# Will the Atlantic become transparent?

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## *Third Edition*

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## Abstract

This paper argues that emerging detection and unmanned vehicle technologies will make the tracking and trailing of all types of submarine significantly easier within a decade. While asking whether the oceans will become "transparent" is misleading, the use of Passive Ocean Acoustic Waveguide Remote Sensing (POAWRS) and distributed netted systems (DNS) in chokepoints such as the GIUK Gap, combined with adaptable long-endurance or rapidly-deployable unmanned underwater vehicles (UUV) and unmanned surface vehicles (USV), look likely to undermine the stealth of existing submarines.

### The "transparent oceans" discourse

In the early 1970s, and again in the 1980s, a discourse emerged that questioned whether emerging underwater detection technologies might soon render the oceans "transparent." This was largely initiated among scientists and arms control experts at the 1970 Pugwash Conference in Racine, Wisconsin, where one scientist reported that new technology "virtually removes all the technical barriers to ocean-wide ASW surveillance and enfolds it in the economic constraints that are dictated by the strategic importance assigned to such a capability" (Anderson, 1971, p.206). The question was subsequently taken up by the strategic community, whose immediate object of investigation was whether such technologies could compromise the survivability of the US or Soviet nuclear ballistic missile-armed submarine (SSBNs) fleet in a surprise first-strike attack.

Most analysts concluded that the combination of advanced stealth technology and the immense difficulty of coordinating such an attack tipped the balance in favour of SSBNs. This was credited with creating strategic stability; since as neither power could guarantee total destruction of the other's SSBN fleet, it afforded the other a second-strike capability. Accordingly, a surprise first-strike was judged an unlikely decision by either power (Feld and Rathjens, 1973, p.273; Purver, 1983, p.418; Garwin, 1983, p.67; Daniel and Zelikow, 1987, p.25; Miasnikov, 1998, n.p.). Such strategic stability continues to be taken for granted today, although the Cold War's abrupt end put the question of ocean transparency to rest – until recently, that is, when the question has resurfaced in respect of digital innovations and advances in detection and signal processing, and the ongoing development of unmanned underwater vehicles (UUVs) and unmanned surface vehicles (USVs).

### Transparent oceans: a reality, ever?

This paper contends that asking whether the oceans will become fully "transparent" is wrong for three reasons. First, the word presents a false binary of "transparent" or "opaque," when any submarine commander will tell you that the ocean space is quite opaque in some places, more transparent in others, but mostly shades of translucent. Transparency is always relative. Instead, this paper uses Garwin's typology of "trailing," "tracking" and "open-ocean search" to compare levels of submarine detection, monitoring and localisation (1983, p.54). *Trailing* describes a situation in which "deployed strategic submarines are kept within range of an attack weapon" (Garwin, 1983, p.54), representing the highest level of transparency. *Tracking* can occur when "the area of uncertainty in which the submarine is deployed […] is much smaller than the overall potential deployment zone" (Garwin, 1983, p.54); Garwin proposes 1,000km$^2$ , though this could be expanded or contracted. *Open-ocean search* applies when "the entire deployment (or hiding) area must be searched" (Garwin, 1983, p.54). The exact size of this area is unknown, but clearly extensive. Submarines may move quickly between these categories: for example, by giving away their position, or by escaping a trail through intelligent manoeuvring.

