Expeditions with MCUP

# Weather

## The Only Constant in Warfare

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23 January 2023

https://doi.org/10.36304/ExpwMCUP.2023.01

**Abstract:** Among the future trends that will affect the U.S. Marine Corps and its ecosystems is climate change. This article examines past impacts of weather on military operations and the effects of climate change on current and future military activities and infrastructure. It makes a security-based assessment for the Marine Corps to develop greater expertise and capability to include climate and meteorological factors into its strategic- and tactical-level planning and operations. Finally, the article concludes with recommendations for the Marine Corps that can mitigate current and future drivers of fragility.

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**Keywords:** military history, weather, warfare, military and climate change, U.S. Marine Corps, U.S. Air Force, hurricanes, China, Taiwan, great power competition, military operations

## Introduction

According to the National Oceanic and Atmospheric Administration (NOAA), the term *weather* refers to atmospheric conditions in a particular location during a three-month period. The term *climate* refers to average weather patterns and trends spread over a period of 30 years.[1] Since the end of World War II, no other military in the world has been as affected by weather as the U.S. military, which operates under various global commands in many different regions of the world, is greatly affected by regional weather.[2] This article details the significant role that weather has had on military operations, from ancient to contemporary times. Specifically, it makes a security-based assessment for the U.S. Marine Corps to develop greater capacity to integrate climate and meteorological expertise into all levels of planning, from procurement decisions to strategic and tactical operational planning.

Weather events such as hurricanes, rising sea levels, hot temperatures, sandstorms, and excessive precipitation can disrupt U.S. military capabilities and facilities.[3] The U.S. Department of Defense (DOD) and the various U.S. military branches are prioritizing climate change by incorporating mitigations plans into military operations and infrastructure projects. At the policy level, the DOD is assessing the impact of current and projected climate change, while the U.S. military is working toward planning mitigation measures to decrease vulnerability to weather events.[4]

Several historical case studies are presented here to demonstrate how weather can impact the conduct and outcome of military campaigns. This is followed by a discussion of the impact that different types of weather have on military activities. The case studies demonstrate that weather will continue to impact military operations in the future. This is followed by a discussion of the impact of weather on future military operations, pertaining specifically to great power conflict between the United States and China as well as China's probable invasion of Taiwan. The article concludes with recommendations in the areas of policy development, military facility design, cooperation with partners, and educational programs that will assist the U.S. Marine Corps in shifting to a more preventive posture.[5] During the next century, climate-induced weather events such as rising sea levels will affect coastal installations, while annual frequent seasonal weather such as hurricanes and extreme rains will affect military operations. Understanding weather patterns and the outcomes of climate change will become even more significant as weather continues to deteriorate further.

Certain examples of the impact that weather has on the U.S. Air Force have been inferred and applied to the Marine Corps, considering there are certain similarities between these two Service branches in terms of their operating environments, aircraft, and infrastructure. The recommendations, examples, and outcomes that pertain to the Air Force also apply to the Marine Corps.

Among the future trends that will impact U.S. national security is climate change. The frequency and intensity of wildfires in the United States and Australia, typhoons in the Asia-Pacific region, droughts in the Middle East, and devastating torrential rains in Europe and China increase every

year. Rising sea levels induced by climate change will surely affect military installations during the next 100 years, while yearly weather changes such as hurricanes and excessive rainfall will increase in severity and frequency. Extreme weather adds new layers of complexity to military planning, as it creates harsher conditions for the military while simultaneously degrading operational capabilities, affecting interdependencies, and disrupting supply chains.[6]

Many military historians, military leaders, and national leaders have understood the importance of weather in warfare. The Roman writer Vegetius wrote in the late fourth century that soldiers should avoid marching in the night through snow or suffer from shortage of firewood and clothes in winter.[7] The Achaemenid king Xerxes I lost nearly half of his naval fleet in storms off the Magnesia peninsula of Greece during the Battle of Salamis in 480 BCE. In 1709, Charles XII of Sweden was defeated at the Battle of Poltava after the fierce Russian winter took a toll on his army. In 1917, during World War I, Crown Prince Rupprecht of Bavaria described rain as the most effective ally in his country's fight against the Allied powers.[8] During World War II, U.S. Army general Dwight D. Eisenhower described weather as the worst enemy of the Allied air forces.[9] Also during World War II, fighting in the Apennine Mountains of Italy slowed to a snail's pace as rains and frost muddled roads to a borscht consistency during the winter of 1943–44.[10]

