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ABRUPT CLIMATE CHANGE

Should We Be Worried?



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www.whoi.edu/institutes/occi/hottopics_climatechange.html

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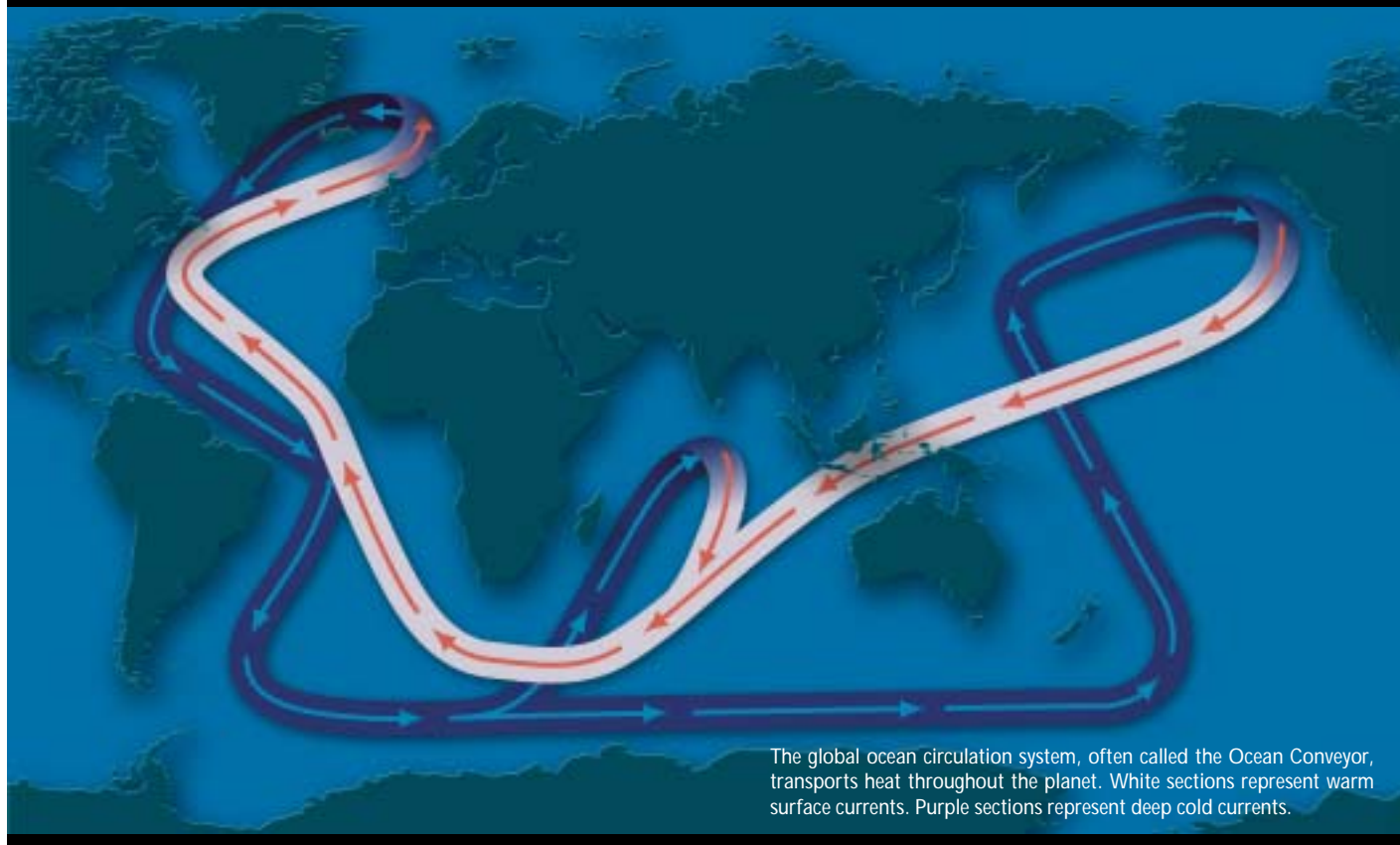
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The Global Ocean Conveyor



The global ocean circulation system, often called the Ocean Conveyor, transports heat throughout the planet. White sections represent warm surface currents. Purple sections represent deep cold currents.

