Arctic Treasure

Global Assets Melting Away

Photo: Capt. Budd Christman/NOAA

Summary of Technical Paper

An Initial Estimate of the Cost of Lost Climate Regulation Services Due to Changes in the Arctic Cryosphere

ABOUT THIS SUMMARY

This is a summary of *An Initial Estimate of the Cost of Lost Climate Regulation Services Due to Changes in the Arctic Cryosphere*, a technical paper written by the following authors:

- **Dr. Eban Goodstein**, a resource economist and director of graduate programs at the Bard Center for Environmental Policy at Bard College in New York.
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The technical paper was reviewed for accuracy by more than a dozen scientists and economists. Responsibility for its research and findings lies solely with the authors.

Preparation of the report was supported by Oceans North, a project of the Pew Environment Group, to promote sound stewardship of North America's Arctic Ocean. For more information and copies of the technical report and background material, please visit www.oceansnorth.org.

About the Pew Environment Group

The Pew Environment Group is the conservation arm of The Pew Charitable Trusts, a non-governmental organization that applies a rigorous, analytical approach to improving public policy, informing the public and stimulating civic life. www.Pewenvironment.org

Photo: Bruno Tremblay, Courtesy of International Arctic Research Center

Arctic Ice

SUMMARY

Ice and snow are defining features of the Arctic. At no point in at least 800,000 years has the Arctic been without sea ice. By some projections the region may lose summer sea ice as soon as 2030. In a sense, the value of this ice is incalculable. Arctic ice defines the homelands and cultures of indigenous peoples and ecosystems that harbor species which are uniquely adapted to this environment.

In another sense, however, part of the value of the frozen Arctic can be estimated in terms of the climate services it provides to the world. Snow and ice reflect sunlight, helping to cool the Earth. Without these reflective surfaces, more sunlight is absorbed, leading to more warming. In addition, permafrost traps methane, a potent greenhouse gas. While many studies have examined the mechanisms by which the frozen Arctic and global climate are interrelated, this report, *An Initial Estimate of the Cost of Lost Climate Regulation Services Due to Changes in the Arctic Cryosphere*, is the first attempt to estimate the dollar cost of global warming brought about by shrinking ice, snow and permafrost.

Key Findings

- Loss of snow, ice and permafrost in the Arctic lead to greater warming of the Earth. This warming effect can be estimated in terms of the equivalent tons of carbon dioxide that would be required to produce the same warming.
- In 2010, the loss of Arctic snow, ice and permafrost is projected to cause warming equivalent to 3 billion metric tons of carbon dioxide, equal to 40 percent of total annual U.S. emissions. By the end of the century, this warming equivalent is projected to double.
- Climate change has widespread impacts on agriculture, energy production, water availability, sea level rise and flooding as well as other non-market effects. Economists estimate some of these impacts on the global economy in dollars per ton of carbon dioxide emitted into the air to arrive at the "social cost of carbon."
- Multiplying the carbon dioxide warming equivalent from Arctic melting by the social cost of carbon dioxide emissions, the economic value of the loss of snow, ice and permafrost can be calculated. This estimate does not take into account other environmental changes, nor does it address the impacts on indigenous populations in the Arctic, along with Arctic species and landscapes that are vulnerable to climate change.
- In 2010, the loss of Arctic snow, ice and permafrost is estimated to cost the world US$61 billion to $371 billion in lost climate cooling services. By 2050, the cumulative global cost is projected to range from US$2.4 trillion to $24.1 trillion; and by 2100, the cumulative cost could total between US$4.8 trillion and $91.3 trillion.
- Further research is needed to fully explore these preliminary results, examine other climate services provided by the frozen Arctic and account for additional costs associated with the loss of snow, ice and permafrost.

