

# ABRUPT CLIMATE CHANGE: INEVITABLE SURPRISES

Until the 1990s, the dominant view of climate change was that Earth's climate system has changed gradually in response to both natural and human-induced processes. Evidence pieced together over the last few decades, however, shows that climate has changed much more rapidly—sometimes abruptly—in the past and therefore could do so again in the future.

Abrupt climate change generally refers to a large shift in climate that persists for years or longer—such as marked changes in average temperature, or altered patterns of storms, floods, or droughts—over a widespread area such as an entire country or continent, that takes place so rapidly and unexpectedly that human or natural systems have difficulty adapting to it. In the context of past abrupt climate change, “rapidly” typically means on the order of a decade.

Severe droughts and other past abrupt climate changes have had demonstrable, adverse effects on human societies. While it is important not to be fatalistic about the threats posed by abrupt climate change, denying the likelihood or downplaying the relevance of past abrupt events could be costly. Increased knowledge is the best way to improve the effectiveness of response; research into the causes, patterns, and likelihood of abrupt climate change can help reduce vulnerabilities and increase our ability to adapt.

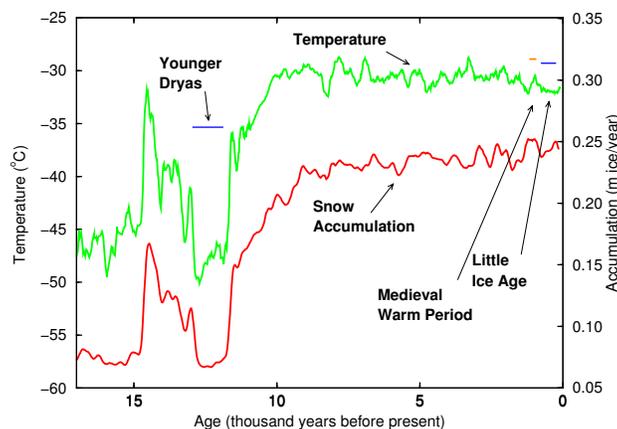
## Evidence of Abrupt Climate Change

Researchers first became intrigued by abrupt climate change when they discovered striking evidence of large, abrupt, and widespread changes preserved in paleoclimatic archives—the history of Earth's climate recorded in tree rings, ice cores, sediments, and other sources. For example, tree rings show the frequency of droughts, sediments reveal the number and type of organisms present, and gas bubbles trapped in ice cores indicate past atmospheric conditions. With such techniques, researchers have discovered repeated instances of large and abrupt climate changes over the last 100,000 years during the slide into and climb out of the most recent ice age—local warmings as great as 28°F (16°C) occurred repeatedly, sometimes in the mere span of a decade.



Ice is one of Earth's best record keepers, revealing features of the climate when the ice was deposited. These deep ice cores from Greenland are stored in the main archive of the National Ice Core Laboratory in Denver.

Some of the best known and most well studied widespread abrupt climate changes started and ended the Younger Dryas cold interval, a near global event that began abruptly about 12,800 years ago and ended even more suddenly about 11,600 years ago (see Figure 1). Climate records show that much of the northern hemisphere was affected by extraordinary cold, dry,



**Figure 1.** Climate changes in central Greenland over the last 17,000 years show a large and rapid shift out of the ice age about 15,000 years ago, an irregular cooling into the Younger Dryas event, an abrupt shift out of the event (a warming of about 8°C in a decade) toward modern values.

windy conditions; dust and other wind-blown materials were more abundant in Greenland by a factor of 3 to 7, and methane concentrations were lower indicating loss of wetland areas, among other evidence. The 110,000-year-long ice-core records from central Greenland, and many other climate records, indicate that the Younger Dryas was one in a long string of abrupt climate changes.

More recently, less dramatic though still rapid climate changes have continued to occur. For example, a multidecadal drought is implicated in the collapse of the classic Mayan civilization in the ninth century. Paleoclimatic records from the last 10,000 years include apparent abrupt shifts in hurricane frequency, flood regimes, and droughts. Examples of abrupt change in the past century alone include the rapid warming of the North Atlantic from 1920 to 1930 and the Dust Bowl drought of the 1930s.

