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Fluid Foundations: Ocean Transparency, Submarine Opacity, and Strategic Nuclear Stability

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The development and detonation of atomic weaponry at the end of World War Two so shocked established political and military thought that it can be accurately described as a "Nuclear Revolution."[1] The expectation that nuclear weapons would continue to be used in conflict, and the emerging bipolar tension, stoked premonitions of eminent international disaster. Aversion to their continued use, combined with fear of giving them up, produced a period of contradiction and adjustment in the missions and strategies of the armed forces. A nuclear strategy was needed to reconcile the extreme strength and extreme vulnerability attendant to the Nuclear Revolution, and to find a use for apparently un-useable weapons. "Deterrence theory" was meant to provide a practicable stopgap while more radical political solutions were formulated, but it was eventually fully incorporated into military doctrine,

[1] Bernard Brodie, *Some Strategic Implications of the Nuclear Revolution* (University of Utah Press, 1959); Michael Mandelbaum, *The Nuclear Revolution: International Politics Before and After Hiroshima* (Cambridge University Press, 1981); Robert Jervis, *The Meaning of the Nuclear Revolution: Statecraft and the Prospect of Armageddon* (Ithaca: Cornell University Press, 1989).; Avery Goldstein, *Deterrence and Security in the 21st Century: China, Britain, France, and the Enduring Legacy of the Nuclear Revolution* (Stanford, Calif: Stanford University Press, 2000).

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strategy, and force structure.[2] Deterrence theory relies on the idea that the threat of nuclear retaliation will prevent an enemy from starting a nuclear conflict. For deterrence to function, however, requires assurance that the victim of a "first strike" will be able to respond after an initial attack. Thus, deterrence hinges on the maintenance of a "secure second strike" capability that cannot be reliably eliminated in a disabling first strike [3] As land-based delivery vehicles became more targetable, military strategists sought ways to guarantee the ability to retaliate against a first strike. Although other means were pursued, such as hardened and mobile ballistic missiles and "launch on warning" postures, nuclear-powered and nuclear-armed submarines (SSBNs) were understood to be the most survivable, and therefore most reliable, secure second strike capability. In assuming the mantle of deterrence, they became a "keystone of global military strategy."[4] The ability of SSBNs and their ballistic missiles (SLBMs) to remain invulnerable to a nuclear first-strike is a function of their ability to hide beneath the surface of the ocean, which is opaque to most forms of surveillance.

The opacity of the ocean is a product of its unique features, which tend to thwart traditional surveillance technologies. Opacity varies over time, however, evolving with new scientific understandings of the operational environment and innovation in sensing and hiding technologies. Scientific study of the undersea environment helps illuminate where and how the "signatures" of SSBNs can be detected. Advances in information technologies such as radar, sonar, and satellites allow users to locate and track objects of interest with increasing degrees of precision. Sophistications in oceanographic modeling and computer processing assist in separating smaller and smaller signals from background noise. All of these innovations contribute to transparency. However, science and technology have also produced increasingly sophisticated "hiding" techniques and "cloaking" technologies, which attempt to evade detection by reducing submarine signatures or enhancing background noise. These are means of rebuilding opacity. As science adds detail and precision to our understanding of the operational environment, and as technological innovations add to our capabilities to "hide and seek," ocean opacity may be subject to incremental erosions and/or sudden collapse as submarines become visible, and therefore targetable. Because the opacity of the submarine environment is foundational for submarine-based strategic nuclear deterrence, its degradation entails serious potential volatility.

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[2] Jonathan Schell, *The Fate of the Earth, and, The Abolition*, Stanford Nuclear Age Series (Stanford, Calif: Stanford University Press, 2000).

[3] Jervis, *The Meaning of the Nuclear Revolution*.

[4] H.D. Smith, "The Development and Management of the World Ocean," *Ocean & Coastal Management* 24 (1994): p. 7.

The significance of ocean opacity for strategic nuclear stability – the subject of this article – implies that the basic condition of nuclear peace is a material one. Because scientific advancement and technological change continuously alter the relationship between transparency and opacity in the operational environment of nuclear forces, this basic condition cannot be understood as permanent. Transparency is a continuous variable that creates conditions of possibility for nuclear strategy. The argument outlined here seeks to contribute to the development of theories of the nuclear peace by focusing on the potential for radical change in the visibility and targetability of strategic nuclear weapons. It also contributes to the literature on the emerging "age of transparency," in which government strategies based on secrecy are increasingly undermined by new technology.[5] Transparency is typically understood to have benefits for political, economic, and social life.[6] In the security realm, transparency about intentions and capabilities discourages irrational wars and facilitates negotiated settlements.[7] Transparency in the location of nuclear forces, however, is more likely to be destabilizing insofar as it alters the incentives and vulnerabilities assumed by contemporary nuclear force structures. Most concerning for theories of nuclear deterrence are the conditions under which the "secure second strike" remains secure, because invulnerability of some nuclear forces is thought to dis-incentivize a counter-force first strike (against military targets). Indeed, many proponents of offense/defense theory suggest that secure second-strike weapons, and in particular SLBMs, are functionally defensive and therefore help stabilize and pacify international politics.[8] The fabric of the international system in the nuclear era rests in large part on a particular premise about the interaction between technology and geography, which favors deterrence. Because of these high stakes, the conditions of invulnerability, or survivability, remain an essential focus for theorists of nuclear peace, but are incomplete without careful examination of their fluid material foundations.

By tracing the evolving relationship between technology, the ocean environment, and nuclear force structure during and after the Cold War, this article aims to challenge the prevailing confidence in the permanence of SSBN-based deterrence. While acknowledging that

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[5] Sean P. Larkin, "The Age of Transparency: International Relations Without Secrets," *Foreign Affairs*, 18 April 2016.

[6] David Brin, *The Transparent Society: Will Technology Force Us to Choose between Privacy and Freedom?*(Reading, Mass.: Perseus Books, 1998); Ann Florini, *The Right to Know Transparency for an Open World* (New York: Columbia University Press, 2007); Micah L Sifry, *Wikileaks and the Age of Transparency*, 2011.

[7] Kristin M. Lord, *The Perils and Promise of Global Transparency: Why the Information Revolution May Not Lead to Security, Democracy, or Peace*, SUNY Series in Global Politics (Albany: State University of New York Press, 2006), p. 27.

[8] Michael E Brown et al., eds., *Offense, Defense, and War* (Cambridge, Mass.: MIT Press, 2004).

technological change results from human choices, the approach taken here highlights the ways that geography and technology create possibilities, conditions, and incentives for nuclear strategy. The first section will describe major advances in transparency as the impetus for altering nuclear force structure away from land-based bombers and ballistic missiles. The most basic reason for investment in nuclear-armed submarines was the expectation that maritime opacity would persist. It did so for many decades, producing a kind of complacency regarding the security of the secure second strike. However, improvements in transparency, and thus challenges to opacity, have continued to advance. The second section will forward the claim that transparency is now finally on the near horizon of technological possibility. The incentives for transparency, and the number of actors pursuing it, have expanded since the Cold War, and driven advancements in sensor, platform, and data processing technologies. The final section considers the security and political implications of achieving a high level of transparency. It asks an important question about strategic obsolescence, and puts transparency in the context of on-going debates about SSBN modernization. The overall analysis suggests that the emergence of ocean transparency is highly plausible, and has concerning implications for nuclear strategies, postures, and force structure.

Cold War "Hide and Seek"

> The arms race is always, in effect, afloat on a stream of technical discovery…it is always as much a race against the scientific unknown as against the adversary per se.[9]

The 1960s were a significant decade for the maturation of the Cold War conflict. In the United States, calculations of qualitative and quantitative advance in Soviet nuclear forces, though often misguided, helped drive massive new expenditures on strategic nuclear weapons and delivery vehicles. The strategic nuclear "triad" force structure emerged quickly, but was subject to upgrades and modifications throughout the Cold War. The 1960 deployment of SSBNs armed with Polaris ballistic missiles by the United States represented a significant investment in invulnerable strike forces whose primary job was to maintain a credible threat of nuclear retaliation.[10] In 1961, the Polaris-armed SSBN was completely invulnerable to Soviet anti-submarine warfare (ASW). However, the Soviet Union responded to Polaris with major new ASW programs, and although their success was limited, Navy and Department of Defense

[9] Schell, p. 60.

[10] Norman Polmar and Kenneth J Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines* (Washington, D.C.: Potomac Books, Inc., 2004), p. 167

officials were seriously concerned about the potential of an ASW "breakthrough."[11] As the Cold War marched on, advances in weaponry and targeting made land-based nuclear delivery systems increasingly vulnerable to a counter-force first strike, which amplified the strategic importance of invulnerable SLBMs.[12]

The strategic studies literature has recognized the role of inter-service rivalry, perceptions of Soviet force structure, and the relationship between the Navy and oceanographers as partial explanations of why and how the US military shifted the mantle of "mutually assured destruction" towards SSBNs.[13] While changes in the strategic balance, and perceptions of the strategic balance, are the result of numerous interconnected and overlapping factors, very few accounts capture the full detail of relevant Cold War history. Social and institutional explanations are incomplete insofar as they overlook the crucial relationship between the geophysical properties of a particular operational environment (ocean, atmosphere, or space) and the technology designed to operate there. The interaction between evolving technologies of sensing, hiding, and destroying and the growing knowledge of the ocean environment drove Cold War defense expenditures towards a submarine-centric strategic nuclear deterrent.

