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OUTLOOK

The hunt for Red October in warmer oceans

Climate change and anti-submarine warfare

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Summary

Security scholars have traditionally looked at climate change from the perspective of civil wars, migrations and pervasive instability.

NATO has recently started looking at climate change as one of the main threat-multipliers characterizing the current international system.

Climate change can have a real impact on interstate rivalry and strategic competition, specifically by affecting water temperatures, currents and salinity, and thus sonar performance – a key asset in submarine and anti-submarine warfare.

Forty years ago, the U.S. Naval Institute Press, which specialises in naval history and military strategy, took the unusual step of publishing a work of fiction, *The Hunt for Red October*. To this day it remains the most well known work it has ever published – thanks in part to the epynomous movie featuring Alec Baldwin, Sean Connery and James Earl Jones. The plot of the book/movie centres around three main protagonists: Soviet Navy Captain Marko Remius, the Commanding Officer of the Soviet submarine "Red October" who is attempting to defect to the U.S.; Jack Ryan, a CIA intelligence officer who understands the true intensions of Captain Marko Remius; and Caterpillar, the extremely quiet and revolutionary propulsion system developed by the Soviet submarine industry that allows their underwater boats to avoid advanced U.S. acoustic systems' detection – the very reason U.S. intelligence favours Captain Remius' defection.[1] Nowadays, a "Caterpillar system" would no longer revolutionise submarine warfare. Since the release of *The Hunt for Red October*, quieting technology for submarines has made significant advances, to the point that further improvements are unlikely, and those countries that were lagging behind are catching up.[2] A new factor, however, promises to change the range and therefore the probability of acoustic detection of submarines in the future: climate change.

NATO, in recent years, has begun to pay increasing attention to the issue for its broader implications, including the environmental sustainability of its Allies' military forces and the impact on countries affected by pervasive instability.[3] With our research, however, we are among the first to show that climate change directly affects NATO's traditional core mission: deterrence and defence. Specifically, climate change influences submarine detection because of its effect on underwater sound propagation – the primary means for anti-submarine warfare. Sound propagation is a function of water temperatures, salinity and depth. It follows that climate change, by dint of warming sea surface temperatures and melting Arctic ice, may affect patterns of underwater sound propagation, and hence submarine and anti-submarine warfare operations. To investigate whether, and to what extent, climate change will affect future submarine and anti-submarine operations, we conducted a series of ocean acoustic simulations in the North Atlantic and in the Western Pacific. With these simulations, we compare patterns of underwater sound propagation in the past (1970-1999) and in the future (2070-2099). The only parameters that change in our simulations are those influenced by climate change, water temperatures and salinity. With this research design, we can therefore provide a first assessment of how climate change influences underwater sound propagation, and hence anti-submarine warfare. We find that acoustic detection will become more difficult in most areas but is going to become significantly more difficult in the North Atlantic than in the Western Pacific. Our findings have direct implications for strategic stability.

To start, given that submarine detection range will decrease much more in the North Atlantic than in the Western Pacific, NATO adversaries such as China and Russia could increase their submarine operations in the former in order to draw NATO assets and resources away from other areas, including the Western Pacific. This is not a remote possibility. Throughout the 2010s, Russia increased its submarine operations in the Atlantic, and China put significant effort toward accessing the Atlantic through the Arctic Ocean.[4] In light of our results, some NATO countries may wish to put their growing focus on the Indo-Pacific into strategic context, and consider the potential need for more assets and resources in the North Atlantic in the coming decades.

Moreover, our results also contribute to the debate about the future of submarines. Some believe that advances in sensing technology will make submarines less effective in maintaining their stealth advantage in the decades ahead. As a result, some have called for the cancellation of submarine programmes.[5] Our findings question this view: policymakers should think carefully about adopting drastic decisions about long-term defence acquisition projects such as submarines, especially given the exorbitant re-entry barriers that the submarine defence industry faces.[6] In this regard, our research has important implications for force structures, given the differences in detectability between the surfare and underwater realms. According to many observers, surface fleets are becoming much more vulnerable because of the strengthening capabilities of surveillance and strike assets. Our finding that submarines are becoming less detectable in many areas means that, in comparative terms, submarines are going to play an even more important role in the future, including for striking land targets. This conclusion echoes some analyses that suggests the submarine may be the only platform that can carry out destruction of enemy air defences (DEAD) in a highly contested environment.[7]

