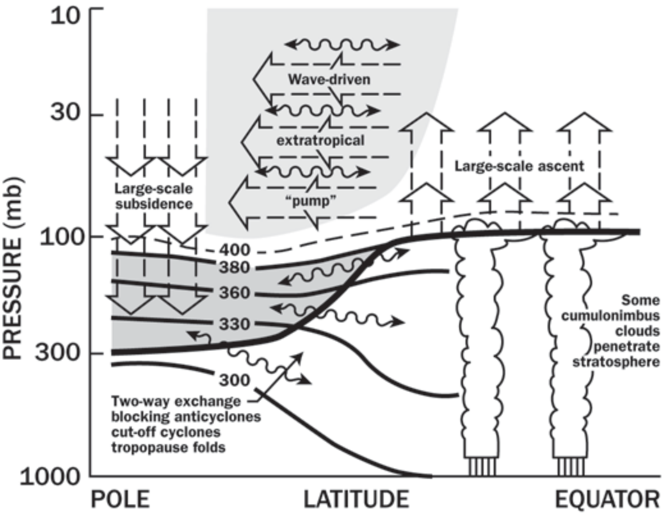
One of Jim's most influential stratosphere papers during the 1970s involves stratospheric sudden warmings. He asked his graduate research assistant, Clifford Mass, to write the computer code for a simplified dynamical model that he believed would be capable of simulating the sudden warming phenomenon, capturing the essential processes that Matsuno had identified when he visited in 1968–1969. In the first set of experiments that Mass performed, he found that the stratospheric circulation settled down to a steady-state that was in equilibrium with the imposed tropospheric planetary wave force, which was also steady. In this run the amplitude of the stratospheric response to the tropospheric planetary wave force was quite modest. However, when he increased the amplitude of the steady planetary wave force beyond some critical threshold value, the solution became oscillatory and the stratospheric response became much stronger. The Holton and Mass paper presenting these results stimulated considerable interest because their finding of regime-like behavior in the stratospheric circulation presaged the numerous papers relating to multiple equilibria that were written a few years later.

Jim was deeply interested in observed phenomena, but he wrote very few papers that could be classified as observational in their own right. Ironically, one of them proved to be his most widely cited paper. In it he made a strong case, based on statistical evidence, that the equatorial stratospheric QBO influences the wintertime stratospheric polar night jet to sudden warming by shifting the latitude of the zero-wind line in the basic state zonal flow. The statistical relationships that emerged in the study were just barely significant, but Jim elected to go ahead and publish them because he had the benefit of his *a priori* hypothesis that the stratospheric planetary waves feel the position of the zero-wind line. The Holton and Tan paper has withstood the test of time and has stimulated many subsequent studies. Although the analysis in it was restricted to stratospheric levels, it was subsequently shown to have implications for the tropospheric circulation, as well, thereby providing predictive information (albeit limited) up to a year in advance based on the phase of the QBO.

By 1980 Jim was recognized as one of the leaders in the field of dynamic meteorology and the fledgling department that he had joined back in 1965 had come to be recognized as one of the world's leading academic institutions in his field. His research interests had ranged from abstract geophysical fluid dynamics in his PhD research, to equatorial stratospheric dynamics in the late 1960s, to tropical tropospheric waves and stratospheric sudden warming in the 1970s.

Research 1980–2004

The controversy surrounding the proposed SuperSonic Transport aircraft in the early 1970s marked the beginning of a period of growing societal interest in the chemistry and dynamics of the stratosphere. By the late 1970s atmospheric chemists were beginning to worry that chlorofluorocarbons released in the troposphere could reach the stratosphere and catalyze the destruction of ozone there, posing a serious risk to human health. With the discovery of the Antarctic ozone hole in 1985, it immediately became apparent that their concerns were well founded. Jim became a leader in the research community dedicated to advancing our understanding of the dynamics of the stratosphere, which