Photo: Jeremy Potter/NOAA

Arctic Ocean—Canada Basin

INTRODUCTION

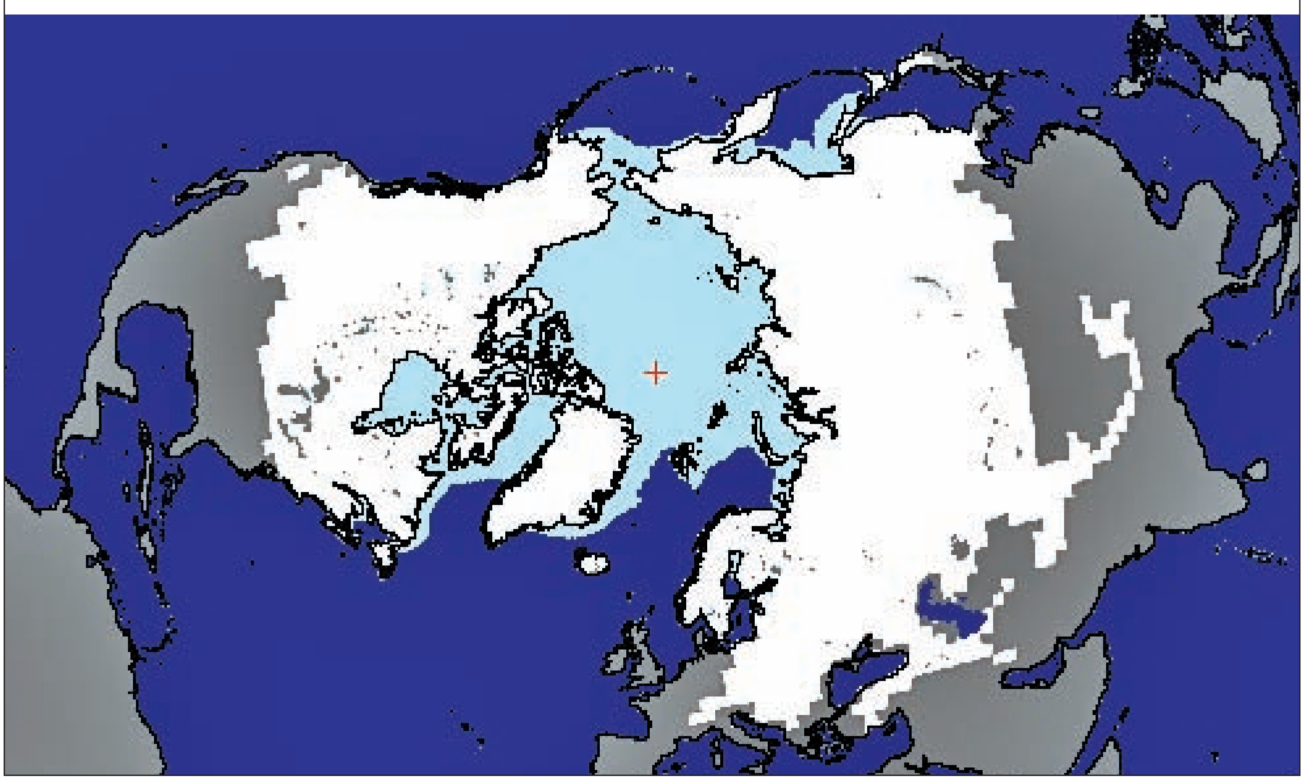
The report addresses three specific contributors to global climate regulation: sea ice, snow and permafrost. These components of the Arctic have been studied and modeled by a number of other scientists. Their role in climate regulation is relatively straightforward:

- Sea ice and snow reflect sunlight, helping to keep the Earth cool. The loss of sea ice and snow means that more solar energy is absorbed, leading to increased warming. This warming from diminishing sea ice and snow can be expressed in terms of its equivalent in greenhouse gas emissions. In other words, melting snow and ice are an additional contributor to global warming.
- Permafrost, or permanently frozen ground, holds vast quantities of methane, a potent greenhouse gas. As permafrost thaws, the release of methane increases the concentration of greenhouse gases in the atmosphere. As with the loss of snow and ice, additional methane represents a non-industrial source of warming.

Because of the difficulty of modeling predicted effects, several other mechanisms by which the frozen Arctic affects global climate and people around the world are not included in this preliminary analysis. These include changes to ocean currents caused by disappearing sea ice, possible additional warming from release of methane hydrates stored underwater in the continental shelves, and changes to the way carbon dioxide is emitted and taken up in Arctic ecosystems.