Today, U.S. President Joseph R. "Joe" Biden Jr. has placed climate change at the center of U.S. foreign policy and national security. According to the DOD, climate change has the power to hinder military missions.[11] One of the priorities for U.S. Secretary of Defense Lloyd J. Austin III is climate

change.[12] The DOD's 2010 *Quadrennial Defense Review Report* recognized climate change as a critical component in future military planning.[13]

According to researcher Elizabeth G. Boulton, climate change is a hyperthreat that has warlike destructive capabilities.[14] In contrast to widely used terms such as *climate crisis*, the term *hyperthreat* spotlights the harm, violence, and destruction that can and will be caused by the unraveling of the world's climate systems.[15] The hyperthreat is presently advancing and will arrive from the year 2030 onward.[16] In Boulton's "PLAN E" concept, the approach to dealing with climate change is securitized by applying the theories of war to combatting the hyperthreat.[17] PLAN E incorporates localized distributed solutions such as robust protection of soils, rivers, forests, grasslands, agricultural areas, and flora and fauna.[18]

Each geographical region of the world has its own weather patterns that come with peculiar problems. In Western Europe, rain has presented a major difficulty, while in Eastern Europe snow is more severe. Wars have been started there in summer only to be impeded by the frozen terrain of winter and the wet mud of spring. Various studies have concluded that climate change will create more frequent extreme weather events that directly impact U.S. national security.[19]

## Historical Impacts of Weather on Military Operations

Case studies signify the decisive role that weather can play as a determinant in warfare. The three case studies discussed below are the Battle of the Teutoburg Forest, fought between Germanic tribes and the Roman Empire in 9 CE; Operation Barbarossa, fought between Germany and the Soviet Union in 1941–42; and the heat and torrential rains that affected U.S.

military operations during the Vietnam War in 1965–73. There are similarities between the marshy and foggy paths in the Teutoburg Forest and *rasputitsa* on the Russian front to the contemporary weather patterns of the Indo-Pacific region. Notably, the German Army's winter campaign in Eastern Europe during World War II is significant to the U.S. Marine Corps as it focuses on operating in the Arctic region.

*Teutoburg: Asymmetric Warfare and Weather*

In 9 CE, Germanic tribes ambushed and annihilated three Roman legions in the Teutoburg Forest of Central Europe.[20] *T*he Roman column, slowed down by supply carts, meandered for 15 kilometers in a marshy *landscape interspersed with several lakes, ponds, and* narrow, saturated, and foggy forest paths. Each Roman soldier carried an estimated 89 pounds of gear. *Roman h*istorian Dio Cassius recorded that Roman general Publius Quinctilius Varus's soldiers were having a hard time chopping down trees and building roads and bridges. The Germanic warriors hurled javelins at the legions from hilltops while small groups attacked isolated soldiers. As the increasingly chaotic and panicky group of Roman legionnaires and cavalrymen moved forward, the Germans attacked from behind the trees, cutting off all possibility of retreat.[21]

*The wet, soggy environment of* the Teutoburg Forest *was not suited for Roman warfare.*[22] The violent rain and wind separated the soldiers and made their forward movement treacherous due to slippery ground.[23] Romans soldiers found it difficult to fight in heavy downpour, as their heavy armor got stuck in the muddy sludge; the rain soaked and loosened their bowstrings, rendering them inoperable; and their wood and hardened

leather shields became soggy and cumbersome. German cavalry slaughtered fleeing Roman cavalry units. The disciplined Roman Army would have triumphed in open fields, but they were at a great disadvantage in the marshes, with no room to maneuver and exhausted after days of guerrilla attacks.[24] The Romans ultimately lost three legions and 10,000 noncombatants.[25]

The Battle of the Teutoburg Forest changed European history. Tremors were felt across the Roman Empire. As news of the disaster spread, Roman bases in Germanic areas were hastily abandoned.[26] The Rhine River became the militarized border between the Roman Empire and the Germanic tribes for 400 years. Rome's inability to conquer Germania laid the foundations for the Western Empire's fall. The Battle of the Teutoburg Forest created a boundary between Germanic and Latin cultures that lasted 2,000 years.[27]

