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Talking Points

The Evidence for Global Warming

While the debate over what to do about [global warming](#) heats up even faster than the environment, scientists have made substantial progress in recent years in defining the threat and estimating its likely impacts. The picture they paint is worrisome. The evidence suggests that humans are altering the atmosphere in ways never before seen. The only question is how damaging the consequences might be, and what can be done to head off or adapt to the worst.

The research requires great sophistication and care because of the complexity of the Earth's climactic system. The world has been in a warming phase since the end of the [Little Ice Age](#), a prolonged cooling period, in the mid-19th century. Scientists have to try to disentangle this natural trend from the additional warming that man is creating by burning fossil fuels that emit heat-trapping greenhouse gases or by cutting down trees that would otherwise remove carbon dioxide from the atmosphere.

Scientists used to think it might take decades before we had a clear signal of man-made global warming. Even then, they thought it would probably be hidden in esoteric data that few laymen could understand. Yet now all sorts of things seem to be happening right in front of our eyes — shrinking glaciers, thinning sea ice at the North Pole, huge chunks breaking off the Antarctic ice sheets, intense hurricanes, and scorching heat waves in Europe, to name a few. Are these signs that the adverse impacts of human-caused warming have arrived sooner than once expected?

Skeptics say these things are most likely part of the natural variation of Earth's climate, unrelated to man-made warming. And no definitive answer is yet possible for many of these dramatic events that symbolize the global warming threat in popular discourse. Given the dreadful possibilities that perfectly legitimate worst-case scenarios imply, there would be no excuse for failing to act under any circumstances. But given the huge potential consequence of the debate, it's important to examine all the evidence carefully. So let's look at the various pieces of the global warming debate one at a time.

The Consensus

The biggest question is the one on which there is least dispute. The leading scientific organizations with relevant expertise have overwhelmingly adopted the view that human-induced global warming is a serious problem. [The United Nations' Intergovernmental Panel on Climate Change](#), which has mobilized hundreds of scientists to analyze the evidence, has gotten progressively more concerned; it now holds

humans responsible for most of the warming observed over the past 50 years. The science academies of the United States and 10 other industrial nations issued a [joint statement](#) last year citing "strong evidence that significant global warming is occurring" and calling for "prompt action" to combat it. [The American Meteorological Society](#), the [American Association for the Advancement of Science](#), and the [American Geophysical Union](#) have all chimed in with similar statements. Only the [American Association of Petroleum Geologists](#), with deep ties to the fossil fuel industry, has demurred.

Meanwhile, the vast majority of research reports in leading scientific journals tend to support the prevailing view that human activities are mostly responsible for driving up temperatures. An [analysis of 928 abstracts from leading scientific journals between 1993 and 2003](#) found that about 20 per cent explicitly endorsed that consensus, another 55 per cent implicitly accepted it and went on to evaluate impacts or propose mitigation strategies, and the remaining 25 per cent took no position. Not a single paper disagreed with the consensus. A rebuttal survey by a British social anthropologist found fewer papers that endorsed the consensus and 34 that rejected or doubted it, but that survey in turn was [sharply criticized](#) for distorting what the abstracts actually said.

Still, there is plenty of disagreement over how fast the climate will change and how dire the consequences might be. In Canada, which is having its own climate-change debate, some [60 scientists signed an open letter](#) in April decrying the "alarmist forecasts" of the United Nations and suggesting that concern over greenhouse gases should actually be diminishing. They were countered by an [open letter from 90 other scientists](#) endorsing the U.N. consensus and calling for a national strategy to deal with climate change.

Scary Scenarios

Analyses of the gases trapped in ancient ice cores from [Antarctica](#) have revealed that important greenhouse gases have reached their highest atmospheric concentrations in at least 650,000 years. The concentrations will only get worse as cars, power plants and other burners of fossil fuels continue to pump carbon dioxide into the air and deforestation and other changes in land use slow the rate at which these gases are withdrawn from the atmosphere. Other things being equal, the rise in these gases will cause temperatures to rise. That's simple physics, agreed to by all sides.

