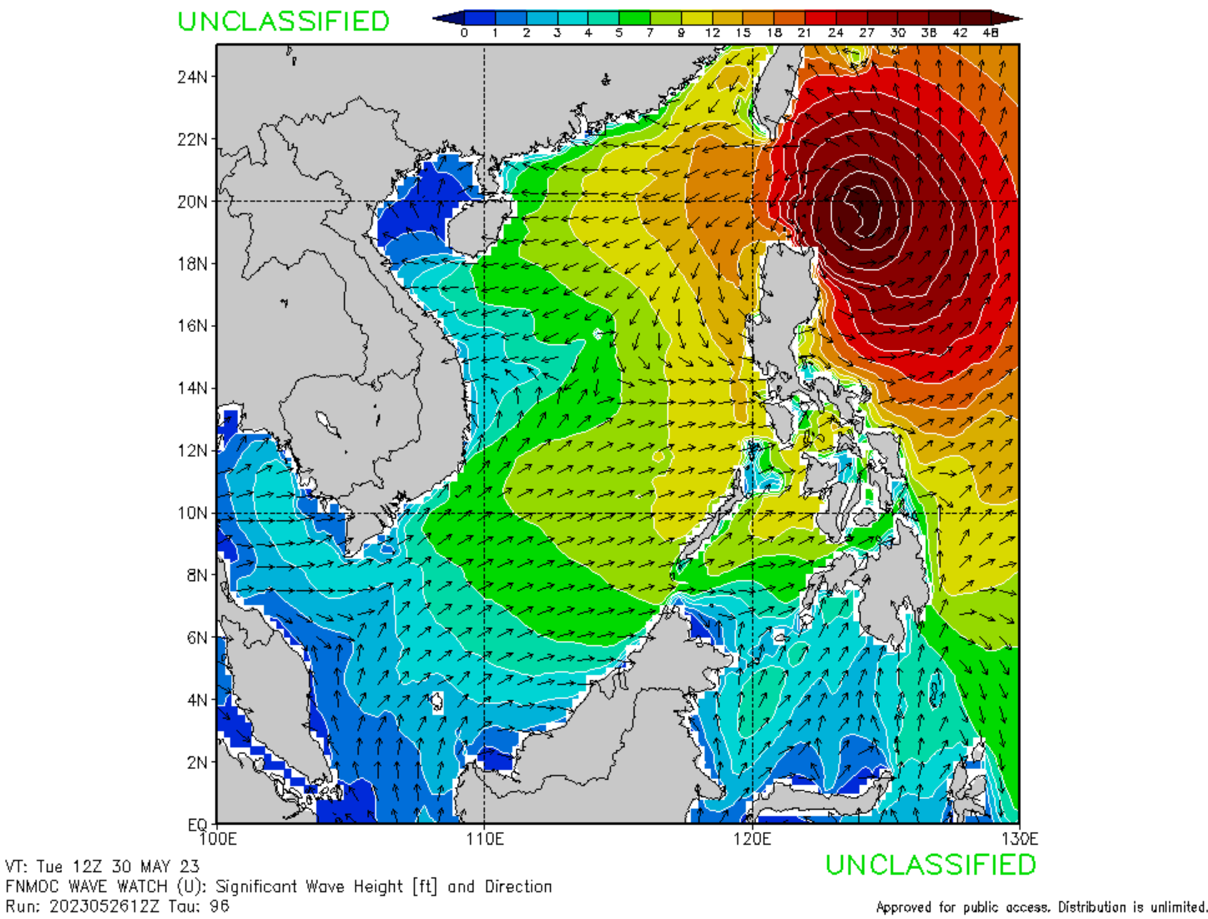
Impact of Climate Change on Naval & Marine Corps Operations



Model of Wave height in S China Sea (.25 deg). Fleet Numerical Meteorology and Oceanography Center. *(https://www.fnmoc.navy.mil/wxmap_cgi/cgi-bin/wxmap_single.cgi?area=ww3_scs&dtg=2023052612&prod=sgwvht&tau=096&set=SeaState)*

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Contents

Introduction

Since recognizing climate change as a threat to military operations in 2010, the Department of Defense (DOD) has continued to recognize the relevance and increasing impacts of climate change to national security.[1] Recent U.S. Executive Orders require the DOD to take climate change into account in armed forces operations.[2,3] In 2021, the DOD released the Climate Adaptation Plan, which identifies specific lines of effort that emphasize the requirements needed to combat and prepare for climate change within the branch services, including the focus area for Line of Effort two of assessing "current and future equipment" to "train and equip a climate-ready force."[4] Each service also has identified various pathways, implementing action, and climate adaptation plans.[5] The Department of the Navy (DON) issued a Climate Strategy, *Climate Action 2030*, that aims to strategically tackle threats imposed by climate change to the DON forces.[6] For the U.S. Naval forces, the range of operations that may be impacted includes critical assets utilized in the fleet by both the Navy and the Marine Corps; this includes Naval ships, aircraft, submarines, expeditionary forces, and installations. Some impacts expected in each combatant command are shown in Figure 1 from the DOD Climate Risk Analysis, along with some cross-cutting, cascading and/or global impacts.[7]

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[1] Department of Defense. (2010). *Quadrennial Defense Review Report*. https://dod.defense.gov/Portals/1/features/defenseReviews/QDR/QDR_as_of_29JAN10_1600.pdf

[2] Exec. Order No. 14008, 86 FR 7619 (2021). https://www.whitehouse.gov/briefing-room/presidential-actions/2021/01/27/executive-order-on-tackling-the-climate-crisis-at-home-and-abroad/

[3] Exec. Order No. 14057, 86 FR 70935 (2021). https://www.whitehouse.gov/briefing-room/presidential-actions/2021/12/08/executive-order-on-catalyzing-clean-energy-industries-and-jobs-through-federal-sustainability/

[4] Department of Defense. (2021). *Department of Defense Climate Adaptation Plan*. https://www.sustainability.gov/pdfs/dod-2021-cap.pdf

[5] Department of the Army. (2022). *United States Army Climate Strategy*. https://www.army.mil/e2/downloads/rv7/about/2022_army_climate_strategy.pdf; Department of the Army (2022). *Army Climate Strategy Implementation Plan*. https://www.army.mil/e2/downloads/rv7/about/2022_Army_Climate_Strategy_Implementation_Plan_FY23-FY27.pdf; Department of the Air Force. (2022). *Air Force Climate Action Plan*. https://www.safie.hq.af.mil/Portals/78/documents/Climate/DAF%20Climate%20Action%20Plan.pdf?ver=YcQAZsGM_Xom3DkNP_fL3g%3d%3d; Department of the Air Force. (2023). *Air Force Climate Campaign Plan.* https://www.af.mil/Portals/1/documents/2023SAF/DAF_Climate_Campaign_Plan.pdf

[6] Department of the Navy. (2022). *Department of the Navy Climate Action 2030.* https://www.navy.mil/Portals/1/Documents/Department%20of%20the%20Navy%20Climate%20Action%202030.pdf?ver=ScwuxX5mGr9jXT1ewRvlxg%3d%3d&timestamp=1653339650456

[7] Department of Defense. (2021). *Department of Defense Climate Risk Analysis*. https://media.defense.gov/2021/Oct/21/2002877353/-1/-1/0/DOD-CLIMATE-RISK-ANALYSIS-FINAL.PDF

