The Discovery of Global Warming

February 2018

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.) This list of milestones includes major influences external to the science itself. Following it is a list of other external influences.

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 13.7°C.

First Industrial Revolution. Coal, railroads, and land clearing speed up greenhouse gas emission, while better agriculture and sanitation speed up population growth.

1824
Fourier calculates that the Earth would be far colder if it lacked an atmosphere. =>Simple models

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

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

1896
Arrhenius publishes first calculation of global warming from human emissions of CO_2. =>Simple models

1897
Chamberlin produces a model for global carbon exchange including feedbacks. =>Simple models

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. =>Modern temp's

Milankovitch proposes orbital changes as the cause of ice ages. =>Climate cycles

1938
Callendar argues that CO_2 greenhouse global warming is underway, reviving interest in the question. =>CO2 greenhouse

1939-1945
World War II. Military 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. =>Government

1955
Phillips produces a convincing computer model of the global atmosphere. =>Models (GCMs)

1956
Ewing and Donn offer a feedback model for quick ice age onset. =>Simple models

Plass calculates that adding CO_2 to the atmosphere will have a significant effect on the radiation balance. =>Radiation math

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

Revelle finds that CO_2 produced by humans will not be readily absorbed by the oceans. =>CO2 greenhouse

1958
Telescope studies show a greenhouse effect raises temperature of the atmosphere of Venus far above the boiling point of water. =>Venus & Mars

1960
Mitchell reports downturn of global temperatures since the early 1940s.=>Modern temp's

Keeling accurately measures CO_2 in the Earth's atmosphere and detects an annual rise. =>CO2 greenhouse 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. =>Radiation math

1965
Boulder, Colorado meeting on causes of climate change: Lorenz and others point out the chaotic nature of climate system and the possibility of sudden shifts. =>Chaos theory

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 changes. =>Climate cycles

1967
International Global Atmospheric Research Program established, mainly to gather data for better short-range weather prediction, but including climate. =>International

Manabe and Wetherald make a convincing calculation that doubling CO_2 would raise world temperatures a couple of degrees. =>Radiation math

1968
Studies suggest a possibility of collapse of Antarctic ice sheets, which would raise sea levels catastrophically. =>Sea rise & ice

1969
Astronauts walk on the Moon, and people perceive the Earth as a fragile whole. =>Public opinion

Budyko and Sellers present models of catastrophic ice-albedo feedbacks. =>Simple models

Nimbus III satellite begins to provide comprehensive global atmospheric temperature measurements. =>Government

1970
First Earth Day. Environmental movement attains strong influence, spreads concern about global degradation. =>Public opinion

Creation of US National Oceanic and Atmospheric Administration, the world's leading funder of climate research. =>Government

Aerosols from human activity are shown to be increasing swiftly. Bryson claims they counteract global warming and may bring serious cooling. =>Aerosols

1971
SMIC conference of leading scientists reports a danger of rapid and serious global change caused by humans, calls for an organized research effort. =>International

Mariner 9 spacecraft finds a great dust storm warming the atmosphere of Mars, plus indications of a radically different climate in the past.=>Venus & Mars

1972
Ice cores and other evidence show big climate shifts in the past between relatively stable modes in the space of a thousand years or so, especially around 11,000 years ago. =>Rapid change

Droughts in Africa, Ukraine, India cause world food crisis, spreading fears about climate change. =>Public opinion

1973
Oil embargo and price rise bring first "energy crisis". =>Government

1974
Serious droughts since 1972 increase concern about climate, with cooling from aerosols

suspected to be as likely as warming; scientists doubt all theories as journalists talk of a new ice age.=>Public opinion

1975
Warnings about environmental effects of airplanes lead to investigations of trace gases in the stratosphere and discovery of danger to ozone layer. =>Other gases

Manabe and collaborators produce complex but plausible computer models which show a temperature rise of a few degrees for doubled CO_2. =>Models (GCMs)

1976
Studies show that CFCs (1975) and also methane and ozone (1976) can make a serious contribution to the greenhouse effect. =>Other gases

Deep-sea cores show a dominating influence from 100,000-year Milankovitch orbital changes, emphasizing the role of feedbacks. =>Climate cycles

Deforestation and other ecosystem changes are recognized as major factors in the future of the climate. =>Biosphere

Eddy shows that there were prolonged periods without sunspots in past centuries, corresponding to cold periods. =>Solar variation

1977
Scientific opinion tends to converge on global warming, not cooling, as the chief climate risk in the next century. =>Public opinion