The Frozen Arctic:

The light blue shows the average January sea ice from 1979 to 2005. Average January snow extent from 1967 to 2005 is shown in white.[1]



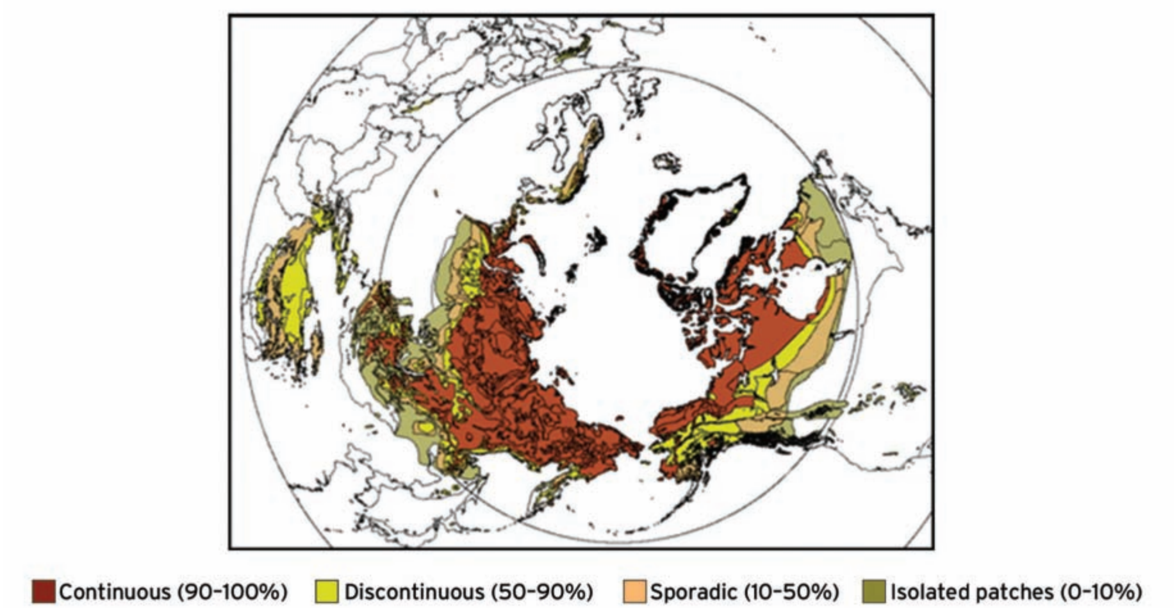
INTRODUCTION

For these reasons, the preliminary estimates summarized in the report are likely to understate the cost of the melting and thawing Arctic to global climate regulation. Further work is required to make this assessment more comprehensive. Nonetheless, the current evaluation predicts that the melting of the frozen Arctic occurring this year alone could cost the world in the range of US$61 billion to $371 billion in climate regulation services over time. By 2050, those costs are projected to add up to US$2.4 trillion to $24.1 trillion; by 2100, the report predicts cumulative costs could be US$4.8 trillion to $91.3 trillion.

Photo: Benjamin Jones and Christopher Arp, U.S. Geological Survey, Alaska Science Center

Arctic Coastal Erosion

Extent of Permafrost in the Northern Hemisphere[2]