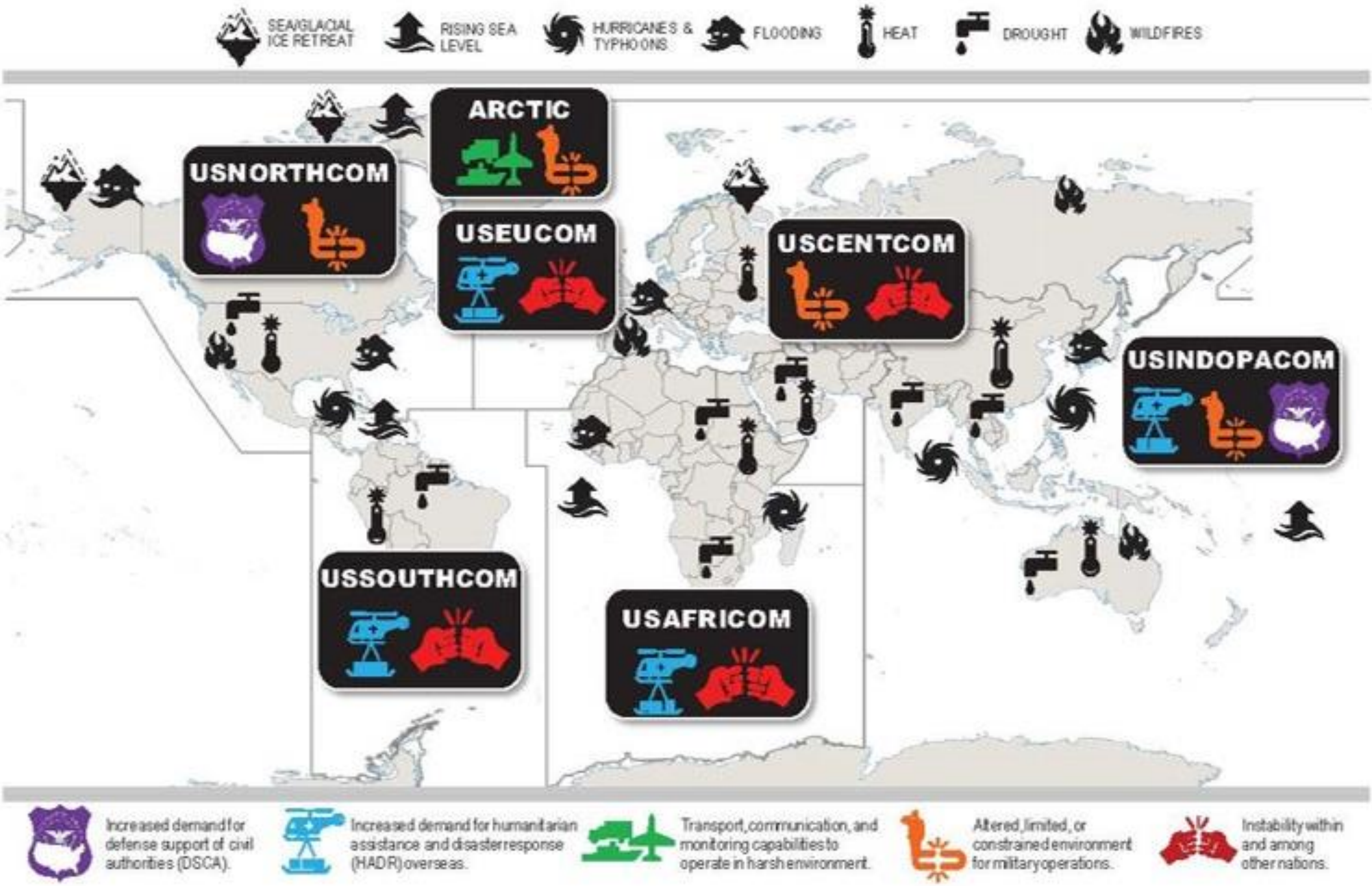

Figure 1: Representative Climate Change Hazards and Potential Impacts on DOD Global Missions

A persistent challenge faced by the DON is accurately identifying and understanding the true impacts of climate change on Naval and Marine Corps operations; the Navy has a history of efforts to realize the impacts, dating back to the 1950s.[8] Many climate change impacts are predicted to reduce Naval capabilities while some impacts will be benign, and others may even be beneficial to operations. Understanding, projecting, and predicting climate change impacts are not only important for strategic and operational planning, but also for tactical planning. Other countries, such as France, have formally recognized the need for climate adaptation in their militaries and have set forth efforts to integrate climate change impacts and preparedness into their respective force structures.[9] The UK House of Commons recently released a report, entitled *Defense and Climate Change*, noting that "Defence can do much more to measure and reduce its carbon emissions — without eroding military capability. The Armed Forces, defence acquisition and the defence estate — both at home and abroad — will also need to adapt to respond to the impacts of climate change over the coming decades, with consequences for geostrategy, defence readiness, resilience and the effective delivery of military effect."[10] To assist in this adaptation, the availability of intergovernmental climatology data and analysis is ever increasing.[11] Harnessing these tools can assist the DON in better understanding what is required to meet its operational mission in a changing climate and environment and increase its resilience in the face of these impacts.

Background

Approach

The research team conducted an extensive literature review (Appendix A) to catalogue existing resources that identify how climate change may impact Naval systems. The literature collected includes reports and studies both internal and external to the Naval Postgraduate School (NPS) and included both governmental and non-governmental institutions. The review was aimed at producing search results that could show impacts on systems, platforms, operational tempo and other potentially relevant operations. Along with climatological key words, other key words included "environmental changes" and "impacts associated with climate changes." The initial findings of the literature review identified that there are only a few studies that capture climatological changes and impacts associated with Naval operations; those that do exist focus on the Arctic regions but offer little operational context. The climate research directory that was produced in the literature review remains a key element in identifying knowledge gaps, target research, and analysis priorities.

Much of the focus of existing work has captured climate impacts on strategic capabilities in the armed forces, as climate change acts as a threat multiplier and continues to influence and exacerbate conflict around the world. Some studies also assessed the geopolitical implications of climate change on security, particularly in the Arctic regions, but, again, without operational context. Of the studies that focused on specific environmental implications, most of the work focused on Naval infrastructure. Identifying more complete areas of study along with key gaps in research helped build the initial framework for research which was constructed to catalogue the various aspects in which a changing

[8] Crawford, N. (2023, April 17). The US Navy and climate change. *MRonline.* https://mronline.org/2023/04/17/the-u-s-navy-and-climate-change/#ednref_1
[9] Ministere Des Armees. (2022). *Climate & Defence Strategy*. https://www.defense.gouv.fr/sites/default/files/ministere-armees/Presentation%20Climate%20ans%20defence%20strategy.pdf
[10] United Kingdom House of Commons. (2023). *Defence and Climate Change.* https://committees.parliament.uk/publications/41129/documents/200843/default/
[11] Intergovernmental Panel on Climate Change. (2023). *IPCC Sixth Assessment Report (AR6) Synthesis Report.* https://www.ipcc.ch/report/ar6/syr/downloads/report/IPCC_AR6_SYR_LongerReport.pdf

climate may impact Naval platforms, systems, operations, Areas of Responsibility (AORs), and warfare areas. This research aims to focus on the Naval capabilities that may be impacted by climate change and inform stakeholders of the platforms investigated for potential risks and future adaptation needs. This study is also aligned with the Chairman of the Joint Chiefs of Staff Instruction directive that was issued in March 2023 that guides Meteorological and Oceanographic capabilities in support of the Combatant Commanders' plans, training, and exercises. Under this guidance, the Chief of Naval Operations is delegated the additional responsibility for "Climate monitoring, analysis, and prediction capabilities for the atmosphere and ocean in support of maritime operations and other domains as appropriate."[12]

Intergovernmental Panel on Climate Change Projections

The assessment of climate impacts to naval operations required review and analysis of historical and projected changes to the operating environment, as well as the factors affecting those changes. This study specifically considered operations in the first island chain region of the INDOPACOM AOR. Many of the operations conducted in this area are limited by climatic environmental drivers such as temperature, wind speed, precipitation, and salinity which determine ancillary effects like sea state, visibility, underwater sound speed, and currents.

The most comprehensive source of global climate change analysis comes from the United Nations' Intergovernmental Panel for Climate Change (IPCC). The IPCC collaborates across 195 member countries, including the United States and China, to assess shared climate literature and provide governments at all levels with information to develop climate policies and support international climate change negotiations. In 2023, the IPCC released the Synthesis Report of the Sixth Assessment Report (AR6), summarizing findings from three IPCC Working Group Reports and three Special Reports (published since 2018). Each working group report and special report builds on shared data and findings while providing additional focus on specific areas as follows:

- Working Group Report I– AR6 Climate Change 2021: The Physical Science Basis;
- Working Group Report II – AR6 Climate Change 2022: Impacts, Adaptation and Vulnerability;
- Working Group Report III – AR6 Climate Change 2022: Mitigation of Climate Change;
- Special Report: Global Warming of 1.5°C (2018);
- Special Report: Climate Change and Land (2019); and,
- Special Report: The Ocean and Cryosphere in a Changing Climate (2019).