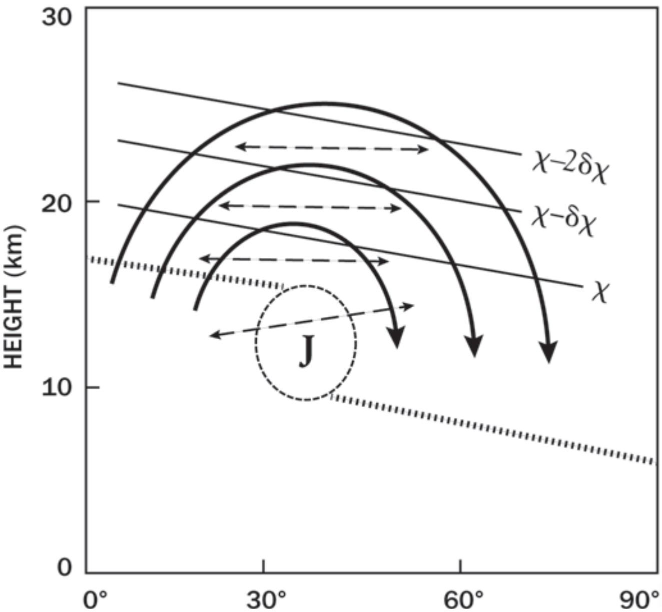
This sketch first appeared as Fig. 3 of Jim's 1995 review paper summarizing the processes that produce an exchange of air between the troposphere and stratosphere, emphasizing the key role of the "wave-driven extratropical pump" in regulating the strength of the Brewer-Dobson circulation. The wide line depicts the tropopause and the thick arrows depict the mass flux in the BDC. In the early work on stratosphere-troposphere exchange it was assumed that the rate at which the stratosphere is ventilated is determined by the processes depicted by the squiggly arrows.

serves as a reaction chamber in which chlorofluorocarbons are processed to liberate chlorine oxide and other highly reactive trace species that catalyze the destruction of ozone.

With just a few exceptions,[4] Jim's research from 1980 on was focused on stratospheric dynamics with emphasis on two major topics: the force of the equator-to-pole mean meridional circulation cell that ventilates the stratosphere, the so-called "Brewer-Dobson circulation;"[5] and the processes that transform tropospheric air (as defined by its chemical makeup) into stratospheric air in the rising branch of the Brewer-Dobson circulation, within the so-called tropical transition layer. During this phase of his career, Jim played an important role in the NASA programs. He provided strong intellectual leadership on the Science Team of the Upper Atmosphere Research Satellite that was launched in 1991. Later he joined John Gille, whom he had met in graduate school, and John Barnett on the science team of the High Resolution Dynamics Limb Sounder and helped shape the project's goals. Collaborations with Barnett and the group at Oxford, which involved frequent travel to the UK, made this work particularly enjoyable for him. Unfortunately, the instrument was not launched until a few months after Jim's death, so he did not live to see the fruits of those labors.

Among the major drivers of the Brewer-Dobson circulation are gravity waves with horizontal scales too small to be resolved in global atmospheric general circulation models. Like vertically propagating planetary waves forced from below, gravity waves tend to amplify as they disperse upward until they break, at which point they exert a body force on the planetary-scale background flow. Building on the ideas that motivated their earlier work on the theory of the QBO, Lindzen and Holton independently devised simple schemes that could be used to parameterize this body force. In Lindzen's 1981 scheme, the gravity waves were assumed to fall into two categories: waves that are stationary relative to the rotating earth and waves that propagate eastward with a phase speed of twenty meters per second (Lindzen 1981). Jim described his own scheme in a paper published a year later as "a slight modification of the parameterization developed by Lindzen." By including both eastward- and westward-propagating gravity waves, he was able to substantially improve the performance. Jim continued to pursue this topic in his later papers and during the 1990s. Working with his departmental colleague Dale Durran, research associate Joan Alexander, and with students and postdocs, he performed high-resolution numerical simulations that resolved the stratospheric gravity waves forced by tropospheric convection.

Jim was also interested in the role of the strong planetary waves in the Northern Hemisphere during winter in driving the Brewer-Dobson circulation. Haynes and colleagues (Haynes et al. 1991) developed a formal way to infer the frequency-dependent response of the Brewer-Dobson circulation to the breaking of waves of all kinds. Through personal contact and correspondence with the authors,[6] Jim was among the first to learn about their so-called "downward control principle" that, in its simplest form, relates the upward mass flux through a given pressure surface and equatorward of a prescribed latitude to the vertically integrated eddy-induced zonal force at the prescribed latitude, where the vertical integration extends from the given pressure surface up to the top of the atmosphere. By this time, the atmospheric dynamics community was becoming aware that wave breaking in the extratropics acts as a suction pump, pulling tropospheric air into the stratosphere in the rising branch of the Brewer-Dobson circulation. Jim realized that the downward control principle could be used to estimate the specific contribution of the breaking of extratropical planetary waves to force the upward mass flux, making use of readily available data on the eddy fluxes of heat and zonal momentum. Through his lucid workshop explanations and his authoritative review papers, he was influential in promoting the notion within the broader atmospheric science community that the rate at which the stratosphere is ventilated by tropospheric air is governed not by the frequency and intensity of tropopause folding events that inject stratospheric air into the troposphere in extratropical latitudes, as had previously been believed, but rather by wave



