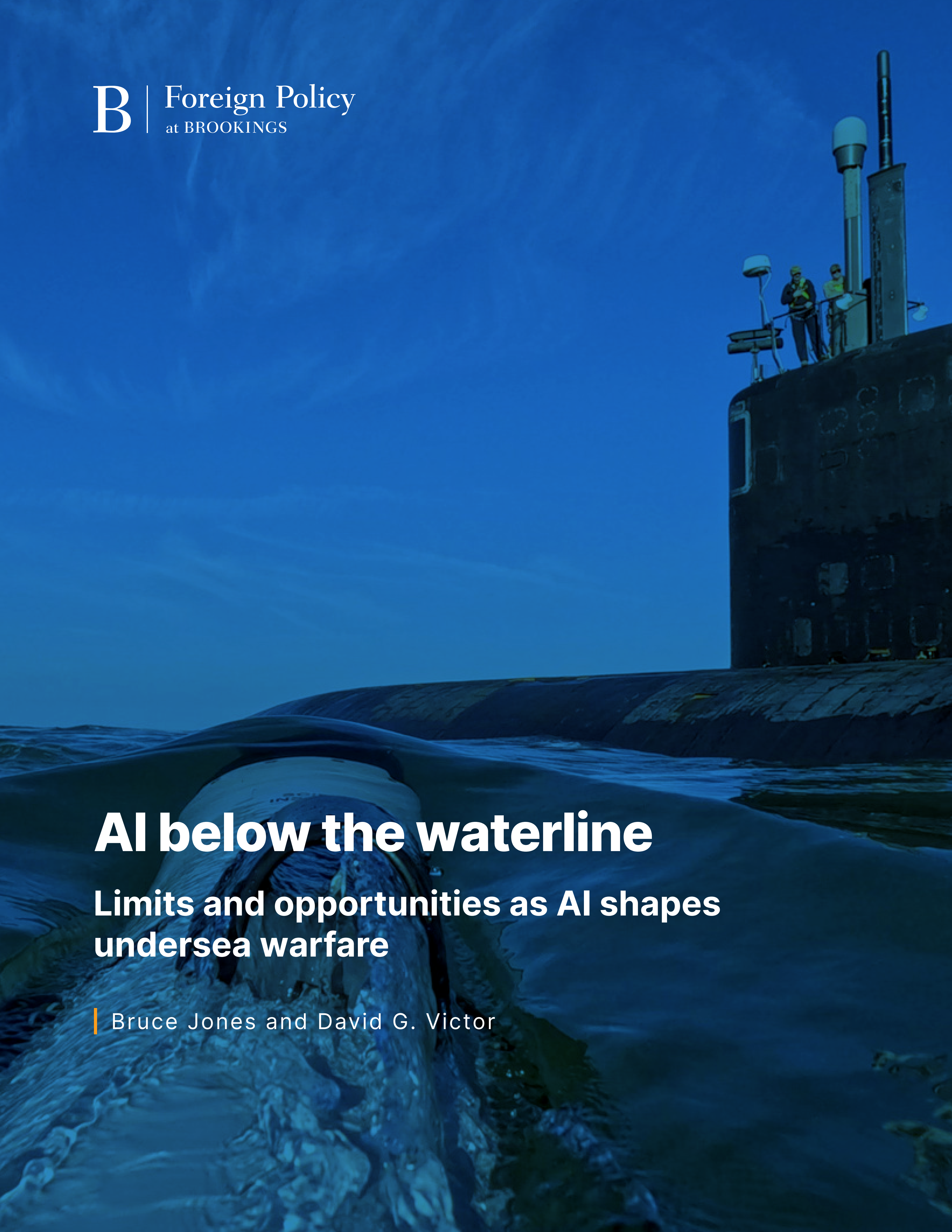

Foreign Policy at BROOKINGS

AI below the waterline

Limits and opportunities as AI shapes undersea warfare

Bruce Jones and David G. Victor

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Executive summary

Undersea operations are vital to contemporary American strategies for power projection, sea control or denial, and for naval war against rivals. Undersea platforms also carry the majority of America's deployed nuclear warheads, providing an essential, secure second-strike capacity. And as surveillance and precision-strike regimes have matured and globalized, the stealth advantages of the undersea realm have grown in salience. What's more, seabed data cables now carry more than 90% of U.S. command-and-control communications, making a robust undersea presence essential for military operations, as well as for the digital economy—and increasingly for artificial intelligence (AI) itself.

The centrality of secure, capable subsurface forces is widely recognized by strategists.[1] Much murkier, however, is whether and how the innovations of AI—and complementary technologies, such as robotics—could affect or even transform the subsurface environment. Most commentary about AI's impacts on warfare reasons by analogy. Above the waterline, these innovations seem poised to enable "kill webs" of interconnected devices, with many automated functions that traditional, entirely human-controlled forces can't match—changing the battlefield and the nature of threats. Much commentary postulates that similar AI-driven transformations will make the undersea realm increasingly "transparent" and permit system-wide awareness and AI-assisted or even automatic, highly skilled decisionmaking below the surface.

We are skeptical. Undersea information webs and autonomy are severely limited because communication and sensing at a distance are physically much more challenging underwater than above the waterline. We offer a different vision, anchored in those physical limitations and focused on the core missions of the undersea forces: survivability and force projection through stealth. Rather than global kill webs, AI-enhanced undersea platforms and sensors are much more likely to operate as a mosaic of loosely coupled local networks, constrained by the difficulty of seeing and communicating across long distances without revealing presence. Small pods of linked crewed and autonomous vehicles, supported by local AI and connected at the edges of wider networks, are the likely future of AI undersea. In some specific places, such as constrained waterways and chokepoints, rich networks of sensors and communications may allow for more web-like systems.

One implication is that solitary, stealthy submarines—both nuclear-armed and fast attack—will continue to have extremely high value for a survivable and capable underwater force. Another is that in assessment, physical proximity to the theatre of operations is more important than the traditional distinction between offense and defense. All else equal—a condition that is hard to measure and assess with precision in the middle of a technological revolution—AI will create an advantage near home shores and near a subset of allies who are physically proximate to the operating frontier and integrated into detection and communication systems compatible with those of the United States. For the United States, realizing the full potential of AI-assisted systems will require theatre-proximate allies able to lay and secure cables and offer secure communication.

AI will also transform oceanography, a field that the United States has long led, by improving pattern recognition, guiding underwater uncrewed vehicles in collecting ocean measurements, and integrating key insights from science and the environment into naval operations. U.S. advantages in this field are eroding as China rapidly invests in oceanographic science and, especially, data-collection platforms.

Finally, AI systems themselves are becoming highly dependent on seabed data cables. This infrastructure is vulnerable to disruption, and current U.S. doctrine and capacity for defending that infrastructure are insufficient, particularly as Russia and China build tools to detect, track, cut, or interfere with them.[2]

The AI revolution is real. But below the waterline, the laws of physics, for now, make the seas far from transparent, render undersea kill webs infeasible, and make planning for such webs dangerous. The uncertainty surrounding how these technological revolutions play out has big implications for force design and reinforces age-old insights about Pentagon procurement. Investments should emphasize shortened procurement cycles, rapid experimentation, and adaptation while being guided by a clear understanding of the difference between AI above and below the waterline.

Introduction

Western military planners are betting that AI will transform battlefields. They see powerful new tools—including big data analytics, machine learning algorithms, and AI-assisted autonomy—changing virtually every aspect of military affairs, from clerical functions to logistics to refined sensing and targeting. Conceptually, it is thought that the opportunities offered by AI will replace the concept of a kill chain with a "kill web," as networks of remote sensors and cloud-based data sets optimize the real-time detection and avoidance of threats with the application of force across battlefields. Already, the proliferation of satellites, precise over-the-horizon radars, high-bandwidth long-range communications, low-cost drones, and cyber tools is changing battlefields. Waning are the days of the fog of war, marked by too little useful information; the new world, it appears, is a "clog of war," in which massive volumes of data threaten to overwhelm timely decisionmaking.