The Synthesis Report provides summary findings pertinent to the larger audience, drawing correlation between anthropogenic greenhouse gas (GHG) emissions and climate impacts and describing mitigation strategies. The AR6 report I, *The Physical Science Basis*, offers details on impacts to the ocean and specific regions, including East Asia and the East China Sea.[13]

The reports cite various peer-reviewed data sources and models for projections, but the primary synthesis of those models was performed using the Coupled Model Intercomparison Project Phase 6 (CMIP6) from the World Climate Research Program. Most of the IPCC reports use the period 1850–1900 as a baseline. This timeframe represents the earliest period of sufficient globally complete observations to

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[12] Chairman of the Joint Chiefs of Staff. (2023). *Meteorological and Oceanographic Support*.
[13] The report does summarize the impacts of natural drivers (volcanic and solar primarily) as having minimal impact of ±0.1°C on global surface temperatures.

estimate global surface temperature and is used as an approximation for pre-industrial conditions. The following historical global averages are reported.[14]

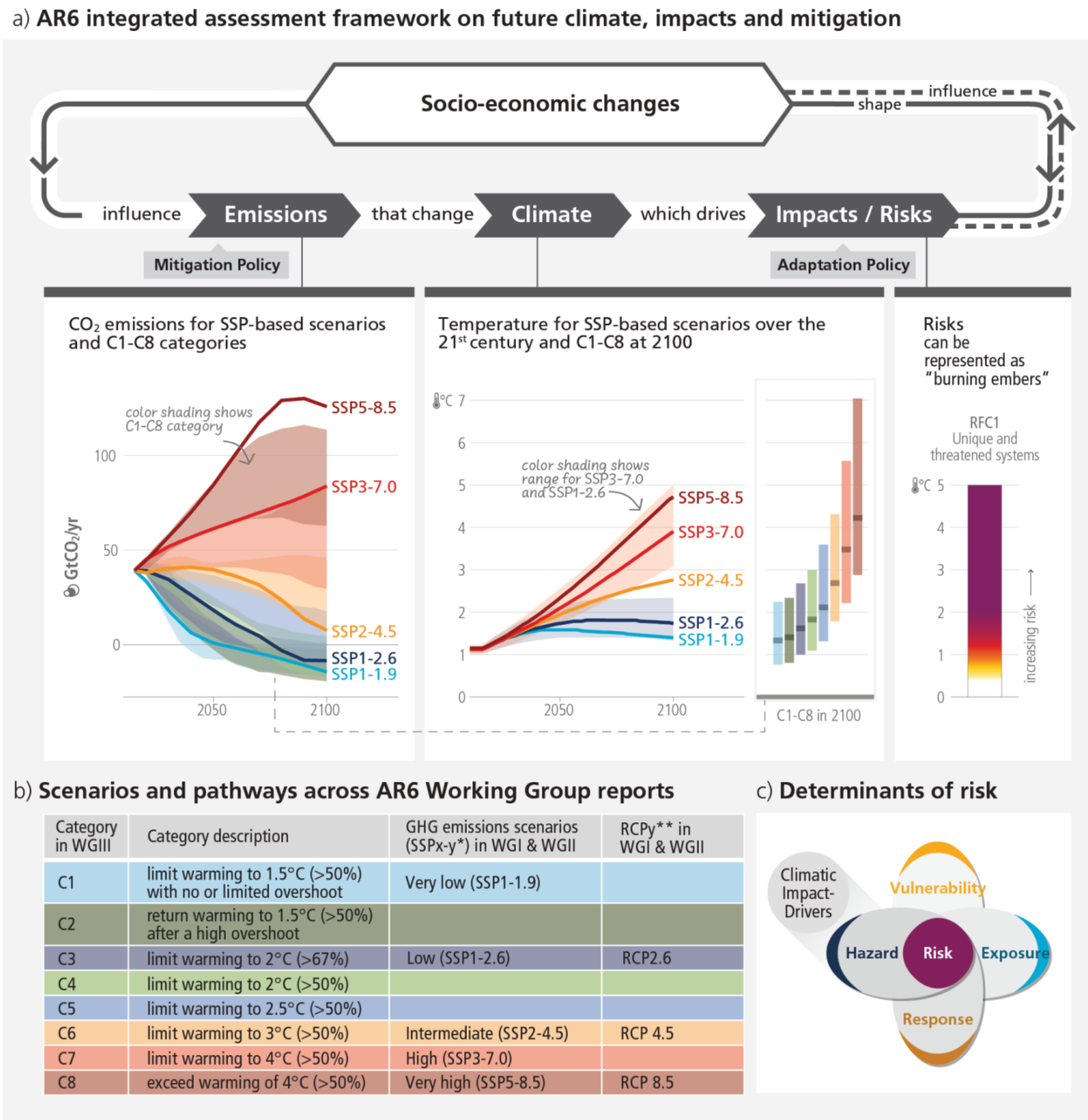
- The average global surface temperatures in 2011-2020 were 1.1°C above the baseline period with larger increases over land (1.59 °C) than over the ocean (0.88°C).
- Ocean warming accounted for 91% of the heating in the climate system, with land warming, ice loss and atmospheric warming accounting for about 5%, 3% and 1%, respectively.
- Global mean sea level increased by 0.20 m between 1901 and 2018. The average rate of sea level rise was 1.3 mm per year between 1901 and 1971, increasing to 1.9 mm per year between 1971 and 2006, and further increasing to 3.7 mm per year between 2006 and 2018.
- Hot extremes (including heatwaves) have become more frequent and intense across most land regions since the 1950s, while cold extremes have become less frequent and less severe. Marine heatwaves have approximately doubled in frequency since the 1980s.
- The frequency and intensity of heavy precipitation events have increased since the 1950s over most land areas, for which observational data are sufficient for trend analysis.
- Salinity contrasts have increased since the 1950s, near the ocean surface and in the subsurface with high-salinity regions becoming more saline and low-salinity regions becoming fresher. It is highly likely that the Pacific and the Southern Oceans have freshened and that the Atlantic has become more saline.

The IPCC's projection of future global warming and associated impacts uses five pathways to project the amount of warming associated with levels of GHG emissions. These are referred to as Shared Socio-economic Pathways (SSP1 to SSP5). Figure 2 shows the relationship between CO_2 emissions and warming. The IPCC reports that current modelled pathways representing implemented policies at the end of 2020 would lead to global warming of 3.2°C by 2100. The Paris Agreement and other coordinated approaches to limit warming have set targets to reduce emissions to limit warming to 1.5°C or 2°C in the midterm; however, global efforts and commitments are not currently on track to hit those targets. Regardless, global warming will continue to increase in the near term in nearly all modeled pathways. The projected impacts follow:[15]

- With every additional increment of global warming, changes in extremes continue to become larger. Additional warming will lead to more frequent and intense marine heatwaves and is projected to further amplify permafrost thawing and loss of seasonal snow cover, glaciers, land ice and Arctic sea ice.
- Continued global warming is projected to further intensify the global water cycle, including its variability, global monsoon precipitation, and very wet and very dry weather and climate events and seasons.
- The portion of global land experiencing detectable changes in seasonal mean precipitation is projected to increase with more variable precipitation and surface water flows over most land regions within seasons and from year to year.
- Ocean acidification, ocean deoxygenation, and global mean sea level will continue to increase in the 21st century. However, increased acidification and deoxygenation are expected primarily in the global open ocean.

[14] Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.
[15] Romero, H. Lee and J. (2023). *Climate Change 2023: Synthesis Report*. IPCC.

- A general pattern of fresh ocean regions getting fresher and salty ocean regions getting saltier will continue in the 21st century.



Category in WGIII	Category description	GHG emissions scenarios (SSPx-y*) in WGI & WGII	RCPy** in WGI & WGII
C1	limit warming to 1.5°C (>50%) with no or limited overshoot	Very low (SSP1-1.9)	
C2	return warming to 1.5°C (>50%) after a high overshoot		
C3	limit warming to 2°C (>67%)	Low (SSP1-2.6)	RCP2.6
C4	limit warming to 2°C (>50%)		
C5	limit warming to 2.5°C (>50%)		
C6	limit warming to 3°C (>50%)	Intermediate (SSP2-4.5)	RCP 4.5
C7	limit warming to 4°C (>50%)	High (SSP3-7.0)	
C8	exceed warming of 4°C (>50%)	Very high (SSP5-8.5)	RCP 8.5

Figure 2: IPCC Reported Scenarios and Warming Levels

Chapter 12 of the IPCC AR6, the *Physical Sciences Basis* report, includes a synthesis specific to a region around Taiwan – and refers to this region as East Asia. Climate change impacts to that region are summarized as follows.[16, 17]

- The major concerns in East Asia are associated particularly with droughts and floods, heat extremes, and tropical cyclones.
- Projections show continued warming over Asia in the future with contrasted regional patterns across the continent.
- Mean surface seawater temperature (SST) is projected to increase as shown in Figure 3.
- Extreme heat events are very likely to become more intense and/or more frequent in East Asia by the end of 21st century.
- Mean near-surface wind speeds are declining. Observations since the 1950s show a decrease approximately –0.1 metres/second per decade, as shown in Figure 4.
- Relative sea level rise is very likely to continue in the oceans around Asia.
- There have been frequent marine heatwaves (MHW) in the coastal oceans of Asia, connected to the increase between 0.25°C and 1°C in mean SST of the coastal oceans since 1982–1998. There is high confidence that MHWs will increase around most of Asia.
- Mean precipitation is likely to increase in most areas of northern, southern, and East Asia (Figure 5) **Error! Reference source not found.**in different scenarios, and monsoon circulation will also increase seasonal contrasts.