Modeling the distribution of the gases involved in the catalytic destruction of ozone in the stratosphere with height or pressure as the vertical coordinate requires consideration of two competing transport mechanisms: the Brewer-Dobson circulation (BDC), and the irreversible mixing by eddies. Prior to the 1980s, the connection between the driving of the overturning motion and the eddies was known, but only qualitatively. In Jim's diagram, where the overturning is depicted by the thick solid arrows, the isentropic mixing by the dashed arrows, and the mixing ratios by contours, it is clear that the BDC tends to twist the contours clockwise while the eddy mixing tends to oppose this tendency. The short, elegant paper in which the diagram appeared went on to show how, using some simple approximations, it was possible to link the strength of the eddies to that of the BDC and the slopes of the surfaces of constant mixing ratio.

breaking that takes place higher in the stratosphere.

As a specific application of the downward control principle, Jim argued that the pronounced annual temperature cycle in the tropical cold-point tropical tropopause, with the minimum temperature in January, is attributable to the stronger land-sea thermal contrasts and more extensive mountain ranges in the Northern Hemisphere. These conditions drive stronger wintertime planetary waves that induce a stronger Brewer-Dobson circulation with stronger tropical upwelling and attendant adiabatic cooling. Stratospheric dynamicists are still arguing about the relative importance of high-latitude stratospheric planetary waves versus lower latitude, synoptic-scale waves in forcing the Brewer-Dobson circulation, but it is agreed that the downward control principle is applicable.

Satellite-borne measurements of water vapor indicate that the layers of air that passed upward through the tropical cold point during the boreal winter, when temperatures and dew points are lowest, are drier than the intervening layers. As alternating dry (January) and moist (July) layers rise into the lower stratosphere, they retain their identity for a year or two, tracing the ascent of tropospheric air into the lower stratosphere. Corresponding layers are seen in carbon dioxide, for which the annual cycle in the troposphere is carried upwards into the stratosphere, and in hydrogen cyanide, the variations of which are believed to arise from seasonal variations in biomass burning. This so-called "tropical tape recorder," which is clearly evident in time-height sections, serves as visible evidence of the existence of the upward branch of the Brewer-Dobson circulation, and it provides an independent check on estimates of the mean rate of ascent derived from the downward-control principle and other diagnostic techniques.

In the early literature on troposphere-stratosphere exchange, the "freeze drying" of air ascending out of the tropical troposphere was envisioned as taking place in updrafts of deep convective clouds with overshooting tops that have enough upward momentum to carry them high above their level of neutral buoyancy. Jim found it difficult to believe that sufficient quantities or air could be processed by convection alone to account for the dryness of the air entering the stratosphere. Following the discovery of layers of subvisible cirrus cloud at levels in the vicinity of the cold-point tropopause (~17 km) in the 1990s, he began to wonder whether more significant freeze drying could be occurring along quasi-horizontal air trajectories in which air is being gently lifted in planetary-scale waves. He became a strong proponent of the notion that the boundary between tropospheric and stratosphere air in the tropics should be viewed as a "tropical transition layer" extending from roughly 14 to 18.5 km and bounded by the subtropical jets, in which widely spaced overshooting cumulonimbus cloud tops coexist with much more widespread, optically thin, stratiform cloud layers in which air parcels are undergoing radiative heating along with freeze drying. This idea is now widely accepted.

Jim's Legacy to Atmospheric Science

Jim will be remembered for the clarity of his scientific explanations and his classic diagrams, four of which are reproduced at the end of this memoir. His devotion to teaching science is reflected in the numerous books, book chapters, and review articles that he wrote over the course of his career. Frustrated by the lack of an atmospheric dynamics textbook suitable for use in his undergraduate classes at UW, he decided to write one of his own. He was able to produce book chapters at a rate of about one per month, handwritten on yellow pads and given to one of the department secretaries for transcription. The equations had to be typeset by the publisher. The first edition of his book, *An Introduction to Dynamic Meteorology*, was published in 1972 by Academic Press, later bought by Elsevier. Jim produced three subsequent editions of the book with progressively more user-friendly problem sets and solutions. The fourth edition, published in 2004, contains problems that can be worked using MATLAB.

