



Arctic Ice Loss Threatens National Security: A Path Forward

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Abstract: Global warming is causing a dramatic reduction in Arctic sea and land ice and thawing permafrost. Because of the Arctic's role in influencing climate, loss of Arctic ice is affecting weather patterns globally and in the Northern Hemisphere in particular. Events such as droughts and coastal flooding, exacerbated by global warming, result in food and water shortages and mass human migrations that can destabilize governments and threaten U.S. national security interests. The loss of sea ice is also changing the geo-political situation in the Arctic. An emerging class of technologies associated with the restoration of Arctic ice can slow global warming and mitigate the threats posed to our national security and foreign policy by the changing geo-political situation in the region and globally. This article posits that an emerging class of technologies associated with the restoration of Arctic ice can slow global warming and mitigate the threats posed to our national security and foreign policy by the changing geo-political situation in the region and globally. It recommends that the United States fund efforts to study Arctic ice restoration technologies and take the lead in developing and coordinating an international response to mitigate Arctic sea ice loss and the impending global warming crisis.

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Fall 2020 | 622

Anthropogenic global warming¹ is accelerating the unprecedented loss of Arctic sea ice, land ice and snow, and thawing permafrost. The Arctic has played an essential role in regulating global climate that has resulted in the historically moderate weather that has helped foster our civilization. Now, global warming is upsetting that stability, threatening global socioeconomic, environmental, and political systems that threaten U.S. national security. To date, global efforts to keep greenhouse gas emissions below a level that scientists agree would avoid the worst damages from global warming have been seriously lacking. This article proposes a solution using emerging technologies that would delay the onset of the worst detrimental effects of global warming. This delay would give the world time to introduce adequate policies that limit greenhouse gases emissions and lower the risk of increased friction among the nations in the Arctic.

The Role of the Arctic Ice in Global Climate

The Arctic affects global oceanic and atmospheric circulation patterns, influencing weather patterns in the Northern Hemisphere (NH). Cold Arctic temperatures have played a central role in keeping the global climate relatively stable throughout human history. As the world warms due to anthropogenically-driven global warming, the temperature rises even faster in the Arctic. A recent National Oceanic and Atmospheric Administration (NOAA) study reports that the Arctic has warmed twice as fast as the rest of the planet, a phenomenon known as Arctic Amplification.² While the mean global temperature has increased by about 1°C,³ the Arctic has experienced a warming of about 2°C in the same time period. Rapid warming in the Arctic has led to a dramatic loss of sea ice. Arctic sea ice area at the end of summer 2019 was the second lowest since satellite observations began in 1979.⁴ (See Figure 1.) These changes are occurring rapidly. In most simulations of future global warming, the Arctic Ocean becomes practically sea-ice free (sea-ice area <1 million square km) in September for the first time before the Year 2050.⁵

¹ Anthropogenic global warming refers to the fact that the average annual temperature of the Earth is rising in response to human activities predominately in the form of greenhouse gas emissions and deforestation. The warming is disrupting circulation patterns and the chemical composition of the atmosphere and the oceans. The net result is a change in typical weather patterns that humans have been experiencing for thousands of years. This is referred to as climate change.

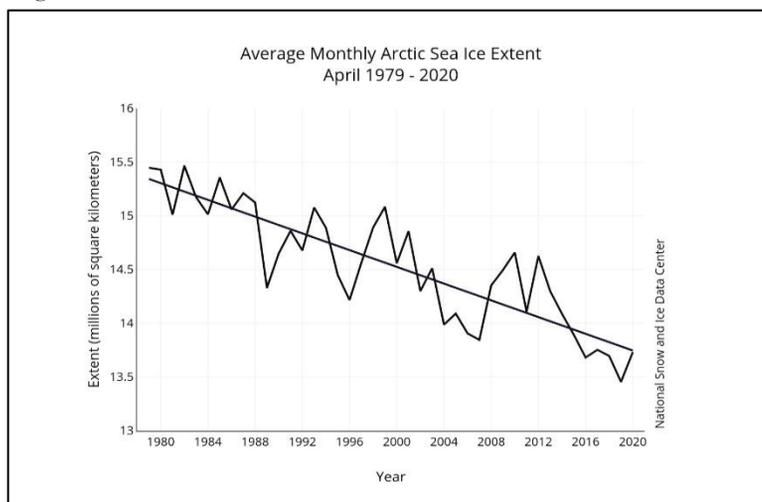
² Jacqueline Richter-Menge, Matthew Druckenmiller, and Martin Jeffries, eds., Arctic Report Card, 2019. See securethefuture2100.org for a more complete description of the interaction between the Arctic and global climate.

³ Degree Celsius above pre-industrial temperatures averaged from 1850-1900. See, e.g., “NASA, NOAA Analyses Reveal 2019 Second Warmest Year on Record,” NASA, 2020, <https://www.giss.nasa.gov/research/news/20200115/>.