What's not agreed to is how worrisome the temperature increase will be. [The global average surface temperature rose about 1 degree Fahrenheit](#) over the 20th century. The change hardly seemed noticeable, except in polar regions where the increases were larger. Yet even that seemingly small increase is affecting the global environment by thawing the frozen tundra, melting mountain glaciers, adding to stress on coral reefs, causing some species to change habitats, and increasing the number of hot days while decreasing the number of cold days, to cite a few examples. And the warming trend may be picking up speed. The last few decades of the 20th century were probably the warmest in a thousand years.

Skeptics have an answer for this. They say surface temperatures were probably as high or higher during the [Medieval Warm Period](#)

that ushered in the last millennium, well before humans emitted vast amounts of greenhouse gases. That suggests to them that today's warming might simply be a continuation of long-term natural cycles. But the magnitude and geographic extent of the warmth back then is uncertain. The high temperatures may have been regional and may not have permeated the whole globe.

And for the rest of this century, temperatures will almost certainly keep rising. The Earth has been storing heat in its oceans, which means there is about 1 degree Fahrenheit more warming in the pipeline that will occur during this century even without any additional greenhouse emissions. All major components of the climate system are warming — the lower atmosphere, the surface, and the seas — so the heating cannot readily be attributed to natural mechanisms that transfer heat from one part of the globe to another.

The projections for the future also get far more worrisome than that 1 degree. Various scenarios used by climate modelers suggest that [average surface temperatures could easily rise another 4 to 8 degrees Fahrenheit by the end of the century](#), based on mid-range projections. That is a level that many experts deem dangerous.

If the warmer climate increases the destructive power of hurricanes and typhoons, as two studies indicate it already has, the storm devastation could get worse on coasts that lie along their traditional paths. If the massive ice sheets on [Greenland](#) and Antarctica melt faster than long estimated — a trend that some recent studies suggest has already started — the added water could drive up sea levels by several feet in this century, inundating some low-lying coastal areas. If mountain glaciers around the world continue to shrink rapidly, as seems likely, areas that rely on them to store water and release it slowly may face shortages of drinking water. If high temperatures allow disease-carrying insects and plant pests to invade new areas, as some studies show is beginning to happen, or if higher temperatures increase the frequency of heat waves and heavy rainfall, as the world's science academies deem likely, then the health and environmental consequences could be significant.

None of this is settled science or sure to happen. But these and other potential risks show what's at stake in the climate debate, and underscore the need to act promptly to head off the worst dangers.

The following are some of the most frequently cited red flags for global warming, and a rough rating of how well the alarms stand up under scientific scrutiny.

Rising Sea Levels: Risk is Clear, Magnitude Uncertain

Sea levels have already been rising steadily in a warming world — roughly half a foot over the past century — partly because heat causes water to expand and partly because the water from melting

glaciers ultimately find their way to the sea. There is some evidence that the rate of the rise may be accelerating, but whether this is a trend or a temporary natural fluctuation is not yet clear. Either way, future sea levels are sure to be higher than they are today.

One plausible, middle-of-the-road scenario suggests that, by the end of this century, thermal expansion and glacier water may cause the globe's average sea level to have risen roughly half a foot to a foot and a half. That would cause hardship in low-lying areas, but it would probably be manageable for most of the world.

Some plausible scenarios suggest that sea levels could easily rise by three feet or so by the end of the century. That level could threaten tens of millions of people who live in the low-lying river deltas of places like [Bangladesh](#), [Vietnam](#) and [Egypt](#) and would flood many populated atolls. In this country, the rising seas could inundate perhaps 6,000 square miles of dry land that is less than three feet above high tide, of which 5,000 square miles is currently undeveloped. A typical sloping beach might be pushed a hundred yards inland. Decisions would have to be made on where to spend money to hold the sea back and where to let it advance. Then there's a worse-case possibility. The big threat would come if the ice sheets in Greenland or Antarctica were to dump a large portion of their contents into the sea, driving sea levels far higher in centuries to come. That is the nightmare that would bury a huge chunk of Florida under water, force the evacuation of low-lying cities in Asia, and submerge stretches of lower Manhattan — but probably not until some distant era.