Jim developed a strong professional relationship with Academic Press, serving as editor of its International Geophysics Series and its *Encyclopedia of Atmospheric Sciences*. He also wrote a shorter book entitled *The Dynamic Meteorology of the Stratosphere and Mesosphere*, published by the American Meteorological Society in 1975 in its Meteorological Monographs series. His more ambitious monograph, *Middle Atmosphere Dynamics*, co-authored with David Andrews and Conway Leovy and published ten years later, has been cited more than two thousand times and is still considered one of the standard references in the field. Jim's technical writing has been praised for its accessibility, lucidity, succinctness, and detail. During his 38 years of service as a faculty member at UW, Jim supervised the dissertations of 26 PhD students and 7 masters degree students, and he hosted the numerous postdocs and visiting scientists whose names and periods of residence at UW are listed in the Appendix. He was generous in sharing credit with others and had a remarkable ability to encourage, mentor, and inspire students and younger colleagues on the UW faculty.[7]

Jim was not known for seeking out positions of leadership, but when called upon, he was able to rise to the occasion, handling administrative tasks with the same competence that characterized his endeavors as a scientist. During his term as chair of the department (1998–2003) he guided his faculty through important programmatic, budgetary, and personnel decisions, and he was able to work constructively with the UW higher administration to garner necessary resources. He presided over the hiring of three academic faculty members and set the stage for the hiring of a fourth, triggering a virtual renaissance in the makeup of the faculty. As soon as he arrived in the department, he began to cultivate enduring friendships with younger faculty members, introducing them to friends, colleagues, funding opportunities, and hiking trails. Because of his remarkable efficiency in the use of time, he was able to manage the duties of the chairmanship without losing his good spirits or the momentum in his research.

Jim served on numerous boards, review committees, and advisory committees for agencies and institutions in the United States and abroad. In addition to his service to NASA, he served terms on the Council of the American Meteorological Society, the National Center for Atmospheric Research Science Advisory Committee, the Visiting Committees for Earth and Atmospheric Sciences at MIT and the Woods Hole-MIT Joint Visitors Program, the National Technical Advisory Committee for the Department of Energy's National Institutes of Global Environmental Change, and the Atmospheric Sciences Advisory Committee for the Electric Power Research Institute. He also served a four-year term as a co-chief editor for the Journal of the Atmospheric Sciences.

Jim's numerous honors include the American Meteorological Society's Meisinger Award (1973) for young scientists, its Second Half Century Award, and its most prestigious research award, the Carl G. Rossby Medal. He also received the American Geophysical Union's most prestigious research award, the Roger Revelle Medal. He was a member of the National Academy of Sciences (elected in 1994) and a fellow of both the American Meteorological Society and the American Geophysical Union. His outstanding service as a reviewer is reflected in an AMS Editors Award and the National Academy's J. M. Luck Award. He was awarded an honorary doctorate from Stockholm University and an honorary professorship from the University of Buenos Aires.

Family

At the beginning of his senior year at Harvard, Jim deliberately arrived in Boston a week early to meet incoming girls during freshman orientation. It was at a mixer that week that he first met Margaret Pickens, a biochemistry major at Radcliffe who he would marry three years later. After Jim completed his PhD in 1964, they moved to Stockholm for Jim's postdoctoral year.[8] It was while they were living in Stockholm in 1964 that their first son, Eric, was born.

Soon after they arrived in Seattle in September 1965, Jim and Margaret purchased a house in a residential neighborhood less than a mile from the UW campus, where Margaret still resides, complemented by a large canvas tent for family car camping. Compared with Boston, Seattle offered relatively little in the way of cultural life at that time. Much of their social life was built around friendships with families in Jim's department and with neighbors. During the years that followed, they took full advantage of Seattle's expanding cultural offerings. They particularly enjoyed theater; they attended "The Rep" regularly and they had season tickets at the newly established A Contemporary Theater and the Intiman Theater. Jim and Margaret were avowed anglophiles who derived great pleasure from Beatles songs, silly Monty Python skits, Gilbert and Sullivan operettas, the serialized novels on Masterpiece Theater, and live performances of both classic and modern British plays.

Margaret shared Jim's penchant for clarity and efficiency. Their home was notable for its efficient use of space and energy; a remarkable absence of weeds, chipped paint, and mildew; and the latest kitchen gadgets and counter tops. Most of their furniture was of Scandinavian design: simple, with clean lines.[9] Just as Jim did most of the writing, graphics, and typing of his own manuscripts, he did much of the home maintenance, including both exterior and interior painting, installing a roof with cedar shakes, and (under Margaret's direction) the landscaping for their yard and garden, which included a greenhouse.

