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How Climate Change Challenges the U.S. Nuclear Deterrent

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List of Acronyms

CMRA	Climate Mapping for Resilience and Adaptation
DAR	Defense Access Roads
DCAT	Department of Defense Climate Assessment Tool
DOD	U.S. Department of Defense
DOE	U.S. Department of Energy
EHW	explosive handling wharf
EIS	Environmental Impact Statement
FEMA	Federal Emergency Management Agency
ICBM	intercontinental ballistic missile
IPCC	Intergovernmental Panel on Climate Change
LC	launch center
LF	launch facility
MAF	missile alert facility

List of Acronyms Continued

NDAA	National Defense Authorization Act
NFHL	National Flood Hazard Layer
NOAA	National Oceanic and Atmospheric Administration
RCP	Representative Concentration Pathway
SLBM	submarine-launched ballistic missile
SSBN	ballistic missile submarine
STRATCOM	U.S. Strategic Command
SWFLANT	Strategic Weapons Facility Atlantic

Summary

Climate change could have mission-altering impacts on the U.S. nuclear deterrent. This paper examines the range of climate change challenges and threats that could detrimentally affect each leg of the U.S. nuclear triad in different and increasingly serious ways. In doing so, the paper helps to advance broader, ongoing efforts to account for climate change in U.S. national security policies. It also aims to inform and help initiate a larger conversation about the vulnerabilities of all nuclear weapons programs to climate change. Gaining greater clarity about these vulnerabilities now is essential to mitigating the worst effects of climate change on nuclear weapons in the future.

The paper highlights the following key findings:

- Naval Submarine Base Kings Bay is vulnerable to rising sea levels and flooding that could significantly affect its capacity to service U.S. ballistic missile submarines (SSBNs). Because Kings Bay is one of two bases equipped to support the U.S. SSBN fleet, climate change effects there could have serious repercussions for the broader deterrence mission of the submarine leg of the nuclear triad.

- At Minot Air Force Base, warming temperatures may accelerate flooding that could impact the accessibility of the base's intercontinental ballistic missile (ICBM) silos and facilities. This accessibility issue could have cascading effects on the larger ICBM deterrence mission, potentially limiting the reliability of some missiles by delaying scheduled maintenance or deliveries.

- Increasing temperatures and incidences of extreme precipitation at Whiteman Air Force Base pose potential risks to the nation's stealth nuclear bombers. Climate change impacts that prevent aircraft from freely taking off from or landing at Whiteman may have some implications for the readiness of the larger bomber leg, especially as related to the accessibility of nuclear weapons storage sites.

Importantly, this analysis should be viewed as a descriptive assessment of potential future outcomes based on current trends, not as a prediction. What actually transpires will depend on how the United States prepares for, mitigates, and adapts to these challenges. The paper concludes by offering five recommendations for ways to do so:

- The U.S. Department of Defense (DOD) and the U.S. Department of Energy (DOE) should conduct climate change vulnerability assessments of all their nuclear installations and facilities to determine how and when climate change could impact each site's unique nuclear systems, operations, and activities.

- The DOD should invest in dynamic climate change modeling and both interagency and nongovernmental partnerships to ensure U.S. nuclear decisions and planning are informed by the most accurate climate change projections.

- The DOD and other agencies should be required to complete forward-looking studies of potential climate change impacts on any future nuclear actions, including the construction and deployment of modernized nuclear systems.

- The DOD should adopt a mission-level focus in its climate adaptation planning and establish a workstream specifically focused on the nuclear mission. An initial deliverable of this work should be a dedicated climate action plan for the U.S. deterrence mission.

- The DOD should integrate climate change scenario exercises into nuclear planning to simulate potential climate-nuclear crises and develop mitigation and adaptation plans. Key considerations should include how the climate scenario may impact local and global nuclear operations, nuclear command and control assets, base personnel, and local communities, with the exercise results incorporated into nuclear planning efforts.

Introduction

The United States is investing billions—if not trillions—of dollars to modernize its nuclear arsenal. This modernization effort aims to ensure its nuclear systems will be able to deliver the U.S. deterrence mission for decades to come, motivated at least in part to address a changing geostrategic environment. But how much do these plans account for a changing *geophysical* environment? Specifically, how will climate change affect the capacity of U.S. nuclear systems to support the nation's deterrence mission?

This paper aims to present some initial answers to this underexplored question. In doing so, it helps to advance broader, ongoing efforts to account for climate change in U.S. national security policies. Time is of the essence to ensure the United States is prepared to account for and effectively address the potential mission-altering impacts of climate change on the nation's nuclear deterrent.

The analysis is organized around the U.S. nuclear triad: ballistic missile submarines (SSBNs), intercontinental ballistic missiles (ICBMs), and bomber aircraft. Climate change effects—such as rising sea levels, extreme weather events, and warmer temperatures—present a range of challenges and threats that could have detrimental impacts on each leg of the triad in different and increasingly serious ways. To assess these varied impacts, this paper examines climate change risks at a military base associated with each system: Naval Submarine Base Kings Bay, where rising sea levels and flooding could significantly affect the base's capacity to service U.S. SSBNs; Minot Air Force Base, where warming temperatures may accelerate flooding that could impact the accessibility of the base's ICBM silos and facilities; and Whiteman Air Force Base, where warming temperatures and incidences of extreme precipitation pose potential risks to the nation's stealth nuclear bombers.

Drawing on findings from these assessments, the paper considers the broader implications of climate change for each leg of the triad. Importantly, this analysis should be viewed as a descriptive assessment of potential future outcomes based on current trends, not as a prediction. What actually transpires will depend on how the United States responds. The paper concludes by offering recommendations for how the United States can better prepare for, mitigate, and adapt to these climate change challenges to the nuclear deterrent.

The State of Play

Climate change is widely recognized as a "threat multiplier"—not only does it present environmental challenges with vast and far-reaching consequences, but it also exacerbates existing security challenges and risks.[1] While often considered in the context of particularly fragile or volatile regions, this link between climate change and security also holds broader implications for an increasingly dangerous and evolving strategic security environment.

The U.S. Department of Defense (DOD) has identified climate change as a "critical national security threat."[2] To address this threat and in response to President Joe Biden's Executive Order 14008 to put "the climate crisis at the center of United States foreign policy and national security,"[3] the DOD released a series of notable policy and planning documents on climate security in 2021—the Climate Risk Analysis,[4] Climate Adaptation Plan,[5] and Installation Exposure assessment.[6] These documents collectively track the department's plans and progress toward integrating "the security implications of climate change into key strategic documents, programs, and international partner engagements."[7]

Notably, the Installation Exposure assessment presents high-level findings from the DOD Climate Assessment Tool (DCAT). The tool, which is not publicly available, provides screening-level assessments of the vulnerability of U.S. military installations to climate change hazards.[8] To do so, it calculates a climate hazard exposure score for each installation. The scores have no objective meaning but are instead used to rank installations' relative climate exposure risk.[9] The DCAT is designed for use by installation-level planners and engineers, military department leadership, and broader DOD leadership to inform decisionmaking, both in terms of investments and resource prioritization as well as larger policy considerations.[10]

While this work should be applauded, analytic gaps remain. Importantly, there is no specific, systematic, and sustained focus on the implications of climate change for the U.S. nuclear deterrent. Given the centrality of the nuclear triad to U.S. national security interests—to say nothing of the scale of resources already slated for modernizing these systems—this gap is stark and troubling. If climate change is indeed both a threat multiplier and a critical national security threat, special attention must be given to this threat vis-à-vis "the backbone of America's national security."[11]

Outside of the Pentagon, important research has been done on the intersection of nuclear and climate. Some work focuses on the likely disastrous environmental consequences of a nuclear war,[12] with related research focused on examining how climate change could undermine the integrity of sites that store radioactive waste from weapons testing programs.[13] Other work focuses on the role of nuclear power in the clean energy transition,[14] including some emerging research that assesses the potential security and safety implications of climate change for states with nuclear energy—and, in some cases, also nuclear weapons—programs.[15] But collectively, this research also gives little attention to potential ways climate change could affect how the United States bases, postures, and operates its nuclear weapons.