Greenland: A Potential Disaster

Of all the Arctic lands, Greenland is the one causing scientists the most consternation. The huge island is covered by a massive ice sheet, almost two miles thick in some places. If completely melted it would release enough water to raise sea levels around the world more than 20 feet. But almost no one deems that prospect likely on any time scale not measured in centuries or millennia.

For years now scientists have been debating whether Greenland is gaining ice or losing it. Snowfalls at higher elevations in the interior have been adding to the mass of ice while melting has occurred at lower elevations and along the edges. There has been no firm agreement on the net balance.

So why worry?

What's caused a sudden spike in alarm was a [completely unexpected finding last year](#) that the amount of ice flowing into the sea from large coastal glaciers in southern Greenland has almost doubled in the past decade. Outlet glaciers have started moving toward the sea much faster than before. That is either because floating ice tongues that held them back have disintegrated in the warming climate or because water from ice that is melting on top of the glaciers has poured down crevasses and lubricated the surface beneath — or most likely a combination of both.

These unnerving developments still do not mean that a huge part of the ice sheet will slip off of

Greenland any time soon. But it does mean that Greenland has likely fallen into a net annual loss of ice and will be contributing more to rising sea levels than was previously anticipated. It is possible that the slide rate will subside in coming years. But some experts think Greenland could reach a tipping point where feedback mechanisms will accelerate the loss of ice indefinitely.

Antarctica: Another Long-Range Danger

The continent at the South Pole is so vast and so frigid it is hard to think of it being endangered by rising temperatures. But worrisome things are happening on the far western fringes of the continent. It was breathtaking back in 2002 when a block of floating ice the size of Rhode Island [disintegrated rapidly](#) and separated from the Larsen-B ice shelf. And that was only the largest of many blocks of ice that have broken off the floating ice shelves adjoining the Antarctic Peninsula, a narrow strip of land that juts northward and has the warmest weather on the continent. Such blocks are already floating, so their melting has no effect on sea levels. But the ice shelves act like a stopper, and their disappearance can open the way for land-based ice behind them to flow into the sea, as is already happening in some areas.

As with Greenland, there is strenuous debate about whether Antarctica as a whole is gaining or losing ice. The losses have mostly occurred at the edges of [the West Antarctic Ice Sheet](#), which comprises about 10 percent of the continent, while the far larger [East Antarctic Ice Sheet](#) has been slowly gaining mass in the interior from increased snowfall. The studies are conflicting: they find either a net gain or net loss continent-wide.

New evidence suggests the situation is deteriorating. A recent [satellite study](#), the most comprehensive survey yet, shows a much greater loss of ice than previously estimated in the west and a roughly steady state in the east, suggesting that Antarctica is clearly falling into the loss column. The study covered only three years so no one is sure whether it has detected an abnormal blip or an accelerating downward trend driven by the region's recent warming, and it used a new technological approach that needs more validation.

It will take time to determine what the long-range future for Antarctic ice will be. Climate models suggest that the continent could actually gain a little ice in this century, through increased snowfall, thereby reducing sea levels slightly. But that projection could change if the current migration of Antarctic ice to the sea continues or accelerates.

The worst-case nightmare has long been that the West Antarctic Ice Sheet, which is partly grounded on land below sea level, might disintegrate entirely under the combined pressures of higher air temperatures above and warming seas below. If it did, it could release enough ice to raise sea levels by roughly 15 to 18 feet some hundreds of years in the future.

Melting in the Arctic: The Threat is Here

When it comes to melting ice, the Arctic is getting the most popular attention. Surface temperatures have

risen for the past several decades, the sea ice that covers the [Arctic Ocean](#) has been thinning and shrinking, and some of the permafrost on land has been thawing. Some scientists predict that, by the end of the century, the Arctic may be completely ice-free in the summer, though not in the winter.

Once again, skeptics argue that there is less than meets the eye. They note that temperatures in the Arctic seem to be within range of those encountered in the not-so-distant past. [Some studies](#) have found that temperatures in parts of the Arctic were actually higher in the 1930's than today, though whether that was true of the Arctic as a whole is difficult to say because of a paucity of data.

What has clearly changed is the size and thickness of the floating ice cap. The area covered by sea ice has expanded and contracted over the last century, but in the mid-1970's it started a steep decline toward a record low last year.