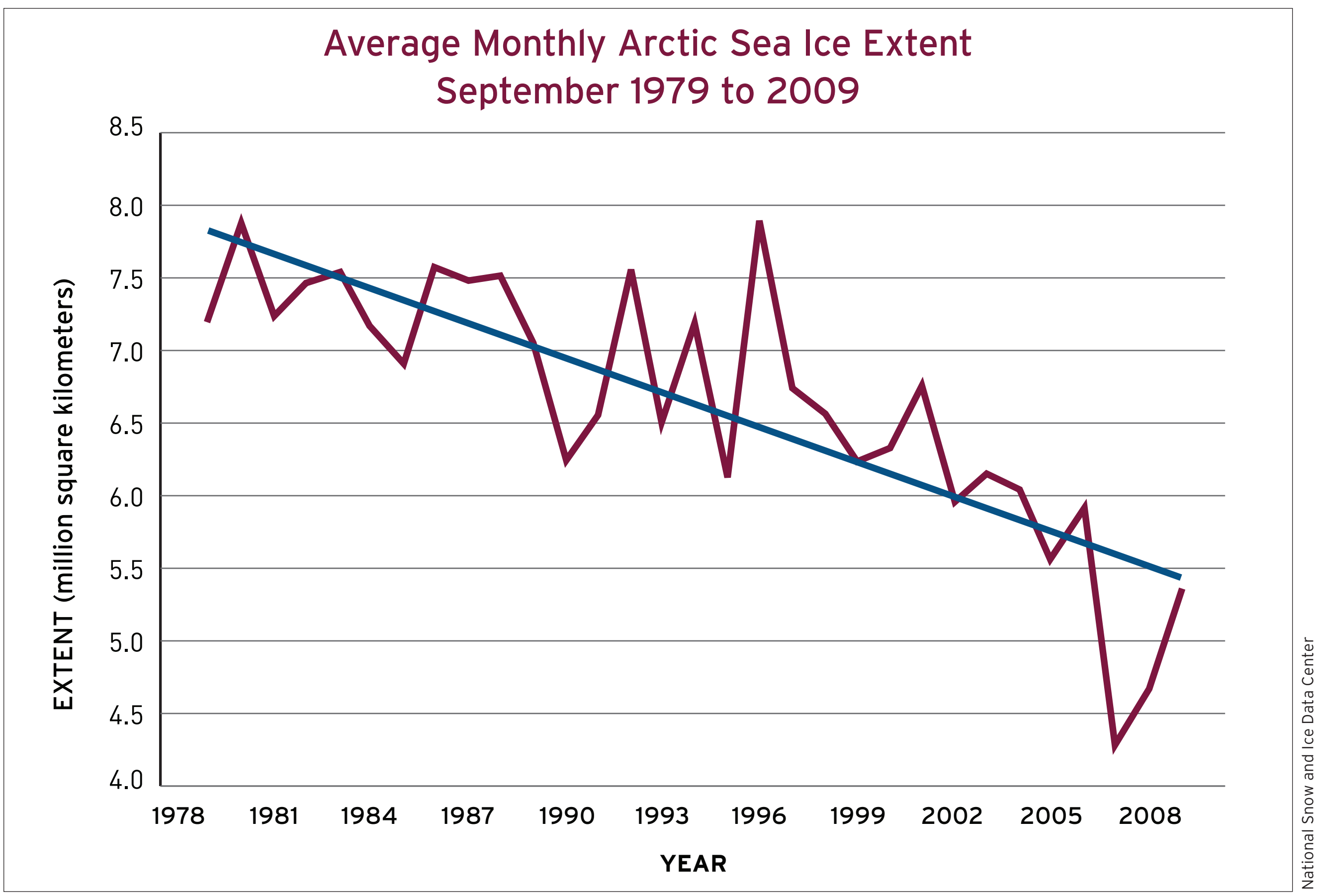


THE FROZEN ARCTIC

The Arctic's permanent ice takes three forms: sea ice, permafrost and glacial ice. In addition, the Arctic has extensive snow cover for much of the year, and sea ice expands greatly during the winter. Ice in all these forms, including snow, is rapidly diminishing.