Shifting the Mantle of Deterrence

The most important feature of nuclear submarines was not that they could carry nuclear-tipped weaponry, but that they could do so without being located, targeted, and destroyed. The fact that SSBNs had this "opacity advantage" over other nuclear forces was not determined by strategists, but was the outcome of rapid growth in the capabilities of surveillance technology. This revolution in transparency was driven by advances in existing sensing technologies like radar, computer processing, and the development of new sensing

[11] Polmar and Moore, pp. 126, 185.
[12] Karl Lautenschlager, "The Submarine in Naval Warfare, 1901-2001," *International Security* 11, no. 3 (1986): pp. 126, 130.
[13] Peter R. Beckman, ed., *The Nuclear Predicament: Nuclear Weapons in the Twenty-First Century*, 3rd ed (Upper Saddle River, N.J: Prentice Hall, 2000); Thomas S Burns, *The Secret War for the Ocean Depths: Soviet-American Rivalry for Mastery of the Seas* (New York: Rawson Associates Publishers, 1978); Jacob Darwin Hamblin, *Oceanographers and the Cold War: Disciples of Marine Science* (Seattle: University of Washington Press, 2005); Austin Long and Brendan Rittenhouse Green, "Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy," *Journal of Strategic Studies* 38, no. 1–2 (2 January 2015): 38–73, https://doi.org/10.1080/01402390.2014.958150.

platforms: surveillance aircraft and reconnaissance satellites.[14] It radically increased the vulnerability of land-based weapons systems and command and control centers to a disabling first strike. Although advances in transparency and targeting have been on going throughout military history, the shock of direct visual surveillance from air and space was highly concentrated during the early Cold War period. Transparency has major implications for force structure because it changes the value of existing weapons systems, such that the number and size of weapons is no longer a reliable indicator of strength.[15] Even thousands of nuclear bombs and missiles cannot achieve credible retaliation if they can all be simultaneously located and destroyed. The increase in transparency during the early Cold War was so acute as to raise the specter of a debilitating or decapitating first strike whereby the enemy could prevent nuclear damage to itself, representing a serious challenge to deterrence-based strategy.

Transparency increases vulnerability by enabling better targeting. Specifically, the United States feared growing Soviet capabilities in ballistic missile accuracy and anti-ballistic missile (ABM) technology. These twin developments were seen as eroding the secure second strike from two sides, in that they made a first strike maximally destructive, and provided some defense against any second strike capabilities that might remain.[16] Although US nuclear-armed submarines could effectively hide from Soviet ASW during the early 1960s, strategists anticipated that this might change. Polaris-armed submarines were aging, and both Polaris and Poseidon missile systems had relatively limited ranges that constrained the size and location of patrol areas. The Americans believed that the incentives for a Soviet strike were growing, because the credibility of "mutually assured destruction" was waning, and therefore in 1966 Secretary of Defense Robert McNamara commissioned the "STRAT-X" study. The purpose of STRAT-X was to undertake a comprehensive analysis of nuclear force structure, in order to figure out how to maximize survivability in the event of a first strike scenario.[17] McNamara wanted specific investment proposals; executives from major defense contractors were involved, and each of the 124 projects surveyed had to be unique relative to existing platforms. The proposed projects "ranged from the sublime to the ridiculous," and included putting ICBMs in hardened subterranean silos, on trucks or railcars to make them mobile on land, on barges to make them mobile on existing or constructed waterways, on surface ships at sea, and

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[14] Daniel Deudney, *Whole Earth Security: A Geopolitics of Peace* (Washington, D.C., USA: Worldwatch Institute, 1983), p. 6.

[15] Deudney, p. 31.; Stephen D. Biddle, *Military Power: Explaining Victory and Defeat in Modern Battle* (Princeton, NJ: Princeton Univ. Press, 2004).

[16] Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 183.

[17] Polmar and Moore, pp. 183–84.

on seabed platforms.[18] Many of the proposals came from an Air Force that knew its monopoly on the nuclear arsenal was threatened. Since 1960, the Air Force had considered multiple "shell game" missile arrangements, the purpose of which was "to achieve invulnerability and deception by shifting the missiles among multiple silos."[19] Despite the fact that only two of the 124 proposals were sea-based, the final recommendations from the STRAT-X study included two land-based and two sea-based schemes. This balanced conclusion simply reflected inter-service politics, however, and the Navy's underwater long-range missile system (ULMS) was the only proposal eventually developed into the Trident missile system.[20] By the early 1970s, ULMS would become the agreed upon basis of mutual deterrence between the superpowers.[21]

Expectations of Opacity

The Navy's ULMS proposal was pursued for multiple reasons, but the most basic is the character of the maritime operational environment. The Navy was well prepared to argue in favor of submarine-launched ballistic missiles (SLBMs), because of its pre-existing, mutually beneficial, and productive relationship with oceanographers.[22] Proving that the SSBN concept was the most efficient and effective way to maintain credible retaliation throughout the period for which the STRAT-X study was commissioned (1975-85) required assessing the likelihood that the ocean would remain opaque in the face of technological innovation. The Navy had two decades of experience conducting research into the nature of the maritime operational environment, as part of the broad post-World War Two effort to identify new strategic missions for the military services. Defining what naval forces, especially submarines, were capable of required basic oceanographic research. Knowledge of the maritime environment received a major boost during the International Geophysical Year (1957-58), an international cooperative scientific effort "aimed to extend synoptic data collection over the entire Earth" and with a large number of projects focused on ocean properties.[23] The IGY was supposed to ease Cold War

[18] D. D. Dalgleish and Larry Schweikart, *Trident*, Science and International Affairs Series (Carbondale: Southern Ill. Univ. Pr, 1984), p. 42.
[19] William F. Grover, *The President as Prisoner: A Structural Critique of the Carter and Reagan Years*, SUNY Series in the Presidency (Albany: State University of New York Press, 1989), p. 137.
[20] Dalgleish and Schweikart, *Trident*; Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 184.
[21] Thomas S Burns, *The Secret War for the Ocean Depths: Soviet-American Rivalry for Mastery of the Seas* (New York: Rawson Associates Publishers, 1978), p. 32.
[22] Jacob Darwin Hamblin, *Oceanographers and the Cold War: Disciples of Marine Science* (Seattle: University of Washington Press, 2005).
[23] Hamblin, p. 30.

tensions, but one of the Soviet projects, the Sputnik satellite, signaled the potential for a major advancement in surveillance capabilities and catalyzed the search for new foundations of strategic deterrence.

The basic reason for the persistence of ocean opacity is a geophysical fact: only sound travels through ocean water in a way that is useful for long-range sensing technologies. Electromagnetic radiation, and therefore radar, does not penetrate the ocean's surface well.[24] In other words, the atmosphere is transparent in a way that the ocean is not. Oceanographic labs and institutions working with the Navy characterized in detail what this geophysical reality meant for the possibilities of "hiding" and "seeking" in the ocean. In the late 1940s, oceanographers discovered natural sound channels that trapped and focused low frequency sound, suggesting the viability of passive acoustic sensing via arrays of sonar hydrophones.[25] In the course of investigating the acoustic environment in the North Atlantic and around important sea lines of communication, the significance of thermal layering, depth, and seafloor terrain for obstructing and distorting sound propagation became clearer.[26] Oceanographers also described and characterized the sources and nature of ocean background "noise," a critical step in defining the signal-to-noise ratio that ultimately determines the acoustic visibility of submarines. Because these geographical and geophysical features of the ocean determined the possibilities and obstacles for acoustic sensing, oceanographic data, especially bathymetric charts and bathythermograph data, were subject to security classification: "oceanographic data presented a case in which basic science itself was a commodity of extreme importance to the Navy's operations."[27] This accumulated knowledge about the oceanic operational environment led military strategists to conclude that the advantage of SSBNs over anti-submarine warfare (ASW) would persist in the face of technological innovation. The acoustic sensing technologies best suited to the hydrosphere had limited range and could be easily thwarted with defensive technology such as noisemakers.

Investments in Transparency

Submarines became the foundation of nuclear deterrence because passive acoustic sensing could not make the ocean fully transparent, but the superpowers still invested in

[24] Deudney, *Whole Earth Security*, p. 26.
[25] Owen R. Jr. Cote, "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines," 2000.
[26] Hamblin, *Oceanographers and the Cold War*, pp. 40–41.
[27] Hamblin, p. 56.

detection technologies. The Soviet Union deployed its first modern nuclear-powered. nuclear-armed submarines in 1968, and despite a pre-existing "tremendous acoustic advantage" the United States wanted to maximize the chances of tracking them.[28] The first major projects were passive sonar arrays, linked by radio or submarine cable to centralized computer processing centers that would separate the "signal" from the "noise." Referred to as "SOSUS" (Sound Surveillance System), these hydrophones placed along undersea cables were extensive enough to detect very low frequency signals, which propagate farther than high frequencies. By 1958, the United States had SOSUS systems along the entire eastern seaboard, in Hawaii, and along parts of the Pacific seaboard. By 1965, a network of passive acoustic hydrophones spanned the "GIUK" gap, which served as a primary means of egress for Soviet submarines entering open ocean patrol areas. By the 1970s there were over 20 SOSUS installations at global strategic locations, including important chokepoints such as the Straits of Gibraltar. This regional acoustic detection strategy was combined with a "coordinated ASW" response that included surface ships and surveillance aircraft utilizing active sonar and radar on the surface of the ocean. Although active sonar is more effective at localization, it has a shorter range and reveals the presence of a seeker, and was generally eschewed by US submarines during the Cold War, in favor of passive acoustic sensing.[29]

The Soviet Union also invested in passive sonar arrays, although they were inferior to SOSUS.[30] Upon realizing their vulnerability to detection in the open ocean, in the mid-1970s Soviet SSBNs adopted a "bastion" strategy whereby they remained in the "marginal ice seas of the Soviet Arctic littoral," avoiding traversal of the SOSUS arrays but keeping SLBMs within strike range of the United States.[31] This hiding strategy was possible because of the development of long range of SLBMs, and because any attack on Russian SSBNs was expected to come from US attack submarines.[32] The bastion strategy partially redressed Soviet submarine vulnerability by creating a zone of "active defense" in which detection was possible, but localization required risky transit into the heavily defended and Soviet-controlled Barents Sea.[33]

[28] Cote, "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines."
[29] Tom Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy* (Lexington, Mass: Lexington Books, 1987), pp. 217–18; Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 149.
[30] Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 186.
[31] Cote, "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines."
[32] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p, 7.
[33] Stefanick, p. 7.