⁴ 2019 was tied with 2007 and 2016 as the years with the second lowest sea ice areas since satellite observations began.

⁵ Dirk Notz et al., Arctic sea ice in CMIP6. *Geophysical Research Letters*, 47, 2020, <https://doi.org/10.1029/2019GL086749>, Also, see the article <https://nationalpost.com/>

Figure 1



Decrease in Sea ice extent (area) as a function of time showing the dramatic loss of sea ice in the Arctic that has dramatic consequences for regional and global climate and weather and is increasing tensions in the Arctic region.

While scientists have identified several processes contributing to Arctic amplification, in this article we focus on the positive feedback mechanism called sea ice reflectivity.⁶ It plays a significant role in Arctic amplification that we believe can be leveraged to slow global warming. Several studies show that the sea ice reflectivity feedback alone is responsible for a significant fraction of global warming—the equivalent of up to 25 percent of the warming due to CO₂ emissions from 1979 to 2008.⁷ Author Peter Wadhams estimates that the warming due to the land-snow-ice feedback is roughly equivalent to an additional 25 percent of global CO₂ emissions and are disrupting Arctic atmospheric and oceanic circulation patterns.⁸ As Arctic sea ice continues to disappear with increasing global warming these feedback loops will become even more important. *The interaction of these feedback processes has turned Arctic warming from a consequence into a driver of global warming.*

[news/world/new-study-predicts-arctic-ocean-will-be-ice-free-in-summer-by-middle-of-this-century.](#)

⁶ Scientists refer to surface reflectivity as albedo. We will use the term reflectivity in this article.

⁷ Kristina Pistone, et al., “Observational determination of albedo decrease caused by vanishing Arctic sea ice,” *Proceedings of the National Academy of Science*, vol. 111, no. 9, 2014, pp. 3322-3326.

⁸ Peter Wadhams, *A Farewell to Ice: A Report from the Arctic* (New York: Oxford University Press, 2017).

The loss of Arctic sea ice has been linked to extreme weather in the Northern Hemisphere. Polar temperatures have warmed two to three times as fast as subtropical temperatures. This warming weakens the jet stream making it more likely to create stationary weather patterns persisting for many days. A weakened polar jet stream has been linked to the extreme weather events of 2018. Temperatures in the southwest United States rose above 37.8°C (100°F) for days, heavy rains and floods inundated the mid-Atlantic states, and California experienced unprecedented droughts and wildfires. The Southwest witnessed a persistent heat wave, and the mid-Atlantic endured heavy flooding. Japan, Scandinavia, and much of Europe had persistent heat waves leading to wildfires in Greece⁹ *As global warming continues to heat the Arctic there is also a significant risk of reaching a tipping point, where the effects of climate change go from advancing gradually to changing dramatically very quickly.* Veerabhadran Ramanathan, professor of atmospheric and climate sciences at Scripps Institute of Oceanography, said: “Losing the reflective power of Arctic sea ice will lead to a warming equivalent to one trillion tons of CO₂ and advance the 2°C threshold [within] 25 years. Any rational policy would make preventing this a top climate priority for world leaders.”¹⁰

Consequences of a Changing Arctic and Threats to Regional National Security

The changes in the Arctic due to anthropogenic global warming are affecting the health and well-being of Arctic peoples and their food security. A warming Arctic is damaging infrastructure due to thawing permafrost and erosion that is already affecting indigenous peoples. For thousands of years, people like the Yup’ik Native Americans have lived as seasonal nomadic hunters.¹¹ After establishing the village of Newtok in 1949, the Yup’ik were recently forced to abandon this settlement due to climate change. Twelve other Arctic communities may need to relocate.¹² Relocation of these villages presents both a financial, as well as a moral, challenge regarding how to treat these Native Americans in an equitable fashion addressing both their cultural and their financial needs.

Permafrost thawing has detrimental physical and economic effects on other Arctic infrastructure. Approximately 70 percent of the infrastructure in the global Arctic region is built on permafrost, of which 33 percent is susceptible to severe damage from thaw-related ground instability. Much of the Russian ocean ports,

⁹ Michael Mann, “The Weather Amplifier; Strange waves in the jet stream foretell a future full of heat waves and floods,” *Scientific American*, March 2019; and Michael Mann, et al., “Influence of Anthropogenic Climate Change on Planetary Wave Resonance and Extreme Weather Events,” *Science Report*, vol. 7, no. 45242 (2017), <https://www.nature.com/articles/srep45242>.

¹⁰ Robert Monroe, Research Highlight: Loss of Arctic’s Reflective Sea Ice Will Advance Global Warming by 25 Years, 2019, <https://scripps.ucsd.edu/news/research-highlight-loss-arctics-reflective-sea-ice-will-advance-global-warming-25-years>.