AI can, in theory, offer a great unclogging—finding and tracking signals in the noise at much greater speed and accuracy, at lower cost, and pinpointing the most important information for targeting and other decisions. At the same time, these innovations do not erase the age-old games of cat and mouse in intelligence: AI's advantages in signal processing, for example, may be offset by adversaries who poison training and operational data to confuse AI systems and their ability to learn.

The drive to apply AI to the battlefield has several motivations. The real and infectious attention to how AI will affect society, and how to harness AI tools for advantage, has unsurprisingly become central to security discussions too. AI-fueled transformations could be particularly relevant for China, the West's most advanced rival, which is rapidly building its systems for "informatized war," including "counter-system systems" designed to attack American sensors, communications, and command and control.[3] And both Western and non-Western militaries are observing in real time the ways in which AI-enabled autonomous vehicles, both individually and in swarms, have transformed crucial parts of the battlespace in Ukraine and in the Strait of Hormuz. These real-world transformations of battlefield advantage have created searing mental models of possible futures—even if those models are often sloppy.

The AI revolution, while real, is not immune to the laws of physics. Above the waterline—in the air, in space, on land, and on the water's surface—high-speed, wide-bandwidth communication is relatively easy. That's a boon to AI systems that thrive on being fed massive amounts of information that can provide situational awareness and guidance across a whole kill web in real time. Above sea level, a suite of innovations created over the last few decades—sensors for detection, computers for signal processing and tracking, control systems, virtual reality, and robotic devices such as drones—is becoming interlinked and poised to become much more capable thanks to AI. What is being observed today is likely just the early skirmishes in a profound technological revolution.

All this is different below the waterline, where remote sensing is much more difficult, and communication is even harder. The big advantages of machine learning—synthesizing huge amounts of complex information, finding patterns, and optimizing across a kill web—don't affect the subsurface in the same way, because the spatial extent of sensing and unwired communication is so much smaller. The physical topology of undersea AI-enhanced systems is much more local, except where they can link to cables or above-surface transmitters. The very strength of high-end subsurface warfare, the ability to stay hidden, strongly favors staying away from sea level and fixed infrastructure. Undersea platforms can link to global kill webs, but only by sacrificing some portion of their stealth.

For AI and autonomy, the great divide is not AI's intrinsic capabilities but the waterline.

The American technological advantage in conventional subsurface warfare—the dangerous game of hide-and-seek or hunter-finder—is both real and long-standing, though steadily shrinking, and rests on stealth. AI can enhance that stealth in design (e.g., the modeling and manufacturing of quieter and more capable propellers), in evasion (e.g., AI-assisted networks of acoustic chaff), in sensing (e.g., faster processing of signals from passive sonar arrays), and possibly in some aspects of offense (e.g., self-steering torpedoes with longer ranges). It already allows for autonomous UUVs (unmanned underwater vehicles; the undersea equivalent of drones). But unlike in the air and on land, where large swarms are feasible, the number and range of undersea devices will be sharply limited by the short reach of high-speed, high-bandwidth underwater communication (today, lasers, limited to hundreds of meters). Pods, not swarms, are the appropriate metaphor. AI will add capability but not (yet) transform the core dynamic of undersea operations, where the pace of advantage is a function of stealth. Silent solitude will remain the keystone for underwater force.

For a decade, there has been a rising clamor about how new sensors, communications, and suites of AI tools will make the seas "transparent" and integrate the subsurface forces with the rest of a kill web.[4] What's more, U.S. planners contemplating hot conflicts with China (and other countries) seek instruments of surveillance and of strike that can operate in "denied" or at least contested battle spaces at a lower risk to human life and at a lower cost than traditional platforms. AI, it is hoped, will redress a long-term, steady decline in the number of traditional platforms and greater threats to those platforms from anti-access weapons.

Our argument, which others are beginning to articulate as well, is that those claims are often exaggerated, even hyperbole.[5] If anything, AI is more likely in the near term to advantage navies playing "zone defense" than long-range offense. The United States, having focused on the stealthiness of a few vehicles rather than the swarminess of many, is in some respects already playing catch-up in creating the conditions—large numbers of platforms and connected sensors in battlefields of interest—that allow for maximal use of AI, not sustaining a lead. The United States is also behind the curve in developing techniques—as much as technologies—to protect its bases and ports, which could be vulnerable to significant disruption from UUVs deployed from what appear to be commercial ships traveling in commercially trafficked waters.

We will make our argument in three parts.

First, we explain why sea level remains a profound physical barrier. Absent the arrival of reliable, low-cost, and ubiquitous quantum communication—a possibility, but still seemingly far in the future—water's physical properties make it a severe barrier to sensing and communicating. That barrier has been the root of subsurface stealth since the invention of submarines. On top of that, the oceans are steeped in peril and noise. Giant storms and severe currents create perilous conditions near the surface. Noise throughout—from biology, the physical planet, and the expanding marine economy—makes it particularly hard to finger and track military signals. Planners and procurers should skeptically interrogate defense technologies that claim to make the seas "transparent" or allow for long-distance kill webs undersea.

Second, notwithstanding real physical limits, we outline how AI and related technologies can be harnessed to improve undersea operations—examining every point along the chain from the construction of vessels to maintenance and tactics.

Third, we examine the implications for current and future strategy, including where and how the AI revolutions will interact with existing underwater assets. Strategically, an AI-enabled subsurface fleet is one where stealthy platforms probably matter even more than today. The linkages between these platforms, undersea robots, and fixed sensors will be in pods—mosaics of tightly linked local assets, with these pods more loosely linked at various distances.[6] Creating the linked edges of these mosaics will be far easier to achieve close to shore than in the open ocean. The traditional submariner who "disappears" for weeks will retain important roles in this mosaic undersea future.

Why the waterline matters

The effects of AI on military forces depend not just on the machinery of AI but also on how AI systems obtain inputs, track targets, exchange information, and interface with strategic decisionmakers and tactical firing systems. Sensing and exchanging huge quantities of information is much easier to do in physical environments where light and radio waves move freely. Both the inputs—such as from sensors—and the communication of raw and processed information change radically underwater.

To understand how the subsea environment is different, it is helpful to consider the contrasting opposite: space. The proliferation of remote sensing and navigational satellites since the 1970s—and especially in the last two decades—has created the phenomenon of global persistent intelligence, surveillance, and reconnaissance (ISR).[7] The result has been the production of massive volumes of raw and processed data, such as about the location and movement of targets and their attributes—key elements for a kill web.

The ease of communication and "seeing" helps explain the geographical scope of AI systems. It affects the physical size of the fully integrated kill web along with the command-and-control systems that turn AI into a useful military tool. But this changes underwater. As Francesco Tonolini and Fadel Adib summarize: "While radio waves can travel over long distances in air, they die exceptionally fast in water … while acoustic waves can travel over long distances underwater, they reflect off the water's surface and hence cannot carry information across the water-air boundary."[8]

These physical constraints on communication have a direct impact on the topology of subsurface forces. To first order, topology depends on the speed and bandwidth of communication systems—attributes that are determined by the frequency at which communication systems operate. Very low frequencies can penetrate long distances without much interference from water (or land)—to the extreme, essentially at an oceanic scale. But those systems carry paltry amounts of information. They are more like global pagers or the Batman symbol: a way to signal the need to communicate and a bit of information, but not the medium for detailed instruction. At the opposite extreme are very-high-frequency systems—high-frequency radio waves or lasers—that carry huge amounts of information in theory but are most impeded by molecular interference in liquid water, as well as general weather and atmospheric conditions. For many of these, the distances they straddle are measured in meters or single-digit miles.

American submarines (and those of some partners and rivals) respond to these realities of physics by using a series of multi-mode masts attached to the ship's sail that operate across a range, from super-low-frequency, low-, medium-, high-, very-high-, and extremely-high-frequency signals. This has enabled American submarines to serve as essential ISR nodes, including in otherwise hard-to-penetrate areas. Below the water's surface, communication is mostly limited to pulsing pager-like messages on very-low-frequency receivers and sending short messages hidden in sonar signals. Any active transmission raises the risk of detection. Communicating at higher bandwidths requires coming closer to the surface and snaking a wire to the waterline or, at periscope depth (PD), poking above the water's surface via other antennas fixed to the ship. PD opens a world of opportunity for communication but also raises the risks of detection, a risk anathema to submariner culture and effectiveness. This tension is evident in the world's most important zones for ISR—such as inside the first island chain and in the littoral waters around Russia—where new radars can more reliably detect submarines' periscopes when they break the surface.[9]

That there are physical limits to communication does not mean that improvements are not possible. Indeed, a flood of innovations is expanding the effective size of communication webs and widening bandwidths while tamping down the risks of detection that come from loitering near the surface or transmitting in ways that broadcast presence. These innovations will plausibly alter the topology of the subsurface, at least a bit, but they are not yet changing the fundamentals. They may create a subsurface environment that reliably allows devices—manned and unmanned—to operate in local pods, rather than in global kill webs.

