

MEETING SUMMARIES

JIM ANGELL'S CONTRIBUTIONS TO METEOROLOGY

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Over the past half century, Jim Angell has made pioneering contributions to meteorology, especially to our understanding of climate variability, stratospheric processes, and the ozone layer. On 4 November 2003, many colleagues and friends gathered at the National Oceanic and Atmospheric Administration (NOAA) Science Center in Silver Spring, Maryland, for a 1-day symposium reviewing and honoring Jim's career achievements and celebrating his 80th birthday (which was 2 November). This article highlights some of Jim's contributions, both as reviewed during the symposium, and as captured in poems composed in his honor and recited at a birthday dinner celebration.¹ Jim's memories are interspersed in italics. More information about Jim Angell and the Angell Symposium, including photos, some presentations, his publications list, and more poems, can be found on the Angell Symposium Web site (www.arl.noaa.gov/ss/climate/AngellSymposium.html).

Though as a child I was fascinated with the weather, especially snowstorms, throughout high school and even into college I never thought to make a career of

THE JIM ANGELL SYMPOSIUM

What: Friends and colleagues of Jim Angell gather to review his achievements in celebration of his 80th birthday
When: 4 Nov 2003
Where: NOAA Science Center, Silver Spring, Maryland

the weather, or indeed of being a scientist at all (my father was a sociologist). However, when we entered World War II and I learned that the army was training meteorologists, my early love came to the fore, and I volunteered for the army with the hope of getting into a meteorology program. Alas, I was too late, the army already having more than enough meteorologists. Despite this disappointment, I was still interested in the field of meteorology (though I have often wondered since whether that was actually the best career choice for me), and after my army discharge got a bachelor's degree in mathematics at the University of Michigan under the three-semester-a-year program and joined the Weather Bureau in Albuquerque, ostensibly as a Forecaster-in-Training but actually as an Observer.

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Thus, I started my meteorological career on the bottom rung, so to speak, which was probably good. However, after a seemingly endless number of midnight shifts, I decided this was a hard way to get ahead in the field and went to the University of California, Los Angeles (UCLA) where I got a master's degree in 1948 (having flunked the Oral the first time around).

After about two years as a Teaching Assistant in the undergraduate labs, I became a graduate-lab instructor under J. Bjerknes. It was there that I learned to be very precise in my work, but also very skeptical of things meteorological. Accordingly, one day in the laboratory, I questioned an aspect of his pet "unstable ridge" theory, which involved the air not being able to maintain gradient balance when rounding a sharp ridge at jet stream level, accelerating toward low pressure, and upon deceleration, "digging out" a trough to the east. Very unlike Bjerknes, who was the most gentle, and gentlemanly, person you could imagine, he responded (in front of the lab), "How dumb can you be?" which was pretty embarrassing but also taught me to be a little more circumspect.

I had what might be considered "lucky breaks" at UCLA. First, because I was in the Meteorology Office when the person they initially wanted for the job was not, I got the job working on a Weather Bureau objective forecasting scheme for the Los Angeles basin, which included an orientation trip back to Weather Bureau Headquarters in Washington D.C., where I met the personnel and made many useful contacts. Second, because I had just finished the Northern Hemisphere weather map analyses (up to 100 mb) used by Bjerknes and Yale Mintz in their study of meridional momentum flux, I was available to work on a Naval Research Laboratory-supported study of John Mastenbrook's constant level balloon (transosonde) trajectories. Under advisor Morris Neiburger, this made for an almost perfect Ph.D. thesis because the data were unique, hardly anyone else had access to them, and I was plumbing the unknown with an advisor who was really interested in the topic. After many months of being the earliest car in the parking lot, the 200-page thesis was accepted at the end of 1956.

Along the way, I experienced an amazing example of the power of intuition when, sitting in on Professor J. Holmboe's difficult Advanced Dynamics class because my Ph.D. Orals were coming up, but not paying much attention to what was being presented (I had passed the course earlier by dint of pure memorization of the streams of vector equations he wrote across the blackboard), I suddenly thought one evening it could be very embarrassing if he asked me a question and I couldn't answer. So I buckled down to study the more recent material, and incredibly, the very next

day for the first time ever, he turned to me and asked a question I could not possibly have answered if I had not studied the evening before. Holmboe responded to my answer with, "That is exactly right." The class was incredulous, and I sat there smugly thinking, "There is my Ph.D., right there."