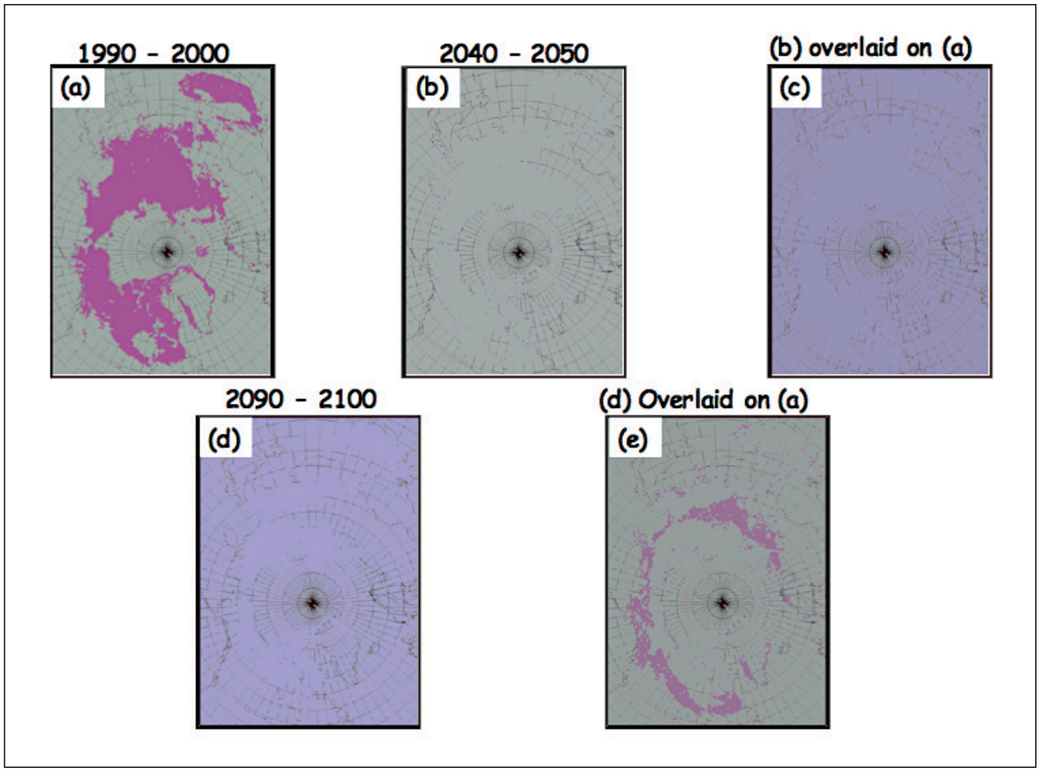
The decline of sea ice is perhaps the most dramatic change underway in the Arctic. The extent of summer ice has declined since record-keeping started in 1953, and in 2007 dropped to the lowest level to date. The next two years, 2008 and 2009, were the second- and third-lowest years on record. As recently as five years ago, most models predicted that the Arctic would have year-round sea ice for the rest of the 21st century. Today, many scientists predict that an ice-free summer may occur in the Arctic by mid-century at the latest and perhaps as soon as 2030. The reduction of sea ice that occurs each year decreases the amount of sunlight reflected by ice and increases the amount absorbed by the open ocean, warming the Earth and leading to further melting of sea ice.

Permafrost is also warming throughout most of the Arctic. Although the complete loss of permafrost will take centuries, it is already occurring at its southern margins. The connection between thawing permafrost and release of greenhouse gases is complex. A clear trend emerging from this complexity is an increase in methane emissions in the last ten years. Many scientists expect this trend to continue.

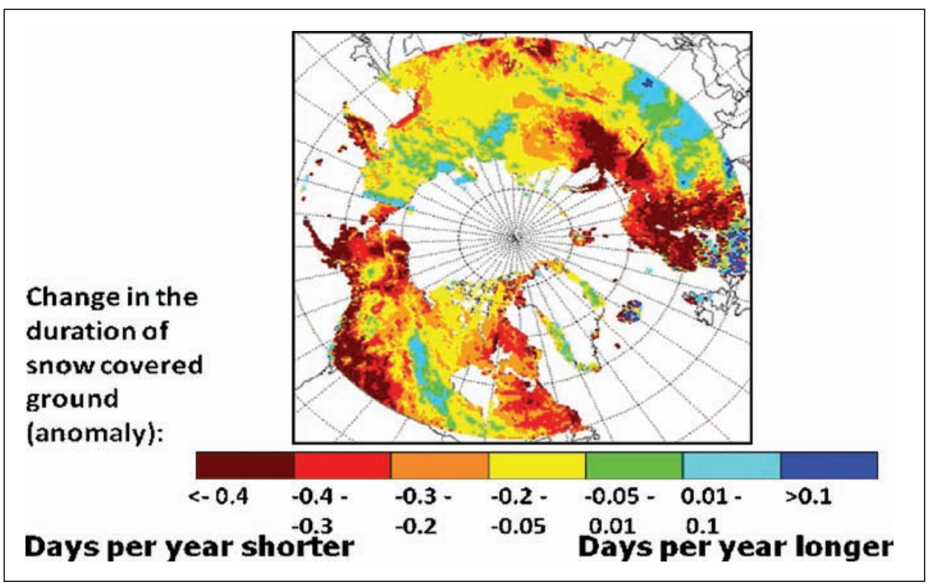


September ice extent from 1979 to 2009 shows a continued decline. The September rate of sea ice decline since 1979 has increased to 11.2 percent per decade.[3]

THE FROZEN ARCTIC



Distribution of permafrost from 1990 to 2100, showing loss of permafrost by 2050 (Panel c) and by 2100 (Panel e).[4]



From 1970 to 2000, the number of days of snow-covered ground decreased by an estimated 2.5 days per decade across the pan-Arctic.[5]

THE FROZEN ARCTIC

Snow covers a vast area of the Northern Hemisphere each winter, but that area has been shrinking as the snow season grows shorter. This means that more sunlight is absorbed rather than being reflected back to space and that more heat is taken up by the Earth's surface. The resulting increased warming results in less snow cover and further warming, producing a positive feedback to climate change.