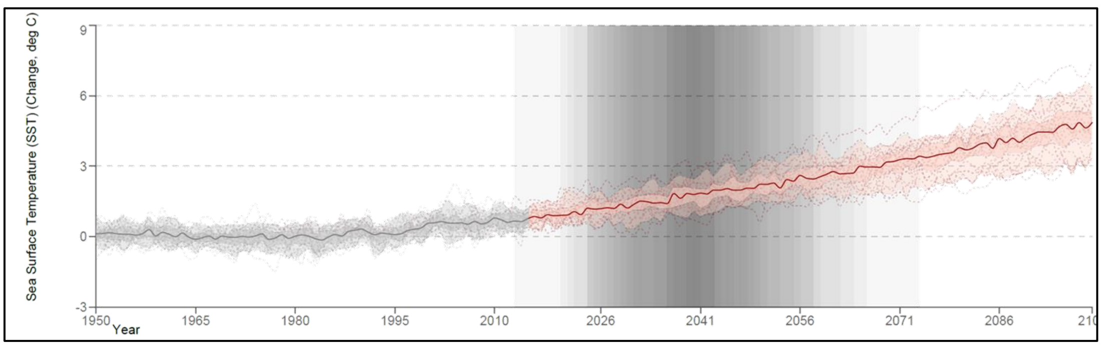


Figure 3: Sea Surface Temperature Change, projection if warming is limited to 2°C (East Asia)

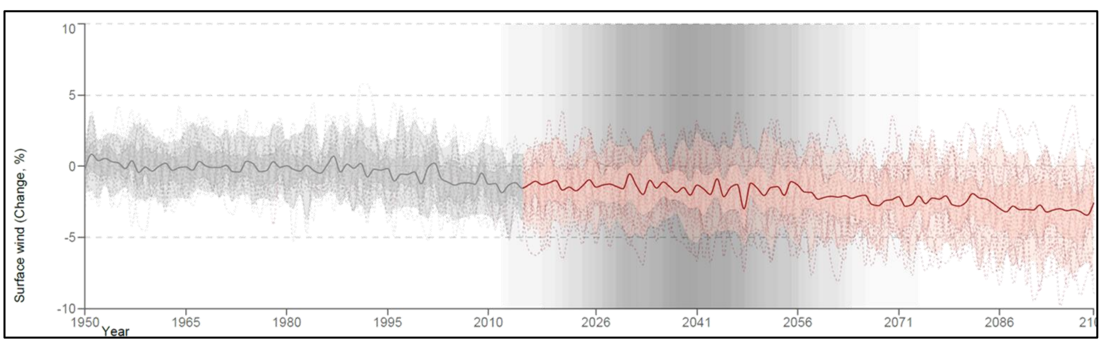


Figure 4: Change in Surface Wind Speed, projection if warming is limited to 2°C (East Asia) (Defense n.d.)

[16] Ranasinghe, R., A.C. Ruane, R. Vautard, N. Arnell, E. Coppola, F.A. Cruz, S. Dessai, A.S. Islam, M. Rahimi, D. Ruiz. (2021). *Climate Change 2021: The Physical Science Basis*. Cambridge University Press.
[17] Intergovernmental Panel on Climate Change. (2021). *WGI Interactive Atlas: Regional synthesis*. http://interactive-atlas.ipcc.ch/

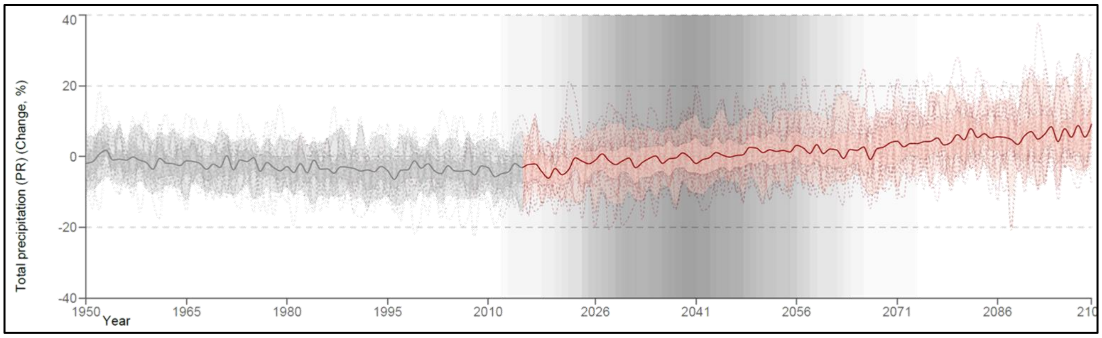


Figure 5: Total Precipitation Change, projection if warming is limited to 2°C (East Asia)

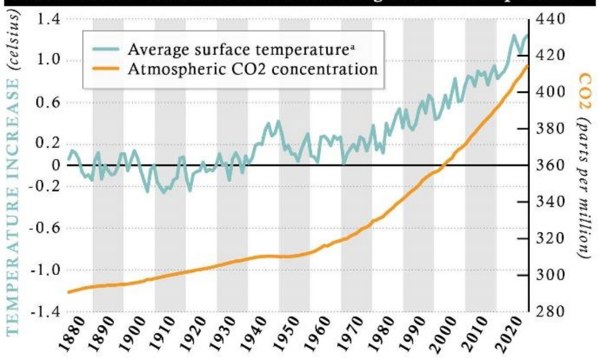
Examples of these intensified events are already occurring. A 2023 typhoon that hit Guam highlights how these weather events are being amplified by climate change and effect and stress military operations in the Pacific.[18] Typhoon Mawar was the strongest storm to hit the island in the last two decades, and caused extensive damage, loss of power, and personnel permanent changes were briefly paused to and from the military base. Cleanup of the base and island came with assistance from the Federal Emergency Management Agency as well as U.S Army Pacific and Task Force West aiding in the disaster relief efforts. While readiness was not affected, some planned exercises had to adjust following the typhoons impact.[19]

There are many effects of climate change that will have an impact to human security, both nationally and internationally, as indexed by the National Intelligence Council's estimate on *Climate Change and International Responses Increasing Challenges to US National Security Through 2040*.[20] All of the climate change effects listed below in Figure 6 have implications to security, such as increased heat, heavy precipitation & flooding, drought, sea level rise, and tropical cyclones.

[18] Roston, E. (2023, May 25). Guam Typhoon Highlights Climate Threat to U.S. Military in Pacific. https://www.japantimes.co.jp/news/2023/05/25/world/climate-change-threat-us-pacific-strategy/
[19] Mongilio, H. (2023, June 12). Guam Bases Continue Clean Up as Military Moves to Island Postponed. https://news.usni.org/2023/06/12/guam-bases-continue-clean-up-as-military-moves-to-island-postponed
[20] National Intelligence Council. (2021). *National Intelligence Estimate: Climate Change and International Responses Increasing Challenges to US National Security Through 2040*. https://www.dni.gov/files/ODNI/documents/assessments/NIE_Climate_Change_and_National_Security.pdf

Climate Change Effects and Impacts Intensifying as Greenhouse Gas Emissions and Temperatures Increase

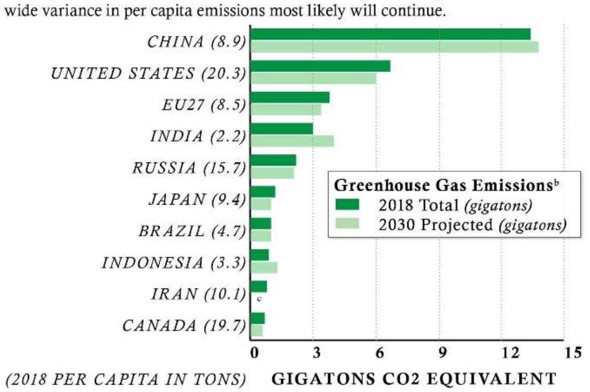
Global Rise in Carbon Dioxide and Average Surface Temperature



a. Compared to 1880-1900 average

Top 10 Current and Projected Greenhouse Gas Emitters

The top 10 emitters in 2018 accounted for about 70 percent of global emissions. The wide variance in per capita emissions most likely will continue.



b. Excluding land use change emissions.
c. We lack a 2030 projection for Iran.

