A Chronology of Important Events in the History of Air Pollution Meteorology to 1970

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1. Introduction

In a recent historical survey, Griffiths (1977) has given a chronicle of items of meteorological importance. Because such a large field has been covered in Griffith's work, many items of special interest to the subfields of meteorology have, of necessity, been omitted. Stern (1977) has recently discussed the problems of writing a complete history of air pollution. This paper continues the initiative begun by Griffiths and Stern by compiling a chronicle of important events in the history of air pollution meteorology to 1970. The author has tried to be as unbiased as possible in the selection of items to be included in this list. The explosion of research and resulting papers in the last two decades, however, would have made many choices of recent work more subjective than perhaps history will view them. Hence, work since 1970 has not been included.

2. Early Period (2000 B.C. to A.D. 1772)

During the period before the Industrial Revolution, the groundwork for the science of meteorology was being laid. The important events in meteorology for this period have been given by Griffiths (1977). The birth of air pollution meteorology came during this period when it was recognized that the atmosphere could contain constituents that were obnoxious to health and comfort.

B.C.

*2000 ABRAHAM beheld the smoke of the country go up as the smoke of a furnace (Gen. 19: 28).

*900 KING TUKULTI of Egypt comments on the odor from asphalt mining in the town of Hit, 160 km west of Babylon.

*400 HIPPOCRATES associates the city with air pollution.

A.D.

1 STRABO's *Geography* notes industrial air pollution in Tyre.

61 *Seneca* comments, "As soon as I escaped from the oppresive atmosphere of the city [Rome], and from that awful odour of reeking kitchens which, when in use, pour forth a ruinous mess of steam and soot, I perceived at once that my health was mended." (1)[1]

852 LONDON is known for its foul air; EDINBURGH is called "Auld Reekie" in tribute to its smoking chimney pots.

1170 MAIMONIDES writes of Rome, "The relation between city air and country air may be compared to the relation between grossly contaminated, filthy air, and its clear, lucid counterpart." (2)

London's air pollution problems began during the reign of the Plantagenets with the introduction of bituminous coal into the city. This coal was called "sea coal" because it came from several large outcroppings that had been found along the NE coast and the Firth of Forth. By 1228, the practice of burning sea coal was fairly general among brewers and smiths, although the general population was not enthused. Agitation against London's smoky atmosphere was led by the nobility and clerics (Brimblecombe, 1976).

1257 QUEEN ELEANOR protests that Nottingham was too smoky and therefore uninhabitable. She departs for the cleaner air at Tutbury Castle, 40 km away.

1273 The FIRST SMOKE ABATEMENT LAW is enacted in London prohibiting use of coal as "prejudicial to health."

* An approximate date.
[1] Numbers in parentheses indicate sources listed in the Appendix.

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1285–88 Commissions are set up in LONDON to find a solution to the pollution problem.

1307 Commissions being unable to arrive at a satisfactory solution to the problem, EDWARD I prohibits the use of coal.

1377 Importance of CHIMNEY HEIGHT in pollutant dispersal is recognized; London regulates minimum heights. (3)

During the fifteenth and sixteenth centuries, depletion of Britain's forest raised the cost of wood for use as a fuel, leading to a switch to coal for domestic heating.

1542 JUAN RODRIQUEZ CABRILLO sails into Los Angeles Bay. Upon observing the smoke from Indian fires on shore rise and spread after hitting an elevated inversion, he names it "The Bay of Smokes."

1578 ELIZABETH I is annoyed by smoke from coal. An ordinance is passed prohibiting use of sea coal in London when Parliament is in session.

