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Canada's Arctic Over-the-Horizon Radar: Early-Warning for the Defence of North America?

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The Government of Canada announced a key system for its long-awaited Arctic Over-the-Horizon Radar (A-OTHR) system in March 2025, partnering with the Government of Australia to buy the technology powering Canberra's world-class Jindalee Over-the-Horizon Radar Network (JORN). When the A-OTHR comes online in 2029, its primary function will be to provide early-warning detection and long-range tracking of aerospace threats to major population centres in North America. The A-OTHR announcement marks the culmination of eight years of growing recognition by Canadian and American senior leaders and political elite that "the homeland is no longer a sanctuary."[1]

The JORN system relies on over-the-horizon technology, which has been consistently modernized and upgraded with technical advancements in radar detection since the 1970s. The system relies on refracting radio frequencies off the ionosphere, bending in upper atmosphere, to be able to see beyond line-of-sight at long distances. In contrast, the current early-warning radar in the North American Arctic, the North Warning System, cannot detect objects over-the-horizon. Instead, it serves as a direct, line-of-sight tripwire. Canada's use of OTH-R technology provides greater fidelity and domain awareness, as the JORN uses tiles to continuously scan large surveillance areas rather than fixed locations.[2]

The A-OTHR is part of the $38.6 billion investment package the Government of Canada has committed to defend Canada, contribute to continental defence, and ultimately help modernize the North American Aerospace Defense Command (NORAD).[3] NORAD is the binational Canada-US command with the enduring mandate to provide aerospace warning, aerospace control, and maritime warning for Canada and the continental United States. Successive NORAD Commanders have sounded the alarm that Canadian and American radar capabilities are no longer sufficient in deterring or detecting against threats to the homeland, describing a vulnerable North America which cannot come to the aid of the Western alliance should the continent be held hostage or threatened by a resurgent Russia and rising China. Canadian prime ministers and American presidents have also reflected this understanding, gradually moving towards intensified and renewed cooperation to defend our shared continent in a series of joint statements since 2017.

Canadians' thinking about how secure they were changed given Russia's full-scale, illegal invasion of Ukraine in February 2022 and the re-election of US President Donald Trump in November 2024. Prime Minister Carney's announcement of the JORN procurement shows that Canada is moving at the speed of urgency the threat environment demands, packaging A-OTHR as part of an announcement which tackles threats "In, To, and Through" the Canadian Arctic.[4] The purchase also shows Canada's diversification of its economic and security relationships, turning to a like-minded ally, other than the United States, to purchase technology for the defence of the continent. Australia's has experience with surveilling its northern approaches and deep whole-of-society collaboration on consistently modernizing the JORN. This reflects Canada's commitment to understanding the severity of the global threat environment and working with like-minded allies to pursue common objectives.

First, this primer traces the evolution of early-warning systems that have enabled NORAD to detect, deter, and defend against threats to Canada and the United States since the 1950s. Second, it furnishes a comprehensive analysis of the current threat environment relative to North American. Third, it examines numerous joint statements and policy commitments made by Canadian and US political leadership from 2017 to 2025, demonstrating the gradual recognition that NORAD's capabilities need modernizing and its no-fail mission at risk. Fourth, it analyzes the A-OTHR's announcement and how its capabilities contribute to achieving all-domain awareness of threats travelling *through* the North American Arctic. This primer concludes with future considerations for the A-OTHR. An annex offers an in-depth historical case study of the JORN's development.

The Evolution of NORAD's Early-Warning Mission

The defence of North America has long focused on anticipating air-based threats over the Arctic and northern avenues of approach to the continent. Since 1938, when US President Franklin Roosevelt pledged that the US "would not stand idly by" if Canada was to be threatened by any other empire or adversary, Canada and the United States have jointly defended North America.[5] The hallmark of this cooperation is the binational North American Aerospace Defense Command (NORAD), responsible for the aerospace warning, aerospace control, and maritime control of Canada and the continental United States since 1957. Originally, the focus of defence planners was ensuring early-warning radar systems could keep pace with the technological advancements in weapons systems the Soviet Union could field – strategic bombers, intercontinental ballistic missiles (ICBMs), and later air and sea-launched cruise missiles (A/SLCMs). Soviet technology advanced through the Cold War, meaning Moscow could attack North America undetected. This strategic vulnerability required consistent upgrading of early-warning surveillance systems.

Radar lines in defence of the continent have always focused out and north to provide additional space and time for NORAD to detect, deter, and defend (and at worst case, defeat) a potentially decapitating attack on concentrations of North American military might or political power.[6] This thinking recognizes that Canadian and US airspace is functionally indivisible as a singular North American airspace, and NORAD forces work within an integrated command and control (C^2) structure. Canadians can command Americans on US soil and vice versa.

Radar lines monitoring North American airspace have been consistently modernized, improved upon, and replaced with novel technology to better detect advanced weapons and delivery systems that could strike North

America. NORAD's greatest strength is the command's continuous ability to evolve and keep pace with the global strategic environment - demanding cutting-edge radar engineering for advanced early-warning to achieve its enduring mission of having The Watch 24/7 over North America.

The first of these radar systems dates to 1946 and the legacy of strategic bombing in the Second World War. The Pinetree Line of 39 radar sites, was built to act as a "tripwire." Doing so provided the separate Canada and US air defence commands with more time to scramble aircraft flying north to intercept Soviet bear bombers, which would, in theory, cross the North Pole (the fastest route from the USSR to the US) and strike southern Canada or the United States.[7] The Pinetree Line could detect aircraft 200 miles away, but was limited by its geographical position close to major population centres (i.e. Soviet targets), its inability to detect low-flying aircraft, and its pulses could be easily jammed.

Recognizing the Pinetree Line's ineffective technology and southern location, joint Canada-US research and development on doppler radar began in 1951 amid broader discussions of additional radars.[8] To achieve "defence in depth," Canadian and American interceptors would have to meet Soviet bombers further northward to repeatedly attack and weaken them before they could reach their targets.[9] In pursuit of providing at least three to six hours of advanced notice, the Distant Early Warning (DEW) Line was paid for and built by the US across the 69th parallel in the Canadian High Arctic. A marvel of technological and engineering prowess, the 63-site radar line was constructed in just two years between 1955-1957.[10] The rationale for the construction of the DEW Line was that it would be built so far northward that decision-makers would have at least four hours of advance notice to a Soviet bear bomber attack, providing US Strategic Air Command (SAC) with time to activate its strategic retaliatory strike aircraft and move into position for further orders.[11] Anti-aircraft weapons could be readied, SAC-assigned aircraft could be dispersed away from bases to protect retaliatory strike capabilities, private aircraft could be told of areas to avoid, and civil defence plans on the ground in cities could be put into motion.[12]

At the same time as DEW Line preparations began, construction of the Mid-Canada Line (MCL – also referred to as the McGill Fence) was requested by the Canada-US Military Study Group in 1953.[13] The MCL would be positioned further northwards than the Pinetree Line at the 55th parallel. This line, built in tandem and complimentary to the DEW Line, allowed for detection and tracking of speed and direction to alert the Air Forces' of the location of a Soviet bomber.[14] The MCL was built with Canadian-developed bistatic radar technology, with a single transmitter and receiver antenna able to see aircraft as high as 65,000 feet.[15] The strategic rationale for the redundancy of the MCL, positioned further south than the DEW's tripwire, was described as "[providing] the function of confirming the warning of attack and of indicating the direction in which it is heading and alerting the air defence forces in more detail to get into position to meet the attack."[16] Once an aircraft crossed the DEW Line, constant surveillance was lost which meant anticipating precise targets was difficult without another supplementary radar line. The MCL was operational by 1958.[17]

In the era of the Cold War's arms race, the DEW Line could not see nor track the newly developed Soviet ICBMs with 5,500-kilometre ranges. Tracking and early-warning detection for this new Soviet threat originally rested with the US satellite-based Missile Defense Alarm Systems (MIDAS) in the early 1960s,[18] and later the US Ballistic

Missile Early Warning System (BMEWS) with radars in Clear, Alaska, Pituffik, Greenland, and Flyingdales, United Kingdom. [19] While the DEW remained useful at detecting bear bombers, it became further obsolete by the mid-1980s with cruise missile proliferation.