Outstanding questions therefore remain unaddressed: What challenges does climate change pose to the U.S. nuclear deterrent? How will climate change impact each leg of the triad? Will these impacts vary? Could these impacts require the United States to alter the ways in which it executes its deterrence mission? And how can the United States better prepare for the likely dangerous convergence of climate change and nuclear weapons?

Climate Change and the U.S. Nuclear Triad

To begin to address these questions, it is necessary to analyze the impacts of climate change on each leg of the U.S. nuclear triad: SSBNs, commonly referred to as the sea leg; ICBMs, the ground leg; and bomber aircraft, the air leg. For each leg, this paper focuses on a representative military base tasked with housing, maintaining, and operating the nuclear system. After reviewing the nuclear activities and missions at the bases as characterized in open-source literature, the paper utilizes relevant climate models to examine plausible future scenarios based on two greenhouse gas emissions pathways—lower emissions and higher emissions—over midcentury and late-century time horizons. The emissions pathways correspond to intermediate and high future warming scenarios, which are projected to amplify the climate hazards most likely to impact the different legs of the triad—namely, sea level rise, extreme flooding events, and extreme heat. The time horizons track these hazards to the projected midlife and end life of the systems currently under development as part of the U.S. nuclear modernization effort: the Columbia-class SSBN, Sentinel ICBM missile (previously termed the Ground Based Strategic Deterrent), and B-21 Raider strategic bomber. The four resulting climate change scenarios presented for each leg of the triad are not predictions but rather potential future outcomes, especially if no preventive measures are taken to mitigate their effects.

Based on these findings, the section then discusses the implications of those climate change effects for operations related to each base's nuclear mission. Where applicable and possible given available information, it identifies mitigation efforts the government is already taking. The analysis concludes by generalizing how these climate change impacts may affect the larger deterrence mission of each leg of the triad. Similar to the climate scenarios, these assessments should be viewed as potential future outcomes and not necessarily predictions. Given the stakes involved in the U.S. nuclear enterprise, however, even the possibility of these impacts requires serious, high-level consideration.

The Sea Leg

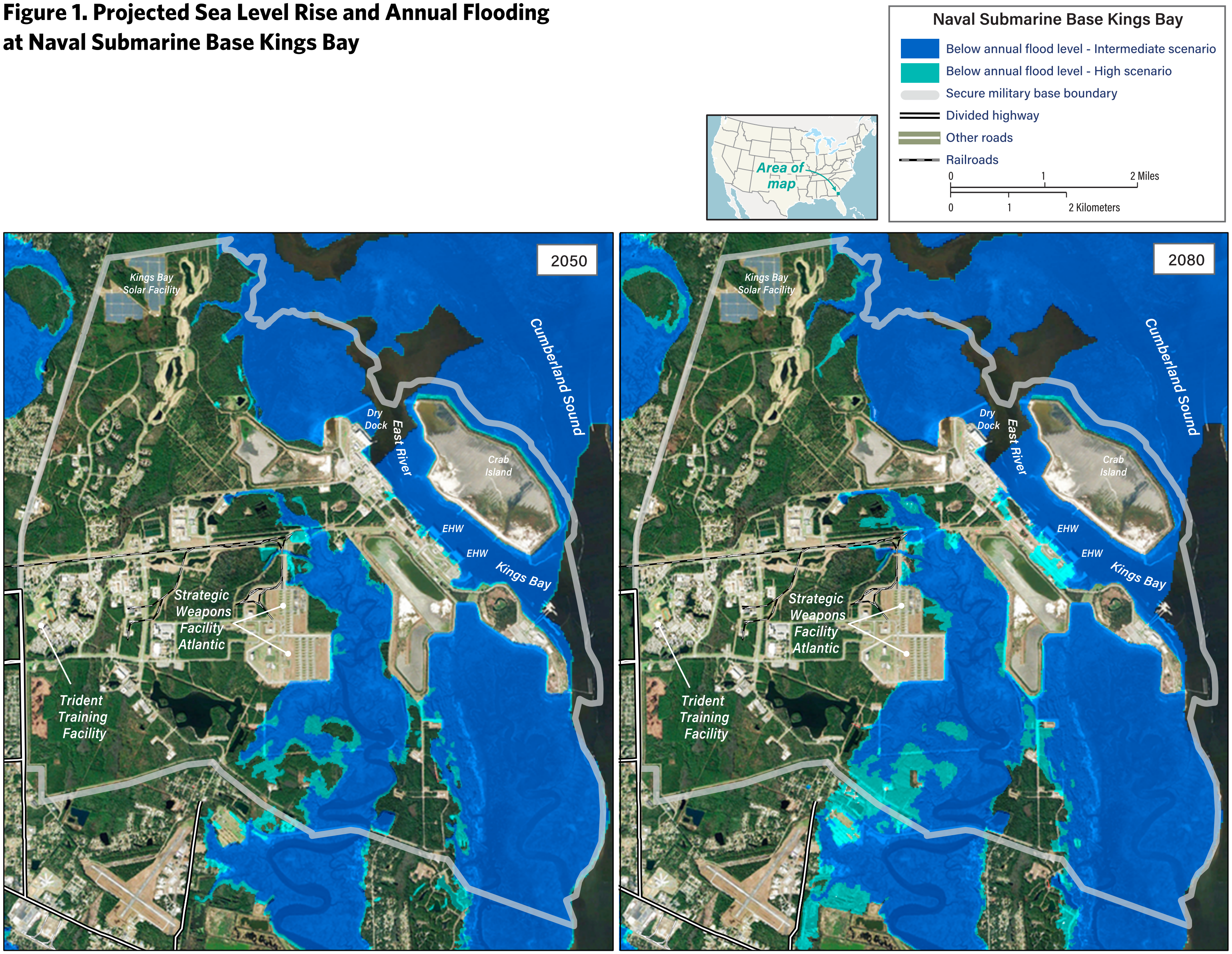
Naval Submarine Base Kings Bay is the Atlantic hub of the SSBN fleet. It is the home port of six Ohio-class submarines, which will be progressively replaced by now-in-development Columbia-class submarines starting in the 2030s.[16] Located on the southern coast of Georgia just north of the Florida border, Kings Bay has three primary commands that contribute to U.S. nuclear deterrence.[17] The Trident Training Facility trains sailors to operate and maintain SSBNs.[18] The Trident Refit Facility is tasked with maintaining and repairing SSBNs at the base's refit wharves and dry dock[19]—the largest dry dock in the Northern Hemisphere, which recently received a nearly $600 million refurbishment.[20] And the Strategic Weapons Facility Atlantic (SWFLANT)—a complex comprising twenty-four buildings and two explosive handling wharves (EHWs)—stores, maintains, and assembles Trident II D5 submarine-launched ballistic missiles (SLBMs) and their warheads for the SSBN fleet.[21]

Given its location, sea level rise and annual flooding pose the greatest challenges to Kings Bay and the sea leg of the triad. According to sea level rise projections by the National Oceanic and Atmospheric Administration (NOAA) and its interagency partners, the global mean sea level is projected to rise by 3.3 feet (1 meter), compared to a 2000 baseline, by 2100 in an intermediate sea level rise scenario and 6.6 feet (2 meters) in a high sea level rise scenario.[22] The probability of each scenario varies according to different projections of global net greenhouse gas emissions and associated warming by the end of the century, as characterized in the Sixth Assessment Report by the Intergovernmental Panel on Climate Change (IPCC).[23] The probability associated with the intermediate sea level rise scenario increases as projected end-of-century warming increases under higher emissions pathways.[24] Notably, this scenario also tracks closely with the current observation-based trajectory of global mean sea level rise, only significantly deviating from the current trajectory in about 2085.[25] The high sea level rise scenario is considered fairly unlikely under any IPCC emissions and warming pathway;[26] however, the potential for this worst-case scenario cannot be disregarded, especially as some processes that may contribute to sea level rise and could become especially prominent contributors in the future are not yet fully understood.[27]