Jayne Doucette, WHOI Graphic Services

Are we overlooking potential abrupt climate shifts?

Most of the studies and debates on potential climate change, along with its ecological and economic impacts, have focused on the ongoing buildup of industrial greenhouse gases in the atmosphere and a *gradual* increase in global temperatures. This line of thinking, however, fails to consider another potentially disruptive climate scenario. It ignores recent and rapidly advancing evidence that Earth's climate repeatedly has shifted *abruptly* and *dramatically* in the past, and is capable of doing so in the future.

Fossil evidence clearly demonstrates that Earth's climate can shift gears *within a decade*, establishing new and different patterns that can persist for decades to centuries. In addition, these climate shifts do not necessarily have universal, global effects. They can generate a counterintuitive scenario: Even as the earth as a whole continues to warm gradually, large regions may experience a precipitous and disruptive shift into colder climates.

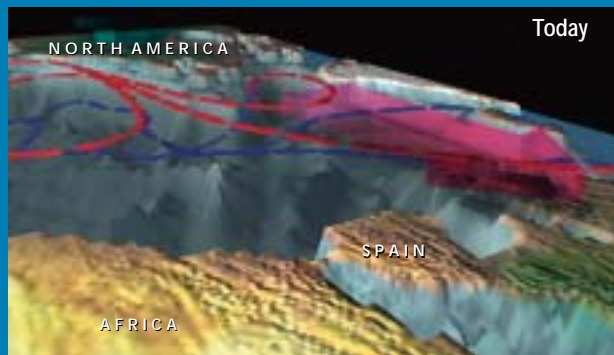
This new paradigm of abrupt climate change has been well established over the last decade by research of ocean, earth

and atmosphere scientists at many institutions worldwide. But the concept remains little known and scarcely appreciated in the wider community of scientists, economists, policy makers, and world political and business leaders. Thus, world leaders may be planning for climate scenarios of global warming that are opposite to what might actually occur.¹

It is important to clarify that we are *not* contemplating a situation of *either* abrupt cooling *or* global warming. Rather, abrupt regional cooling and gradual global warming can unfold simultaneously. Indeed, greenhouse warming is a destabilizing factor that makes abrupt climate change more probable. According to a 2002 report by the US National Academy of Sciences, "available evidence suggests that abrupt climate changes are not only possible but likely in the future, potentially with large impacts on ecosystems and societies."²

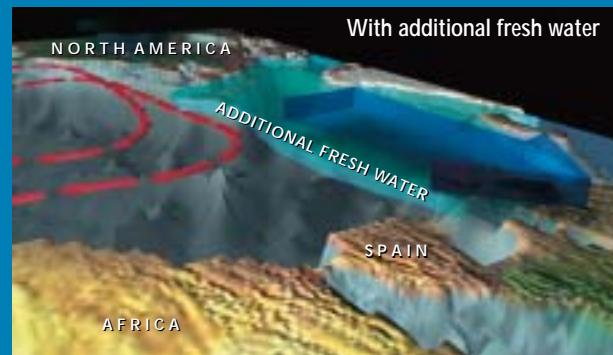
The *timing* of any abrupt regional cooling in the future also has critical policy implications. An abrupt cooling that happens within the next two decades would produce different climate effects than one that occurs after another century of continuing greenhouse warming.

The Conveyor's Achilles' Heel?



Today

The Ocean Conveyor is propelled by the sinking of cold, salty (and therefore denser) waters in the North Atlantic Ocean (blue lines). That creates a void that pulls warm, salty surface waters northward (red lines). The ocean gives up its heat to the atmosphere above the North Atlantic Ocean, and prevailing winds (large red arrows) carry the heat eastward to warm Europe.