*Snow Blockades and Muddy Quagmires on the Eastern Front*

During Operation Barbarossa, the invasion of the Soviet Union by Nazi Germany in 1941, the German Army advanced within reach of the Soviet capital of Moscow. But temperatures of negative 40 degrees Celsius froze weapon systems, shut down engines, and immobilized soldiers who were not equipped with proper clothing for a winter campaign. The winter of 1941–42 resulted in high attrition of materiel and affected production leading to a shortage of equipment. According to German Army general Heinz Guderian, chief of the General Staff of the Germany Army High Command, preparations made for that winter were extremely inadequate, roads became canals of bottomless mud, and vehicles could advance at snail's pace with great wear and tear on the engines.[28]

The German Army, like the Roman legions in the Teutorburg Forest, followed rudimentary trails that meandered through farmland, scattered fields, pastures, ponds, and bogs. As they progressed, the lines of German troops became dangerously extended and were easily attacked by the Russians. Russia's harsh winter and sticky mud brought an end to Operation Barbarossa.

During the summer of 1941, the German logistical system had begun to fall apart due to the heat, dust, and mud of the Eastern front. Many German tanks lacked filters, while those equipped with filters were clogged with dust. Huge dust clouds raised by convoys triggered Russian air attacks that decimated vehicles and horses.[29] The German Army's *2d Panzer Group*, operating in the Oryol area of the Soviet Union, lost 60 percent of its tanks.

In the autumn of 1941, the German Army's maneuver warfare came to a halt due to glutinous swamps and an ocean of mud that was formed by rains. Russians call these muddy conditions *rasputitsa* (Russian: season of bad roads), which make transport and logistics difficult.[30] Dry roads became saturated with sludge and were impassable even on foot. German vehicles consumed twice as much of their usual fuel from a decreasing supply, larger trucks frequently got stuck, and vehicles sank to their axles in sludge.[31] Only 10 percent of German tanks survived the autumn muddy season.

During the winter of 1941–42, the movement of tracked vehicles became restricted due to limited ground clearance in deep snow. Machine guns' recoil liquid froze. The impact of mortars was absorbed by the snow. Mines often became dysfunctional due to the accumulation of snow on detonators and fuses. The Germans' logistics network broke down as a high rate of mechanical failure led to a shortage of trucks. Panzer divisions could

not repair damaged tanks and other vehicles because parts could not get through.[32] The plunges in temperature that accompanied storms damaged the external piping of sophisticated German locomotives, significantly reducing the number of engines available.[33]

During the 1939–40 Battle of Suomussalmi, fought between the Soviet Union and Finland, Finnish soldiers on skis had used guerrilla tactics to ambush Russian convoys stuck in snow. The Soviet Union lost 140,000 troops in the campaign due to cold or starvation, compared to 26,000 lost by the Finns.[34] Learning from the war in Finland, highly mobile and experienced Russians ski troops from elite Siberian divisions now maneuvered and attacked the Germans on the eastern front. The Soviet spy Richard Sorge provided valuable intelligence to Soviet leader Joseph Stalin during this period, including that Germany's Axis ally Japan would turn south to fight the United States and the United Kingdom instead of north to invade Siberia. Consequently, Stalin was able to transfer well-trained and -equipped Siberian divisions to the Soviet capital of Moscow to operate in harsh winter conditions there.[35]

The freezing conditions on the eastern front took a toll on soldiers. Nighttime temperatures fell as low as negative 45 degrees Celsius, which led to hypothermia. Boots, socks, and trousers that had become wet during the day stiffened and froze at night, leading to frostbite. Ultimately, Operation Barbarossa petered out on the peripheries of Moscow.

*Vietnam: Raging Heat and Torrential Rains*

The weather of Vietnam lengthened the Vietnam War and contributed to the protracted strategy of the Viet Cong, an armed Communist organization

allied with North Vietnam. Weather profoundly impeded U.S. Air Force operations and air strikes on critical targets in Vietnam, so much so that the issue reached the highest levels of the U.S. government, to include President Lyndon B. Johnson.[36] In addition, weather often interfered with reconnaissance activities and the monitoring of surface-to-air missile (SAM) sites. The U.S. Army typically replaced equipment every eight years. During the Vietnam War, this was cut to two years.