Extrapolating from these global projections, figure 1 depicts likely sea level rise and annual flooding at Kings Bay in 2050—about the year of the planned midlife of Columbia-class submarines—and 2080—about the planned end life of the submarines.[28] Notably, the maps do not include potential storm surge. Global warming is expected to contribute to an increase in the severity of extreme weather events such as hurricanes. Warmer atmospheric and oceanic conditions facilitate the evaporation-condensation cycle that encourages more rain and stronger winds, both of which contribute to more powerful storms.[29] Paired with rising sea levels, these extreme events would contribute to considerably higher storm surge.[30] But it is difficult to project the frequency of such extreme events, hence the exclusion of their effects here. Existing studies and tools that demonstrate the substantial impacts of storm surge on Kings Bay, especially as related to the usability of base land, provide useful, supplementary reference points.[31]

According to the projections presented in figure 1, under all scenarios and time horizons, the dry dock as well as the Trident Training Facility building should remain relatively unaffected by sea level rise and annual flooding, although both facilities may be more vulnerable to high storm surge.[32] The former is likely due to some natural protection afforded to the dry dock by Crab Island and the latter because the building is situated about four miles back from the East River. Meanwhile, sea level rise and annual flooding are projected to affect the roads connecting SWFLANT to the EHWs as well as areas in and around the EHWs and, to a lesser extent, the dry dock. The potential severity of these effects expectedly increases from the intermediate to the high sea level rise scenario and from the 2050 to the 2080 time horizon and would only be exacerbated by storm surge.[33]

Figure 1. Projected Sea Level Rise and Annual Flooding at Naval Submarine Base Kings Bay



Source: International Mapping.
Note: International Mapping created this map by drawing on data from the U.S. Geological Survey Harrietts Bluff topo map, NOAA Kings Bay pile driving map, ESRI satellite imagery, World Street Map (WGS84), Climate Central Coastal Risk Screening Tool, Living Atlas of the World, NOAA Coastal Digital Elevation Models (DEMs), and 2022 Sea Level Rise Technical Report data files.

Implications for Kings Bay

These climate change effects could plausibly compromise some aspects of the base's nuclear operations, especially as related to the SWFLANT mission, which requires reliable routes to transport the Trident D5 missiles to and from the SSBNs. Satellite imagery indicates that one main road connects the SWFLANT complex, where D5 missiles are presumably assembled, to the EHWs, where D5 missiles are presumably loaded and unloaded onto the SSBNs.[34] This road must be robust enough to handle the transport of D5 missiles, which, when fully assembled, weigh upwards of 130,000 pounds—1.6 times heavier than the federal limit for interstate highways.[35]

There are two bridges over which this main transport road crosses a river that divides the SWFLANT complex and the EHWs. In all four climate change projections, sea level rise combined with annual flooding is projected to bloat the river and inundate increasingly larger portions of the road, damaging and undermining the bridges and the road itself. To mitigate the effects of this flooding, the DOD will likely have to reinforce the road and lengthen the bridges. Given the progressive worsening of sea level rise, this may not be a one-off endeavor but rather a persistent investment as the century progresses.

Most problematic, especially when factoring in additional damage caused by storm surge, this road could at times become unpassable. This could hamper the base's ability to ensure SSBNs are equipped with viable D5 missiles. While the nature and frequency of D5 missile maintenance is unclear in the open source, the navy has indicated that the aging missiles will need more regular maintenance.[36] More frequent and severe flooding that impacts the transport of the missiles could delay or upset these service operations. Readiness may even be affected if, for example, a submarine deployment is delayed because its missile servicing was disrupted by a particularly extreme flood. In addition to any regular missile maintenance, this missile transport effort might be particularly pressing when the life-extended D5 missiles (D5LE), which will be deployed on the first eight Columbia-class submarines, will have to be replaced by a further life-extended missile (D5LE2).[37]

In addition to impacts on SLBM transports, other roadways and facilities along the waterfront are projected to be increasingly inundated as sea level rise and annual flooding increases throughout the century—that is, the water's edge will push further and further inland. Such inundation is particularly stark in the high sea level rise scenario in 2080, though not negligible in the intermediate projections, especially in terms of access to the EHWs. It may also pose similar issues for the refit wharves further upriver between the EHWs and the dry dock, where general maintenance and crew exchanges take place as part of the submarines' regular in-port visits. This encroachment holds important implications for the base's usability of waterfront land and could require the base to elevate or move facilities inland, likely at a significant and potential repeat cost.[38]

Given the vulnerability of its coastal installations to rising sea levels, flooding, and extreme weather events, the navy is particularly attuned to climate change effects. As such, it has started to address some of these challenges at Kings Bay. It has, for example, pursued various projects with local community partners aimed at increasing base resilience and conserving natural habitats as part of the DOD Readiness and Environmental Protection Integration Program.[39] This includes identifying natural infrastructure solutions, such as living shorelines, to protect the base and surrounding communities from sea level rise and flooding.[40] Additionally, while primarily developed to contribute to the navy's renewable energy goals, the Kings Bay Solar Facility also provides some potential energy security should flooding in the surrounding community disrupt the base's connection to commercial energy services.[41]

Implications for the SSBN Mission

Even with some mitigation and protection efforts in place, significant challenges remain. Under all four climate change projections presented in figure 1, sea level rise and annual flooding are expected to increase substantially at Kings Bay throughout the century. Kings Bay is one of only two U.S. bases equipped to fully support the SSBN fleet, so climate change effects that disrupt the base's capacity to service and maintain SSBNs could hamper the submarine leg's ability to complete its broader deterrence mission—to assure the United States' capability to launch a nuclear strike anywhere, anytime.[42]

Perhaps most significant would be if these climate change effects prevented submarines from entering or departing port at any given time, whether due to a particularly severe flood or even more incremental sea level rise disrupting docking capacity at Kings Bay's waterfront facilities. To the extent that climate change will make them more severe, extreme weather events will exacerbate this accessibility issue. A severe hurricane, for example, could displace enough sediment to make already fairly shallow waterways into Kings Bay unpassable for the SSBNs. This, in turn, would extend periods of inaccessibility as waterways would have to be dredged, which would likely come at a substantial cost, as suggested by annual maintenance dredging efforts that can run upwards of $20 million.[43]

Keeping SSBNs at sea or moving them off base more often to cope with climate change effects would impact routine submarine maintenance and crew exchanges. Exchanging crews at sea is possible, a process the navy appears to be exercising more regularly.[44] But surfacing to conduct at-sea exchanges makes the submarines more detectable, at least for the amount of time it takes to swap out 150-person crews and replenish supplies.[45] Moreover, while personnel and supply replenishments can occur at sea, routine maintenance cannot. Remaining out of port means postponing an average thirty-five days' worth of general servicing after each deterrent patrol.[46] By potentially undermining the stealth and health of SSBNs, these climate change implications therefore stand to increase the vulnerability of the most survivable leg of the triad.

Notably, an inaccessible Kings Bay would also pose challenges to the United Kingdom's SSBN fleet. The United Kingdom does not own its own missiles but rather has purchased the rights to fifty-eight U.S. Trident D5 missiles, which it replenishes at Kings Bay.[47] Because the United Kingdom relies solely on SSBNs to execute its deterrence mission, an inability to access those missiles could be especially detrimental to that mission.

