U.S. Climate Change Science Program

Synthesis and Assessment Report 3.4

Abrupt Climate Change Summary and Findings

Rapid change in glaciers, ice sheets, and hence sea level	Changes to the hydrologic cycle, including drought and flooding	Change in the Atlantic Meridional Overturning Circulation (AMOC)	Rapid release to the atmosphere of methane
Will there be an abrupt change in sea level?	Will there be an abrupt change in the hydrologic cycle?	Will there be an abrupt change in the Atlantic Meridional Overturning Circulation?	Will there be abrupt change in atmospheric methane?

Abrupt climate change is defined as a large-scale change in the climate system that takes place over a few decades or less, persists (or is anticipated to persist) for at least a few decades, and causes substantial disruptions in human and natural systems.

Four types of abrupt change in the geologic record stand out as being so rapid and large in their impact that, if they were to recur, they would pose clear risks to society in terms of our ability to adapt:

- **Rapid change in glaciers, ice sheets, and hence sea level.**
- **Widespread and sustained changes to the hydrologic cycle, including drought and flooding.**
- **Abrupt change in the Atlantic Meridional Overturning Circulation, a critical component of global climate, characterized by the northward flow of warm, salty water in the upper layers of the Atlantic Ocean.**
- **Rapid release to the atmosphere of methane, a powerful greenhouse gas, trapped in permafrost and in ocean sediments.**

The following questions from the report address the potential for abrupt climate change related to global warming this century.

Will there be an abrupt change in sea level?

Small changes in sea-level rise have significant societal and economic impacts through coastal erosion, increased susceptibility to storm surges and resultant flooding, groundwater contamination by salt intrusion, loss of coastal wetlands, and other issues. An increase in global sea level largely reflects a contribution from the expansion of warming sea water and from the melting of land ice.

An abrupt change in sea level from the melting of land ice is possible, but predictions are highly uncertain due to shortcomings in climate models involving key physical processes. For example, recent rapid changes at the edges of the Greenland and West Antarctic ice sheets show acceleration of flow and thinning, with the velocity of some glaciers increasing more than twofold. Glacier accelerations causing this imbalance have been related to enhanced surface meltwater production penetrating to the bed that lubricates glacier flow as well as to ice-shelf removal, ice-front retreat and glacier ungrounding that reduce resistance to flow.

The present generation of climate models does not capture these processes.

Additionally, interaction of warm ocean waters with the periphery of the large ice sheets represents a strong potential cause of abrupt change in the big ice sheets. Regions likely to experience future rapid changes in ice volume are those where ice is grounded well below sea level, such as the West Antarctic Ice Sheet or large glaciers in Greenland.

Inclusion of these ice-sheet and glacier processes into future modeling experiments will likely lead to sea-level rise projections for the end of the 21st century that substantially exceed those presented in the Intergovernmental Panel on Climate Change fourth assessment report (IPCC AR4).

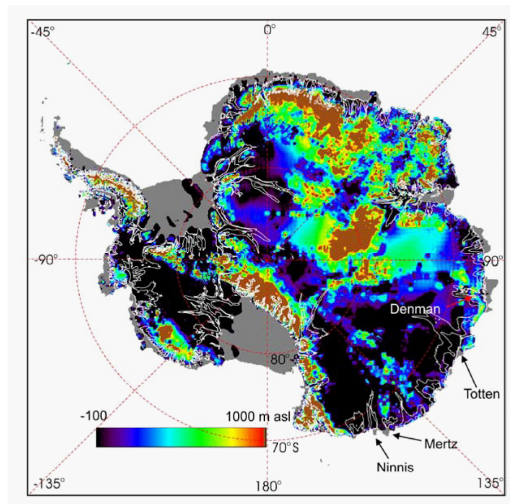


Image of Antarctica highlighting areas below sea level (in black), fringing ice shelves (in dark gray), and areas above sea level (in rainbow colors). Interaction of warm ocean waters with the periphery of the ice sheet represents a strong potential cause of abrupt change in ice volume. Regions likely to experience future rapid changes are those where ice is grounded well below sea level.