Submarine warfare and climate change

Submarine warfare is one of the most secretive realms of military activity. This stems from the strategic importance of submarines, as well their features. Submarines conduct three main missions: to defend their own coasts by threatening enemy warships; to hunt enemy submarines and neutralize adversaries' threats to one's own fleets and to strike enemy territory. Land-strike exists in two versions, conventional and nuclear. The former complements countries' long-range surface and airborne land-attack capabilities. The latter is one of the possible legs of a country's nuclear deterrent (along with for example strategic bombers and intercontinental ballistic missiles, or ICBMs). Submarines also come in two main configurations: conventional and nuclear propelled. Conventional submarines are cheaper, but their underwater autonomy (the time they can stay underwater) is limited. However, recent progress in

1 Tom Clancy, *The Hunt for Red October* (Annapolis, MA: Naval Institute Press, 1984).

2 The People's Liberation Army Navy: A Modern Navy with Chinese Characteristics (Washington, D.C.: U.S. Office of Naval Intelligence, August 2009), 22; Christopher P. Carlson and Howard Wang, "China Maritime Report No. 30: A Brief Technical History of PLAN Nuclear Submarines, *CMSI China Maritime Reports* 30 (2023).

3 For a summary, see Jens Stoltenberg, *The Secretary General's Report: NATO Climate Change and Security Assessment: Third Edition 2024* (Brussels: NATO, 2024).

4 Magnus Nordenman, *The New Battle for the Atlantic: Emerging Naval Competition with Russia in the Far North* (Annapolis, MD: Naval Institute Press, 2019).

5 Tory Shepherd, "Will All Submarines, Even Nuclear Ones, Be Obsolete and 'Visible' by 2040?," *The Guardian*, October 4, 2021, https://www.theguardian.com/australia-news/2021/oct/05/will-all-submarines-even-nuclear-ones-be-obsolete-and-visible-by-2040.

6 John Birkler, John F. Schank, Giles K. Smith, Fred Timson, James Chiesa, Marc Goldberg, Michael G. Mattock, Malcolm MacKinnon, *The U.S. Submarine Production Base: An Analysis of Cost, Schedule, and Risk for Selected Force Structures* (Santa Monica, CA: The RAND Corporation, 1994).

7 Owen R. Coté, Jr., "Assessing the Undersea Balance Between the U.S. and China," in *Competitive Strategies for the 21st Century: Theory, History and Practice*, ed. Thomas G. Mahnken (Palo Alto, CA: Stanford University Press, 2012), 184-205.

air-independent propulsion has significantly extended their underwater cruise times. Nuclear-powered submarines, conversely, are much more expensive but have potentially unlimited underwater autonomy.

Submarines offer a unique capability: they exploit the vastness of the seas and the oceans to hide from enemy sensors and strike enemy targets. The most effective sensors for detection (radar, radio, laser) are also severely attenuated in seawater. However, the seas and the oceans also pose several dangers, such as unpredictable currents that can suddenly take a submarine beyond its "crushing depth," collisions with natural or artificial obstacles, corrosion resulting from salinity that can weaken the external hull, and hydrostatic pressure, which exposes submarines to constant cycles of compression and decompression that further weaken the outer hull. As a result, submarines are also extremely vulnerable: while a tank crew can dismount and a fighter pilot can eject, a submarine crew has no easy and immediate means of escape. A defect in production, an onboard malfunction, a human error, or an enemy attack can determine the fate of a submarine. For this reason, stealth is not only the key advantage of submarines, but also a necessity.

The primary means of detecting submarines is through underwater sound propagation. Active sonars, like radar, emits an acoustic signal (a "ping") and captures its return. Passive sonars, like the human ear, captures sound from the environment, and tries to identify those generated by enemy submarines, such as the propulsion system, the turbulence and the crew. Active sonar alerts the adversary, wherease passive sonar does not.