With additional fresh water

If too much fresh water enters the North Atlantic, its waters could stop sinking. The Conveyor would cease. Heat-bearing Gulf Stream waters (red lines) would no longer flow into the North Atlantic, and European and North American winters would become more severe. (See computer animation at www.whoi.edu/institutes/occi/climatechange_wef.html)

Are we ignoring the oceans' role in climate change?

Fossil evidence and computer models demonstrate that Earth's complex and dynamic climate system has more than one mode of operation. Each mode produces different climate patterns.

The evidence also shows that Earth's climate system has sensitive thresholds. Pushed past a threshold, the system can jump quickly from one stable operating mode to a completely different one—"just as the slowly increasing pressure of a finger eventually flips a switch and turns on a light," the NAS report said.

Scientists have so far identified only one viable mechanism to induce large, global, abrupt climate changes: a swift reorganization of the ocean currents circulating around the earth. These currents, collectively known as the Ocean Conveyor, distribute vast quantities of heat around our planet, and thus play a fundamental role in governing Earth's climate.

The oceans also play a pivotal role in the distribution and availability of life-sustaining water throughout our planet. The oceans are, by far, the planet's largest source of water. Evaporation from the ocean transfers huge amounts of water vapor to the atmosphere, where it travels aloft until it cools, condenses, and eventually precipitates in the form of rain or snow. Changes in ocean circulation or water properties can disrupt this hydrological cycle on a global scale, causing flooding and long-term droughts in various regions. The El Niño phenomenon is but a hint of how oceanic changes can dramatically affect where and how much precipitation falls throughout the planet.

Thus, the oceans and the atmosphere constitute *intertwined* components of Earth's climate system. But our present knowl-

edge of ocean dynamics does not match our knowledge of atmospheric processes. The oceans' essential role is too often neglected in our calculations.

Does Earth's climate system have an 'Achilles' heel'?

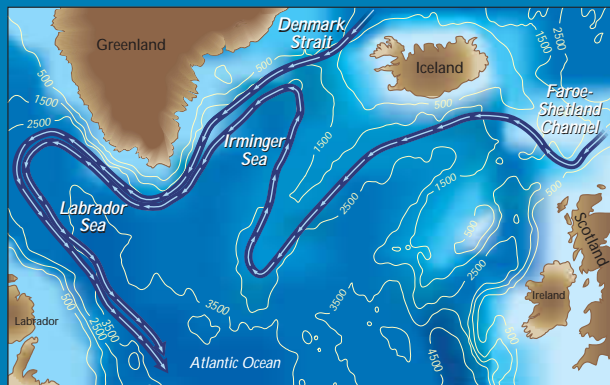
Here is a simplified description of some basic ocean-atmosphere dynamics that regulate Earth's climate:

The equatorial sun warms the ocean surface and enhances evaporation in the tropics. This leaves the tropical ocean saltier. The Gulf Stream, a limb of the Ocean Conveyor, carries an enormous amount of heat-laden, salty water up the East Coast of the United States, and then northeast toward Europe.

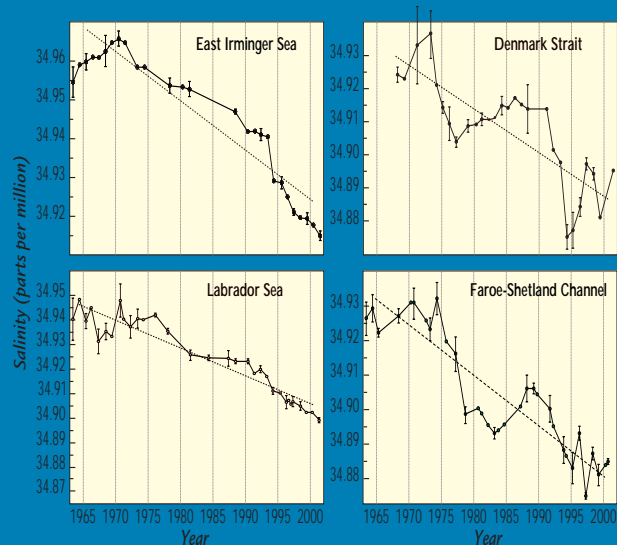
This oceanic heat pump is an important mechanism for reducing equator-to-pole temperature differences. It moderates Earth's climate, particularly in the North Atlantic region. Conveyor circulation increases the northward transport of warmer waters in the Gulf Stream by about 50 percent. At colder northern latitudes, the ocean releases this heat to the atmosphere—especially in winter when the atmosphere is colder than the ocean and ocean-atmosphere temperature gradients increase. The Conveyor warms North Atlantic regions by as much as 5° Celsius and significantly tempers average winter temperatures.