An example of local, low-bandwidth communications undersea is the Navy's use of Raytheon's "Deep Siren" system—expendable buoys that can communicate upward with satellites and downward with submarines, creating a locally linked communications network that can allow submarines to engage in one-way exchanges of messages without surfacing.[10] These buoys can be dropped from passing ships or maritime patrol aircraft to get a message to a submarine, or they can be ejected from a submarine to send a message to command headquarters. Gliders that utilize these systems can operate inside areas where the buoys are deployed and adjust to the water column, finding an optimal path for longer-range communications—though distances beyond several miles depend heavily on environmental conditions. The system uses a low-bandwidth frequency, which allows for longer-range communications but with the tradeoff informed by physics: severe limits on the bandwidth of data that can be communicated. Further, since long-wavelength systems work underwater by putting acoustic energy into the water column, they raise the risks of detection (if not decoding) by listening adversaries. Using expendable buoys and gliders as transmission nodes lowers detection risks when compared with the submarine itself doing the pinging, but since these systems are localized, they can nonetheless cue vicinity to waiting anti-submarine warfare assets. Hunters gain advantage when they are tipped off on when the shadows of stealth are narrowed.

Experiments in higher-bandwidth communication hold the promise of more—but not yet. While intriguing, these innovations serve mostly to highlight the real limitations for any high-bandwidth underwater communication with known technologies. Kyocera, a Japanese company, has the most advanced (publicly revealed) technology. In September 2025, Kyocera announced that it had achieved undersea wireless communications at a high-speed rate of 750 megabits per second (about the speed of good home Wi-Fi systems with fiber optic links to the internet) with no latency, in a prototype system featuring Kyocera lasers.[11] The test took place off the coast of Numazu City in an ocean setting, gathering data measurements of marine environment parameters such as turbidity, water temperature, chlorophyll concentration, salinity, and illuminance. The test succeeded in generating real-time communications, but with real limits: they were operating only about 7 meters underwater, and the distance it succeeded in connecting was a maximum of 1.5 meters. Hydromea, a Swiss-based company, is also using optical modems for wireless undersea communication on autonomous vehicles. Their product, the Luma, boasts a greater effective distance—about 50 meters.[12]

The laws of physics have been unrelentingly inconvenient underwater, which has led innovators to look at ways that subsurface systems could communicate by breaking the air-water barrier. A prototype study written by scholars at the Massachusetts Institute of Technology in 2018 (and funded by the Office of Naval Research) examined what it called "translational acoustic-RF communication (TARF)."[13] As the authors described it, this would enable "underwater nodes to directly communicate with airborne nodes by transmitting standard acoustic signals. TARF exploits the fact that underwater acoustic signals travel as pressure waves, and that these waves cause displacements of the water surface when they impinge on the water-air boundary." To decode the transmitted signals, the authors write, TARF uses an airborne radar to measure and decode these surface displacements.[14] This type of communication could make obsolete the need for middleman surface vessels or data mules[15] (for example, buoys deployed in an operating zone) by sending submarine data straight to an airborne asset.

So far, the TARF approach to breaking the air-sea barriers reveals some potential, but under highly constrained conditions: water tanks and swimming pools that, convenient for prototype science, have no surface turbulence. In such conditions—with waves no more than 16 centimeters, conditions known to surfers as "flat calm"—the TARF can achieve communication rates of up to 400 bits per second. More inconvenient is that, for now, transmitters and receivers must be aligned precisely along a vertical axis—in effect, the highly visible airborne asset positioned on this axis paints a telescopic bullseye on the waterline. Lifting shadows and making it easier for hunters to search runs is exactly contrary to submarine stealth.

Another way to break the air-sea surface is to do that physically—with more sophisticated data mules to relay communications. One idea is to have a surface drone that can also move undersea—so that the vehicle itself penetrates the air-water barrier. That's how WaveGlider from Liquid Robotics (owned by Boeing) works—a bit like a sophisticated surfboard, with batteries and antennas, but tethered to a drone-like vehicle.[16] Together, the surfboard and the underwater drone use the ocean's own wave movement to carry it forward, and the whole time, it is operating on the surface and underneath the water. This potentially allows the WaveGlider to communicate with submarines via acoustic channels (albeit with intrinsic limitations of bandwidth and risks of detection) and then transmit on the surface to wireless air or satellite feeds.[17] Another vessel being tested is Ocean Aero's Triton, a data-collection vehicle that operates on the surface but can dive. Because it can work on the surface, it can also be in communication with other surface vehicles; thus, as one executive put it, "A swarming concept is being worked on as we speak."[18] Yet another direction of innovation is reflected in SubSeaSail, which combines wind and solar power to sail the surface but can also operate up to 100 feet below the surface.

These and similar innovations offer important advantages to the Navy. Although primarily designed to help sample weather and water column data, they could also potentially serve as part of local pods or perhaps deliver modest quantities of supplies in denied environments.[19] But they all operate within real limits in range, carried energy, bandwidth, and stealth. And given the range and sensitivity of radars that can detect even periscopes poking above the waterline, these devices add a nontrivial degree of risk of detection or at least cueing to guide anti-submarine responses. They can add to the efficacy of local pods of interconnected devices; absent deeper innovation, they do not offer the prospect of more revolutionary change below the waterline.

Because cats and mice evolve together, it should not be surprising that China is also working to address the communications problem. In one study, Chinese researchers report having developed an underwater wireless communications system with a high-power laser diode transmitter and a sensitive silicon receiver. This combination, they report, is able to achieve 1 gigabyte per second transmission speeds over a 250-meter range, beating the Japanese test.[20] So far, the Chinese tests appear to have been only in pools, not in ocean conditions.

In short: as much as navies would like to tie their undersea devices into a kill web, physics is defining a different future. As one interlocutor put it to us: "Everyone wants to have an ocean 'internet of things.' But in the oceans, there's no internet!"

There is no kill web below the waterline. Instead, these three key attributes remain durable:

1. With few exceptions, sensing must be done by platforms in close proximity to the target or target environment. The exception is when adversaries sail noisy submarines, as the Soviets did until the 1970s, and the Chinese still do—for now. Newer, much quieter Chinese submarines[21] will rapidly move us towards the same reality we faced in the Atlantic in the 1980s: long-distance sensors could not meet the challenge, and proximate sensing was the essential requirement. This is true not only of remote sensing (e.g., the passive detection of sonar signals) but also of the physical sampling of the water column, which is a key input into the oceanographic models used to evaluate and predict key marine conditions. These include the location of the thermocline—the shift in temperature near the ocean's surface, below which it is harder for surface vessels to detect submarines—as well as marine weather, which affects navigation, noise, and other factors, and the ocean's sound speed profile. A huge amount of subsurface sensing is also done by physical devices connected to cables on the ocean floor—either dedicated military networks (e.g., the Sound Surveillance System, known as SOSUS, networks that sense submarines approaching the United States) or devices added to dual-use cable systems.[22]

2. Communication is constrained by a tradeoff between data volume and distance. Aside from pager-like signals, all high-speed, high-bandwidth two-way communications require either close proximity or operations near the surface (and thus more vulnerability to detection) or both. Breaking that axiom requires data mules or other relay devices that raise the risk of detection.