Jim and Margaret were legendary for their hospitality to Jim's faculty colleagues and their families and to the numerous graduate students, postdocs, and visiting academics who spent time in the department. For many years, one of the highlights of the department social calendar was the annual Fourth of July party at the Holtons', one of which featured unseasonably cold weather and homemade ice cream. After dark, Jim and the children set off the latest pyrotechnics from China in the street in front of their home as guests and neighbors looked on apprehensively. Other occasions featured Margaret's gourmet dinners.

Jim and Margaret's younger son, Dennis, was born in Seattle in 1968 with Down syndrome. Coming to terms with that diagnosis was the toughest trial that Jim and Margaret had to face as a couple. Margaret put aside her career plans so that she could devote herself to providing the extra help that Dennis was going to need. When Dennis was still a baby, their older son, Eric, was enrolled in a preschool at the Developmental Psychology Lab on the UW campus. As Margaret was picking Eric up from preschool one day, she observed a special program in the building for children with developmental delay and she decided to enroll Dennis in it early. That is when Val Dmitriev, who taught a preschool class and also worked in the special program, spotted Dennis in a carrier on his mother's back, his legs in casts and his head drooping to one side. Dmitriev explained her ideas about starting intervention during infancy and she asked Margaret if she would like her child to participate in an infant stimulation program. At that point Margaret lifted Dennis out of the carrier, handed him to Dmitriev, and said, "Here." That was the beginning of the Down Syndrome Program at the UW. Margaret and Eric stayed an extra hour each day while Dmitriev applied her recently learned principles of behavior to helping Dennis meet developmental milestones. Dennis made remarkable progress and Dmitriev produced a movie titled, "The Operant Conditioning of a Down Syndrome Infant," which starred Dennis. Dennis's pediatrician was so impressed with his progress that he encouraged his pediatric colleagues in Seattle to refer their infant patients with Down syndrome to Dmitriev.

By the time Dennis was two and a half years old, Dmitriev's work with toddlers had expanded to include eleven children, and she was receiving federal funding to start a Down syndrome preschool at UW in January 1971. As a preschooler in her program, Dennis continued to inspire innovations that became standard practice. He was the first to learn to read and the first to use sign language. The first words that he spoke were the words that he read and signed. Soon all the children in his class were reading, and those who were not verbal or who were hard to understand were signing. Patricia Oelwein, his teacher, remembers it being "a very, very exciting time. The children showed us just how remarkable they could be, and Dennis led the way."[10]

As Dennis approached adulthood, he needed more social interaction than Jim and Margaret were able to offer him at home. After exploring the various possibilities for group living arrangements, they arranged for him to live in a community called New Hope Farms in Goldendale, WA, where he resided happily until his death due to diabetes in 2007. In 1995, when New Hope Farms was on the verge of closure because of staffing problems and financial difficulties, Jim responded to their call for help. Under his leadership as chair of the board of trustees, the home was able to stabilize the staff positions and to develop a more sustainable business plan. Jim and Margaret also played an important role in the community of parents who had children living at New Hope Farms.

Jim and Margaret's years in Seattle were punctuated by sabbaticals, which took them to distant places. Their most memorable sabbatical experience was in 1973 and 1974, when they lived in Cambridge, England, hosted by Michael McIntyre, Adrian Gill, and colleagues at the Department of Applied Mathematics and Theoretical Physics at the University of Cambridge. Other sabbatical trips included three-month visits to Florida State University in Tallahassee in 1971, the National Center for Atmospheric Research in Boulder in 1973, and the Commonwealth Scientific and Industrial Research Organization in Melbourne, Australia, in 1979. By the time their boys started high school, they had been educated in four different school districts on three different continents.