Box 1. Climate Change and SSBN Deployments in the Arctic

Climate change effects are not isolated to Kings Bay. One of the primary drivers of sea level rise—the melting of ice sheets and glaciers—could have a profound impact on how the United States conducts nuclear deterrence via its submarine leg. For instance, the United States is not known to conduct SSBN deterrence patrols in the Arctic, at least as is suggested in the open source.[48] To launch a SLBM from the region, a SSBN would have to surface—that is, break through thick layers of Arctic ice. The United States has demonstrated a capacity to surface through that ice with its non-nuclear-armed submarines,[49] but unlike Russia, it has not demonstrated such a capacity with its SSBNs.[50] It may find little operational utility in doing so given the requisite lengthy surfacing times,[51] not to mention the potential damage such a maneuver could inflict on the multibillion-dollar systems.[52]

The rapid melting of Arctic ice and prospect of more ice-free months per year could minimize and, at times, eliminate this surfacing-through-ice requirement.[53] If so, the United States may seek to expand its SSBN patrols to the Arctic due to potential operational advantages. Launching a SLBM from the region, for example, would reduce attack warning times in a contingency. Moreover, Russia does not currently have sufficient early-warning satellite capabilities to monitor the region, a gap the United States may seek to exploit.[54] Any such expansion of U.S. deterrence patrols to the Arctic would constitute a substantial shift in the submarine leg's mission.

While these challenges to the sea leg of the triad may be speculative, they are not implausible nor can they be resolved with greater resource allocation alone. Climate change may require the United States to significantly adapt its SSBN posture to ensure that the submarines can still effectively strike anywhere, anytime.

The Land Leg

Located in northwest North Dakota, Minot Air Force Base hosts two key nuclear systems: B-52H Stratofortress bombers and Minuteman III ICBMs. This analysis focuses on the base's ICBM mission, specifically the 91st Missile Wing's mission to operate, maintain, and secure Minuteman III missiles.[55] About 135 of these missiles are housed across 150 underground launch facilities (LFs), or missile silos, located in the base's 8,500-square-mile missile field.[56] In addition to servicing the missiles, the 91st Missile Wing is responsible for staffing fifteen missile alert facilities (MAFs)—which house underground launch control centers used to monitor and control the LFs[57]—around the clock to maintain the "day-to-day alert" status of the ICBM leg of the triad.[58] By 2036, the wing is expected to operate, maintain, and secure Sentinel missiles, which will replace the Minuteman III missiles. As part of the Sentinel program (previously termed the Ground Based Strategic Deterrent), the Minot missile wing will oversee 150 modernized LFs and eight launch centers (LCs), upgraded versions of the MAFs.[59]

Historical events suggest extreme flooding may be of particular relevance in considering the impacts of climate change on Minot's ICBM mission. But unlike the sea level rise and annual flood models presented above, it is difficult to model extreme flooding over long time horizons; too much uncertainty remains around projecting its frequency. Temperature and precipitation trends, though, can be reasonably projected into midcentury and late-century time horizons, reflecting about the midlife and end life of the Sentinel system.[60] Table 1 presents these data for lower and higher emissions pathways in Ward County, North Dakota, where the base and much of its missile field are located. The data come from the Climate Mapping for Resilience and Adaptation (CMRA) assessment tool,[61] a high-level screening tool developed by U.S. interagency partners that draws on climate models developed for the Fourth National Climate Assessment.[62]

Table 1. Projected Annual Very Hot Days and Average Total Precipitation at Minot Air Force Base

	Midcentury (2035–2064)		Late century (2070–2099)	
	Lower emissions	Higher emissions	Lower emissions	Higher emissions
Annual days with maximum temperature > 90º F	28 days	33 days	35 days	59 days
Average annual total precipitation	17 inches	18 inches	18 inches	18 inches

Source: Climate Mapping for Resilience and Adaptation.
Note: The modeled history (1976–2005) saw an average of 9 days with temperatures above 90 degrees Fahrenheit and 17 inches of annual precipitation.

Temperature and precipitation data are useful here as they may affect extreme flooding events. An increase in the annual number of very hot days—days with maximum temperatures above 90 degrees Fahrenheit—from the modeled history of nine days per year to upwards of twenty-eight days across all four climate change projections could, for example, impact snowmelt.[63] Not only can warming initiate winter thawing earlier in the year, but it could also accelerate snowmelt, turning a typically gradual process into a rapid one that increases flood risks.[64] In terms of projected precipitation trends, the Fourth National Climate Assessment explains:

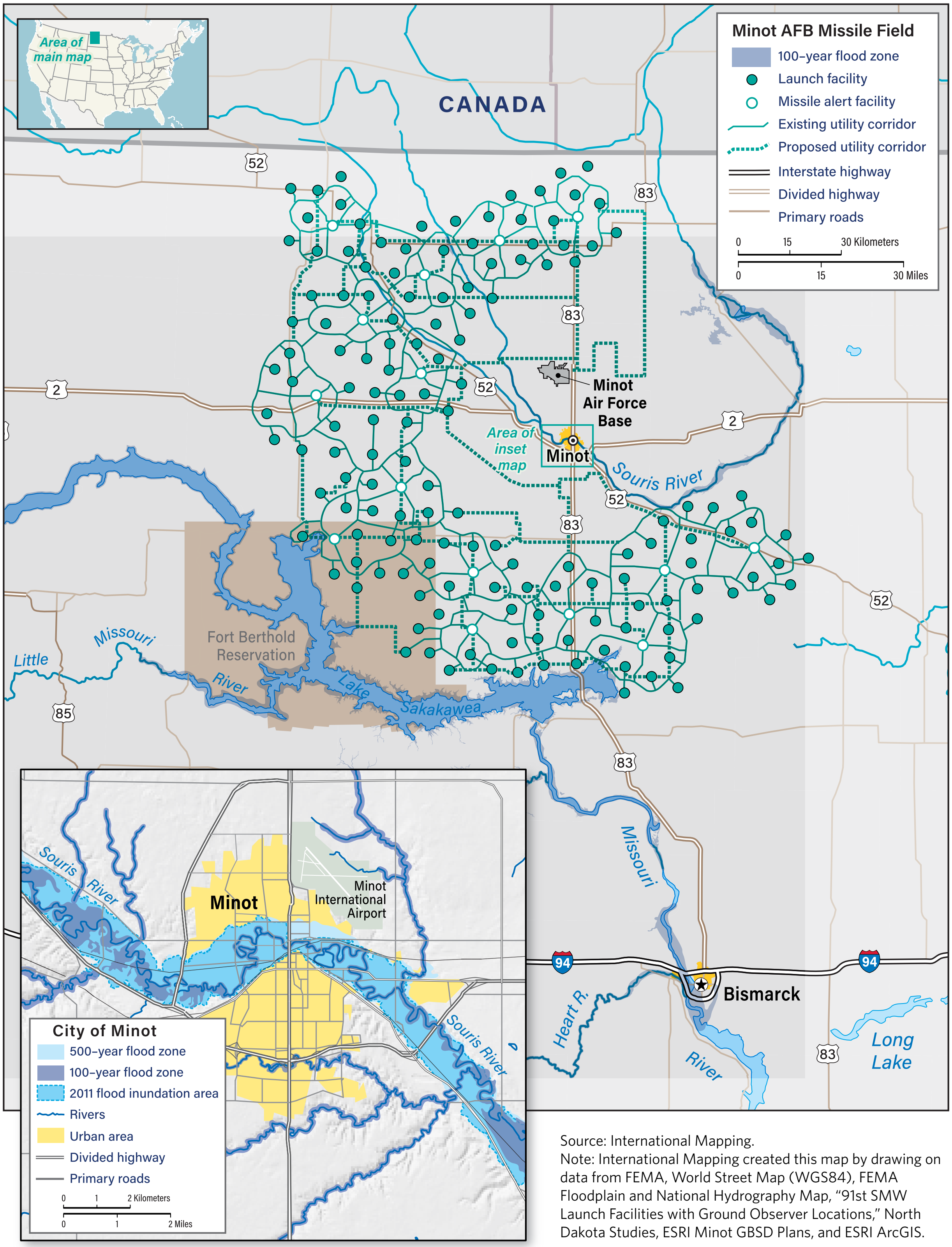
> Precipitation and streamflow projections show only modest changes, but many areas within the [Northern Great Plains] are already subject to a high degree of year-to-year variability—both wet and dry years. Low-probability, but high-severity and high-impact, events are the result of large variability . . . [, which] is likely to become more common in a warmer world.[65]

In short, these climate change effects could exacerbate extreme flooding that has already devastated the region on several occasions.

