Timeline/Milestones

Here are gathered in chronological sequence the most important events in the history of climate change science. (For a narrative see the Introduction: Summary History.) The list of milestones includes major influences external to the science itself. Following that is a list of additional external influences 1950-1980. On the Website, nearly all items have links to essays.

1800-1870
- Level of carbon dioxide gas (CO_2) in the atmosphere, as later measured in ancient ice, is about 290 ppm (parts per million). Mean global temperature (1850-1870) is about 13.6°C**.**
- First Industrial Revolution. Coal, railroads, and land clearing speed up greenhouse gas emission, while better agriculture and sanitation speed up population growth.

1824
- Joseph Fourier calculates that the Earth would be far colder if it lacked an atmosphere.

1859
- Tyndall discovers that some gases block infrared radiation. He suggests that changes in the concentration of the gases could bring climate change.

1896
- Arrhenius publishes first calculation of global warming from human emissions of CO_2.

1897
- Chamberlin produces a model for global carbon exchange including feedbacks.

1870-1910
- Second Industrial Revolution. Fertilizers and other chemicals, electricity, and public health further accelerate growth.

1914-1918
- World War I. Governments learn to mobilize and control industrial societies.

1920-1925
- Opening of Texas and Persian Gulf oil fields inaugurates era of cheap energy.

1930s
- Global warming trend since late 19th century reported.
- Milankovitch proposes orbital changes as the cause of ice ages.

1938
- Callendar argues that CO_2 greenhouse global warming is underway, reviving interest in the question.

1939-1945
- World War II. Grand strategy is largely driven by a struggle to control oil fields.

1945
- US Office of Naval Research begins generous funding of many fields of science, some of which happen to be useful for understanding climate change.

1956
- Ewing and Donn offer a feedback model for quick ice age onset.
- Phillips produces a somewhat realistic computer model of the global atmosphere.
- Plass calculates that adding CO_2 to the atmosphere will have a significant effect on the radiation balance.

1957
- Launch of Soviet Sputnik satellite. Cold War concerns support 1957-58 International Geophysical Year, bringing new funding and coordination to climate studies.

• Revelle finds that CO_2 produced by humans will not be readily absorbed by the oceans.

1958 • Telescope studies show a greenhouse effect raises temperature of the atmosphere of Venus far above the boiling point of water.

1960 • Mitchell reports downturn of global temperatures since the early 1940s.
• Keeling accurately measures CO_2 in the Earth's atmosphere and detects an annual rise. The level is 315 ppm. Mean global temperature (five-year average) is 13.9°C.

1962 • Cuban Missile Crisis, peak of the Cold War.

1963 • Calculations suggest that feedback with water vapor could make the climate acutely sensitive to changes in CO_2 level.

1965 • Boulder, Colo. meeting on causes of climate change: Lorenz and others point out the chaotic nature of the climate system and the possibility of sudden shifts.

1966 • Emiliani's analysis of deep-sea cores shows the timing of ice ages was set by small orbital shifts, suggesting that the climate system is sensitive to small changes.

1967 • International Global Atmospheric Research Program established, mainly to gather data for better short-range weather prediction but including climate.
• Manabe and Wetherald make a convincing calculation that doubling CO_2 would raise world temperatures a couple of degrees.

1968 • Studies suggest a possibility of collapse of Antarctic ice sheets, which would raise sea levels catastrophically.

1969 • Astronauts walk on the Moon, and people perceive the Earth as a fragile whole.
• Budyko and Sellers present models of catastrophic ice-albedo feedbacks.
• Nimbus III satellite begins to provide comprehensive global atmospheric temperature measurements.

1970 • First Earth Day. Environmental movement attains strong influence, spreads concern about global degradation.
• Creation of US National Oceanic and Atmospheric Administration, the world's leading funder of climate research.
• Aerosols from human activity are shown to be increasing swiftly. Bryson claims they counteract global warming and may bring serious cooling.

1971 • SMIC conference of leading scientists reports a danger of rapid and serious global climate change caused by humans, calls for an organized research effort.
• Mariner 9 spacecraft finds a great dust storm warming the atmosphere of Mars, plus indications of a radically different climate in the past.

1972 • Ice cores and other evidence show big climate shifts in the past between relatively stable modes in the span of a thousand years or so.

1973 • Oil embargo and price rise bring first "energy crisis."

1974 • Serious droughts since 1972 increase concern about climate, with cooling from aerosols suspected to be as likely as warming; scientists are doubtful as journalists talk of a new ice age.