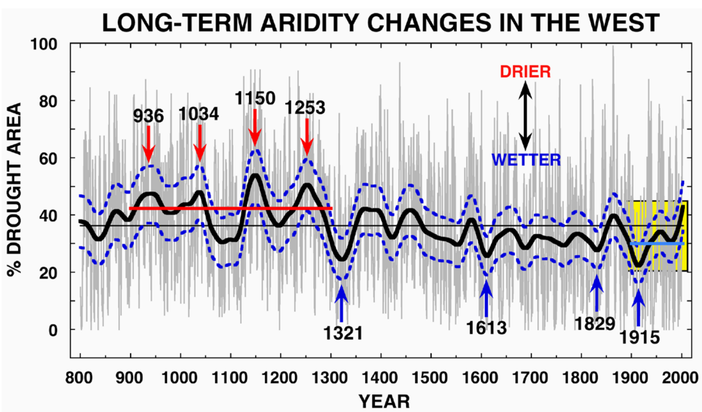
Will there be an abrupt change in the hydrologic cycle?

Variations in water supply—protracted droughts in particular—are among the greatest natural hazards facing the United States and the globe today and in the foreseeable future. Droughts can develop faster than the timescale needed for human societies to adapt to the change. Thus, a severe drought that persists for several years to a decade or more can be regarded as an abrupt change, although it may not reflect a permanent change of state of the climate system.

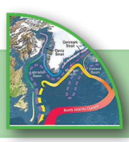
Climate model studies over North America and the global subtropics indicate that subtropical drying will likely intensify and persist in the future due to greenhouse warming. This drying is predicted to move northward into the southwestern United States. If the model results are correct, then the southwestern United States may be beginning an abrupt period of increased drought.

These anticipated changes in land hydrology will increase problems at both extremes of the water cycle, stressing water supplies in many arid and semi-arid regions while worsening flood hazards and erosion in many wet areas.

Historic droughts over North America have been severe, but not nearly as prolonged as a series of “megadroughts” reconstructed from tree rings from about A.D. 900 up to about A.D. 1600. Because these megadroughts occurred under conditions not too unlike today’s, the United States still has the capacity to enter into a prolonged state of dryness even in the absence of increased greenhouse-gas forcing.



Percent of area affected by drought in the western United States over time. Examples of “megadroughts” are indicated by the red arrows. The modern era is highlighted in yellow for comparison.



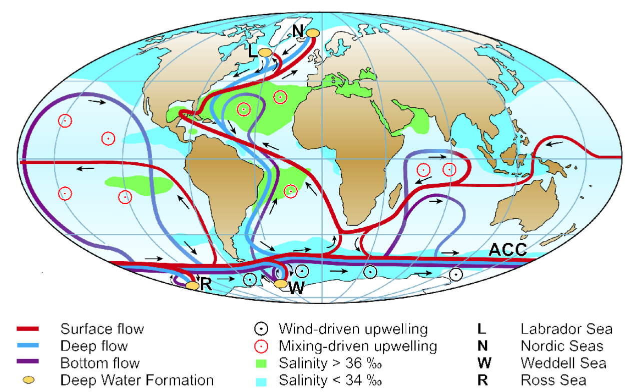
Will there be an abrupt change in the Atlantic Meridional Overturning Circulation (AMOC)?

The AMOC is an important component of the Earth’s climate system, characterized by a northward flow of warm, salty water in the upper layers of the Atlantic and a southward flow of colder water in the deep Atlantic. This ocean-current system transports a substantial amount of heat from the Tropics and Southern Hemisphere toward the North Atlantic, where the heat is transferred to the atmosphere. Changes in this ocean circulation could have a profound impact on many aspects of the global climate system including summer climate conditions over North America and Western Europe.