## Triggers of Abrupt Climate Change

Abrupt climate change can occur when the Earth system gets pushed across a threshold, whether by some sudden event like a massive volcanic eruption or by the

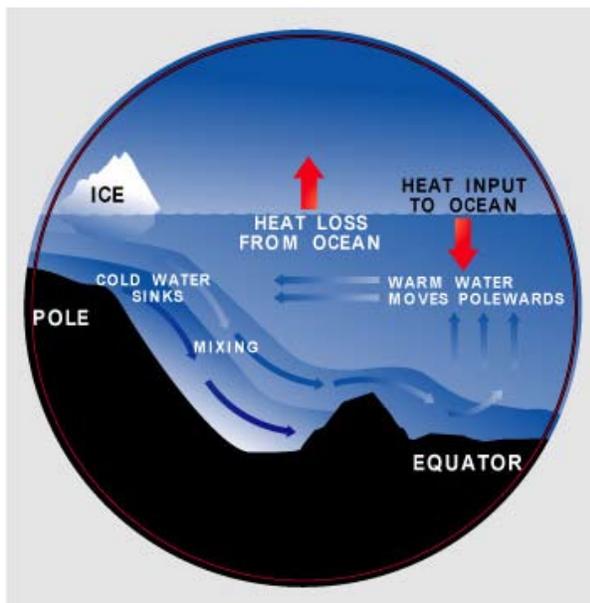
accumulation of more gradual forces, or “forcings” on the system. Much as the slowly increasing pressure of a finger eventually flips a switch and abruptly turns on a light, or as a passenger’s leaning more and more over the side of a canoe will at some point cause the craft to suddenly capsize, the slow effects of drifting continents or wobbling orbits or changing atmospheric composition may “switch” the climate to a new state. The more rapid the forcing, the more likely it is that it will “flip a switch,” causing an abrupt change on the time scale of human economies or global ecosystems. Such forcings may occur through perturbations in key components of the Earth system such as:

**Oceans.** Because water has enormous heat capacity, oceans typically store 10-100 times more heat than equivalent land surfaces. Thus the oceans exert a profound influence on climate through their ability to transport heat from one location to another. Changes in ocean circulation, and especially the thermohaline circulation in the North Atlantic (see Figure 2) have been implicated in abrupt climate change of the past such as the Younger Dryas. Floods of glacial meltwaters that would have freshened the North Atlantic and reduced the ability of its waters to sink, immediately preceded the coolings of the Younger Dryas and another short cold event 8,200 years ago, suggesting causation.

**Cryosphere.** The portion of the Earth covered in ice and snow, the cryosphere, greatly affects temperature. When sea ice forms, it increases the planetary reflective capacity, thereby enhancing cooling. Sea ice also insulates the atmosphere from the relatively warm ocean, allowing winter air temperatures to steeply decline and reduce the supply of moisture to the atmosphere.

Glaciers and snow cover on land can also provide abrupt-change mechanisms. The water frozen in a glacier can melt if warmed sufficiently, leading to possibly rapid discharge, with consequent effects on sea level and atmospheric flow patterns. Meanwhile, snow-covered lands of all types maintain cold conditions because of their high reflectivity and because surface temperatures cannot rise above freezing until the snow melts.

**Atmosphere.** The atmosphere is involved in virtually every physical process of potential importance to abrupt climate change, providing a means of rapidly propagating the influence of any climate forcing from one part of the globe to another. Atmospheric temperature, composition, humidity, cloudiness, and wind determine the Earth’s energy fluxes. Wind fields help dictate the ocean’s surface circulation and upwelling patterns. Atmospheric-moisture



**Figure 2.** This schema shows the basic mechanism of the North Atlantic thermohaline cycle. Cold water sinks in the North Atlantic and travels throughout the world’s oceans. It gradually warms, becomes less dense and mixes to the surface. It then moves back towards the North Atlantic carrying heat absorbed along the way. The cycle continues. Without this cycle, the north would be colder and the south would be slightly warmer.

