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The Discovery of Global Warming

February 2011

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 (CO₂) 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

Fourier calculates that the Earth would be far colder if it lacked an atmosphere. =>[Simple models](#)

1859

Tyndall discovers that some gases block infrared radiation. He suggests that changes in the concentration of the gases could bring climate change. =>[Other gases](#)

1896

Arrhenius publishes first calculation of global warming from human emissions of CO₂. =>[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 CO₂ 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](#)

1956

Ewing and Donn offer a feedback model for quick ice age onset. =>[Simple models](#)

Phillips produces a somewhat realistic computer model of the global atmosphere.

=>[Models \(GCMs\)](#)

Platt calculates that adding CO₂ 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 CO₂ 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 CO₂ 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 CO₂ level. =>[Radiation math](#)

1965

Boulder, Colo. 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 CO₂ 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.

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 are doubtful as journalists talk of a new ice age. =>[Public opinion](#)

1975

Warnings about environmental effects of airplanes leads 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 several degrees for doubled CO₂. =>[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 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 CO₂ 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 showing future greenhouse warming. =>[Aerosols](#)

Some scientists predict greenhouse warming "signal" should be visible by about 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, as greenhouse warming becomes prominent in mainstream politics. =>[Government](#)

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 CO₂ and temperature went up and down together

through past ice ages, pointing to powerful biological and geochemical feedbacks. =>[CO₂](#)

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

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 testimony 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 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 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

"Super El Niño" causes weather disasters and warmest year on record (approximately matched by 2005 and 2007). 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 end of last ice age, is "very likely," with 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 levels 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](#); =>[Solar variation](#)

"An Inconvenient Truth" documentary persuades many but sharpens political polarization.

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](#)

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.

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

Level of CO₂ in the atmosphere reaches 385 ppm.

Mean global temperature (five-year average) is 14.5°C, the warmest in hundreds, and probably thousands 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 CO₂ =>[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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