



The Secretary General's Report

# NATO Climate Change and Security Impact Assessment

Third Edition 2024



# Foreword

This past year, NATO has faced a profoundly challenging security environment. While continuing to adapt its deterrence and defence posture to the challenge posed by Russia's aggression, NATO has also had to contend with impacts of accelerating climate change on security. 2023 and 2024 have been marked by more frequent and intense bouts of extreme heat, catastrophic floods across much of Central Europe and the Western Balkans, and devastating wildfires in vast areas of the Mediterranean region and North America. Throughout these upheavals, NATO has demonstrated its unflinching resolve in ensuring that the Alliance's posture remains fit for purpose in a rapidly changing environment, while at the same time reducing NATO Allies' dependence on fossil fuel imports from Russia and adapting to the ongoing energy transition, including in the military.

Allies have collectively recognised the increasing interaction between climate change and traditional security risks, and the scale and pace at which climate-related challenges affect NATO's operating environment. In response, they have moved to adapt to the new security reality, including by agreeing NATO's ambitious yet realistic Climate Change and Security Action Plan at the 2021 Brussels Summit. That Action Plan sets out our fourfold commitments to address the climate crisis: build our awareness of the impacts of climate change on security; adapt our military capabilities and our societal resilience to ensure our continued operational effectiveness and prosperity; reduce the greenhouse gas footprint of the NATO enterprise; and integrate climate change into our outreach efforts with our wide network of partners.

This third edition of NATO's Climate Change and Security Impact Assessment seeks to raise understanding of the effects of climate change on our security. These effects are complex, non-linear and co-evolving. They touch our citizens' lives, strain resilience within and outside NATO Allies, and pose direct and indirect challenges to the fulfilment of NATO's core tasks, including the defence of the Euro-Atlantic area. This Impact Assessment explores some of these challenges for each of NATO's operational domains – land, sea, air, space and cyber – as well as the escalating effects of climate change on our resilience commitments and the global security environment.

This Impact Assessment is a manifestation of the commitment that Allies made in NATO's 2022 Strategic Concept: for NATO to become the leading international organisation when it comes to understanding and adapting to the impact of climate change on security. No region of the world or operational domain will be untouched by climate change. NATO remains determined in its collective ambition to better understand, adapt to, and mitigate the effects of climate change on Allied security. I hope that this Impact Assessment provides a valuable foundation for the next stages of this essential work.



**Jens Stoltenberg**

Secretary General, NATO



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# Executive Summary

Climate change is a defining challenge of our time, with a profound impact on Allied security. At the 2021 Summit in Brussels, NATO Heads of State and Government (HOSG) endorsed a Climate Change and Security Action Plan and agreed that NATO should aim to become the leading organisation when it comes to understanding and adapting to the impact of climate change on security.

This third edition of NATO's Climate Change and Security Impact Assessment (CCSIA) responds to the demand for increased Allied awareness of the impact of climate change on security. Expanding on the key findings of the 2023 edition, this report outlines the impact of various climate-related risks on NATO's strategic environment, military assets and installations, missions and operations, as well as on NATO's resilience and civil preparedness. It includes three geographic case studies, examining the impact of climate change on NATO presence in Kosovo, the Rovajärvi shooting and training area in Finland, and the North Warning System – a joint Canadian and US early-warning radar system for North American defence. Additionally, the report evaluates the performance of submarines, naval helicopters, and military transport planes in a changing climate. Lastly, it assesses the implications of climate change on NATO's potential adversaries and strategic competitors, and examines the climate security impact of Russia's war against Ukraine.

The report draws on contributions from across the NATO Enterprise, including the NATO Military Authorities (NMAs), NATO Science & Technology Organization Centre for Maritime Research and Experimentation (STO CMRE) and the NATO-accredited Climate Change and Security Centre of Excellence (CCASCOE). The CCSIA can be used to inform a more proactive approach to the Alliance's short-, medium- and long-term decision-making on appropriate responses to the climate challenge, as well as to improve NATO's adaptive capacity.

This Impact Assessment seeks to complement and build on other lines of work, including by providing analytical evidence to inform:

- Planning, training and exercising through the incorporation of new scenarios brought about by climate change.
- Capability development and procurement decisions to maintain operational effectiveness in future operating environments.
- The adoption of sustainable design principles in military infrastructure and platform acquisition.
- NATO's cooperation with partner countries and international organisations, as appropriate.
- NATO's innovation community, including the Defence Innovation Accelerator for the North Atlantic (DIANA) and the NATO Innovation Fund (NIF), in targeting their investments and challenges.
- The integration of Women, Peace and Security and human security considerations into NATO's climate change and security work strands, including science and technology, and training and exercises.

# Impact of Climate Change on NATO

## The Changing Climate

Over the last year, internationally recognised entities whose reports inform NATO's work on climate change and security highlighted twin themes: the speed and scale at which the climate crisis continues to unfold, and the overwhelming urgency of addressing the root causes of climate change. According to the World Meteorological Organization (WMO), for example, 2023 was the hottest year on record, with the global average near-surface temperatures reaching 1.45°C (with a margin of uncertainty of  $\pm 0.12^\circ\text{C}$ ) above pre-industrial levels.<sup>1</sup> The past nine years (2015 - 2023) have been the warmest years within the 174-year observational record of the WMO.

Similarly concerning observations have been made regarding the loss of Arctic sea ice, rising ocean levels, soil degradation, reduced fresh water availability, and the global increase in the number of extremely hot days. The Greenland ice cap is losing an average of 30 tonnes of ice an hour, which is 20% more than previously thought. Concurrently, global average sea level rose by about 0.76 centimetres from 2022 to 2023, according to NASA. In total, the global average sea level has risen about 9.4 centimetres since 1993. According to 2022 United Nations estimates, up to 40 percent of all soils worldwide are moderately or severely degraded.<sup>2</sup>

## NATO's Evolving Security Environment

In 2023, Russia persisted in its brutal war of aggression against Ukraine, with devastating humanitarian, social, economic and environmental consequences. Instability in NATO's southern neighbourhood worsened due to the outbreak of conflict in the Middle East, and Allies faced growing competition from authoritarian states, including the People's Republic of China (PRC). Simultaneously, as this Impact Assessment report will show, non-traditional security challenges like climate change continued to test NATO's resilience, with escalating effects on Allied security and defence at the strategic, operational and tactical levels.<sup>3</sup>

For NATO Allies, the impact of rising air and sea temperatures was most readily observed in extreme weather events: catastrophic floods and wildfires devastated large areas of Europe and North America, affected Allied citizens' lives and livelihoods, and resulted in severe economic damage. These and other extreme weather events have put pressure on critical military and civilian

infrastructure, and required additional military deployments to support civilian authorities (see illustrative examples below).

#### **FACTS AND FIGURES:**

- **In 2022, weather-related disasters internally displaced 32.6 million people globally, exceeding conflict. In 2023, however, displacements associated with weather-related disasters decreased by a third compared to 2022.**
- **60,000 – 70,000 excess deaths have been associated with the 2022 extreme heatwaves in Europe.**
- **10 billion euros of damage was caused by the 2023 August flash floods in Slovenia – about 16% of the country’s GDP.**
- **In 2023, 2,214 military personnel were engaged in response to wildfires in Canada, for a total period of 131 days. According to the Canadian Wildfire Evacuation Database, 297 evacuation orders were issued nationally by the middle of September 2023, numbering some 235,000 people.**
- **99 people died and 7,500 people were evacuated in the Hawaii forest fires of August 2023, the most lethal forest fire in the US in over 100 years.**
- **93,000 hectares were burned between August and September 2023 in north-eastern Greece.**

Looking ahead, Allied military forces will be required to adapt to hotter temperatures and increasingly more challenging, extreme and unpredictable operating environments, as well as to prepare for an increasing demand to assist civilian authorities when disasters strike. This is a trend which is highly likely to continue given the increased frequency of environmental disasters and the uncertainty regarding the extent of the future impacts.

In addition to dealing with a physical operating environment altered by climate change, Allied forces must also contend with the intensifying indirect (second and third order) impacts of climate change on security – both in the Euro-Atlantic area and in the Alliance’s broader neighbourhood. Although the relationship between climate change and armed conflict is complex, a growing body of authoritative research and analysis<sup>4</sup> notes that climate change has the potential to contribute to higher levels of conflict, instability, and violence, but along indirect pathways.<sup>5</sup> Indirect impacts of climate change, such as climate-induced instability, large-scale population movements, and disruptions of global supply chains, are likely to alter the strategic environment in the medium to long term. In addition, “tipping point” climate events – such as abrupt changes in key oceanic currents, or the collapse of agriculture systems – could fuel a rapid escalation of instability and displacement in regions already experiencing climate stress.

There are important regional differences in climate vulnerability. The Middle East, North Africa and Sahel regions have emerged as climate change hotspots. The countries of the Sahel are particularly vulnerable, due to harsh regional climate conditions, a high dependence on subsistence agriculture and livestock raising, and limited adaptive capacity. NATO’s 2022 Strategic Concept recognises that “conflict, fragility and instability in Africa and the Middle East directly affect our security and the security of our partners” (para. 11). The regional impacts of climate change will also be increasingly felt in the Indo-Pacific region. From increased risk of bushfires in countries like Australia and New Zealand, to extreme weather events and sea-level rise affecting island nations, climate change already constitutes a major threat to the security and well-being of Indo-Pacific inhabitants.