1978
Attempts to coordinate climate research in US end with an inadequate National Climate Program Act, accompanied by rapid but temporary growth in funding. =>Government

1979
Second oil "energy crisis." Strengthened environmental movement encourages renewable energy sources, inhibits nuclear energy growth. =>Public opinion

US National Academy of Sciences report finds it highly credible that doubling CO_2 will bring 1.5-4.5°C global warming. =>Models (GCMs)

World Climate Research Programme launched to coordinate international research. =>International

1981
Election of Reagan brings backlash against environmental movement to power. Political conservatism is linked to skepticism about global warming. =>Government

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 that incorporate aerosols and show future greenhouse warming. =>Aerosols

Some scientists predict greenhouse warming "signal" should become visible around the year 2000. =>Modern temp's

1982
Greenland ice cores reveal drastic temperature oscillations in the space of a century in the distant past. =>Rapid change

Strong global warming since mid-1970s is reported, with 1981 the warmest year on record. =>Modern temp's

1983
Reports from US National Academy of Sciences and Environmental Protection Agency spark conflict; greenhouse warming becomes a factor in mainstream politics. =>Government

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

1985
Ramanathan and collaborators announce that global warming may come twice as fast as expected, from rise of methane and other trace greenhouse gases.=> Other gases

Villach Conference declares consensus among experts that some global warming seems inevitable, calls on governments to consider international agreements to restrict emissions.=> International

Antarctic ice cores show that CO_2 and temperature went up and down together through past ice ages, pointing to powerful feedbacks. =>CO_2

Broecker speculates that a reorganization of North Atlantic Ocean circulation can bring swift and radical climate change. =>The oceans

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

1987
Montreal Protocol of the Vienna Convention imposes international restrictions on emission of ozone-destroying gases. =>International

1988
News media coverage of global warming leaps upward following record heat and droughts plus statements by Hansen. =>Public opinion

Toronto conference calls for strict, specific limits on greenhouse gas emissions; UK Prime Minister Thatcher is first major leader to call for action. =>International

Ice-core and biology studies confirm living ecosystems give climate feedback by way of methane, which could accelerate global warming. =>Other gases

Intergovernmental Panel on Climate Change (IPCC) is established. =>International

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. =>Public opinion

1990
First IPCC report says world has been warming and future warming seems likely. =>International

1991
Mt. Pinatubo explodes; Hansen predicts cooling pattern, verifying (by 1995) computer models of aerosol effects. =>Aerosols

Global warming skeptics claim that 20th-century temperature changes followed from solar influences. (The solar-climate correlation would fail in the following decade.) =>Solar variation

Studies from 55 million years ago show possibility of eruption of methane from the seabed with enormous self-sustained warming. =>Rapid change

1992
Conference in Rio de Janeiro produces UN Framework Convention on Climate Change, but US blocks calls for serious action. =>International

Study of ancient climates reveals climate sensitivity to CO_2 in same range as predicted independently by computer models. =>Models (GCMs)

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

1995
Second IPCC report detects "signature" of human-caused greenhouse effect warming, declares that serious warming is likely in the coming century. =>International

Reports of the breaking up of Antarctic ice shelves and other signs of actual current warming in polar regions begin affecting public opinion. =>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 US Senate in advance). =>International

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. =>Modern temp's

Qualms about arbitrariness in computer models diminish as teams model ice-age climate and dispense with special adjustments to reproduce current climate. =>Models (GCMs)

1999
Criticism that satellite measurements show no warming are dismissed by National Academy Panel. =>Modern temp's

Ramanathan detects massive "brown cloud" of aerosols from South Asia. =>Aerosols

2000
Global Climate Coalition dissolves as many corporations grapple with threat of warming, but oil lobby convinces US administration to deny problem. =>Public opinion

Variety of studies emphasize variability and importance of biological feedbacks in carbon cycle, liable to accelerate warming. =>Biosphere

2001
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 =>Impacts and possible severe surprises. Effective end of debate among all but a few scientists. =>International

Bonn meeting, with participation of most countries but not US, develops mechanisms for working towards Kyoto targets. =>International

National Academy panel sees a "paradigm shift" in scientific recognition of the risk of abrupt climate change (decade-scale). =>Rapid change

Warming observed in ocean basins; match with computer models gives a clear signature of greenhouse effect warming. =>Models (GCMs)

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

2003
Numerous observations raise concern that collapse of ice sheets (West Antarctica, Greenland) can raise sea level faster than most had believed. =>Sea rise & ice

Deadly summer heat wave in Europe accelerates divergence between European and US public opinion. =>Public opinion