1661 JOHN EVELYN publishes *Fumifugium* or the "Inconvenience of Aer and Smoke of London Dissapated: Together with Some Remedies Humbly Proposed." This was the first serious work on air pollution. (4)

1662 JOHN GRAUNT publishes *Natural and Political Observations upon the Bills of Mortality*, a statistical examination of the health of an urban population that hypothesizes that much of London's public health problems are due to air pollution. (5)

1684 JOHN EVELYN comments, "London by reason of the excessive coldness of the air hindering the ascent of the smoke, was so filled with the fuliginous steam of sea coal, that one could hardly see across the street." (6)

1692 ROBERT BOYLE becomes aware of anthropogenic influence on atmospheric composition and suggests methods for analyzing trace components in the air. (7)

1699 JOHN EVELYN diary notes that the fog in London has become so thick as to be hazardous to the traveler. (6)

1750s Under stable conditions, LONDON's urban plume is observable at distances of 100 km. (8)

1750 J. HALL describes dispersion of toxic elements from the smelting and casting of metals and their effects on health. (9)

1772 Date marks the start of the INDUSTRIAL REVOLUTION.

B. WHITE in his preface to the 1772 edition of John Evelyn's *Fumifugium* proposes that commercial chimney stacks be built high enough to allow the effluent to rise above the surrounding buildings and disperse into the atmosphere and that bituminous coal be treated to remove all its smoke. (10)

3. Middle Period (1772–1918)

With the start of the Industrial Revolution, atmospheric pollution spread along with heavy industry across Europe and into North America. Again, Great Britain was among the first to recognize the problems of pollution and appointed a number of committees with some resulting, though ineffectual, legislation. The First Select Committee in 1819 made it clear that furnaces and engines could be built to greatly reduce or eliminate smoke and gases. The Second Select Committee in 1843 recommended a bill to deal with nuisances from furnaces and steam engines, but none was ever enacted. Two years later, the Third Select Committee reported that, with the present state of knowledge, no law could be applied to the fireplaces of common houses in London, which contribute greatly to the pollution of the atmosphere. In other words, nothing could be done about the pollution problem.

In 1873, London began to be plagued by a series of severe pollution episodes. Pollution was on the rise in other areas as well, resulting in passage of more comprehensive legislation both in Britain and North America.

During the period, the groundwork for the study of atmospheric turbulence and diffusion was laid.

1847 TOWNS IMPROVEMENT ACT was passed in Britain. Factory furnaces were to be constructed to consume smoke.

1853, 1856 PALMERSTON ACTS empower police to enforce British antismoke regulations.

1855 A. FICK proposes an equation for one-dimensional diffusion. (11)

1873–74 PERSISTENT FOGS laden with soot and sulfur dioxide plague LONDON through the winter. During the period 9–11 December 1873, a heavy pea-soup fog results in 650 excess deaths. (12)

1875 BRITISH PUBLIC HEALTH ACT mentions need for smoke abatement. All commercial furnaces are expected to consume as much as possible of their own smoke.

1880 LONDON experiences SEVERE SMOG on 26–29 January, and excess deaths are reported as 1176. (12)

1881 Chicago passes FIRST AMERICAN SMOKE ORDINANCE.

W. F. POLLOCK describes urban plume: "When the wind blew from Brighton, England across the English Channel," the urban smoke pall was "flung for miles like a black and dismal banner." (13)

1882 LONDON experiences SEVERE SMOG, and excess deaths are noted. (12)

1883 O. REYNOLDS publishes first significant paper on turbulence theory defining the critical Reynolds number for the transition from laminar to turbulent flow. (14)

1888 F. RUSSEL comments on the relationship between smoke and fog in London. (15)

1891 LONDON experiences SEVERE SMOG, and excess deaths are noted. (12)

1892 3-DAY LONDON SMOG results in 779 excess deaths. (12)

1894 REYNOLDS demonstrates the great apparent diffusivity and viscosity caused by turbulence. (16)

1897 HUY, MEUSE VALLEY, BELGIUM, hit by 3-DAY POISONOUS FOG.

1905 London physician HAROLD A. DES VEAUX denotes the combination of smoke and natural fog in urban air as "smog." (17)

1907 TORONTO passes antismoke control act.

CHICAGO requires permits for fuel-burning equipment.

1909 GLASGOW, SCOTLAND, experiences a 5-WEEK SMOG. Deaths are 2–4 times the presmog levels. (17)

1912–14 Studies at MELLON INSTITUTE of the University of Pittsburgh suggest air pollution is a health hazard.

