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WALKER, GILBERT THOMAS

(*b*. Rochdale, Lancashire, United Kingdom, 14 June 1868, *d*. Surrey, United Kingdom, 4 November 1958), *statistics, electrodynamics, meteorology*.

The Walker Circulation was named after the man who systematically studied, identified, and named the "Southern Oscillation." Credit also goes to him for linking the monsoon with other global meteorological features. Swings of the Southern Oscillation were later linked by Jacob Bjerknes with the El Niño phenomenon in the equatorial Pacific Ocean. Bjerknes coined the term "Walker Circulation" describing the east-west vertical circulation in the equatorial plane. Walker's name is also part of the statistical "Yule-Walker equations," where his contribution arose in conjunction with an attempt to develop a model for the Southern Oscillation phenomenon. His success in his work concerning the Southern Oscillation and teleconnections can be explained to some extent by his climatological expertise, but to a larger extent was a result of his expertise in mathematics and statistics, coupled with a dedicated effort to solve the problem of climate forecasting. Walker was elected a Fellow of the Royal Meteorological Society, Royal Astronomical Society, Royal Aeronautical Society, an Honorary Fellow of Imperial College, and a corresponding member of most of the meteorological societies of Europe.

Walker's Background. The eldest son and fourth child of a family of seven (some sources indicate that there were eight), Walker was born in Rochdale, Lancashire. Soon after, the family moved to Croydon in London, where his father Thomas, a civil engineer, became the borough's chief engineer. Thomas Walker was a pioneer of the use of concrete in the construction of dams. Gilbert was admitted to Whitgift School in 1876 and won a scholarship to St. Paul's School in 1881. At St. Paul's School, a famous nursery of university scholars, he showed his gift for mathematics and command of subjects in both the arts and sciences. He excelled in pure and applied mathematics and at the age of seventeen was awarded a prize for an essay on the dynamics of gyroscopes. In 1885 he gained an Exhibition Scholarship in mathematics at Trinity College, Cambridge University, and in 1899 graduated as Senior Wrangler as first man in the Mathematical Tripos. Two years later Walker was elected to a fellowship at Trinity College and was appointed a lecturer in mathematics in 1895.

At the turn of the twentieth century, Walker was awarded the Adams Prize for a paper on electromagnetic fields, receiving a personal commendation from Lord Kelvin. Walker was a "mathematician to his finger-tips" (Simpson, 1959) and was elected Fellow of the Royal Society in 1904 on the strength of his research in pure and applied mathematics, including "original work in dynamics and electromagnetism before ever he turned his thoughts to meteorology" (Normand, 1958). He also received the degree of ScD from Cambridge University the same year. Among his first papers (published in 1895) was one that dealt with the purely mathematical subject of the properties of Bessel functions (solutions to specific differential equations). Walker was recognized in London and Cambridge scholarly circles as a mathematician of high ability who had achieved high academic honors.

In addition to being a mathematician, Walker was also a painter of watercolors and an accomplished flutist, making changes to the instrument that are still retained in its modern form. He published several papers on the flight of birds, having made observations of them with a telescope at Simla in India. Walker was intrigued by the dynamics of projectiles and spinning tops, and his fascination with the throwing sticks of indigenous peoples led him to have a special interest in boomerangs. He was adroit in the practical throwing and worked out the mathematics of the flight of the boomerang, writing a book titled *Boomerangs* in 1902. As a result of these activities, his nickname at Cambridge was "Boomerang Walker." In addition, he was an expert ice skater, a mountaineer, and a naturalist.

Director of the Indian Meteorological Service and Research on World Weather. In 1903 Sir John Eliot, the second director of the India Meteorological Service who was about to retire, returned to England in search of a successor as chief meteorological reporter to the government of India and director-general of Indian observatories. Eliot proposed to the government of India that the Service should be reorganized with a small staff of trained British scientists at its headquarters. The government agreed and established a new meteorological department with a director-general of observatories and three imperial meteorologists. Walker seemed an unlikely candidate in 1904, at age thirty-six, to head India's growing meteorological service since he had no formal meteorological training, but he had many qualities that were suitable for this position. Eliot chose Walker because he saw the need for his successor to be someone with strong mathematical abilities. In 1903 Walker left academia, preparing for his new post by visiting meteorological services in Europe and the United States, and he became the director of the Indian Meteorological Department the next year. Eliot retired on the last day of 1903 and Walker took charge on the following day. Like Eliot before him, he pressed for the appointment of scientific assistants. Walker chose J. Patterson, J. H. Field, and G. C. Simpson for the first three imperial meteorologist positions. They all proved to be first-class meteorologists and they subsequently became directors of meteorological services in Canada, India, and United Kingdom, respectively.