¹¹ Craig Welch, “Climate change has finally caught up to this Alaskan village,” *National Geographic*, <https://www.nationalgeographic.com/science/2019/10/climate-change-finally-caught-up-to-this-alaska-village/>.

¹² Yessenia Funes, “U.S. Native Coastal Communities Moving Due to Change Climate Change,” *Colorlines*, May 5, 2017.

Siberian villages, industrial facilities, and northern transportation facilities are threatened with collapse due to the excessive warming in the northern regions. A recent example is the oil spill from a storage tank that burst due to melting permafrost in Norilsk Russia and sent 150,000 barrels of diesel fuel toward the Arctic Ocean.¹³ Damage to buildings, power stations, pipelines, manufacturing facilities, roads, and railways have a value estimated to be in the \$100's of billions.¹⁴

These changes are also increasing tensions in the area that threaten U.S. national security. Since the end of the Cold War the Arctic has largely been the domain of indigenous peoples, nature and scientific research. While military communities have regarded the region as a theatre of operations, the severe weather and prevailing sea ice have made operations extremely difficult. The U.S. has traditionally not devoted many resources in the area. The Arctic Council, a key intergovernmental organization that is composed of Russia, Canada, Denmark (Greenland), Iceland, Sweden, Finland, and the United States, was nominated for the 2018 Nobel Peace Prize for its collaborative efforts to preserve the Arctic for indigenous peoples and scientific research. Global warming-induced changes in the Arctic are jeopardizing these collaborative efforts. Loss of sea ice is accelerating the effects of global warming. Retreating Arctic land and sea ice and snow causes land erosion and permafrost thawing which disrupt Arctic communities and their way of life. While the warming of the Arctic is providing the potential for individual nation states to exploit natural resources and open up shipping lanes that are in the short term economically attractive, the longer-term consequences of this warming could be destabilizing and threaten to unravel long-standing cooperation among Arctic nations.

The possibility of an ice-free Arctic summer will make clear water passages possible in the Arctic for the first time in human history, potentially opening up the region to commercial shipping, mineral extraction, fishing and tourism thereby increasing tensions in the region (see Figure 2). If all nations vie for access to these open sea lanes and natural resources, it will change the balance of power in the region. Both Russia and Canada have proposed charging for passage through the Northern Sea Route (NSR) and North West Passage (NWP), respectively.¹⁵ In a 2019 speech before the Arctic Council, U.S. Secretary of State Michael Pompeo said that the Trump administration believes “the region has become an arena for power and for competition.”¹⁶ Also, the North Atlantic Treaty Organization (NATO) refers to the region as one of great power competition as Russia and other nations look to exploit

¹³ Andrew Kramer, “Major Fuel Spill in Russia’s North Spreads Toward Arctic Ocean,” *New York Times*, June 9, 2020, <https://www.nytimes.com/2020/06/09/world/europe/russia-arctic-oil-spill.html>.

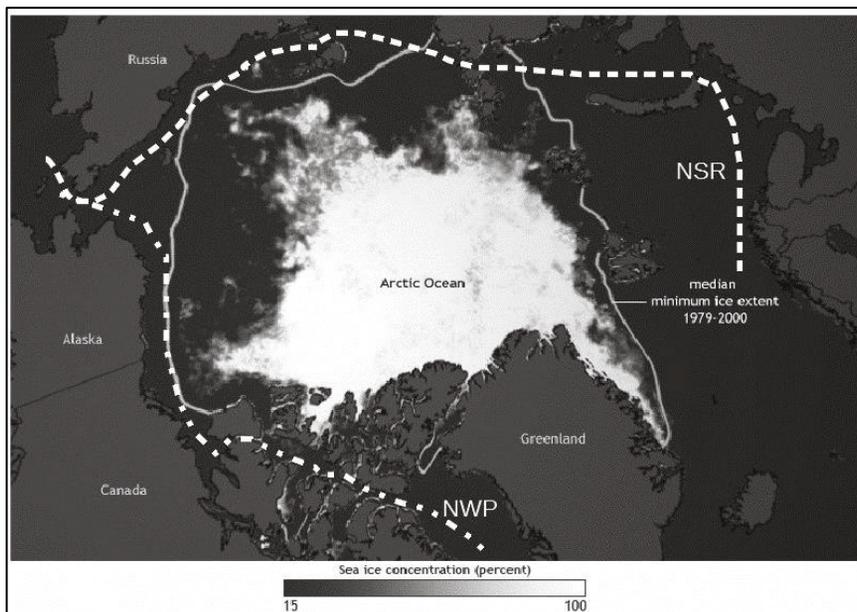
¹⁴ Jan Hjør, et al., “Degrading permafrost puts Arctic infrastructure at risk by mid-century,” *Nature Communications*, vol. 9, no. 5147 (2018).

¹⁵ Statement of General Curtis Scaparrotti before the Senate Armed Services Committee, March 8, 2018.