After receiving his Ph.D., Jim was offered a position in the Special Projects Branch of the U.S. Weather Bureau (now NOAA's National Weather Service) by Lester Machta. That branch evolved into the NOAA Air Resources Laboratory (ARL), where Jim has spent his entire career. Having retired from federal service in the spring of 2000, Jim continues to work on climate and ozone research at NOAA/ARL in Silver Spring, Maryland.

There was a lot of difference between the Weather Bureau of 1956 and the NOAA of today. At that time, the Central Office was not in a very nice section of town, and the handful of people in the Special Projects Branch were housed in the stables of the old Spanish Embassy along with the rats and the fumes from cars idling in the alley. Since there were only a few hundred people in the whole Central Office, one got to know them all after a couple of years. It was a very homey place with lots of camaraderie, hardly the situation today.

The Chief of the Bureau had been for many years Francis Reichelderfer, a former naval officer (sound familiar?). He was austere, but a gentleman to the core, and quite friendly when one got to know him, as most of the Bureau did. I ran into him one day at the National Zoo, where he had come with his wife (a very gracious lady) and I with four young (and not so gracious) children. I was impressed when he remembered my name. It turned out he knew my grandfather, who was a Michigan judge, and he became surprisingly interested in me and my career. I began to be invited to high-level meetings in his office as an "observer," and heard many interesting things such as "how we must get behind the curve" from an air force general (yes, even then). I had the sense he was interested in me joining the management ranks of the Bureau, which I had no interest in whatsoever. My association with Reichelderfer ended when I went to the Met Office in England for a year, since he retired soon after I returned.

GROUNDING IN OBSERVATIONS, TAKEN ALOFT BY BALLOONS. "The work being done in climate today rests on the early efforts of scientists such as Jim," said Richard D. Rosen, NOAA Assistant

Administrator for Oceanic and Atmospheric Research, in remarks welcoming participants to NOAA. Jerry Mahlman [former Director of NOAA's Geophysical Fluid Dynamics Laboratory, now at the National Center for Atmospheric Research (NCAR)] gave an overview of Jim's career, noting his strong focus on analysis of observations, particularly from balloon-borne instruments, to address emerging scientific challenges, ranging from the transport and dispersion of air pollution to long-term climate change and stratospheric ozone depletion. Jerry noted Jim's "passion for observations with a purpose," remarking that "he carefully examined the data, acknowledged its flaws, and decided whether or not he was seeing new physical insights into atmospheric behavior."

GLOBAL TEMPERATURE MONITORING AND RESEARCH. Jim set out to monitor the variability and trends of atmospheric temperature three decades ago, when he identified a global network of 63 radiosonde stations and a methodology of analysis of seasonal anomalies of zonal, hemispheric, and global temperature at the surface and in different atmospheric layers in a seminal paper (Angell and Korshover 1975). The datasets he developed covered the period from the 1958 expansion of the radiosonde network for the International Geophysical Year to the near present. Angell extended and analyzed data from this network to identify numerous climate signals, from short-term seasonal and interannual variations to long-term trends. The network continues to provide meaningful results, although in a recent paper (Angell 2003), Jim removed nine stations with anomalous trends from the record.

In addition to his work with radiosonde data, Jim was among the first to use data from meteorological rocketsondes to explore temperature variations at higher stratospheric altitudes (Angell 1987). His comprehensive explorations of temperature observations often made insightful and original connections with related parameters, including early stratospheric water vapor data (Angell and Korshover 1976), sea surface temperature and pressure observations (Angell and Korshover 1984; Angell 2000), Indian monsoon rainfall data (Elliott and Angell 1987), sunshine duration and cloudiness observations (Angell 1990), atmospheric carbon dioxide concentrations, and, most notably, stratospheric ozone and ozone profile data (Angell and Korshover 1964; Angell 1980).