How much of this can be blamed on greenhouse gas emissions? Some experts attribute the ice loss to a cyclical shift in wind patterns. The winds pushed part of the floating ice around the Arctic, thinning it in some areas, piling it up thickly in others, and flushing some out into the North Atlantic. What looks like a disappearing ice cap may really be a partially displaced ice cap, they say. But that is not a universal opinion. Other experts contend that, even as the winds have become less of a factor in recent years, the ice cap is still contracting, suggesting that rising temperatures are now the main driver.

The biggest worry is that "feedback processes" may take hold and drive the Arctic into deeper trouble. Ice reflects sunlight back into space but open water absorbs most of the sun's energy. As the water warms up, it melts more ice and exposes more sea to absorb more heat in a cascading process that could become self-sustaining.

The Arctic is subject to so much natural turbulence that some experts believe it may well go through periods in the next few decades when the region cools again and its ice pack grows. But in the long run, computer simulations show, greenhouse gases will dominate over natural causes and will drive the region toward higher temperatures and less ice.

Thawing Permafrost: An Iffy Prognosis

Huge stretches of tundra in the Arctic consists of "permafrost" that is frozen solid for some or all of the year. But over the past several decades, some of the permafrost has thawed, making once-hard roads less usable, damaging buildings, railroads and airport runways in northern Russia, and causing trees and telephone poles to tilt drunkenly in the suddenly soft terrain. This is causing practical problems in areas reliant on more solid footing.

What it bodes for the future of climate change is still unclear.

Some scientists fear a looming catastrophe, if the massive amounts of carbon locked up in permafrost are released and add their weight to greenhouse warming, or if permafrost that turns into boggy marshes

releases methane, an even more potent greenhouse gas. That is already happening on a small scale, and it could get worse.

Optimists argue that the softer ground and rising temperatures will allow shrubs and other plants to invade formerly frigid areas, and such vegetation will absorb carbon dioxide from the air, reducing the concentration of greenhouse gases. But even if that happens, some scientists say it could make things worse. As trees and shrubs spread north, they could absorb more sunlight than the lighter tundra did, further warming the local climate.

Only a small percentage of the permafrost has degraded so far, but the [Arctic Climate Impact Assessment](#) suggested that 10 to 20 per cent of the current permafrost area might degrade over the next hundred years. What impact that would have on the release of greenhouse gases won't be clear until we have more evidence. This is a much more iffy situation than is presented by Greenland and Antarctica, where there is clear reason for concern.

Mountain Glaciers: The Best Evidence

Mountain glaciers are probably the single best indicator of climate change because they are highly responsive to changes in temperature, precipitation and solar radiation. Glaciers are retreating rapidly almost everywhere, including [the Himalayas](#), [Alps](#), Canadian Rockies, [Andes](#), not to mention our own [Glacier National Park](#), the Washington Cascades, and the coast of Alaska.

The loss of ice in mid-latitude mountain ranges has been huge. Glaciers monitored in the European Alps lost half their volume between 1850 and 1994. Those in the Caucasus lost half of their volume between 1894 and 1970, and those in the Tian Shan range between [Kazakhstan](#), [Kyrgyzstan](#) and [China](#) declined 22 percent from 1955 to 1995.

Naysayers are right when they point out that glaciers have been retreating in an irregular pattern since the end of the Little Ice Age. But the melting seems to have accelerated in recent years and some leading glaciologists think the 20th-century retreat lies outside the range of normal climate variability. The [World Glacier Monitoring Service](#) in Zurich concluded that the "[spectacular loss in length, area and volume of mountain glaciers during the 20th century](#)" was probably not driven by human activity at the start but now may be increasingly propelled by human influences. A panel convened by the National Academies asserted in a recent report that the retreat of glaciers around the world appears in many cases to be "unprecedented during at least the last 2,000 years."

Kilimanjaro: Dubious Evidence

[Africa's tallest mountain](#), 19,000-foot-high Kilimanjaro in [Tanzania](#), has become a favorite icon of those concerned about global warming. But this is one case in which the link is debatable. The mountain has been featured in Senate discussions of global warming, and in Al Gore's new movie "[An Inconvenient](#)

[Truth](#)", partly because of eye-catching then-and-now pictures that show a good cap of ice and snow in the past and a balding top today. The discussions include an obligatory reference to Ernest Hemingway's famous short story, "The Snows of Kilimanjaro," providing a literary backdrop for the lament about the rapidly shrinking glaciers at the summit.