Climate change also heavily affects the operational and strategic environment in the High North. The circumpolar Arctic continues to experience warming at about four times the global average, with profound implications for the environment, local communities, access to, and the security of the region.<sup>6</sup>

Climate change exacerbates strategic competition. According to the 2023 NATO Allied Command Transformation’s (ACT) Strategic Foresight Analysis, resource scarcity and the scramble for the global commons are expected to intensify and drive further instability, competition and conflict, with indirect implications for regional resilience, security and NATO

operations. Instability and conflict also dramatically exacerbate the pre-existing vulnerabilities of many different groups, bringing human security and Women, Peace and Security considerations to the forefront of the climate security discussion.

NATO's potential adversaries and strategic competitors have been found to exploit climate-related stresses across NATO. This is evident in the growth of climate and energy transition-related disinformation, designed to erode the public pressure and the political will that is necessary for a more ambitious climate action. At the same time, NATO's potential adversaries and strategic competitors are not immune to the effects of climate change. The potential consequences of climate variables on

domestic stability in the countries concerned, as well as their foreign and security decision-making, are important considerations for security and defence planners across NATO.

Looking ahead, NATO will need to implement its commitment to a strengthened deterrence and defence posture, and fulfil its three core tasks, in harsher and more unpredictable operating environments. At the same time as managing concurrent direct and indirect impacts of climate change, NATO will be required to navigate the ongoing energy transition. This confluence of challenges poses unprecedented dilemmas for members of the Alliance.

## Climate Change Impacts on NATO's Potential Adversaries and Strategic Competitors

Climate change will not only impact the security of NATO's Allies but also Russia, and strategic competitors such as the People's Republic of China (PRC). Russia's and the PRC's adaptive capacity (or lack thereof) and the likely responses to a warming world – including in the military – are important considerations for security and defence planners across NATO.

As for Russia, the effects of changing climate have been particularly evident in its Arctic and southern agricultural zones, and include permafrost thaw, increased flooding, prolonged droughts and heatwaves, as well as a growing number and severity of natural disasters.<sup>7</sup> The projected changes to Russia's climate could heighten socio-political and economic stresses. For example, extreme environmental conditions could negatively impact population health and labour productivity, spur migration and displacement, disrupt the provision of essential services, and deteriorate living conditions overall. These internal challenges may influence the foreign and security policy decision making.

Although Russia acknowledges that global warming presents a serious problem, its response to climate change to date has been based on a careful weighing of costs and benefits. The focus has been on *adaptation* to the physical impacts of climate change, rather than mitigation strategies that address the root causes.<sup>8</sup> Climate security is largely absent in Russian military planning and thinking, with no concrete actions having been taken to adapt military bases to the effects of climate change – with the

sole exception of the Arctic region.<sup>9</sup> There, Russia has adapted to cold, dark and harsh conditions and developed substantial capability to support military operations in remote ice-covered areas.

The PRC faces threats from sea-level rise, severe weather events, intensifying heatwaves and droughts, desertification (notably in the north-east of the country) and glacial melt.<sup>10</sup> In addition to potential economic and socio-political impacts across the country, the effects of climate change on the PRC can have repercussions for the rest of the world. Food security may be considered an example. As climate change increasingly affects global food systems, some countries (including the PRC) are working to acquire large amounts of agricultural land abroad, as well as developing effective trade conduits for trade in foodstuffs, to ensure their long-term food security and diversify food supplies.<sup>11</sup> Concurrently, the PRC's agricultural production, which currently feeds approximately 20% of global population, plays a critical role in the global food supply chain, and any substantial climate impacts on it will have global implications.

In response, China emphasises both adaptation and mitigation measures, all while balancing economic development with climate goals.<sup>12</sup> In the military, limited reports suggest energy efficiency improvements and alternative fuel use, as well as development of capabilities that can simultaneously provide disaster relief while maintaining military readiness.<sup>13</sup>



## NATO's and Allies' Military Installations and Assets

Direct hazards associated with climate change, such as heatwaves, floods, droughts, fires, erosion and extreme winds, are likely to impact military equipment and weapon systems, including both armed and unarmed vehicles, crewed and uncrewed aircraft, surface and underwater vessels, protective equipment, small arms and light weapons. Military installations, fixed and mobile, and training areas are also vulnerable to climate change effects, with the level of vulnerability and exposure varying by geographic location. For instance, military facilities in NATO's northernmost latitudes are at risk from permafrost thaw, which compromises structural integrity, while low-lying areas in Europe face increasing flood risk. In the south of the Alliance, assets and installations find themselves at risk from extreme heat.

Climate change hazards can lead to higher maintenance and repair costs, pose safety risks to military personnel, and ultimately, affect military effectiveness and readiness. Additionally, if training areas become inaccessible or unusable, NATO Allies'

ability to train troops – both domestically and internationally – could be severely impacted.

In addition to affecting military equipment, climate change hazards pose increased operational stress on military personnel. Direct health impacts on NATO forces include an increasing incidence of heat stress, the risk of frost injuries, and respiratory problems from dust storms, local air pollution, or wildfire smoke exposure,<sup>14</sup> potentially limiting training and operations. Indirect impacts range from psychological effects on soldiers responding to natural disasters to a higher incidence of vector-, food- and water-borne infectious diseases in various operating contexts. The provision of military medical services can also be affected in climate change-affected operating contexts. Notable risks include stresses on cold-storage supply chains in hotter environments; impaired or contested access to fresh water; and a higher frequency of medical interventions being conducted under extreme environmental conditions.



Source: German Armed Forces.

# NATO's Missions and Operations

One of NATO's core tasks is crisis prevention and management. To effectively prevent and respond to crises that could affect Allied security, it is crucial to maintain the military capacity to conduct a wide range of operations and missions globally, even amidst a changing climate. Current examples of such operations and missions include NATO's multinational training and capacity-building effort in Iraq, operations and activities in the maritime domain (namely the Alliance's Standing Naval Forces, Operation Sea Guardian and the Aegean Activity), air policing in several Allied countries, or the NATO-led Kosovo Forces (KFOR) and the NATO Advisory and Liaison Team (NALT), which will be examined in more detail below.

Many of NATO's missions and activities take place in regions which are already vulnerable to extreme heat, heavy rainfall, dust storms and other extreme

weather events. NATO Mission Iraq (NMI), for example, is particularly affected by heatwaves. In recent years, deployed personnel faced frequent bouts of extreme heat, with outdoor temperatures reaching 50°C and indoor temperatures exceeding 60°C, pushing equipment and personnel beyond their limits. The situation has been further compounded by the concurrent increase in the frequency of dust storms, which reduce visibility, disrupt both air and road transportation by clogging equipment, and adversely affect the health of military personnel. The number of "black flag weather days" – days when temperatures exceed 35°C and operations are restricted or ceased altogether for health and safety reasons – continue to increase, which causes operational disruptions and compromises training and readiness.<sup>15</sup>

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## Case Study: NATO Presence in Kosovo

South Eastern Europe, including Kosovo, has been identified as one of the planet's "warming hot spots".<sup>16</sup> The accelerated heating of the atmosphere in the region is leading to extreme weather events, such as 2017 and 2022 wildfires, and severe flooding that Kosovo experienced in 2023. Such events are expected to grow in frequency and intensity. Coupled with Kosovo's socio-economic vulnerability and challenging security environment, climate change can have detrimental consequences for both Kosovo and NATO's presence on the ground.<sup>17</sup>

Since June 1999, NATO has been leading a peace-support operation in Kosovo focused on building peace and stability in the area, supporting wider international efforts. Today, approximately 4,500 Allied and Partner troops operate across Kosovo as part of NATO's Kosovo Force (KFOR).<sup>18</sup> KFOR continues to implement its mandate – based on the UN Security Council Resolution 1244 of 1999 – by contributing to ensure a safe and secure environment for all people living in Kosovo and freedom of movement, at all times and impartially.<sup>19</sup> KFOR is the third security responder, after the Kosovo Police and EULEX, with which it works in close coordination. In addition, the NATO Advisory and Liaison Team (NALT) further supports security