Internal Arms Racing

It is easy to overlook the essential stability of ocean opacity throughout the Cold War. Investments in both hiding and detection produced incremental advances in both capabilities for decades. This technological arms race was driven by more than just competition between the hiding Soviet Union and the seeking United States; it continued largely because of the institutional structures in which it was embedded. The US military regularly produced reports detailing expected innovations in Soviet technology, and therefore improvements in Soviet capability. A lack of reliable intelligence led the Americans to imagine "worst case scenarios" that drove reactive investments. Because the tasks of detection and concealment were contracted out to different labs and research institutions, internal competition increased the budgets for both. Improvements in passive acoustic sensing technology, especially SOSUS, pushed American submarine designers to build quieter submarines. This "technical competition between listeners and hiders," all occurring within US research institutions, drove American submarine and ASW technology forward in what was perceived as a race with the Soviets, but is more accurately understood as an internal race.[34] Yearly ASW exercises in the 1960s generated performance analyses that were used to justify defense expenditures to fill "gaps" in capabilities. Despite this dynamism in technological capability, nuclear deterrence remained stable because of the opportunities for hiding provided by the ocean environment.

Cold War Opacity

Because passive sonar relied on submarines making noise, both sides pursued quieting in vessel design and operation. Nuclear power was the first major design innovation for the purposes of concealment, because it decreased the need to surface regularly. The previous classes of diesel-electric submarines had to surface or snorkel periodically to recharge their batteries, making them vulnerable to multiple modes of detection. However, the first generation of nuclear submarines was also constantly noisy, as opposed to the intermittent loudness of diesel electric subs that had to surface regularly.[35] Indeed, even a stopped nuclear submarine generates noise from its power plant, whereas a submarine running on only electric power is very quiet.[36] Despite this, US nuclear submarines maintained opacity throughout the Cold War through hiding techniques that reduced acoustic signatures or created decoy signals. The

[34] Cote, "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines."
[35] Cote, p. 21.
[36] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 9.

United States developed nuclear-powered submarines first, and designed their internal parts to be quieter; the Polaris-armed submarines deployed in the 1960s "were superior in all respects to contemporary Soviet ballistic missile submarines."[37] The shape of submarine hulls was contoured to reduce the active sonar signature, and operators used hiding techniques like slow speeds, limited communications, and travel below the thermocline (temperature layer that obstructs the use of sonar). Both superpowers invested in decoys and noisemakers, which could multiply the number of apparently valid targets, or even eliminate the possibility of acoustic detection altogether.[38] During the Cold War, maintenance of ocean opacity was assured by continued innovations in concealment technologies.

The United States maintained a "unique and enduring advantage" in passive acoustics throughout the Cold War, but even the most optimistic assessments of its "seeking" capabilities do not conclude that Soviet SSBNs could be located and targeted with enough certainty to incentivize a US first strike.[39] Eventually Soviet submarines began to get quieter. Investment in "hiding" technologies may have been accelerated by intelligence about SOSUS sold to the Soviets by US Navy Chief Warrant Officer John A. Walker, who leaked naval secrets from 1967-85.[40] The maturation of Soviet quieting technologies in the early 1980s appeared as bipolar convergence on an "opacity advantage," leading one US Admiral to predict that "at some point, nobody will be able to find a submarine with anything."[41] Official Navy reports expressed confidence in the persistent advantage of "hiding" over "seeking" technologies (which were really mostly "listening"), and took for granted the resilience of strategic invulnerability in the face of technological innovation.[42] When a Russian official conveyed his confidence in 1992 that space-based radar and optical detection systems were five to ten years away from achieving strategic transparency, US scientists expressed strong skepticism.[43] Despite this confidence in opacity, the US Air Force continued proposing alternative basing schemes, including in deep

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[37] Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 167.
[38] Richard L. Garwin, "Will Strategic Submarines Be Vulnerable?" *International Security* 8, no. 2 (Fall 1983): pp. 59–60; Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 284.
[39] Austin Long and Brendan Rittenhouse Green, "Stalking the Secure Second Strike: Intelligence, Counterforce, and Nuclear Strategy," *Journal of Strategic Studies* 38, no. 1–2 (2 January 2015): pp. 38–73.
[40] Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 285.
[41] Cote, "The Third Battle: Innovation in the U.S. Navy's Silent Cold War Struggle with Soviet Submarines."
[42] Garwin, "Will Strategic Submarines Be Vulnerable?" p. 63; Lautenschlager, "The Submarine in Naval Warfare, 1901-2001," p. 132.
[43] Polmar and Moore, *Cold War Submarines the Design and Construction of U.S. and Soviet Submarines*, p. 186.

space, in an effort to reclaim part of the mantle of "mutually assured destruction."[44] Instead of pursuing alternative schemes for opacity, the US military augmented the SOSUS system in the mid-1980s, adding surveillance ships towing sonar arrays hundreds of meters long. Information from SOSUS and towed arrays were processed together, and became known as the Integrated Undersea Surveillance System. Despite these minor improvements in sensing technology, "hiding" had the advantage on both sides when the Cold War ended, and the secure second strike was therefore assured.

Post-Cold War Fluid Foundations

> …the greatest advantages are to be gained not so much by mounting gigantic industrial efforts as by fishing new devices out of the unknown. At bottom, it stems from each side's well-justified fear that the other side will arrive at an advantageous discovery first. (An example would be a device that could detect the positions of submarines from a great distance).[45]

Confidence in the persistent advantage of hiding over seeking has, since the end of the Cold War, co-existed with warnings about the specter of ocean transparency. However, technological advances have only recently made the expectation of transparency truly compelling.[46] The momentum of a broad-based and well-funded effort to discover and document the oceans has produced new scientific understanding and technology, and overcome key barriers to Cold War ocean sensing like limited platform penetration and slow data processing.[47] In particular, new maps of the operational environmental help separate the signal from the noise. New motivations have engaged industry in the process of developing enabling technologies. Continued improvements in acoustic sensing are also joined by innovations in non-acoustic sensing. Oceanographers speak breathlessly of being "poised on the brink of a series of improvements" from "transformational technologies" that will facilitate

[44] "Design and Construction of Deep Underground Basing Facilities for Strategic Missiles: Briefing on System Concepts and Requirements," Workshop Conducted by the U.S. National Committee on Tunneling Technology, Commission on Engineering and Technical Systems (National Research Council, 1982); Robert H. Chisholm, "On Space Warfare: Military Strategy for Space Operations" (Maxwell Air Force Base, Alabama: Airpower Research Institute, June 1984)
[45] Schell, p. 60.
[46] Paul Ingram, "Trident: The Need for a Comprehensive Risk Assessment," Short policy brief (BASIC, 23 November 2015); Paul Ingram, "Will Trident Still Work in the Future?" Short policy brief (BASIC, 22 January 2016).
[47] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*.

"truly synoptic observations of ocean regions and processes."[48] The accelerating pace of technological change carries risks, however, and may nullify the utility of SSBNs for strategic nuclear deterrence as new sensors and platforms make the ocean increasingly transparent.[49] This section assesses and supports the claim that technological innovations will spread across the ocean in the next few decades and achieve an unprecedented degree of transparency.[50] Before examining how transparency might be achieved, it is important to understand why crossing this threshold is increasingly likely.

New Motivations

The end of the Cold War marked the decline of a major driver of investment in submarine hiding and seeking technologies. In the last two decades, a powerful new motivation for understanding and monitoring the ocean has materialized: climate change. The urgency and shared vulnerability of this planetary problem demands tremendous investment in redressing gaps in our knowledge of atmosphere-ocean interactions. Especially relevant are the details of carbon and heat storage, the dynamics of thermohaline circulation, and the effects of ocean acidification on marine ecosystems. Much of this data is dual use; for example, measuring changes in stratification and mixing in the water column informs scientists about the effects of global warming on ocean circulation, and submariners about the likely pathways for sound propagation. Increasingly precise measurements of sea surface height help characterize regional variation in sea level rise, but could also potentially be capable of detecting the wakes of passing submarines.

As oceanography is an "observational science," marine scientists prioritize increasing, diversifying, and achieving a higher resolution for the data flows coming from the ocean.[51] This entails the establishment of coordinated observation programs that address the need for data at

[48] Deborah Ann Glickson et al., eds., *Oceanography in 2025: Proceedings of a Workshop* (Washington, D.C: National Academies Press, 2009), pp. 93, 21, 41.
[49] Ingram, "Will Trident Still Work in the Future?" p. 3.
[50] James Clay Moltz, "Submarine and Autonomous Vessel Proliferation: Implications for Future Strategic Stability at Sea," Project on Advanced Systems and Concepts for Countering WMD (U.S. Naval Postgraduate School Center on Contemporary Conflict, December 2012), p. 18; Bryan Clark, "The Emerging Era in Undersea Warfare," Studies (Center for Budgetary and Strategic Analysis, 22 January 2015), p. 8.
[51] Glickson et al., *Oceanography in 2025*, pp. 51, 59.

larger and longer scales by deploying floating, steered, and in situ sensing platforms.[52] Autonomous drones on and under the surface are being tested and deployed to gather scientific data throughout the ocean.[53] Operators of these sensory arrays describe what they are doing as "essentially providing an extension of the internet over the oceans."[54] A participant in the National Research Council's workshop *Oceanography in 2025* described the discipline's essential aim: "our goal is to make the ocean as transparent as possible."[55]

The breadth and depth of scientific effort makes civilian and government oceanographers an independent strategic force in the technological balance between opacity and transparency, a new constituency with strong motivations to discover, detail, and document ocean processes. Their open access model for data sharing helps redress funding shortfalls and geographic limitations, and represents a reversal of the Cold War practice of classifying oceanographic data. This effort contributes to the detection of SSBNs because sensing technology is dual use, but also because the improved scientific understanding of the ocean makes it easier for sensors to distinguish the signal from the noise.