Friendships

Jim kept in touch with high school and college friends throughout his life. Like his mother, he was an inveterate letter writer. Up until the 1980s his letters were scrawled in his distinctive, backward-tilted, half-printed script, not a work of art but clearly legible. Jim attributed the reversed tilt to his left-handedness. His long letters always expressed genuine interest in and concern for the person to whom he was writing, and they often

Jim and Son Eric climbing in the Cascades.
(Photo courtesy of Dennis L. Hartmann.)

contained candid comments reflecting his own outlook on life. For example, in a letter to Richard Lindzen in 1992, Jim acknowledged that Lindzen had made some good points in his critique of the politics of global warming and went on to write:

> *In the end, though, I continue to send money to the Sierra Club for the parochial reason that they do effectively fight for the preservation of our old growth forests—which I want for hiking territory—(I could care less about the spotted owl.) I've noticed that in our political world, desirable results are often obtained through foolish arguments.*

Jim's friendships were inextricably linked to shared physical exercise of various sorts, often in hostile environments: running, hiking, skiing, and later in life, biking. He began running at lunchtime with faculty colleagues Richard Reed and Peter Hobbs during his first year at UW and continued that practice for nearly forty years with a wide range of running partners, friends and associates from within and outside of the department. Jim rarely ran alone. With friends he climbed Mt. Rainier and a selection of other high peaks in Washington and Colorado, and he ran in numerous marathons, many of them in the rain. On their legendary bicycle trips, he and his "biking buddies," as he referred to them, endured downpours, hailstorms, swarms of mosquitoes, and asphalt-softening heat. In all but the most arduous of exploits, maintaining a spirited, good-humored conversation with his buddies was as important to him as the activity itself. In the last summer of his life, he enjoyed an idyllic walk across England with three close friends on the Wainwright (Coast-to-Coast) Trail.[11]

Jim retained his physical fitness, his mental acuity, and his youthful demeanor as he aged, but his doctors were becoming increasingly concerned that he was at risk of a heart attack or stroke because of a defective heart valve. Treatment would have entailed major surgery with risks of its own. He elected to defer treatment and hope for the best. He died March 3, 2004, two weeks after he collapsed while exercising with his running buddies at lunchtime on the track at the UW Husky Stadium.

ACKNOWLEDGEMENTS

This memoir is based on conversations with Jim's wife, Margaret, material compiled by Dennis Hartmann and Peter Webster for the James R. Holton Memorial Symposium on January 30, 2006, at the Annual Meeting of the American Meteorological Society, and contributions from Richard Lindzen, James Anderson, Joseph Pedlosky, John Young, John Gille, Peter Haynes, Roland Madden, Joan Alexander, Clifford Mass, and Jim and Margaret's friend, Patricia Oelwein.

photo and graphics credits

p. 6: from Wallace, J. M., and V. E. Kousky 1968. Observational evidence of Kelvin waves in the tropical stratosphere. *J. Atmos. Sci.* 25: 900-907.

p. 9: Courtesy of Roland A. Madden

p. 11: from J. R. Holton 1986 "Meridional Distribution of Stratospheric Trace Constituents" *J. Atmos. Sci.* 43: 1238-1242.

p. 13: from J. R. Holton et al.1995 "Dynamical aspects of stratosphere-troposphere exchange." *Reviews of Geophysics* 33: 403-439.

NOTES

1. John Young recalls that Jim tried his hand at modeling the behavior of discrete idealized vortices on the beta plane using his project's newly acquired PDP computer.
2. Jim's belief that both thermal and frictional boundary layers need to be considered has been borne out in recent simulations with an atmospheric general circulation model (Jiang et al. 2007).
3. At least half seriously, Michael McIntyre draws an analogy between this paper and the Michelson-Morley experiment in the sense that it falsifies a preexisting hypothesis (the notion suggested by my PhD thesis that the downward propagation of successive easterly and westerly wind regimes in the QBO is due to advection), thus assuring that the QBO must be wave-driven.
4. The most notable exception is Jim's paper co-authored with Peter Webster on energy dispersion across the upper tropospheric westerly wave duct that prevails over the eastern equatorial Pacific during the boreal winter.
5. To mark the fiftieth anniversary of Brewer's seminal paper on the transport of water vapor and the seventieth anniversary of Dobson's paper on the transport of ozone), a three-day workshop on the Brewer-Dobson Circulation was held at the University of Oxford where Brewer worked from 1948 to 1962 and Dobson from 1920 to 1956. Jim and Alan Brewer were the keynote speakers at the event. Jim was excited to have opportunity to become acquainted with Brewer, who was still active at the time.
6. Peter Haynes had previously been a postdoc at the University of Washington, where he interacted extensively with Jim. Michael McIntyre had been one of Jim's principal hosts when he was on sabbatical at Department of Applied Mathematics and Theoretical Physics in Cambridge in 1973–1974, and they became close friends.
7. Jim's support of younger scientists extended beyond his students and his departmental colleagues. For example, Brian Hoskins recalls, "When I first met Jim during the 1970s, I looked on him as one of the tops in the subject and myself as a new boy on the block. I was then amazed how friendly and approachable he was."
8. While living in Stockholm in 1964–1965, Jim and Margaret rented the apartment of oceanographer Claes Rooth, who had just moved to the United States.
9. In their dining room hung large paintings of their sons, Eric and Dennis, by Muriel Dyer, the mother of Tim Palmer's wife, Gill, whom they met during Palmer's postdoctoral year in Seattle during 1981–1982.