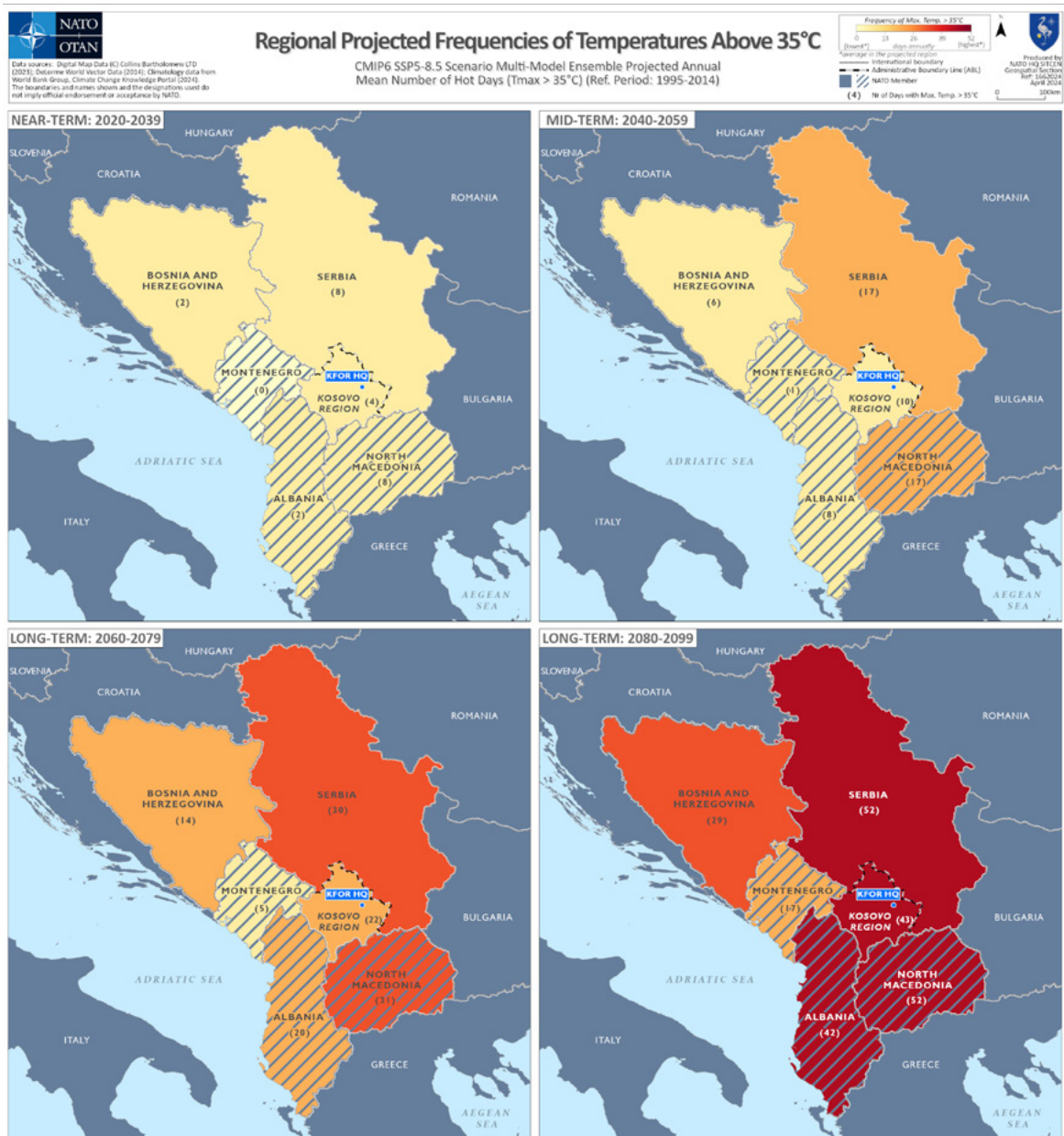
organisations in Kosovo exercising civilian control and democratic oversight. NALT's capacity-building support to Kosovo Security Forces (KSF) covers crisis response, disaster management, and civil protection.

Kosovo faces a number of challenges relating to the environment. Environmental crime, such as illegal woodcutting and waste dumping, poses significant challenges to the ecosystem and the environment. These activities not only degrade natural resources and ecosystems but also exacerbate the impacts of climate change by increasing pollution levels and reducing the ability of forests to act as carbon sinks. KFOR has been involved in monitoring environmental crimes and assessing the safety of approximately 12 sites where toxic and radioactive materials are stored – many of which are inadequate for safe storage. KFOR and the KSF conduct monthly assessments of these facilities to help ensure they do not pose additional environmental hazards.

In addition, KFOR has been instrumental in providing assistance in the aftermath of extreme weather events. In 2016, following a request for support from local authorities, KFOR supported flood disaster relief operations in Skopje (North

Macedonia) with heavy lift and engineer assets, including loaders, excavators and dumper trucks.<sup>20</sup> In 2022, KFOR provided support in preventing the spreading of forest fires. Due to mild winters recorded in January 2021, December 2022 and January 2023, Kosovo experienced two severe flooding events which devastated several cities and villages, and resulted in drinking water cuts, power outages and evacuations.<sup>21</sup> In the above instances, the KSF's search and rescue team provided support during the floods, with KFOR on standby to intervene within means and capabilities.<sup>22</sup> KFOR is not only able to provide immediate disaster relief, but engineering and construction support as well: KFOR engineers are frequently called upon to evaluate bridges, roads and buildings after flooding.

Apart from flooding, extreme heat and particulate matter in the atmosphere have been posing challenges for missions and assets, including vehicles. To better understand the impact of extreme heat on the region, projected temperature changes over time were analysed.<sup>23</sup> Looking at days per year where temperatures rise above 35°C, the number dramatically increases over time. In the near-term (2020-2039), only 4.4 days with temperatures above 35°C are projected in the summer months. In the long term (2060-2079), that number rises to 21.2 days per annum. At the end of century (2080-2099), under the worst-case SSP5-8.5 scenario, Kosovo is predicted to experience 39.2 days per year with temperatures exceeding 35°C.



Under the worst-case SSP5-8.5 scenario, there will be a 4°C temperature increase between the near-term and end-of-century periods, which can have dramatic consequences in the region and increase the number of “black flag weather days”. Although the predicted temperature increase is not as extreme as in some other geographic areas where NATO operates, it is still significant enough to amplify existing threats in an already hot environment and reduce operational days. Even in the near term, this trajectory is expected to adversely affect productivity, potentially disrupting operations, and increasing heat- and air pollution-related mortality.<sup>24</sup> Additionally, projections of higher temperatures and increased wildfire risks, reduced precipitation, and population growth suggest that by 2050, four of Kosovo’s five water basins may face water stress or scarcity, which can

affect water supplies for both the local population, as well as KFOR and NALT personnel.<sup>25</sup>

In conclusion, climate-related stresses can impact the work of security actors in Kosovo in several ways. First, the increase in climate-related events could put heightened demand on the KSF to provide support to civilian authorities. Supporting the development of civil emergency planning and crisis management capabilities, and the capacity to respond to climate events will need to remain a core element of the NALT Terms of Reference. In addition, this can also increase the demand for KFOR resources to directly assist the Institutions in Kosovo.

## Resilience and Civil Preparedness

Individual and collective resilience underpins all three core tasks of NATO. More frequent extreme weather events in the Euro-Atlantic area continue to exert increasing pressure on the resilience of individual Allies and, consequently, on NATO as a whole. This challenges the ability of NATO Allies to deliver essential services to their populations and military forces across critical sectors such as communications, energy, transportation, healthcare, and food and water. NATO relies on both civil and commercial resources and infrastructure to ensure the swift and efficient deployment and support of its military forces. Therefore, it is crucial for Allies to prepare and adapt to the impacts of climate change and environmental degradation, and to integrate these considerations into their national security strategies. Some impacts of climate change, across the Baseline Requirements for national resilience that Allies have collectively agreed, are explored below.

### CIVIL TRANSPORT SYSTEMS

The vital role of air, land, and sea transportation systems in delivering essential services such as energy, medical supplies, and food means that any potential disruption can be highly problematic for civilian populations and armed forces alike. Heat and cold extremes can impact civil transport systems in a number of ways. The heavy snow and freezing rain that struck parts of northern and

central Europe in December 2023 caused major highways to be blocked and airport operations to cease.<sup>26</sup> Similarly, the European heatwave in the summer of 2022 resulted in buckled roads, warped train tracks and expanded bridges in many locations in Western Europe,<sup>27</sup> forcing temporary stoppages, emergency repairs, and major reductions to transport capacity, resulting in major delays and widespread disruptions.

### CIVIL COMMUNICATIONS SERVICES

As extreme weather events become more common, the telecommunications sector and its infrastructure will face increasing difficulties. To illustrate, the 2023 wildfires in Canada severely impacted telecommunication infrastructure. The fires destroyed the electric grid that powered cellular sites by burning the wooden power poles, incinerated power and communication cables, and damaged base station infrastructure.<sup>28</sup> In the aftermath of such events, restoring power can take days, and full repairs can take weeks. Beyond wildfire incidence, extreme heat damage can shut down and disrupt services across the mobile network, leaving businesses and individuals unable to communicate.<sup>29</sup> The loss of communications capability is especially problematic during critical emergency rescue responses that are required during these events. In addition, civil communications services are vulnerable to

cascading effects from the loss of electrical power, which can lead to local outages if backup power systems lack sufficient capacity. International cable landing stations have also been identified as points of vulnerability for global network connectivity due to rising seas, erosion and storm surges.<sup>30</sup> Additionally, GEO satellites can experience signal blockage, reduced performance, or failure during extreme rain or snow events.

## **ENERGY SUPPLIES**

Extreme weather events can strain critical energy infrastructure of NATO Allies, potentially impacting energy production, transmission and distribution. For instance, during the 2022 and 2023 heatwaves, France, which relies on nuclear energy for about 70% of its electricity, experienced a notable drop in nuclear energy production. This was due to lower cooling water supplies and scheduled maintenance. As temperatures rise and water levels decrease, the ability to use river water to cool reactors becomes less feasible. This reduction in nuclear power not only strained France's energy supply but also affected neighbouring countries dependent on electricity imports through interconnected grids. Heatwaves and droughts can also compromise hydroelectricity generation, which can lead to an overall increase in fossil-fuel power generation to make up for the gap.<sup>31</sup>

## **FOOD AND WATER RESOURCES**

Climate change, biodiversity loss, and ecosystem degradation are interrelated and mutually reinforcing, and together they significantly affect food and environmental security. The increasing frequency of extreme weather events, coupled with shifting precipitation patterns, have not only diminished the yield of major crops but also heightened the risk of simultaneous harvest failures in major food producing countries across NATO. In the summer of 2022, Spain, France, Italy, Germany, Romania, and Hungary struggled with prolonged droughts and intense heatwaves.<sup>32</sup> As a result, European cereal production (notably grain maize) plummeted by 9% compared to 2021 levels.<sup>33</sup> Concurrently, the dry and scorching

weather depleted water reservoirs, which severely limited freshwater irrigation. Extreme weather affects other critical infrastructure, such as energy and transportation, and can disrupt food storage and transport, and potentially lead to large-scale wastage, further threatening food supplies. Other elements of the food system, such as livestock and fisheries, are becoming comparably strained by large-scale ecological changes.