2004
First major books, movie, and art work featuring global warming appear. =>Public opinion

2005
Kyoto treaty goes into effect, signed by major industrial nations except US. Work to retard emissions accelerates in Japan, Western Europe, US regional governments and corporations. =>International

Hurricane Katrina and other major tropical storms spur debate over impact of global warming on storm intensity. =>Sea rise & ice

2006
In longstanding "hockey stick" controversy, scientists conclude post-1980 global warming was unprecedented for centuries or more. =>Modern temp's The rise could not be attributed to changes in solar energy. =>Solar variation

"An Inconvenient Truth" documentary persuades many but sharpens political polarization. =>Public opinion

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. =>International

Greenland and Antarctic ice sheets and Arctic Ocean sea-ice cover found to be shrinking faster than expected. =>Sea rise & ice

2008
Climate scientists (although not the public) recognize that even if all greenhouse gas emissions could be halted immediately, global warming will continue for millennia. =>CO_2

2009
Many experts warn that global warming is arriving at a faster and more dangerous pace than anticipated just a few years earlier. =>International

Excerpts from stolen e-mails of climate scientists fuel public skepticism. =>Public opinion

Copenhagen conference fails to negotiate binding agreements: end of hopes of avoiding dangerous future climate change. =>International

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

2012
Controversial "attribution" studies find recent disastrous heat waves, droughts, extremes of precipitation, and floods were made worse by global warming. =>Impacts

2013
An apparent pause or "hiatus" in global warming of the atmosphere since 1998 is explained; the world is still warming (as the next three record-breaking years would confirm). =>Modern temp's

2015
Researchers find collapse of West Antarctic ice sheet is irreversible, will bring meters of sea-level rise over future centuries. =>Sea rise & ice

Paris Agreement: nearly all nations pledge to set targets for their own greenhouse gas cuts and to report their progress.=>International

Solar electricity and wind power become economically competitive with fossil fuels in some regions.

Mean global temperature is 14.8°C, the warmest in thousands of years. Level of CO_2 in the atmosphere goes above 400 ppm, the highest in millions of years.

Additional External Influences 1950-1980

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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 above 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 all the important discoveries (the ice ages, the infrared absorption of carbon dioxide, etc.) were effectively "external."

1950s:
Research on military applications of radar and infrared radiation promotes advances in

radiative transfer theory and measurements =>Radiation math — Studies conducted largely for military applications give accurate values of infrared absorption by gases =>CO2 greenhouse — Nuclear physicists and chemists develop Carbon-14 analysis, useful for dating ancient climate changes =>Carbon dates, for detecting carbon from fossil fuels in the atmosphere, and for measuring the rate of ocean turnover =>CO2 greenhouse — Development of digital computers affects many fields including the calculation of radiation transfer in the atmosphere =>Radiation math, and makes it possible to model weather processes =>Models (GCMs) — Geological studies of polar wandering help provoke Ewing-Donn model of ice ages =>Simple models — Improvements in infrared instrumentation (mainly for industrial processes) allow very precise measurements of atmospheric CO_2 =>CO2 greenhouse.

1960s:
Analysis of automobile and airplane exhaust pollution brings recognition of complex chemical and light interactions in the atmosphere, especially involving ozone =>Other gases — Research on urban air pollution, and related industrial and military applications,improves knowledge of aerosols and atmospheric turbidity =>Aerosols — Studies of fallout from nuclear weapons tests give improved picture of circulation of aerosols in the stratosphere =>Aerosols— Studies of fallout and pesticides foster worries that human technology can bring world-wide disaster =>Public opinion — 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 =>Models (GCMs) — Studies of rice paddies and other biological and agricultural entities show emission of large quantities of methane =>Other gases.

1970s:
Neutrino experiments and new astrophysical theories suggest that the Sun could be a variable star =>Solar variation — Models of glacier flow, developed by generations of glaciologists, reveal a possibly catastrophic instability in the Antarctic ice sheet =>Sea rise & ice — Fallout from nuclear weapons tests, slowly penetrating the oceans, reveals deep circulation patterns =>The oceans — 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 =>Climate cycles — Ocean geologists find huge deposits of methane-bearing ices in the world's seabeds =>Other gases — Continued rapid improvement of digital computers and software makes possible fairly realistic models of complex systems like climate =>Models (GCMs) — Nimbus-III and other satellites, designed chiefly for weather prediction, provide global data essential for climate modelling =>Models (GCMs).

After about 1980, efforts that would be relevant to global warming were generally undertaken with an awareness of potential connections.

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