Second, the question is premised on Cold War thinking that imagines extending the SOSUS network to become ocean-wide. SOSUS (Sound Surveillance System) was the United States' classified system of fixed hydrophone arrays, accompanied by monitoring stations on nearby friendly territories and first activated in 1961 (Hennessy and Jinks, 2015, p.327). Garwin, for instance, proposes that "[a]bout 500,000" short-range direct-path passive bottom-mounted hydrophones covering the entire SSBN operating area "on a 10-km grid […to] do the job reliably" (1983, p.66). Yet while cabled systems will not be abandoned entirely, they are less adaptable, vulnerable to trawlers, sabotage and obsolescence, more expensive and require heavy ocean engineering (Yang, 2014, p.261), and trends suggest that many roles will be filled by mobile systems. As mobile sensing platforms are more dynamic and responsive to stimuli, there is less need for the entire ocean to be rendered permanently and simultaneously see-through with a regularised, close-knit net. Nevertheless, this form of thinking looks likely to persist, including in the critiques of sceptics of submarine vulnerability. For instance, a relatively even spread of sensors is implicitly imagined by Rear Admiral Gower when he suggests that "a viable search and detection plan could be conceived for the open ocean" requiring "high tens of thousands or low hundreds of thousands of UUVs" (2016, n.p.).

Third, and relatedly, full-ocean transparency is tactically unnecessary if submarines can be located soon after they emerge from port or as they pass through chokepoints (or "gateways") – narrow areas through which submarines must pass in order to reach a larger body of water – and reliably trailed or tracked as they patrol.[1] We could call this "selective ocean transparency." Indeed, between the 1960s and 1980s, the US and NATO partners used nuclear-powered attack submarines (SSN) to trail comparatively noisier Soviet submarines, sometimes for entire patrols, with high reliability and without full ocean transparency. This typically began after a Soviet submarine's bearing was picked up by SOSUS hydrophone chains deployed in chokepoints. To reach the Atlantic Ocean, Soviet submarines from the Northern Fleet needed to pass through the GIUK gap (between Greenland, Iceland, and the UK), and often the gap between Bear Island and Norway. Similarly the Black Sea Fleet needed to pass through the Turkish Straits and the Strait of Gibraltar to access the Atlantic, and so on. Tactically, this approach is sensible; most submarines will be sensed in a small area, as per the Pareto principle, and it is more efficient to maintain contact with a verified submarine than try to continually re-sense them. However, although legal in international waters, nobody likes being followed, and trailing tends to increase political tensions and is dangerous for submariners, who risk both attack and collisions.

NATO's trailing approach was limited, and ultimately stopped working, for two reasons. Firstly, there were always insufficient numbers of SSNs to trail all Soviet submarines reliably: the primary reason that strategic thinkers felt that a US surprise first-strike was unthinkable. Secondly, Soviet submarines grew significantly quieter around the late 1970s, due to spies like Walker, Whitworth and Pelton who revealed to the Soviets unknown SOSUS chains and details of "cable tapping, the trailing and secret sub designs" (Lehman, 2002, p.320), an issue compounded by an increasing propensity to patrol under noisy sea ice. From a US asymmetric sensing advantage, the advantage now lay with submarine stealth for both sides. To tip the balance back in favour of anti-submarine warfare (ASW) and recreate a fleet-wide trailing programme, should it be wished, two things would need to happen: sensing would need to overcome quieting, and vehicles of sufficient quantity and sensitivity would need to be developed and deployed to track or trail each submarine, including in difficult to access areas like under Arctic ice. The following analysis of technical developments in ASW would suggest that this is conceivable within a couple of decades if technical capability is matched by the political will and resources required for deployment.

1 This does not hold true for emerging UUV threats, on which further research is necessary.

## Stealth-compromising developments in sensing

Sensing has advanced significantly since the Cold War; an overview of these advances can be found in Appendix I of BASIC's *The Inescapable Net* report (Hambling, 2016) and the British Pugwash Workshops: *Emerging Undersea Technologies* report (Naughton and Brixey-Williams, 2016). This section will analyse first the implications of the recent development of new and developing forms of active and passive sonar, Ocean Acoustic Waveguide Remote Sensing (OAWRS) and Passive Ocean Acoustic Waveguide Remote Sensing (POAWRS) respectively, and subsequently, the implications of distributed netted sensor (DNS) systems.