## **MASS CASUALTIES AND DISRUPTIVE HEALTH CRISES**

Climate-related stressors significantly influence human health, disease spread and health system resilience. In 2022, over 61,000 people were reported to have died due to the intense heatwaves in Europe alone, with an estimated 56% more heat-related deaths in women than men, relative to population.<sup>34</sup> The estimated death toll from the 2023 heatwave was comparably high.<sup>35</sup> The 2023 wildfire season claimed additional lives in Europe and North America. These extreme events have increased emergency interventions, hospitalisations, and fatalities, often exceeding the capacities of health systems and challenging their resilience across NATO. Climate change, habitat loss and increased human-animal contact are proven drivers of infectious disease threats, including novel pandemics and vector-borne illnesses like malaria. Such pressures can limit the capacity for civil support to national and NATO military efforts.

## **UNCONTROLLED MOVEMENT OF PEOPLE**

Extreme weather events may trigger climate displacement and large-scale movements of people within and between countries, potentially straining the ability of the receiving communities or nations to provide essential services, such as health care, food and water, energy, communications and transport. Moreover, increased demand on transportation and communications networks may seriously impair the ability of national civil authorities and the armed forces to concurrently address other threats and hazards and, as necessary, to execute civil and military defence plans.



Source: Canadian Armed Forces.

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## Disaster Response

The increase in extreme weather events can overwhelm national civil protection capabilities and resources. Increasingly, civilian authorities turn to militaries for assistance in conducting disaster response activities. In 2023, in response to Canada's worst wildfire season to date, 2,214 military personnel were deployed for a total period of 131 days, supporting evacuations, firefighting and emergency logistics across six provinces and territories. During the catastrophic floods of August 2023 – described as the country's worst natural disaster since its independence in 1991 – Slovenia's armed forces performed critical rescue and evacuation services. In the US, over 600 military personnel from different branches of the Armed Forces and the National Guard were deployed in support of the wildfire management in Maui. This was one of the largest US military deployments in response to a single hazard in recent years.

In many cases, the combined civil and military capacities of a nation are insufficient to cope with a disaster, necessitating international military support. In 2023, there were 29 international military deployments to respond to climate-related emergencies in 14 countries.<sup>36</sup> For instance, Greece

received assistance from a dozen Allies in July 2023, including military support, to cope with record wildfires that triggered the largest evacuation in Greek history. Similarly, in August 2023, Slovenia received military support from NATO Allies, including helicopters and pontoon bridges to help manage the consequences of a large-scale flood.

As these and other examples show, the requirement to manage increasingly frequent environmental hazards might impact the availability of Allied militaries for other deployments linked to deterrence and defence posture, such as trainings and more traditional military tasks. As extreme weather events grow in frequency and intensity, this tension is expected to intensify further. Observers suggest that new rapid response structures beyond militaries may be needed to address the long-term challenges posed by climate change.<sup>37</sup>

NATO, with its unique blend of civilian and military tools, is well placed to support national responses to climate-related disasters. Strengthening civil-military cooperation and enhancing civil emergency response capabilities are among the tools available to Allies.

# Impact of Climate Change on Five Operating Domains

## Maritime Operating Domain

In the maritime domain, naval forces and capabilities are increasingly impacted by the effects of climate change. These include modifications to air and ocean temperatures, salinity, wind speed, precipitation patterns, surface and underwater currents, the extent of sea ice coverage, and marine life.<sup>38</sup> The weakening of the Atlantic Meridional Overturning Circulation (AMOC)<sup>39</sup> – a major climate stabiliser that influences the Gulf Stream – might cause abrupt and dramatic changes in the future that are not yet fully assessed.

Such effects are challenging maritime operations and capabilities in a number of ways. Storm surge and sea-level rise endanger coastal military infrastructure – from ports and dry docks to base housing and offices – necessitating alterations in coastal navigation routes and potentially impacting the frequency and scope of military training and exercises. Increased ocean acidification and salinity accelerate the corrosion of surface ships, while rougher seas shorten the life-cycle of shafts and propellers, which affects their performance and requires more frequent maintenance regimes.<sup>40</sup> Additionally, the increase in ocean temperatures has important implications for the cooling

requirements of ship propulsion systems and other essential systems that may otherwise overheat.<sup>41</sup>

When it comes to naval radars and sensors, studies conducted by NATO's Science & Technology Organization Centre for Maritime Research and Experimentation (CMRE) in 2023 found that expected changes in the height of the so-called "atmospheric surface evaporative duct"<sup>42</sup> and heavy rain will impair radar performance, especially at higher frequencies, affecting situational awareness. Additionally, changing water temperature and acidification also affect underwater acoustics, with possible implications for submarine operations and anti-submarine warfare (described in more detail below).

Concurrently, the changing climate expands the nature and scope of naval missions. Due to the growing volume of maritime traffic in more challenging and unpredictable sea conditions, military and security forces are and will continue to be increasingly required to address concurrent emergencies such as search-and-rescue and disaster response operations in new theatres, like the High North.<sup>43</sup>

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## Case Study: Submarine Operations and Anti-Submarine Warfare

Submarines' ability to operate and manoeuvre deep beneath the ocean surface makes them undetectable by human sight, electro-optical sensors, radar systems, and infrared cameras commonly used above water. In anti-submarine warfare (ASW), the use of sonar, which uses underwater acoustics,

remains the primary means to detect, locate, identify and track enemy submarines at long distances.

Researchers at STO CMRE conducted a series of studies commissioned by the NATO Office of the Chief Scientist aimed at understanding *if* and *how*



Source: STO CMRE.

an altered ocean environment could affect sonar detection in key NATO geographic areas. Their analysis shows that climate change affects both the *transmission loss*<sup>44</sup> and *ambient noise* – two key aspects of the sonar equation, which determine whether a submarine can be detected or not – in a number of ways.

Underwater sound speed varies with temperature, salinity and ambient pressure (which is a function of depth).<sup>45</sup> As a consequence acoustic propagation is highly susceptible to the effects of climate change.<sup>46</sup> The detected increases in ocean acidification – coupled with changes in ocean dynamics, temperatures, salinities and sea ice cover – will directly affect transmission loss. Increased transmission loss weakens the sound radiated by or reflected by a submarine, reducing the strength of the received signal. Conversely, decreased transmission loss will increase the probability and range of submarine detection. Ambient noise level is directly related to natural phenomena such as wind, surface waves, rain and Arctic sea ice cracking, as well as human and animal activity, such as commercial traffic, tourism, natural resources exploitation, and the changing migration patterns of marine mammals and other species. Increased

maritime traffic in some areas may increase ambient noise, masking the acoustic signals radiated by submarines. Conversely, the decrease or relocation of marine species to new regions may lower ambient noise, leading to easier detection. In short, lower ambient noise and stronger sound signals will make detection easier, whereas stronger ambient noise and weaker sound signals make detection more difficult.<sup>47</sup>

The first exploratory study conducted by the STO CMRE compared the effects of projected changes in ocean temperature and salinity on acoustic propagation loss at six locations in the North Atlantic and in the Western Pacific at the end of the 21<sup>st</sup> century (in comparison to the end of the 20<sup>th</sup> century).<sup>48</sup> Results indicated that the examined Western Pacific areas will not experience significant changes due to changing temperature and salinity levels, whereas two of the examined Atlantic areas presented large sound speed variations along the ocean depths, resulting in a significant increase in future acoustic transmission loss due to these changing variables. The STO CMRE research also draws attention to how these implications are regionally site-specific, and can vary from one area to another.



A subsequent study offered a detailed analysis of how sonar performance might be affected by the changing sound speed. Data from observations and three CMIP6 high-resolution climate models under the worst-case SSP5-8.5 scenario from 1980 to 2050 at four locations in the North Atlantic Ocean and Mediterranean Sea were analysed in 2023. The results depict a future decrease in specific key sonar parameters in some regions, with the High North exhibiting the greatest sensitivity to changing climate conditions. Increasing acoustic transmission losses at high latitudes, due to changing temperature and salinity levels, are likely to be compounded by future modifications to the Arctic soundscape, mainly caused by new sea ice conditions and associated increases in human and animal activity.

The research results have several implications for NATO, both for Allied ASW capabilities and nuclear deterrence based on ballistic-missile submarines. CMRE analysis indicates that in certain regions,

climate change will affect the probability and the range of detection of enemy submarines. In the North Atlantic, an increase in transmission loss may require a greater number of underwater sensors. As a consequence, the monitoring of North Atlantic seas, and even some choke points, is likely to become more difficult.<sup>49</sup> In comparison, the magnitude of the change is projected to be much more moderate in the Western Pacific.

In addition to environmental challenges induced by climate change, experts note that technological change – namely improvements in acoustic quieting and sonar detection technologies, including signal processing, in the years ahead – will also affect anti-submarine warfare and the finder-hider competition.<sup>50</sup> Such advancements may modify the above results and will need to be incorporated into future sonar performance studies.<sup>51</sup>

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## Case Study: The High North / Arctic

The circumpolar Arctic continues to experience warming at about four times the global average, with implications for the environment, local communities, access to, and security of the region – both at sea and on land.<sup>52</sup> With Finland's and Sweden's accession, Allied territory in northern latitudes has increased and so has NATO's expertise of operating in such a challenging environment.