New Maps

As the ocean becomes increasingly "sensor rich," new types and quantities of data are producing a more detailed picture of the ocean.[56] Cold War era maps and models were so rife with assumptions and elisions that they are best understood as "works of extrapolation, interpolation and inspiration, not mere measurement."[57] Oceanographers are now deploying advanced sensory networks to refine these maps by providing more of the necessary information to create accurate representations. In particular, advances have been made in mapping the topography and composition of the sea floor. The integration of GPS satellites has

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[52] Glickson et al., *Oceanography in 2025*; Henry A. Ruhl et al., "Societal Need for Improved Understanding of Climate Change, Anthropogenic Impacts, and Geo-Hazard Warning Drive Development of Ocean Observatories in European Seas," *Progress in Oceanography* 91, no. 1 (October 2011): pp. 1–33.; Russell B. Wynn et al., "Autonomous Underwater Vehicles (AUVs): Their Past, Present and Future Contributions to the Advancement of Marine Geoscience," *Marine Geology* 352 (June 2014): pp. 451–68.

[53] John Markoff, "No Sailors Needed: Robot Sailboats Scour the Oceans for Data," *The New York Times*, 4 September 2016.

[54] Denise Deveau, "Big Data to Help Keep Fresh Water Clean, Manage Waste and Detect Tsunamis," *Financial Post*, 10 September 2014.

[55] Glickson et al., *Oceanography in 2025*, p. 154.

[56] David Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," Parliamentary Briefings on Trident Renewal (BASIC, March 2016).

[57] "The See-Through Sea," *The Economist*, 7 June 2016.

improved the precision of acoustic data collection, and new understandings of the "deep scattering layer" minimize inaccurate soundings. However, the requirement of using surface vessels still limits the range of sonar bathymetry. Since the 1990s, satellite radar altimetry has been used to produce wider area measurements of several sea surface properties, from which oceanographers can glean information about the seabed.[58] In 2014, the first new map of the ocean floor in twenty years was produced from satellite altimetry data, and it was twice as accurate as the last one.[59] This map is open access, available on Google Earth. The refinement of such maps matters for submarine detection because the contours of the seabed strongly condition and obstruct sound propagation, so that better maps improve acoustic detection techniques. This kind of basic knowledge about the physical ocean is "the foundation of all ASW objectives."[60]

Enabling Technologies

The complexity and variability of the ocean environment vastly increases the computational requirements of separating the signal from the noise.[61] Since the Cold War, advances in digital processing, solid-state memory, and lithium batteries have increased computational power while decreasing computer size.[62] These technologies enable small sensing platforms to process information *in situ*, and communicate and coordinate across multiple platforms, allowing them to operate as a "swarm." Scientists are currently testing the use of artificial intelligence software to increase the autonomy and integration of the swarm.[63] Operation as a network will enhance the potency of sensors, especially when they are mobile and can automatically optimize their behavior or position.[64] Yet, exploitation of these possibilities requires a new generation of platforms, because Cold War vehicles are too large

[58] "The See-Through Sea."
[59] Scott Sutherland, "Thousands of Undersea Mountains Unveiled as New Gravity Map Strips Away Earth"s Oceans," *The Weather Network*, 20 October 2014.
[60] Stephen J. Coughlin, "Reclaiming Antisubmarine Dominance," *U.S. Naval Institute Proceedings* 139, no. 1 (January 2013): pp. 40–45.
[61] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 13.
[62] Glickson et al., *Oceanography in 2025*, p. 36.
[63] Lonny Lippsett, "A Robot Starts to Make Decisions on Its Own.," *Oceanus* 48, no. 1 (June 2010): pp. 28–29.
[64] Carlo Kopp, "Evolving ASW Sensor Technology," *Defence Today*, December 2010, 26; D.T. Hughes et al., "Collaborative Multistatic ASW Using AUVS: Demonstrating Necessary Technologies" (MAST, Stockholm, Sweden: NATO Undersea Research Centre, 2009), p. 1.

and expensive to effectively operate in a large and mobile network. Aerial, surface, and submarine drone technology satisfies the need for this capability.

A major obstacle to ocean transparency during the Cold War was the persistent gap between detection of a submarine and the localization required for effective targeting. The relative ease of detection using static acoustic platforms preceded the more difficult task of localization using mobile platforms. Autonomous Underwater Vehicles (AUVs) or "drones" can collapse the spatial and temporal distances between detection and localization. When contemporary AUVs are widely distributed, equipped with effective short-range sensors, and networked together, "detection and localization will be simultaneous."[65] With large numbers of drones, the location of an SSBN is "compromised" all at once – the idea is that detection by one AUV automatically triggers the others to swarm together in pursuit, calculating the target's trajectory in real time.[66] These drones can carry any type of sensor including towed passive arrays, and operate in risky maritime environments (because although they are fragile, they are also relatively cheap and unmanned).[67] They could also potentially operate as weapons delivery platforms, or kamikazes, although the primary ASW missions envisioned for AUVs do not include weapons engagement.[68] Enabling drones to track targets automatically complicates countermeasures like evasive maneuvering, deep diving, and the use of decoys. If the full suite of small, autonomous sensing platforms is developed as planned, the outcome is likely to be "highly disruptive" for the existing balance between hiding and seeking.[69] The degree of transparency this scenario represents would be unprecedented, and is currently within the realm of technological possibility.

AUVs are still an emerging technology, but the commercial, scientific, and military sectors are all investing in research and development. Networked underwater drones represent a superior, and potentially cheaper, means of mapping and monitoring the ocean environment. Because AUVs are seen as a major growth market, companies that design sensors, communications, power sources, and vessels are increasingly involved in developing specialized versions of these technologies.[70] In the commercial sector, AUVs produce detailed

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[65] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 5.
[66] Ingram, "Trident: The Need for a Comprehensive Risk Assessment," p. 2.
[67] David Blagden, "What DARPA"s Naval Drone Could Mean for the Balance of Power," *War on the Rocks*, 9 July 2015; Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare."
[68] Robert W. Button et al., *A Survey of Missions for Unmanned Undersea Vehicles*, RAND Corporation Monograph Series (Santa Monica, CA: RAND, 2009), p. 20; Andrew Krepinevich, "Maritime Competition in a Mature Precision-Strike Regime" (Center for Budgetary and Strategic Analysis, 2014).
[69] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare."
[70] J.R. Wilson, "UUVs Hit Their Stride," *Military & Aerospace Electronics*, April 2016, pp. 19–20.

maps of the seafloor in order to identify the best locations for offshore drilling, deep seabed mining, and the position of submarine telecommunications cables. Once operations are underway, AUVs can inspect and monitor technological systems and assist in making repairs. For oceanographers, AUVs are an important new tool for exploring hydrothermal vents, toxic cold seeps, and other benthic marine habitats. Some underwater drones can already operate to a depth of 6000 meters and adapt to unexpected conditions, but advancements in their endurance and flexibility are still anticipated.[71] In particular, marine scientists are developing underwater gliders that rely on buoyancy engines, "a slow but frugal form of travel with a tiny power requirement."[72] These gliders can travel long distances over months, and oceanographers use them to collect large-scale data on chemical and geophysical properties of the ocean. Gliders have also been used to measure radiation levels, inspect icebergs and submarine volcanoes, and follow whales. They have significant dual use potential, especially because gliders are extremely quiet, which makes the acoustic sensors they carry more effective. The Chinese in particular are developing the "academic base" for this technology, although US defense contractors lead in the production of diverse prototypes.[73]

The United States military has invested in several different types of drone programs. The P-8 Poseidon surveillance plane is currently equipped to release Coyote drones from the same tubes used to deploy sonar buoys. Although their mission time is limited to 90 minutes, these aerial drones can be recovered and reused.[74] The Defense Advanced Research Projects Agency's (DARPA) "Upward Falling Payload" program envisions pre-positioned nodes concealed on the vast seabed, which can be activated and deployed immediately. The current design releases payloads that float to the surface and deploy aerial drones.[75] In terms of underwater drones, the Navy has for some time used small, remotely operated vehicles for search and rescue and minesweeping operations.[76] A new autonomous drone, the Large Displacement Unmanned Underwater Vehicle, represents a significant advance. Designed for intelligence and surveillance, this small system will be "stowed, launched and recovered by multiple-host platforms," including ships, attack submarines, and SSBNs.[77] Finally, DARPA"s

[71] Wynn et al., "Autonomous Underwater Vehicles (AUVs)."
[72] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," p. 5.
[73] Hambling, pp. 5–8; Wilson, "UUVs Hit Their Stride."
[74] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare."
[75] Jeffrey Krolik, "Upward Falling Payloads (UFP)," Program Information (Defense Advanced Research Projects Agency, 9 December 2013).
[76] Blagden, "What DARPA"s Naval Drone Could Mean for the Balance of Power"; Geoff Dyer, "US to Sail Submarine Drones in South China Sea," *Financial Times*, 17 April 2016.
[77] Patrick Tucker, "Navy Plans To Deploy A Submarine Drone Squadron By 2020," *Defense One*, 27 October 2015.

autonomous surface vessel – the "Anti-Submarine Warfare Continuous Trail Unmanned Vessel" (ACTUV) – is currently in the sea trial phase. Designed to detect and automatically track submerged vessels, this 130-foot unmanned vessel can operate autonomously for 70 days, and carry diverse non-conventional sensor technologies.[78] These drone programs each erode the opacity of the ocean in their own way, and are intended to operate in a network with aircraft or submarines that may pursue actual engagement with enemy vessels. The overall goal is to connect multiple types of mobile, deployable, and in situ sensors into a network that autonomously and automatically reacts to maintain the precise location of a potential target.