### OAWRS and POAWRS

OAWRS is a game-changing type of active sonar, able to rapidly and robustly sense "thousands of square kilometers" (Jain *et al,* 2014, p.180) at an areal rate "roughly one million times greater than that of conventional fish-finding methods" (Makris *et al,* 2006, p.660). For this, "OAWRS relies on […] the ocean environment to behave as an acoustic waveguide, in which sound propagates over long ranges via trapped modes" (Naughton and Brixey-Williams, 2016, p.2). POAWRS is a large-aperture, densely sampled, coherent hydrophone array, towed in tests by a research vessel. Using POAWRS, a team of scientists was able to "detect, localize and classify vocalizing [marine mammals] from multiple species instantaneously over an approximately 100,000 km$^2$ region" (Wang *et al,* 2016, p.366). Each POAWRS set-up requires just a receiver array, which costs around $1m, while an OAWRS system also requires a source, which can cost as much as $2m and as little as $200k (depending on the components' quality). These two sonar types are several orders of magnitude more effective than the next best system.

While OAWRS has been tested by detecting fish formations, and POAWRS by detecting the songs of marine mammals, Professor Makris of MIT explained at Pugwash's E*merging Undersea Technologies* workshop that this kind of large-range detection and classification could be performed from various kinds of oceanic noise-making sources, with no minimum frequency.

The discrete frequencies emitted by submarines can be detected even when they are trying to minimise their sound output (misleadingly named "silent running"). This includes the low-frequency (0.1-10 Hz) of the rotating propellers, which can travel very long distances as absorption is negligible; hull and nuclear-power plant noise, which is usually "[no] greater than 100 Hz" (Miasnikov, 1998, n.p.); cavitation, the noise of bubbles produced by a ship's propeller or bow; flow (a.k.a. self- or hydrodynamic) noise, of water displacement while moving; and submarine transient noise, such as the short and easily-identified sounds of "opening of torpedo tubes, steering manoeuvres, starting mechanical or hydraulic machinery, etc." (Lurton, 2002, pp.112-113). The aggregate of these discrete frequencies gives each submarine a unique "signature" or "acoustic portrait" by which it can be identified. POAWRS could be deployed widely peacetime, while heavily-protected OAWRS sources might be deployed in smaller numbers during peacetime or in much larger numbers during a crisis.

Over areas of roughly 100km in diameter, OAWRS can localise objects to within 15m in range and provide updates every 75 seconds (Makris, 2016b). Provided that the resonant frequencies scattered by the objects are known, objects as small as a single salmon can be sensed, and man-made objects can be distinguished from organic objects (Naughton and Brixey-Williams, 2016, p.2). Using POAWRS, objects smaller than submarines can be localised to 17m at a range of 1km, and as this scales linearly, to within 1.7km at a 100km range, etc. (Makris, 2016b).

The maximum detection range for a stealth submarine by a single OAWRS array is not known, and will also vary according to features of the water such as depth, salinity and thermoclines. However, assuming for the sake of argument that it is 50km from the source, it would take around 15 overlapping OAWRS units to cover the 800km or so gap between the UK and Iceland *(see fig. 1 overleaf).* A second overlapping chain could further improve localisation accuracy, making use of the properties of a multistatic sonar array. Even if the range were lower, the overall implication is it could be possible to track and even localise all submarines passing through chokepoints with only a small chain of autonomous or remotely operated OAWRS arrays.