Given the Arctic's rapidly transforming environment, military planners must account for both technological and logistical challenges when operating in northern latitudes. This is due to a combination of the region's harsh and increasingly unpredictable climate, including broken ice, high wind speeds, strong tidal currents and therefore stronger waves, low water and surface temperatures, long distances, darkness, remoteness, limited military and critical infrastructure, and limited radar and satellite coverage.<sup>53</sup> These challenges are further compounded by the limited number of vessels and aircraft capable of operating safely in the Arctic.

On land, coastal erosion, permafrost degradation and flooding from storm surges – which are characteristic of northern latitudes – put military

infrastructure and installations at risk. Currently, permafrost thaw jeopardises the integrity of four of the eight US Department of Defence installations in the Arctic, namely Pituffik Space Base in northwestern Greenland, Eielson Air Force Base, Fort Wainwright, and Alaska Radar System and North Warning System (examined in more detail below).<sup>54</sup> Additionally, floods, snow or storms can block supply routes and hamper transitions in posture and training, while increased precipitation could undermine the load-bearing capacity of soil and roads. Fighting boreal forest fires, which have been sweeping across the Arctic region,<sup>55</sup> will put additional pressure on military personnel and assets. It is also expected that with thawing permafrost, Cold War era military dump sites (like those in Alaska, Greenland and Russia), might emerge, and risk becoming sources of contamination for the surrounding environment and Arctic inhabitants.<sup>56</sup>

As Arctic sea ice recedes, access for state and non-state actors will increase. The High North is already seeing an uptick in human activity, with fishing fleets expanding operations, resource extraction drawing interest beyond traditional regional actors, and further growth in commercial shipping

and tourism. This increased activity raises the risk of maritime incidents and accidents taking place, placing greater responsibilities on militaries and security forces to provide search-and-rescue (SAR) operations in environments and over distances that pose serious logistical challenges.

There are also important human and environmental security considerations. The circumpolar Arctic is inhabited by approximately four million people. Disruptions in ecosystems, biodiversity loss, shifting weather patterns, thawing permafrost and coastal erosion are impacting resource-based livelihoods, curtailing access, and otherwise undermining the health and prosperity of local communities.<sup>57</sup>

Finally, scientific cooperation with Russia in the Arctic region was put to a halt following Russia's full-scale invasion of Ukraine. This was followed by the cessation of scientific data sharing from Russia's Arctic monitoring stations. While the region's population and economic activity are small in global terms, physical changes in the Arctic have an outsized effect on global weather and climate patterns both at sea and on land.<sup>58</sup> With Russia

accounting for approximately 50% of the Arctic landmass and 17 out of 60 field stations belonging to the Arctic research network, scientists warn that missing data from Russia can cause Arctic climate blind spots and compromise the accuracy of global climate models, severely impairing climate forecasting.<sup>59</sup>

Strategic challenges are unfolding in parallel. From a defence planning perspective, climate change adds complexity to the regional security dynamic and will shape future operational deployments. Melting Arctic conditions will present the Alliance with new opportunities but also vulnerability if left unchecked.<sup>60</sup> Force manoeuvre possibilities will increase<sup>61</sup>, new infrastructure will be called for (and will need to be defended), and competition for resources, such as fish stocks, is likely to accelerate. These evolving characteristics will create uncertainty. Maintaining freedom of navigation will be critical for NATO to maintain deterrence in the future. Additionally, the Alliance faces increasing geopolitical competition and growing militarisation of the region, with increased Russian activity that needs to be monitored, assessed, and deterred. Arctic experts and observers suggest tensions in the future could arise over different interpretations of the Law of the Sea (UNCLOS), extension of the continental shelf, marine living resources – notably illegal, unregulated and unreported fishery in the Barents Sea – and Svalbard.<sup>62</sup>

Alongside the effects of Russia's war against Ukraine, climate change is helping to drive new security cooperation. Beijing, which depends on Russia for access to the Arctic, has been primarily involved in scientific research and economic activities in the region. In April 2023, however, Russia and the PRC signed a memorandum of understanding (MoU) to strengthen maritime law enforcement cooperation. Under this MoU, the PRC's Coast Guard and Russian Federal Security Services (FSB) agreed to enhance joint efforts to combat terrorism, illegal migration, smuggling and illegal fishing.<sup>63</sup> Another MoU, signed between Russian and the PLA navies followed in April 2024, stipulating expanded cooperation in the field of search and rescue at sea. The dual-use nature of the PRC's capabilities in the Arctic and the MoUs potentially serving as a precursor for broader security cooperation warrants increased attention. Arctic experts and observers suggest that much will depend on the degree of trust between the two governments regarding Arctic policy.<sup>64</sup> Russia so far has been reluctant to allow the PRC to develop a military presence in the Arctic.



Source: Finnish Defence Forces.

## Land Operating Domain

The escalating impacts of climate change are presenting complex tactical and operational challenges in the land domain. The Canadian wildfires in 2023 are a stark example of this. Operation LENTUS, the Canadian Armed Forces' response to domestic emergencies,<sup>65</sup> has seen substantial deployments to address forest fires, highlighting the increased demands on military resources. As noted above, other NATO members have similarly contended with domestic wildfires, which tested their resilience.

The July 2023 wildfire in central Greece, which threatened a Hellenic Air Force ammunition depot near Nea Anchialos, illustrates the risks natural disasters pose to military infrastructure.<sup>66</sup> The thermal load caused explosions of varying intensity,<sup>67</sup> with blast protection embankments mitigating some of the damage.<sup>68</sup> This incident underscores the benefit of leveraging Allied experience and incorporating climate change considerations into risk mitigation planning for protection of military installations, including in anticipation of periods of extreme heat. Examples of such measures are maintaining firebreak zones around military infrastructure, and re-assessing risks in areas where they have not been required in the past.

In addition to safety risks, wildfires transform vast areas, posing additional challenges in the land domain where vegetation is crucial for natural cover, concealment, and tactical manoeuvrability. The loss of dense foliage complicates ambush setups, and affects visibility and engagement ranges, influencing strategic and tactical decisions.<sup>69</sup> Understanding the changing topography is vital for planning and executing military operations. The increased frequency and intensity of extreme weather events necessitates more frequent re-analysis of terrain, a task which requires specialist resources, including precise geospatial capabilities.

As for human factors, exposure to extreme temperatures causes an increase in heat-related illnesses. In 2022, analysis of the South Korean Armed Forces Medical Command (AFMC) data found that 90.3% of heat injury cases occurred in the Army, when compared with Air, Maritime and Marine Corp. In 2023, with a temperature increase of just 0.6°C, heat injury cases rose by 25.9%, with a further surge during early July's extreme heat. Specialised forces with specific equipment may face additional challenges from extreme heat.<sup>70</sup> For example, chemical, biological, radiological and nuclear (CBRN) defence operations rely on hot, bulky protective equipment that becomes difficult to use in extreme temperatures.<sup>71</sup>

Innovations and standards being developed by the STO Human Factors and Medicine Panel into physiological monitoring will soon provide a clearer and real-time risk picture.<sup>72</sup> A re-evaluation of training patterns, uniforms, load carriage, and exertion patterns may be necessary to mitigate these risks.<sup>73</sup>

The land domain also faces unique challenges within armoured vehicles. Testing by the Canadian Ministry of Defence during the Afghanistan war indicated significant risks for tank crews, who became operationally ineffective within 1-2 hours at external temperatures of 35-44°C.<sup>74</sup> Personal and/or micro-cooling solutions for tank crew were used in mitigating these effects.<sup>75</sup> Such solutions require energy which places additional demands on overall vehicle power requirements, and in this way compete with combat capabilities, such as active and passive defence measures and Intelligence, Surveillance and Reconnaissance (ISR) capabilities.

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## Case Study: Rovajärvi Shooting and Training Area (Finland)

Lapland, the northernmost region of Finland, is home to Lapland Air Defence Command and the planned air base for Finland's first F-35s. It also hosts winter combat training at Rovajärvi – the main firearm area of the Finnish Defence Forces, which is also the largest unified military exercise and shooting training area in Western Europe. Rovajärvi has a surface area of 1,070 square kilometres, of which approximately one third is designated for live-fire exercises. It is used especially for the largest national military exercises, in which up to 3,500 people participate. The exercise area is used around 200 days a year, of which 135 on average are shooting days.<sup>76</sup>

According to a climate vulnerability and exposure assessment produced by the Finnish Defence Administration, the period 2011-2020 was around 0.6°C warmer than the 1981-2010 reference period, with southern Lapland projected to warm by approximately 1.9-5.8°C by the end of this century. The most significant climate-related risks until mid-century relate to the average increase in daily temperatures, precipitation and humidity. Concurrently, snow and frost days are projected to decrease. As for the length of thermal seasons, winters are expected to shorten by 30-40 days, summers to extend by around 20-30 days, with springs and autumns remaining largely unchanged.

The projected changes to Finland's climate have a number of implications for the effectiveness and readiness of the Finnish Defence Forces. Decreased soil frost combined with increased precipitation can undermine the soil bearing capacity and affect operational readiness by complicating transitions during training. The projected increase in average rainfall, the frequency and intensity of rainy days, storms (including rainstorms), and floods, could directly affect existing infrastructure and roads. Icy rain and longer periods of near-zero temperatures are expected to increase in frequency in Lapland by mid-century. In turn, increased ice accretion from freezing rain might affect military equipment and, consequently, pose health and safety risks to conscripts and military personnel.

Warmer winters with more fluctuating temperatures result in repetitive freeze-thaw cycles, which damage roads and other military infrastructure,

and consequently can hamper transitions in training. Warmer winters and shorter periods with snow cover already complicate winter combat training in southern Finland. This could extend to Lapland if warming trends continue. As elsewhere in the Arctic, thawing permafrost can release long-frozen pathogens, presenting severe health risks for military personnel and Arctic populations alike.