Image courtesy of the Marian Koshland Science Museum of the National Academy of Sciences.

transport—most prominently, through precipitation—helps govern the freshwater balance, overall water circulation, and the dynamics of glaciers.

**Land surface.** The reflective capacity of the land can change greatly, with fresh snow or ice sheets reflecting more than 90% of the sunlight striking them while dense forests absorb more than 90%. Changes in surface characteristics can also affect solar heating, cloud formation, rainfall, and surface-water flow to the oceans, thus feeding back strongly on climate.

**External factors.** Phenomena external to the climate system can also be agents of abrupt climate change. For example, the orbital parameters of the Earth vary over time, affecting the planet's distribution of solar energy. Fluctuations in solar output—prompted by sunspot activity or the effects of solar wind—may cause major climate fluctuations. The drying of the Sahara in the Holocene is linked to variations in the Earth's orbit around the sun.

## Global Warming as a Possible Trigger

Greenhouse gases such as carbon dioxide are accumulating in the Earth's atmosphere and causing surface air temperatures and subsurface ocean temperatures to rise. These gradual changes, along with other human alterations of the climate system (e.g., land-use changes), are producing conditions in the Earth's climate that are outside the range of recent historical experience. Although it is not known whether these or future changes will trigger more abrupt climate changes, past abrupt climate changes have been especially common when the climate system itself was being altered.

A question of great societal relevance is whether the North Atlantic circulation, including the Gulf Stream, will remain stable under the global warming that is expected to continue for the next few centuries. A shutdown of the circulation would not induce a new ice age, but would cause major changes both in the ocean (major circulation regimes, upwelling and sinking regions, distribution of seasonal sea ice, ecological systems, and sea level) and in the atmosphere (land-sea temperature contrast, and the intensity, frequency, and paths of storms).

Other potential impacts of a global-warming induced abrupt climate change could be associated with increased frequency of extreme events related to land-surface hydrology. Great variability in precipitation patterns, ranging from heavy rainstorms and flooding to persistent drought, might become more common. In particular, some models suggest that greenhouse warming will cause El Niño manifestations to become stronger and more frequent. It is important to note that not all models agree on the potential impacts of global warming on abrupt climate change.

## Improving our Understanding

Scientists don't know enough about the details of abrupt climate change to accurately predict it. With better information, society could take more confident action to reduce the potential impact of abrupt changes on agriculture, water resources, and the built environment, among other impacts. A better understanding through research of such things as sea-ice and glacier stability, land-surface processes, and atmospheric and oceanic circulation patterns is needed. Moreover, to effectively use any additional knowledge of these and other physical processes behind abrupt climate change, more sophisticated ways of assessing their interactions must be developed, including:

**Better models.** At present, the models used to assess climate and its impacts cannot simulate the size, speed, and extent of past abrupt changes, let alone predict future abrupt changes. Efforts are needed to improve how the mechanisms driving abrupt climate change are represented in these models and to more rigorously test models against the climate record.

**More paleoclimatic data.** More climate information from the distant past would go a long way toward strengthening our understanding of abrupt climate changes and our models of past climate. In particular, an enhanced effort is needed to expand the geographic coverage, temporal resolution, and variety of paleoclimatic data.

**Appropriate statistical tools.** Because most statistical calculations at present are based on the assumption that climates are not changing but are stationary, they have limited value for nonstationary (changing) climates and for climate-related variables that are often highly skewed by rapid changes over time—such as for abrupt-change regimes. Available statistical tools themselves need to be adapted or replaced with new approaches altogether to better reflect the properties of abrupt climate change.