Climate change and changing oceans

Climate change and global warming are having a significant impact not only on the atmosphere but also on the oceans, whose physical properties are changing as a result. At different rates and speeds across the world, the oceans are becoming warmer, not only at the surface, but also at depth. They are experiencing changes in salinity due to imbalances in the water cycle and extensive ice melting. The change in the main features of the oceans, in turn, has many important implications, including for the directions and magnitudes of the main ocean currents and the way sound travels through water – i.e., underwater sound propagation, the central pillar of submarine and anti-submarine warfare.[8]

Sonar exploits underwater acoustic propagation to detect, identify and track submarines. However, the speed and range of sound varies depending on many factors, in particular water temperatures and salinity. In the same way that changes in humidity can affect visibility by altering fog patterns, changes in water temperatures and salinity can affect underwater sound propagation and the range and probability of acoustic detection. In fact, sound waves travel quite differently in warmer and saltier waters in comparison to colder and fresher waters. Because different areas across the oceans have different baseline water features (e.g., the Mediterranean being warmer and saltier than the North Sea), and because the effects of climate change on the ocean environment are not uniform across all areas (e.g., some areas are experiencing more rapid temperature increases or salinity changes than others), it is not possible to understand and predict the implications of climate change for antisubmarine warfare without rigorous scientific analyses.

For this reason, we have carried out oceanic acoustic simulations to investigate how variations in water and salinity will influence underwater sound propagation for areas that have critical geostrategic relevance in the North Atlantic and in the Western Pacific.

Oceanic acoustics simulations and the effects of climate change

To estimate how changes in the oceanographic conditions related to global warming are influencing the effectiveness of sonar systems, we conducted area-specific ocean-acoustic simulations through state-of-the-art numerical acoustic models. We carried out these simulations using historical values on water temperature and salinity for the past (average for 1970-1999), as well as future values derived from climate models (average for 2070-2099). By comparing past and future results about underwater sound propagation, we can infere the effect of climate change – given that the only changing variables, water temperature and salinity, are derived from climatological models. This approach is similar to the "difference-in-means" methods used by economists, political scientsts and sociologists– e.g., comparing a trend in given area before and after an "exogenous" shock. This approach gives us rigorous results and is independent of the models we use, since these models affect both past and future values.

Our results show that in most areas, the range at which submarines can be detected is shrinking when we compare the 1970-1999 averages with those of 2070-2999. This is particularly true in areas where the ocean is warming rapidly, such as the North Atlantic and, to a lesser extent, the Western Pacific. Off the Bay of Biscay in the North Atlantic, the range of detection of a submarine decreased from 60km to 35km, whereas between the first and the second Island Chains in the Western Pacific, from 10km to 7km – a more limited change in absolute terms, but still a 20% decrease in relative terms, between the first and the second. Conversely, in the Sea of Japan, the area where North Korean submarines would operate, the range of detection for submarines operating at 100m depth would increase from 10km in the past to 45km in the future due

8 Robert J. Urick, *Principles of Underwater Sound* (New York: McGraw-Hill, 1983).

Bathymetric Map Showing the Areas Analyzed

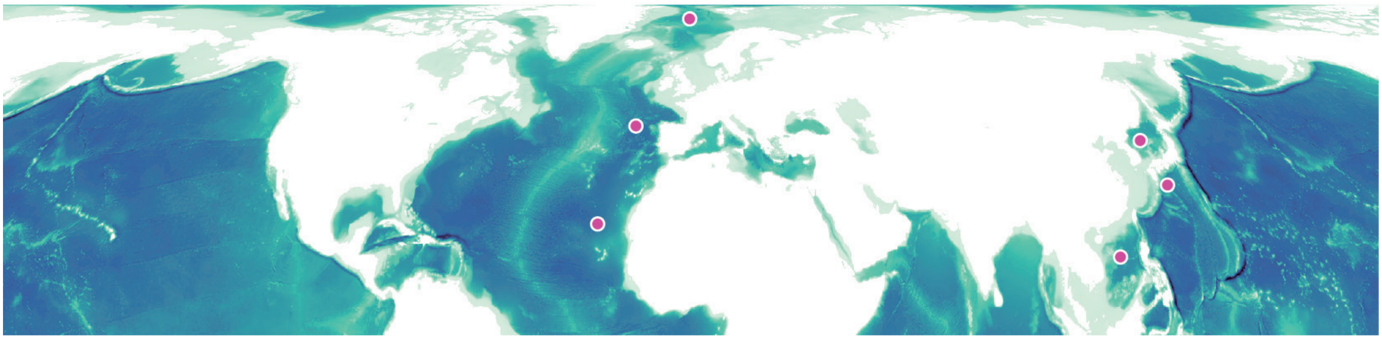

Figure 1. Bathymetric Map showing the areas analyzed
Source: National Center for Environmental Information.

to a mix of variation in water salinity and temperature, as well as currents.