Current and Projected Climate Change Effects and Impacts

Climate Change Effect	Current (at 1.1°C average warming)	1.5°C Warming	2°C Warming	Impacts to Human Security
Heat	5 percent of global population exposed to severe heat waves once in 20 years	14 percent of global population exposed to severe heat waves once in five years	37 percent of global population exposed to severe heat waves once in five years	More intense and frequent heat waves will reduce labor productivity, increase frequency and intensity of wildfires, undermine human health, and lead to loss of life
Heavy Precipitation and Flooding	25 percent of land with significant increase in once-in-a-century floods	17 percent increased frequency of precipitation extremes over land	37 percent increased frequency of precipitation extremes over land	Increased flooding will lead to economic losses, increased calls for humanitarian assistance, and loss of life
Drought	Observed increase in frequency and intensity of droughts in southern Europe, northern Africa, and Near East	Around 132 million more people exposed to severe droughts	Around 194 million more people exposed to severe droughts	More frequent, intense, and longer droughts will undermine food security in developing countries, cause more extreme wildfires, increase political instability, and drive migration
Sea Level Rise	8 to 9 inches higher with the rate of increase doubling in the last 30 years compared to the 20th century	Total projected rise of between 11 and 32 inches, with a median of 19 inches	Total projected rise of between 11 and 38 inches, with a median of 22 inches	Rising sea levels will increasingly imperil coastal cities and exacerbate storm surges that damage infrastructure and inundate water systems
Arctic Ice Melt	13 percent decline per decade of sea ice extent since 1979 90 percent decline of at least five year old thick ice	Probability of an ice-free summer—defined as less than 15 percent ice concentration—is one every 42 years	Probability of an ice-free summer—defined as less than 15 percent ice concentration—is one every five years	Accelerated melting of Arctic ice sheets will affect ocean circulation and salinity, threaten local ecosystems, and increase competition over resources and transit route access
Tropical Cyclones	Global annual average has remained level since 1980 but geographic distribution has shifted, with more cyclones in the North Atlantic and northern Indian Oceans	Additional 2.1 category-4 hurricanes per year, compared to 2018 Additional 1.2 category-5 hurricanes per year, compared to 2018	Additional 1.4 category-4 hurricanes per year, compared to 2018 Additional 1.2 category-5 hurricanes per year, compared to 2018	More frequent, destructive, and shifting tracks of cyclones will lead to trillions of dollars in economic losses in tropical zones, increase calls for humanitarian assistance, drive population displacement and migration, and lead to loss of life
Coral Reefs	33 percent threatened with loss	Projected long-term degradation of 70-90 percent	Projected long-term degradation of more than 99 percent	The disappearance of coral reefs will eliminate an ecosystem that serves 500 million people, impacting economic and food security
Biodiversity	50 percent of terrestrial mammals and 25 percent of birds already under threat are affected by climate change	8 percent of plants, 6 percent of insects, and 4 percent of vertebrates will lose at least half of their geographic range	16 percent of plants, 18 percent of insects, and 8 percent of vertebrates will lose at least half of their geographic range	Loss of species will increase human health risks and threaten food security

Figure 6: Example Effects of Climate Change Impacts to Human Security

Operations: Context for Use Case Scenario around Taiwan

This study focused on naval operations in the Taiwan region within the INDOPACOM AOR including Flight Operations, Surface Warfare, Undersea Warfare, and Expeditionary Warfare. The 2020 Tri-service Maritime Strategy describes the US Navy, US Marine Corps, and US Coast Guard commitments to ensure global maritime security with forward-deployed naval forces.[21] That strategy document also describes the maligned behavior and growing naval capabilities of the People's Republic of China (PRC) and describes the PRC as the most pressing, long-term strategic threat. The 2022 National Defense Strategy further prioritizes strategic competition with China, describing the PRC's "*coercive and increasingly aggressive endeavor to refashion the Indo-Pacific and international system,*" and as being the "*most comprehensive and serious challenge to U.S national security*."[22] Furthermore, under the Tri-Service Maritime Strategy, deterring aggression from PRC in the Indo-Pacific region is a top defense priority.[23]

The 2023 Annual Threat Assessment from the U.S. Office of the Director of National Intelligence describes the PRC's desire to unify with Taiwan and suggests the PRC will pressure Taiwan to unify and will react to increased U.S.-Taiwan engagement. That annual assessment, and the Tri-Service Maritime Strategy, both describe PRC's posturing for such a conflict with the U.S. and Allies to include a larger and more capable naval fleet and the world's largest missile force designed to strike U.S. and Allied forces in Guam and in the Far East with resources from ballistic missiles to maneuverable cruise and hypersonic missiles.[24]

It is clear from the Annual Threat Assessment, as well as Naval and DoD Strategy that near-term and future naval operations will likely remain focused on the PRC threat, and that Taiwan will be a central strategic and geopolitical priority. The sea-lanes around Taiwan, including the Taiwan Straits, South China Sea, and East China Sea will be key engagement zones within the INDOPACOM AOR.

The Tri-Service Maritime Strategy also describes capabilities key to naval operations in the contested environment of the Indo-Pacific. The following specific capabilities are described and form the basis for operations assessed in and around Taiwan as follows.

- We will protect the U.S. homeland and our Allies with ballistic missile defense assets and maintain continuous strategic deterrence against the use of weapons of mass destruction.
- We will leverage the concepts of Distributed Maritime Operations, Littoral Operations in a Contested Environment, and Expeditionary Advanced Base Operations to support Joint Force Commander objectives.
- We will destroy adversary forces by projecting power from attack submarines, fifth-generation aircraft, naval expeditionary forces, unmanned vehicles, and maritime raids.

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[21] U.S. Navy, U.S. Marine Corps, U.S. Coast Guard. (2020). *Advantage at Sea*. https://media.defense.gov/2020/Dec/16/2002553074/-1/-1/0/TRISERVICESTRATEGY.PDF

[22] U.S. Department of Defense. (2022). *The 2022 National Defense Strategy of the United States of America*. https://media.defense.gov/2022/Oct/27/2003103845/-1/-1/1/2022-NATIONAL-DEFENSE-STRATEGY-NPR-MDR.PDF

[23] U.S. Navy, U.S. Marine Corps, U.S. Coast Guard. (2020). *Advantage at Sea*. https://media.defense.gov/2020/Dec/16/2002553074/-1/-1/0/TRISERVICESTRATEGY.PDF

[24] U.S. Office of the Director of National Intelligence. (2023). *Annual Threat Assessment of the US Intelligence Community*. https://www.dni.gov/files/ODNI/documents/assessments/ATA-2023-Unclassified-Report.pdf

- Our seaborne forces will deliver devastating offensive strikes, surviving adversary counterattacks using coordinated jamming, maneuver, and defensive systems.
- Low-footprint and low-signature Marine Corps elements operating from the sea to the shore will use maneuver, cover, and concealment to employ lethal long-range precision fires.
- Combined volleys of networked munitions, coming from multiple axes of attack, will overpower adversary defenses.
- Resilience for protracted conflict, including communications, assured sustainment, survivable battle management networks, and reconstitution, will enable our forces to remain in the fight.
- Complementing our forces closest to the threat, Naval Service warships will exploit our control of the seas.
- Maneuverable strike forces—composed of multiple carrier strike groups, surface action groups, and expeditionary strike groups, and augmented by unmanned platforms— will launch overpowering air and missile attacks from unexpected directions.
- Our long-range systems and hypersonic weapons will provide global strike capabilities against targets ashore.
- Logistics and auxiliary ships will surge to establish refueling, rearming, resupply, revive, and repair points.[25]

Establishing resilience to climate impacts is essential to meeting these capabilities.

[25] U.S. Navy, U.S. Marine Corps, U.S. Coast Guard. (2020). *Advantage at Sea*. https://media.defense.gov/2020/Dec/16/2002553074/-1/-1/0/TRISERVICESTRATEGY.PDF

Case Study

INDOPACOM Targeted Region

Figure 7: INDOPACOM AOR [U.S. Indo-Pacific Command]

The INDOPACOM region as shown in Figure 7 was chosen by assessing the gathered feedback and research to analyze the effects the changing climate would have on specific operation types, platforms, and weapons systems in a specific geographic region. The area focuses on a high priority region within the first island chain of the Philippines Sea and Taiwan. Due to the classification of capability and limitation information from certain operations/platforms, some of the results are classified as SECRET and can be accessed in the classified report by request via SIPR.[26]

The first island chain serves as a strategic area for National Security. The National Intelligence Estimate also finds that this area is also extremely vulnerable to the effects of climate change. This group of islands could become more unstable with the increase in climate driven disasters, causing a loss in security for those countries as well as the U.S. due to the geopolitical strategy risks in the region. Given the Pacific Island nations' vulnerability and lack of adaptivity to climate change, China's interest in these islands has been questioned as the country continues to step in to offer help to other island nations while strategically gaining ground that impedes on sovereignty, and the encroaching proximity to the U.S. coastline. In addition to the threat of sea level rise and flooding, the islands and Pacific region in general also have the potential of facing a loss in biodiversity and fisheries collapse due to overfishing that could further the food insecurity of the region.