But records of past climates—from a variety of sources such as deep-sea sediments and ice-sheet cores—show that the Conveyor has *slowed* and *shut down* several times in the past. This shutdown curtailed heat delivery to the North Atlantic and caused substantial cooling throughout the region. One earth scientist has called the Conveyor "the Achilles' heel of our climate system."³

Dramatic Changes in the North Atlantic



Subpolar seas bordering the North Atlantic have become noticeably less salty since the mid-1960s, especially in the last decade. This is the largest and most dramatic oceanic change ever measured in the era of modern instruments. This has resulted in a freshening of the deep ocean in the North Atlantic, which in the past disrupted the Ocean Conveyor and caused abrupt climate changes.



What can disrupt the Ocean Conveyor?

Solving this puzzle requires an understanding of what launches and drives the Conveyor in the first place. The answer, to a large degree, is salt.

For a variety of reasons, North Atlantic waters are relatively salty compared with other parts of the world ocean. Salty water is denser than fresh water. Cold water is denser than warm water. When the warm, salty waters of the North Atlantic release heat to the atmosphere, they become colder and begin to sink.

In the seas that ring the northern fringe of the Atlantic—the Labrador, Irminger, and Greenland Seas—the oceans release large amounts of heat to the atmosphere and then a great volume of cold, salty water sinks to the abyss. This water flows slowly at great depths into the South Atlantic and eventually throughout the world's oceans.

Thus, the North Atlantic forms the headwaters of the Ocean Conveyor. The plunge of this great mass of cold, salty water helps propel the global ocean's conveyor-like circulation system. It also actively draws warm, salty tropical surface waters northward to replace the sinking waters. This process is called "thermohaline circulation," from the Greek words "thermos" (heat) and "halos" (salt).

If cold, salty North Atlantic waters did not sink, a primary force driving global ocean circulation could slacken and cease. Existing currents could weaken or be redirected. The resulting reorganization of the ocean's circulation would reconfigure Earth's climate patterns.

Computer models simulating ocean-atmosphere climate dynamics indicate that the North Atlantic region would cool 3° to 5° Celsius if Conveyor circulation were totally disrupted. It would produce winters twice as cold as the worst winters on record in the eastern United States in the past century. In addition, previous Conveyor shutdowns have been linked with widespread droughts throughout the globe.

It is crucial to remember two points: 1) If thermohaline circulation shuts down and induces a climate transition, severe winters in the North Atlantic region would likely persist for decades to centuries—until conditions reached another threshold at which thermohaline circulation might resume. 2) Abrupt regional cooling may occur even as the earth, on average, continues to warm.