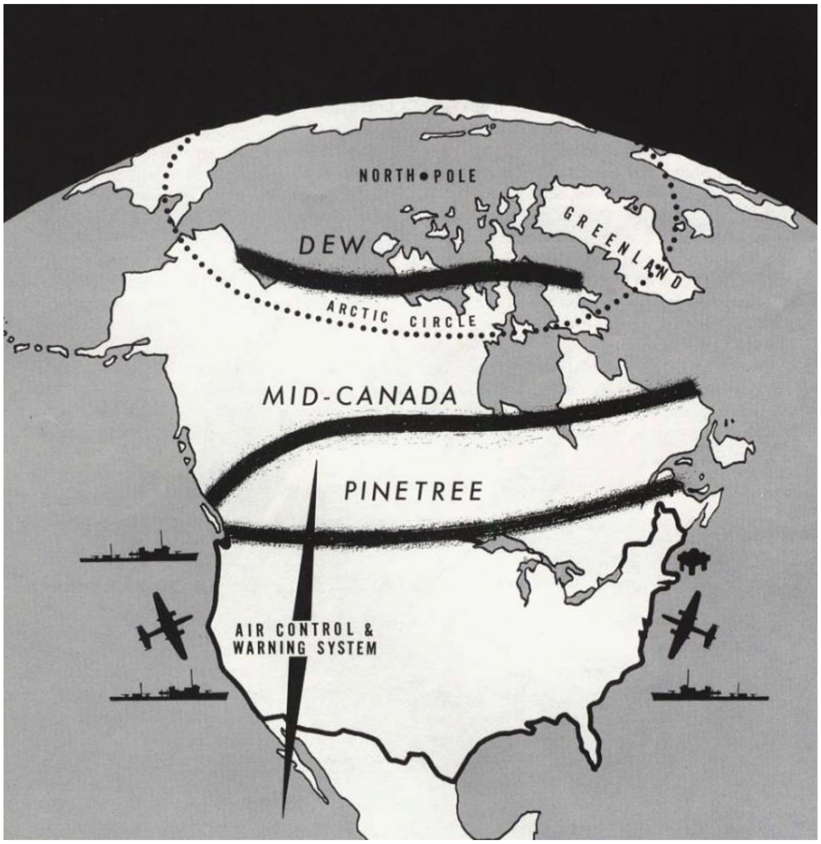

Figure 1: Pinetree, Mid-Canada, and Distant Early Warning (DEW) radar lines, 1960.[20]

The current early-warning radar supporting NORAD is the North Warning System (NWS), a series of 36 short and 11 long-range, uncrewed radars across Alaska, Yukon, the Northwest Territories, Nunavut, and Labrador. Politically approved by President Ronald Reagan and Prime Minister Brian Mulroney at the 1985 Shamrock Summit and built between 1986 and 1992 using 1970s technology, the NWS is oriented to look northwards for Soviet bombers and low-flying cruise missiles.[21] Designed for the strategic environment at the end of the Cold War, its feed are sent to NORAD command centres in Colorado Springs, North Bay, and Anchorage.[22] NORAD has invested in the Pathfinder Initiative, which uses machine learning and artificial intelligence to detect more information buried in sensor data from across systems like the NWS to allow radar operators and analysts to see more.[23] While the NWS "was not designed to detect modern weapons and delivery systems, such as long-range cruise and hypersonic missiles," its utility for continental defence remains as a tripwire system with continuing operation and maintenance of the line.[24]

Years of limited commitment to North American and Arctic defence and security after the end of the Cold War in 1991 was followed by the turn inwards to focus on homeland security and terrorism following the attacks of

September 11th, 2001. Today, North America finds itself in a new, geopolitically-induced international security environment that challenges assumptions, thinking, and capabilities about how to defend the continent in the face of global threats and challenges.

The Changing International Security Environment

Concern over the ability of early-warning infrastructure supporting NORAD's aerospace warning mission to adequately detect airborne threats dates to at least 2011, prompted by the proliferation of two distinct delivery systems. First, the development of Russian long-range air and sea-launched cruise missiles (A/SLCMs) rendered the NWS outdated. The system was not built with in-flight tracking capabilities, therefore revealing a situational awareness gap. Second, by 2017, Russian was developing and testing hypersonic glide vehicles (HGVs) and cruise missiles. These platforms are maneuverable in flight and fly at greater than Mach 5. This meant that another new delivery system was undetectable by the NWS, leaving North America vulnerable to attack without warning.[25]

During the same time, Moscow's long-range patrols around the North American Arctic and Pacific coastlines began to pick up in quantity since 2007, a signal of Russian exercises to test and probe NORAD responses to the Alaska Air Defence Identification Zone (AADIZ). An ADIZ is "used by states to monitor and identify aircraft approaching their sovereign airspace and assess possible threats to national security."[26] While these sorties are normally professional, expected, and carried out safely, sending a signal that Russia still has global reach, a Russian Su-35 manoeuvred close to American interceptor in a manner described as "unsafe, unprofessional, and endangered all" in September 2024.[27] Earlier that summer, Russia and China jointly buzzed the AADIZ for the first time, signalling intensifying competition with the US. Alaskan Senators Dan Sullivan and Lisa Murkowski decried these flights as escalatory.[28] These weapons systems and the gaps they create, combined with increased signalling, have created conditions required for rethinking what it means to defend and secure North America against outward, inward, symmetric, and asymmetric threats across all domains.

Defence planners and strategists quickly recognized the peril these advanced weapons and capabilities posed to the continent (or homeland in US parlance). Combined with legacy thinking of preference for kinetic solutions over non-kinetic options, and the prioritization of single threats in single domains rather than a multi-threat, multi-domain threat environment, meant that decision-makers had to think outside the proverbial box.[29] In 2020, then-Commander of NORAD/USNORTHCOM General Terrence J. O'Shaughnessy (2018-2020) testified to the US Senate Armed Services Committee that:

> the Arctic is no longer a fortress wall, and our oceans are no longer protective moats; they are now avenues of approach for advanced conventional weapons and the platforms that carry them. Our adversaries' capability to directly attack the homeland has leapt forward, and they are engaged in overt, concerted efforts to weaken [the US'] technological, economic, and strategic advantage.[30]

O'Shaughnessy, nearing retirement, was bold in his assessments of the threat environment posed by Russia and China. Russia had previously demonstrated their use of conventionally armed cruise missiles in Syria, committed to Cold War-era readiness levels for its heavy bomber fleet and a build-up of cruise-missile capable vessels, modernization of its strategic nuclear forces, and expansion of its Arctic military infrastructure.[31] Reflecting this, Canadian analysts Ernie Regehr and Kelsey Gallagher have systematically charted Russia's Arctic infrastructure over the last ten years, showing 32 Russian military sites in their Arctic region (more than double of any like-minded Arctic state).[32] Beyond Russia, O'Shaughnessy also viewed Beijing's rapid military modernization and efforts to extend their global reach as willingness to directly challenge the US by adopting and contributing technology to advance novel Russian delivery systems.