¹⁶ Michael Pompeo, “Looking North: Sharpening America’s Arctic Focus,” May 6, 2019 <https://www.state.gov/looking-north-sharpening-americas-arctic-focus/>.

undersea natural resources.¹⁷ A number of states are responding to one of the most dramatic and significant drivers of climate change consequences around the globe—the melting of the Arctic—not by increasing cooperation on addressing climate change, but rather by maneuvering for geostrategic advantage.¹⁸

Figure 2



The 2019 Arctic Sea Ice Minimum Is Second Lowest on Record. Mean 1981-2010 average minimum ice extent is shown as a solid line and 2019 ice extent is shown as the white area. The dot-dashed line represents the Northwest Passage and dashed line represents the North Sea Route. Changes in Arctic sea ice due to anthropogenic global warming is affecting the health and well-being of Arctic peoples and their food security, as well as increasing tensions between foreign nations, <https://eoimages.gsfc.nasa.gov/>.

For example, Russia is moving aggressively to expand and secure its position in the Arctic. Since Russia has no warm water ports with access to open ocean it must depend on its Arctic installations for direct access to the sea. Russian President Vladimir Putin portrays the NSR as a future “global, competitive transport artery” that is “the key to the development of the Russian Arctic and the regions of the Far East.”¹⁹ Rob Huebert, senior research fellow with the Center for Military and Strategic Studies, warns that “Russia is serious about the militarization, remilitarization, or securitization

¹⁷ Brett Tingley and Tyler Rogoway, “The U.S. Can’t Buy Greenland But Thule Air Base is Set to Become More Vital Than Ever Before,” *The Drive*, Sept. 2019, <https://www.thedrive.com/the-war-zone/29541/>.

¹⁸ Steve Brock, et al., *The World Climate and Security Report 2020*, International Military Council on Climate and Security, Feb 2020, www.imccs.org.

¹⁹ Steve Brock, et al., *The World Climate and Security Report 2020*.

of the Arctic.”²⁰ He points out that the revival of air and land bases, officially for search and rescue purposes, also possess runway capacities to handle Russia’s bomber and fighter fleets. Russia has resumed fighter patrols, and has tested the Kinzhal Dagger hypersonic missile in the region.²¹ The Russian government currently has over 50 airfields and ports in the Arctic region.

Russia has an icebreaker fleet that is significantly larger than that of all other Arctic nations combined and is preparing to launch its first weaponized icebreaker in 2023.²² By contrast the United States has one operational heavy icebreaker, U.S. Coast Guard Cutter (USCGC) Polar Star, and one medium icebreaker, USCGC Healy. The United States recently issued a contract for three new Polar Security Cutters, the first of which is expected to be delivered in 2024.²³

Top U.S. military officials have voiced concerns about Russia’s aggressive moves in the Arctic. Testifying before the Senate Armed Services Committee in April 2017, Admiral Harry Harris, U.S. Pacific Command, said: “Of particular note are Russian efforts to build presence and influence in the High North. Russia has more bases north of the Arctic Circle than all other countries combined, and is building more with distinctly military capabilities.”²⁴ In testimony before the same panel in 2018, General Curtis Scaparrotti, U.S. European Command, cautioned that Russia is revitalizing its northern fleet and bases in “anticipation of increased military activity . . .” Russia is increasing its qualitative advantage in Arctic operations, and its military bases will serve to reinforce Russia’s position with the threat of force.”²⁵

China also sees economic opportunity in an ice-free Arctic and is moving to secure a position in the region. It sees the potential for a cheaper northern passage for goods (as opposed to transiting through the Panama Canal), and a source of oil and natural resources. China has declared itself an Arctic nation and in 2013, the Arctic Council granted it “Observer” status. China has expanded its Belt and Road Initiative (BRI), its global development infrastructure project, to include a “Polar Silk Road” strategy to expand its influence in the Arctic region. The new initiative encourages the building of infrastructure and expanding commercial shipping routes.

²⁰ Malte Humpert, “U.S. military warns against Russian Arctic expansion,” *Arctic Today*, March 23, 2018, <https://www.arctictoday.com/u-s-military-warns-russian-arctic-expansion/>.

²¹ Tom Demerly, “Russia Test Fires New Kh-47M2 Kinzhal Hypersonic Missile,” *The Aviationist*, March 12, 2019, <https://theaviationist.com/2018/03/12/russia-test-fires-new-kh-47m2-kinzhal-hypersonic-missile/>.

²² Brendan Cole, “Russia Unveils ‘Unique’ Weaponized Icebreaker as It Eyes Arctic Oil and Gas,” *Newsweek*, Oct. 28, 2019, <https://www.newsweek.com/russia-arctic-ivan-papanin-icebreaker-1468057>.

²³ Joseph Trevithick, *The Drive*, April 2019, <https://www.thedrive.com/the-war-zone/27647/ behold-americas-new-and-desperately-needed-heavy-icebreaker>.