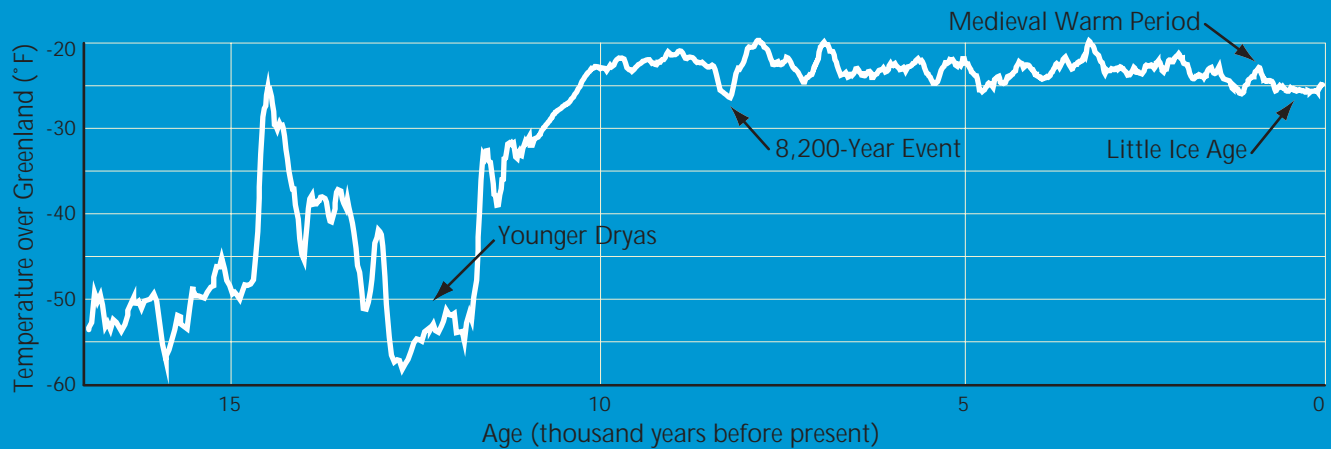
Are worrisome signals developing in the ocean?

If the climate system's Achilles' heel is the Conveyor, the Conveyor's Achilles' heel is the North Atlantic. An influx of fresh water into the North Atlantic's surface could create a lid of more buoyant fresh water, lying atop denser, saltier water. This fresh water would effectively cap and insulate the surface of the North Atlantic, curtailing the ocean's transfer of heat to the atmosphere.

An influx of fresh water would also dilute the North Atlantic's salinity. At a critical but unknown threshold, when North Atlantic waters are no longer sufficiently salty and dense, they may stop sinking. An important force driving the Conveyor could quickly diminish, with climate impacts resulting within a decade.

In an important paper published in 2002 in *Nature*, oceanog-

A Long Record of Abrupt Climate Changes



Ice cores extracted from the two-mile-thick Greenland ice sheet preserve records of ancient air temperatures. The records show several times when climate shifted in time spans as short as a decade.

- **The Younger Dryas**—About 12,700 years ago, average temperatures in the North Atlantic region abruptly plummeted nearly 5°C and remained that way for 1,300 years before rapidly warming again.
- **The 8,200-Year Event**—A similar abrupt cooling occurred 8,200 years ago. It was not so severe and lasted only about a century. But if

a similar cooling event occurred today, it would be catastrophic.

- **The Medieval Warm Period**—An abrupt warming took place about 1,000 years ago. It was not nearly so dramatic as past events, but it nevertheless allowed the Norse to establish settlements in Greenland.
- **The Little Ice Age**—The Norse abandoned their Greenland settlements when the climate turned abruptly colder 700 years ago. Between 1300 and 1850, severe winters had profound agricultural, economic, and political impacts in Europe.

raphers monitoring and analyzing conditions in the North Atlantic concluded that the North Atlantic has been freshening dramatically—continuously for the past 40 years but especially in the past decade.⁴ The new data show that since the mid-1960s, the subpolar seas feeding the North Atlantic have steadily and noticeably become less salty to depths of 1,000 to 4,000 meters. *This is the largest and most dramatic oceanic change ever measured in the era of modern instruments.*

At present the influx of fresher water has been distributed throughout the water column. But at some point, fresh water may begin to pile up at the surface of the North Atlantic. When that occurs, the Conveyor could slow down or cease operating.

Signs of a possible slowdown already exist. A 2001 report in *Nature* indicates that the flow of cold, dense water from the Norwegian and Greenland Seas into the North Atlantic has diminished by at least 20 percent since 1950.⁵

At what threshold will the Conveyor cease?