Later in 2020, O'Shaughnessy (post-retirement) and then-NORAD Deputy Director of Operation Peter Fesler outlined options to solve North America's security vulnerabilities. In "Hardening the Shield: A Credible Deterrent & Capable Defense for North America," they outline how the changed security environment of the 2010s brings new challenges for the existential mission of defending North America. Avenues of approach to the continent in the air and maritime domains have become contested with advanced strike weapons, new delivery systems, and new thinking to gain an information advantage by limiting the US and Allies' ability to mobilize forces by disrupting Allied economies and logistics/supply lines. This logic is prompted by both a return of great power competition (between the US, Russia, and China) and a US Unified Command Plan designed for a post-Cold War era of American hegemony.[33] Their driving argument is that strategic planners have long neglected the homeland in favour of fighting war far away from the continent, projecting global power to wage conflict closer to the enemy by using North America's strategic geography of being surrounded by oceans to Washington's advantage.[34]

Now, the development and deployment of advanced long-range weapons, which outpace existing early-warning systems, combined with adversarial expertise in exploiting the West's vulnerabilities in all domains, fosters the concern that adversaries of the West will seek out "ways to disrupt [US] deployments before they even leave the North American continent."[35] If the homeland is vulnerable, the US military can no longer maintain its global superiority nor its freedom to manoeuvre unencumbered.[36] The targeting critical infrastructure in North America could pull US focus away from a peripheral theatre of contestation or conflict elsewhere (i.e. Eastern Europe, the Middle East, or the South China Sea). Therefore, O'Shaughnessy and Fesler's solution to this strategic folly was to suggest a new defence architecture that is focused on offensive capabilities for USNORTHCOM and centralizing it as the US Combatant Command with the most resources and attention from Congress. Importantly, they posit that US strategists should target adversaries' "archers" (the launch platforms) rather than the "arrows" (the missiles), which has been the historical preference of how to defend the homeland. In their mind, tracking and, if needed, pre-emptively striking launch platforms would be the most effective way to deter an adversary as destroying launch platforms is a monetarily and strategically costly effect for an adversary to withstand.[37]

This new threat environment places the North American Arctic at the centre of defending the homeland because of the geographic avenues of approach and global pivot in attention to the circumpolar Arctic. This thought process was further emphasized and explained in strategies and doctrine by O'Shaughnessy's successor General Glen Van Herck (2020-2024). The 2021 NORAD and USNORTHCOM Strategy identified the Arctic as a "changing physical and strategic environment and is a zone of international competition."[38] The strategy's overarching goal is to better defend Canada and the US in the Arctic through increased domain awareness. A better understanding of what is happening *in* the Arctic provides NORAD and USNORTHCOM decision-makers with more time to move "farther left of bang" (i.e., before an event occurs) and offers them a wider range of response options. This allows the binational command to pre-emptively deter and detect threats to the continent in competition and crisis.[39]

In line with the Pentagon's concept of connecting all sensors from all military services into a single network (known as Joint All-Domain Command and Control or JADC2), achieving All-Domain Awareness helps NORAD meet globally-induced security challenges. This first objective involves utilizing "sensors and systems that provide persistent and complete battlespace awareness, from subsurface to space and cyberspace. This essential capability increases warning time for national leadership against multiple threats, expanding available response options. Fused data can also be transmitted across the globe to benefit every combatant commander and create global information dominance."[40]

The second objective, Information Dominance, involves the ingestion of data into a global system-of-systems network. This ecosystem is bolstered by artificial intelligence and machine learning, which enables decision makers to access selected data in near real time. Information dominance, alongside concepts such as Joint All-Domain Command and Control (JADC2), would combine stove-piped information, data, and raw intelligence into a "cloud-based computing environment." The all-encompassing ecosystem would be constantly fed from all-domain awareness sensors, some of which are located *in* or surveilling threats travelling *through* the Arctic.[41] Sensor examples include early-warning radar lines, underwater sound surveillance systems (USOSUS), and common operating pictures from civilian agencies, other government departments, and all branches of the armed services. This also includes allied intelligence which may be shared with NORAD.

These two components lead to decision superiority, the third pillar which senior leaders are trying to achieve (or "get after" in military parlance). Decision superiority is about providing decision-makers with the most comprehensive amount of relevant information and context, options sets, and decision-making space as possible, with kinetic and non-kinetic options. Information dominance "tools" like all-domain awareness sensors, or analysis fuelled by "multiple intelligence and sensor information streams" is conducted by machine learning and artificial intelligence.[42] In layperson's terms, advanced sensor and intelligence networks are fed into a state-of-the-art computing system which provides a variety of flexible response actions for the NORAD Commander, depending on the situation at-hand, faster than humans can.

By relying on advanced computing systems to process information faster than a human can, three objectives can be achieved. First, analysts can be moved to different issues of need, freeing up personnel and manpower. Second, decision-makers can be recommended options nearly instantaneously and can bring in other actors faster. Third, responsive decision-making enables leaders to get "inside" the observe-orient-decide-act (OODA) loop of an adversary, providing more time for the US to respond "left" or before a launch through information messaging to sow doubt in competitors' minds. [43]

These objectives can assist with pre-emptively changing force posture to move in time to respond before an adversary acts. Essentially, decision superiority is critical force multiplier in a global threat environment. Van Herck describes the critical need to "know when aircrews are stepping to their aircraft, when ships and submarines are planning to sail, and when missile operators and systems are preparing to launch,"[44] which builds directly off the need for greater domain awareness and the targeting of archers, rather than arrows, as O'Shaughnessy suggested.

Van Herck described Russia's military doctrine as one where Moscow "envisions nonnuclear strikes on an adversary's critical infrastructure to compel termination of an escalating conflict, and it has repeatedly demonstrated its ability to hold our homelands at risk through heavy bomber patrols near North America."[45] Similarly, China has capable conventionally-powered cruise missiles and a "robust ability to threaten our critical infrastructure in the cyber domain."[46] This thinking leads to O'Shaughnessy, Van Herck, and scholars Andrea Charron and James Fergusson to suggest that that deterrence by punishment is no longer a viable option for a world with two peer competitors to the United States, advanced strike weapons, and violent extremism. Instead, deterrence by denial and raising an adversary's costs of action is best achieved through all-domain tracking and early-warning of all approaches to North America, protecting both traditional and non-traditional targets in the process.[47]

Current NORAD and USNORTHCOM Commander General Gregory Guillot (2024 – Present) has built on O'Shaughnessy and Van Herck's strategic assessments. Guillot's previous experience as Deputy Commander of US Central Command (USCENTCOM) influenced his perception of the global security environment. In his testimony to the US Senate Armed Services Committee in 2025, Guillot highlighted that after "years of steady investment, our strategic competitors have the means to overcome… favorable geography and advanced technology" to hold the homeland at risk.[48] "NORAD faces the most complex and dynamic threat environment" in the command's history, with three concerning trends to the continent: growing risk of a war with a strategic adversary; growing alignment between strategic adversaries Russia, China, North Korea, and Iran; and, growing adversary capabilities to threaten the homeland.[49]

NORAD and USNORTHCOM analysts suggest that specific weapon capabilities and adversaries' intentions show there is a wide range of kinetic threats able to target North America and allies. North Korea possesses 14 ICBMs, including the Hwasong-19 which can carry a thermonuclear payload. Its solid-state design lessens preparation time for launch. Iran currently has a self-imposed 2,000-mile limit on its missile technology. However, based on the kingdom's space surveillance program, analysts hypothesize that Tehran could develop a field-capable ICBM within 5 years.

The gravest concern to strategic stability is the proliferation of hypersonic glide vehicle (HGV) delivery systems, such as Moscow's low-flying, manoeuvrable Avangard which can carry nuclear and conventional payloads when married to an ICBM at Mach 20 to 27. Analysts posit that HGVs are designed to be deployed as the first strike, serving as a precursor to a massive, overwhelming nuclear attack. HGVs could also be utilized as last-ditch, retaliatory strikes to control escalation from climbing the ladder. China's People's Liberation Army's (PLA) Shang III Type 093B submarine with guided missiles has the range to target critical military infrastructure in Alaska, as can the 5,000 kilometre-range Dongfeng-27 HGV.[50] Beijing's novel fractional orbital bombardment system (FOBS) can fly under space-oriented radar with a "trajectory that approaches North America from the south rather than the traditional northerly vector for which our legacy early-warning radars were designed." Guillot testified that these adversarial capabilities "will severely challenge our ability to detect and characterize an inbound attack and determine an appropriate response during a conflict,"[51] which will erode global strategic stability amongst the great powers.

