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 some of the 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 (1850-1890) is roughly 13.6°C**.**
• First Industrial Revolution. Coal, railroads, and land clearing speed up greenhouse gas emissions, while better agriculture and sanitation speed up population growth.

1824
• Fourier proposes that the Earth would be far colder if it lacked an atmosphere.

1859
• Tyndall demonstrates that some gases block infrared radiation, and notes that changes in the concentration of the gases could bring climate change.

1879
• International Meteorological Organization begins to compile and standardize global weather data, including temperature.

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. Military grand strategy is largely driven by a struggle to control oil fields.

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

1955
• Phillips produces a convincing computer model of the global atmosphere.

1956
• Ewing and Donn offer a feedback model for abrupt climate change.
• 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.
• First meeting of experts concerned with global warming warns that a rise in sea level is likely, with "immense flooding" of shorelines.

1965 • Boulder, Colorado 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 and Broecker's analysis of ancient corals show that the timing of ice ages was set by small orbital shifts, suggesting that the climate system is sensitive to small perturbations.

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 U.S. 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.

• Droughts in Africa, Ukraine, India cause world food crisis, spreading fears about climate change.

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

1974 • Cooling from aerosols suspected to be as likely as warming; some journalists talk of a new ice age but scientists doubt all theories, call for more research.

1975 • Warnings about environmental effects of airplanes lead 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 a few 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 chief climate risk in the 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 production.

• Hansen and others show that sulfate aerosols can significantly cool the climate, raising confidence in models that incorporate aerosols and show future greenhouse warming.

• Some scientists predict greenhouse warming "signal" should become visible around 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 a factor in mainstream politics.

• Speculation over catastrophic climate change following a nuclear war, or a dinosaur-killing asteroid strike, promote realization of the atmosphere' fragility.

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.

1986
• Meltdown of reactor at Chernobyl (Soviet Union) cripples plans to replace fossil fuels with nuclear power.

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 statements 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 persuade 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.)
• Geologists discover massive extinction event 55 million years ago, associated with global heating caused by increase in greenhouse gases.

1992
• Conference in Rio de Janeiro produces UN Framework Convention on Climate Change, but U.S. blocks calls for serious action.
• Study of ancient climates reveals climate sensitivity to CO_2 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 "fingerprint" 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, solar electricity, and other energy alternatives.
• International conference produces Kyoto Protocol, setting targets for industrialized nations to reduce greenhouse gas emissions if enough nations sign onto a treaty (rejected by U.S. Senate in advance).

1998
• A "Super El Niño" makes this an exceptionally warm year, equaled in later years but not clearly exceeded until 2014. 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 of Sciences panel.
• Mann's "hockey stick" data indicates current warming is historically unprecedented.
• Ramanathan detects massive "brown cloud" of aerosols over South Asia.

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

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

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 level faster than most had believed.
• Deadly summer heat wave in Europe accelerates divergence between European and U.S. public opinion.

2004
• 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.
• European Union initiates "cap and trade" market to reduce emissions.
• Hurricane Katrina and other major tropical storms spur debate over impact of global warming on storm intensity.

2006
• In longstanding "hockey stick" controversy, scientists conclude that post-1980 global warming was unprecedented for centuries or more. The rise could not be attributed to changes in solar energy.
• "An Inconvenient Truth" documentary persuades many but sharpens political polarization.
• China overtakes the United States as the world's biggest emitter of CO_2.

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.

2008
• Climate scientists point out that even if all greenhouse gas emissions could be halted immediately, global temperature will remain elevated for millennia.

2009
• Many experts warn that damage from climate change is arriving at a faster pace than was anticipated just a few years earlier.
• Excerpts from stolen e-mails of climate scientists fuel public skepticism.
• Studies find total carbon emitted determines global temperature; the "budget" for avoiding dangerous heating is mostly used up.
• Copenhagen conference fails to negotiate binding agreements: end of hopes of avoiding severe future climate change.

2011
• Reaction to nuclear reactor disaster at Fukushima (Japan) ends hopes for a renaissance of nuclear power.

2012
•"Attribution" studies find some recent disastrous heat waves, droughts, extremes of precipitation, and floods were made worse by global warming.

2013
• An apparent pause or "hiatus" in global warming of the atmosphere since 1998, publicized by skeptics, is explained; the world is still warming (as following years would confirm).

2015
• Researchers find collapse of West Antarctic ice sheet may be irreversible, bringing meters of sea-level rise over future centuries.
• Rise of methane in atmosphere accelerates, threatening dangerous feedbacks.
• Paris Agreement: nearly all nations pledge to set their own targets for greenhouse gas cuts and to report their progress.

2016
• Solar electricity and wind power become economically competitive with fossil fuels in some regions. Fossil fuel CO_2 emissions stop climbing exponentially, slow rise continues.

2018
• IPCC report on 1.5°C warming says that to avoid dangerous climate change, greenhouse gas emissions must be in sharp decline by 2030.

2019
• Increasing disasters (tropical cyclones, wildfires, etc.) join scientists' warnings to spur public demonstrations and civil disobedience.

2021
• Sixth major IPCC report warns that catastrophic outcomes cannot be ruled out.
• Glasgow conference spurs pledges to restrict emissions—not enough to avoid dangerous climate change, but risk of catastrophic change is reduced.

2022
• Democrats in U.S. Congress pass legislation providing subsidies to reduce the nation's greenhouse gas emissions.

2024 • Mean global temperature (five-year average) is 14.9°C, the warmest in tens of thousands of years. Level of CO_2 in the atmosphere is 423 ppm, the highest in millions of years

Additional 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 give a key to ancient climate changes and 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.