There is no doubt that the glaciers are disappearing. One expert who has studied the mountain closely calculates that the [glaciers could be entirely gone in 10 to 15 years](#). He puts at least part of the blame on global warming. But other scientists have considerable doubt that rising temperatures have been the main culprit.

The ice on Kilimanjaro has been in retreat since at least the 1880's, with the greatest decline occurring at the beginning of that period, when greenhouse gas concentrations were much lower. The dominant reasons for this long-term loss of ice, some researchers say, were a prolonged dry spell in East Africa that deprived the mountain of snowfall, and a reduced cloud cover that allowed more solar radiation to reach the mountaintop where it vaporized the ice by a mechanism unrelated to temperatures. Deforestation on the foothills may also have removed a local source of moisture. Global warming may have added its weight to the scales — [one expert calls it premature to exonerate warming](#) — but the snows were probably doomed to disappear even without its help. The National Academies panel judged that Kilimanjaro's glaciers "may be shrinking primarily as a continuing response to precipitation changes earlier in the century."

Hurricanes: An Unsettled Question

The ravages of [Hurricane Katrina](#) last year triggered an outpouring of popular speculation that global warming had already begun to wreak havoc in the form of extreme storms. Hurricanes and typhoons (the name used in the Pacific) draw their energy from warm surface waters, so it is only logical that as the waters warm up, hurricanes should become more powerful. Yet climate scientists on all sides of the global warming debate say it is a mistake to blame any one storm on global warming let alone carbon dioxide emissions. The debate now raging among experts is whether the intensity of hurricanes and of typhoons have increased beyond normal bounds in recent years, and if so, why. Is it global warming or other more traditional drivers, like vertical wind shears and rotational flows in the atmosphere?

The issue is difficult to resolve because our understanding of hurricane formation is still rudimentary and historical data on hurricanes is sketchy. Before the age of satellites, which began in about 1980, hurricanes that failed to hit land or pass over a ship often escaped notice, so it is difficult to know how many very powerful storms there really were in past decades. Even today, judging a hurricane's wind speed is as much art as science. American and Japanese typhoon warning centers sometimes differ by two whole categories in how they classify a storm's intensity.

[Two separate scientific papers last year shocked meteorologists](#) by reporting an increase in the destructive power of the big storms over the past few decades, well before any such effect had been anticipated. One paper found [an increase in the frequency of very severe storms](#), those in [Categories 4](#)

[and 5.](#) The other found a [doubling in destructive potential over the past 30 years](#).

Other specialists disagree. They see no sustained increase in hurricane intensity and attribute hurricane behavior mostly to cyclical changes in the atmospheric conditions that hatch hurricanes rather than global warming. This is very much an unsettled issue, with eminent leaders of the field staking out contrary positions.

Biological Impacts: A Clear and Present Danger

The United Nations assessments have already documented a wide range of impacts on living things and the ecosystems they inhabit. Various plants, insects, birds and fish in the northern hemisphere have shifted their ranges toward the north or to higher elevations as those areas become warmer and more welcoming to them. Some plants are flowering earlier, migratory birds are returning earlier, and the growing season is growing longer in higher latitudes.

There are spirited debates over how deleterious these changes are but some of the changes are clearly harmful to some forms of life. In the Netherlands, migratory birds and the caterpillars their chicks feed on have responded at different rates to rising temperatures, with the result that chick hatching is now out of sync with the peak caterpillar food supply. In Canada, the mountain pine beetle has moved northward into areas once too cold for it, where it has devastated the pines in a wide area of forest. And on the North Sea coast of Britain, tens of thousands of seabirds failed to raise any young in a massive breeding failure in 2004. The event, whose cause and extent is still being investigated, was likely due to rising water temperatures that, by reducing the abundance of plankton, also reduced the abundance of small fish that the seabirds feed upon.