Security challenges posed by adversaries' capabilities and "growing willingness to challenge the United States on the global stage"[52] exacerbates the inequities that a deterrence by punishment postures provides. Given that viable and credible deterrence depends on the US and Canada's ability to warn of incoming threats soon enough to ready defences and retaliatory measures, a denial posture seeks to preclude competitors from holding North America hostage.[53] Indeed, adversaries may seek to disrupt domestic day-to-day life through the cyber domain, hold critical and economic infrastructure such as power grids or airfields at risk of being destroyed with uncrewed aerial systems (UASs or drones), or disrupt the free flow of forces and resupply from the North American coasts.

These tactics would serve as a precursor to conflict elsewhere, taking advantage of distracted Allied attention away the Indo-Pacific or Europe as O'Shaughnessy and Fesler theorize. Because of the global nature and speed of the threat environment, and with the fastest vector to attack North America being through the Arctic, achieving all-domain awareness enables senior leaders to have better situational awareness of threats travelling *through* the North American Arctic to strike southern targets.[54]

Therefore, the Arctic is inextricably linked to the broader defence of the continent for "globally-integrated layered defences that incorporate geography (forward regions, approaches, and the homeland layers), domains (air, land, sea, space, cyber, electromagnetic, and cognitive), and whole-of governments/nations."[55] Van Herck describes our "competitors' global actions require "concepts that integrate homeland defense and strategic deterrence into every aspect of our defense."[56] The notion of Arctic security, accordingly, is implicitly tied to broader US goals of achieving global power projection, deterrence and strategic stability, and maintaining influence.[57] Consequently, the North American Arctic is the geographic linchpin for ensuring credible and capable defence of North America.

Joint Canada-US Statements on NORAD Modernization

The need to modernize NORAD reflective of the changing international security environment and focus on the North American Arctic has been increasingly recognized at the high-political levels in the Canada-US relationship. In their first meeting in February 2017, Prime Minister Trudeau and President Trump's joint statement reaffirmed that Canada and the US are:

> indispensable allies in the defense of North America and other parts of the world, through NATO and other multilateral efforts. Our troops have time and again fought together and sacrificed their lives for our shared values. [NORAD] illustrates the strength of our mutual commitment. United States and

> Canadian forces jointly conduct aerospace warning, aerospace control, and maritime warning in defense of North America. We will work to modernize and broaden our NORAD Partnership in these key domains, as well as in cyber and space.

The Canadian commitment to replace the CF-18 fleet was "welcomed."[58] This is the first mention in a joint political statement of the need to modernize NORAD, and was reiterated in the 2017 defence white paper *Strong, Secure, Engaged* (*SSE*).

SSE pledged to ensure a secure North America, "active in a renewed defence partnership in NORAD with the United States."[59] This includes "expand[ing] Canada's capacity to meet NORAD commitments by improving aerospace and maritime domain awareness and response and enhancing satellite communications."[60] To jointly detect, deter, and defend against threats to North America, "Canada will cooperate with the United States on Arctic security and will examine the requirements to meet all-perils threats to the continent through NORAD modernization. This will also involve working collaboratively to enhance shared situational awareness and early-warning in the northern environment."[61] Funding was attached to *SSE* for the Royal Canadian Air Force (RCAF) to procure a new fighter platform, but there was no explicit budget attached for NORAD modernization efforts or the increasingly critical need to replace the NWS. There was, however, a brief mention of working towards a "bilateral collaboration to seek an innovative technological solution" for its replacement.[62]

Hemispheric defence and international security were also highlighted in the December 2018 Canada-US Ministerial 2+2 between the foreign and defence ministers/secretaries, but NORAD was mentioned only as an example of a mutual, enduring commitment to defend the continent. (There was no mention of modernizing the binational command.)[63] Another meeting in this format has not been used again in the Canada-US relations for defence and security collaboration.

Following the contentious relationship between Trump and Trudeau, exacerbated by trade disputes and personalities, Trudeau and President Joe Biden's "Roadmap for a Renewed Canada-US Relationship" in February 2021 sought to "revitalize" the "historic alliance" and "steadfast friendship," "bound by history and geography."[64] The agreement's sixth pillar, "Bolstering Security and Defence," focused on "expand[ing] cooperation on continental defence and in the Arctic, including by modernizing [NORAD]."[65] This commitment is situated within the recognition that the NWS is no longer able to adequately detect nor provide ample early-warning time for new air-breathing threats. The US relies on allies and partners to help achieve its interests in a changing circumpolar Arctic which, at that time, could be characterized by Russian buildup, Chinese investments, and increased commercial activity (all of which are broadly characterized as explanations for increased global attention to the Arctic in the Pentagon's congressionally mandated 2019 Arctic Strategy update).[66]

The third high-level joint statement followed the Roadmap in August 2021, with Minister of National Defence Harjit Sajjan and Secretary of Defense Lloyd Austin "reaffirm[ing] our commitment to supporting NORAD's ability to detect, deter, and defend against aerospace threats [including threats transiting the northern approaches] and to detect maritime threats to North America, today and in the future."[67] The U.S.-Canada Joint Statement on NORAD Modernization described how the shared security and defence of North America allows for global presence. Vulnerabilities allow for challenges from great power competitors and their rapid technological advancements combined with climate change.

The Sajjan-Austin announcement outlined deliberate, coordinated investments by the DoD and DND in priority areas to ensure continued continental security. The first investment is to attain effective situational awareness, "especially in the northern and maritime approaches to the continent," through next-generation over-the-horizon radar systems and a system-of-systems approach of Canadian and US sensors from the sea floor to outer space. Second, enhanced command and control systems to ingest and fuse together sensors from all-domains into a single common operating picture for better informed decision-making; as well as investing in robust and resilient communications in remote and contested environments. Third, upgraded and modernized infrastructure for new capabilities will support NORAD operations to "deter, and if necessary, defeat threats," including in the Arctic and northern regions. Fourth, Ottawa and Washington will jointly invest in collaborative research, development, and innovation top meet the rapid pace of threats and evolving solutions to countering them.[68]

The spring of 2022 represented a turning point for Canada's commitments to modernizing NORAD. Russia's full-scale and illegal invasion of Ukraine primed Canadians to think more seriously about Canada's defence capabilities. Political decision-makers reacted accordingly. Then-Minister of National Defence Anita Anand justified Canada's "bold and aggressive" stance on continental defence as a reaction to her blunt assessment of the state of the world "that appears to be growing darker" in May 2022. Elaborating on global uncertainty and instability, Anand described the growing realization of the severity of the threats to North American as: "In this new world, Canada's geographic position no longer provides the same protection it once did. And in this new world, the security environment facing Canada is less secure, less predictable and more chaotic."[69]

Following these remarks, Anand and Trudeau visited NORAD Headquarters in Colorado Springs. The first Prime Minister to visit since his father in 1977,[70] Trudeau, Anand, and Austin discussed the importance of NORAD's binational structure; the command's ability to detect, deter, and defeat threats to North America; the evolving threat environment posed by new technologies; recent geopolitical developments (and almost certainly touted Canada's steadfast support for Ukraine and broader contributions to international security); and priorities for the development of NORAD's capabilities and future of continental defence.[71] This readout shows dedicated attention from both states to modernizing the command.[72]