3. Remaining on station while sensing and communicating requires power, which for the subsurface means onboard power stations (or power-sipping devices that can extract modest energy from waves) or a strategy for recharging without detection. More power means bigger size, cost, and risk of detection—to the extreme, submarines with onboard nuclear reactors. (The smallest nuclear-powered submarine the United States ever commissioned was about 45 meters in length, about the same length as a Boeing 737.) Solar-powered gliders are being offered as possible solutions, but those are easy to see and destroy. On top of that, solar arrays don't work at night, and the energy that a small-sized platform can generate over a typical day (and store in batteries) is limited by the platform's sun-facing area—a constraint that limits gliders to slow speeds and power-sipping sensing and communications.

These attributes mean that sensing and control systems must work in close physical proximity, such as with a crewed platform networked with a handful of unmanned systems. To operate autonomous devices in the geography where conflict is most likely in the near to medium term (e.g., the littoral waters around China's eastern shore, the seas near Russia, or in the Persian Gulf), the United States needs to range any subsea device over distances that can be thousands of miles. That's true even if operating from Guam—a device intended for undersea stealth and launched from Guam must travel over 1,500 miles before it is within the first island chain. Servicing these devices—maintenance, recharging, disentangling from fishing nets, and such—requires safe zones for operation (or long commute distances), which means that a subsea presence depends heavily on a global infrastructure network. In this sense, America's traditional geographic advantage—the stopping power of the oceans—is a significant disadvantage when it comes to planning for offensive operations, defense of allies, or control of distant sea-lanes.

One implication of the value of proximity is that AI is more likely to be relevant with edge rather than cloud topology. The utility of autonomous devices in a network is limited by the network's size and each platform's capabilities. Above the waterline, a well-functioning network is marked by network effects in which the value of each new networked device multiplies value to all the others—kill webs. Underwater, the logic of networking plays out differently. Fast networks, where AI is most useful, operate over the spatial extent of the well-connected devices—local pods in a mosaic. Slow networks, akin to what the submarine force has today, apply to the vast expanse of the oceans.

Undersea AI in practice: Opportunities from the factory floor to the warhead

While we are skeptical that AI will usher in an era of subsurface kill webs or even have much impact on force topology, AI technologies can still have a big impact on subsurface assets in many other ways, from design and manufacturing to maintenance.

Building and operating submarines

To explore the ways that enterprise AI can aid the process of building and operating submarines, it is important to situate the context: a nuclear-powered submarine is one of the most complex pieces of engineering in all of modern industry. Even the seemingly simple task of bending heavy plates and I-beams of high-yield steel is highly complex. So too are cutting and refining the edges of cut pieces and welding them together such that the seams can withstand the intense pressures a submarine experiences at its maximum depth. That's before 120,000 purpose-built parts, forged in many cases by bespoke tools, are threaded together inside the pressure hull.[23] Next, some of the world's most sensitive acoustic sensors are built inside the pressure hull or wrapped into the submarines' coating. Finally, the nuclear reactor is situated on its float raft in the boat's center. Even comparatively simple tasks like supply chain management are very complex here and ideally suited for improvement through enterprise AI.

Building the boat. As it is, the current generation of nuclear-powered submarines (SSNs)—built by General Dynamics Electric Boat, in Quonset Point, Rhode Island, and Groton, Connecticut, and by Huntington Ingalls Industries in Newport News, Virginia—have for decades been designed with computer-aided design and manufacturing systems. These systems have a long history of making it possible to cut and precision-weld (by robots, partly) sections of the hull. But for decades, there have been known limits: for example, finalizing the weld of a complex S-bend pipe in the narrow reaches of a submarine bow is a human job, not a robot's, and will be for some time. Some tasks, however, are ripe for more AI-assisted automation in design and manufacture, along with advanced simulation—itself a beneficiary of AI-assisted detection of patterns—and with advances in robotics. As with modern aircraft, advanced design, manufacturing, and simulation make it possible to construct and certify virtual twins that can be used to predict the full range of a vessel's performance before launch—all the while cutting costs through deeper investments in robotic welding and assembly that reduce turnaround time and the number of physical laborers required per boat. Since submarine platforms hinge on a combination of performance—depth, speed, agility, sensing, and weapons management—and stealth, the ability to design alongside simulation is exceptionally valuable. Here, the U.S. Navy may want to look beyond traditional suppliers to deepen its knowledge base. For example, in surface shipbuilding, Italy's Fincantieri is recognized as having some of the most advanced protocols for AI-enabled welding, a skill it honed on surface ships.[24] Similarly, Sweden's Saab Kockums has a higher proportion of its boats built by robots than its American counterparts,[25] while South Korea has made significant advances in automating onboard processes, requiring fewer crew.

So far, few of these frontier design and manufacturing skills (e.g., robotic 3D printing) have advanced much beyond conventional semi-automated design and manufacturing; that reality, along with the slow pace of turnover in naval equipment, means that these revolutions have not yet had a big impact on the existing fleet, except through some retrofits (such as advanced sonar systems). All of this should be integral to the design and construction of the next-generation attack submarine, the planned SSN-X, as should the use of embedded AI to put acoustic disinformation into the water column.

Here, though, we are clear-eyed: AI-improved design and manufacturing (with AI integrated into robots and additive manufacturing devices) will allow much more capable submarine production, but it will also help U.S. adversaries as well. China is already significantly outpacing the West in the sheer number of submarines that it is producing, and it is ahead of the United States in using robotics to build submarines.[26] Keeping pace with China would require much farther-reaching changes than simply faster adoption of AI and robots.

Operating and maintaining the boats. Another source of potential innovation is in using AI and AI-supported tools to operate the boats themselves, including preventive maintenance and intelligent aging. Once again, there could be value in learning from allies, notably South Korea's Hanwha, which has driven automation across multiple functions on its submarines, from the Combat Management System to navigation, steering, and management of propulsion systems.[27] The U.S. Navy, which already operates some of the world's most advanced software and uses advanced algorithms for fire control and targeting, can accomplish more—especially by rethinking submarine operations to treat "pods" of boats, interconnected with varying degrees of bandwidth and with uncrewed vehicles, as integral units.

Of particular importance is the use of AI models for preventive maintenance. The nuclear submarine force has a robust culture of testing and preventing component and system failures. That's a product of history and doctrine and the simple reality that nuclear culture is highly risk-averse and attentive to routine. Using AI tools to speed up the detection of potential problems can both ease crew stress and reduce time in maintenance.[28] As is already happening with commercial nuclear reactors, AI can even start to transform nuclear culture so that risk aversion can be retained for its safety value while allowing much greater operational agility and real-time awareness of reactor status, maintenance, and performance limits.

One of the key skills taught in reactor training is how to manage a reactor within physical limits. AI-assisted training using data from reactors with large arrays of sensors can help operators learn those skills while reducing cognitive demands and raising performance and safety. Combined with improved equipment design, such as in pumps and pipes, such AI tools might also decrease reactor system noise. By easing burdens on crew, the Navy could distribute similar personnel numbers across more at-sea deployments. Increasing the share of days ships spend at sea versus in the shipyard should be a major goal for the U.S. fleet—to say nothing of much more strained fleets like that of the Royal Navy. A boat designed with intelligent systems and maintained with those systems may, in time, substantially erase the difference between "operations" and "maintenance." Except for major dry-dock overhauls, a working boat is one that is gathering and applying the data needed for continuous improvement and maintenance. To some degree, we are already seeing this revolution occur in aircraft systems. Companies have already introduced options for shipbuilding, notably Palantir's ShipsOS, which shows promise in this area.

Ocean modeling

Long before a submarine or a drone enters the water, one of the world's largest science complexes has undertaken a vast amount of data collection to model general ocean flow and dynamics—skills that are important for predicting weather, the location of different slabs of ocean water (notably, the acoustically important thermocline), and storm events that can create turbulence in the water column. This information is highly germane for both air and surface operations, but it is vital for submarine operations, which rely on both detailed models and specific sampling to assess the temperature and salinity of the water column at various depths. These factors shape how sound moves through the ocean's various layers. The more sophisticated the modeling and the more accurate the local sampling, the more precise a submarine's understanding of the "sound speed profile"—the key piece of information it needs to evade detection and to position itself most effectively to find opponents.

AI tools are already in play in supporting this effort on both fronts: processing massive data sets and optimizing active sampling methods and strategies.