The 2011 Souris River flood is particularly illustrative. Prompted by a confluence of events, including above average snowpack and large rainfall in both Canada and North Dakota, the historic flood inundated the city of Minot. The city is located just 14 miles south of the base and is home to many base personnel, more than a thousand of whom were displaced by the flood.[66] While the base managed to avoid significant damage, the flood reportedly made seven LFs inaccessible due to damaged and inundated access roads.[67] Additionally, the base, which reportedly draws on the city's commercial water utilities, had to cut its water consumption in half.[68] And even while not directly impacted by the flood, operations at the base and in the missile field were impacted by "localized pooling" around "a handful" of LFs caused by the large winter snowmelt.[69] Airmen relied on sandbags and water pumps for months to stave off a serious water infiltration issue. Importantly, this snowmelt challenge suggests that even in the absence of an extreme flood, a smaller set of cascading events could also have damaging impacts.

To help visualize potential future flooding impacts, figure 2 depicts flood zones in the Minot missile field as well as the city of Minot. The 100-year flood zones indicate areas that have a 1 percent chance of flooding in a given year and the 500-year flood zone a 0.2 percent chance.[70] The data are derived from the Federal Emergency Management Agency (FEMA) National Flood Hazard Layer (NFHL), an authoritative flood mapping resource that the air force also drew on when conducting its Environmental Impact Statement (EIS)—a legally mandated environmental assessment of any major, proposed federal action—for the Sentinel program.[71] However, the FEMA data are an imperfect resource. Most notably, the NFHL does not cover the complete missile field area, and of the area covered, much of the data are outdated.[72] This is problematic and suggests that the DOD is relying on both incomplete and potentially outdated flood data in conducting its environmental impact studies and, presumably, other planning and strategy efforts associated with Minot's ICBM operations.

Figure 2. Minot Air Force Base Missile Field Flood Zones



Source: International Mapping.
Note: International Mapping created this map by drawing on data from FEMA, World Street Map (WGS84), FEMA Floodplain and National Hydrography Map, "91st SMW Launch Facilities with Ground Observer Locations," North Dakota Studies, ESRI Minot GBSD Plans, and ESRI ArcGIS.

Setting aside these limitations, figure 2 draws on FEMA data given the NFHL's wide recognition as an authoritative source and the air force's reliance on the data in the Sentinel EIS.[73] The map presents as much FEMA data as are publicly available, including data from a dedicated assessment of the city of Minot conducted after the 2011 flood.[74] As illustrated, the base and many of the LFs and MAFs do not sit in flood zones, at least as currently mapped by FEMA. Some utility corridors do, however, especially near Lake Sakakawea, where some LFs also come quite close to the 100-year flood zone. Additionally, the map indicates that some key highways and primary roads intersect with 100-year flood zones. Given its scale, the map does not indicate whether access roads, including unpaved roads that provide access to isolated LFs and MAFs, are in flood zones.

Implications for Minot

More severe flooding, or even a cascade of smaller flooding events, could impact Minot's ICBM deterrence mission in a number of ways. Such flooding could, for example, displace base personnel and their families, as the 2011 flood did. This could have substantial implications for workforce morale and readiness, especially if airmen are living in emergency accommodations and spending their off-duty time rebuilding their homes.[75] Such circumstances may also require some personnel to be temporarily removed from the DOD Nuclear Weapons Personnel Reliability Program, meaning they would no longer be certified to perform their nuclear weapons–related duties.[76]

More severe flooding could also exacerbate existing water infiltration challenges at the LFs and MAFs. In addition to particularly acute challenges posed by snowmelt in 2011, the Sentinel EIS suggests water infiltration is a fairly regular issue "during spring thaw" even though no LFs or MAFs sit in FEMA-designated flood zones.[77] Since water infiltration can contribute to a range of issues, including the corrosion of key structural components and even the potential flooding of underground facilities, more severe flooding may require additional mitigation efforts and resources beyond the current approach—which largely relies on sandbags and water pumps—with both budgetary and personnel implications.[78]

Nevertheless, additional water infiltration challenges prompted by more severe flooding seems likely to be more of a nuisance than an issue that would necessitate a substantial operational change at Minot. By contrast, if such flooding inundates or damages access roads, that could pose a serious issue to the base's staffing and maintenance operations. As indicated, many of these roads are unpaved and are thus particularly vulnerable to flooding. As was reportedly the case in 2011, flooding of these roads could make some LFs or MAFs inaccessible. A lack of access to MAFs could delay staffing rotations, requiring a deployed team to stay on beyond the standard weeklong shift.[79]

The helicopter squadron stationed at Minot could mitigate this staffing impact by transporting rotational crews by air. The squadron could not, though, similarly transport the heavy materials and equipment regularly needed for missile maintenance.[80] Unpassable access roads could therefore disrupt and delay Minot's missile maintenance efforts, with potentially far-reaching consequences if the roads remain unpassable for extended durations.

This is an especially difficult challenge given the sheer weight of maintenance transports. Many unpaved access roads are not equipped for such heavy transports as is, let alone if compromised by flooding. The DOD has made some effort to address this issue through the Defense Access Roads (DAR) Program, through which the DOD contributes to highway maintenance given the unusually high impact of defense activities.[81] A special segment of the DAR Program is dedicated to the "extraordinary maintenance" associated with ICBM transports,[82] including transports conducted as part of Minot's deterrence mission.[83] While useful, the DOD may need to adapt this seemingly reactive program to accommodate more proactive efforts to ensure Minot's access roads remain usable in the face of more severe flooding events.

Implications for the ICBM Mission

Importantly, even an extremely severe flood is unlikely to make all LFs or MAFs in the Minot missile field inaccessible. Moreover, Minot is one of three air force bases with ICBM facilities; F.E. Warren Air Force Base in Wyoming and Malmstrom Air Force Base in Montana also oversee 150 LFs. All three bases are located in the Missouri River Basin, suggesting a possibility that all of them could be impacted by a particularly wet year, but probably not at the same extremes. More severe flooding is therefore unlikely to fundamentally undermine the ICBM leg's deterrence mission—to maintain the ability to carry out a prompt and overwhelming strike.[84] Relatedly, because control of the collective 450 LFs is distributed among forty-five MAFs across the three bases, such flooding would not likely necessitate any change in the alert status of ICBMs, although decreasing the number of MAFs from fifteen to eight LCs at each base as part of the Sentinel modernization effort presumably concentrates the potential impact of flooding on this collective command and control structure.[85]

However, the potential that more severe flooding could make any LF or MAF inaccessible for an extended duration could have some cascading effects on the ICBM leg's deterrence mission. Of particular concern would be a scenario in which an extreme flood event prevents the scheduled delivery of a weapon or limited life component, a supply chain issue of sorts that could undermine the reliability of some missiles. Delays in reinstalling missiles removed from their LFs for maintenance, for example, could delay scheduled—and potentially critical, time-sensitive—maintenance for other missiles, assuming maintenance crews would prioritize getting the removed missile back online.[86] Such a delay could therefore result in unplanned periods in which the United States could not generate its full ICBM force. If a limited life component—part of a nuclear warhead that has a shorter operating life than the expected life of the warhead—is not replaced on schedule, that could adversely affect the reliability of the weapon, even to the point of nonoperationality.[87] Additionally, if severe flooding occurred during Sentinel construction, which will entail upgrading one LF every week for the next nine years, it would seriously disrupt an already tight construction timeline, likely with significant cost implications.[88]

These outcomes are worst-case scenarios that, again, would be unlikely to impact all missiles simultaneously and therefore unlikely to undermine the overall readiness of the ICBM leg of the triad. Yet, even the possibility that climate change could impact the reliability of some ICBMs to deliver a prompt strike at any time may require the United States to reassess its capacity to maintain its missile force based on current planning.