In June 2022, Minister Anand articulated Canada's contribution to the coordinated and deliberate investments that Sajjan and Austin had previously outlined. Describing the United States as Canada's "most important ally, our strongest partner, and our closest friend," Anand announced the largest investment in the binational defence command since 1985 when the DEW Line was upgraded to the NWS. The Trudeau Government committed $4.9 billion over six years, and $40 billion over twenty years, "to deliver new capabilities to protect Canadians for generations to come."[73] The timing of this announcement, parceled into five priority areas to be fully delivered by 2039, was politically salient give the broad quad-partisan support in Parliament after Russia's invasion of Ukraine.[74]

First, modernizing surveillance systems reflects the geostrategic reality that crossing the North Pole represents the fastest way for Russia to strike North America using various delivery systems. A Northern Approaches Surveillance System, to detect threats earlier and more precisely, will include an Arctic Over-the-Horizon Radar system to track from the Canada-US border to the Arctic Circle; a Polar Over-the-Horizon Radar system to track from the Arctic Circle northward over the archipelago; and a highly-classified joint Canada-US Arctic sensor network called Crossbow using non-radar detection systems.[75]

Second, technology-enabled decision making will support the tremendous amount of data from the new early-warning and surveillance infrastructure.[76] Initiatives such as the NORAD Cloud-Based Command and Control (CBC2) will expand on the Pathfinder Initiative (which combines siloed information into a single common picture)[77] to leverage artificial intelligence and machine learning so that decision-makers can make informed, rapid decisions at the speed of relevance. Satellite communications infrastructure will support operations across the Canadian North, and a new positioning, navigation, and timing capability will assist with air navigation in remote areas throughout the country. Finally, a new Canadian Combined Air Operations Centre (CAOC) will "plan, direct, monitor, control, and coordinate domestic, continental and global operations 24/7/365."[78]

Third, investing in defensive capabilities will provide decision-makers with an expanded range of defeat options, such as advanced short, medium, and long-range air-to-air missiles compatible with Canada's future fifth generation fighter fleet. This will allow for the RCAF to track, assess, and engage possible targets.[79]

Fourth, new infrastructure and support capabilities will allow the Canadian Armed Forces (CAF) to launch and sustain presence across the country. This pillar includes air-to-air refueling and strategic tanker capacity by acquiring 9 CC-130 Husky aircraft,[80] NORAD Quick Reaction Alert capabilities at bases across Canada,[81] and Northern Operational Support Hubs (NOSHs) at NORAD Forward Operating Locations (FOLs) in Inuvik, Yellowknife, Iqaluit, and Goose Bay.[82]

Fifth, investing in research, development, and innovation reflects the rapid pace of technological advancements adversaries have made in recent years. Baskets of focus include developing space systems; integrated air and missile defence; autonomous systems; uncrewed aerial systems; cyber intelligence and operations; and quantum-enabled capabilities. These advancements will enable force readiness, a capable forward presence, situational awareness, and mitigating the deleterious effects of military operations on climate and the environment.[83]

The investments were met with widespread praise and acclamation. US Ambassador David Cohen highlighted how NORAD is the "crown jewel" of joint Canada-US defence cooperation and capabilities, stating that "as threats evolve, NORAD must evolve with them." Repeating language found in *SSE*, Cohen celebrated Canada's "commitments to ensure the continued defense and security of North America," and that "the stronger and safer we are at home, the more we are capable of engaging, acting, and leading together on the global stage."[84] These capabilities are responses to what the RCAF and CAF broadly need to ensure the security of Canada and the continent.

In March 2023, President Biden visited Ottawa to address Parliament where defence spending was high on the agenda (following in both Obama's and Trump's efforts to have Canada spend 2 percent of its GDP on defence).[85] Fresh off the release of the US *National Defense Strategy* (*NDS)* in October 2022, which declared Russia as the "acute" threat and China as the "pacing" threat to US interests and hegemony, the focus of the Pentagon was now firmly on defending the homeland rather than the away game. Because of "increasingly sophisticated conventional missile capabilities that are able to target critical infrastructure in North America," the NDS doubled-down on committing to work with Canada to improve early-warning surveillance.[86]

In his address to Parliament, Biden described NORAD's binational integration as an example of the "exceptional" Canada-US relationship, and "an incredible symbol of the faith we have in one another and the trust we place in each other's capabilities."[87] The US president also touted Canada's investments in infrastructure for next-generation fighter aircraft, undersea surveillance systems, and over-the-horizon radars to enhance binational early-warning capacity.[88]

Biden and Trudeau's March 2023 Joint Statement explicitly "celebrate[d]" the achievements first outlined in the 2021 Roadmap. The two leaders affirmed that "our highest priority is to protect our citizens and our sovereign territory." Canada's commitments to do so included investments in infrastructure at the FOLs to support fifth generation fighter aircraft, mobility/refueling assets, and airfield improvements to support personnel, fuel, and munitions. This will allow NORAD to deter, detect, and defend against Russia and China "for years to come." The statement reaffirmed Canada was in the process of "procuring and fielding of two next-generation Over-the-Horizon radar systems covering the Arctic and Polar approaches, the first by 2028 to enhance early-warning and domain awareness of *North American approaches*" [emphasis added].[89]

Years of joint statements at the highest political levels show a persistent and demonstrated commitment by Canada and the US to modernize NORAD. This reflects the recognition global threat environment evolved throughout the 2010s, exposing vulnerabilities adversaries can exploit. The 2022 NORAD modernization commitments, and the ongoing follow-through of them, shows Canada understands the gravity of the international security situation and its connections to domestic and continental defence. In the long-awaited March 2024 defence policy update, *Our North: Strong and Free (ONSAF)*, an unprecedented focus is placed on defending the Canadian Arctic in a world shaped by trends of climate change, rising authoritarianism, and disruptive technologies.[90] *ONASF* declares the number one priority of the Canadian Armed Forces is to "detect, deter, and defend against threats to or attacks on Canada," with the second being against threats to North America.[91] *ONSAF* notably tied the 2022 commitments to the newly shaped world by highlighting the plan as a "fundamental component of our response to the growing threat environment affecting Canada and the Arctic and North America more broadly. These efforts are important first steps that […] will restore the military advantage that we have long enjoyed on the continent, and ensure that Canada, the Arctic, and our approaches do not become an avenue of attack on North America."[92]

The Canada-US relationship reached a historic nadir in Spring 2025. The aligned priorities of Biden-Trudeau quickly vanished with Trump's re-election and the president's bombastic, blustering rhetoric about Canada, suggesting that Canada should become the "51st state" or else face crippling and punitive economic turmoil through tariffs and protectionism to bring manufacturing back to the US. This undermined thirty-five years of free trade and ninety years of broader Canada-US trade cooperation, rocking Canadians' views on the US and its security guarantees (with a Canadian poll by scholars Mathieu Landriault and Mirva Salminen showing that Canadians consider the US to be the largest security threat in the Canadian Arctic).[93] Canadians' fears of US annexation, considered long extinguished, have roared back.[94] Prime Minister Carney campaigned on a strong response against Trump's tariffs, vowing to renegotiate a "new economic and security relationship" with our most important ally, and diversify and deepen our relationships with other like-minded allies.[95]

Arctic Over-the-Horizon Radar

> [T]oday, I'm announcing that our government will be working with our longstanding defen[c]e and security partner, Australia, to build a long-range over-the-horizon military radar system. This is an investment of more than $6 billion in the most advanced and efficient radar system. The over-the-horizon radar system will enable Canada to detect and respond to both air and maritime threats over our Arctic faster and from further away. It will most fundamentally keep all Canadians safe.[96]
>
> The Right Honourable Mark Carney, Prime Minister of Canada
> Iqaluit, Nunavut, 18 March 2025

On 18 March 2025, his fifth day in office, Prime Minister Carney "announced key measures to reinforce Canada's security and sovereignty in the Arctic," a strategic priority of the new government.[97] In his first domestic trip, Carney visited Iqaluit to announce a $6 billion agreement with the Government of Australia to co-develop Over-the-Horizon Radar technology to "help advance the rapid establishment of Canada's planned Arctic Over-the-Horizon Radar system" and strengthen domain awareness of Canada's Northern approaches.[98] This is a generational investment in early-warning technology for the defence of North America. Part of $38.6 billion commitment to modernize NORAD, the Arctic Over-the-Horizon Radar (A-OTHR) promises to "provide long-range surveillance of the northern approaches to the major population centers in North America."[99] The current NWS is unable to detect the advanced missiles and aerial weapons technology adversaries are able to deploy to strike at or hold North America hostage. A-OTHR will help to address this surveillance gap.