[26] Please e-mail POC Marina Lesse via SIPR to obtain a copy of the classified report: marina.i.lesse.civ@mail.smil.mil

NIC NATIONAL INTELLIGENCE COUNCIL

Climate Change in Select Highly Vulnerable Countries of Concern

The IC identified 11 countries and two regions of great concern from the threat of climate change. Building resilience in these countries and regions would probably be especially helpful in mitigating future risks to US interests. Two regional arcs also stand out because these groups of countries are clustered together, are relatively poor, and have little capacity to assist their neighbors.

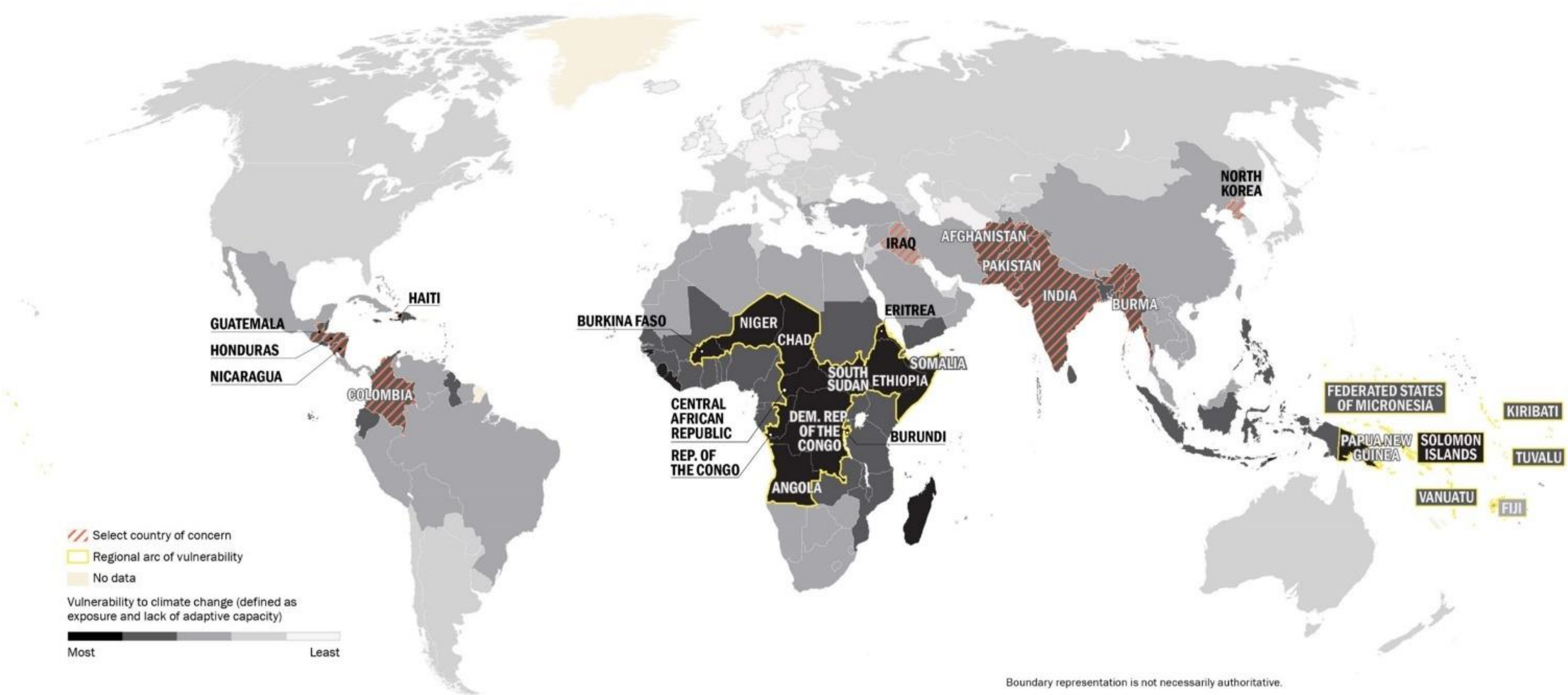

Figure 8: Climate Change in Select Highly Vulnerable Countries of Concern [National Intelligence Estimate on Climate Change]

Research Methods

Meteorology & Oceanography (METOC) capabilities and limitations ("caps & lims") documents were gathered to assist in the analysis of the priority platforms. These documents are frequently referenced for "go"/ "no-go" criteria based upon specific environmental factors and serve as guiding functions for decision makers.[27] This is especially important in understanding under what conditions it is both feasible and safe to operate in the given environment, as seen in Figure 9, where degradation to a specific platform or operation is considered. To coordinate with the priority platforms, both classified and unclassified caps & lims documents are referenced. These documents serve as a guiding predictor of operability paired with the climatological projection outputs.

Researchers partnered with a parallel study conducted by researchers at the Center for Naval Analyses (CNA) entitled *Climate Change Implications for Navy Operations, Platforms, and Systems: Setting a Research Agenda*. This joint research effort enabled a well-rounded approach of studying climate impacts on naval operations; while the NPS research team focused on a particular subregion, the CNA researchers focused on physics couplings of sensors and platforms impacted by climatic environmental drivers and a research gap analysis.[28] Other strategic partners offered feedback in workshops and consultations including the Center for Excellence in Disaster Management & Humanitarian Assistance (CFE-DMHA) Climate Change Impacts INDOPACOM program, the Joint Typhoon Warning Center, the US Pacific Fleet (PACFLT) Commander, and the INDOPACOM METOC community.[29]

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[27] Joint Chiefs of Staff. (2018). *Meteorological and Oceanographic Operations*. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_59.pdf

[28] Filadelfo, R., Ilachinski A. and Starcovic S.. (2023). *Climate Change Implications for Navy Operations, Platforms, and Systems: Setting a Research Agenda*.

[29] The METOC Officer who worked on this project (LCDR Jacobs) traveled to Hawaii as part of his Nimitz Research Group requirements and spoke directly with the Commander of PACFLT as well as his METOC colleagues, receiving valuable feedback and insight that shaped our case study focus area. The Nimitz Research Group is a group of students at NPS that was launched in 2022 by PACFLT and sits within the Naval Warfare Studies Institute. The group serves as an extension of PACFLT and leverages NPS student and faculty expertise to provide solutions for the PACFLT Commander.

METOC IMPACTS TO SELECTED OPERATIONS			
OPERATION	FAVORABLE (No Degradation) (GREEN)	MARGINAL (Some Degradation) (AMBER)	UNFAVORABLE (Significant Degradation) (RED)
ARFOR OPERATIONS			
BRIDGING	WIND < 10 KTS	WIND 10-34 KTS	WIND > 34 KTS
ARMOR GUN SIGHTS	VIS > 2000 m	VIS 1000-2000 m	VIS < 1000 m
TOW MISSILE	VIS > 3000 m	VIS 2000-3000 m	VIS < 2000 m
HELICOPTER (LIFT)	CIG > 500 FT	CIG 300-500 FT	CIG < 300 FT
(no specific airframe)	VIS > 1600 m	VIS 800-1600 m	VIS < 800 m
	NO ICG/TURBC	LGT OR MDT	SVR TURBC/ICG
		TURBC OR ICG	
HELICOPTER (ATTACK)	CIG > 2600 FT	CIG 1100-2600 FT	CIG < 1100 FT
(no specific airframe)	VIS > 4000 m	VIS 1000-4000 m	VIS < 1000 m
	WIND < 25 KTS	WIND 25-50 KTS	WIND > 40 KTS
			TEMP > 90F
	NO PRECIP	MDT PRECIP	HVY PRECIP
	NO Thunderstorms	FEW Thunderstorms	SCT Thunderstorms
HELLFIRE MISSILE	CIG > 2000 FT	CIG 800-2000 FT	CIG < 800 FT
	VIS > 5000 m	VIS 3000-5000 m	VIS < 3000 m
CLOSE AIR SUPPORT	CIG > 2000 FT	CIG 1000-2000 FT	CIG < 1000 FT
(For Army Planning Purposes)	VIS > 8000 m	VIS 3200-8000 m	VIS < 3200 m
AERIAL RECON	< 2/8 CLD COVER	2/8-4/8 CLD COVER	> 4/8 CLD COVER
	VIS > 8000 m	VIS 4800-8000 m	VIS < 4800 m
	Aerial Recon covers three levels — Strategic (above 25,000 ft), High (8,000 - 25,000 ft), and Low (below 3,000 ft). Cloud cover is for at or below flight (operating) level.		
GROUND RECCE	VIS > 3000 m	VIS 1000-3000 m	VIS < 1000 m
PARADROP	WIND < 13 KTS	WIND 13-18 KTS	WIND > 18 KTS
			CIG < 1000 FT
		LGT PRECIP	MDT/HVY PRECIP
	DA < 4000 FT	DA 4000-6900 FT	DA > 6900 FT
	(DA = Density Altitude)		
NBC OPERATIONS		WIND < 10 KTS	WIND > 30 KTS
			WIND CALM
			Wind From Enemy
	Stable Atmosphere	Neutral Stability	Unstable Atmosphere
	NO PRECIP	LIGHT PRECIP	MDT/HVY PRECIP
SMOKE		WIND 5-10 KTS	WIND < 5 KTS
			WIND > 19 KTS
			Wind From Enemy
			TEMP > 120 F
		MDT PRECIP	HVY PRECIP

