NATIONAL ACADEMY OF SCIENCES
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REPORT IN BRIEF

Abrupt Impacts of Climate Change: Anticipating Surprises

Both abrupt changes in the physical climate system and steady changes in climate that can trigger abrupt changes in other physical, biological, and human systems present possible threats to nature and society. Abrupt change is already underway in some systems, and large scientific uncertainties about the likelihood of other abrupt changes highlight the need for further research. However, with recent advances in understanding of the climate system, some potential abrupt changes once thought to be imminent threats are now considered unlikely to occur this century. This report summarizes the current state of knowledge on potential abrupt changes to the ocean, atmosphere, ecosystems, and high latitude areas, and identifies key research and monitoring needs. The report calls for action to develop an abrupt change early warning system to help anticipate future abrupt changes and reduce their impacts.



Credits: (*left*) Landsat 7 Science Team and NASA GSFC; (*center*) youTrust.org; (*right*) ©iStock.com/Moorefam

The possibility of abrupt climate change—large shifts in climate that take place over periods as short as decades or even years—is the topic of increasing scientific research because of the potential for such changes to happen faster than human or natural systems could respond. Such rapid changes have taken place before: for example, information on past conditions from sources such as fossils and ice cores provides evidence of sudden shifts in ocean and air circulation in Earth's past (see Box 1). Now, with the current rate of carbon emissions changing the climate system at an accelerating rate, there is growing concern over the increased potential for abrupt climate changes in the near future.

A growing body of research is helping scientists gain a better understanding of abrupt climate change. There is a new recognition that, in addition to abrupt changes in the climate system itself, steady climate change can cross thresholds that trigger abrupt changes in other physical, natural, and human systems. For example, human infrastructure typically has been built to accommodate current climate variability, but gradual climate changes can cause abrupt changes in its utility—such as when rising sea levels suddenly surpass sea

Box 1. Abrupt Change in Earth's Past

One example of past abrupt change in Earth's climate occurred at the end of the Younger Dryas, a millennium-long period of cold climatic conditions and drought in the Northern Hemisphere that occurred about 12,000 years ago. The Younger Dryas abruptly terminated in a few decades or less—an event associated with the extinction of 72 percent of the large-bodied mammals in North America.

What is Abrupt Change?

Abrupt change can take place in the physical climate system (termed "abrupt climate change") and in the physical, biological, or human systems as a result of steady climate change (termed "abrupt climate impacts"). The primary timescale of concern is years to decades. A key characteristic of these changes is that they can unfold faster than expected, planned for, or budgeted for, forcing a reactive, rather than proactive, mode of behavior. These changes can propagate systemically, rapidly affecting multiple interconnected areas of concern.

Figure 1. As climate changes, some species may fare better in the new conditions, causing abrupt shifts in the balance of ecosystems. For example, the warmer temperatures brought by climate change have led to outbreaks of pine bark beetles (*left*) by speeding up reproductive cycles and allowing more beetles to survive over winter. Increased populations of the insects have destroyed large areas of this Colorado forest.

Credits: (*left*) Dion Manastyrski, (*right*) Anthony Barnosky

walls, or when thawing permafrost causes the sudden collapse of pipelines, buildings, or roads.

Ecosystems also are susceptible to abrupt transitions when gradually changing climate conditions reach thresholds that affect the survival of plant and animal species. For example, as air and water temperatures rise, species such as the mountain pika and some ocean corals will no longer be able to survive in their current habitats, and will be forced to relocate or rapidly adapt. Those populations that are unable to do so will be in danger of extinction.

Better scientific understanding and improved abilities to observe and simulate abrupt climate change would help researchers and policymakers anticipate abrupt changes and prioritize mitigation efforts. This report examines current knowledge about the likelihood and timing of potential abrupt climate changes, discusses the need for developing an abrupt change early warning system to help anticipate major changes before they occur, and identifies gaps in scientific understanding, monitoring, and modeling capabilities.

Current Scientific Knowledge of Abrupt Changes

Recent data show several abrupt changes are already underway, making these changes a primary concern for near-term societal decision making and a priority for research. For example, warmer Arctic temperatures have caused a rapid decline in sea ice over the past decade (see Figure 2). This rapid decrease could potentially have large and irreversible effects on various components of the Arctic ecosystem, as well as substantial impacts on Arctic shipping and resource extraction with significant geopolitical ramifications. Understanding and predicting future changes in Arctic sea ice will require maintained and expanded observations of sea ice thickness and extent, as well as improved modeling of sea ice within global and regional climate models.