This OTHR technology will be based off the Royal Australian Air Force's (RAAF) Jindalee Operational Radar Network (JORN). The JORN is a series of three, fixed ground stations near Longreach in Queensland (Radar 1 – R1), Laverton in Western Australia (Radar 2 – R2), and near Alice Springs in the Northern Territory (Radar 3 - R3). The surveillance feeds are sent to the Battlespace Surveillance Centre (formerly the JORN Coordination Centre (JCC)) at RAAF Base Edinburgh in Southern Australia.[100] Compared to traditional direct line of sight or straight line radar systems, the JORN "works by refracting high-frequency electromagnetic waves off the ionosphere[101] between 70 and 350 kilometres above sea level in Earth's upper atmosphere.[102] When the waves are transmitted back into the Earth's atmosphere and "hit" a metal surface, either in the air or at sea, the corresponding energy is reflected back to the ground station receiver. The fainter the energy, the further away the metal object is. The data is then ingested and processed in computer systems so that radar operators can see the air and sea avenues of approach in real time. As ionospheric waves bounce and refract, the radar system can see greater fidelities further away, attaining more data and information (awareness) of the areas it is surveilling.

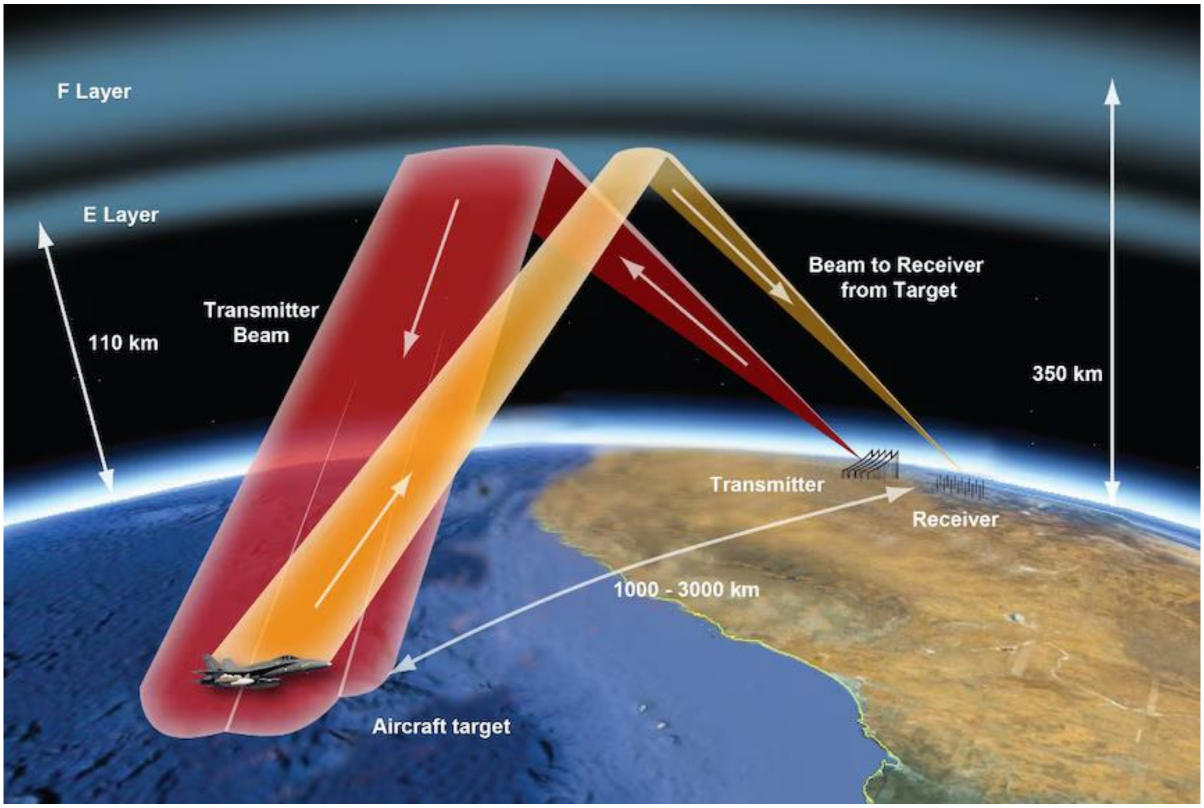

Figure 2: JORN works by transmitting radio waves into the ionosphere which bounce back down onto the earth's surface.[103]

Based off the JORN's unclassified capabilities, the A-OTHR is expected to surveill 1,000 - 3,000 kilometres into the Canadian Arctic. Based in Southern Ontario, the system will provide early-warning for threats travelling *through* the Canadian Arctic to strike "major population centres."[104] The A-OTHR requires two transmit sites and two receiver sites to support initial operational capability by the end of 2029. As of August 2025, National Defence has announced two land acquisitions: the first in Bexley Township, north of Kawartha Lakes for a permanent transmit site; and, the second, a preliminary receive site in Clearview Township, west of Barrie. Work on both locations is expected to begin in winter 2026.[105] Concerns of community members in Clearview over potential future land expropriation by National Defence shows the need for greater clarification on the impacts of the A-OTHR on the surrounding environment and community livelihoods.[106] The receive and transmit sites must be physically separate as to not interfere with the sound frequencies of continuous wave radar, requiring flat and dry land, a reliable power supply, and distance from radio noise sources.[107]

Carney's announcement emphasized how A-OTHR represents a critical component of achieving all-domain awareness and modernizing NORAD. The system will provide "advanced early-warning and long-range surveillance, enabling faster detection and tracking of a wide range of threats in our Northern air and maritime approaches, while strengthening NORAD domain awareness in the defence of Canada and North America."

Furthermore, Carney stated that "Canada intends to work with the Government of Australia to further develop OTHR technology to our mutual advantage and will work closely with the United States to ensure the interoperability of domain awareness solutions for the defence of North America."[108] Pushing back on criticism that domestic technology (which has yet to be tested at the scale of JORN) was not chosen, Carney highlighted the Australian technology is the "most advanced and efficient radar system" globally, with Canadian research still years away from deployment.[109]

Canada chose to purchase an advanced, sixth-generation design that will be ready for operational use by the end of the decade.[110] Rather than depending solely on the United States to lead the technological development of next generation radar (given Canada's lack of domestic capacity), Ottawa bought the technology from a Commonwealth ally that is also "very interested in detecting, deterring and defending against threats" given China's presence off its northwest coast.[111] In fact, Canadian officials stated that the decision was not "intended as a signal of Ottawa's push to reduce Canada's supply chain independence from the United States," but serves as "an example of Canada and the U.S. working closely together as allies to face any broader threat from a more aggressive Russia, and China's assertions of its right to Arctic maritime passages and resources." Two senior Canadian officials stated that US personnel in NORAD supported Canada's acquisition. [112]

Canada, like Australia, has traditionally viewed its northern avenues of approach over the Arctic as the most likely scenario in which an air-breathing threat will fly through to attack the nation or the continent. Australia has a deep culture of concern over being attacked by air since the Japanese attacks on Darwin in the Second World War.[113] Similarly, Canada's North is a geographic vector to major population centres. The two countries have small, sparse populations in their comparatively underdeveloped Northern regions.