1915 G. I. TAYLOR publishes "Eddy Motion in the Atmosphere," a paper in which the mixing length concept was introduced. (18)

1917 A. E. WELLS recognizes the importance of stack height and plume buoyancy in reducing ground-level concentration. (19)

4. Modern Period (1918–70)

a. Part 1: 1918–40

With the conclusion of World War I, the possibility of future gaseous warfare brought increased interest in atmospheric diffusion processes. Research was carried out by the Chemical Defense Establishment at Porton, England. Among the scientists involved in the study were L. F. Richardson, G. I. Taylor, and O. G. Sutton. Much of the research, however, was classified, and the results did not reach the literature until years later.

1918 J. S. OWENS publishes "The Measurement of Atmospheric Pollution." (20)

1920 L. F. RICHARDSON uses time-lapse photography to study smoke diffusion. (21)

1921 G. I. TAYLOR introduces the transfer theory for Fickian diffusion and the concept of homogeneous turbulence. (22)

1923 O. F. T. ROBERTS proposes solution for Fickian diffusion equation for instantaneous point source. (23)

1925 L. F. RICHARDSON and D. PROCTOR obtain data for dispersion over long distances from balloon releases. (24)

First comprehensive work on urban air pollution problems, *The Smoke Problem of Great Cities,* by W. N. SHAW and J. S. OWENS, is published. (25)

L. PRANDTL proposes mixing length based upon momentum transport theory. (26)

W. SCHMIDT theoretically treats three-dimensional diffusion problem. (27)

1926 L. F. RICHARDSON shows diffusion agents as eddies of a size comparable to the distance between particles. (28)

1930 LARGE-SCALE SMOG is reported in industrial MEUSE RIVER VALLEY in Belgium. Mixture of SO_2, H_2SO_4, HF, NO_2, and CO produce 60–80 excess deaths and 6000 are taken ill. (12)

1931 H. LETTAU models pollution patterns over KOENIGSBURG, F.R.G. (29)

1932 O. G. SUTTON develops a point source diffusion equation assuming a Gaussian distribution. (30)

BRITISH ELECTRICAL INDUSTRY committee recommends that stack heights be 2½ times the height of surrounding buildings. (31)

M. A. GIBLETT categorizes atmospheric turbulence based upon the character of the wind-direction trace and vertical temperature gradient—a forerunner of the Brookhaven classification of stability. (32)

1933 J. R. ASHWORTH publishes study of pollution in an industrial center, Manchester, England. (33)

1935 G. I. TAYLOR introduces the concept of homogeneous and isotropic turbulence. (34)

1936 C. H. BOSANQUET and J. L. PEARSON develop a point-source diffusion model using statistical concepts similar to those of G. I. Taylor and O. G. Sutton. (35)

U.S. PUBLIC HEALTH SERVICE publishes an early look at air pollution in American cities. (36)

1937 M. ROTSCHKE correlates typical diurnal variation of pollutants to periodic variability of atmospheric stability. (37)

1937–39 Major survey of atmospheric pollution in LEICESTER, ENGLAND. (38)

1938–40 Investigation of atmospheric pollution by heavy industry at TRAIL, B.C., CANADA. (39)

1940 R. H. SHERLOCK and E. A. STALKER define the critical windspeed for aerodynamic downwash from a stack. (40)

b. Part 2: 1941–60

Research in air pollution slowed during the hostilities of World War II. London, in fact, used smoke in the city to conceal targets from German bombers. After the war, the advent of the nuclear age brought another research push in atmospheric diffusion similar to that in the post–World War I years. The pollution problems in the cities continued to increase. London and Donora, Pa., experienced major pollution episodes. The development of electronic computers in the late 1940s brought with it advances in computer modeling of the atmosphere and the distribution of pollutants.