The big data sets come from a combination of several satellite systems, including those owned and operated by the U.S. Navy, by the Pentagon, and—crucially—by several allies. This network of satellites is necessary for the kind of global coverage required for simultaneous U.S. operations in the Atlantic, Pacific, Indian, Arctic, and Southern oceans, plus their littoral seas. This encompasses billions of daily satellite-based observations. These and other sources of observational data feed ocean models operated by the Navy in partnership with the National Oceanic and Atmospheric Administration and informed by comparisons with models developed across the broader oceanographic, weather, and climate science communities.

AI is likely to accelerate further improvements in modeling the entire ocean-atmosphere system, which is already improving substantially. One indication of this progress is the erosion of a long-standing assumption that weather modeling would always be more precise than climate modeling. Weather prediction has traditionally been viewed as constrained by atmospheric chaos, with reliable forecasts extending about a week into the future. Today, however, climate models—because they comprehensively capture the underlying oceanic and atmospheric properties—are often outperforming weather models. Their success points the way to modeling techniques that rely on large-scale pattern identification—a core strength of AI—to improve model performance.

In a world of advanced processing of big data sets, how we generate the data to feed those data sets is of great consequence. Efforts to curtail the flow of ocean and atmospheric data to AI-enabled ocean and climate models will achieve the opposite of their intended effect: removing a crucial asset from undersea operations while handing adversaries a planning and operational advantage. We need more sampling, not less, and richer models, not constrained ones.

AI is also already playing a big role at the opposite end of the geographical spectrum: in highly localized sampling. Highly local sampling is essential, particularly in the littoral waters that feature prominently in U.S. defense planning, including those along the Chinese and Russian coasts. Littorals are usually shallow, but more consequentially, they are complex. Here's how one U.S. government study describes this: "A characteristic that is commonly assigned to littoral waters … is complexity, exemplified by much shorter scales of variability in both space and time compared to the deep waters of the open ocean. Important features of the littoral regions include tides, irregular and tide-produced internal waves, diurnal variations, variable bottom topography, and a cluttered acoustic and visual background—all of which make ASW [anti-submarine warfare] operations more difficult."[29]

In situ measurement is essential, but also dangerous, for it puts assets close to enemies where they can be observed or seized. Measurement can be done, in part, by surface ships, specifically T-AGS survey ships operated by U.S. Meteorological and Oceanographic Command.[30] But when operating near adversary coastlines or in well-defended waters, smaller targets are a better option.

For this, the U.S. Navy currently has two major programs that are being supported by AI. One capability is a network of smart buoys floating at specified depths to collect a continuous stream of data about temperature and salinity—two key pieces of information about the water column. That information can then be shared with the fleet.[31] Meanwhile, AI-enhanced data fusion enables ocean-condition estimates and models to be updated more quickly than before. A second capability is the "Littoral Battlespace Sensing-Glider." It resembles a missile that gracefully moves through the water at roughly half a knot, dives up to depths of 1,000 meters, and loiters for three to five months, depending on battery life.[32] These gliders can be controlled from U.S. Navy survey ships or autonomously piloted by a software package with the slightly whimsical name "GHOST"—the Guidance of Heterogeneous Observations Systems software.[33] One of GHOST's advantages is that it uses the ocean's currents to sail the gliders with greater efficiency, extending their battery life and thus their sea observation time.

The AI revolution will affect oceanography in at least two ways, with potentially profound implications for how oceanographic information is used strategically (e.g., force location and confidence in second-strike capabilities) and tactically (e.g., detection of targets and firing solutions). One profound change is the use of AI to integrate huge data sets. U.S. and now Chinese oceanographic programs have deployed huge numbers of robotic sensors in the oceans to measure basic physical (e.g., temperature and salinity) and, in a more limited way, biological attributes. Synthesizing that data and using it to guide new measurements and models is an ideal task for AI. In time, it is likely that such synthesis can help improve models used to estimate oceanographic parameters of key interest to naval operations, such as the global, undulating location of the thermocline. How much of an improvement will be realized in practical ways is, at this time, hard to say.

The other profound change in oceanography will unfold more slowly, but it is one that AI is already causing in other fields. The judgement and intuition of expert oceanographic knowledge is scattered across many people and disciplines. Much of it has attributes of craft and experience. When the military wants help applying science to some high-value, unique operation, it can go to the actual individuals with the foremost oceanographic expertise and tap that knowledge directly. A more automatic synthesis of frontier knowledge will plausibly help the field of oceanography push the frontier further—because AI will become an extremely knowledgeable post-doctoral scholar—and will also help apply that knowledge for naval operations. Often on a ship, "science" sits in a corner, interpreting some data and contributing to tactical moves driven mainly by other factors. Putting an elite AI oceanographer on every ship—and in the strategic planning systems for the Navy as a whole—could be transformative.

At the tactical edge

AI will also help at the tactical edge—that is, in combat operations on board the boat—in at least four ways. Each is defined by edge AI, or AI that is installed on devices or platforms themselves. This stands in contrast to networked, cloud-based AI, which requires reliable high-bandwidth communications between the device and the cloud repository where data are stored and processed. With advances in communications and AI-based skills to interpolate incomplete communications, the “edge” will probably grow in size as boats share information and implement field operations jointly with other devices.

First, AI and machine learning can likely help boats—especially newer classes of boats built with effectors meshed into their coating—in generating acoustic signals designed to confound adversary sensors. This can involve seeing patterns in natural ocean background noise and then using active sound generation to mimic those. It can also involve creating nonindustrial noise, putting important misinformation into the adversary’s sensor (and their own AI-supported interpretation of those signals).

Onboard AI can also help with the reverse problem—the introduction of acoustic disinformation by adversaries.[34] This is likely to be a growing challenge, as adversaries seek to poison training systems and detectors with false acoustic data.

Second, AI-enabled tools embedded in submarines’ combat systems can improve intelligence synthesis. Many data streams contribute to a submarine’s combat system, including data collected by the submarine itself and data received from elsewhere. Using AI to process those reams of data and identify patterns at a fraction of human operator speed would provide a clear advantage.

Third, speed of fire control. If an advanced AI and compute system can generate a targeting solution (“fire control solution,” in naval parlance) in 40 seconds instead of 60 seconds, that’s a 20-second gain that could easily be the difference between firing first and firing second—which is all the difference in the world.

Fourth, in final target acquisition. Already, the Mark 48 torpedo has autonomous targeting software, which is partly controlled by information conveyed via a thin wire that unspools from the torpedo in the first instance (for several miles or the duration of the torpedo run). Once separated from the wire, the Mark 48 fixes and refixes targets autonomously, using basic image recognition software.[35] More powerful image recognition and navigation software, installed on the torpedo itself, could amplify these weapons’ range and autonomy. This communication is two-way as well, with the torpedo able to transmit information back to the submarine. This is the outer perimeter of edge computing: an onboard advanced graphics processor can improve the interpretation of sensing information needed to track targets by reducing time to lock on targets, increasing the proficiency of an already proficient weapon.

The story with torpedoes is already evident in airborne Tomahawks. To oversimplify, these weapons operate in two modes: with preloaded targets computed at the time of launch, and with targets acquired or updated in flight. Already, a subset of Tomahawks can connect and update via satellite or theater ships and aircraft once they rise above the water’s surface and become airborne; as above-the-water kill webs get richer and faster with AI, the effect of this will increase. Of course, battlefield use of these weapons must contend with interference and disorientation, forcing a tradeoff between the robustness of fixed, preset targets and the flexibility of adjusting targets on the fly, which is inherently more vulnerable to interference. For Tomahawks and torpedoes, data mules that convey high-bandwidth encrypted data may help determine how that balance plays out, as they can allow for more reliable communication with devices en route to targets.

Surface ships and air assets in anti-submarine warfare

It should be briefly noted that sensing and operating in the undersea space happens not just under the waterline but also on the ocean's surface and from low-flying aircraft. By dint of operating above the waterline, platforms operating in these domains can be linked into cloud-based AI systems with long-range communications—kill webs.