The U.S. Air Force lacked all-weather capability. Rain and low clouds grounded helicopters and planes. Dense water concentrations in clouds caused compressor stalls in aircraft engines.[37] Heat and humidity caused fogging problems in the canopies of fighter aircraft flying at low altitudes. Moreover, during Vietnam's dry season daytime temperatures in the Saigon area and across the Mekong Delta rose to the 90s Fahrenheit. U.S. Army and Marine Corps troops who had been acclimatized to the North American climate had difficulty patrolling in extreme heat. During midday, the troops became dangerously overheated and dehydration and heat stroke were serious problems.[38] During the monsoon season, U.S. logistical and fire support bases and night defensive positions became swamps. Troop movements were hampered as mud hindered tanks and armored personnel carriers, with the vehicles slipping off wet rudimentary roads. Torrential downpours created thick, sticky mud, while high river levels slowed or stalled supply convoys.

**Weather and Future Military Operations**

Weather events such as typhoons and heavy rains will play a pivotal role in any future conflict between United States and China in the Indo-Pacific

region. The U.S. experience in Vietnam will influence its role in any future conflict with China. Seperately, China will find it difficult to invade Taiwan due to the volatile weather in the Taiwan Strait.

*Great Power Competition*

The United States will have to consider weather in its great power rivalry with China. Summer heatwaves, floods, droughts, and typhoons all impact China. In 2020, heavy rainfall affected 27 of China's 31 provinces.[39] These rains killed more than a million animals across 1,678 large farms in Henan Province, leading to concerns of disease outbreaks.[40] Internet and power outages, water shortages, and flooding of tunnels and subways disrupted transportation networks as the provincial capital of Zhengzhou experienced heavy rains. In 2020, the Yangtze River flood affected more than 30 million people and cost in excess of $30 billion USD.[41]

*The Dragon Is Adrift in the Taiwan Strait*

The island country of Taiwan is defended by six natural deterrents: its coastline, monsoons, tides, mud, a limited number of beaches, and a small yearly window for invasion due to weather conditions.[42] The Taiwan Strait is notorious for typhoons, which increases friction for the Chinese People's Liberation Army Navy. During Taiwan's two monsoon seasons, torrential rains makes visibility nil, and high winds generate 20- to 30-foot waves. During the calmer summer months, the waves average six- to eight-foot swells.[43] Dense fog in springtime often prevents shipping in the strait.

Wind and heavy rainfall in the area of Taiwan could make a landing by the Chinese People's Liberation Army difficult.[44] Rugged landing points on

the island's beaches and mountainous topography are hardly desirable for an amphibious assault.[45] Chinese tanks would be vulnerable to Taiwan's military due to the low tide exposing several miles of muddy coastline. A funnel effect causes unpredictable currents near the coastline, and Chinese landing craft would be hit broadside as strong winds blow from north to south.[46]

**Weather Implications for the U.S. Marine Corps**

Climate change will have a significant impact on the economic and social conditions that contribute to mass migration, food shortages, regional instability, vector-borne diseases, political crises, civil unrest, and state failure. This will affect U.S. national security, as allies and partners may request military assistance.[47] The DOD has identified numerous risks related to climate change, to include extreme temperatures, precipitation, drought, coastal erosion, permafrost degradation, riverine flooding, rising sea levels, and hurricanes.[48]

Frequent and extreme weather events will surely impact modern warfare.[49] Weather could affect the supply chains and logistical capacity of the U.S. Marine Corps during a runup to a potential war or destabilize ongoing military operations. Extreme drought in Africa or flooding in the Indo-Pacific region could affect the Marine Corps' warfighting capabilities.[50] For the United States Africa Command, drought, deserts, and weather in rain forests are all crucial factors in mission planning.[51] Floods, earthquakes, typhoons, and tsunamis are a concern for the United States Indo-Pacific Command. Weather conditions in the Mediterranean region impact

intelligence, surveillance, and reconnaissance (ISR) and logistics operations for the United States European Command.[52]