One persistent challenge for hypothetical networks of swarming AUVs is the need to communicate between vehicles. Individual mobility and group coordination requires wireless communication. Underwater acoustic communications are low bandwidth and must occur at close range, such that coverage of a wide area requires a large number of AUVs with sophisticated on board "reasoning."[79] Surface radio communications have a longer range, but require making the AUV vulnerable by surfacing and/or raising antennas.[80] While networked underwater communication is the subject of on-going research, one simple solution would be the deployment of a large number of AUVs that could be distributed across a wide area without too much distance between them. Another option is networking with other platforms, such as "gateway buoys," whose primary purpose is the facilitation of networked communication. These methods carry their own costs and vulnerabilities.

Improvements in Acoustic Detection

Despite some technological advances, the balance between acoustic methods of hiding and seeking remains about where it was at the end of the Cold War. Acoustic systems locating submarines have been both downgraded and enhanced. Several of the SOSUS networks operated by the US military have been shut down or repurposed for non-military ends.[81] A small set of regional sonar arrays, however, has been augmented and updated in three ways: by adding new kinds of mobile sensors, improving communication between sensors, and

[78] Richard R. Burgess, "Follow That Sub," *Seapower*, July 2013; A. Prasad, "Darpa Builds Drone to Hunt down Submarines," *International Business Times*, 16 February 2016.
[79] Hughes et al., "Collaborative Multistatic ASW Using AUVS: Demonstrating Necessary Technologies."
[80] Button et al., *A Survey of Missions for Unmanned Undersea Vehicles*, p. 103.
[81] William J. Broad, "Scientists Fight Navy Plan to Shut Far-Flung Undersea Spy System," *The New York Times*, 12 June 1994; Edward C. Whitman, "First-Generation Installations and Initial Operational Experience," *Undersea Warfare*, Winter 2005; Jeremy Page, "Underwater Drones Join Microphones to Listen for Chinese Nuclear Submarines," *The Wall Street Journal*, 24 October 2014.

networking with the hydrophone arrays of allies.[82] The development and deployment of multi-static sonar entails technical performance improvements, and facilitates operation in a larger network.[83] The Integrated Undersea Surveillance System includes SOSUS arrays, the Surveillance Towed Array Sensor System, and other fixed and mobile acoustic systems. The operational concept envisions a global network of submarine "seekers," including deployable sensors that connect readily with other platforms and the hydrophones of allies, "like an underwater internet."[84] This vision has only been partially realized in the "sector location" tactic that coordinates P-8 Poseidon surveillance planes, satellites, passive hydrophones, and surface ships towing arrays. One basic obstacle is the slow communication speeds through water, which were described by one authority as "roughly where the Internet was 30 years ago."[85] The acoustic environment of the East Asian littoral seas, where the concept has primarily been tested, is especially challenging for passive sonar.

The challenging littoral environment, combined with improvements in submarine quieting in the late Cold War, prompted western navies to increase their investment in active sonar technology.[86] Mid-frequency active sonar was already a standard tactical tool for surface ships, but lower frequencies promised superior detection ranges. Low-frequency active (LFA) sonar was developed in the late 1980s and deployed in the 1990s on towed arrays, which could be placed below the warm surface layer.[87] Variable depth LFA sonar quickly became the "sensor of choice" among western navies, although it still operates among a wider network of mobile and fixed passive arrays. Active sonar faces many of the same challenges as passive sonar in the littoral environment, including high ambient noise, reverberation, and coastal mixing that

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[82] Jeremy Page, "Underwater Drones Join Microphones to Listen for Chinese Nuclear Submarines," *The Wall Street Journal*, 24 October 2014; Jeremy Page, "As China Deploys Nuclear Submarines, U.S. P-8 Poseidon Jets Snoop on Them," *The Wall Street Journal*, 24 October 2014; Barbara Honegger, "Naval Postgraduate School Pioneers "Seaweb" Undersea Sensor Networks," *Naval Postgraduate School Public Affairs*, 12 August 2010; "Captain Nemo Goes Online," *The Economist*, 9 March 2013; Dale Green, "Autonomous 4D Underwater Environmental Sampling.," *Sea Technology* 46, no. 10 (October 2005): pp. 51–53.

[83] Robert Been et al., "Multistatic Sonar: A Road to a Maritime Network Enabled Capability" (Undersea Defence Technology Europe, Naples, Italy: NATO Undersea Research Centre, 2007), p. 9.

[84] Owen R. Jr. Cote, How will new Submarine Sensors and Payloads Influence Naval Warfare in the 21st Century? 4 June 2012; "Captain Nemo Goes Online."

[85] Page, "Underwater Drones Join Microphones to Listen for Chinese Nuclear Submarines."

[86] John Pike, "Low-Frequency Active (LFA)," Intelligence Resource Program (Federation of American Scientists, 21 June 1997).

[87] Angela D'Amico and Richard Pittenger, "A Brief History of Active Sonar," *Aquatic Mammals* 35, no. 4 (1 December 2009): p. 430.

disrupts temperature and density-based ocean layers.[88] Active sonar also entails a high risk of detection and counter-attack, and is politically unpopular because of the harm it causes to charismatic mega fauna like dolphins and whales.[89] While this has led the Navy to restrict the total usage of LFA sonar, DARPA currently has a prototype program to equip an AUV with active sonar.[90]

Investments in acoustic detection also take place within fisheries management, where the technique of Ocean Acoustic Waveguide Remote Sensing represents a significant advancement in the ability to monitor fish populations. This low frequency technique, which uses the continental shelf to guide horizontal sound waves, can generate "instantaneous wide-area sensing of marine life over thousands of square kilometers."[91] The passive sonar version of waveguide remote sensing has been able to detect individual marine mammals from their vocalizations.[92] The scientists working to innovate this technique suggest that it is applicable to the detection and localization of individual submarines.[93] The active sonar version has been described as "game-changing," and although it has not yet been deployed by militaries, its utility for ASW is rapidly being recognized.[94]

Evasive and defensive strategies remain generally effective against acoustic sensing. These include slow travel and hiding in "shadow zones" to reduce submarine signatures.[95] Even when they are widely distributed and finely tuned, passive acoustic arrays are easily destroyed or confused by defensive technology. This is a basic acoustic advantage for opacity: "The provision of hundreds or thousands of such noisemakers could well eliminate the possibility of detecting submarines in the first place."[96] Total acoustic transparency may be unlikely, but sensor improvements still degrade the opacity of the ocean. When deployed on

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[88] Richard Scott, "Sound Effects: Low Frequency Active Sonar Comes of Age," *Jane"s Navy International* 120, no. 4 (1 May 2015): p. 26.

[89] "Lethal Sounds" (Natural Resources Defense Council, 6 October 2008),

[90] Shelby Sullivan, "Distributed Agile Submarine Hunting (DASH)" (Defense Advanced Research Projects Agency, n.d.).

[91] Ankita Jain et al., "Feasibility of Ocean Acoustic Waveguide Remote Sensing (OAWRS) of Atlantic Cod with Seafloor Scattering Limitations," *Remote Sensing* 6, no. 1 (20 December 2013): pp. 180–208.

[92] Delin Wang et al., "Vast Assembly of Vocal Marine Mammals from Diverse Species on Fish Spawning Ground," *Nature* 531, no. 7594 (2 March 2016): pp. 366–70.

[93] Carol Naughton and Sebastian Brixey-Williams, "British Pugwash Workshop: Emerging Undersea Technologies" (National Liberal Club, Whitehall: British Pugwash, 9 May 2016), p. 2.

[94] Sebastian Brixey-Williams, "Will the Atlantic Become Transparent?" vol. 2 (Pugwash conferences on science and world affairs, British Pugwash, 2016).

[95] "How Do Submarines Stay Undetected?" *The Telegraph*, 22 October 2014.

[96] Garwin, "Will Strategic Submarines Be Vulnerable?"

new platforms, and networked with other types of sensors, passive and active sonar still play an important role in the detection of SSBNs.

Innovations in Non-Acoustic Detection

At the end of the Cold War, non-acoustic detection methods were more theoretical than operational, and all were vulnerable to the same basic countermeasure: traveling deep.[97] The primary difficulties were technical: separating the signal from the noise, and accounting for environmental variability. Platform options were limited to aircraft and satellites, and each provided insufficient coverage.[98] However, in the last two decades, technological advances in both sensors and platforms have created new possibilities for non-acoustic detection. The full development and integration of these sensing methods into operational platforms may entail major transparency gains. Four types of non-acoustic detection will be considered, each of which benefits from advances in sensor platforms.