For example, arguably the most mature uncrewed naval systems in the U.S. fleet to date are the medium unmanned surface vessels (USVs), the Sea Hunter and the Seahawk. They are tasked with providing an autonomous aide to anti-submarine warfare. They are built in a trimaran shape and from a distance, they look more like sailboats than naval vessels, albeit ones where the sails have been replaced with radio towers. Weighing in at around 156 tons, their hulls are exactly wide enough to hold a standard-sized shipping container on their surface.[36] Inside the hold, there's room for a couple more shipping containers' worth of goods across their length—or a load of weapons, sonar equipment, or replacement parts. Critically, the ships can also attach a towed array—providing a lower-cost, no-risk-to-humans component to anti-submarine tracking teams.

Similarly, one can readily imagine long-range aerial drones being reequipped with magnetic anomaly detection radars, maritime patrol aircraft being retooled for remote flying, and other adaptations or innovations that would enable the fleet to use the robotics to ply the airspace and water surface for AI-boosted anti-submarine warfare. Such devices could also perform other important below-the-waterline functions, such as dropping new seabed sensors into place and dropping data mules.[37] USVs can also be used to recover data mules—though not without some degree of detection risk.

In planning for war, of course, it is important to consider how communications equipment and infrastructure will be destroyed and degraded—as well as how the "clog of war" will create even more powerful needs for AI-based systems that separate signal from noise. In effect, kill webs designed for cyber, electronic, and kinetic warfare will be degraded and/or compromised. Thus, to the extent that the undersea force is relying on air or surface assets to aid its operations—even low-cost, readily replaceable ones—it will have to plan for their support to likely be disrupted. AI systems informed in real time about disruption will become more capable; those unable to stay current, such as due to communication difficulties below the waterline, will not.

Put differently, while there's a lot of focus on how to use AI to more fully integrate the submarine world into joint information and command networks, it's arguable that we should be looking at things the other way around. Perhaps we should be focused on ensuring other parts of the armed services learn from submariner culture and from operations characterized by pods rather than webs—thanks to the submariner's reliance on stealth, long periods of solo operations, and heavy reliance on interpretation of the commanders' intent.

Undersea drones

This leaves the question of how the AI revolution is affecting the design and deployment of fully autonomous devices—especially long-range, long-endurance undersea drones and undersea vehicles that can operate as weapons. Can robotics, enhanced with AI, deliver below the waterline what swarms of Ukrainian and Iranian drones have done to air warfare?

We've already outlined the fundamental physical barriers to such an approach: the limits on long-range, high-bandwidth communications and the challenge of power consumption will place sharp limits on using long-range UUVs as weapons. Still, small pods of UUVs, if they can be delivered to theater, can perform important bespoke tasks, including:

- Placing additional sensors in situ when existing sensors have been damaged or degraded.
- Using mini-swarms of drones to serve as a kind of chokepoint barrier—though here, there are important questions to be solved about the risk of full autonomy versus devices that “go hot” only upon receipt of directed communications.
- Employing UUVs as decoys—already, some NATO allies are using decoy UUVs in the European context, as is Russia.
- Resupplying of low-size but high-need equipment.

As we’ve already documented, a UUV launched and recovered from a submarine (via a torpedo tube) can provide additional options for communication with the fleet under conditions (now more pervasive) where even briefly coming to periscope depth increases the risk of detection. The U.S. Navy is actively experimenting with UUVs to see where they could provide the most benefit, as Vice Admiral Robert Gaucher laid out in Proceedings in October 2025.[38] This includes torpedo tube launch and recovery of a Yellow Moray REMUS 600 UUV from a submarine.[39] This has also happened between U.S. and allied submarines—but that is only possible with a subset of allies in which there is adequate complimentary between platforms, an upfront investment in training and shared doctrine, and established trust.[40]

TABLE 1

Notable UUV programs

Country	UUV	Length (meters)	Range (nautical miles)	Payload missions
United States	Orca XLUUV	26 m	6,500 nmi	▪ ISR ▪ Minelaying ▪ Seabed warfare ▪ Strike missions
United States	REMUS 600/620	4.3 m	286 nmi	▪ ISR ▪ Mine countermeasures ▪ Torpedo tube launch and recovery missions
Australia	Ghost Shark XL-AUV	6 m	2,000 nmi	▪ ISR ▪ Strike missions
China	HSU 001	4.5 m	Unknown	▪ ISR
China	AJX002	18-20 m	1,000 nmi	▪ Minelaying
China	XXLUUV	42 m	10,000 nmi	▪ ISR
Russia	Poseidon Autonomous Torpedo	24 m	5,400 nmi	▪ Nuclear-armed torpedo for nuclear deterrence
United Kingdom	XV Excalibur	12 m	1,000 nmi	▪ A testbed for trialing ISR and other payloads
Norway	Hugin Endurance	10 m	1,200 nmi	▪ ISR ▪ Mapping and surveying ▪ Mine-detection missions

Source: Sources via company websites, Naval News, U.S. Naval Institute, HI Sutton, Janes, Navy Lookout, and the Bulletin of the Atomic Scientists.

*nmi is nautical miles

The United States can operate UUVs and will have to defend against them. That's a challenge for an oceangoing navy and for a country with many exposed ports and other soft marine targets. We know that China is experimenting with containerized missile launchers, operating off of what appear to be commercial ships; it is no major stretch of the imagination to picture modified ships able to deploy one-way UUVs, including loitering devices, that could significantly damage and interrupt operations at major U.S. naval bases and port facilities.

Using UUVs for ISR missions has many advantages. These vehicles can carry a variety of specialized sensing equipment, for example, different types of sonar, magnetometers, and hydrophones. If launched from a submarine, a surface ship, or land in proximity to the area of focus, UUVs can expand sensing capabilities in a specific area. They can dive deeper to collect data or gather imagery, which is important for monitoring undersea infrastructure.[41] However, the essential limit remains: if they communicate via the surface, they risk detection; if they stay underwater, there are sharp limits to the UUV's ability to share collected intelligence.

Mines

Minelaying capabilities are still dominated by aircraft and surface ships. For instance, the U.S. Navy's arsenal of mines can be delivered by P-8 and P-3C maritime patrol aircraft, F/A-18 Hornet/Super Hornets, Aegis-class destroyers and other battleships, as well as Los Angeles-class submarines.[42] UUVs are being designed for minelaying as well. Some modern mines launched from submarines are essentially loitering torpedoes, which detonate once specific acoustic signals are detected from a nearby vessel; these could also be launched from UUVs with a sufficiently large payload, like the Boeing Orca, which has been put back into production after a pause. (Here, the limitations come largely from distance—the quantity of energy required to transit a large ocean drains the UUV's energy before it arrives on mission.)

Undersea vehicles play a role in current mine-hunting and minesweeping operations, though these vehicles' autonomy is limited. Aircraft cover a larger area quicker than a UUV can, and many UUVs still require surface ships to launch them. Remotely operated vehicles are in service on these ships. The AN/SLQ-48 mine neutralization vehicles on Avenger-class minesweepers and now Independence-class littoral combat ships are tethered and remote-controlled from surface vessels to detect and destroy mines. These remotely operated vehicles can place an explosive charge on the bottom of mines—destroying them—and can cut the cables of moored mines. The vehicle has an extremely low acoustic signature, making it nearly undetectable by any mines. As a remotely controlled system, it is not fully autonomous and relies on human operators aboard the surface vessel to function and a tethered cable for data transmission.[43]

Sailors attached to Explosive Ordnance Disposal Mobile Unit 2 and a Chilean Navy explosive ordnance disposal technician prepare an MK18 Mod 1 Swordfish unmanned underwater vehicle for a marine deployment exercise during UNITAS LXV, September 6, 2024. (Mass Communication Specialist 1st Class Hunter S. Harwell/U.S. Navy via DVIDS)

The appearance of U.S. Department of War (DoW) visual information does not imply or constitute DoW endorsement.

Therefore, with today's technology, proximity to the minefields is still essential to conducting minesweeping operations. As Bryan Clark described in an interview about clearing the Strait of Hormuz of mines, these assets will "have to be in someplace like Oman or in the UAE, or even on a ship. They'll have to be defended." As he put it, "even though the robots don't mind getting shot at, the people operating them ashore [do]."[44] For the foreseeable future, even robotic minesweeping requires proximate human control or territory.