Glacial ice, including the Greenland Ice Sheet, holds vast quantities of water. If the Greenland Ice Sheet melted entirely, sea level would rise about seven meters (23 feet) around the world. As with the thawing of permafrost, the entire loss of Arctic glacial ice including Greenland's ice would take centuries or longer if warming continues at current rates. Nonetheless, the impacts are already becoming apparent. Because assessments of the social cost of carbon emissions, as discussed below, attempt to capture the impacts of sea level rise, the report does not separately attempt to quantify effects from the melting of glacial ice.

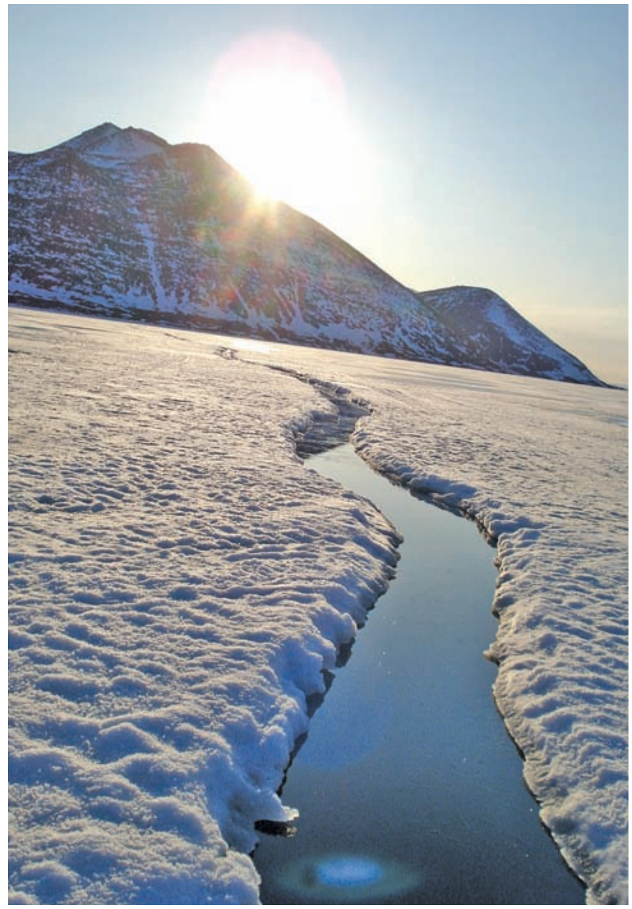


Photo: Chris Debicki

Ice Lead

CALCULATING CARBON DIOXIDE EQUIVALENTS

The loss of sea ice and snow causes the surface of the Earth to warm. Converting this surface warming to warming of the atmosphere allows the warming effect to be expressed in terms of the amount of carbon dioxide that would have to be released into the atmosphere to cause the same amount of warming. The methane released from thawing permafrost can also be converted to carbon dioxide equivalents (See chart page 8).

The report's analysis suggests that the combined heating effect from the loss of sea ice and snow and the increased release of methane from permafrost in 2010 is roughly equal to releasing an additional 3 billion metric tons of carbon dioxide into the atmosphere. For comparison, this equals 42 percent of current annual U.S. emissions of greenhouse gases. By the end of the century—barring an international effort to significantly reduce global warming—the report estimates that the melting Arctic could contribute annual warming equivalent to between 4.7 and 7.8 billion metric tons.