Many types of sensors have extended their ranges while reducing their size and cost, which makes placing a large quantity on small platforms both attractive and feasible.[99] When these platforms are mobile like AUVs, they can follow an SSBN as it travels into the deep. Progress has even been made against the problem of "biofouling," which degrades sensors and reduces their service life.[100] New types of sensors are emerging, and marine scientists have a strong interest in the development and deployment of non-acoustic sensors. The signatures that can be observed by non-acoustic detection methods depend on the properties of the submarine itself, and its interactions with the ocean environment. These can include electromagnetic effects, biological disturbances, internal and surface waves, temperature change, optical reflectivity or absorption, and chemical or radioactive tracers.[101] A survey of the most promising non-acoustic detection methods suggests that their contribution to ocean transparency may be significant.

LIDAR measures distance using the reflections of lasers, and the method has been successfully used in seafloor mapping and mine detection.[102] Although LIDAR has been the

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[97] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 17.
[98] Stefanick, pp. 23–24.
[99] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," p. 9.
[100] Javeed Shaikh Mohammed, "Micro- and Nanotechnologies in Plankton Research," *Progress in Oceanography* 134 (May 2015): pp. 451–73.
[101] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 183.
[102] Kopp, "Evolving ASW Sensor Technology," p. 29.

subject of optimism regarding submarine detection, it is unlikely to overcome the problem of "backscatter" from the clouds and sea surface, which reduces the signal strength.[103] This method of non-acoustic detection is ultimately thwarted by ocean geophysics; "there is no possibility of strategically significant blue-green laser ASW because even the optimum laser color does not penetrate (in a round-trip) to the comfortable operating depth of existing submarines."[104] LIDAR might be useful for short-range localization of shallow submarines, but it is ineffective for wide-area surveillance.[105] These barriers are unlikely to be overcome by technology.

Another non-acoustic signature that could theoretically be detected is the effect of submarine transit on marine microorganisms, especially those with bioluminescent reactions.[106] Because oceanography had an early and persistent focus on geophysical systems – encouraged by the Office of Naval Research – detection and modeling of chemical and biological systems is especially immature.[107] Yet, marine scientists increasingly understand these conceptually distinct systems as a single integrated biogeochemical system, such that it is theoretically possible to measure biological effects as proxies for the physical effects of submarines. Some biological effects are being actively monitored; ocean color remote sensing from satellites is used to derive productivity baselines from algal blooms.[108] Also, the relevance of micro- and nanotechnology for plankton research is increasingly recognized.[109] However, these biological sensor systems remain fundamentally immature, and this detection method is easily evaded by diving deep, where less prevalent bioluminescence is too deep to shine up to the surface.[110]

A more promising technique, Magnetic Anomaly Detection (MAD) seeks out disturbances in the Earth's magnetic field caused by the transit of a submarine. MAD is a mature technology that is deployed by patrol aircraft, but it has a limited range that makes it incapable of wide area surveillance.[111] Plans to deploy MAD on aerial drones launched from

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[103] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 21.
[104] Garwin, "Will Strategic Submarines Be Vulnerable?" p. 61.
[105] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 22.; Naughton and Brixey-Williams, "British Pugwash Workshop: Emerging Undersea Technologies," p. 3.
[106] G.G. Wren and D. May, "Detection of Submerged Vessels Using Remote Sensing Techniques," *Australian Defence Force Journal*, no. 127 (1997): pp. 11–13.
[107] Hamblin, *Oceanographers and the Cold War*; Glickson et al., *Oceanography in 2025*.
[108] David Blondeau-Patissier et al., "A Review of Ocean Color Remote Sensing Methods and Statistical Techniques for the Detection, Mapping and Analysis of Phytoplankton Blooms in Coastal and Open Oceans," *Progress in Oceanography* 123 (April 2014): pp. 123–44.
[109] Mohammed, "Micro- and Nanotechnologies in Plankton Research."
[110] Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 18.
[111] Wren and May, "Detection of Submerged Vessels Using Remote Sensing Techniques," p. 10.

patrol aircraft (specifically the P-8 Poseidon) could expand its range, but a more significant breakthrough exists on the horizon. The application of "Superconducting Quantum Interference Devices" (SQUID) to MAD promises major advances in sensitivity and range. SQUID magnetometers have been used in oil exploration, mapping tectonic faults, and biomedical imaging.[112] The emergence of micro-cryogenic cooler technology enables the application of SQUID to military surveillance.[113] Increasingly detailed maps and models of the Earth's magnetic field complement the increased sensitivity of SQUID sensors, and decrease false alarm rates. "The full potential of MAD techniques remains to be exploited in operational systems," but the availability of drone platforms and the improvement in sensor range makes this detection technology promising.[114]

Another promising technique looks for disturbances in the circulation of ocean water. The passage of a submarine creates internal waves in the vertical layers of the ocean, and two types of surface waves that trail behind it. Earth systems scientists regularly use satellite-based remote sensing to measure properties of the sea surface such as its height, temperature, salinity, color, and surface currents. Yet surface waves remain difficult to detect because of "the enormous variability of ocean surface conditions."[115] The resolution and coverage of sea-surface measurements is insufficient to detect these patterns with consistency and precision. Internal waves below the surface may actually be more promising for detection. Oceanographers of all types could benefit from more informed maps and models of ocean layering and turnover, and such knowledge is also critical for understanding the challenge of climate change.[116] This sought-after knowledge provides important information about environmental variation that could be useful for separating a signal from noise. Internal waves caused by the transit of a submarine propagate a long distance along density layers, so the signal is not miniscule. Satellite-based Synthetic Aperture Radar is capable of identifying the main features of internal waves from the modulations they cause at the sea surface.[117] Advances in scientific knowledge about ocean layering will improve the precision of this detection technique.

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[112] Jennifer Ouellette, "SQUID Sensors Penetrate New Markets," *Industrial Physicist* 4, no. 2 (June 1998): p. 21.
[113] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," pp. 3–4.
[114] Kopp, "Evolving ASW Sensor Technology," p. 28.
[115] Kopp, p. 28.
[116] Victor Klemas and Xiao-Hai Yan, "Subsurface and Deeper Ocean Remote Sensing from Satellites: An Overview and New Results," *Progress in Oceanography* 122 (March 2014): p. 2.
[117] Klemas and Yan, p. 6.

Transparency through Technological Presence

Technological developments in the last few decades have overcome major technical hurdles to detection that had ensured the persistence of opacity throughout the Cold War. AUVs solve two problems for surveillance: they make it impossible to hide in the deep, and they reduce noise by getting sensors closer to the signal. Acoustic sensing is still limited by the problem of noise, but augmented through the deployment of multiple networked platforms. At least two non-acoustic signatures – magnetic anomalies and internal waves – are increasingly detectable. The "robotization of the oceans" is beginning, and the number and variety of stationary and mobile sensors is projected to increase drastically in pursuit of military and non-military objectives.[118] Even if sensors themselves are limited, greater transparency may be achieved through sheer technological presence. The multiple drivers of these technologies, and the investment of militaries in both hiding and seeking, mean that no one is in control of this situation.

Transparency Potentials and Opacity Advantages

> As long as the oceans remain opaque – that is, as long as submarine concealment outpaces detection capabilities – this underwater deterrent should remain invulnerable.[119]

> December 2056: The last piece was put in place. The inability to detect nuclear submarines lurking in the ocean depths by satellite had long been the technical stumbling block. Now, at last, a new-generation satellite-based laser had made the dreams of "making the oceans transparent" come true. No subs had the cloaking tech to shield themselves -- we hoped.[120]

Ocean transparency is a continuous variable whose value at any given time is determined by the current state of hiding and seeking technologies. The first revolution in transparency during the early Cold War prompted a re-evaluation of nuclear force structure in order to avoid the destabilization associated with incentivizing a first strike. Somewhere along

[118] Matt Simon, "Brave Robots Are Roaming the Oceans for Science," *Wired*, 13 April 2015.
[119] Ann L. Hollick, *U.S. Foreign Policy and the Law of the Sea* Princeton, (N.J.: Princeton University Press, 1981), p 9.
[120] Ron Rosenbaum, "The Nuclear Question," *Scientific American*, January 2013.

the continuum of ocean transparency, there exists another threshold of destabilizing transparency. Although detection and localization is still very taxing, even for advanced navies, it is progressively getting easier to find SSBNs.[121] The success of "mutually assured destruction" depends on the maintenance of invulnerable retaliatory capabilities, on both sides of a potential conflict. The survivability of strategic nuclear weapons undergirds crisis stability, a proxy for the risk of nuclear exchange.[122] If strategic nuclear submarines (SSBNs) become vulnerable to pre-emptive attack because of transparency, the implications for nuclear force structure, policy, and strategy could be profound.

Force Structure Changes

The modernization plans of several nuclear powers assume that opacity will endure. The potential of ocean transparency is a bigger concern for the western nuclear powers, which rely more heavily on submarines for survivability.[123] The United States deploys sixty percent, France deploys over eighty percent, and Great Britain deploys one hundred percent of its strategic nuclear forces on SSBNs.[124] Two of these powers – the United States and United Kingdom – are preparing to build a new class of SSBNs to replace their Trident-era submarines. These new SSBNs are based on contemporary technical designs, but are expected to patrol the ocean for the next several decades.[125] Because the procurement process involves multiple parochial interests, there is no guarantee of a good investment.[126] Also, because each SSBN costs more than a billion dollars (USD), many policymakers want to know exactly what they are buying. Risk assessments surrounding ocean transparency play a critical role in the decision to replace and modernize Trident-era submarines, both in the United States (Ohio class) and United Kingdom (Vanguard class).