The situation in India after the famines of 1877 and 1899 was desperate. Millions had died as a result of droughts that were caused by the failure of the monsoons. There was an urgent need to try to better understand the monsoon and the seasonal rains associated with this event. By the last decade of the nineteenth century, the forecasts were often completely incorrect, partly as a result of a lack of rigorous meteorological or statistical basis but also because of a change in the climate system that Eliot had documented in his 1904 paper. The scientific merit of any kind of weather forecasting was still a subject of great debate in Europe at the turn of the twentieth century, and the idea of the long-range forecasting of monsoons was thought by many to be an unachievable task. Scientific attempts to forecast the monsoon rains had started approximately twenty-five years before Walker's arrival in India, with official forecasts being issued beginning in 1886.

These efforts led to the tentative identification of predictor variables for the monsoon, including Himalayan snow cover and atmospheric pressure at other locations such as Australia and southern Africa. Other prior meteorological research also indicated that connections existed between the variations in atmospheric pressure at distant locations. Walker faced a situation in which no quantitative theory for forecasting the Indian monsoon was available with any agreed explanation of the general circulation. Using some of the earlier studies, Walker began his investigation to improve Indian monsoon forecasts using statistical techniques, having realized that the mathematical and dynamical meteorological theories of the time were insufficiently developed for the task.

Walker noticed the connection between statistics and the forecasting of the monsoon, and he became the first to apply statistical methods to the problem. He became a pioneer in the use of correlations and their statistical significance testing in meteorology (Normand, 1953). Walker made use of the techniques of correlation, regression, and harmonic analysis. The first of his many meteorological papers appeared in 1909, titled "Correlation in Seasonal Variation of Climate," and was published in the *Indian Meteorological Memoirs*. He realized that he could not tackle monsoon forecasting by means of mathematical analysis based upon established techniques, and he chose to use empirical techniques. Building on the works of Henry Blanford (the first director of the Indian Meteorological Department), Sir Norman Lockyer and his son William, H. H. Hildebrandsson, John Eliot, and others, he calculated statistical lag correlations between antecedent meteorological events within and outside India and the subsequent behavior of the Indian monsoon.

Walker obtained pressure, temperature, and rainfall records for the previous forty-year period. He also sought out time series of other parameters such as river flood stages, mountain snow pack depths, lake levels, and sunspot activity in an effort to identify the key relationships. Each weather record was averaged by season within each year and then grouped by season to form four time series for each variable at each station. He began extensive statistical studies of correlations with worldwide meteorological data to find a way of forecasting the yearly changes in the monsoon, which, he was convinced, were in some way tied to global weather. It was during this time, when World War I had taken away Walker's European staff and had drained him of most departmental resources for routine work, that he created a "human computer," using his Indian clerical staff to compile numerous tables of global correlation coefficients—numerical measures of the closeness of the relationship between any two variables.

Walker's mathematical talents were fundamental in these efforts. Where a method did not exist to handle a particular statistical problem, Walker invented one to suit the situation. Some of these methods were innovative for the time, and to statisticians, the name "Walker" is applied to the Yule-Walker recursion, a set of equations used to discern periods in time-series analysis. Walker employed Yule's modern notation for correlation, introduced in 1907, and attached probable error to statistics such as the correlations coefficient. Even though the network of meteorological observations was sparse, especially over the Pacific Ocean, Walker tried to decompose the variations in large-scale weather into a few dominant centers of action.

As he sorted through world weather records, he recognized some patterns of rainfall in South America and the associated changes in ocean temperatures. He also found a connection between barometric pressure readings at stations on the eastern and western sides of the Pacific (Tahiti and Darwin, Australia). Based on statistical techniques and through careful interpretation of correlation tables, Walker was able to identify three pressure oscillations. Walker noticed that when pressure rises in the east, it usually falls in the west, and vice versa, and he used the term "Southern Oscillation" to explain this changing pattern. Besides

Southern Oscillation, he named the seesaw in pressure between the Icelandic Low and Azores High the "North Atlantic Oscillation" (NAO), and the seesaw in the Pacific, the "North Pacific Oscillation" (NPO). Walker also stated that the Southern Oscillation is the predominant oscillation. He noted a tendency of the Southern Oscillation to persist for at least one or two seasons using his correlation tables, suggesting the potential for using the Southern Oscillation in forecasting world weather. These findings were all published in a series of papers titled "World Weather" in the mid-1920s to 1930s, when Walker had returned to England from his tenure at the Indian Meteorological Department. Thus, when Jacob Bjerknes later identified the atmospheric circulation related to the Southern Oscillation, he named it after Walker, stating that it "must be part of the larger 'Southern Oscillation' statistically defined by Sir Gilbert Walker" (Bjerknes, 1969).