10. Patricia Oelwein's book, *Teaching Reading to Children with Down Syndrome*, features a photo of Dennis in the foreword. It has rivaled Jim's textbook in terms of number of sales, and she has provided training in the method in fifteen countries.
11. He was joined by atmospheric scientists Peter Webster and Michael Fritsch and running buddy Robert Ingalls.

STUDENTS

PhD

Baldwin, Mark Phillip 1987,

Beres, Yadwiga, PhD., 2002

Bliss, Vernon LeRoy 1980

Chang, Chih-Pei 1972

Choi, Woo Kap 1990

Colton, Donald Erwin 1973

Dunkerton, Timothy James 1980

Gettelman, Andrew 1999

Hess, Peter George 1988

Iredell, Mark D. 1988

Jou, Ben Jonq-Dao 1985

Mass, Clifford Fred 1978

Meyer, Walter Davidson 1969

Mote, Philip Whitfield 1994

Mullendore, Gretchen 2003

O'Sullivan, Donal Joseph 1986

Pfister, Leonhard 1977

Potter, Brian Edward 1994

Ray, Eric Andrew 1997

Rosenlof, Karen Hepler 1994

Rosmond, Thomas Evans 1972

Sayler, Bentley J. 1996

Yulaeva, Elena 1997

Zhu, Xiaoli 1990

Zhu, Xun 1987

MS

Andersen, Roger Hollis 1973

Eichel berger, Scott 2001

Hess, Peter George 1983

Nappo, Carmen Joseph Jr 1968

Ray, Eric Andrew 1993

Sayler, Bentley J. 1993

Tan, Hsiu-Chi 1981

POSTDOCTORAL RESEARCH ASSOCIATES

Alan O'Neill (October 1979–October 1980)

Tim Dunkerton (September 1980–December 1981)

Tim Palmer (September 1981–August 1982)

William Wehrbein (September 1977–June 1981)

Neal Butchart (December 1982–December 1984)

Peter Haynes (1984–1985)

Walter Robinson (February 1985–August 1987)

Shigeo Yoden (October 1985–September 1987)

John Austin (March 1988–February 1990)

Robert Fovell (September 1988–December 1990)

Masaaki Takahashi (June 1989–June 1991)

Ping Chen (January 1992–April 1994)

Pablo Canziani (September 1992–April 1994)

Joan Alexander (September 1992–August 1994)

Christof Appenzeller (September 1995–September 1996)

James Kettleborough (January 1997–December 1998)

Takeshi Horinuchi (April 1997–April 1999)

Stephen Griffiths (January 2003–December 2005)

Stefan Fueglistaler (May 2003–October 2005)

Warwick Norton (November 2003–January 2005)

REFERENCES

Arnt Eliassen (1952). Slow thermally or frictionally controlled meridional circulations in a circular vortex. *Astrophys. Norv*. 5:50.

Harvey P. Greenspan and Louis N. Howard (1963). On a time dependent motion of a rotating fluid. *J. Fluid Mech*. 17:385–404.

Peter H. Haynes, Crispin J. Marks, Michael E. McIntyre, Theodore G. Shepherd, and Keith P. Shine (1991). On the "downward control" of extratropical diabatic circulations by eddy-induced mean zonal forces. *J. Atmos. Sci*. 48:651–678.

Xianan Jiang, Ngar-Cheung Lau, Isaac M. Held, and Jeff J. Ploshay (2007). Mechanisms of the Great Plains low-level jet as simulated in an AGCM. *J. Atmos. Sci*. 64:532–547.

Richard S. Lindzen (1967). Planetary waves on beta-planes. *Mon. Wea. Rev*. 95:441–451.

Richard S. Lindzen (1981). Turbulence and stress owing to gravity wave and tidal breakdown. *J. Geophys Res*. 86:9707–9714.

Taroh Matsuno (1966). Quasi-geostrophic motions in the equatorial area. *J. Met. Soc. Japan*. 44:25–43.

Taroh Matsuno (1971). A dynamical model of the stratospheric sudden warming. *J. Atmos. Sci*. 28:1479–1494.