## Ecological and Economic Impacts

One way of understanding the potential impacts of abrupt climate change is to think about how it could disrupt the timely replacement, repair, or adaptation of “capital stocks,” whether of natural systems or nations' economies. For example, a rapid sea-level rise could inundate or threaten coastal populations; significant changes in patterns of droughts or frosts could destroy forests or agricultural systems; and sudden temperature shifts could render improperly insulated, heated, or cooled buildings uninhabitable.

To date, however, relatively little research has addressed the ecological and economic impacts of abrupt

climate change; most studies focus on gradual climate change. Given the accumulating evidence of past abrupt changes and their capacity to affect human societies, some attention should be focused on potential future abrupt change scenarios. Concurrently, impact-assessment models need to be made increasingly sophisticated so they can accommodate diverse variables and represent interactions and outcomes in ways that more closely approximate reality.

## Adapting to Abrupt Climate Change

Although our understanding of the causes and consequences of relatively abrupt changes in climate is imperfect, it makes sense to develop practical strategies that could be used to reduce economic and ecological systems' vulnerabilities to change. In that spirit, it is worth investigating "no-regrets" policies that provide benefits whether an abrupt climate change ultimately occurs or not. By moving scientific and public-policy research in directions that enhance system adaptability, it might be possible to reduce vulnerability at little or no net cost.

For example, the phaseout of chloro-fluorocarbons over the past two decades, and their replacement with relatively benign gases having shorter atmospheric residence times, reduced nations' contributions to global warming while also diminishing the risks posed by ozone depletion.

No-regrets measures in anticipation of abrupt climate change could include low-cost steps to: slow climate change; improve climate forecasting; slow biodiversity loss; improve water, land, and air quality; render institutions more robust to major disruptions; and adopt technological innovations that increase the resiliency of market and ecological systems (see sidebar).

The potential value of such measures is not restricted to the United States. With growing globalization, adverse

social and economic impacts are now more likely than ever to spill across national boundaries. It is especially important that the needs of poorer countries, which could be highly vulnerable to the effects of abrupt climate change, be given sufficient attention and support.

### Potential No-Regrets Strategies

The report highlights a few policy areas to explore in developing no-regrets options:

**Energy policies.** Options to slow climate change, such as moving away from coal-burning toward other fuels, can also have benefits in reducing health or environmental effects of emissions.

**Ecological policies.** In land-use and coastal planning, managers may be helped by information on the effects of nonlinear climate changes on ecosystems. Scientists and government organizations at various levels could collaborate to develop and implement regulations and policies that reduce environmental degradation of water, air, and biota.

**Forecasting of weather and weather-related events.** The frequency and intensity of hurricanes and other storms could increase as a result of an abrupt climate change, having large societal impacts. Efforts to improve forecasting and alert capabilities can reduce the loss of life by facilitating evacuations.

**Institutions.** Research should be conducted on improved institutions that will allow societies to withstand the greater risks associated with climate change, for example, water systems that better withstand drought, and insurance systems that hold up to increased demands for losses due to fires, floods, and storms.

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**Committee on Abrupt Climate Change: Richard B. Alley** (*Chair*), Pennsylvania State University, University Park; **Jochem Marotzke**, Southampton Oceanography Centre, United Kingdom; **William Nordhaus**, Yale University, New Haven, Connecticut; **Jonathan Overpeck**, University of Arizona, Tucson; **Dorothy Peteet**, National Aeronautics and Space Administration, New York, New York; **Roger Pielke, Jr.**, Center for Science and Technology Policy Research, University of Colorado, Boulder; **Raymond Pierrehumbert**, University of Chicago, Illinois; **Peter Rhines**, University of Washington, Seattle; **Thomas Stocker**, University of Bern, Switzerland; **Lynne Talley**, Scripps Institution of Oceanography, La Jolla, California; **J. Michael Wallace**, University of Washington, Seattle.

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**For more information**, contact the Ocean Studies Board at 202-334-2714. *Abrupt Climate Change: Inevitable Surprises* is available from the National Academies Press, 500 Fifth Street, NW, Washington, DC 20001; 800-624-6242 or 202-334-3313 (in the Washington area); [www.nap.edu](http://www.nap.edu).

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