Dubbing Jim "The Monitoring Expert," V. Ramaswamy [NOAA/Geophysical Fluid Dynamics Laboratory (GFDL)] noted five hallmarks of his career: incessant research, breadth of exploration,

Poems, written in honor of Jim Angell at the symposium

Clickety clackety
hail NOAA's Angell.
Troposphere's guardian,
stratosphere's knight.
Environmentally
data collecting, but
always concerned about
getting it right.
—S. Fred Singer

There once was a fine lad named James
who found that balloons weren't just games
he pulled out their data
'cause sooner or later
they would bring him his multiple fames.
—Jerry Mahlman

Jim with his network of sites, 63,
studies temperature change in the atmosphere-free.
He calmly considers (without any panic)
effects on the change of eruptions volcanic.
His ongoing study of T trends, decadal,
will continue no doubt as long as he's able.
His service to science is quite an example
so lets give him credit and LOUD APPLAUSE ample.
—Becky Ross

Jim measured the polar vortex as it would grow,
though his pencil and calculator made him a little slow,
a true pioneer in the field,
such insights his statistics would yield,
and he took us where no one else knew where to go.
Jim studied volcanoes, the vortex and QBO,
he put on quite a scientific show,
a gentlemen is he,
a most pleasant person with which to be,
and from his friends, a gracious thanks, we now bestow!
—John Lanzante

Our friend Jim has a strong reputation
for analysis of data and not speculation
east winds changing to west
were the ones he knew best
he called it the quasi-biennial oscillation.
—Bill Randel

meticulous analyses, prompt reports, and exemplary collegiality. Ram congratulated and thanked him for his contributions to several major assessment activities, including the Stratospheric Processes and Their Role in Climate (SPARC) Temperature Trends and Ozone Assessment Panels, the World Meteorological Organization/United Nations Environment Programme (WMO/UNEP) Scientific Assessments of the Ozone Layer, and the Intergovernmental Panel

on Climate Change assessment reports.

OZONE STUDIES. Jennifer Logan (Harvard University) traced the course of Jim's ozone investigations. His pioneering analyses documented three dominant influences on inter-annual variability of stratospheric ozone: the quasi-biennial oscillation (QBO), the solar cycle, and major volcanic eruptions. Jim conducted the first comprehensive analysis of the QBO in column ozone (Fig. 1; Angell and Korshover 1964). He turned his attention back to ozone in the early 1970s when concerns were first raised about ozone depletion. In a landmark paper (Angell and Korshover 1973), he 1) showed the "quasi-biennial fluctuations" in ozone as a function of latitude and their relationship to the winds; 2) provided a careful analysis of the relationship between ozone and sunspot number, a controversial subject at the time; 3) analyzed long-term trends in column ozone, which was increasing in the 1960s; and 4) found no evidence for a reduction in ozone resulting from nitric oxide produced by nuclear bomb tests.

The biggest disappointment of my scientific career was not being the one to first detect the Antarctic Ozone Hole phenomenon. Since at the time I was one of the very few people in the world monitoring total ozone on a near-real time basis, I should have done so. The British paper announcing the discovery was not published until early 1985, yet already in the Antarctic spring of 1980 the total ozone values at the South Pole station of Amundsen-Scott were 15% below normal. The reason for not taking more notice of the anomalously low values was that the total ozone measurements at the station had been plagued with problems due to the change in observing crew every year. Consequently, as in the case of the National Aeronautics and Space Administration (NASA) satellite data, I simply did not believe the very low values. There was no way to confirm the low measurements because Amundsen-Scott was the only American total ozone station in Antarctica, and the British Antarctic stations were not reporting their data to the World Ozone Data Center in Toronto at