The short answer is: We do not know. Nor have scientists determined the relative contributions of a variety of sources that may be adding fresh water to the North Atlantic. Among the suspects are melting glaciers or Arctic sea ice, or increased precipitation falling directly into the ocean or entering via the great

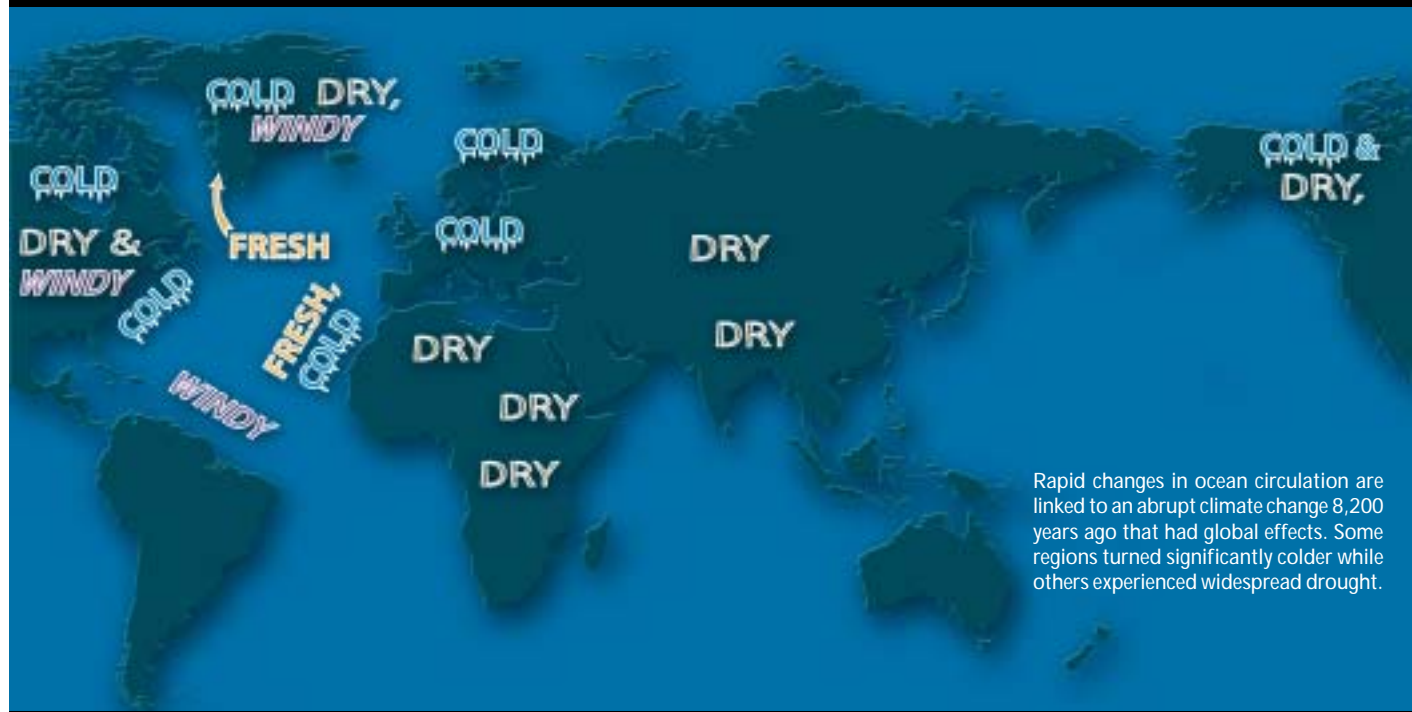
ivers that discharge into the Arctic Ocean.⁶ Global warming may be an exacerbating factor.