*Rising Sea Levels and Hurricanes*

Sea levels are expected to rise along the U.S. coastline and in the Indo-Pacific region, which will cause damage to military infrastructure.[53] More than 30 U.S. military installations are vulnerable to rising sea levels and storm surge. Rising sea levels will disrupt low-lying training facilities, cause flooding, and disrupt supply chains.[54] A three-foot increase in sea level rise will threaten 128 coastal installations, about 43 percent of which are naval installations valued at roughly $100 billion USD.[55] There are currently 1,774 U.S. military sites throughout the world that are located on coastlines.[56] Approximately 45 percent of the 292 military sites are within 2 kilometers of the coastline and were affected by flooding in recent years.[57]

With a total of 29 military bases in the area, Hampton Roads, Virginia, has the largest concentration of U.S. military sites in the world. It has hundreds of kilometers of waterfront on three major rivers and the Atlantic Ocean, and its low-lying topography makes it vulnerable to flooding from relative rises in sea level.[58] Since 1857, there have been 65 hurricanes that have come within 150 nautical miles of Hampton Roads.[59] The United States' Naval Station Norfolk, the largest naval base in the world, is located in the Hampton Roads area. In 2003, Hurricane Isabel, a Category 2 storm, flooded about 6 percent of the area, while in 2011, Hurricane Irene, a Category 1 storm, brought a 7.5-foot storm surge to the naval station. During this century, water levels in the area could rise from 4.5 to nearly 7 feet.[60]

Approximately 75 U.S. Air Force sites, including 6 major installations and numerous mission-critical communications and radar sites, are located within 2 kilometers of the U.S. coastline and at a height of 0 to 6 feet above sea level.[61] According to a report by the U.S. House of Representatives Committee on Armed Services, the $1 billion USD Air Force radar installation in the Marshall Islands could be underwater by 2035.[62] In 2018, Hurricane Michael, a Category 5 storm, caused unprecedented damage to Tyndall Air Force Base in Florida, harming the flight line, drones, runways, housing, and the marina and leading to a temporary shutdown of all operations. The estimated repair cost is about $3 billion USD.[63] Rising sea levels also threaten Langley Air Force Base in Virginia, which is 8 feet above sea level and home to the Air Force's Air Combat Command.[64] About 200 facilities at Langley Air Force Base were affected by Hurricane Isabel in 2003, with estimated damages totaling more than $160 million USD.[65]

Andersen Air Force Base on Guam is the only permanent Air Force air base in the western Pacific for strategic heavy bombers. Its water and energy supplies are located in low-elevation areas that are prone to rising sea levels.[66] Flooding will impact naval and air force operations and communications systems at the base.[67] In Alaska, several of the Air Force's early warning radars and communication installations are facing challenges due to rising sea levels, diminishing sea ice and thawing permafrost. This has damaged essential infrastructure such as runways and seawalls that are estimated to cost $25 million USD to repair.[68]

Flooding from torrential rains led to $64 million USD in damages to 160 U.S. Army facilities in the southwest United States.[69] In 2018, Marine Corps Base Camp Lejeune, Marine Corps Air Station Cherry Point, and

Marine Corps Air Station New River, all located in North Carolina, suffered heavy damage from Hurricane Florence, with recovery costs at approximately $3.6 billion USD.[70] Camp Lejeune in particular is vital for U.S. national security, as it hosts the largest concentration of Marines in the world.[71]

*Extreme Hot Temperatures*

Extreme hot temperatures are currently increasing in frequency, leading to permafrost thaw and seasonal weather shifts. In the Middle East, flight operations during the hot summer season are affected by melting asphalt on aircraft runways.[72] According to a joint report by *Inside Climate News* and NBC News, high temperatures will jeopardize the health of U.S. military servicemembers and reduce training and operations. In 2018, 2,792 cases of heat exhaustion were reported, an increase of almost 60 percent during the preceding decade. As Africa and the Middle East become hotter, the higher temperatures there could disrupt U.S. military operations.[73] Aircraft performance is affected by a loss of payload capacity, range, and loiter time over enemy territory.[74] Helicopter lift and payload capacity is also affected due to reduced air density.