Another abrupt change already underway is increased extinction pressure on plant and animal species. The current pace of climate change is probably as fast as any warming event in the past 65 million years, and the rate is projected to increase over the next 30 to 80 years. Biologically important climate attributes—such as the number of frost-free days, length and timing of growing seasons, and the frequency and intensity of extreme events—are changing so rapidly that some species can neither move nor adapt fast enough. This gradual climate pressure, in combination with other sources of habitat loss, degradation, and over-exploitation, is already putting some species at greater risk of extinction.

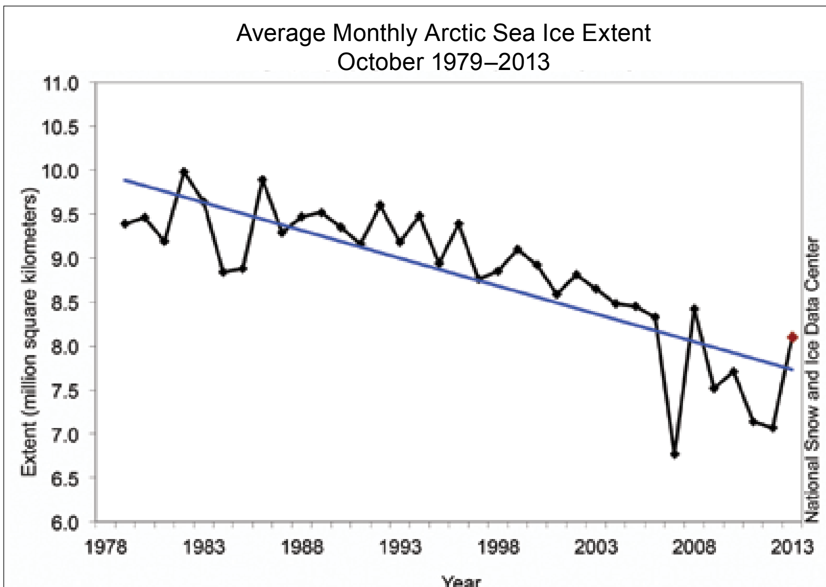

Figure 2. Late summer Arctic sea ice extent has decreased substantially since the satellite data record began in 1979, and has been particularly low over the past seven summers.

Credit: National Snow and Ice Data Center

Large uncertainties about the likelihood of some potential abrupt changes highlight the need for expanded research and monitoring. For example, as climate warms, the destabilization of the West Antarctic Ice Sheet could raise sea level rapidly, with serious consequences for people living in coastal communities. Many of the glaciers of West Antarctica are particularly sensitive to a warming climate because their bases are located well below sea level, and are therefore sensitive to thermal erosion by the warming oceans (see Figure 3). In addition, rising sea level helps float the ice, further destabilizing the ice sheets. Such a rapid destabilization of the West Antarctic Ice Sheet is plausible this century, with an unknown although probably low probability. Current ice-sheet models do not account for the full suite of physical processes that take place where ice meets ocean—and therefore, future rates of sea-level rise from the West Antarctic Ice Sheet may be underestimated. Improved understanding of key physical processes and inclusion of them in models, together with improved projections of changes in the surrounding ocean, are required to reduce uncertainties and to better quantify worst-case scenarios.

Two decades of focused research has helped scientists determine that some abrupt changes, widely discussed in the scientific literature because they were once identified as potential threats, are unlikely to take place over the near term. For example, the probability of a rapid shutdown within this century of the Atlantic Meridional Overturning Circulation—an ocean current that moves warm water from the upper layers of the Atlantic northwards and brings colder water south—is now understood to be low. A second example is the potential rapid release of large amounts of carbon currently stored in high latitude regions as permafrost soils and methane-containing ices. According to current scientific understanding, as temperatures rise these carbon stores are poised to play a significant amplifying role in the century-scale buildup of greenhouse gases in the atmosphere—but are unlikely to do so abruptly.

The committee examined the available evidence for these and several other potential abrupt changes to the ocean, atmosphere, ecosystems, and high latitude regions and assessed the likelihood for each, identifying key research and monitoring needs. This work is summarized in **Table S.1***.