It is very likely that the strength of the AMOC will decrease by approximately 25–30 percent over the course of the 21st century in response to increasing greenhouse gases, which will affect the distribution of heat in the North Atlantic. Even with the projected moderate AMOC weakening, it is still very likely that on multidecadal to century time scales a warming trend will occur over most of the European region downstream of the North Atlantic Current in response to increasing greenhouse gases, as well as over North America.

It is very unlikely that the AMOC will undergo a collapse or an abrupt transition to a weakened state during the 21st century. It is also unlikely that the AMOC will collapse beyond the end of the 21st century because of global warming, although the possibility cannot be entirely excluded.

The summer arctic sea-ice cover has undergone dramatic retreat since satellite records began in 1979, amounting to a loss of almost 30 percent of the September ice cover in 29 years. Climate model simulations suggest that rapid and sustained September arctic ice loss is likely in future 21st century climate projections. It is notable that climate models are generally conservative in the modeled rate of Arctic ice loss as compared to observations, suggesting that future ice retreat could occur even more abruptly than simulated in almost all current models.



Schematic of the ocean circulation associated with the global Meridional Overturning Circulation (MOC), with special focus on the Atlantic section of the flow (AMOC).

Will there be abrupt change in atmospheric methane?

Methane is a potent greenhouse gas. Concern about future abrupt release in atmospheric methane stems largely from the possibility that the massive amounts of methane present in a solid form known as methane hydrate in ocean sediments and in permafrost may become unstable in the face of global warming. Warming or release of pressure can destabilize methane hydrate, forming free gas that may ultimately be released to the atmosphere.

Although there are a number of suggestions in the literature about the possibility of a dramatic abrupt release of methane to the atmosphere, modeling and evidence from ancient ice cores do not indicate such a release to the atmosphere within the last 100,000 years or in the near future.

While a catastrophic release of methane to the atmosphere in the next century appears very unlikely, it is very likely that climate change will accelerate the pace of persistent emissions from both hydrate sources and wetlands. Current models suggest that wetland emissions could double in the next century. Methane release from the hydrate reservoir will likely have a significant influence on global warming over the next 1,000 to 100,000 years.

The most likely region to experience a dramatic change in natural methane emission is the northern high latitudes, where there is increasing evidence for accelerated warming, enhanced precipitation, and widespread permafrost thaw.

Options for enhancing abrupt climate change research include:

- Reducing uncertainties in estimates of mass balance and deriving better measurements of glacier and ice-sheet topography and velocity through improved observation of glaciers and ice sheets
- Addressing shortcomings in ice-sheet models currently lacking proper representation of the physics of the processes likely to be most important in potentially causing an abrupt loss of ice and resulting sea-level rise
- Improving existing capabilities to forecast short- and long-term drought conditions and making this information more useful and timely for decision-making to reduce drought impacts
- Improving our understanding of the dynamic causes of long-term changes in oceanic conditions, the atmospheric responses to these ocean conditions, and the role of soil-moisture feedbacks to advance drought prediction capabilities
- Improving the theoretical understanding of the processes controlling the AMOC, including its inherent variability and stability, especially with respect to climate change
- Improving long-term monitoring of the AMOC, in concert with parallel efforts to more confidently simulate the AMOC and predict its future behavior, including the risk of an abrupt change
- Prioritizing the monitoring of atmospheric methane abundance and its isotopic composition with spatial density sufficient to allow detection of any change in net emissions from northern and tropical wetland regions
- Prioritizing methane modeling efforts focused on (i) processes involved in releasing methane from the hydrate reservoir and (ii) the current and future climate-driven acceleration of release of methane from wetlands and terrestrial hydrate deposits
- Improving understanding of past abrupt changes through the collection and analysis of those proxy records that most effectively document past abrupt changes in sea level, ice-sheet and glacier extent, distribution of drought, the AMOC, and methane and their impacts

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