More autonomous and semi-autonomous mine-countermeasure capabilities are under development but aren't currently fielded at scale. One example is the Barracuda, an untethered, semi-autonomous system that is designed to track and identify various types of mines and neutralize them (with a human executing the final decision). The system was tested in July 2025, and the program aims to reach initial operational capability and initial production by 2030.[45] The second program is the Mine Countermeasures (MCM) USV, a long-endurance, semi-autonomous vehicle equipped with multiple MCM payloads, including for minesweeping, minehunting, and mine neutralization. It will also be able to deploy the Barracuda payload. It is capable of being launched and recovered by littoral combat ships, other vessels of opportunity, or from shore.[46] Once fielded, this could extend the range of proximity required for operations.

Regardless of how autonomous the undersea component of minelaying or mine-clearing missions becomes, the drones remain reliant on surface vessels or other manned assets to launch them. They also need to be launched closer to the area that needs to be demined. It is not efficient to deploy a UUV with mine-related capabilities from shore hundreds of miles away. Access to allied geography close to where a potential conflict will occur will remain an essential part of any solution set here.

Cables and sensors

Last but very much not least, there are new technologies that can allow the cables that link seabed sensors to land to become sources of sensing themselves.

In the commercial space, the use of in-place cables as sensor platforms is largely being supported by the United Nations-mandated SMART (Science Monitoring and Reliable Telecommunications) Subsea Cables initiative, a joint task force of the International Telecommunication Union, the World Meteorological Organization, and the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization.[47] Simply put, these programs help governments add sensors to the cables themselves, transforming them from simple transmission bands into a network of additional sensors on the seabed. These sensors can measure ocean temperature, bottom pressure, seismic activity, and disruptions. This program was designed to enable environmental monitoring but has potential strategic purposes as well. At present, the United States is exploring options here via what's known as its Networked Expeditionary Routing and Exchange for Undersea Systems, or NEREUS.

These initiatives face the same limits that drive our overall analysis: the requirement for physical proximity. That is, SMART cables turn existing links into sensors, but only where the equipped cables are already physically present. And that's a pretty small set of geographies. Cables in very shallow waters are often buried in the seafloor to protect against intentional and unintentional damage, meaning that applying sensors to these cables would be relatively useless for sensing submarines or other vehicles. Over time, cables have been clustered along the most obvious routes on the seabed. Only a tiny fraction of the seafloor is either covered by cables or within sensing range of them. The location of most of these is well known and easily avoided by adversary submarines.

Furthermore, AI use is driving huge increases in data use and transmission, which is increasing the need for cables as well as overseas data centers. The underlying dynamics are making this infrastructure ever more essential to the American polity and driving a wider mission set for the undersea force.

An important note here: subsea cables are highly vulnerable to disruption or destruction, and both China and Russia have developed deep-sea devices for cable cutting.[48] The primary tools for seabed repair are vulnerable surface ships or exceedingly "exquisite" vessels like the USS Jimmy Carter, the most expensive single submarine ever built, with its extended platform for seabed warfare operations—including cable repair. Yet, for all of the USS Jimmy Carter's sophistication, this modified Seawolf-class submarine can be outmaneuvered by China's and Russia's cable-cutting drones for one simple reason: being uncrewed, they can reach depths far below those that even the deepest-diving crewed submarines cannot attain.

An important potential development in this domain is the decision to focus the so-called "Pillar II" of the AUKUS program between Australia, the United Kingdom, and the United States on the codevelopment of UUV payloads that can protect seabed cables. Such tools could regularly "patrol" cables and, upon detecting any form of interference, communicate to a wider set of platforms to respond, probably via a data mule or by breaching the surface. (In this case, the detection risk is not a major variable.) This kind of approach is going to be increasingly necessary as the United States' reliance on undersea data transmission grows and the risk to host cables grows simultaneously.

Conclusion: AI and the U.S. undersea strategy

A traditional question to ask of technological revolutions is whether they confer advantages for the offense or defense. For AI, especially in the subsurface domain, it is hard to arrive at robust answers. Other factors such as physical presence and stealthiness appear, at least for now, to have much bigger impacts on the missions of U.S. submarine forces. It is also because current U.S. doctrine imagines the United States performing a series of functions far from its shores—e.g., a potential defense of Taiwan or a Baltic nation—that blend offensive and defensive attributes. What's more, it's difficult to determine whether advances in pattern recognition and autonomous guidance favor the offense or the defense. On the one hand, they could make offensive kill webs—even if they are much less interconnected underwater—more lethal. On the other hand, they could strengthen the defense by enabling pods or solitary autonomous systems to operate from boats designed for stealth and acoustic decoys. There is a risk that the assumptions underlying the kill web concept—namely, that it confers advantage to the offense—will instead offer significant advantages to the defense. The full answers are unknowable today.

What is more knowable is how AI affects the value of networks and information.

The key innovations in AI relate to integration of information—the assembly of dispersed information and the rapid, skillful identification of patterns. This is why AI-enabled kill webs above the waterline are so lethal. Plausibly, they are also able to self-assess skills and faults—to "self heal"—and thus enhance their performance even during the "clog of war." Below the waterline, these network effects are much smaller, but they are not zero. They benefit from presence, whether it is swarms of locally connected edge AI pods of drones or larger networks of platforms and interconnected pods. Since remote sensing and rapid communications are so challenging underwater, physical presence matters.

The oceans are vast, and sensing and communications face severe limitations. The value of physical presence creates a home advantage, where "home" is one's physical waters or waters controlled by allies with whom we have robust, trusted relationships. Where larger numbers of platforms are interconnected, such as around the first island chain, the network effects are the greatest. In principle, these network effects can extend geographically over much greater distances with more platforms—a strategy that China is, more or less, following today.[49] An alternative strategy is to create presence through allies, especially those with highly capable assets that can operate in high-value locations. The key to this strategy is allied relationships and interoperability of platforms—in effect, arrangements that emerge only where trust is deep, skills are shared, and technological advances are mutually understood.

TABLE 2

Key U.S. allies and their importance in the undersea

Ally	Capabilities
Norway	■ Strategic geography in the Arctic and the Greenland-Iceland-United Kingdom (GIUK) Gap. ■ Kongsberg is a leading company with its Hugin UUVs and sensing technologies. ■ Capable submarine fleet and the future Type 212CD project with Germany.
Japan	■ Robust conventional submarine fleet and submarine industrial base. ■ Cutting-edge ocean mapping technologies and world leader in mapping the seafloor of its exclusive economic zone. ■ Leader in deep-sea mining, conducting the world's first experiment to continuously extract deep-sea mud containing rare earths. ■ Sensors in geographic proximity to China, the Western Pacific, and the first island chain. ■ NEC Corporation is one of the few subsea cable laying companies in the world.
Australia	■ Focus on UUVs, with Anduril's Ghost Shark now a program of record. ■ The AUKUS partnership and its cooperation on undersea payloads and UUVs, as well as the future SSN-AUKUS submarine.
United Kingdom	■ The AUKUS partnership and building the future SSN-AUKUS submarine and the undersea components of Pillar II of the agreement. ■ Continuous at-sea nuclear deterrent with ballistic missile submarines (SSBNs). ■ Strategic basing and proximity to the North Atlantic and Arctic oceans for Russian submarine tracking.
France	■ Naval Group is a leading maritime defense company producing submarines and subsea technology. ■ At-sea nuclear deterrent with the Le Triomphant-class SSBNs and the forthcoming, next-generation Invincible-class SSBNs. ■ Alcatel Submarine Networks is one of the few subsea cable laying companies in the world.
Sweden	■ Strong submarine base and technology, with Saab being a major global leader in the sector. ■ Strategic geography along the Baltic Sea.
South Korea	■ Advanced conventional submarine program and industrial base, with the potential for acquiring nuclear-powered submarines. ■ SK Hynix and Samsung are global leaders in AI chips, particularly in memory chips.
Canada	■ Shared testing and surveillance sites with the US. ■ Strategic geography in the Juan de Fuca Strait, North Atlantic, and Arctic. ■ Commissioned acquisition of advanced conventional submarines with Germany and Norway. ■ Ocean Networks Canada, which operates world-leading observatories and deep-sea cable infrastructure. Also participates in SOSUS networks.