The 2023 Climate Change Adaptation Plan of the Finnish Defence Administration identifies a number of measures to manage climate-related risks to military activities in the Rovajärvi area. These include addressing climate risk in the life-cycle management of military materiel, accounting for changes in winter conditions in conscript training, reviewing operating instructions for floods, storms and icy rain, and improving data collection on extreme weather events as well as medical intelligence and the monitoring of tick-borne infections. The impacts of climate change are taken into account throughout the defence planning process, as well as in budgeting for the maintenance of military assets and equipment. Additional issues to note include:

- The heating requirements for buildings will decrease, while the need for cooling will increase in the summer period. More building automation must be provided to regulate temperature, air flow and humidity levels.
- The availability of adequate snow disposal sites and ploughing equipment must be ensured, taking into account high annual variations in snow cover.
- The need for de-icing/anti-icing treatment will increase.
- Increased moisture fatigue<sup>77</sup> may result in more frequent maintenance and repair of infrastructure and equipment.
- As international deployments expand and current warming trends continue, there is a growing need to remove invasive species and pathogens from equipment.<sup>78</sup>

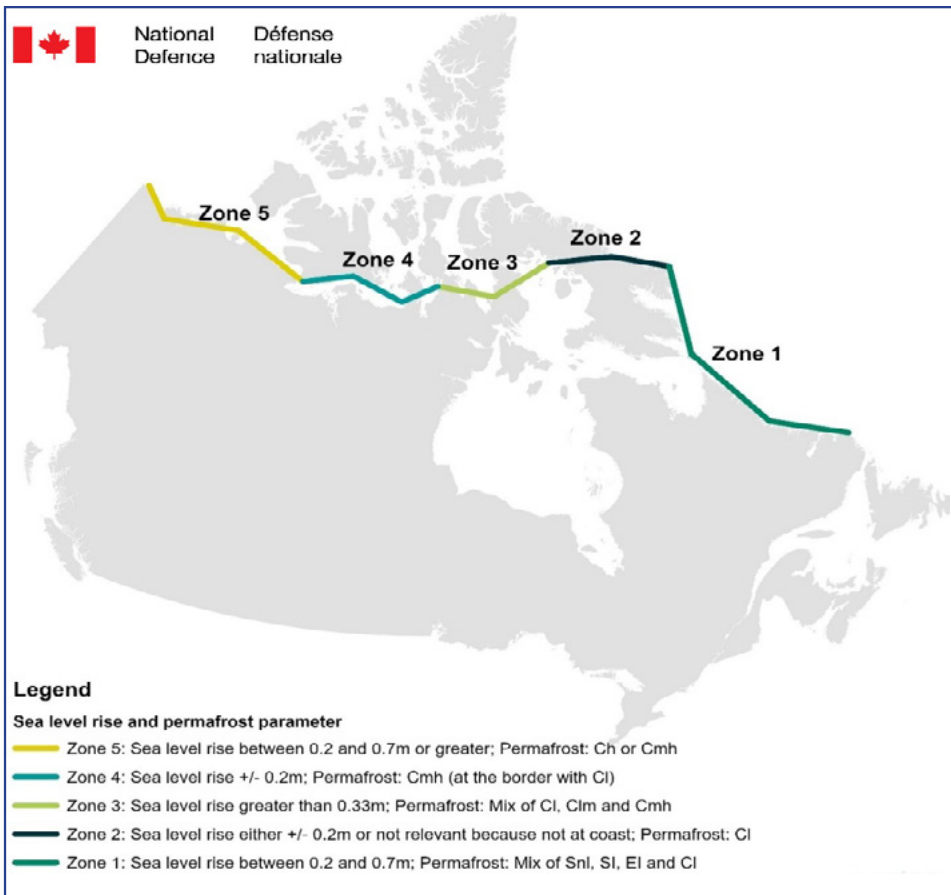
## Case Study: North Warning System (NWS)

The North Warning System (NWS) is a joint Canadian and US early-warning radar system for the air defence of North America. The NWS is a linear array of radar sites located in the Canadian North and Alaska that together provide surveillance of the airspace across North America's polar region.

The NWS spans across some of the most climate-vulnerable landscape in Canada. The risk of coastal erosion, changes to sea levels and to the sea ice regime, permafrost thaw, and increased convective storm activity are all expected to increase through the century, with some of these impacts

already being felt at some locations. Access to and operation of these sites are at risk from the changing northern landscape.

A climate change vulnerability assessment was conducted to flag vulnerabilities among Canadian NWS sites at a regional scale as part of a larger study across the Canadian Defence portfolio as a whole. For this evaluation, the NWS "Line" was segmented into five representative climate zones. The delineation of these climate zones was based on differing climatic conditions related to permafrost and sea level change characteristics.



### Permafrost Classification Legend

Ch: Continuous; high ice content  
 Cm<sub>h</sub>: Continuous; medium-high ice content  
 Cl<sub>m</sub>: Continuous; medium-low ice content  
 Cl: Continuous; low ice content  
 E<sub>l</sub>: Extensive discontinuous; low ice content  
 S<sub>l</sub>: Sporadic discontinuous; low ice content  
 S<sub>nl</sub>: Sporadic discontinuous; low-nil ice content

The historical climate along the NWS Line is characterised by cold winters, cold to mild summers, and year-round precipitation. Climate change will lead to an increase in temperature throughout the year with a particularly large increase during the winter months. This will result in reduced occurrences of extreme cold days, higher annual minimum temperatures, and fewer cold spells. Extreme heat days, with maximum temperature above 24°C and heat-waves are expected to increase in frequency.

Additionally, an increase in the annual rainfall amounts of between 37% and 69% among NWS sites and seasonally shifting precipitation patterns is expected by the middle of the century. The length and severity of droughts are projected to increase, as is the frequency of heavy precipitation events. A heavy rainfall event that historically could have been expected every 100 years will instead occur between every 14 to 23 years by the middle of the century. The increase in short-duration, heavy-precipitation events is, in part, associated with an increase in convective storm activity which will also lead to an expected increase in lightning strikes. Furthermore, wildfires are projected to become more frequent and more severe. These climate-driven trends along the NWS Line are also expected to intensify throughout the second half of the century.

The climate change vulnerability assessment focused on the climate-related impacts to NWS infrastructure with categories based on real

property archetypes (e.g., buildings, sensitive electronic equipment, and power and heating infrastructure). These were assessed in a high emission scenario against hazard indicators that could cause damage to considerations such as infrastructure, loss of operational capacity, financial costs, and harm to Canadian Armed Forces (CAF) members and civilian employees.

Several noteworthy climate change vulnerabilities were identified for the NWS. Three key examples were:

- Loss of sea ice and sea level change (expected to rise in some zones and fall in others), leading to increased coastline exposure to tides, turbulent waves, and storm surges, resulting in increased erosion and sedimentation along the NWS Line, putting coastal access points and land-based infrastructure at risk.
- Permafrost thaw resulting in ground instability and uneven settlement of surface soils, putting the integrity of infrastructure, runways, fuel pipelines, and other land-based infrastructure at risk.
- Increased wildfire activity across the country resulting in the degradation of air quality and visibility, which could impact access to and operation of the remote NWS sites during the maintenance season.

## Air Operating Domain

Climate change significantly impacts all aspects of the air domain, from the physical performance of aircraft, through the safety of equipment and infrastructure, to the structure and planning of flight operations.<sup>79</sup> The interconnected nature of the challenge necessitates a comprehensive approach to three key areas: airspace, air missions and operations, and air equipment. The following analysis of the impact of climate change on the air operating domain is supported by two case studies: 'Naval Helicopters – Rotary Wing Capabilities' and 'C-17 Cargo Planes'.

Starting with airspace, climate change causes significant shifts in environmental conditions, leading to greater weather volatility and unpredictability, intensified turbulence, and a higher frequency of extreme weather events. These challenges require aircraft to operate in harsher conditions, complicating flight planning and increasing flight risks. In particular, rising temperatures reduce air density – arguably the most important physical factor affecting aircraft performance (during take-off and landing).<sup>80</sup>



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## Case Study: Naval Helicopters – Rotary Wing Capabilities