²⁴ Statement of Admiral Harry Harris before the Senate Armed Services Committee, April 27, 2017.

²⁵ Statement of General Curtis Scaparrotti before the Senate Armed Services Committee, March 8, 2018

Of greater concern to the U.S. and its allies should be China's move to solidify its role in the region by partnering with Arctic nations. In 2017 Premier Xi Jinping called for China and Russia to jointly build the Polar Silk Road through the Arctic, fostering greater East-West trade.²⁶ Recent reports suggest that Russia has requested that China help finance and develop Russian ports and infrastructure along its NSR. These press reports are consistent with China's wishes to "work with all parties to build a "Polar Silk Road" by "encouraging its enterprises" to "participate in infrastructure construction" for polar routes. There also have been reports of China expressing an interest in developing Arctic routes with Canada.²⁷

U.S. military installations in the Arctic region are becoming more difficult and expensive to operate because of land erosion and permafrost melting caused by global warming. For example, Thule Air Force Base, the northernmost U.S. military installation in the world and the only one north of the Arctic circle, represents U.S. interests in the Arctic region and is a critical component of U.S. Air Force Space Command and the North American Aerospace Defense Command.²⁸ The radar systems located at Thule are a central component of the U.S. early warning system that are tasked with detection and tracking Intercontinental Ballistic Missiles heading for North America. Thule already experiences damage its runways and taxiways due to thawing permafrost.²⁹ This is an example of the increased costs and consequences of expanding U.S. operations in the area.

Global Warming Consequences and Threats to National Security and U.S. Foreign Policy

The DoD considers climate change as a threat to our national security and a complication to U.S. foreign policy. In 2016, The Center for Climate & Security stated

The U.S. military has for years been a leader in addressing the risk to national security posed by climate change—a phenomenon that acts as a "threat multiplier," exacerbating natural disasters, water, food and energy insecurities, contributing to conditions that can catalyze

²⁶ Yasmeen Rasidi, *Citizen Truth*, Aug. 19, 2019, <https://citizentruth.org/china-africa-belt-and-road-initiative/>.

²⁷ Mark Rosen, "Will China Freeze America Out of the Arctic?", *The National Interest*, Aug. 14, 2019.

²⁸ Tala Hussein, "Thule Air Base: inside the US's northernmost military base in Greenland," *Air Force Technology*, June 5, 2019; and Brett Tingle and Tyler Rogoway, "The U.S. Can't Buy Greenland But Thule Air Base Is Set to Become More Vital Than Ever Before," *The Drive*, Sept. 23, 2019.

²⁹ Kevin Bjella, "Thule Air Base Airfield White Painting and Permafrost Investigation," 2012, <https://apps.dtic.mil/dtic/tr/fulltext/u2/a583138.pdf>.

conflict, instability, and state failure, and exacerbating existing security risks ... to U.S. national security, and potentially creating new ones.³⁰

In particular, water and food scarcity leads to mass migrations, especially in parts of the world that are least prepared to adapt.³¹ Today, almost 785 million people do not have access to clean water and almost two billion lack access to adequate sanitation. It is reasonable to expect that this number may double.³² Climate change contributes to high tide flooding with severe storms surges in coastal regions. World-wide, between 340 million and 500 million people live on land that is projected to be below annual flood levels by 2050 and 2100, respectively. This scenario would create an enormous refugee crisis. These kinds of climate-enhanced disasters destabilize governments and fuel radicalization.³³

The drought that led to the mass migrations in Darfur in the Sudan is regarded largely as triggering the first mass migrations that can be linked to climate change.³⁴ Current violent conflicts, such as in Syria and Yemen, have been linked by several scholars to prolonged water scarcity.³⁵ Climate change exacerbated severe drought in the Fertile Crescent, driving farmers to move to the cities, and helped trigger uprisings that eventually led to the Syrian civil war.^{36,37} To be sure, poor decisions on the part of the Syrian government also played an important role in this conflict. Still, this case represents a cautionary tale of how poor governance and climate change can exacerbate a natural phenomenon into a crisis, pitting the world's superpowers against one another. While conflicts are often attributed to a combination of different causes, it is

³⁰ Francesco Femia, Caitlin Werrell, Marcus King, eds., *The Climate and Security Advisory Group: Briefing Book For A New Administration: Recommended Policies And Practices For Addressing The Security Risks Of A Changing Climate* 2016, <https://climateandsecurity.org>.

³¹ "High and Dry: Climate Change, Water, and the Economy," World Bank Group, 2016, The World Bank, Washington, D.C.; and *The Global Climate in 2011-2015, Weather Climate Water*, Geneva. World Meteorological Organization, 2016.