R. Alan Plumb and Angus David McEwan (1979). The instability of a forced standing wave in a viscous stratified fluid: a laboratory analog of the quasi-biennial oscillation. *J. Atmos. Sci*. 35:1827–1838.

John M. Wallace and Vernon E. Kousky (1968). Observational evidence of Kelvin waves in the tropical stratosphere. *J. Atmos. Sci*. 25:900–907.

Michio Yanai and T. Maruyama (1966). Stratospheric wave disturbances propagating over the equatorial Pacific. *J. Met. Soc. Japan*. 44:291–294.

SELECTED BIBLIOGRAPHY

1965 The influence of viscous boundary layers on transient motions in a stratified rotating fluid: Part I. *J. Atmos. Sci.* 22: 402–411.

The influence of viscous boundary layers on transient motions in a stratified rotating fluid: Part II. *J. Atmos. Sci.* 22: 535–540.

1968 With J. M. Wallace. A diagnostic numerical model of the quasi-biennial oscillation. *J. Atmos. Sci*. 25: 280–292.

With R. S. Lindzen. A note on 'Kelvin' waves in the atmosphere. *Mon. Wea. Rev*. 96: 385–386.

With J. A. Businger. Ice on Venus: Can it exist? *Science* 161: 915–916.

With R. S. Lindzen. Theory of the quasi-biennial oscillation. *J. Atmos. Sci*. 25: 1095–1107.

1972 With R. S. Lindzen, 1972: An updated theory for the quasi-biennial cycle of the tropical stratosphere. *J. Atmos. Sci*. 29: 1076–1080.

An Introduction to Dynamic Meteorology. New York: Academic Press.

1976 With C. F. Mass. Stratospheric vacillation cycles. *J. Atmos. Sci*. 33: 2218–2225.

1980 With H-C. Tan. The influence of the equatorial quasi-biennial oscillation on the global circulation at 50 mb. *J. Atmos. Sci*. 37: 2200–2208.

1982 With P. J. Webster. Cross equatorial response to middle-latitude forcing in a zonally varying basic state. *J. Atmos. Sci*. 39: 722–733.

The role of gravity wave induced drag and diffusion in the momentum budget of the mesosphere. *J. Atmos. Sci*. 39: 791–799.

1983 The influence of gravity wave breaking on the general circulation of the middle atmosphere. *J. Atmos. Sci*. 40: 2497–2507.

1986 Meridional Distribution of Stratospheric Trace Constituents. *J. Atmos Sci.* 43: 1238–1241.

1987 With D. G. Andrews and C. B. Leovy. *Middle Atmosphere Dynamics* New York: Academic Press.

1990 On the global exchange of mass between the stratosphere and troposphere. *J. Atmos. Sci.* 47: 392–395.

1992 With R.D. Fovell and D. Durran. Numerical simulations of convectively generated gravity waves in the stratosphere. *J. Atmos. Sci*. 49: 1427–1442.

1993 With K. H. Rosenlof. Estimates of the stratospheric residual circulation using the downward control principle. *J. Geophys. Res*. 10: 465–479.

1994 With E. Yulaeva and J. M. Wallace. On the cause of the annual cycle in tropical lower stratospheric temperatures. *J. Atmos. Sci.* 51: 169–174.

1995 With P. H. Haynes, M. E. McIntyre, A.R. Douglass, R.B. Rood, and L. Pfister. Stratosphere-troposphere exchange. *Reviews of Geophysics*. 33: 403–439.

1996 With P. W. Mote, et al. An atmospheric tape-recorder: the imprint of tropical tropopause temperatures on stratospheric water vapor. *J. Geophys. Res.* 101: 3989–4006.

2001 With C. Piani, C. D. Durran, and M. J. Alexander. A numerical study of three dimensional gravity waves triggered by deep tropical convection and their role in the dynamics of the QBO. *J. Atmos. Sci.* 57: 3689–3702.

With A. Gettelman. Horizontal transport and the dehydration of the stratosphere. *Geophys. Res. Lett.* 28: 2799–2802.

2003 With J. A. Curry and J. A. Pyle (Eds.). *Encyclopedia of Atmospheric Sciences.* London: Academic Press.

Published since 1877, *Biographical Memoirs* are brief biographies of deceased National Academy of Sciences members, written by those who knew them or their work. These biographies provide personal and scholarly views of America's most distinguished researchers and a biographical history of U.S. science. *Biographical Memoirs a*re freely available online at www.nasonline.org/memoirs.