The greater worry is that some species may be pushed toward extinction. Reputable scientists are predicting that extinctions may occur on a massive scale as species fail to adapt or move quickly enough to cope with rising temperatures. Skeptics, on the other hand, see signs that many species will move more rapidly into previously cold areas than they will retreat from warmer areas, with the result that they will actually extend their ranges and thus become more resistant to extinction.

Still, some birds and other creatures are clearly suffering adverse effects already. The fate of many species may depend on whether the rate of climate change accelerates, making it harder for them to adapt quickly.

Polar Bears in Peril: An Emerging Risk

The species at highest risk live in the Arctic, where the icy world they depend on is melting away around them. Indeed, Time magazine, in a cover story warning us to ["Be Worried. Be Very Worried,"](#) depicted the Arctic's plight with a photograph of a polar bear on a small ice floe, staring forlornly at broken water it would have to swim through because of gaps in the ice cap. [Polar bears](#) are classified as marine mammals because they spend much of the year on the Arctic sea ice, which enables them to reach the

seals they prey on and which serves as a platform for mating and building dens. As the sea ice contracts, their options are narrowing.

Polar bears were once in grave peril from unsustainable hunting. Less than four decades ago their numbers dropped to as few as 5,000, which earned them a spot on our endangered species list. But today, thanks to an international effort to control hunting, the numbers have rebounded to a healthy 20,000 to 25,000 bears, broken up among some 20 distinct population groups.

The main evidence that global warming may be having a deleterious impact comes from one population in West Hudson Bay, [Canada](#), near the southernmost edge of the bears' range. Although it is not yet evident that the population of bears there has declined, there is good evidence that the average weight of adult bears has dropped, as has the number of cubs being born and surviving. Researchers attribute these downtrends to an earlier breakup of sea ice because of rising temperatures. The bears are forced to leave the ice and the seals they prey on earlier than in the past, with the result that they have less fat stored on their bodies to help them through the lean months when females give birth.

Elsewhere, except for a region where unsustainable hunting remains a problem, most polar bear populations are believed to be stable or increasing. But the data is spotty, and there was [a disturbing report](#) recently in which American and Canadian scientists described three cases of polar bear cannibalism in the Beaufort Sea area north of Alaska and western Canada in 2004. The scientists hypothesized that large male polar bears stalked, killed and partially ate other polar bears because longer ice-free seasons kept them from their normal food. Other polar bears in the same general area seemed in poorer condition than bears elsewhere, suggesting nutritional problems.

The real concern is whether further warming and shrinkage of sea ice might drive the bears to extinction. Optimists note that polar bears have existed as a distinct species for some 200,000 to 250,000 years and have already made it through a comparably warm period in the distant past without disappearing entirely. But the Arctic Climate Impact Assessment, conducted by nations with lands in the Arctic, concluded that polar bears are unlikely to survive as a species if there is an almost complete loss of summer sea ice, as some climate models predict may happen before the end of this century. Environmentalists have petitioned the Interior Department to list the polar bear as a threatened species, but wildlife experts in Canada's Inuit regions, which depend on revenue from bear hunting, insist that the future of polar bears is secure. The Department's inquiry may shed further light on the bears' future prospects.

Staring Into the Future

With all of the most prestigious scientific organizations convinced that global warming is an increasing menace — and with the vast majority of research articles in leading scientific journals tending to support that consensus — it would seem wildly irresponsible not to believe it is important to curb emissions. These are the institutions with the most expertise, and they have been studying the issue in unparalleled depth and breadth. Their judgment deserves the utmost respect and attention.

That doesn't make it necessary to accept every piece of evidence that's offered. It's possible that in looking so hard for patterns in the data, some experts might be overstating the importance of short-term changes in the environment.

We may not know for decades whether grave harm is on the way, but meanwhile we may be adding hundreds of new coal-fired power plants around the world to meet rising energy needs, locking ourselves into a vast carbon-emitting infrastructure that will last for many decades. The world keeps pumping greenhouse gases into the atmosphere in what amounts to a huge uncontrolled experiment, and a gamble that all will turn out fine. But if even the more moderate projections of global warming turn out to be true, we will be gambling the well being of later generations for short-term advantage. And if the worst-case scenarios turn out to be accurate, we could be dooming much of the planet to a very unpleasant future.

Lela Moore contributed research for this article.

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