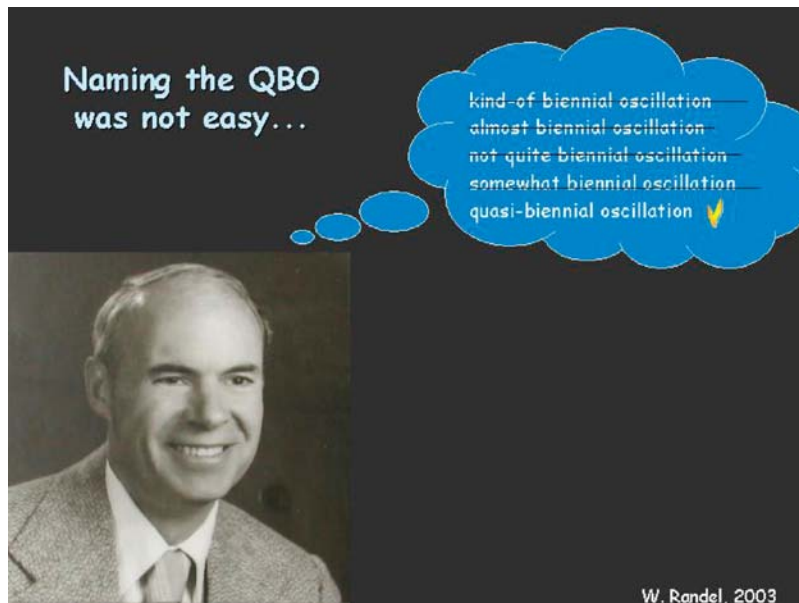


Fig. 1. Jim Angell coined the term quasi-biennial oscillation in a 1964 paper (Angell and Korshover 1964).

the time. Hence, it was a missed opportunity to become better known.

Jim's search for trends in ozone later expanded to include the first analyses of trends in the Umkehr and ozonesonde data, after models predicted the vertical profile of ozone loss. Recurring themes in his analyses of ozone over a 35-yr period are examination of the relationship of ozone to the QBO (Angell and Korshover 1973), solar cycle (Angell 1989), and volcanic eruptions (Angell 1997). His concern over data quality is another constant, as is his search for consistency among the various ozone records from Dobson, Umkehr, and sondes. He laid the groundwork for later work on ozone trends as statisticians entered the field and as satellite data became available; the QBO and solar cycle are now included as explanatory variables in all regression estimates of ozone trends.

"It is hoped that this discussion has directed the reader's attention to the complex nature of the total-ozone variation, both in time and space. Because of uncertainty concerning the raison-d'être of much of the variation, it is extremely difficult at this time to evaluate accurately man-made influences on ozone amount. Consequently, when considering the possible effects of the supersonic transport on stratospheric ozone, for example, we must be very careful that any changes noted reflect the human influence and would not have occurred naturally. For conscientious scientists, this may be the most difficult determination of all" (Angell and Korshover 1973).

DISCOVERY AND CHARACTERIZATION OF THE QUASI-BIENNIAL OSCILLATION. Bill Randel (NCAR) reviewed Jim's contributions to understanding the stratospheric QBO and noted that he was one of the first scientists to recognize its importance in global climate variability. His careful work with sparse datasets documented the global dynamical structure of the QBO and quantified its influence on a variety of meteorological fields and trace constituents. Angell and Korshover (1962, 1963) quickly followed the 1961 discovery of the biennial oscillation and characterized the propagation characteristics and global structure (including extension into middle latitudes).

In 1964, Angell and Korshover coined the term "quasi-biennial oscillation" and documented correlated variations in global temperatures, ozone, and tropopause height. Further original work included quantifying QBO variations in equatorial Kelvin waves and the QBO influence on global ozone variability, identifying QBO signals in the polar vortex (Angell and Korshover 1975; Angell 2001), and documenting effects on tropical tropopause temperatures and associations with stratospheric water vapor (Angell and Korshover 1976), both topics of current stratospheric water vapor investigations. Angell also documented QBO effects on tropospheric circulation patterns, in particular surface pressure variations in the "centers of action" (the North Atlantic and North Pacific subtropical high pressure systems; Angell and Korshover 1974); his pioneering results agree well with recent estimates of surface QBO effects. Over the past 40 years, Jim has contributed over 20 publications on the structure and global influence of the QBO.

Although we may have been the first to coin the term quasi-biennial oscillation, we certainly did not discover it. Lester Machta had noticed that the U2s flying up and down the west coast of the Americas, with the purpose of detecting Soviet nuclear tests, were reporting an annual variation in tropical zonal wind at a height of about 20 km. He reported this to Julius Korshover and myself, and we were puzzling over it when Dick Reed et al. published their famous 1961 paper. In any event, the U2 record was a relatively short one, and since the flights were basically at the same height, there would have been no way to detect the downward propagation of the oscillation, so any publication of ours along this line would have paled in relation to that of Reed et al.