Carney and Australian Prime Minister Anthony Albanese confirmed the government-to-government sale of the JORN's technology in a phone call prior to the announcement, cementing Australia's largest-ever defence deal.[114] This signaled the opportunity for other middle-power states working to work together to address evolving security needs at a time when US – best exampled by the recent trilateral meeting of Canadian, Australian, and British Air Force deputies about sharing best practices for operating OTHRs.[115]

Carney's announcement serves multiple purposes. First, for the prime minister's political objectives, buying from Australia diversifies the security and economic relationships that he campaigned on during the spring election. Australia is a like-minded, trustworthy ally who is already integrated into Canadian networks as a Five Eyes intelligence sharing partner. The JORN is a product of decades of Australian ingenuity, commitment to pursuing excellence in defence science, and is likely to prove politically popular in Canada given it is not an American product.

Defence spending and capabilities' deficits have subjected Canada to criticism at home and abroad. A bipartisan US Senate letter in May 2024 states "profound disappointment" over Canada's defence spending, with immense pressure to boost it coming at that year's NATO summit in Washington.[116] American commentators have declared that our capabilities' deficit is the gravest threat to the NATO, describing the North American Arctic as NATO's "soft underbelly." Canadian commentators have repeated this message, which threatens core Canadian national interests given political rhetoric of annexation coming out of the Trump White House.[117] Some Canadian analysts have advocated for policymakers to "'think Arctic' when they think of foreign affairs and defence," encompassing all Arctic issues as matters critical to defence and security.[118] The A-OTHR purchase is a strong signal Canada understands the threat environment and signalling behind its intention to address early-warning vulnerabilities in defending the continent.

As Arctic security analyst Whitney Lackenbauer observes, combining all Arctic-related issues under an "Arctic security" umbrella confuses what are threats *in, to*, or *through* the region. Combining all challenges as one does not account for the unique actors, governance systems, and military and security mandates across the Canadian North. Doing so does not represent NORAD's role in the defence of the continent and does not delineate what NORAD's actual role is in the Canadian North.

An example of threats *in* the region can include the collapse of single point-of-failure power system for an isolated community – originating and remaining a regional issue. A threat *to* the Arctic originates from outside the region but poses challenges inside of it. For example, the COVID-19 pandemic was brought to the Canadian North with the encompassing wide-range of public health and safety challenges.[119]

In a NORAD Modernization, or *through* context, the Arctic component is that Russian or Chinese bombers or missiles or other forms of advanced delivery systems will launch from outside the North American Arctic, travel over and through it southbound, before striking major population centres, strategic military sites, or titans of industry. When senior leaders sound the alarm that "the Arctic is no longer a fortress wall," the pursuit of all-domain awareness sensors and systems located in the Arctic to provide early-warning capabilities allows strategists to locate forces further northward to intercept and provide a capable deterrence through presence.

The crux of NORAD Modernization – achieving greater situational awareness and capabilities to respond to an impending threat to North America – is not about Arctic security as much as it is about the defence of North America as a whole. NORAD is not designed to repel an attack on the Arctic, otherwise the defence infrastructure of the Command would be positioned in the region. Due to geography, Canada's contribution to the binational command's early-warning surveillance mandate is being able to effectively track incoming aerial and maritime-based threats through its Arctic given it is the fast avenue to strike the continent.

While the A-OTHR system, given its name, is understood as protecting the Canadian Arctic given its name, the system is instead being designed to surveil the Arctic *approaches* to North America, critical infrastructure based in the Canadian North, and serves as a major Canadian contribution to NORAD. Indeed, previous joint statements by Biden and Trudeau highlights the surveillance of the Northern approaches.[120]

Carney's March announcement, labelled as protecting national security and sovereignty, laid out a funding package broken down into three distinct initiatives: the continental defence of North America with the A-OTHR announcement; the defence of the Canadian North with $420 million to expand a "greater, sustained, and year-round CAF presence in the Arctic,"; and community resiliency with $253 million for power plant upgrades, critical housing infrastructure, home renovations, and a transfer to the Nunavut Nukkiksautiit Corporation for development of a hydroelectric facility.[121] This money bolsters security at numerous levels (national, territorial, and community), highlighting Ottawa's autonomy over its decisions as a key message of exercising its sovereignty.

The A-OTHR will complement a future Polar Over-the-Horizon Radar system (P-OTHR), which will be built at the northward-most edge of the A-OTHR's surveillance range by 2034 to detect threats emanating from over the pole.[122] Its location is yet to be determined, but Inuvik, Northwest Territories is a possibility given its strategic placement as a NORAD FOL and the recent contract to "design, built, install, and operate a new radar defence system in the Northwest Territories."[123] Additionally, overcoming the limitations posed by the aurora borealis and other weather in patterns in the upper atmosphere is critical to enable the deployment of the P-OTHR. Canada's use of OTH-R in the Arctic will be novel, given the reflection of the aurora borealis cluttering data on radar pictures. Solving this operational reality is a priority for National Defence and Defence and Research and Development Canada, who have partnered with researchers working on algorithms and artificial intelligence tools to help provide easier radar identification in the northern avenues of approach.[124]

The P-OTHR will help in "identifying earlier indications and warnings" of adversaries preparing to launch, such as knowing "when aircrews are stepping to their aircraft, when ships and submarines are planning to sail, and when missile operators and systems are preparing to launch."[125] The US Air Force announced in April 2025 that environmental assessments would take place for the "construction and operation of Homeland Defense Over-The-Horizon Radar (HLD-OTHR) transmission and receiver sites in the northwest" Five cities in Oregon (Ontario, Burns, and Christmas Valley), Nevada (McDermitt), and Idaho (Mountain Home) have been identified as potential sites.[126] All of these radar systems contribute to NORAD's global area of operations for missile warning, enabling all-domain awareness of all air avenues of approach to the continent. Their sensor data will contribute to information dominance and decision superiority within the system-of-systems which provide senior leaders with options.

The decision to place the A-OTHR in Southern Ontario will enable the radar to see as far north as Mary River, Nunavut on Baffin Island and as far east as the southeastern coast of Greenland – using the JORN's reported 3,000 kilometre surveillance tile range and 1,000 kilometre minimum detection.[127] The system's two receive and transmit sites in the Kawartha Lakes region will be supported by another set of transmit and receive sites, along with beacons that measure radar frequencies and ionospheric conditions in the Canadian Arctic. It is possible that another set of transmit and receive sites could be installed in the Canadian North (as the JORN has three radars that operate in tandem). Work on installing A-OTHR-related infrastructure in the region "may be advancing faster than publicly disclosed."[128]

The Bexley Township transmit site of 163 hectares of vacant property was chosen for its "flat and dry area, limited environmental constraints, [and] close to electrical power sources."[129] Timelines are moving quickly as the property is expected to be flattened and cleared beginning in winter 2026 so that equipment install and radar operationalization can be finalized for stage 1 operations in 2029. Full operationalization of the A-OTHR is anticipated by 2043, as details on how many receive and transmit sites will be built are unclear.[130]

Numerous questions remain about the government-to-government sale, practicalities, and technicalities regarding the A-OTHR's installation and deployment. The A-OTHR's installation location in Southern Ontario has raised questions about environmental and health impacts to the local environment and populations.[131] What about the impacts on communities and sensitive ecosystems in the Canadian North for supporting infrastructure? Where will beacons in the north be placed and are they in areas easily serviceable? Can a sparsely populated and serviced territory such as Nunavut provide supporting infrastructure for energy-intense radar lines without jeopardizing electricity, with demand already over capacity?