THE COST OF CARBON

Carbon dioxide is the most prominent of several factors contributing to global warming. Carbon dioxide-equivalents can be calculated or estimated for the other factors, creating a standard unit of measure when discussing global warming and its causes. Economists have developed several estimates of the "social cost of carbon," the net global cost of climate change impacts on agriculture, energy production, water availability, sea level rise and flooding as well as other factors for periods up to 100 years from one additional ton of carbon dioxide emitted to the atmosphere. Inherent in these calculations is the persistence of carbon dioxide in the atmosphere, since a ton of carbon dioxide released today will have impacts for the rest of the century. Determining the social cost of carbon dioxide and its equivalents requires additional assumptions and calculations.

One category of assumptions concerns the effect that a ton of carbon dioxide will have over time. If carbon emissions continue to increase, each successive ton has a greater impact than preceding ones and the impact of each ton increases during its lifetime in the atmosphere. This results when greater temperature increases cause greater impacts, incurring ever-greater costs. Various estimates have been made about how much additional impact each ton of carbon dioxide will have and how rapidly the economic costs will rise.

Another assumption in this category concerns the sensitivity of the world's climate to carbon dioxide levels. In part, uncertainty in this area is due to questions concerning feedbacks such as those outlined in the previous section. At what point does global warming trigger large additional releases of methane from thawing permafrost, which would increase temperatures still further? The increase in average global temperature from a doubling of carbon dioxide levels from pre-industrial levels is likely to be at least 3 degrees Celsius, and may be as high as 6 degrees Celsius.

On the economic side, estimating the cost today of effects that take place decades from now involves calculations that incorporate a process known as discounting. In essence, discounting is an attempt to capture the cost of using money now for a benefit that accrues in the future. In the meantime, that money is unavailable for other purposes. In the short term, discount rates are readily estimated and are in constant use in forms such as interest rates for loans and savings. In the longer term, discount rates involve greater uncertainties and thus create a wider range of estimates for projections across several decades.

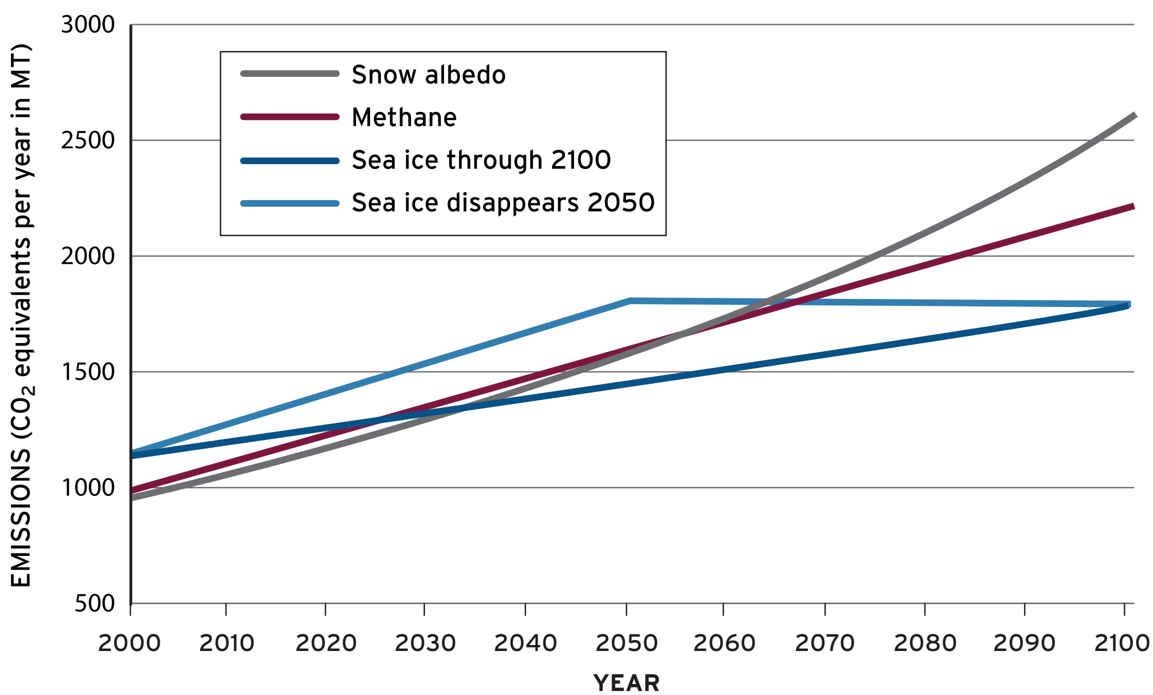
Finally, there is the question of what effects are caused by global warming and thus what should be included in cost estimates for those effects. Several attempts have been made to quantify the impacts and to calculate the social cost of a ton of carbon dioxide released into the atmosphere. These estimates incorporate the assumptions outlined above using different rates, resulting in estimates ranging at the extreme from $13 to $798 per metric ton. The report employs three more central estimates—$22, $46 and $104 per metric ton—which come from studies by the U.S. Environmental Protection Agency in 2008 and 2009 and Sir Nicholas Stern, the former World Bank president, who completed a study of climate costs for the United Kingdom in 2006.