Temperatures at Al Dhafra Air Base in the United Arab Emirates, which hosts Lockheed Martin F-22 Raptor fighters and the Joint Air Warfare Center, can reach 125 degrees Fahrenheit. High summer temperatures at Ali Al Salem Air Base in Kuwait have shut down some civilian aircraft electronic systems and regularly grounded U.S. Air Force flights. Heat affects the engine starts of newer bomber aircraft and threatens the structural integrity of strategic heavy bombers and unmanned aerial vehicles (UAV).[75] During

Operation Iraqi Freedom, the United States-led invasion of Iraq in 2003, weather delayed maintenance on Boeing E-3 Sentry Airborne Warning and Control System (AWACS) aircraft, as heat kept maintenance personnel off the radar domes.[76]

*Sandstorms*

In the Middle East, sandstorms, or *haboobs*, frequently disrupt ground and air operations. In 1979, a dust storm contributed to the failure of Operation Eagle Claw, a U.S. military attempt to rescue hostages begin held in Iran. Of the eight U.S. Army helicopters participating in the operation, one was grounded after running into a dust storm, another returned to its aircraft carrier, and a third was damaged. One helicopter collided with a transport aircraft, bursting into flames and killing eight U.S. military personnel. Sand caused the malfunctioning of hydraulic systems, electrical problems, and disabled flight instruments.[77] In areas of low visibility, pilots could neither see the ground from as low as 75 feet, nor could they see the other aircraft. The operation's failure led to the establishment of the U.S. Special Operations Command, the Joint Special Operations Command, and the Air Force Special Operations Command.

During the Gulf War in 1990–91, sandstorms damaged equipment and delayed operations.[78] Nearly one-half of Coalition air sorties were affected by weather. Just 17 of 31 days were free of low-level clouds or sandstorms. The first 19 percent of strikes by Lockheed F-117 Nighthawk attack aircraft on the Iraqi capital of Baghdad were affected as the missiles missed their targets, while Tomahawk cruise missiles required a lengthy targeting process and could not be retargeted after launch.[79] The abrasive

effect of fine sand damaged helicopter engines and rotor blades.[80] Later, during Operation Iraqi Freedom in 2003, U.S. operations were stalled for three days due to a massive sandstorm.[81]

*Heavy Clouds and Precipitation*

Thunderstorms cause advanced aircraft to crash due to turbulence, icing, low visibility, wind shear, and microbursts. Rain, winds, and clouds can damage an aircraft just as easily as enemy missiles and aircraft.[82] During World War II, weather hampered Allied air operations in Burma as rains inundated forward airfields during the rainy seasons in 1943 and 1944.[83] During the Korean War, the air superiority of the United Nations (UN) was nullified as the North Korean Army launched ground assaults during low-visibility weather conditions. During Operation Urgent Fury, the U.S. invasion of Grenada in 1983, storms delayed the insertion of helicopter-borne units while an aircraft crashed and four U.S. Navy SEALs (Sea, Air, and Land) were lost at sea.

Precipitation floods airports, weakens radar signals, impacts flight safety, hampers reconnaissance, damages stealth aircraft, affects bombing accuracy and battle damage assessment, interferes with laser-guided bombs, and balances the temperatures of objects and their surroundings, thereby limiting use of infrared systems. Numerous aircraft in the U.S. arsenal today are especially vulnerable to precipitation, including the Boeing E-3 Sentry AWACS, the General Atomics MQ-1 Predator UAV, the General Atomics MQ-9 Reaper UAV, the Sikorsky HH-60 Pave Hawk helicopter, the Sikorsky MH-53 Pave Low helicopter, the Boeing KC-135 Stratotanker aerial refueling and transport aircraft, and the McDonnell Douglas KC-10 Extender

aerial refueling and transport aircraft. In September 2002, a Predator UAV flying over Southwest Asia entered a cloud, lost communication with its controller, and crashed.[84]

## Recommendations

The losses experienced by the U.S. Air Force from extreme weather events demonstrate the U.S. Marine Corp's similar vulnerability to climate change. The recommendations that follow enable the Marine Corps to develop and disseminate information about climate change and predict and monitor the weather. These recommendations will enhance the capability of the Marine Corps to address the critical issues related to climate change and weather events.

### *Marine Corps Base and Facility Design*

A comprehensive approach will be required to ensure that the Marine Corps' base infrastructure is prepared for a changing climate. The activities begun by the Air Force demonstrate the practical steps that can be implemented by the Marine Corps at its installations and bases that are affected by rising sea levels, higher storm surges, riverine flooding, and other consequences of climate change.