³² *Progress on drinking water, sanitation and hygiene: 2017 update and SDG baselines*. Geneva: World Health Organization (WHO) and the United Nations Children's Fund (UNICEF), 2017. <https://apps.who.int/iris/bitstream/handle/10665/258617/9789241512893-eng.pdf;jsessionid=27F469A9EDD2CE5D1D799B4C0AD0FF36?sequence=1> /.

³³ "Migration and Climate Change," International Organization for Migration, 2008.

³⁴ Alex Perry, "How to Prevent the Next Darfur. Step one: Get serious about climate change." *Time*, May 7, 2007.

³⁵ Peter Gleick, "Water, Drought, Climate Change, and Conflict in Syria," *Weather, Climate, and Society*, vol. 6, no. 3, 2014, pp. 331-340.

³⁶ Colin Kelley, et al., "Climate change in the Fertile Crescent and implications of the recent Syrian drought," *Proceedings of the National Academy of Sciences*, vol. 112, no. 11, 2015, pp. 3241-3246.

³⁷ Craig Welch, "Climate Change Helped Spark Syrian War, Study Says," *National Geographic*, 2015.

becoming more evident that future water insecurity will play a greater role in conflict situations.”³⁸

Global warming also impairs the capability of our military to protect U.S. national interests. For example, 128 U.S. military bases are currently under threat from rising sea levels, especially in the Arctic. Infrastructure, such as bridges, roads, rail, ports, and aviation structures are required for DoD to move personnel and equipment in response to disasters as well as potential conflicts.

Responding to These Threats Using Emerging Technologies

The world’s response to the growing climate crisis has been inadequate. Progress in mitigation has not been made fast enough. Experts say that the nations of the world are not on track to meet even the modest targets set in the Paris Accord to limit warming to 2°C. Additionally, current efforts will not be enough to prevent catastrophic damage to the climate, peoples and economies of the world.

It is time to consider steps that may provide additional time to develop more serious mitigation efforts and stretch out the cost of mitigation. Traditional geo-engineering approaches, such as Stratospheric Aerosol Injection (SAI),³⁹ are by design large-scale because they seek to offset the regional warming caused by greenhouse gases emissions. Once started, such interventions are difficult to stop because the injected aerosols stay in the stratosphere for years. If there are unintended consequences, models show that there is often a rebound and overshoot in temperature, called a termination effect.

There are emerging non-traditional technological solutions that can mitigate the damage caused by global warming and also diffuse tensions that threaten U.S. national security. One class of these technologies is Arctic Sea Ice Restoration (ASIR) that seeks to increase the reflectivity of sea ice during the summer months to prevent ice melt.⁴⁰ It is local by design and therefore its impact is smaller and easier to control. The goal of ASIR is to break the sea ice reflectivity feedback loop and take advantage of the natural Arctic amplification to mitigate warming over a larger region. The aim is to slow global warming. These technological solutions have no demonstrated unintended consequences and are easily reversible.

To date, no major deployments of any geoengineering approach have been attempted. Several small demonstration projects, in laboratories or small-scale deployments, have been carried out along with some modeling efforts. Considerably more research, modeling and engineering studies are needed before these many different geoengineering approaches can be seriously considered for full scale deployment. Three ASIR approaches that have been proposed to date and are

³⁸ Willem Ligtoet, et al., “Water, climate and conflict: security risks on the increase?” June 2017, <https://www.researchgate.net/publication/317687776>.

³⁹ *Climate Intervention: Reflecting Sunlight to Cool Earth*, National Research Council, 2015, (Washington, D.C.: The National Academies Press), <https://doi.org/10.17226/18988>.

⁴⁰ Lou Del Bello, “Not All Geoengineering Is as Terrifying as You May Think,” *Futurism*, Jan. 1, 2018.

presented below. Since these approaches are local, they are easily reversible and have no known termination effects.

Scientist Leslie Field and colleagues⁴¹ have proposed a localized Arctic sea ice reflectivity restoration technology whose aim is to restore the Arctic ice's natural function of reflecting sunlight and thereby reducing warming of the ocean by reflecting solar radiation. The concept is to increase the reflectivity of young ice by applying a thin layer of reflective hollow silica-glass microspheres onto the surface of the ice. This treatment would increase the reflectivity of ice by about 50 percent, reducing the absorption of solar radiation that heats the ocean and causes more ice loss. The materials used in the treatment are reported to be nontoxic, consisting of silica (the primary material in sand, and most rocks). Biototoxicological testing to date, has shown no adverse impact on wildlife. A climate modeling study, designed to simulate the potential impact of the reflectivity modification scheme over the entire Arctic Ocean showed that yearly application of the material on the Arctic sea ice over the period 2000–2040 will cause ice volume to increase from 0.5 percent to 1 percent per year, with increased ice thickness of 20 cm to 1 m. The climate modeling also shows that a large part of the Arctic sees temperatures decreasing by more than 1.5°C after application.⁴² An Arctic-wide deployment, however, is simply a base case, but not a realistic scenario for deployment. Strategies for a targeted deployment of these microspheres in smaller areas, for example in the Fram Strait,⁴³ through which much ice export has been seen in the past several decades, may be a key leverage point for ice restoration. The total cost of deployment could range from \$1-5 billion per year while potentially averting trillions of dollars of climate-change-induced damages. Results from the modeling and the field work are promising, but more and larger field and modeling tests are required to understand fully the effects and consequences of this technique.