By these logics, AI may actually confer bigger advantages to China. Beijing has strategically deployed massive numbers of sensors in the South and East China Seas in pursuit of its primary objective: protecting the waters close to China's shores. This is a far easier task than that of the United States, which is seeking to threaten territory that is adjacent to those waters and distant from the continental United States.[50] By permitting the assimilation of many faint signals, AI, with lots of devices, advantages the home team.

Just so in the European context—where littoral seas are shallower and bounded, and a rich array of defensive networks such as sensor cables are already in place—AI's strengths empower defense. For more than a decade, Russia has been sailing its revamped submarine fleet, its new, specialized submarines, and its deep-sea drones in ways that have threatened an array of European seabed infrastructures—communications cables, power lines, and fuel pipelines.[51] Responding to these threats placed significant strains on European anti-submarine warfare capabilities, which were needed to detect Russian operations, as well as on the active surveillance and intervention capabilities required to identify and repair the damage. These defensive systems had been allowed to wither in the post-Cold War era. Some recapitalizations of surface and air assets (e.g., U.K. and Norwegian participation in the P-8 program) have helped address the imbalance; the deployment of new autonomous vehicles to complement these crewed systems will enhance defenses further. Specifically, NATO's Baltic Sentry operation has made extensive use of Saildrone and other USVs to expand its surveillance coverage.

TABLE 3

Different maritime domains and their undersea importance

Maritime domain	Importance	Key undersea operations
First island chain	■ Proximity to China and a network of capable U.S. allies.	■ Fixed-cable sensor networks allow faster tracking of submarines in narrow waterways like the Luzon Strait or the Ryukyus. ■ Closer-range UUV operations that can be launched from shore. ■ Mine warfare. ■ Cooperation with Japan, Taiwan, and the Philippines.
Pacific Ocean	■ Hawaii and Guam offer significant submarine capabilities. ■ U.S. submarine transits from the West Coast. ■ Deep ocean favors stealth.	■ Submarines remain much stealthier and harder to track in the expanse of the Pacific. ■ Submarines are less prone to fixed cable sensor networks.
Atlantic Ocean	■ U.S. submarines transit to Europe and the Middle East. ■ Deep ocean favors stealth.	■ ASW operations on Russian submarines. ■ Submarines are less prone to fixed-cable sensor networks.
Taiwan Strait	■ China contingency. ■ Undersea cable sabotage. ■ Major trade route. ■ Mine warfare.	■ Relatively shallow waters and fixed-cable sensors in and around the strait make submarine operations more difficult. ■ Japan's southern islands are an important area for fixed-cable operations.
Strait of Hormuz	■ Maritime chokepoint for energy trade and undersea cable traffic. ■ Mine warfare.	■ Fixed sensors in the strait and proximity for launching UUVs or rapid mining operations, as seen in the Iran war.
Strait of Malacca	■ Maritime trade and transit chokepoint.	■ Fixed-cable sensor networks and a heavily monitored maritime chokepoint for surface ships and submarines, though the waters are too shallow for submarines to stealthily operate from.
Baltic Sea	■ Russian hybrid warfare. ■ Undersea cable and energy pipeline sabotage. ■ Mine warfare. ■ Proximity to Russian Baltic Fleet and to NATO allies.	■ Sweden and the Baltic NATO allies play major roles in undersea sensing, surveillance, and ASW. ■ NATO's Baltic Sentry mission aims to protect critical undersea infrastructure. ■ UUVs can be launched from shore at closer range and faster speed to target.

Maritime domain	Importance	Key undersea operations
Mediterranean Sea	■ Sea control of chokepoints on each end. ■ Undersea cables and energy pipelines. ■ Submarine transits between the Atlantic, Europe, and the Middle East.	■ Fixed-cable sensor networks. ■ NATO collective ASW capability (France, Italy, etc.). ■ UUV operations are more conducive with a lot of shoreline.
Red Sea	■ Maritime transit chokepoint, with the Suez Canal and the Bab el-Mandeb Strait on either side.	■ Transiting submarines from the Mediterranean to the Arabian Sea and vice versa. ■ Enclosed sea makes drone and UUV operations more effective.
Arctic Ocean	■ Russian SSN and SSBN operations and transits.	■ Submarines can be much stealthier and better hidden from aerial ASW assets while under ice. ■ Sensor and surveillance networks along the GIUK gap monitor Russian submarines exiting their bastion in the Barents Sea.

The emergence of new technologies and the businesses that create them will also require the Pentagon to change how these systems are procured. A mosaic of manned and unmanned systems in the joint force will alter operational plans, and the Pentagon, as an institution, must keep up.[52] In testing these new unmanned systems, the risk aversion which is endemic in U.S. defense procurement must be loosened. The Pentagon has spent much of the past decade in slow, iterated testing of UUV systems it subsequently abandoned, leaving the Navy with no effective UUV programs as late as 2025. Recent decisions to bring back on stream two programs—Snakehead and Orca—that had previously been closed down and changes to procurement processes herald the prospect of more rapid progress now, though at the time of drafting, it is too early to know the results.

Until recently, the effort to marry AI to the undersea—to use a powerful new tool to boost one of the most important of America's military advantages—has proceeded through the wrong model: integrated swarms of undersea robots linked in real time to global kill webs. The "kill web" concept is wrong for the subsea, and using the wrong metaphors has big implications for force management. Trying to bring submarines and other below-the-waterline platforms into a "web" will expose them to detection and run contrary to the submarine culture of "disappearing" for long stretches, with lots of local delegation to the edge.

Hence, the Navy is right, in its recent policy documents, to modulate its expectations of undersea drones, and to continue to push for an expansion of the major, crewed platforms on which the undersea force relies.

More realistic models should replace every part of that metaphor: distributed small pods of crewed and uncrewed platforms using edge AI, relying heavily on stealth, and loosely linked to wider networks. The most likely evolution of AI undersea is along two dimensions:

- Loosely connected "pods" of devices that can deliver acoustic and kinetic effects, operating in close proximity to one another. Such pods would add limited uncrewed options in narrow geographies and modest offensive capabilities to traditional crewed platforms.
- Tightly connected networks of sensors close to shore or in littoral waters, substantially aiding defensive operations.

These realities for how AI will affect forces below the waterline have big implications for AI management: the need for expert training of AI systems in local contexts, pods of edge AI, and less expectation that full-scale automated webs of devices will emerge even with significant improvements in technology.

A key implication is that pairing crewed and uncrewed systems will be essential and should be the starting point for design and acquisition of UUV systems. The design of the SSN-X will likely need to be modified to make this intrinsic to the function of the planned ship, and even the upcoming block of Virginia-class boats can be modified to allow for more integrated UUV pairing. In corporate terms, tighter partnerships between traditional platform designer/manufacturers and firms innovating with UUVs would seem like an efficient pathway forward.

A second central implication lies in the question of alliances. A world in which AI reshapes the subsurface domain—by enabling networks constrained by the limits of long-distance sensing and communications, while simultaneously increasing the importance of subsea cables—is one in which security will depend heavily on cooperation with a subset of allies. They provide what the United States cannot: physical presence, local intelligence on the subsea environment, and control over the cable landing points that are vital to global networks. Not all allies offer these advantages equally, and U.S. strategy should be clear-eyed about its various allies and partners' distinctive strengths and limitations. Given the strategic significance of undersea warfare and seabed infrastructure, the United States should highly prize its allies that have proximate geography and invest in undersea sensors and intelligence, as well as cognate technologies.

Above all, our argument leads to this conclusion: Even with major advances in computing power and machine learning, crewed submarines will remain the vital backbone of undersea power. Stealth will remain the crucial determinant of mission performance. Confidence in stealth has allowed the Navy to concentrate more firepower in single submarine vessels, which has saved money; fear that stealth advantages may erode might lead the Navy over time to disperse that firepower across more submarines. But stealth, for the foreseeable future, will remain the central principle. The use of AI-enhanced onboard oceanographic tools can aid stealthiness, while the use of edge AI-assisted tools—some embedded into the very coating of submarines themselves—may provide additional instrumentation at the tactical layer. And precisely because of AI-enabled kill webs above the waterline, stealthy operations below it will continue to increase in salience—for both the United States and its adversaries.

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