1975
• Warnings about environmental effects of airplanes leads to investigations of trace gases in the stratosphere and discovery of danger to ozone layer.
• Manabe and collaborators produce complex but plausible computer models which show a temperature rise of several degrees for doubled CO_2.

1976
• Studies find that CFCs (1975) and also methane and ozone (1976) can make a serious contribution to the greenhouse effect.
• Deep-sea cores show a dominating influence from 100,000-year Milankovitch orbital changes, emphasizing the role of feedbacks.
• Deforestation and other ecosystem changes are recognized as major factors in the future of the climate.
• Eddy shows that there were prolonged periods without sunspots in past centuries, corresponding to cold periods.

1977
• Scientific opinion tends to converge on global warming as the biggest climate risk in next century.

1978
• Attempts to coordinate climate research in U.S. end with an inadequate National Climate Program Act, accompanied by temporary growth in funding.

1979
• Second oil "energy crisis." Strengthened environmental movement encourages renewable energy sources, inhibits nuclear energy growth.
• U.S. National Academy of Sciences report finds it highly credible that doubling CO_2 will bring 1.5-4.5°C global warming.
• World Climate Research Programme launched to coordinate international research.

1981
• Election of President Reagan brings backlash against environmental movement; Political conservatism is linked to skepticism about global warming.
• IBM Personal Computer introduced. Advanced economies are increasingly delinked from energy.
• Hansen and others show that sulfate aerosols can significantly cool the climate, raising confidence in models showing future greenhouse warming.
• Some scientists predict greenhouse warming "signal" should be visible by about the year 2000.

1982
• Greenland ice cores reveal drastic temperature oscillations in the span of a century in the distant past.
• Strong global warming since mid-1970s is reported, with 1981 the warmest year on record.

1983
• Reports from U.S. National Academy of Sciences and Environmental Protection Agency spark conflict; greenhouse warming becomes prominent in mainstream politics.

1985
• Ramanathan and collaborators announce that global warming may come twice as fast as expected, from rise of methane and other trace greenhouse gases.
• Villach conference declares expert consensus that some global warming seems inevitable, calls on governments to consider international agreements to restrict emissions.

• Antarctic ice cores show that CO_2 and temperature went up and down together through past ice ages, pointing to powerful feedbacks.
• Broecker speculates that a reorganization of North Atlantic Ocean circulation can bring swift and radical climate change.

1987 • Montreal Protocol of the Vienna Convention requires international restrictions on emission of ozone-destroying gases.

1988 • News media coverage of global warming leaps upward following record heat and droughts plus testimony by Hansen.
• Toronto Conference calls for strict, specific limits on greenhouse gas emissions; U.K. Prime Minister Thatcher is first major leader to call for action.
• Ice-core and biology studies confirm living ecosystems give climate feedback by way of methane, which could accelerate global warming.
• Intergovernmental Panel on Climate Change (IPCC) is established.

1989 • Fossil-fuel and other U.S. industries form Global Climate Coalition to tell politicians and the public that climate science is too uncertain to justify action.

1990 • First IPCC report says world has been warming and future warming seems likely.

1991 • Mt. Pinatubo explodes; Hansen predicts cooling pattern, verifying (by 1995) computer models of aerosol effects.
• Global warming skeptics claim that 20th-century temperature changes followed from solar influences. (The solar-climate correlation would fail in the following decade.)
• Studies from 55 million years ago show possibility of eruption of methane from the seabed with enormous self-sustained warming.

1992 • Conference in Rio de Janeiro produces UN Framework Convention on Climate Change, but US blocks calls for serious action.
• Study of ancient climates reveals climate sensitivity in same range as predicted independently by computer models.

1993 • Greenland ice cores suggest that great climate changes (at least on a regional scale) can occur in the space of a single decade.

1995 • Second IPCC report detects "signature" of human-caused greenhouse effect warming, declares that serious warming is likely in the coming century.
• Reports of the breaking up of Antarctic ice shelves and other signs of actual current warming in polar regions begin to affect public opinion.

1997 • Toyota introduces Prius in Japan, first mass-market electric hybrid car; swift progress in large wind turbines and other energy alternatives.
• International conference produces Kyoto Protocol, setting targets to reduce greenhouse gas emissions if enough nations sign onto a treaty.

1998 • “Super El Niño” causes weather disasters and warmest year on record (approximately matched by 2005 and 2007). Borehole data confirm extraordinary warming trend.
• Qualms about arbitrariness in computer models diminish as teams model ice-age climate and dispense with special adjustments to reproduce current climate.

1999
• Criticism that satellite measurements show no warming are dismissed by National Academy Panel.
• Ramanathan detects massive "brown cloud" of aerosols from South Asia.