Though we have invested in, and now rely on, a global network of meteorological stations to monitor fast-changing atmospheric conditions, at present *we do not have a system in place for monitoring slower-developing, but critical, ocean circulation changes.*

The great majority of oceanographic measurements was taken throughout the years by research ships and ships of opportunity—especially during the Cold War era for anti-submarine warfare purposes. Many were taken incidentally by Ocean Weather Stations—a network of ships stationed in the ocean after World War II, whose primary duty was to guide transoceanic airplane flights. Starting in the 1970s, satellite technology superseded these weather ships. The demise of the OWS network and the end of the Cold War have left oceanographers with access to *far fewer* data in recent years than they had in past decades.

Initial efforts to remedy this deficit are under way,⁷ but these efforts are nascent and time is of the essence. Satellites can measure wind stress and ocean circulation globally, *but only at the ocean surface.* Also recently launched (but not nearly fully funded) is the Argo program—an international program to seed the global ocean with an armada of some 3,000 free-floating buoys that measure *upper* ocean temperature and salinity. Measuring *deep* ocean cur-

8,200 Years Ago—An Abruptly Colder, Drier Earth



Rapid changes in ocean circulation are linked to an abrupt climate change 8,200 years ago that had global effects. Some regions turned significantly colder while others experienced widespread drought.

R. B. Alley et al., in *Geology*, 1997

rents is critical for observing Conveyor behavior, but it is more difficult. Efforts have just begun to measure deep ocean water properties and currents at strategic locations with long-term moored buoy arrays, but vast ocean voids remain unmonitored.

New ocean-based instruments also offer the potential to reveal the ocean's essential, but poorly understood, role in the hydrological cycle—which establishes global rainfall and snowfall patterns. Global warming affects the hydrological cycle because a warmer atmosphere carries more water. This, in turn, has implications for greenhouse warming, since water vapor itself is the most abundant, and often overlooked, greenhouse gas.

What can the past teach us about the future?

Revealing the past behavior of Earth's climate system provides powerful insight into what it may do in the future. Geological records confirm the potential for abrupt thermohaline-induced climate transitions that would generate severe winters in the North Atlantic region. A bad winter or two brings inconvenience that societies can adapt to with small, temporary adjustments. But a persistent string of severe winters, lasting decades to a century, can cause glaciers to advance, rivers to freeze, and sea ice to grow and spread. It can render prime agricultural lands unfarmable.

About 12,700 years ago, as Earth emerged from the most re-

cent ice age and began to warm, the Conveyor was disrupted. Within a decade, average temperatures in the North Atlantic region plummeted nearly 5° Celsius.

This cold period, known as the Younger Dryas, lasted 1,300 years. It is named after an Arctic wildflower. Scientists have found substantial evidence that cold-loving *dryas* plants thrived during this era in European and US regions that today are too warm. Deep-sea sediment cores show that icebergs extended as far south as the coast of Portugal. The Younger Dryas ended as abruptly as it began. Within a decade, North Atlantic waters and the regional climate warmed again to pre-Younger Dryas levels.

A similar cooling occurred 8,200 years ago. It lasted only about a century—a blip in geological time, but a catastrophe if such a cooling occurred today.

Are 'little ice ages' and 'megadroughts' possible?

Scientists are investigating whether changes in ocean circulation may have played a role in causing or amplifying the "Little Ice Age" between 1300 and 1850. This period of abruptly shifting climate regimes and more severe winters had profound agricultural, economic, and political impacts in Europe and North America and changed the course of history.

During this era, the Norse abruptly abandoned their settlements in Greenland. The era is captured in the frozen landscapes

of Pieter Bruegel's 16th-century paintings and in the famous painting of George Washington's 1778 crossing of an icebound Delaware River, which rarely freezes today. But the era is also marked by persistent crop failures, famine, disease, and mass migrations. "The Little Ice Age," wrote one historian, "is a chronicle of human vulnerability in the face of sudden climate change."⁸

Societies are similarly vulnerable to abrupt climate changes that can turn a year or two of diminished rainfall into prolonged, severe, widespread droughts. A growing body of evidence from joint archaeological and paleoclimatological studies is demonstrating linkages among ocean-related climate shifts, "megadroughts," and precipitous collapses of civilizations, including the Akkadian empire in Mesopotamia 4,200 years ago, the Mayan empire in central America 1,500 years ago, and the Anasazi in the American Southwest in the late 13th century.⁹

Rapid changes in ocean circulation associated with the abrupt North Atlantic cooling event 8,200 years ago have also been linked simultaneously with widespread drying in the American West, Africa, and Asia.¹⁰ Regional cooling events also have been linked with changes in the Southwest Asian monsoon, whose rains are probably the most critical factor supporting civilizations from Africa to India to China.¹¹

What future climate scenarios should we consider?