Another ASIR approach has been proposed by Steven Desch and colleagues. Wind-powered pumps would pump ocean water from underneath the ice to the top surface during the Arctic winter.⁴⁴ The water would freeze, delaying or reducing the ice melt during the summer and, over time, could restore some of the ice pack to its original thickness and extent. Theoretically, the additional ice would decrease Arctic amplification and lessen the detrimental effects that were discussed earlier. The idea has conceptually developed a system that could increase the thickness of the ice by about 1 m over the course of an Arctic winter, representing about a 70 percent thickening of the ice. The scientists estimated that a system that could cover 10 percent of the Arctic Ocean spread over ten years would require one million devices annually and cost about \$50 billion per year. To date this concept has been tested in laboratory

⁴¹ Leslie Field, et al., "Increasing Arctic sea ice albedo using localized reversible geoen지니어ing," *Earth's Future*, vol. 6, 2018, pp. 882–901, <https://doi.org/10.1029/2018EF000820>.

⁴² Subarna Bhattacharyya, et al., "Modeling and Assessing Impact of Artificially Enhancing the Arctic Sea Ice Albedo," 2018, <https://www.essoar.org/doi/abs/10.1002/essoar.10500552.1>.

⁴³ The Fram Strait is located between Greenland and Svalbard.

⁴⁴ Steven Desch, et al., "Arctic ice management," *Earth's Future*, vol. 5, 2017, pp. 107–127.

settings and numerical simulations have been conducted.⁴⁵ The wind-driven pumps are conceptual at this point and much engineering work is required to ensure that the devices would survive the harsh Arctic winter. This method is not as mature as the previous approach.

A third technology, called Marine Cloud Brightening (MCB), sprays nanoscale condensation nuclei into the marine boundary layer (<1000 meters in altitude) to make existing clouds brighter. Such brightening has the potential to keep large portions of the Arctic cooler. More research is necessary to evaluate the efficacy of such an approach as well as the potential for unintended consequences. A prototype MCB experiment was carried out recently in Australia to develop a technique that could potentially delay coral bleaching in the waters of the Great Barrier Reef.⁴⁶

The costs of large-scale deployments of any ice restoration approach are difficult to predict accurately at present. Estimates of tens of billions of dollars annually, or roughly 0.1 percent of GWP, have been suggested. While such costs are large, the avoidance of the staggering costs of damages due to global warming must be considered. Evaluating only the cost of climate-related disasters, it is estimated that in just a recent two-year period, 2016 through 2018, such disasters cost the world \$650 billion. In North America alone, those costs were estimated to be \$415 billion.⁴⁷ Munich Re, the world's largest reinsurance firm, blamed climate change for \$24 billion of losses in the California wildfires.⁴⁸ Cost estimates for climate change-related disasters and associated infrastructure, agricultural, economic and human health impacts by 2040 are staggering. In just the next two decades, these costs are estimated to be \$54 trillion world-wide. This staggering cost projection suggests that timely and assertive restoration approaches, if proven safe and subject to appropriate governance, could be an effective tool to fight global warming while human societies seek to reduce greenhouse gases emissions.

The Path Forward: Creating a New Federal Initiative

While Arctic ice restoration ideas are promising, much more research is needed to determine the feasibility and consequences of these approaches. Testing needs to be phased up to large-scale field experiments in the Arctic where conditions are harsh. Modeling using the most recent global and regional Global Climate Models are needed to assess the predicted effects of these techniques on global and local climate and weather to identify the most effective locations for possible application. While recently there have been some modeling efforts focused on the effects of large-

⁴⁵ Steven Desch, personal communication.

⁴⁶ Graham Readfearn, "Scientists trial cloud brightening equipment to shade and cool Great Barrier Reef," *The Guardian*, April 2020.

⁴⁷ Jared Shelly, "\$650 Billion and Rising: The Current Cost of Climate Change," *Risk & Insurance*, Feb. 25, 2019.

⁴⁸ Kimberly Amadeo, "Climate Change Facts and Effect on the Economy," *The Balance*, 2020, <https://www.thebalance.com/economic-impact-of-climate-change-3305682>; and Arthur Nelsel, "Climate Change Could Make Insurance Too Expensive for Most People," *The Guardian*, March 21, 2019.

scale geo-engineering approaches, these lack sufficient funding for needed research and development.