The Air Leg

Located in Johnson County, Missouri, about 70 miles east of Kansas City, Whiteman Air Force Base is home to the United States' only stealth nuclear bombers—the B-2 Spirit. As the only operational base for the nation's twenty B-2s,[89] Whiteman is tasked with maintaining, supporting, and operating the bombers.[90] The planes are stored on base in special climate-controlled hangars, in part due to the sensitivity of their radar-absorbent skin.[91] As indicated in figure 3, these hangars are located near the base's weapons storage facility, which houses an estimated 100 nuclear gravity bombs that stand ready to be loaded onto the B-2s.[92]

The B-2s are scheduled to be replaced by the next-generation B-21 Raider stealth bombers in the 2030s.[93] Given the sensitivity of the aircraft's technology, not much information about the B-21s is publicly available, including their estimated service life. The air force is expected to procure at least 100 B-21s, each of which will be capable of carrying both nuclear gravity bombs and new air-launched nuclear cruise missiles in addition to conventional weapons. The new B-21s will be deployed across three air force bases—Dyess in Texas, Ellsworth in South Dakota, and Whiteman.[94] Ellsworth has already been selected as the first deployment location and, after a second B-21 EIS is completed in 2024, it is probable that Whiteman will be selected to undergo construction and modernization to serve as the second location.[95]

Figure 3. Whiteman Air Force Base

Source: International Mapping.
Note: International Mapping created this map by drawing on data from World Street Map (WGS84) and ESRI Satellite Imagery.

Missouri is generally characterized by variable weather, making it difficult to model trends in extreme climate hazards, such as tornadoes or thunderstorms, in and around Whiteman. Of all the bases considered in this paper, Whiteman is therefore the hardest to assess in terms of climate change impacts, highlighting that climate modeling and monitoring cannot be fully standardized across DOD installations. Of the climate change trends that can be reasonably modeled into the future, two are worth considering. Drawing on CMRA data, table 2 presents projected temperature and precipitation trends in Johnson County along two emissions pathways and two time horizons.[96]

Table 2. Projected Annual Very Hot Days, Average Total Precipitation, and Very Heavy Precipitation Days at Whiteman Air Force Base

	Midcentury (2035–2064)		Late century (2070–2099)	
	Lower emissions	Higher emissions	Lower emissions	Higher emissions
Annual days with maximum temperature > 90º F	75 days	84 days	86 days	114 days
Annual days with maximum temperature > 100º F	15 days	21 days	22 days	48 days
Average annual total precipitation	41 inches	41 inches	41 inches	42 inches
Annual days that exceed 99th percentile precipitation	8 days	8 days	8 days	9 days

Source: Climate Mapping for Resilience and Adaptation.
Note: The modeled history (1976–2005) saw an average of 35 days with temperatures above 90 degrees Fahrenheit, 3 days with temperatures above 100 degrees Fahrenheit, 40 inches of annual precipitation, and 6 days that exceeded 99th percentile precipitation.

Temperatures at Whiteman are projected to rise substantially throughout the century. Compared to the modeled history of thirty-five days per year with maximum temperatures above 90 degrees Fahrenheit, these days are projected to more than double in three of the scenarios and more than triple in the late-century, higher emissions scenario. Meanwhile, depending on the scenario, Whiteman is projected to experience five to sixteen times as many annual days with maximum temperatures above 100 degrees Fahrenheit compared to the modeled history of three days.

Annual average precipitation is not projected to change much compared to the modeled history of 40 inches in any of the climate change projections. Warmer temperatures, though, will cause more extreme precipitation events. Hotter air holds more moisture and thus increases the intensity of rainfall.[97] More intense rainfall, in turn, increases the risk of flash flooding.[98] In terms of the frequency of these more intense precipitation events, all of the climate change projections indicate that Whiteman will experience more very heavy precipitation days—defined as days that exceed ninety-ninth-percentile precipitation—thus indicating a likely higher frequency of flash flood events.

Implications for Whiteman

The projected increases in heat and extreme precipitation events could affect Whiteman's bomber mission. Extreme heat poses challenges to both base personnel and the base's nuclear systems. More very hot days means more black flag conditions, an air force designation for the highest heat stress risk under which personnel activities are severely limited and some even suspended.[99] More black flag days could thus negatively impact Whiteman's operational capacity as well as its training capacity. Of particular concern, these conditions could affect B-2 or B-21 pilots' readiness by limiting on-the-ground cockpit times.[100]

Concerning the bombers themselves, extreme heat could ground the planes or, at minimum, affect takeoff and landing as well as payload and fuel capacity due to associated air density issues; warmer air is less dense, making it harder for aircraft to generate lift.[101] B-2s have been lab-tested to withstand temperatures up to 120 degrees Fahrenheit, a maximum temperature projected for the late-century, high emissions scenario.[102] But open-source literature does not provide clear data on the temperature at which the planes might be grounded and/or at which payload and fuel capacity may have to be reduced to alleviate the lift challenge. Even less is known about the potential temperature limitations of the B-21s. By comparison, commercial aircraft of relatively similar size—although with much smaller wingspans—are typically grounded at 118 degrees Fahrenheit.[103]

Even if Whiteman does not experience regular grounding level temperatures, extreme heat could impact the bombers' radar-absorbent skin. As is, the B-2 skin is sensitive to heat and humidity and requires special, intensive maintenance.[104] It is unclear whether the B-21s will face similar challenges, as open-source research indicates some advancements have been made in developing a more resilient stealth skin.[105] Yet, expecting similar sensitivities does not seem out of the question, especially as the B-21s will reportedly require new hangars partly to accommodate their "complexity."[106] Assuming these hangars will be climate-controlled like the B-2 hangars, Whiteman will also likely have to expend more energy and budgetary resources to keep internal temperatures sufficiently cool on more increasingly hot days.

More flash flood events could also impact operations at Whiteman. A massive flooding incident at Offutt Air Force Base—home of U.S. Strategic Command (STRATCOM)—in 2019 provides an example of the impacts flooding can have on air base operations. Particularly relevant here are the implications of runway flooding. During the Offutt flood emergency, nine aircraft had to be evacuated before floodwaters inundated about a quarter of the base's runway,[107] as seen in figure 4.[108] The rest of the base's planes were moved to higher ground and forcibly grounded while the runway remained flooded.[109]

Figure 4. Flooding at Offutt Air Force Base, March 2019

Source: Tech. Sgt. Rachelle Blake/U.S. Air Force.

A flash flood at Whiteman could prompt a similar evacuation effort if such flooding threatened the base's only runway. Even if the bombers evacuated in time—a potential challenge given the rapid nature of flash flooding—there are limited locations with appropriately sized, climate-controlled facilities where the planes can make temporary base.[110] Additionally and perhaps most problematically for the base's deterrence mission, the bombers would be separated from Whiteman's nuclear weapons storage site—the only bomber base storage site in the United States that currently stores gravity bombs—until the runway was cleared.[111] These potential risks and implications of a flooded runway may require the air force to consider raising parts of Whiteman's runway that are at lower elevations, as it is doing at Offutt as part of a larger $217 million runway renovation effort.[112]

Implications for the Bomber Mission

The Offutt flood also raises concerns that the DOD may not be sufficiently prioritizing landlocked bases in assessing and addressing climate change risks to defense installations,[113] despite the centrality of bases like Whiteman to the bomber leg's deterrence mission—to provide flexible nuclear strike options.[114] This is a problematic gap as challenges posed by climate change at Whiteman may have some implications for the readiness of the larger bomber leg.