The debate on global change has largely failed to factor in the inherently chaotic, sensitively balanced, and threshold-laden nature of Earth's climate system and the increased likelihood of abrupt climate change. Our current speculations about future climate and its impacts have focused on the Intergovernmental Panel on Climate Change, which has forecast gradual global warming of 1.4° to 5.8° Celsius over the next century.

It is prudent to superimpose on this forecast the potential for abrupt climate change induced by thermohaline shutdown. Such a change could cool down selective areas of the globe by 3° to 5° Celsius, while simultaneously causing drought in many parts of the world. These climate changes would occur quickly, even as other regions continue to warm slowly. It is critical to consider the economic and political ramifications of this geographically selective climate change. Specifically, the region most affected by a shutdown—the countries bordering the North Atlantic—is also one of the world's most developed.

The key component of this analysis is *when* a shutdown of the Conveyor occurs. Two scenarios are useful to contemplate:

Scenario 1: Conveyor slows down within next two decades.

Such a scenario could quickly and markedly cool the North Atlantic region, causing disruptions in global economic activity. These disruptions may be exacerbated because the climate changes occur in a direction opposite to what is commonly expected and they occur at a pace that makes adaptation difficult.

Scenario 2: Conveyor slows down a century from now.

In such a scenario, cooling of the North Atlantic region may partially or totally *offset* the major effects of global warming in this region. Thus, the climate of the North Atlantic region may rapidly return to one that more resembles today's—even as other parts of the world, particularly less-developed regions, experience the unmitigated brunt of global warming. If the Conveyor subsequently turns on again, the "deferred" warming may be delivered in a decade.

What can we do to improve our future security?

Ignoring or downplaying the probability of abrupt climate change could prove costly. Ecosystems, economies, and societies can adapt more easily to gradual, anticipated changes. Some current policies and practices may be ill-advised and may prove inadequate in a world of rapid and unforeseen climate change. The challenge to world leaders is to reduce vulnerabilities by enhancing society's ability to monitor, plan for, and adapt to rapid change.

All human endeavor hinges on the vicissitudes of climate. Thus, the potential for abrupt climate change should prompt us to re-examine possible impacts on many climate-affected sectors. They include: agriculture; water resources; energy resources; forest and timber management; fisheries; coastal land management; transportation; insurance; recreation and tourism; disaster relief; and public health (associated with climate-related, vector-borne diseases such as malaria and cholera).

Developing countries lacking scientific resources and economic infrastructures are especially vulnerable to the social and economic impacts of abrupt climate change. However, with growing globalization of economies, adverse impacts (although likely to vary from region to region) are likely to spill across national boundaries, through human and biotic migration, economic shocks, and political aftershocks, the National Academy of Sciences (NAS) report stated.

The key is to reduce our uncertainty about future climate change, and to improve our ability to predict what could happen and when. A first step is to establish the oceanic equivalent of our land-based meteorological instrument network. Such a network would begin to reveal climate-influencing oceanic processes that have been beyond our ability to grasp. These instruments, monitoring critical present-day conditions, can be coupled with enhanced computer modeling, which can project how Earth's climate system may react in the future. Considerably more research is also required to learn more about the complex ocean-air processes that induced rapid climate changes in the past, and thus how our climate system may behave in the future.

The NAS report is titled *Abrupt Climate Change: Inevitable Surprises*. Climate changes may be inevitable. But it is *not* inevitable for society to be surprised or ill-prepared.

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