THE COST OF THE MELTING ARCTIC

Recent changes and projected trends in snow loss, ice loss and methane releases can be converted into carbon dioxide-equivalents. These carbon dioxide figures can be multiplied by the social cost of carbon. These calculations can be extended into the future using discount rates to evaluate the costs today of future impacts and also using future warming trend estimates to assess the potential for increasing effects over time. The figures given here are preliminary estimates incorporating the more obvious and better-understood changes and impacts. They should thus be regarded as conservative, uncertain, initial estimates.

Despite the uncertainties and the range of estimates involved, the value of the climate cooling services lost from the melting and thawing Arctic this year are estimated to be in the billions of dollars, and could add up to cumulative totals in the trillions of dollars by the middle and end of the century. In short, the

Estimated emissions (in CO2-equivalents per year) through 2100 due to changes in sea ice reflectivity (albedo) from a loss of sea ice (with loss of sea ice by 2050 or with ice remaining throughout the century); snow albedo due to a shorter snow season; and methane due to increased methane emissions from thawing permafrost.[6]



THE COST OF THE MELTING ARCTIC

frozen Arctic is worth a great deal to the planet, enough to justify a more comprehensive examination of its climate cooling value and enough to justify global action to preserve as much as possible of its function to prevent runaway costs from the loss of these frozen assets.

The Cost of the Melting Arctic

YEAR	EPA 2009	EPA 2008	Stern 2006
Cost 2010	$61	$146	$371
Cumulative Cost 2010-2050	$2,401	$7,349	$24,111
Cumulative Cost 2010-2100	$4,857	$19,842	$91,275
Social cost of carbon per metric ton of carbon dioxide equivalents	$22	$46	$104
Discount rate (integrated assessment model)	3%-5%	3%	1.4%-2.7%
Discount rate (net present value)	4%	3%	2%
CO_2e estimates for melting Arctic	Low	Mid-range	High

Summary of the calculations of the cost of losing climate services from sea ice, snow and permafrost in the Arctic from the Technical Report expressed in billions of 2008 U.S. dollars. The low-, mid-, and high-range estimates for 2010 are $61, $146, and $371 billion. Cumulative estimates for 2010-2050 are $2.4, $7.3, and $24 trillion. To the end of the century, cumulative estimates are $4.8, $19.8, and $91 trillion.

ENDNOTES

1 J. Maurer, *Atlas of the Cryosphere*. Boulder, Colo., U.S.A.: National Snow and Ice Data Center (2007). Digital media, <http://nsidc.org/data/atlas/atlas_info.html>.

2 J. Brown, et al., *Circum-Arctic Map of Permafrost and Ground-Ice Conditions*. Boulder, Colo., National Snow and Ice Data Center/World Data Center for Glaciology (1998; revised February 2001). Digital media, <http://nsidc.org/data/atlas>.

3 National Snow and Ice Data Center, <http://nsidc.org/arcticseaicenews/index.html>.

4 A. D. McGuire, et al. "Sensitivity of the carbon cycle in the Arctic to climate change," *Ecological Monographs*, 79: 523 – 55 (2009).

5 S.E. Euskirchen, et al. "Energy feedbacks of northern high-latitude ecosystems to the climate system due to reduced snow cover during 20th century warming," *Global Change Biology* 13:2425-38 (2007), doi:10.1111/j.1365-2486.2007.01450.x

6 Eugenie Euskirchen, based on results in the technical paper *An Initial Estimate of the Cost of Lost Climate Regulation Services Due to Changes in the Arctic Cryosphere*.

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