As indicated, whether due to extreme heat, flash floods, or a cascading set of events, there may be periods in which stealth bombers will not be able to take off from and/or land at Whiteman and thus may be unable to execute their deterrence mission. It helps that, in addition to these bombers, the air force can rely on the B-52 Stratofortress fleet, although only about half of the B-52s are nuclear-capable and none are stealth aircraft so may not be able to fulfill the same mission requirements.[115] To the extent that Whiteman is vulnerable to climate change effects, it also helps that the B-21 fleet will operate out of two additional bases. Moreover, these bases are located in different regions of the United States, suggesting that any particular climate hazard is unlikely to impact the bases to the same extent at the same time.[116]

Even so, the diversification of base locations does not entirely resolve the storage site issue. Even if planes can move, storage sites cannot. The issue is not so much that the weapons themselves are particularly vulnerable to climate change—although underground facilities may encounter water infiltration challenges from more intense flooding events—but rather that climate change effects could force bombers to separate from their home base storage sites for unplanned periods of time. If weapons cannot be loaded onto stealth bombers as planned, that could undermine the readiness of the air leg of the triad. Importantly, as part of the B-21 and the larger U.S. nuclear modernization program, the air force is undertaking efforts to expand the number of bomber bases that store nuclear weapons stealth bombers can carry from one (Whiteman) to five.[117] This expansion could help alleviate the storage site issue. Even if one base becomes inaccessible due to a climate hazard, bombers from that base could evacuate to another bomber base and still have access to an appropriate weapons storage site. But depending on how many weapons are stored at each base and which bombers are assigned nuclear missions in U.S. nuclear war plans, a lack of access to the affected base's storage site could still pose significant challenges to the bomber leg mission.[118]

Box 2. Climate Challenges for Nuclear Weapons Storage

Climate change may pose broader challenges to the storage of U.S. nuclear weapons at both military and Department of Energy (DOE) facilities. Take the Kirtland Underground Munitions Maintenance and Storage Complex, which stores the largest number of U.S. nuclear weapons, most of which are awaiting dismantlement.[119] Located just south of Albuquerque, New Mexico, the complex is projected to face not only more extremely hot days across any climate change scenario,[120] but it could also suffer the effects of the region's megadrought, which has been particularly severe and long-lasting.[121] The weapons themselves are largely insulated from these climate change effects since the actual storage facility is underground. Yet, these effects still pose significant challenges to the complex's larger support activities, including by exacerbating the risk of wildfires. Wildfires could threaten the facility and force personnel to evacuate both the complex and their surrounding homes, just as wildfires have historically threatened Los Alamos National Lab—a DOE facility about 100 miles north of the Kirtland complex where scientists design and simulate the testing of nuclear bombs.[122] Such evacuations would severely disrupt operations at the complex, potentially for extended periods if the fires compromised any part of the facility.

The difficulty of projecting climate change trends at Whiteman suggests the impacts described here are perhaps the most hypothetical, worst-case implications of climate change for any leg of the U.S. nuclear triad. However, the mere possibility that climate change could undermine the readiness of the bomber fleet or adversely affect the DOD's capacity to store weapons and load them onto bombers at any time merits attention and may require the United States to reevaluate the resilience of its bomber facilities and operations.

Recommendations

The analysis presented here highlights potential ways in which climate change could impact the U.S. nuclear triad. Given the high-stakes nature of the nuclear enterprise, the United States should undertake concerted efforts to better prepare for, mitigate, and adapt to these challenges. The following recommendations describe actions the DOD and other key stakeholders can take at the installation, system, and broader deterrent levels to do so.

Conduct Climate Change Vulnerability Assessments of All Nuclear Installations and Facilities

The analysis of the potential impacts of climate change on the U.S. nuclear deterrent presented here is not only limited by its primary focus on three installations but also by information available in the open source. Drawing on more extensive resources and information, the DOD and DOE should conduct in-depth assessments of how and when climate change could impact all U.S. nuclear bases and facilities. These dedicated, site-specific studies should account for the unique nuclear systems, operations, and activities at each site. Importantly, these assessments also need to consider the implications for U.S. nuclear deterrence if the missions at each site are compromised, undermined, or threatened by climate change in any way. Focusing on individual nuclear bases and facilities, as well as deterrence implications, would add important specificity to the DOD's broader, high-level assessments of climate change impacts, which to date have not provided sufficient or sustained attention to the U.S. deterrent.[123]

It is reasonable that such studies be conducted at the classified level owing to sensitive information about the U.S. nuclear enterprise. Some people might argue that publicly identifying climate vulnerabilities could potentially undermine the credibility of the deterrent. However, it is important to also produce unclassified assessments that include as much information as possible. Being transparent about climate change challenges and threats can encourage greater collaboration with interagency and nongovernmental entities to identify and implement mitigation or adaptation measures—and will also encourage greater accountability to follow through on such measures. Implementing mitigation and adaptation plans, especially those that require infrastructure updates or changes, will be long-term endeavors given the nature of budget and resource decisionmaking and planning. Therefore, it is urgent that the DOD and DOE conduct installation vulnerability assessments as soon as possible to ensure those efforts are well underway before climate change effects worsen.

Invest in Dynamic Climate Change Modeling and Partnerships

Modernization efforts for each leg of the U.S. nuclear triad are actively progressing. Given the expected—or, in the B-21 case, assumed—service lives of the modernized systems, key nuclear decisions are made decades in advance of their full implementation. Yet, climate models cannot necessarily project climate change effects over such extended timelines. The above analysis demonstrates that some climate hazards, especially extreme weather events, cannot be adequately modeled at all whether due to the complexity of interactions among various factors that drive these hazards, a lack of observational data of already variable events, or competing perspectives and theories on event attribution.[124] Modernization decisions therefore cannot fully account for the potential impacts of climate change. To address this issue, the DOD should devote additional resources to monitoring and modeling climate change and regularly update their decisions and planning accordingly.

The DOD's existing climate tools are an important starting point. The DCAT, for example, can give nuclear decisionmakers an initial steer in assessing the vulnerability of nuclear installations to climate hazards, although additional efforts are needed to address limitations of the tool, as considered below. To ensure decisions are informed by the most accurate climate change projections, these tools should be dynamic, incorporating regular updates to ensure projections account for current trends and the latest climate science. If governments undertake substantial mitigation and adaptation efforts to reduce global greenhouse gas emissions, for example, projected sea level rise trends may become less severe. The opposite, of course, is also possible if governments do not undertake such efforts. Meanwhile, at a more local level, preventive mitigation efforts taken at Kings Bay may also positively impact projections of how climate change could impact the base. Consequently, changes in projected trends could significantly impact climate change risks at nuclear facilities and must therefore be regularly monitored and factored into nuclear decisions and planning.

Beyond these existing tools, the DOD, with support from Congress, should continue to make and expand its climate monitoring investments, including by building expertise to ensure personnel are adequately trained to incorporate climate modeling into future planning. Climate change–related investments cannot simply focus on installations or regions where disasters have already struck but must be proactive in anticipating possible future conditions and challenges, especially where the United States' nuclear installations are involved. Moreover, as this paper demonstrates, different climate hazards stand to challenge different nuclear facilities and missions. The DOD, therefore, cannot standardize its efforts across installations and regions but rather must diversify its modeling and monitoring efforts.

The DOD should not undertake these efforts alone. The department would benefit from improved interagency and cross-government collaboration, as well as more partnerships with nongovernmental stakeholders. For instance, since the DOD appears to rely on FEMA flood data to conduct its EISs for its nuclear modernization programs, the department should work directly with FEMA to ensure it has the resources and access it needs to complete and regularly update flood mapping of all nuclear installations and their surrounding communities. Doing so would allow for more comprehensive assessments that more accurately consider and account for possible future flooding vulnerabilities or challenges. The DOD can also expand successful programs like the Readiness and Environmental Protection Integration Program and the Sentinel Landscapes Partnership—both of which bring together local, state, and federal stakeholders to implement conservation and resilience measures that help preserve military and local interests—to include all nuclear installations.[125] Establishing and, importantly, contributing funding to these initiatives at all nuclear facilities, including landlocked bases that may not seem as vulnerable to the worst effects of climate change, would help the DOD develop robust local relationships and mitigation measures to ensure the department is best prepared to address worsening climate conditions.