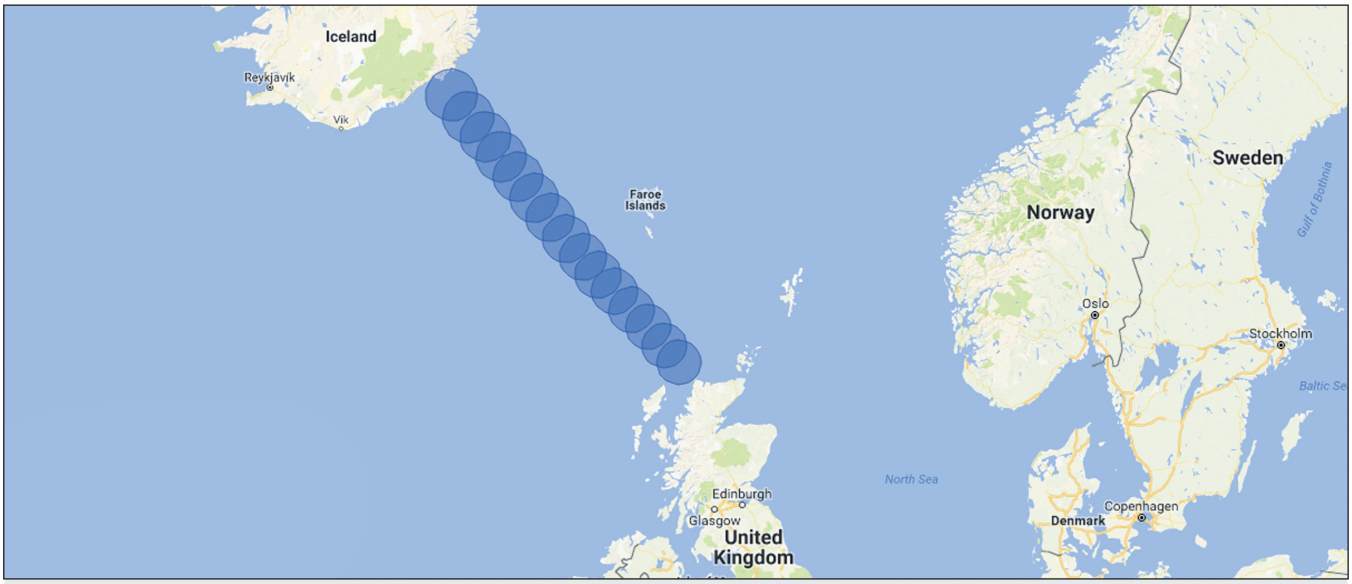


*Figure 1: Circles with a radius of 50km each represent a theoretical detection range for a single OAWRS source and receiver array (Beattie, n.d., n.p.).*

## Distributed Netted Systems

Whereas OAWRS and POAWRS are powerful and centralised, distributed netted systems (DNS) are decentralised and diffuse, and have provoked widespread excitement in recent years. Yang defines a DNS as "many, small inexpensive sensors spatially distributed, and a certain number of mobile nodes, such as autonomous underwater vehicles (AUV), forming an underwater […] network to conduct environmental sensing and target/event detection" (2014, p.262). A DNS is therefore akin to a SOSUS system, but it is important not to push the analogy too far, as it is significantly more adaptable and dynamic. Moreover, a DNS need not be only acoustic, but could fuse various kinds of sensing. Indeed, where previously there was a clear separation between a sensor and vehicle, both conceptually and in command and control procedures, today the traditional lines between "vehicle," "mobile sensor," "node," and indeed, "weapon" are blurring, as all are in service to a complex and contiguous detection and prosecution system that is "greater than the sum of its parts" (Yang, 2014, pp.261-272), and which can be connected into a wider military information grid. Such blurring will bring regulatory issues that require further research.

To date, DNS have been deployed and tested for naval applications in littoral waters. One example is PLUSNet (persistent littoral undersea surveillance network), a joint project between the US Navy's Office of Naval Research (ONR) and the Defense Advanced Research Projects Agency (DARPA) started in 2005. The object is to create "a semi-autonomous controlled network of fixed bottom and mobile sensors, potentially mounted on intelligent unmanned underwater vehicles (UUVs) to keep a constant eye on littoral zones" (Lo, 2012, n.p.). A similar system is Seaweb, developed at the US Naval Postgraduate School in Monterey, but also ONR supported. According to Kim, Yu and Chang, Seaweb provides "acoustic ranging, localization and navigation by the network […] of fixed and mobile nodes distributed across undersea area around 100 to 10,000km$^2$ with the depth of approximately 50 to 300m" (2014, p.95). A third project is RACUN (Robust Acoustic Communications in Underwater Networks), started by the European Defence Agency (EDA) in 2010, which in a test off La Spezia in May 2014 set up a mobile digital network with 16 communication nodes and UUVs that was able to coordinate its activities underwater (Atlas, 2014, n.p.). Challenges still remain, including improving underwater communication between multiple systems, autonomy, processing power, energy generation and battery life, and scaling the system.