Figure 9: METOC Impacts to Selected Operations[30]

[30] Joint Chiefs of Staff. (1999). *Joint Doctrine, Tactics, Techniques, and Procedures for Meteorological and Oceanographic Operations*. https://www.bits.de/NRANEU/others/jp-doctrine/jp3_59%2899%29.pdf

Parameters

The data analyzed utilizes weather data accessed through the Fleet Numerical Meteorology and Oceanography Center's (FNMOC) Advanced Climate Analysis and Forecasting tool (ACAF) as shown in Figure 10. Climatology data was requested and extracted for environmental factors that included the following:

- Surface Wind Speed
- Seas/Wave Height (Sea State)
- Swell (period)
- Sky Cover
- Sea Surface Temperature
- Air Temperature
- Relative Humidity
- Salinity
- Evaporation Duct Height
- Cloud Coverage Percentage
- Cloud Heights (Low, Medium, High)

Most of the available data was averaged between 1980 and 2008, plus or minus a few years depending on which factor was analyzed. For climatology, the ideal time range is at least 10 years between the current observations and what is used for historic data. Other environmental factors that would be ideally utilized include visibility, precipitation, sound speed profiling, and ocean currents. The data was downloaded and processed for three separate locations (North, Strait, South) within the designated area for the case study. This narrowed scope best showcases where Naval operations are likely to take place in the region. ACAF's available data included seasonal mean data as well as Frequency of Occurrence Threshold, which is the percentage of chance of a weather event exceeding a chosen value. The Frequency of Occurrence Thresholds were chosen based on the classified caps & lims documentation aggregated.

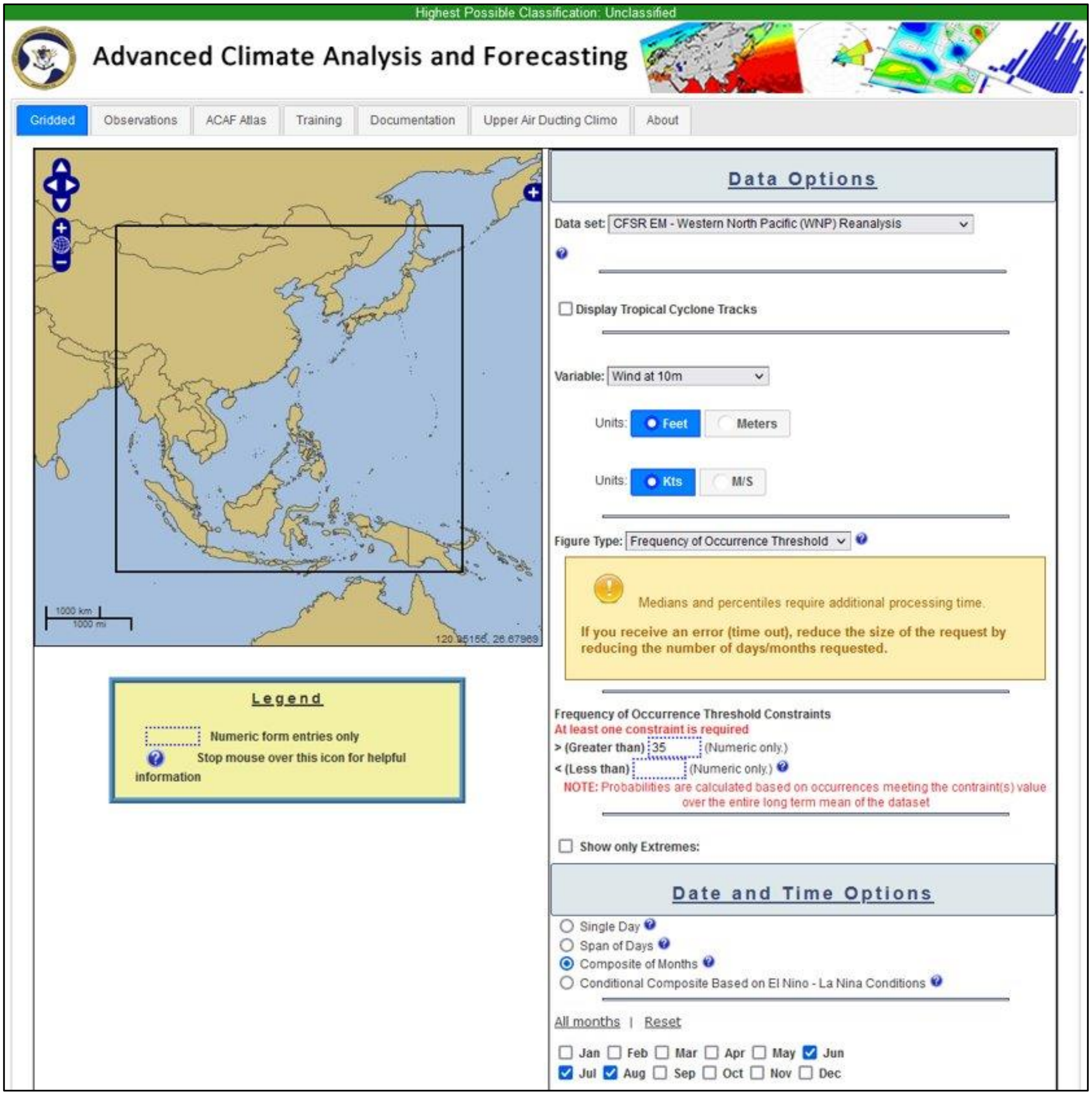

Figure 10: Example of FNMOC's ACAF platform for climatology data

The environmental parameters were chosen based on alignment with the CNA's research as well as interest in how the environmental parameters would affect operations in the given case study area. For example, multiple environmental factors affect flight operations such as surface wind speed and relative humidity. To capture an example of typical operations, platforms from each domain (underwater, surface, air capabilities) were utilized. These platforms include submarines, surface ships, expeditionary landing craft, and aircraft. Specifically, this includes (respectively):

- Attack submarines (SSN);

- Arleigh Burke-class Destroyers (DDG), Aircraft Carriers (CVN), Wasp-class Amphibious Assault ships (LHD), America-class Amphibious Assault Ship (LHA);
- Combat Rubber Raiding Crafts (CRRC), Rigid Hull Inflatable Boats (RHIB), Landing Craft Air Cushion (LCAC) & overall amphibian operations; and
- F/A-18E/F Super Hornet & overall flight operations.

These environmental factors were then processed through Microsoft Excel to create a tool that can use climatological data to dictate whether a system would be negatively affected by the climate effect within a given time range and increased global temperature. **Figure 11** shows an example of how a specific platform's data is currently organized. The DDG and associated operations are shown in this table.

The percentage of chance of threshold exceedance values was noted and inputted into the spreadsheet indicating the platform, platform specific operation, environmental factor considered, and limiting value for what is considered marginal and severe (or unfavorable). Moving through the columns from left to the right, the spreadsheet is sectioned into the three geographic points analyzed and split the data into four seasons: Summer (June, July, August), Fall (September, October, November), Winter (December, January, February), and Spring (March, April, May). The "climo" columns are the ACAF mean aggregate data. Then, IPCC6 CMIP6 data was utilized for percent change in winds, temperatures, and precipitation. This data is available for 1.5, 2, and 3-degree Celsius global warming. This data was recorded in the yellow percentage delta cells.

The example shown in Figure 11 is blank due to the nature of classification in the classified caps & lims documents utilized. There are multiple operations associated with a single platform. In this example, analysis showed that the following operations could potentially be impacted: Flight Quarters, Replenishment At Sea (RAS), and Tomahawk Land Attack Missile capabilities (TLAM).