Mandate "Impact of Environment Statements"

Informed by rigorous research and engagement with key stakeholders, EISs are important assessments designed to determine how major federal actions will affect the environment. This process does not, however, adequately consider how the environment may in turn impact the action being considered. Just nine pages of the nearly 1,000-page Sentinel EIS, for example, explicitly discuss climate change, providing fairly general depictions of climate change effects in the Great Plains and Southwest regions where Sentinel construction activities will take place.[126] Given the potential impacts climate change could have on nuclear and other federal actions, unidirectional EISs are no longer sufficient.

To complement these statements, the DOD and other agencies should also be required to complete "Impact of Environment Statements." These statements should be forward-looking, dedicated assessments of how climate change may impact the federal action at hand. Conducted with as much rigor and engagement as EISs, they should draw on advanced climate modeling—including worst-case scenario projections—to identify relevant climate change hazards over the lifetime of the action. They should evaluate the potential impacts of those hazards at the installation, system, and broader mission levels and identify how and when these impacts can best be mitigated. The statements should also identify how these hazards may affect the lifetime costs of the action, including by factoring in cost estimates of potential mitigation plans. Importantly, the statements should be updated at regular intervals to account for changes in climate modeling.

Congress may have a particular interest in mandating these Impact of Environment Statements especially given the potentially substantial budgetary implications of climate change for planned actions. This carries particular relevance for nuclear modernization efforts, which the Congressional Budget Office estimates will cost $634 billion (in 2021 dollars) throughout the 2020s.[127] Congress should be interested in determining, for example, whether the Sentinel program plans laid out in the Sentinel EIS have adequately accounted for climate change and, if not, how climate change impacts could affect the full costs of maintaining and operating the system later this century. A Sentinel Impact of Environment Statement would help to address this concern and increase the DOD's accountability to effectively plan for and respond to climate change impacts. Congress could mandate these assessments through a dedicated law, similar to how the National Environmental Policy Act mandates EISs, or as part of the annual National Defense Authorization Act (NDAA) process. To initiate this effort and complement the second B-21 EIS currently underway, Congress should require the DOD to complete an Impact of Environment Statement for the B-21 as part of the NDAA for Fiscal Year 2024.

Adopt a Mission-Level Focus in DOD Climate Adaptation Planning

As part of its broader, department-wide climate security work, the DOD should adopt a specific mission-level focus in its climate adaptation planning. The DCAT provides a particularly illustrative example of why it is important to do so. Its climate hazard exposure scores do not currently include a mission metric, an indicator that would consider the contribution of that installation to the deterrence or other key mission. This is problematic to the extent that the DCAT is intended to help DOD leadership make informed investment and policy decisions by comparing the relative exposure between installations—in other words, determining which assets are most vulnerable to climate change and thus require resource prioritization.[128] Failing to incorporate mission considerations into hazard exposure scores risks overlooking the vulnerability of the relatively limited set of assets that support the deterrence mission. For instance, even if Kings Bay is not the most vulnerable DOD installation by purely climate hazard metrics, it should nevertheless be prioritized in climate adaptation planning because it is one of only two bases equipped to service and maintain SSBNs.

Establishing a workstream specifically focused on the nuclear mission would help to ensure the DOD is giving sufficient, sustained attention to climate change impacts on the deterrent. By highlighting the potential mission-altering effects of these impacts, the workstream would facilitate the resource allocation needed to mitigate them where possible, as well as support the broader strategic thinking needed to adapt the deterrence mission to climate change realities. It would also help to ensure the DOD's climate considerations do not stop at the installation level but are also sufficiently integrated into higher-level decisions and strategies, thus helping the DOD deliver on the "climate-informed decision-making" line of effort in its Climate Adaptation Plan.[129]

A key, initial deliverable of this work should be a dedicated climate strategy or action plan for the U.S. deterrence mission, similar to the air force, army, and navy versions released as follow-ups to the DOD's Climate Adaptation Plan. This document should set out ways in which the DOD will operationalize that plan as specifically relevant to the nuclear mission. While driven by nuclear leadership in the Office of the Under Secretary of Defense for Policy, the document should be informed by discussions across the department, including with air force and navy officials, STRATCOM leadership, and personnel at individual nuclear bases and facilities.

Integrate Climate Change Scenario Exercises Into Nuclear Planning

To help fully scope out and think through the risks and challenges posed by climate change to the U.S. nuclear deterrent, the DOD should make use of scenario-based exercises. These discussion exercises should simulate future climate scenarios and associated high-consequence events and task participants both with evaluating how those climate futures would impact the deterrence mission as well as developing mitigation and adaptation plans. Key considerations should include implications for local and global nuclear operations; potential impacts on nuclear command and control assets, including any resulting impacts on warning timelines; and more indirect effects, such as impacts on personnel and local communities. Results from the exercises should be incorporated into nuclear planning efforts, with relevant missions, strategies, and postures adapted accordingly.

The exercises should be based on numerous yet plausible climate change scenarios, including worst-case scenarios as well as those triggered by a cascading set of climate change effects. They could center on climate crises at specific nuclear facilities; regional or global climate change effects that may impact the United States' capacity to fully execute the deterrence mission; or even scenarios in which an opportunistic adversary takes advantage of a climate crisis affecting one or more nuclear facilities. The analysis above highlights a few particularly concerning scenarios worth exercising to fully assess the implications for the U.S. deterrent.

To be most impactful, these exercises should be conducted regularly, not just as a one-off. They should occur in both classified and unclassified settings and include an array of stakeholders, including DOD and DOE officials, relevant base personnel, community representatives, and nuclear and climate experts. Diverse stakeholders will bring unique perspectives that will be essential to developing a comprehensive picture of the challenges climate change poses to the U.S. nuclear deterrent.

The Way Ahead

This paper aims to inform and help initiate a larger conversation about the nexus between climate change and nuclear weapons. While the paper focuses on potential ways in which climate change could affect each leg of the U.S. nuclear triad, more efforts must be made to better understand this underexplored—and likely dangerous—nexus. Future research efforts should consider, for example, the implications of climate change for U.S. nuclear command and control, waste streams, and nuclear activities in particularly climate-vulnerable regions.

These efforts must also move beyond the U.S. context; climate change stands to challenge the nuclear programs of all nuclear-armed states. This appears particularly pressing for states such as North Korea and Pakistan that have already experienced the devastating impacts of climate change effects like extreme flooding. Further research could consider how climate change might affect global nuclear dynamics, including the vulnerability and survivability of nuclear arsenals, escalation risks, and opportunities for multilateral risk reduction efforts.

Ultimately, the climate change–nuclear weapons nexus requires more attention and action by numerous stakeholders. The DOD in particular must undertake concerted efforts now to mitigate the worst effects of climate change on U.S. nuclear weapons in the future. The recommendations presented here offer starting points for doing so. Importantly, they highlight that allocating larger budgets and expending more resources to ensure U.S. modernization efforts currently underway are equipped to deal with various climate change effects will be necessary but insufficient. The United States will have to reassess—and likely adapt—its fundamental nuclear practices, procedures, and policies to effectively address the potentially far-reaching impacts of climate change on its nuclear deterrent.

About the Author

Jamie Kwong is a fellow in the Nuclear Policy Program at the Carnegie Endowment for International Peace. Her research focuses on climate change challenges to nuclear weapons; public opinion of nuclear weapons issues; and multilateral regimes including the P5 Process, the Nuclear Non-Proliferation Treaty, and the Treaty on the Prohibition of Nuclear Weapons.

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