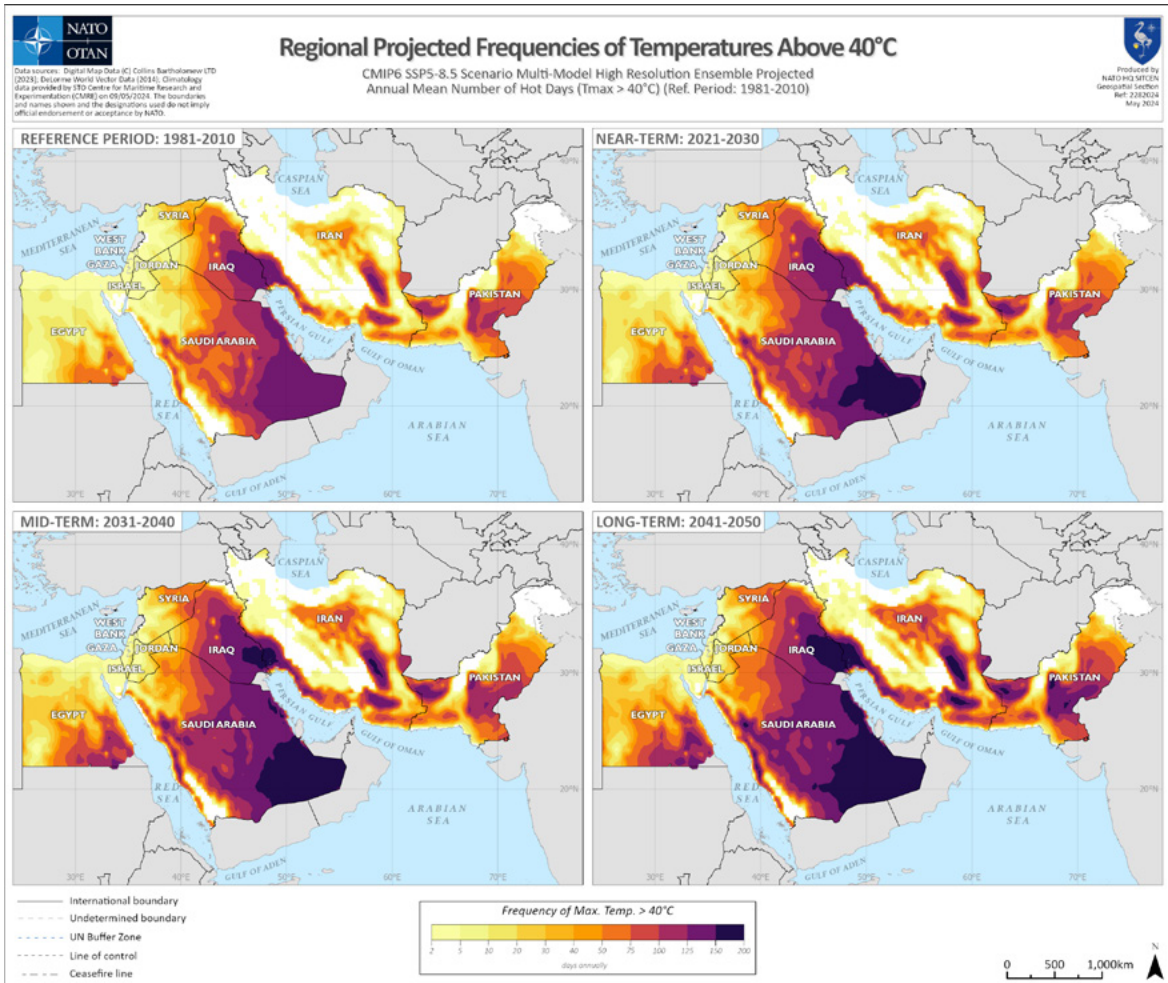
Rotary-wing (RW) aircraft, or rotorcraft, generate lift by rotating around a vertical mast. Warmer temperatures created by climate change will increase density altitude that negatively affects RW aircraft performance, reducing both engine power and rotor efficiency, leading to a diminished power margin, maximum take-off weight, hover ceiling and rate of climb. Additionally, dry and dusty conditions have been found to cause greater component damage due to sand ingestion by gas turbine engines. Degraded visual environment (DVE) has further been documented as a key risk for RW assets.

In 2023, NATO's STO CMRE studied the impact of future scenarios of "Hot Days" on lifting capacity of naval helicopters.<sup>81</sup> Based on data obtained from the US DoD Military Standards and the operations manual of a medium-heavy naval helicopter, at air temperatures of 40°C, maximum take-off weight at sea level is severely affected, limiting operational capabilities to carry embarked fuel, personnel, weapons, and equipment. These challenges are particularly severe when high temperatures occur at already high take-off altitudes, such as in alpine landing points and airbases.

Based on these considerations, the study focused on the "number of Hot Days" (NHD) in a year during which air temperature exceeds 40°C (NHD40),

using data from four CMIP6 high-resolution (20-40 km) climate models under the worst-case climate scenario of SSP5-8.5. Projections of future 10-year and 30-year averaged periods were compared with the reference period (1981-2010).

Analysis of the 1981-2010 period globally shows several hotspots where the annual number of days exceeding 40°C is already high, particularly in northern Africa, the Middle East, the Indian subcontinent and Australia. Projections based on the GCM data anticipate large future increases of NHD40 in these cited areas, with additional significant NHD40 appearing in North America, Central Asia, South-East and East Asia, Europe and Southern Africa. A closer look at NHD40 in the sector spanning from the Equator to 60°N and from West Africa to western India shows large increases for the decade 2041-2050 in northern Africa, Middle East, Iran, Pakistan, India and Central Asia, with more limited increases also in southern Spain and other European areas. Results indicate that air temperature over ocean areas is not likely to exceed 40°C regularly until at least 2050 – the end of our analysed period – with the exception of the Gulf region. Naval helicopter lift operations are likely to become significantly more challenging in numerous future operating contexts (especially operations over land), as increasing temperatures limit the maximum carrying capacity.



From strategic and tactical adaptations, to training for new realities, climate change will affect planning and execution of air force missions and operations. As weather patterns become increasingly more variable, flexibility in operational mission planning, deployment strategies and logistical support will increase in importance for air activities. One notable example is the impact of clear-air turbulence (CAT), which is predicted to increase due to climate change.<sup>82</sup> With the increasing frequency and severity of extreme weather events, the demand for disaster response will increase, which will place additional demands upon air assets to assist when disasters strike.

Finally, the changing climate raises interconnected challenges for air equipment, necessitating more frequent maintenance, complicating operational logistics, and impacting readiness. As engines generate less thrust in thinner air, higher temperatures reduce engine performance and compromise lift capabilities due to longer distances required for take-off and landing. The effects of climate change, such as extreme weather events and rising sea levels, pose risks to the infrastructure required for air equipment to operate effectively, such as coastal air bases. The second case study focuses on the impact of warming air temperatures on the amount of cargo a military transport plane can carry.



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## Case Study: Cargo Capacity of Military Transport Aircraft

The C-17 Globemaster III provides an effective case study for challenges to the air transport sector – being the most flexible transport aircraft in the US Air Force (USAF) fleet. Whilst the USAF remains the C-17's largest user, two NATO Allies (Canada and the UK) own and operate C-17s, as does the multinational Strategic Airlift Capability, which includes 12 NATO Member States.

This case study outlines the findings of a 2022 research project carried out at George Mason University,<sup>83</sup> which used climate-warming projection data from 2020 to 2099 to assess how rising temperatures affect density altitude and, consequently, C-17 performance. More specifically, the research was based on forecasted temperatures and relative humidity values under the “worst-case scenario”, based on CMIP5 datasets and RCP 8.5 during each 20-year period from 2020–2099, as well as elevation data across the study area. Six density altitude areas were identified:  $\geq 215\text{m}$ ,  $\geq 430\text{m}$ ,  $\geq 730\text{m}$ ,  $\geq 1490\text{m}$ ,  $\geq 2188\text{m}$ , and  $\geq 2545\text{m}$ . According to the research findings, the rise in density altitude leads to increased performance degradation, resulting in a weight restriction for the C-17s. The study assessed each of the six US Geographic Combatant Commands and classified them according to the number of months per year that a particular location would be subject to the take-off weight restriction. The following assessment outlines some of the key impacts of climate change on US Africa Command (USAFRICOM) – covering all of Africa except Egypt.

- At the first threshold ( $\geq 215\text{m}$ ), the maximum payload of the C-17 is reduced by 8.5%, which is equivalent to approximately 14,550 pounds. For context, the maximum payload capacity of the C-17 is 170,900 pounds. In practical terms, this would reduce the C-17's cargo allowance by at least one UH-60 Blackhawk helicopter. In the case of the USAFRICOM region, in only the first segment of the warming period (2020–2039) the region is degraded by 8.5% payload reduction throughout the year.
- At the third density altitude ( $\geq 730\text{m}$ ), the maximum payload of the C-17 is reduced by 30%, equivalent to a 50,000-pound decrease in maximum allowable payload at take-off. In practical terms, this would reduce the C-17's cargo allowance by at least one M2A2 Bradley infantry-fighting vehicle. For the USAFRICOM region, this would be applicable to over 70% of the region year-round by the year 2099. Additionally, nearly another 10% of the USAFRICOM AOR is predicted to be classified as “critical performance degradation” by 2099, indicating only one to two months per year that the C-17 is not subject to the nearly 30% percent payload reduction.
- At the fourth density altitude threshold ( $\geq 1490\text{m}$ ), the maximum payload of the C-17 is reduced by 58.5%. Tactically, the C-17, which is outfitted to carry two M2A2 Bradley vehicles, will no longer be able to carry any, given the predicted 100,000-pound decrease in take-off weight.

The study identifies a strategic challenge for military aircraft payload capacities, indicating that strategic lift assets will be substantially degraded, in turn reducing the future ability to conduct air operations in Africa – both military and humanitarian. Tactically, this means that across the entirety of Africa, airlift that previously would have required only five C-17 flights at maximum payload will require an additional sixth flight. Although the C-17 will remain a valuable asset in such operating contexts through to 2099, it will be reduced in efficiency and capability, forcing adaptation to planning and logistics.

In addition to the C-17 Globemaster III performance decrease, analysed in the George Mason University study, capabilities and performance of rotary, tanker, bomber and fighter assets can also be assumed to degrade in a warming climate. As the report authors conclude, NATO Allies must consider climate change and global warming as strategic and tactical variables that threaten Allied militaries' ability to execute operations with the level of efficiency promised by their current aircraft.

## Space Operating Domain

The 2022 Strategic Concept recognises that maintaining unfettered access to and secure use of space is key for NATO's collective defence and security. Climate change-related effects increasingly challenge the ability of NATO members to operate effectively in space, and limit the potential value that space capabilities can add to NATO's missions and operations. Adverse weather patterns and rapidly changing environmental conditions further exacerbate the challenge, in case a rapid satellite replacement is needed due to its loss or failure.