Giving an accurate forecast for when these systems will be ready for large-scale deployment is difficult, although PLUSNet has already been deployed in a classified location, and the US Navy is already using some UUVs for ASW (Page, 2014, n.p.). It seems likely that DNS will be in use in littoral waters around some particularly high value zones, such as around US and allied ports and cities, within the next 5-10 years, before being extended into lower value littoral areas and further into the open ocean. An area in which such technologies are likely to be deployed early is the South China Sea.

DNS could also be deployed in chokepoints, working alongside POAWRS to resume the role played by SOSUS chains: picking up submarines. Among others, this role has been explicitly envisaged for the Aqua-Quad, an "[e]nergy-independent, ultra-long endurance, hybrid-mobility" (Cason III, 2015, p.4) fusion of a sonobuoy and a quadcopter that is currently under development. In tests, it has outperformed the US Navy's long-used, disposable passive acoustic DIFAR (Directional Frequency Analysis and Recording) sonobuoy by a long chalk. According to Loney R. Cason III at Monterey: "[w]e are looking at deploying enough Aqua-Quads to be used as a barrier across some span where there is expected to be enemy submarine traffic. Once any one of the Aqua-Quads on station detects a submarine, the Aqua-Quads will perform a leap-frog type maneuver and continually track and pass target information to each other to track the submarine for as long as possible" (2015, pp.24-25). Though Cason III admits Aqua-Quad still requires "a vast amount" of developing (2015, p.24), how long this takes will depend on the resources behind the project. Further, while the $10,000 cost per Aqua-Quad may seem steep if compared to $500-2,500 per DIFAR sonobuoy, the DIFAR sonobuoy can only stay on station for 8 hours, while the Aqua-Quad has the potential to stay for 200 days (Cason III, 2015, pp.19-20); costs are also likely to fall at scale. With respect to US naval budgets, a large fleet of Aqua-Quads are a drop in the ocean.

> ***"Seaweb is a realization of FORCEnet in the undersea battlespace. […] Our original goal was to create a network of distributed sensors for detecting quiet submerged submarines in littoral waters, where traditional ASW surveillance is challenged by complex sound propagation and high noise. But as Seaweb technology developed, its broader overarching value became evident."***
> – NPS Research Professor Joseph Rice (Honegger, 2010)

## Unmanned Vehicles

Emerging technologies put UUVs and USVs in a position to complement and perhaps take over the role of SSNs and manned surface vehicles in tracking and trailing the submarines of other states from chokepoints, while simultaneously being nodes in a wider DNS.

### Unmanned Surface Vehicles (USV)

The greatest evidence of this trend among USVs is DARPA's ACTUV (Anti-Submarine Warfare Continuous Trail Unmanned Vessel, pronounced "active"), which has been designed and tested to autonomously and continually trail diesel-electric submarines (SSKs) with only sparse remote supervisory control for patrols of three months. Writers like Blagden have argued that if the technology works, ACTUV "may have profound implications for both the naval and nuclear strategic balances" (2015, n.p.), and when the prototype, Sea Hunter, was launched in April 2016, it was announced that it had followed SSKs from 2 km away in trials while adhering to international law (Stella, 2016). However, as SSKs can be quieter than nuclear-powered submarines (running almost silently for long periods on batteries, whereas noise-emitting nuclear reactors must run continuously), ACTUV should also be capable of pursuing SSNs and SSBNs too, though by excluding these roles from the concept of operation it affords the US Government a measure of deniability.