We propose that the United States take a strong leadership position in addressing Arctic climate issues and the possibility of ice restoration. We also propose that the United States establish a new research and development (R&D) initiative inspired by NOAA's National Hurricane Center (NHC). Here both intramural and extramural scientists would perform extensive modeling and monitoring research, and engineers would develop mechanisms to deal with the destructive forces of hurricanes. This new R&D initiative would be focused on Arctic climate restoration and might be called, "National Arctic Ice Restoration Initiative" (NAIRI). NAIRI would be a multiagency coordinated effort comprised of NSF, NASA, NOAA, DoE and DoD earth science and relevant allied programs associated with climate change and climate modeling. Annual funding for NAIRI would be at 2020 levels of appropriate budgets to the above agencies augmented by an aggregated total of \$1 billion annually. Augmented funds would be apportioned through NAIRI among participating agencies and devoted to R&D into methodologies and demonstration projects designed to restore Arctic ice. NAIRI also would place significant emphasis and resources on updating and modernizing climate models incorporating a more accurate representation of the contribution of Arctic climate changes and Arctic ice representation in global warming models, thus improving prediction accuracy and capabilities. NAIRI would solicit and select concepts for research and projects from government, academic, and industry organizations in keeping with the standard practices currently used by NASA and other agencies.

To address the threats of unacceptable climate change, augmented by the degradation and deterioration of Arctic ecosystems, NAIRI would improve scientific knowledge and develop techniques to restore the Arctic to its historic norms. The following represent some obvious areas for needed advancements in scientific understanding:

- Study Arctic ice characteristics and potential for reversing or slowing ice loss.
- Develop a better understanding of the coupling between ice, atmosphere and ocean dynamics, including ocean currents and weather patterns.
- Study the deterioration pathways for Tundra vegetation and methane release.
- Augment satellite, aircraft and surface monitoring of the Arctic region. The region is particularly difficult to access and monitor due to its accessibility for *in situ* measurements and extreme latitude. Monitoring should include measurements of greenhouse gases as well as hydrochlorofluorocarbons (which deplete ozone and are strong greenhouse gases).

Given the predicted deleterious impacts of global warming and associated climate changes, NAIRI would provide a coordinated and rigorous U.S. national multi-agency R&D effort to understand both the potential risks and benefits associated with proposed climate intervention approaches. It is important that the nation, and the

world, have a variety of tools to use to avoid the disastrous impacts of global warming on humans and all ecosystems. It is equally important that the pros and cons of proposed ASIR approaches are fully understood. Only through R&D investments can such understanding be gained. Accordingly, we propose that NAIRI also invest in efforts designed to actively geoengineer climate restoration through a variety of potential approaches. Approaches for restoration would be selected through solicitation and could include, but not be limited to the approaches outlined earlier.

Leading the Way

The destabilizing effect of global climate change threatens national security, both in the United States and globally. The scale and severity of these issues dictate that we do what we can to stop, or at least slow down, these climate changes. Arctic sea ice restoration represents a way of buying time and restoring some stability to the Arctic region. As the world has learned from the Covid-19 pandemic, fast and effective intervention is essential. Delaying such action results in exponentially higher costs both economically and in loss of human life and suffering. Inaction with respect to slowing down the rate of global warming will have similarly devastating consequences in decades to come if action is not taken now.

Similarly, the global governance and policy issues associated with any geoengineering full-scale deployment must be discussed and agreed upon by international bodies. The World Climate and Security Report states “dynamics of increased military and economic activity lay the groundwork for future tensions between Arctic nations, and in the absence of mitigating institutions and political will, may increase the likelihood of conflict between great powers.”⁴⁹ Therefore, we propose the United States take a strong international leadership position in addressing Arctic climate and ice restoration. It is essential that all stakeholders realize that the growing costs of global warming around the world far outweigh any potential short-term economic benefits from Arctic sea routes or mineral extraction. Restoration of Arctic sea ice is perhaps the single largest and safest lever available today to potentially slow global warming. However, before any form of geoengineering can be adopted for large-scale future deployment, there must be *a priori* international governance and policy structures in place. An international effort will be required as many countries have shorelines, landmasses, and interests within the Arctic region and the effects of any Arctic restoration will be felt globally. We must ensure social justice with fair and equitable processes for all countries and peoples potentially impacted in negative ways by these technological approaches to slow global warming. Existing international organizations, such as the United Nations or the Arctic Council, may be suited for such a role. While the challenges associated with implementing these approaches are not insignificant, the challenges to humanity and to U.S. national security associated with doing nothing or acting too slowly will be catastrophic. It is only through a dedicated R&D program into the study and deployment of the emerging technologies discussed

⁴⁹ Steve Brock, et al., *The World Climate and Security Report 2020*, International Military Council on Climate and Security, Feb. 2020, www.imccs.org.

in this article and international cooperation in their deployment that we can slow the damaging effects of global warming and the resultant regional and global instabilities that threaten our national security and confound our foreign policy.