				North Area															
Platform				Climo Summer (JJA)	Climo Fall (SON)	Climo Winter (DJF)	Climo Spring (MAM)	1.5°C Summer (JJA)	1.5°C Fall (SON)	1.5°C Winter (DJF)	1.5°C Spring (MAM)	2°C Summer (JJA)	2°C Fall (SON)	2°C Winter (DJF)	2°C Spring (MAM)	3°C Summer (JJA)	3°C Fall (SON)	3°C Winter (DJF)	3°C Spring (MAM)
Operation	Environmental Factor							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold				"=E4+E4*J3/100"				"=E4+E4*O3/100"				"=E4+E4*T3/100"			
		Severe	Limits																
	Environmental Factor							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																
DDG																			
Flight Quarters	Seas							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold															
		Severe	Limits																
	Winds							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																
RAS	Seas							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold															
		Severe	Limits																
	Winds							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																
	Swell							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold															
		Severe	Limits																
	VIS							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																
TLAM	Seas							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold															
		Severe	Limits																
	Winds							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																
	VIS							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits	% Exceeds Threshold															
		Severe	Limits																
	CIG							% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ	% Δ
		Marginal	Limits																
		Severe	Limits																

Figure 11: Sample of Platform table for climatology capability and limitations analysis

Stoplight Charts

Weather impacts are usually presented to decision makers in a "stoplight chart" fashion. This decision aid acts as an easily understandable and categorized way to help emphasize how those weather projections impact various operational thresholds based on METOC forecasts, giving decision makers an accurate way to manage the operational risks. The criteria of effect to operational impact, as laid out in the JP 3-59 document, are as follows.

- Green = favorable, zero to minimal
- Amber = marginal, moderate
- Red = unfavorable, severe

This criterion enables decision makers to make rational decisions on when an operation could be deemed "go" (green) or "no-go" (red) and is to be used as necessary.[31]

To analyze the impacts climate change will have on Naval operations, a few specific parameters are highlighted utilizing a stoplight chart layout to capture an overview of the scenario and include the asset or platform, environmental factors, stoplight analysis, climatological analysis, and time projections. The parameters align with the CNA analysis, with the environmental factors being directly referenced. The stoplight analysis is drawn from the appropriate caps & lims documents, and the projections were analyzed by the METOC researcher. Ideally, the research captures at least one platform from each domain: underwater, surface, and air. An example in Figure 12 shows how future stoplight charts could be used for a specific region and timescale. In the example, the stoplight chart showcases the platforms most effected by which environmental aspect of climate change, by comparing climatology data to projections. For example, as temperatures warm, the number of days in a season where collections are possible will decrease; where the stoplights are green now, could be yellow or red in the future. Most of the findings related to the stoplight charts are available in the classified report.

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[31] Joint Chiefs of Staff, *Meteorological and Oceanographic Operations.* 2018. https://www.jcs.mil/Portals/36/Documents/Doctrine/pubs/jp3_59.pdf.

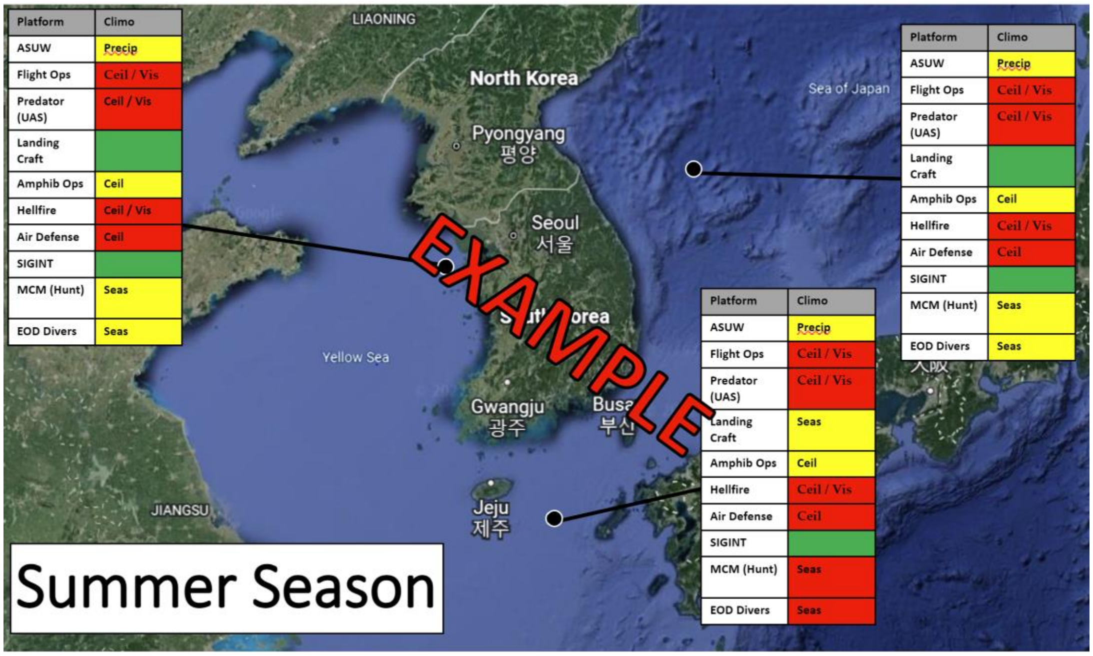

Figure 12: Example of potential stoplight chart to be used for decision makers, LCDR Jacobs

Future Work and Conclusion

In this project, a meteorological approach offers a framework and tool for identifying impacts on naval operations from climate change. While focused on a particular region, this tool can be used across the globe in different operating areas, assuming relevant data is available. The research team emphasizes that future work is necessary to hone the tool and identify commonalities among regions and/or platforms and systems. The following challenges reflect recommendations for next steps in research and analysis.

The climatology analysis framework utilized data that was available given NPS capabilities. The secured space which can be utilized for handling classified material, the Secure Technology Battle Lab (STBL), has limitations on the specific programs available in the classified space. Researchers recommend the use of ArcGIS, Google Earth, MATLAB etc., in both classified and unclassified spaces for future work on this topic.

In addition, missing climatology data including visibility, sound speed profiles, precipitation, currents, turbulence, and other climate impacts data, should be utilized in future work to allow for a more accurate analysis of a specific region. This missing data could be available and unable to be accessed – or it is not easily accessible due to data constraints but should still be considered for future work. Because of data limitations, the chart analysis was not able to be produced accurately. Other data that would be better utilized includes the use of Keyhole Markup Language Zip files (KMZ files) commonly used in Google Earth and similar geographic mapping tools for better analysis. The ACAF tool also presented challenges as it can be inconsistent; different sets of years available for various parameters leads to extra sets of disclosures, ultimately leading to missing data. Because the mean data aggregated from ACAF was diluted, the output did not show an accurate read of climate projections in the area and appeared to be low impact across all parameters. Using a high-resolution time frame would allow for more accurate predictions with monthly being good, daily being better, and hourly measurements being the most ideal source.

To correct for many of the downfalls of the ACAF system, the European Centre for Medium-Range Weather Forecasts (ECMWF) Reanalysis tool version five (ERA5) is recommended. This tool provides more precise atmospheric data of the global climate as it produces hourly estimates for climate variables such as atmospheric, land and oceanic.[32] The images also produced in the ACAF data presented inconsistent legend identifications that could be construed as confusing. Better and consistent color ranges within the pictures produced would warrant easier comparisons between time and space data sets. While the METOC caps & lims documents provided vital information on the platforms and operations analyzed, the documents only provided a limited number of platforms utilized by the DON. Should all information be provided, future work could include a wider range of platforms that are commonly utilized by Naval forces. These platforms include many unmanned systems such as underwater gliders; high altitude, fixed wing intelligence, surveillance, and reconnaissance (ISR) platforms like the MQ-1; the ScanEagle; and other lower altitude group two classified systems.

With our meteorological-focused approach, concerns for operations exist if an asset is unable to operate in an environment that exceeds the respective caps & lims thresholds. Important questions are: *Without usage of this platform/operations in an environment that experiences predicted climate change impacts, what capability has been lost? When can we expect this capability to begin degrading and will it become fully degraded?* While the unclassified version of the analysis tool remains blank, the classified worksheet produces some initial findings that can be accessed via SIPR. This research has been instrumental in laying future groundwork for integrating the understanding of climate change impacts into DON operations. Future work could expand on the operations and platforms utilized as well as use the framework in differing AORs. The information produced by the climate change and impacts to Naval Operations tool has the potential to give stakeholders, decision makers, and operators both an accurate and precise picture of operations in their AOR, leading to strategic strongholds and safer operations.

Appendix A

The Literature Review is available online at https://nps.edu/web/eag/energy-climate/.

Appendix B

The classified report is available via SIPR. To request a copy of the classified report, please e-mail Marina Lesse via SIPR at marina.i.lesse.civ@mail.smil.mil.

[32] European Centre for Medium-Range Weather Forecasts. (2023). *ECMWF Reanalysis v5*. https://www.ecmwf.int/en/forecasts/dataset/ecmwf-reanalysis-v5#:~:text=ERA5%20is%20the%20fifth%20generation,land%20and%20oceanic%20climate%20variables