VOLCANIC EFFECTS ON CLIMATE. Alan Robock (Rutgers University) reviewed the fundamen-

tally new understanding of the effects of volcanic eruptions on climate that resulted from Jim Angell's observational studies of temperature, winds, and ozone concentration in the atmosphere. During the past 50 years in which Jim studied, there were three major volcanic eruptions that produced massive stratospheric sulfate aerosol clouds: Agung in 1963, El Chichón in 1982, and Pinatubo in 1991. Jim used radiosonde and rocketsonde data to study the stratospheric temperature response following these large eruptions, accounting for the effects of the stratospheric quasi-biennial oscillation (Angell and Korshover 1983). In addition, Jim showed that six major eruptions, starting in 1780, produced a significant surface cooling for a couple of years.

Jim was also a pioneer in using the midtropospheric thickness (850–300 mb) obtained from radiosondes to measure tropospheric temperature changes. He was the first to notice that volcanic and El Niño influences have about the same amplitude and time scale and that to delineate the volcanic influence, the El Niño influence needed to be removed. He showed that after doing this, a clear volcanic cooling influence is evident (Angell 1988). Finally, Jim Angell recognized the impacts of volcanic eruptions on stratospheric ozone, associated with the increasing effect of heterogeneous chemistry on volcanic aerosols to liberate anthropogenic chlorine, which catalyzes ozone destruction (Angell 1997).

SOLAR SIGNALS IN CLIMATE. Karin Labitzke (Freie Universitaet Berlin) reviewed Jim's contributions to the identification of solar signals in ozone and climate, noting the controversies surrounding this topic. Recognizing the difficulty of separating solar, volcanic, and anthropogenic influences, all of which have comparable time scales of variability, Angell and Korshover (1973) noted with characteristic caution and care that ". . . evidence for a nearly 11-yr periodicity in total ozone directs one's attention toward the possibility of a relationship with sunspot number . . . we plan to reopen this particular Pandora's box . . ." As the length of data record grew, Angell confirmed and explored the details of the solar signal in ozone in subsequent publications in the 1970s, 1980s, and 1990s, in which he stressed the need to consider (and remove) the solar signal in evaluating long-term ozone trends (Angell 1989). More recently, Jim identified a possible solar influence in atmospheric circulation patterns, showing that the size of the North Polar vortex varies in association both with El Niño and with sunspot number (Angell 2001).

“The rationale for this paper is the belief, nay certainty, that knowledge of past ‘natural’ variations is a prerequisite to detection and comprehension of possible future effects” (Angell 1980).

EL NIÑO–SOUTHERN OSCILLATION SIGNALS IN CLIMATE.

Gene Rasmusson (University of Maryland) provided a comprehensive summary of Jim’s El Niño–Southern Oscillation (ENSO) research, initiated during a 1979–80 sabbatical year at the Commonwealth Scientific and Industrial Research Organisation (CSIRO) in Aspendale, Australia. His contributions are in three general areas of inquiry: 1) ENSO effects on Northern Hemisphere extratropical circulation, 2) the nature and stability of tropical Pacific–monsoon sector relationships, and 3) the impacts of ENSO warm events and volcanic eruptions on interannual tropospheric temperature variability and long-term temperature trends.

Soon after my arrival in Australia, I was given a copy of the Australian El Niño record. There was an amazing similarity between the variation in sea surface temperature (SST) in the eastern equatorial Pacific and the variation in tropical 850–300-mb temperature based on my 63-station radiosonde network. Unfortunately from a priority point of view, I did not immediately submit this straightforward finding for publication but rather examined other relations such as that of El Niño and Indian summer monsoon rainfall as well as U.S. surface temperatures, thus not only delaying the message but diluting it as well. Upon returning to the United States, I found that others had noted the relation, especially Mike Wallace and Gene Rasmusson. All three of us published nearly simultaneously. My only priority remained the El Niño–Indian rainfall relation, which has since deteriorated.