The Air Force is currently incorporating mitigation plans in its operations and infrastructure projects. Langley Air Force Base collaborated with the city of Hampton, Virginia, to study the effects of sea level rise. All new infrastructure will now be constructed at a minimum height of 10.5 feet above sea level.[85] A seawall has been constructed, critical infrastructure such as electrical supply protected, electronic equipment relocated from

ground level to higher elevations, and a floodwater pumping station installed.[86] A flood visualization tool has been deployed to better understand the impact of flooding on base.[87] The U.S. Army's Fort Irwin National Training Center in California and the U.S. Army Corps of Engineers have developed a plan to improve stormwater drainage in response to severe flash flooding.[88]

The Air Force has surpassed the Unified Facilities Criteria (UFC) minimum design standards in rebuilding Tyndall Air Force Base.[89] The UFC system, which is prescribed by the Department of Defense Standard Practice *United Facilities Criteria, Facilities Criteria and Unified Facilities Guide Specifications*, MIL-STD 3007, provides technical guidance, planning, design, construction, sustainment, restoration, and modernization of military infrastructure criteria in accordance with Department of Defense Directive 4270.5, *Military Construction*.[90] The reconstruction of Tyndall Air Force Base merged the Florida Building Code for High Velocity Hurricane Zone requirements of 165 miles per hour since the maximum wind speed of Hurricane Michael reached 161 miles per hour.[91] Patrick Space Force Base in Florida also enforces the Florida Building Code's hurricane requirements and has completed floor elevations for all new constructions.[92]

The Marine Corps should include weather disruptions in installation master planning, natural resource planning, and design and construction standards.[93] Model impact analysis can be conducted at site-specific critical bases and surrounding communities that are likely to experience extreme weather events.[94] The Army Corps of Engineers and Marine Corps should update the UFC standard on installation master planning to include extreme weather effects on vulnerable installations. The Marine Corps can leverage

the Army Corps of Engineers' sea level rise vulnerability assessment of projects and the flood risk reduction standard.[95]

The Marine Corps can also incorporate catastrophic weather vulnerability ratings in its critical infrastructure protection plans and facilities projects planning.[96] It can include the DOD baseline vulnerability assessment survey of more than 7,000 U.S. military bases and facilities.[97] This will assist the Marine Corps in conducting in-depth assessments of likely effects of climate change on worldwide missions.

Critical systems such as information technology infrastructure, fuel tanks and supplies, and heating, ventilation, and air conditioning (HVAC) systems at U.S. military bases should be located at higher levels. Security systems such as bollards and the underground engineering systems of gate boom barrier should be protected from flooding. Elevated roads and storm surge barriers will make vulnerable bases more easily accessible. Aging stormwater infrastructure must be replaced by modern engineering systems. The Marine Corps' coastal bases can integrate nature-based solutions to reduce coastal erosion by expanding wetland ecosystems and restoring mangroves and submerged vegetation.[98] Investing in technologies such as renewable energy that mitigate climate change and offer mission access during extreme weather events remains crucial.

As the U.S. military expands to the Arctic region, the Marine Corps can gain from the U.S. Army's Cold Regions Research and Engineering Laboratory in Hanover, New Hampshire. The Army has a Permafrost Tunnel Research Facility in Alaska that conducts research on permafrost terrains for engineering and military planning.[99] A team including Marine Corps and

other U.S. military leadership can also work with Congress to increase funding for vulnerable bases.

*Simulations and Wargaming*

Marine Corps University (MCU) in Quantico, Virginia, can integrate climate risk analysis in wargaming modeling, scenario building, and simulations.[100] The university can also develop climate risk assessment and weather simulation tools that use data from past weather events and future climate change projections to provide high-level impact assessments on critical infrastructure and weapon systems. The results of these assessments can be incorporated into the construction plans of vital domestic and overseas installations and operational activities. Scenario planning can project sea level rise, storm surge, precipitation, and flooding interactions.[101] Finally, MCU can incorporate the Coastal Assessment Regional Scenario Working Group database, which provides regional sea level scenarios at 1,774 DOD sites worldwide for the years 2035, 2065, and 2100.[102]