Strategic and military implications

When it comes to submarine warfare, analysts, observers and policy-makers tend to focus on the noise generated by friendly and hostile submarines under specific cruise profiles (e.g., at a given speed, at a given depth) and on the relative acoustic advantage or disadvantage that a country possesses.[9] Such attention is intuitive, given that underwater acoustics remains the primary means for submarine detection, and thus the quietness or noisiness of a submarine is critical for maintaining stealth. This focus, however, is incomplete, as it neglects that such quietness and noisiness are a function of the medium through which sound travels and seawater, as the specific properties of that medium at a given location and time affect the range of sound propagation, and hence, the probability of detection for any given range.[10]

Our research has shed light on this aspect and more broadly on one of the many implications of climate change for military operations – the effect on sensor technologies. Adapting to the realities of climate change is not only a matter of technological innovation, but also one of strategic foresight: as the environment continues to change, traditional military doctrines and technologies may no longer be sufficient or appropriate. New technologies, tactics, operational concepts, and strategies will be required to ensure that military forces can continue to protect their national interests in an increasingly unpredictable world.

While NATO has acknowledged and pledged to combat and to adapt to climate change, it has only recently begun to pay attention to the operational implications of climate change for its personnel and fleet.[11] NATO will need to consider the effect of climate change on existing practices and technologies, and to implement adjustments and investments in order to maintain readiness, proficiency and effectiveness. Under some circumstances, detecting submarines will become more difficult. Whereas this change is going to be an advantage for NATO submarine forces, it is also going to be a challenge for NATO anti-submarine forces, which will require more and different resources to deal with current and potential future adversaries.

Moreover, these findings need to be considered in the context of concomitant changes in technologies, including the development of unmanned underwater vehicles (UUV), which are much cheaper to develop and operate than traditional submarines. Most analysts have focused on UUVs by looking at their potential contribution to anti-submarine warfare. However, such platforms could also be used to complement existing submarine fleets,

9 For publicly available data about Soviet/Russian and Chinese submarines, see for example Stefanick, *Strategic Antisubmarine Warfare,* 272-283; E.V. Miasnikov, *The Future of Russia's Strategic Nuclear Forces: Discussions and Arguments* (Moscow: Center For Arms Control, Energy And Environmental Studies, Moscow Institute of Physics and Technology 1995), Appendix 2 - Estimates of Submarine Detection Ranges; Owen R. Coté Jr., "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines," *Newport Paper*, No. 16 (Newport, RI: Naval War College, 2003); Andrew S. Erickson, Gabriel B. Collins, Lyle J. Goldstein, and William S. Murray, "Chinese Evaluations of the U.S. Navy Submarine Force," *Naval War College Review*, Vol. 61, No. 1 (Winter 2008), 68-86; *The People's Liberation Army Navy: A Modern Navy with Chinese Characteristics* (Washington, D.C.: U.S. Office of Naval Intelligence, August 2009, 22); Hans M. Kristensen, "China's Noisy Nuclear Submarines," *Federation of American Scientists* (21 November 2009), https://fas.org; Jeffrey Lewis, "China's Noisy New Boomer," *Arms Control Wonk* (24 November 2009).

10 Mathematically, this is shown by the sonar range equation, in which the noisiness of a submarine (Source Level, or SL) and the attenuation of sound (transmission loss, or TL) have an equal effect on the probability of detection (the detection treshold, or DT, above which a detection happens). SL – TL – NL + AG + PG ≥ DT. In the equation, NL is the Noise Level, or the ambient noise in which the sonar operates; AG is the passive receiver's Array Gain (also known as Directivity Index, or DI), which quantifies the ability of the sonar receiver to distinguish between the signal and the noise by listening from a specific direction within a very small angle; PG is the Processing Gain, which includes gains made possible through advanced signal processing technology.

11 Stoltenberg, *The Secretary General's Report: NATO Climate Change and Security Impact Assessment.*

and act for example as decoys to mislead adversarial anti-submarine forces and further complicate their efforts.

Finally, this also calls for more research at the intersection of climate change and military analysis, a type of research that academic institutions are unlikely to promote because of the specific and diverging incentives of the various fields involved and disincentives for multidisciplinary research. In the same vein, more study is needed that considers the effects of both climate change and technological change, in order to avoid reaching unwarranted conclusions based on questionable assumptions. Finally, our research also calls for wargames that incorporates insights from both military operations and climate change, shedding light on important aspects that have received less attention to date.

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