Angell’s work in collaboration with Bill Elliott 1) confirmed a high correlation between the Southern Oscillation index (SOI) and equatorial Pacific SST, 2) identified a two-season lag of tropical tropospheric temperature relative to equatorial Pacific SST, 3) identified a two-season lag of tropical Pacific SST relative to monsoon rainfall, and 4) identified a lag of the atmospheric carbon dioxide decrease relative to tropical Pacific SST, which increased from one season in the Tropics to three seasons in the polar regions (Angell 1981; Elliott and Angell 1987, 1988). The team also identified secular changes in the correlation of SST with SOI over the course of the twentieth cen-

tury. As Jim often notes with irony, “You need to know when to stop in correlation studies, because just when the correlations seem to be convincing, a longer data record results in the correlations falling to pieces.”

Jim identified ENSO effects on the Northern Hemisphere extratropical circulation, addressing both the four centers of action (Angell and Korshover 1984) and the 300-mb North Polar vortex (Angell 2001), suggesting a link between ENSO and the Arctic Oscillation. Jim also identified and quantified the atmospheric thermal pulse associated with an equatorial Pacific warming and its poleward spread, which allowed him to “back out” the ENSO warming and obtain the volcanic cooling contribution in cases where the two signals overlapped, that is, Agung (1963) and El Chichón (1982). Using this information, he later evaluated the contribution of ENSO warming to the long-term tropospheric temperature trend (Angell 2000).

ATMOSPHERIC TRANSPORT AND BOUNDARY LAYER RESEARCH.

Bruce Hicks, director of the NOAA/Air Resources Laboratory, discussed some of Jim’s early contributions to the understanding of atmospheric dispersion and transport, noting how relevant those studies remain today. Jim’s dissertation research with constant-pressure balloon (transsonde) data (Angell 1961) and his later work, with constant-volume balloons (the tetrahedral-shaped tetroons; Angell 1963) shed light on the long-range transport of air within the United States and across the Pacific Ocean from Japan. Jim conducted flights to study mesoscale urban and sea-breeze influences on atmospheric circulation, inertial oscillations in the atmosphere, vertical velocities in the atmospheric boundary layer, jet stream velocities, and lateral dispersion.

I spent the year 1961–62 working with Frank Pasquill of the British Meteorological Office in Bracknell. Frank was studying atmospheric diffusion at Cardington (where the British housed their big dirigible before its demise) by means of wind vanes attached to the cables of barrage balloons used by the British to help protect London during the Blitz and thus measuring the wind from the fixed-point, or Eulerian, point of view. The tetroons, moving basically with the air flow, measured the wind from the Lagrangian point of view. The ratio of the periodicity of the air at a fixed point, and following the air flow, is important in the estimation of atmospheric diffusion from the customary fixed-point data, and by flying the tetroon past the barrage balloon cables, this could be estimated. The most harrowing experience of my meteorological career was carrying the inflated

tetroon [42 in. (1.07 m) on a side] to its flight level of about 1000 m in an open wicker basket suspended beneath a barrage balloon, often in 30-kt (15.4 m s⁻¹) winds and near-freezing temperatures. The experiment was a great success, however, providing the first direct measure of the Langrangian–Eulerian ratio in the atmosphere.

Under the initial guidance of Don Pack, transponder-equipped tetroons were used routinely for about 30 years to estimate air flow over and above urban areas, including the movement of air pollution and the potential impact of radioactive releases. The tetroon-tracking radars (usually two), as well as most of the radar crew, were from our group in Idaho Falls, under the direction of Ray Dickson. I alternated between tetroon launch crew and radar crew and found the experiments both the most tiring (we usually worked 12-hour shifts) and yet exhilarating experiences of my life, a welcome relief from the office routine. The camaraderie one has under such conditions is a pleasure to behold. The apex of the tetroon experiments was in Los Angeles in 1973 when three triads of tetroons (nine balloons in all) were being tracked at one time by one radar, and with tetroons differentiated by transponders set at different frequencies. My task was to man a balky computer prone to jamming, and put on tape the range and azimuth and elevation angles of the nine tetroons as they flowed in from the radar console. With an individual experiment lasting about 8 h and little opportunity for a rest break, this may well have been the most grueling experience of my meteorological career. The other radar tracked helicopters with air quality instrumentation moving with the tetroon triads, thereby measuring the change in air quality following the air flow.