Full deployment is envisioned for 2018, and costing only $20m to build (Economist, 2016), ACTUVs could be produced in large quantities and assigned to trail fleets of SSKs, SSNs or SSBNs. Multiple ACTUVs per trail would decrease the likelihood of losing a trail, and with help from other nodes in the DNS, increase the likelihood of picking it up again.

Sea Hunter has a top speed of 27 knots (Stella, 2016), only three knots slower than the top speed of the new Astute Class (NAO, 2014, p.45); however, submarines prefer to sail at around 4 knots, as high speeds counterproductively betray their position. Although Blagden argues that "a fully effective and reliable ACTUV system is likely to be decades rather than merely years away" (2015, n.p.), given that it took only two years to launch Sea Hunter after the start of construction (Leidos, 2014), this could be an overestimation. Indeed, the US Deputy Secretary of Defense has said that ACTUV could be used in the Western Pacific within five years (Dyer, 2016, n.p.).

### Unmanned Underwater Vehicles (UUV)

Much has already been written on the now numerous types and examples of underwater vehicle (Lundquist, 2014; Donaldson, 2014), and the concept of "swarming" UUV fleets seems to be vindicated by the high level of scientific research underway on underwater vehicle path-planning (Braca et al, 2014; Hambling 2015; Zhou and Wang, 2016). It is important, both for those with legitimate concerns about swarming and critics, not to sensationalise the idea of swarms, which could inadvertently (or by intention) consign them to science fiction. So-called swarms are simply highly dynamic DNS, and depending on programming, systems might also be developed with group dynamics closer to mammalian "packs," avian "flocks," or simply, "clusters."

Putting swarming aside, technology that would enable long-endurance UUVs to trail submarines under the surface is emerging, much as ACTUVs can on the surface. One example is the ONR's Large Displacement Unmanned Underwater Vehicle (LDUUV), which is being developed to work autonomously for months at a time across hundreds of kilometres, with diverse sensors and payloads. According to Secretary of the Navy, Ray Mabus the US Navy plans to deploy LDUUV on an independent mission "no later than 2020" (Tadjdeh, 2016). Similarly, Boeing's 51-foot Echo Voyager can traverse the ocean for six-month periods, with a 7,500-mile range and at depths of 11,000 feet (Davies, 2016), without the need for a surface ship for launch and recovery, and at a maximum speed of 8 knots. These vehicles will continue to improve with development, and while not as fast as ACTUV, UUVs are stealthier and have greater potential to operate under ice.

**Disclaimer:** Earlier editions of this paper contained a small number of technical errors with respect to the OAWRS and POAWRS systems, which have been amended herein. The third edition revises the timeframe for some of these technologies to reach maturity, based upon new research.

## Conclusions

This paper has argued that with respect to detecting submarines, it is not tactically necessary for entire oceans to be made transparent. Rather, it is more efficient for systems to detect submarines in areas where there is less opportunity to hide (chokepoints, and as they emerge from port), and then to pursue them autonomously. I have called this concept selective ocean transparency, as areas become illuminated or dim according to need. In the concept presented here, a wide-area sensing system like POAWRS or a large Aqua-Quad array could provide the primary cueing information in chokepoints that would enable nodal components of the wider DNS – fixed and mobile sensors, and vehicles like ACTUV, LDUUV and Echo Voyager – to track or trail a submarine on patrol.

Broadly speaking, the more autonomous vehicles assigned to a submarine, the greater the chance that contact could be maintained. The political tensions and threat to strategic stability that such a course of action would create should not be underestimated, however, and may be more dangerous than the technology itself. Nevertheless, chokepoints look likely increase in strategic importance to all states that use them, and to become permanently more transparent. Littoral waters will become more transparent too, first around high value zones, and later more generally, such that trailing becomes relatively easy. With sufficient political will, the US, its allies, and ultimately other states, may find that open ocean search is soon a thing of the past. Further research on how these technologies will affect the submarine patrol areas of different states will be necessary.

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