Climate change can impact ground-based infrastructure that is critical to space operations, such as ground stations, airfields, communication towers, space launch pads, or satellites that are yet to be launched. In 2024, Andøya Spaceport in Norway – the first operational spaceport in continental Europe – experienced three consecutive heavy storms with gusts up to 200km/h, damaging both the launch infrastructure and one of Andøya's communication towers. In addition, the primary launch sites of NATO members – Cape Canaveral Space Force Station in Florida, Vandenberg Space Force Base in California, and French Guiana Space Station – are situated close to coastlines and increasingly find themselves at major risk from coastal erosion, sea-level rise, and flooding. According to NASA estimates, for example, Kennedy Space Center is projected to face one major flood a year by 2050, minor floods every

week, and a sea-level rise of 30-46 centimetres under “high emissions scenario”.<sup>84,85</sup> As a 2022 NATO Review article dedicated to the climate-space nexus underscores, climate-related impacts are of greater concern to Allied space capabilities than they are to Russia and the PRC. This is due to the fact that the majority of launch sites operated by Russia and the PRC are located inland, benefiting from more stable weather conditions.<sup>86</sup>

There are specific weather criteria – including temperature, cloud cover, precipitation, liftoff winds and lightning – that have to be met to ensure that a rocket is safe throughout its entire launch process. Strong wind shears present in the lower and upper layers of the atmosphere that are difficult to predict can influence launch trajectories for satellites and missiles. In 2023, the launch of the American military satellite NROL-70 was delayed by two weeks due to bad weather conditions, as was the launch of Türkiye's first domestic satellite (IMECE).<sup>87</sup> Changes in weather patterns in combination with the aforementioned weather parameters exceeding safe limits are likely to become more frequent and intense as the planet warms. These will challenge the viability of comprehensive space operations in certain regions in the future.<sup>88</sup> The level of vulnerability and exposure will vary by geographic location.

## Cyber Operating Domain

The intersection of cyber defence and climate change represents a complex and increasingly critical area of concern. As the world becomes more interconnected and reliant on digital technologies, the potential for malicious cyber activity to exacerbate climate change issues grows. From cyberattacks on environmental monitoring systems to data manipulation and climate-related disinformation campaigns, the ways in which cyber risk and climate change intersect are vast and varied.

Accurate data is crucial for climate forecasting, modelling and informed policy-making. Cyber attacks involving the manipulation or theft of environmental data can hinder efforts to monitor climate change accurately and implement effective policies. Hack-and-leak attacks<sup>89</sup>, where data is stolen or leaked and potentially doctored, should be a concern when it comes to environmental data and policies.

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## Case Study: Energy Transition and Climate-related Disinformation

The environmental challenges that NATO has faced are compounded by climate-related disinformation. Malign actors seek to erode the public pressure and political will for ambitious climate action, as well as to divert focus and resources away from climate change adaptation and mitigation efforts.

Kremlin-backed actors have been found to be pushing climate change denialism across the Alliance, all while actively attempting to derail climate change mitigation policies and renewable energy investments.<sup>90</sup> Russian state media routinely amplify uncertainty around climate change and downplay the phenomenon as exaggerated or even positive. They frame global warming as a “hoax” and emission-reduction plans as a form of “Western imperialism” engineered to undermine the development of emerging economies.<sup>91</sup> Denial of anthropogenic climate change persists in Russia largely due to the entangled ties between the fossil fuel industry and political power, and the country’s ongoing dependence on fossil fuels as a dominant source of government revenue. Individuals who challenge scientific consensus on climate change continue to hold political power.<sup>92</sup>

A notable increase in Russian disinformation related to the European green energy transition has been observed since the beginning of Russia’s full-scale invasion of Ukraine. According to NATO’s Information Environment Assessment for the period May 2022 to May 2024, Russia was found to be the main driver of hostile communications in online conversations about the green energy transition on social media and web news media.<sup>93</sup> In 2023, efforts to spread mis- and disinformation were evident in the run-up to the COP28 UN Climate Change Conference in Dubai. According to a 2023 report by the Climate Action Against Disinformation (CAAD) – a coalition of over 50 leading climate and anti-disinformation organisations – Russia and the PRC were listed among the countries found to be spreading climate-related disinformation. Russian state-backed accounts weaponised climate debates, with influence campaigns targeting Western countries and emerging and developing

economies respectively.<sup>94</sup> Russian accounts have been found to regularly vilify climate activists – including personal online attacks, gendered disinformation and explicitly negative descriptions of women activists – and demonstrations across Europe.<sup>95 96</sup>

NATO’s potential adversaries and strategic competitors have been found to exploit natural disasters for malign influence campaigns, with the aim to exploit emotions, sow distrust in official response and otherwise impair Allies’ ability to respond effectively to crises, especially when communities are most vulnerable and local institutions are strained.<sup>97</sup> Disaster-related disinformation can also impede rescue and relief efforts, contributing to unnecessary casualties and human suffering that could have otherwise been avoided.

The series of wildfires that hit the island of Maui, Hawaii, in August 2023, were accompanied by numerous falsehoods and conspiracy theories. A covert online campaign that originated in the PRC suggested the disaster was not natural but a deliberate result of a secret “weather weapon” testing by American intelligence agencies and the military.<sup>98</sup> Russia also exploited the Maui fires for political purposes: a day after the fires started, a social media campaign began spreading the phrase “Hawaii, not Ukraine,” suggesting that the aid the US has provided for Ukraine would better be spent at home for disaster relief.<sup>99</sup>

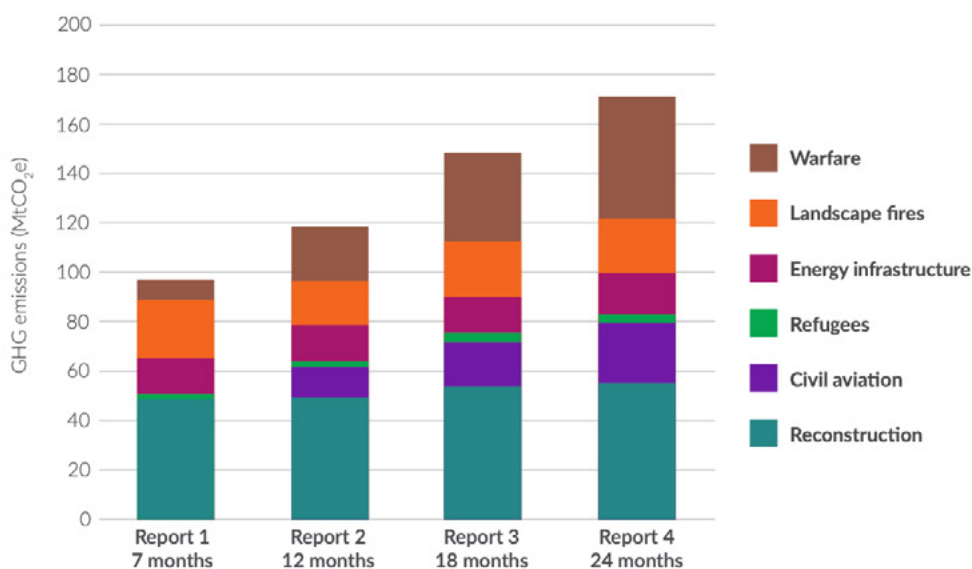
Actors who disseminate climate-related disinformation are often involved in other forms of disinformation. Anti-climate, anti-vaccine, pro-Russia and New World Order conspiracies have been found to go hand-in-hand.<sup>100</sup>

# Climate Impact Assessment of Russia's War Against Ukraine

Military conflict is a significant driver of climate change and environmental damage. Russia's war of aggression is a vivid example: In addition to human suffering, the invasion has had devastating climate and environmental impacts, with far-reaching consequences across Ukraine and beyond its borders. While estimates vary, analysts suggest that up to 175 million tons of carbon dioxide equivalent (CO<sub>2</sub>e) were released during the first 24 months of the war (see figure below).<sup>101</sup> Wildfires caused by attacks on oil deposits, tankers, refineries, and other hostile activities have consumed fields and forests, releasing additional emissions into the atmosphere and reducing the ability of forests to act as carbon sinks.<sup>102</sup> Concurrently, airspace restrictions over Ukraine (and Russia) increased the aviation sector's carbon footprint from civilian aircraft flying longer and more fuel-inefficient routes. The total climate damage is estimated at more than USD 32 billion.<sup>103</sup> Equally concerning is Russia flaring off natural gas,

releasing approximately 9,000 tonnes of CO<sub>2</sub>e per day, as a result of the market conditions created by its unprovoked invasion.<sup>104</sup>

It is estimated that post-war reconstruction might constitute the largest overall source of GHG emissions linked to Russia's full-scale invasion of Ukraine.<sup>105</sup> Ukraine's recovery from the conflict will necessitate rebuilding critical infrastructure, homes, public buildings and industrial sites across the country – and, in the most devastated regions, entire cities. The scale of this necessary reconstruction, particularly concrete and cement production, may produce a substantial amount of additional emissions.<sup>106</sup> Ensuring that post-war reconstruction and recovery follows a green direction will be essential for Ukraine's economic recovery, as well as for its national and environmental security. Both Ukraine and its international partners share this vision.



## Growth of War Emissions

Source: Lennard de Klerk et al., "Climate Damage Caused by Russia's War in Ukraine: 24 February 2022 - 23 February 2024," June 13, 2024.

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**NATO HQ**  
Boulevard Léopold III,  
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