1941 A. N. KOLMOGOROV proposes the similarity hypothesis for small-scale turbulence, the basis for subsequent developments of theories on local structure of turbulence and its applications. (41, 42)

1943 First LOS ANGELES SMOG episode.

1945 E. W. HEWSON describes the fumigation process. (43)

1947 O. G. SUTTON extends his 1932 equation to elevated sources. (44)

1948 DONORA, PA., experiences pollution episode on 27–31 October. Several thousand people are taken ill and 20 deaths are attributed to episode. (45)

LONDON SMOG from 26 November to 1 December results in 700–800 excess deaths. (12)

SWEDEN establishes a precipitation chemistry network. (46)

1949 G. K. BATCHELOR renews work on the mathematical theories of turbulent diffusion in an extended discussion on diffusion in homogeneous turbulence. (47)

INTERNATIONAL JOINT COMMISSION appoints Technical Advisory Committee on Air Pollution for study of Detroit, Mich.–Windsor, Ont., pollution problem due to river traffic. (48)

Zadymlenic gorodov (Smoke in Cities) is published in Soviet Union. (49)

1950 C. H. BOSANQUET, W. F. CAREY, and E. M. HALTON publish first full-scale plume-rise study results. (50)

A. J. HAAGEN-SMIT of California Institute of Technology shows photochemical reactions are the source of Los Angeles smog. (51)

M. E. SMITH and I. A. SINGER of Brookhaven National Laboratory relate wind-trace type to plume dispersion patterns. (52, 53)

1952 Infamous LONDON KILLER SMOG occurs 5–9 December, and 4000 excess deaths due to high SO_2 (0.09–1.34 ppm) and suspended particulate (400–4500 $\mu g/m^3$) are reported. (12)

H. LETTAU studies diffusion in shear zone and introduces a shearing advection correction to K-Theory diffusion. (54)

1952–54 Precipitation chemistry network is extended across SCANDINAVIA, marking the beginning of interest in acid rainfall. (46)

1953 *Micrometeorology* by O. G. SUTTON is published. (55)

J. Z. HOLLAND proposes plume-rise equation incorporating plume buoyancy effects. (56)

A. C. CHAMBERLAIN incorporates wet and dry deposition into O. G. Sutton diffusion model. His washout coefficient for particulate is based upon rainfall rate and raindrop size spectrum. (57)

NEW YORK CITY experiences pollution episode (SO_2 and particulate), and excess deaths are noted. (12)

1955 U.S. CONGRESS authorizes Public Health Service to begin programs of air pollution control.

U.S. ATOMIC ENERGY COMMISSION issues *Meteorology and Atomic Energy,* a summary of atmospheric processes related to the atomic energy industry. (58)

LONDON KILLER SMOG occurs 3–6 January, and 1000 excess deaths due to high SO_2 (0.19–0.55 ppm) and suspended particulate (700–2400 $\mu g/m^3$) are reported. (12)

1956 BRITISH PARLIAMENT passes CLEAN AIR ACT.

PROJECT PRAIRIE GRASS, the Great Plains turbulence field program run at O'Neill, Nebr., begins. (59)

1957 S. M. GREENFIELD first studies the collection of very small atmospheric particulate by cloud droplets that later fall as rain. (60)

F. N. FRENKIEL reports on a mathematical model for air pollution over the city of Los Angeles. (61)

J. S. HAY and F. PASQUILL relate the vertical distribution of particulates to the standard deviation of wind elevation angle. (62)

H. E. CRAMER incorporates σ_y and σ_z into the diffusion equations by relating them to the standard deviation of the azimuth angle and elevation angle, respectively. (63)

1958 D. H. LUCAS proposes theoretical area source model for an urban area. (64)

L. MACHTA develops the first useful model for global-scale diffusions. (65)

1958–59 Extensive urban pollution survey is made for NASHVILLE. (66)