*Cooperation with Partners*

The Marine Corps should collaborate with civilian agencies and international academic and scientific organizations that specialize in the field of climate change.[103] Climate projections from the U.S. Global Change Research Program, the National Climate Assessment, and the National Academy of Sciences can be incorporated into base construction designs. Marine Corps engineers can work with scientists to better understand future climate extremes according to the American Society of Civil Engineers. The Marine Corps can also collaborate with private-sector associations such as the

National Association of Flood and Stormwater Management Agencies, the Association of State Floodplain Managers, and the Natural Hazards Research and Applications Information Center to protect lives, bases, and the economy. Marine Corps plans can include cooperation with security partners on the continuous supply of essential goods and services during degraded conditions.[104]

As a result of climate change, Arctic ice is melting, which leads to an opening of sea lines of communications in the region. Military infrastructure such as air bases and ports in the Arctic could be flooded due to the resultant sea level rise. Heavy military equipment can be deployed in the region due to the reduced snow. Therefore, the Marine Corps and Scandinavian nations could plan Arctic war games that include the impact of weather on logistics. In the Indo-Pacific region, typhoons and flooding are perennial events that could lead to civil disturbances caused by climate-related food and drinking water shortages.[105] Consequently, the Marine Corps could include mitigation measures for climate-related social unrest in wargaming exercises with nations such as the Philippines and Indonesia. Finally, the Marine Corps could capitalize on the capabilities of nongovernmental organizations in observing regional weather patterns and events and integrate the results into a future system.

*A Whole-of-Government Approach*

The Marine Corps should form new partnerships and expand existing climate agreements with federal, state, and local agencies to develop a whole-of-government approach to a challenge that reaches across portfolios and jurisdictions.[106] The Marine Corps can engage with civilian emergency

management agencies such as the Federal Emergency Management Agency (FEMA) for the integration of preparedness, response, recovery, and mitigation activities. A Marine Corps-led climate security advisory group could be established to advise and support future climate risk analyses.[107]. An annual update on the progress could be provided by the various civilian departments and the U.S. military to DOD leadership.[108]

*Education*

The Marine Corps should consider incorporating climate change in its current education, doctrine, and training programs. A course on climate security could be included in MCU's professional military education continuum program. The curriculum should include reports and studies from the defense, scientific, and academic communities.[109] A course exploring lessons learned and case studies involving the effects of weather on warfare should be introduced at the Lejeune Leadership Institute on campus. These educational programs can apprise the public, civilian leaders and military officers, and international stakeholders regarding climate change policies, strategies, and activities.

The School of Advanced Warfighting at MCU could offer courses that deal with disaster planning, emergency management, and the inclusion of weather during logistical planning. A standard review process could be implemented that includes assessing operations and logistics to include risk assessment, mitigation, connectivity, and redundancy.[110] This process should establish a continuity of operations plans so that missions can continue even if individual sites are impacted; ensure communication networks are operational; and launch combined training for the smooth

interoperability of the military and civilian staff during an emergency response.[111]

Finally, the Center for Regional and Security Studies at MCU can develop tactics, techniques, and procedures for weather-related events such as hurricanes, earthquakes, and flooding. The center can also integrate weather-related events according to geographic commands in wargaming workshops.

**Conclusion**

History has shown that misjudging climate change and weather events can lead military forces to defeat. Conversely, a sophisticated understanding of the impact of weather on warfare provides discernable advantages for a military's overall efforts in mitigating the effects of climate change. The capacity to interpret the impact of climate change and weather is more vital than ever today, given that climate change will alter the physical, strategic, and tactical operating environment in future war.[112]

Weather forecasting becomes increasingly significant as the Marine Corps and the rest of the U.S. military operates globally.[113] Mission success will depend on planning that accounts for weather-related complexities and contingencies.[114] Future risks to the Marine Corps' strategies, capabilities, equipment, and partners will increase, and without concerted efforts the challenges faced will be difficult to manage.[115] Crises exacerbated by climate change will increase demand on Marine Corps operations. A climate-ready military force is one that can fight and win around the globe, while anticipating, preparing for, recovering from, and adapting to the evolving climate and security future. Military leaders need to factor in regional and

local weather when planning military operations, or else weather will have an outsized effect on the outcome of those operations.

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