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[121] Jan Joel Andersson, "The Race to the Bottom: Submarine Proliferation and International Security," *Naval War College Review* 68, no. 1 (Winter 2015): 25; Naughton and Brixey-Williams, "British Pugwash Workshop: Emerging Undersea Technologies."
[122] Robert Powell, "Nuclear Deterrence Theory, Nuclear Proliferation, and National Missile Defense," *International Security* 27, no. 4 (Spring 2003): p. 97; Stefanick, *Strategic Antisubmarine Warfare and Naval Strategy*, p. 1.
[123] Ashton B. Carter et al., eds., *Ballistic Missile Defense* (Washington, D.C: Brookings Institution, 1984); Blagden, "What DARPA"s Naval Drone Could Mean for the Balance of Power."
[124] Gregory D. Koblentz, "Strategic Stability in the Second Nuclear Age," Council Special Report (Council on Foreign Relations, November 2014), pp. 9, 13.
[125] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," p. 2.
[126] Dalgleish and Schweikart, *Trident*, p. 4.

In the UK, members of the Labour party have publicly challenged the assumption of persistent opacity, and generated a polarized debate over the wisdom of the planned "like-for-like" replacement of Trident-era SSBNs.[127] The UK deploys all of its strategic nuclear forces on submarines as a strategy of "minimum nuclear deterrence," which is achieved by continuous patrol at sea, and which requires that SSBN forces be capable of surviving a first strike. Opponents of modernization view it as a budgetary issue, and argue that the program delays and ballooning costs are not worth what may be an obsolete technology upon completion.[128] The question of modernization also connects to a more general debate about nuclear disarmament, which divides the Labour party internally. This pattern has occurred before. In the late 1970s, the Chevaline program rapidly modernized Polaris missiles to counter the Soviet ABM threat, a move opposed by vocal proponents of disarmament within the Labour party.[129] Pro-disarmament groups today argue that SSBN vulnerability will overwhelm SSBN utility in the medium term. If SSBNs become detectable, they lose their strategic value as the foundation of minimum deterrence.[130] Without the ability to hide, they argue, "most other dimensions of large submarines (slow, vulnerable and isolated) are weaknesses."[131] These concerns about the reliability of the secure second strike are magnified by the risk of effective cyber espionage and ballistic missile defense.[132] Because patrolling submarines are away from the populated homeland, they make an attractive target for a disabling first strike.[133] The UK"s contribution to strategic nuclear deterrence seems especially vulnerable to transparency, because their "continuous at-sea deterrence" relies on only a single SSBN on patrol at any given time.[134]

In the United States, the fledgling SSBN(X) replacement program has earned support and funding based on the assumption of continued survivability.[135] This decision may reflect

[127] Rowena Mason, "Labour Trident Tensions Resurface over Hiding Capability of Submarines," *The Guardian*, 9 February 2016; Ingram, "Trident: The Need for a Comprehensive Risk Assessment"; Andrew Futter, "Trident Replacement and UK Nuclear Deterrence: Requirements in an Uncertain Future," *The RUSI Journal* 160, no. 5 (3 September2015): pp. 60–67; Nick Ritchie, "Feeding the "monster":Escalating Capital Costs for the Trident Successor Programme" (BASIC, April 2016).
[128] Ingram, "Will Trident Still Work in the Future?" p. 4.
[129] Kristan Stoddart, "The British Labour Government and the Development of Chevaline, 1974-79," *Cold War History* 10, no. 3 (August 2010): pp. 287–314.
[130] Hambling, "The Inescapable Net: Unmanned Systems in Anti-Submarine Warfare," p. 1.
[131] Ingram, "Trident: The Need for a Comprehensive Risk Assessment," p. 2.
[132] Futter, "Trident Replacement and UK Nuclear Deterrence."
[133] Ingram, "Trident: The Need for a Comprehensive Risk Assessment," p. 1.
[134] Futter, "Trident Replacement and UK Nuclear Deterrence," p. 62.
[135] Moltz, "Submarine and Autonomous Vessel Proliferation: Implications for Future Strategic Stability at Sea," p. 20; Ronald O"Rourke, "Navy Ohio Replacement (SSBN[X]) Ballistic Missile Submarine Program: Background and Issues for Congress" (Congressional Research Service, 23 September 2015).

optimism about hiding technologies, or simply the "tendency for America to become a captive of national commitments after they no longer serve national interests."[136] However, were the United States to determine that its SSBNs are vulnerable to detection; the reaction would likely include alterations in force structure. This is because the view that deterrence is fragile or delicate persists in and around the United States military, as an "anxiety that the nuclear balance could tilt abruptly and give an adversary an advantage."[137] This view, in which deterrence is difficult to achieve and easy to lose, takes seriously the possibility of incentivizing a first strike. As such, it places paramount importance on the invulnerability of secure second-strike forces; only "assured" mutual destruction can eliminate nuclear war as a tool of statecraft.[138] From this perspective, oceanic transparency would be extremely destabilizing because it would undermine the survivability of an SSBN second-strike capacity. In this scenario, the United States might not fear an immediate first strike, but military leaders would feel pressure to recover opacity, as McNamara did in calling for the STRAT-X study. This could entail an investment in mobile ICBMs, the next best thing to SSBNs, or a crash program to develop a new weapons system.[139] Given that Russia and China already deploy mobile ICBMs, the perception of a strategic deficiency may be especially acute.

A more likely scenario is that the United States will be able to detect the submarines of its strategic rivals. Russia has maintained and is modernizing its SSBN force, although the number of Russian SSBNs, and their ability to continuously patrol the oceans, has declined significantly in the last two decades.[140] Russia's replacement for Soviet era submarines, the Borey-class SSBN armed with Bulava SLBMs, is already being produced with the goal of deploying eight by 2020, and is designed to counter traditional ASW methods.[141] Any additional SSBN modernization would require massive expenditures and overwhelming political will.[142] Although the Borey-class SSBNs illustrate Russia's commitment to maintaining a sea-based nuclear deterrent, it is unlikely that Russia would be capable of undertaking a crash

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[136] Dalgleish and Schweikart, *Trident*, p. 350.
[137] Adam Mount, "The Indelicate Balance of Nuclear Modernization," *Bulletin of the Atomic Scientists*, 28 January 2016.
[138] Jervis, *The Meaning of the Nuclear Revolution*, p. 9.
[139] Lt Col Matthew E. Dillow, "Nuclear Hell on Wheels: Examining the Need for a Mobile ICBM," CUWS Trinity Site Papers (United States Air Force Center for Unconventional Weapons Studies, June 2015)
[140] Benjamin Schwarz, "The Perils of Primacy," *The Atlantic*, 1 January 2006; Hans M. Kristensen, "Russian SSBN Fleet: Modernizing But Not Sailing Much," *Federation of American Scientists*, 3 May 2014.
[141] Richard Weitz, "Russia Revitalizes Its Submarine Deterrent," *World Politics Review*, 15 January 2013.
[142] Daniel Thomassen, "Russian Blue-Water Navy Is a Pipe Dream," *U.S. Naval Institute Proceedings* 142, no. 11 (November 2016): pp. 22–26.

modernization program to counter new ASW capabilities. Russia's mobile land-based ICBMs, however, may provide some relief against acute vulnerability.

The more interesting case may be China, which has built and deployed several Jin class SSBNs in recent years. A historically restrained nuclear power, China's nuclear force structure is intended to achieve "assured retaliation," which requires a small number of survivable weapons. For many decades, the Chinese leadership seemed to believe that its land-based nuclear forces were sufficient for this strategy.[143] However, recent advances in US weapons systems, including conventional strike forces, missile defense, and SLBM accuracy have raised concerns about the survivability of Chinese deterrent forces.[144] As well, many analysts consider mobile ICBMs locatable, targetable, and therefore vulnerable.[145] In response to these concerns about the survivability of land-based nuclear weapons, China's SSBN program attempts to regain opacity through the "mobility and concealment" possible in the ocean operational environment.[146] SSBNs also have the advantage of signaling China's entry into the top tier of nuclear powers.

The noise level of China's SSBNs has led many to question whether they are actually undetectable.[147] However, China's less-than-perfect submarines are complemented by an anti-access/area-denial (A2/AD) strategy reminiscent of the Soviet Union's bastion strategy. The Arctic environment of the Soviet bastion was favorable for hiding because of the background noise and additional surface opacity provided by the ice cover. The littoral environment of South East Asia is also noisy, and much more crowded. The shallow seas, narrow passages, and myriad islands of this region contain lucrative shipping routes, fisheries and fossil fuel deposits, and Chinese territorial ambitions. This is China's ideal bastion, where its Jin class SSBNs can hide from precise detection, and still be within SLBM range of Alaska, Hawaii, and Guam. It is unclear whether Jin-class SSBNs have been carrying out nuclear deterrent patrols, although

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[143] M. Taylor Fravel and Evan S. Medeiros, "China's Search for Assured Retaliation: The Evolution of Chinese Nuclear Strategy and Force Structure," *International Security* 35, no. 2 (Fall 2010): pp. 48–87.
[144] Keir A. Lieber and Daryl G. Press, "The New Era of Nuclear Weapons, Deterrence, and Conflict," *Strategic Studies Quarterly* 7, no. 1 (Spring 2013): pp. 3–14; Koblentz, "Strategic Stability in the Second Nuclear Age," p. 21.
[145] "Ballistic Missile Submarines: The Only Way to Go" (Stratfor, 24 April2007); Dillow, "Nuclear Hell on Wheels: Examining the Need for a Mobile ICBM"; Long and Green, "Stalking the Secure Second Strike."
[146] Fravel and Medeiros, "China's Search for Assured Retaliation: The Evolution of Chinese Nuclear Strategy and Force Structure," p. 86.
[147] Hans M. Kristensen, "China SSBN Fleet Getting Ready - But For What?" *Federation of American Scientists*, 25 April 2014.

they are presently expected.[148] The overall A2/AD regional strategy aims to frustrate US power projection in the Western Pacific, and especially the seas of Southeast Asia.[149] This requires the ability to detect US attack submarines. To this end, China has deployed its first fixed sonar arrays in the Yellow, East, and South China Seas.[150] China has also made substantial investments in AUV research.[151]

The deployment of SSBNs (and more general military modernization) opens up new strategic possibilities for China, and increases the salience of nuclear weapons in the Asia Pacific security environment.[152] In the competition between hiding and seeking, the littoral environment represents unique possibilities. The small size of regional seas makes saturation coverage easier to achieve, and because AUVs are cheap and unmanned, they are more readily deployed in dangerous areas. Acoustic sensing is especially challenging, however, because "sound transmission...is highly unpredictable because of the seabed's proximity, great variations in sea temperature and salinity, freshwater influx from rivers, and the effect of tides, currents, ice, wind, and waves."[153] Magnetic Anomaly Detection is also more challenging in littorals, where variations in seabed magnetism and the presence of sunken ships generate many false alarms.[154] In contrast, physical surface effects are more pronounced in shallow seas. The key determinant of littoral transparency in Southeast Asia may be the number of on-site and mobile sensors.