1959 F. A. GIFFORD proposes the receptor-oriented coordinate system. (67)

A. S. MONIN applies similarity principles to diffusion from a source. (68)

1960 United States begins regular AIR POLLUTION POTENTIAL FORECASTS.

J. K. ANGELL and D. H. PACK introduce tetroons for pollution trajectory studies in Los Angeles basin. (69)

A. C. CHAMBERLAIN treats problem of washout of soluble gases and vapors. (70)

c. Part 3: 1961–70

The 1960s saw great advances in air pollution meteorology as well as supporting sciences. Computer advances produced faster machines with larger memories, which allowed the rapid advance of diffusion modeling. Advances in micrometeorology, turbulence theory, mesometeorology, cloud physics, and instrumentation, too numerous to mention, were used to further the study of air pollution. Concurrently, air pollution control technology and the knowledge of the effects of pollutants on man, the biosphere, and materials made rapid advances. As the 1960s drew to a close, public awareness of environmental problems reached a high point, and governments were persuaded to take action to control and study the problems of air pollution.

1961 F. POOLER, JR., develops climatological air quality model for Nashville, an early multisource-multireceptor model. (71)

F. PASQUILL proposes several atmospheric stability categories and a relation of plume characteristics to distance downwind for each. (72)

F. A. GIFFORD converts Pasquill's plume characteristics to plume dimensions σ_y and σ_z. (73)

D. B. TURNER relates Pasquill's stability classification to gross weather conditions. (74)

SYMPOSIUM: AIR OVER CITIES, held by U.S. Public Health Service. (75)

1962 *Air Pollution* edited by A. C. STERN is released. (76)

Atmospheric Diffusion by F. PASQUILL is published. (77)

The CONTINUOUS AIR MONITORING PROGRAM (CAMP) begins in nine U.S. cities.

J. HALITSKY uses wind tunnels to study airflow and diffusion around buildings. (78)

WORLDWIDE AIR POLLUTION EPISODE occurs 27 November–10 December with serious health effects. (79)

P. G. SAFFMAN studies effects of wind shear on horizontal atmospheric turbulence. (80)

1963 Study of transboundary pollutant flow in DETROIT-WINDSOR begun. (81)

1964 D. B. TURNER produces NASHVILLE air pollution model for SO_2. (82)

J. F. CLARKE models SO_2 and NO_x for Cincinnati. (83)

P. J. BARRY estimates downwind concentrations of effluent in the vicinity of buildings from field measurements. (84)

1965 P. J. SUMMERS models the urban heat island in Montreal. Model has application to air pollution. (85)

C. E. ZIMMER and R. I. LARSEN propose a log normal distribution for air quality data. (86)

1967 M. E. MILLER and G. C. HOLZWORTH develop urban model using mixing height restrictions. (87)

Workbook for Atmospheric Dispersion Estimates by D. B. TURNER is released. (88)

1968 J. L. MCELROY and F. POOLER, JR., report urban diffusion observations over St. Louis. (89)

Second edition of *Meteorology and Atomic Energy* is published.

Second edition of *Air Pollution* edited by A. C. STERN is published.

1969 J. F. CLARKE describes vertical temperature structure over a city in relation to dispersion of pollutants. (90)

"Plume Rise" by G. A. BRIGGS is issued. (91)

H. H. LETTAU applies climatonomy to urban air pollution problem. (92)

Symposium on Multiple-Source Urban Diffusion Models is held at Chapel Hill, N.C. (93)

S. K. FRIEDLANDER and J. H. SEINFELD develop a dynamic photochemical smog model. (94)

P. M. HAMILTON uses lidar to study smoke plumes for determining plume rise. (95)

d. Part 4: 1970 and the future

With the advent of the 1970s, research into the problems of air pollution meteorology increased at a significant rate. Advances in computer technology, mesoscale forecasting, turbulence and diffusion, instrumentation, modeling techniques, and long-range transport have opened new frontiers in air pollution meteorology. Major field sudies such as METROMEX (Meteropolitan Meteorological Experiment), SURE (Sulfate Regional Experiment), MAP3S (Multistate Atmospheric Power Production Pollution Study), and CAP (Chicago Area Program) and national and international networks for monitoring gaseous concentrations and precipitation chemistry have provided and will continue to provide the raw data for many of the advances.

A decade or so into the future, we will be able to look back and judge the work of the 1970s to determine on whose shoulders the future of air pollution meteorology rests. The advances of tomorrow are born today.

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