Another major disappointment has been the inability to keep the tetroon concept alive, partly because I considered it “my baby,” and partly because at one time it was considered a major breakthrough in the field of mesometeorology. However, the problems of long-distance tracking, continual snagging of power lines, and the worry of airplanes crashing while trying to avoid the tetroon on airport approach have not been surmounted. Fascinating tetroon trajectories showing the influence of the Denver urban heat island on nighttime air flow remain largely unanalyzed and unpublished.

In addition to all the topics mentioned above, Jim also made significant contributions to the study of climate and air quality in the United States. He developed climatologies of air stagnation, cloudiness, and sunshine duration (Angell 1990), each of which plays a role as meteorological controls on the forma-

tion and duration of air pollution episodes. For many years, he monitored variations and trends in cloudiness and sunshine, until changes in observing systems made continuation of the analyses impossible. With the availability of reanalysis data products, and in collaboration with Julian Wang, Angell’s stagnation datasets have been updated and used by NOAA’s National Weather Service as part of its suite of forecast products (Wang and Angell 1999).

SUMMARY. As Johnny Mercer wrote, “Fools rush in where angels fear to tread.” But as the symposium made clear, Jim Angell fearlessly treads just about everywhere in the atmospheric sciences. Carried along largely by data from balloons, he has analyzed everything from the earth’s surface to the stratosphere, examining atmospheric variations on hourly to centennial scales, drawing connections among elements as wide ranging as volcanoes and sunshine, temperature and ozone, and cloudiness and water vapor. Jim remains an active contributor to atmospheric science. As the icing on his 80th birthday cake proclaimed, “Long may the time series continue!” (Fig. 2).

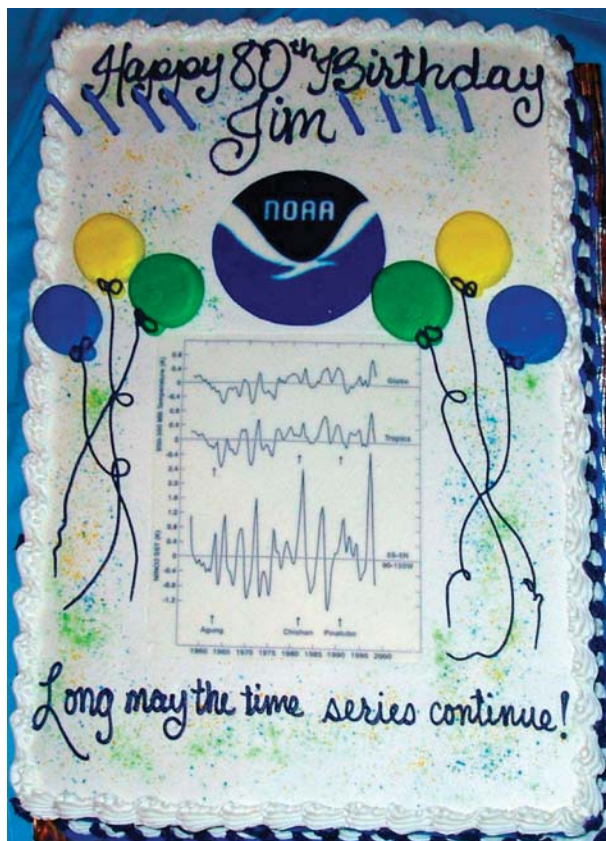


FIG. 2. Birthday cake for Jim Angell, whose analysis of balloon data has led to the creation of important datasets for climate and ozone research and monitoring.

The day after the Angell Symposium, SPARC sponsored a Workshop on “Understanding Seasonal Temperature Trends in the Stratosphere.” The workshop cochairs, Bill Randel and V. Ramaswamy, noted that, “Many of the details of the workshop trace their origin to Jim’s pioneering sonde analyses right from the early days.”

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