Walker also realized that Asian monsoon seasons under certain barometric conditions were linked to drought in Australia, Indonesia, India, and parts of Africa, and mild winters in western Canada. He noted the relationship between oscillations of air pressure in the eastern and western Pacific and the monsoons in India, in addition to the rainfall in Africa. At this point, he was becoming convinced that all these events were part of the same phenomenon. Walker found that the random failure of the monsoon in India often coincides with low pressure over Tahiti, high pressure over Darwin, and calmer winds over the Pacific.

However, during and immediately following Walker's research career, the general reaction within the meteorological community to statistical methods was extreme skepticism. As a result, Walker was publicly criticized for suggesting that climatic conditions over such widely separated regions of the globe could be possibly linked. Others in the field questioned his writings, since they were skeptical of theories that gave a simple explanation of global weather patterns. The main conclusion that Walker presented in 1928 to the Royal Meteorological Society "is that there are three big swayings or surgings: a) The North Atlantic oscillation of pressure between Azores or Vienna on one hand and Iceland or Greenland on the other; b)

The North Pacific oscillation between the high pressure belt and the winter depression near the Aleutian Islands; and c) The southern oscillation, mainly between the South Pacific and the land areas round the Indian Ocean." He later added, "The southern oscillation is more far-reaching than the two oscillations just described, and as the effect of an abnormal season is propagated slowly, it may not appear at the other side of the earth until after an interval of six months or more." He thought this was the key to forecasting the monsoon and seasonal weather. "Examination by statistical methods has brought to light many relationships between seasonal conditions in different parts of the world, usually contemporary but often three months or more apart, and in the latter case knowledge of the earlier conditions in one region may give a rough idea of what will occur later on in the other." With this data he pointed to the possibility of long-range forecasting. Walker's studies held the promise of the prediction of events in regions other than India during a time when important and critical pieces of data were not available. For example, no data were available on the upper air or sea-surface temperatures. Under his directorship, the observatories issued several publications, including *Tables for the Reduction of Meteorological Observations* and *Meteorological Atlas of the Indian Seas and North Indian Ocean*.

Walker was unable, however, to translate his findings into a method that predicts the nature of the monsoons. He conceded that he could not prove his theory, but he predicted that whatever was causing the connection in weather patterns would become known once global meteorological data above ground level, which were not routinely observed at that time, were used in this study. Walker was right in his prediction, but his results were not utilized until 1960, when Jacob Bjerknes expressed an interest in studying the El Niño phenomenon. Bjerknes connected what Walker had found to what others were finding in the ocean and explained the global effects of the El Niño/Southern Oscillation, or ENSO.

Imperial College of Science and Technology. Walker was knighted by the king of England on his retirement in 1924 and became Sir Gilbert Walker, primarily for his accomplishments in directing the Indian Meteorological Department. He then became a professor of meteorology at the Imperial College of Science and Technology, University of London, succeeding Sir Napier Shaw. He not only continued his studies of world weather but also was involved in experimental physics, turning his attention to laboratory studies of convection in unstable fluids, with particular reference to the formation of clouds. Walker, along with his students, studied turbulence and focused on the cellular structure of an unstable fluid. In laboratory experiments, they were able to obtain an array of cellular forms such as polygons and transverse and longitudinal vorticities. Walker retired from Imperial College in 1934, was involved in classified work on meteorological correlations over the Atlantic Ocean region during World War II, and lived in Cambridge until 1950. Thereafter, he did not settle in any one place but lived mostly in Surrey and Sussex.

Walker remained an active researcher after his retirement and continued to write papers on meteorological topics. He served as the editor of the *Quarterly Journal of the Royal Meteorological Society* from 1935 to 1941 and published several papers in this journal, the last in 1947. He became a Fellow of the Royal Society of London in 1905 and served as the president of the Royal Meteorological Society in 1926 and 1927. An Honorary Fellow of Imperial College and a Fellow of the Royal Astronomical Society, he was a corresponding member of most of the meteorological societies of Europe.

Walker married May Constance Carter in 1908 and they had a son and a daughter. May died in 1955. He died at the age of ninety at Coulsdon, Surrey, on 4 November 1958.

In 2001 the Indian Meteorological Society instituted the Sir Gilbert Walker Gold Medal to be presented biennially to an eminent Indian or international scientist recognized in the field of monsoon studies. On 2 November 2006, the University of Reading in the United Kingdom launched the Walker Institute, named in memory of Sir Gilbert Thomas Walker.

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