2000
• Global Climate Coalition dissolves as many corporations grapple with threat of warming, but oil lobby convinces U.S. administration to deny problem.
• Variety of studies emphasize variability and importance of biological feedbacks in carbon cycle, liable to accelerate warming.

2001
• Third IPCC report states baldly that global warming, unprecedented since end of last ice age, is "very likely," with possible severe surprises. Effective end of debate among all but a few scientists.
• Bonn meeting, with participation of most countries but not U.S., develops mechanisms for working towards Kyoto targets.
• National Academy panel sees a "paradigm shift" in scientific recognition of the risk of abrupt climate change (decade-scale).
• Warming observed in ocean basins; match with computer models gives a clear signature of greenhouse effect warming.

2002
• Studies find surprisingly strong "global dimming," due to pollution, has retarded arrival of greenhouse warming, but dimming is now decreasing.

2003
• Numerous observations raise concern that collapse of ice sheets (West Antarctica, Greenland) can raise sea levels faster than most had believed.
• Deadly summer heat wave in Europe accelerates divergence between European and U.S. public opinion.

2004
• In controversy over temperature data covering past millenium, most conclude climate variations were not comparable to the post-1980 global warming.
• First major books, movie and art work featuring global warming appear.

2005
• Kyoto treaty goes into effect, signed by major industrial nations except U.S. Work to retard emissions accelerates in Japan, Western Europe, U.S. regional governments and corporations.
• Hurricane Katrina and other major tropical storms spur debate over impact of global warming on storm intensity.

2007
• Fourth IPCC report warns that serious effects of warming have become evident; cost of reducing emissions would be far less than the damage they will cause.
• Greenland and Antarctic ice sheets and Arctic Ocean sea-ice cover found to be shrinking faster than expected

2009
• Many experts warn that global warming is arriving at a faster and more dangerous pace than anticipated just a few years earlier.
• Level of CO_2 in the atmosphere reaches 385 ppm. Mean global temperature (five-year average) is 14.5°C, the warmest in hundreds, perhaps thousands of years.

Other External Influences 1950-1980

This is a reference list of miscellaneous significant developments that don't fit into any of the other essays: scientific-technical matters that arose altogether independently of the scientific fields covered, and are not included in the list of major "milestones," but that did have a significant influence on climate change studies.

Before the 1950s, there were practically no global warming studies as such, and the important relevant discoveries (the ice ages, absorption of infrared radiation by carbon dioxide, etc.) were all effectively "external."

1950s: Research on military applications of radar and infrared radiation promotes advances in radiative transfer theory and measurements. — Studies conducted largely for military applications give accurate values of infrared absorption by gases. — Nuclear physicists and chemists develop Carbon-14 analysis, useful for dating ancient climate changes, for detecting carbon from fossil fuels in the atmosphere, and for measuring the rate of ocean turnover. — Development of digital computers affects many fields including the calculation of radiation transfer in the atmosphere, and makes it possible to model weather processes. — Geological studies of polar wandering help provoke Ewing-Donn model of ice ages. — Improvements in infrared instrumentation (mainly for industrial processes) allow very precise measurements of atmospheric CO_2.

1960s: Analysis of automobile and airplane exhaust pollution brings recognition of complex chemical and light interactions in the atmosphere, especially involving ozone — Research on urban air pollution, and related industrial and military applications, improve knowledge of aerosols and atmospheric turbidity. — Studies of fallout from nuclear weapons tests give improved picture of circulation of aerosols in the stratosphere. — Studies of fallout and pesticides foster worries that human technology can bring world-wide disaster. — Research on small-scale phenomena in various fields of geophysics (cloud formation, soil moisture, etc.) provides information useful for setting crucial parameters in global computer models. — Studies of rice paddies and other biological and agricultural entities show emission of large quantities of methane.

1970s: Neutrino experiments and new astrophysical theories suggest that the Sun could be a variable star. — Models of glacier flow, developed by generations of glaciologists, reveal a possibly catastrophic instability in the Antarctic ice sheet. — Fallout from nuclear weapons tests, slowly penetrating the oceans, reveals deep circulation patterns. — Studies of ancient reversals of the Earth's magnetic field, measured in continental rocks and the ocean floor, provide a time-marker for climate changes. — Ocean geologists find huge deposits of methane-bearing ices in the world's seabeds. — Continued rapid improvement of digital computers and software makes

possible fairly realistic models of complex systems like climate. — Nimbus-III and other satellites, designed chiefly for weather prediction, provide global data essential for climate modeling.

After about 1980, research that could be relevant to global warming was generally undertaken with an awareness of potential connections.