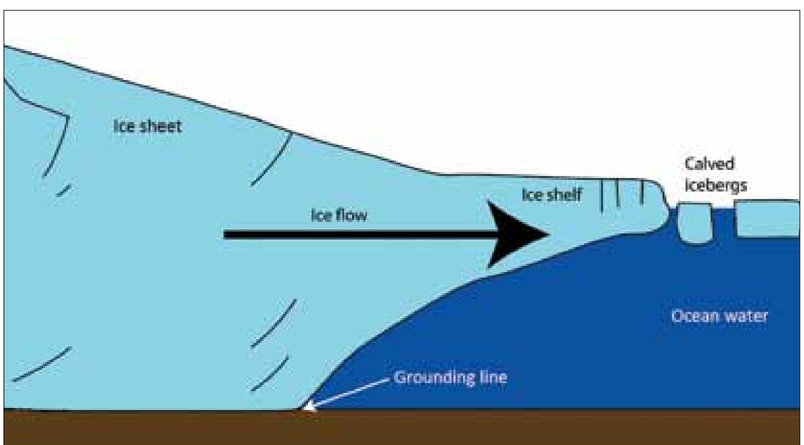

Figure 3. The most rapid melting of ice—which could lead to abrupt sea-level rise—occurs in ice sheets flowing into deep water capable of warming ice from below and carrying away large volumes of calved icebergs. However, current ice sheet models do not account for the full suite of processes that take place where ice meets ocean.

Credit: www.AntarcticGlaciers.org, Bethan Davies

Anticipating Surprises: The Abrupt Change Early Warning System

Some surprises in the climate system may be inevitable, but with improved scientific monitoring and a better understanding of the climate system it could be possible to anticipate abrupt change before it occurs and reduce the potential consequences. Building this ability will require careful monitoring of climate conditions, improved models for projecting changes, and the interpretation and synthesis of scientific data using novel analysis techniques. To address these needs, the committee believes that action is needed to develop an abrupt change early warning system.

Such a system would be part of an overall risk management strategy, providing information for hazard identification and risk assessment. These data would help identify vulnerabilities to assist in tailoring risk mitigation and preparedness efforts and to ensure warnings result in appropriate protective actions, with the ultimate goal or preempting catastrophes.

Much is already known about the design, implementation, and sustainability of early warning systems. Planning for an abrupt change early warning system would benefit from leveraging the experience and knowledge gained as part of existing early warning programs, such as the National Integrated Drought Information System or the Famine Early Warning System

Network. Providing a complete roadmap to a successful abrupt change early warning system was beyond the scope of this report, but the committee has outlined its initial thoughts on what would make such a system successful:

Monitoring: An abrupt change early warning system should expand upon existing monitoring networks, protect and/or augment important networks that are already in place, and develop new ones as needed. Maintaining and expanding these monitoring networks in an era of budget cuts is an area of concern. Examples of specific monitoring needs are listed in **Table S.1***.

Modeling: A successful abrupt change early warning system must consistently iterate between data collection, model testing and improvement, and model predictions that suggest better data collection. Examples of future modeling needs are listed in **Table S.1***.

Synthesis: A necessary part of an abrupt change early warning system is synthesizing knowledge to avoid the trap of data collection without continuing and evolving data analysis and model integration. This will require dedicated teams of researchers, improved collaborative networks, enhanced educational activities, and innovative tools for data analysis and modeling techniques.

To implement an abrupt change early warning system, it will be important to integrate the various components of the project, pay attention to stakeholder priorities, and build the ability to be flexible and adaptive. Thus, designing and implementing an abrupt change early warning system will need to be an iterative process that is revisited and refined as understanding of abrupt climate change, impacts, and social vulnerabilities evolves.

The organizational structure of an abrupt change early warning system would capitalize on existing programs, but will also need to capture the interconnectedness of climate and human systems. Although it could eventually be run as a large, overarching program, such a system might better be started through the coordination, integration, and expansion of existing and planned smaller programs. Careful coordination—to reduce duplication of efforts, maximize resources, and facilitate data and information sharing—will be essential to a successful abrupt change early warning system.

Abrupt climate changes present substantial risks to society and nature. Although there is still much to learn, to ignore the threat of abrupt change would lead to more costs, loss of life, suffering, and environmental degradation. The time is here to be serious about the threat of tipping points, so as to better anticipate and prepare ourselves for the inevitable surprises.

* Table S.1 is available online at http://dels.nas.edu/resources/static-assets/materials-based-on-reports/special-products/abrupt-impacts-table.pdf

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The National Academies appointed the above committee of experts to address the specific task requested by the National Oceanic and Atmospheric Administration, the National Science Foundation, the United States intelligence community, and the National Academies. The members volunteered their time for this activity; their report is peer-reviewed and the final product signed off by both the committee members and the National Academies. This report brief was prepared by the National Research Council based on the committee's report.

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