Risky Strategic Postures

Force structure changes occur slowly, and countries reacting to transparency may pursue interim strategies for achieving nuclear deterrence. One means of making a retaliatory strike secure is to launch the weapons before the first strike hits. In the early Cold War,

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148 Hans M. Kristensen and Robert S. Norris, "Chinese Nuclear Forces, 2016," *Bulletin of the Atomic Scientists* 72, no. 4 (3 July 2016): pp. 205–11.
149 Kyle D. Christensen, "Strategic Developments in The Western Pacific: Anti-Access/Area Denial And The Airsea Battle Concept," *Journal of Military & Strategic Studies* 14, no. 3/4 (2012): pp. 1–24.
150 Lyle Goldstein and Shannon Knight, "Sub Force RISING," *U.S. Naval Institute Proceedings* 139, no. 4 (April 2013): pp. 40–44; Lyle Goldstein and Shannon Knight, "Wired for Sound in the "Near Seas," *U.S. Naval Institute Proceedings*, April 2014.
151 Michael S. Chase et al., "Emerging Trends in China's Development of Unmanned Systems" (RAND Corporation, 2015).
152 Elbridge Colby, "Asia Goes Nuclear," *National Interest*, February 2015.
153 Milan Vego, "The Right Submarine for Lurking in the Littorals," *U.S. Naval Institute Proceedings* 136, no. 6 (June 2010): pp. 16–21.
154 Kopp, "Evolving ASW Sensor Technology," p. 28.

American strategists proposed adopting a "launch on warning" posture until a survivable force – such as mobile ICBMs – could be built and deployed.[155] The adoption of such a posture would in itself be a negative development for strategic nuclear stability; "launch on warning" is understood to significantly increase the risk of accidental war.[156] If countries like the United States and Russia adopt this posture, China, India, and Pakistan are likely to do the same.[157] A "launch on warning" posture would be even more dangerous in South Asia.[158] The possibility of an effective first strike by the United States could destabilize great power politics by encouraging such risky strategic postures, and even military pre-emption.[159] The best way to "de-alert" from a dangerous "launch on warning" posture is to assign the function of retaliation to a completely survivable force.[160]

Transparency does not have to be synoptic to make submarines vulnerable. The small number of SSBNs each national military has on patrol, and the even smaller number of submarine bases, means that sensing technologies can achieve functional transparency before they achieve global-scale transparency.[161] AUV platforms in particular could pick up a submarine as it exits its base or transits maritime chokepoints, and then track its course automatically.[162] This situation, where a state locates all of its rival's SSBNs today, but may not be able to keep track of them tomorrow, is particularly destabilizing. A closing window of first strike opportunity increases crisis instability, which is why forces that are always invulnerable are best for stability.[163]

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[155] Elbridge A Colby et al., *Strategic Stability: Contending Interpretations*, 2013, p. 11.
[156] Bruce G. Blair, *The Logic of Accidental Nuclear War* (Washington, D.C: Brookings Institution, 1993); Bruce G. Blair and Chen Yali, "The Fallacy of Nuclear Primacy," *China Security*, Autumn 2006, pp. 51–77; Steven Starr et al., "New Terminology to Help Prevent Accidental Nuclear War," *Bulletin of the Atomic Scientists*, 29 September 2015.
[157] Bruce G. Blair, "Achieving the Vision of a World Free of Nuclear Weapons" (International Conference on Nuclear Disarmament, Oslo, Norway, 2008).
[158] Frank Von Hippel, R. Rajaraman, and Zia Mian, "U.S.-Russian Lessons for South Asia," *Foreign Policy In Focus*, 2 August 2002.
[159] Geoffrey Till, *Maritime Strategy and the Nuclear Age* (New York: St. Martin's Press, 1984), p. 221; Long and Green, "Stalking the Secure Second Strike."
[160] Walter B. Slocombe, "De-Alerting: Diagnoses, Prescriptions, and Side-Effects" (Re-framing De-Alert: Decreasing the Operational Readiness of Nuclear Weapons Systems in the U.S.-Russia Context, Yverdon, Switzerland, 2009).
[161] Moltz, "Submarine and Autonomous Vessel Proliferation: Implications for Future Strategic Stability at Sea," p. 6.
[162] Moltz, p. 19.
[163] Jervis, *The Meaning of the Nuclear Revolution*, p. 140.

There are many other possible ways that military actors may respond to increasing ocean transparency. The isolated, open-ocean patrols that formerly hid SSBNs safely under the surface may become a thing of the past. The bastion strategy could be adopted by all major nuclear powers, such that SSBNs are kept in noisy, covered, or well-defended areas. Large swarms of AUVs may travel in convoys around SSBNs to disrupt localization by acoustic or non-acoustic measures. Fear of transparency could lead vulnerable nuclear powers to target communications nodes that enable networked sensing, or develop techniques to trawl AUVs out of certain areas. Attempts to sustain survivability could be relatively simple – such as investing in mobile ICBMs or adopting "launch on warning" postures – or complex, involving ASW measures and counter-measures without one having a clear advantage. Any of these scenarios represent a significant risk of instability.

Conclusion

If ocean transparency made nuclear strategic submarines more detectable, locatable, and targetable, the military and political implications would be significant. Yet the topic of SSBN vulnerability is "virtually taboo" in the US Navy's public documents.[164] A culture of complacency has set in regarding the role and missions of SSBNs, such that submariners are poorly equipped to adjust to potentially novel operational realities.[165] Other countries are walking the same path: the planned development of SSBNs by India and Pakistan is driven by a judgment about their superior and durable survivability.[166] This paper challenges the assumption that extrapolations from the past can serve as reliable guides for the future. Specifically, the security of second-strike capabilities, and therefore the assurance of mutual destruction, rests on fluid material foundations. Whether the potential obsolescence of "hiding" technologies occurs as a slow erosion of usefulness, or an avalanche of illumination, could have serious implications for nuclear strategic stability.

The possibility of, and reactions to, ocean transparency present a challenge for the prevailing arms control regime. The force structures created and shaped by existing arms control treaties assume the superior survivability of SSBNs as the foundation of nuclear

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[164] Moltz, "Submarine and Autonomous Vessel Proliferation: Implications for Future Strategic Stability at Sea," p. 2.

[165] Brian McGuirk, "Rekindling the Killer Instinct," *U.S. Naval Institute Proceedings* 138, no. 6 (June 2012): pp. 40–45; Coughlin, "Reclaiming Antisubmarine Dominance."

[166] Iskander Rehman, "Drowning Stability: The Perils of Naval Nuclearization and Brinkmanship in the Indian Ocean," *Naval War College Review* 65, no. 4 (Autumn 2012): pp. 64–83.

deterrence. If transparency were to arrive as a "technological surprise," this feature of the regime sets the stage for instability.[167] The responses to transparency described in the final section each have negative implications for the existing arms control regime. Without invulnerability, nuclear states may pursue a "safety in numbers" approach to achieving a secure second strike, which would require a substantial buildup in weaponry. The pursuit of "launch on warning" postures conflicts with the arms control agenda of "lengthening the fuse."[168] If "mutually assured destruction" were abandoned wholesale, the possible return to a "war strategism" approach that sees nuclear weapons as usable would be especially detrimental to the arms control agenda. An arms control regime that accounts for the possible erosion of transparency might replicate the Treaty on Open Skies, which regulates the frequency and resolution of aircraft surveillance.[169] This strategy would entail rebuilding opacity by treaty where it may be undermined by technology.

It is unlikely that the ocean will become transparent everywhere, all at once. While predicting exactly how and where transparency will be achieved is impossible, this analysis suggests where to look in order to see transparency coming. Broad and precise ocean sensing requires advanced technology, which is restricted to technically proficient actors with substantial funds. However, new motivations and open-access oceanography imply that such innovations may not be limited to the US military. The variegated terrains of the vast ocean create different sets of opportunities and challenges for hiding and seeking in the sea, so that transparency is likely to be a regional phenomenon before it is a global one. Who is investing, and what regions matter, is substantially a function of contemporary international politics. The ocean operational environment has historically been a good place to secure a second-strike capability, but increased understanding and advancing technology may soon undermine the opacity that strategic submarines have hidden behind since the 1960s.

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[167] Colby et al., *Strategic Stability*.
[168] Harold A. Feiveson and Bruce G. Blair, eds., *The Nuclear Turning Point: A Blueprint for Deep Cuts and de-Alerting of Nuclear Weapons* (Washington, DC: Brookings Institution Press, 1999).
[169] Larkin, "The Age of Transparency: International Relations Without Secrets."

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