Is the A-OTHR and JORN partnership a "one and done" build or a living agreement that allows for technology sharing years into the future, ensuring the A-OTHR remains modern and capable of detecting advanced delivery systems? Who are the industrial partners (prime defence contractors such as Lockheed Martin, Raytheon, or BAE Systems) and what commitments have they made to training the Canadian industrial base on the installation and maintenance of the JORN backend technology? Examples of such commitments include Nassituq Corporation's maintenance contract for the NWS,[132] or the Inuvialuit Development Corporation with its recent radar deal.

While NORAD is reportedly content with the A-OTHR acquisition plan, there has been no public comment from political leaders in the US Congress, the Pentagon, or the US Air Force. The JORN will be able to connect into the enormous digital infrastructure supporting NORAD's Cloud-Based Command and Control system (CBC2), likely to include Palantir's Maven system, the DoD's SIPRNet, and Microsoft Azure.[133] What is not clear is which security actor will "own" the data and information the A-OTHR collects and what arrangements to share information with NORAD and other civilian security partners or allies will be made.

Canada "removed all restrictions on air and missile defence of Canada" in July 2025, paving the way for future Canada-US negotiations on the topic as it relates to future integrated air and missile defence (IAMD) for the continental US and Alaska, coined as Golden Dome.[134] As Andrea Charron explains, "Golden Dome will be a system of systems providing layers of defence that includes many detection and defeat platforms,"[135] with the A-OTHR capable of providing domain awareness and surveillance of the northern avenues of approach. Commander Guillot has shared that Golden Dome could be made up of three smaller domes concentrated on domain-awareness, air, and ICBMs. OTH-R fit within the first dome.[136] Minister of National Defence McGuinty stated in October 2025 that Canada is "talking to the United States now about what we call a continental shield, because we're going to need one."[137] What is not yet clear is exactly how Canada will contribute to Golden Dome, how NORAD modernization efforts are linked, or how critical defence infrastructure in Canada will be defended.[138]

It also unclear whether the JORN technology will power the future Polar OTH-R and American HLD OTH-R (with the latter currently tied up in the budgeting process). For Canada, this invites broader questions about the power supply necessary for such an energy-intensive system in remote locations in the Canadian High Arctic. These questions require clarity from National Defence Assistant Deputy Minister for Materiel, the RCAF's Development Office, and the NORAD and USNORTHCOM N-NC/J5 Directorate for Strategy, Policy and Plans.

The A-OTHR process signals that Canada is taking the international security environment seriously, sourcing efficient, world-class, technology to defend the approaches to North America. Ottawa is moving faster than Washington at developing or procuring a radar network to do so, not waiting for homegrown nor American technology. The Jindalee system is revered for its ability to compute, process, and scan large surveillance tiles at distance with incredible speed, enabling senior leaders to have greater situational awareness at the speed of decision-making relevance.

The decades-long development of the JORN is the effort of Australia defence, government, industry, and academic partners, as well as US prime defence manufacturers. Canada benefits from the agreement in terms of speed to build, a wide knowledge base, and diversifying our defence industrial base. The JORN's "cutting edge" technology means the RAAF remains at the forefront of high frequency detection technology, "ensuring the continued development of this critical sovereign capability" for the defence of Australia.[139] Canada's decision to purchase the JORN is an example of the intense understanding to move at the speed of urgency to protect our continent under our own, sovereign decision-making power, and how doing so can be both militarily and politically expedient.

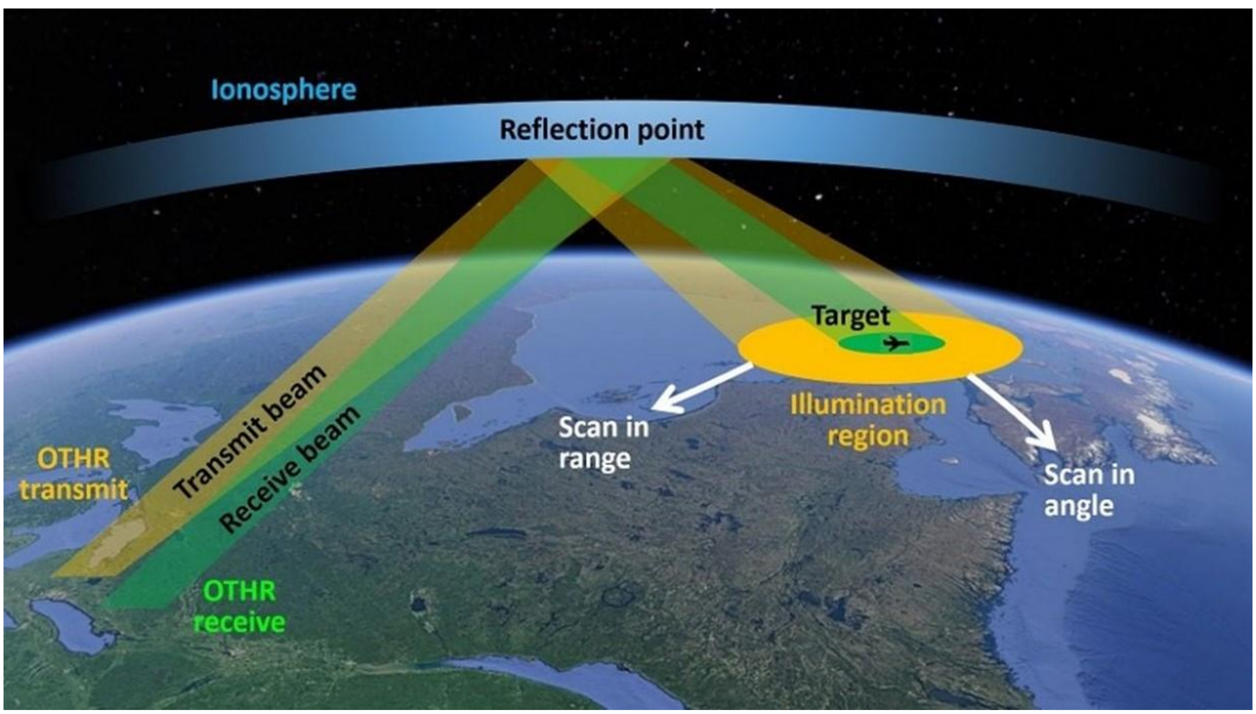

Figure 3: Diagram of the A-OTHR reflecting radio waves off a target.[140]

Conclusion

Canada finds itself in a changing world. The international security environment has worsened in the 2010s and 2020s, shaped by concerning trends of climate change, research and development of advanced aerospace weapons, and the rise of autocratic regimes challenging the rules-based international order.[141] Great power competition between the United States, China, and Russia has returned global security dynamics to Cold War-esque camps. Senior leadership in Canada and the United States have sounded the alarm, as outdated early-warning systems, surveillance sensors, and physical capabilities, many of which were built to deter Soviet cruise missiles in the 1980s, leave North America vulnerable to an attack by our adversaries *through* the Arctic due to Russian and Chinese advances in leading-edge delivery systems.

To achieve awareness across all domains from the seabed to space, Canada has committed significant funding to upgrade NORAD, including detection and tracking systems, over the next two decades. The centrepiece of this modernization is the Arctic Over-the-Horizon (A-OTHR) radar network, powered by the world-class Jindalee Over-the-Horizon Network (JORN) from Australia. The A-OTHR will be able to see 3,000 kilometres north into the approaches to Canada by 2029, so that NORAD can better deter, detect, defend, and defeat air and maritime threats to the continent. Our competitors and adversaries field a wide-range of aerial systems, such as ballistic, hypersonic, cruise, and drones. The JORN has decades of proven ability to provide domain awareness and superior tracking capabilities, and its ability to be paired with a fast computer processing system will provide the NORAD Commander with technology-enabled decision-making and decision superiority in competition, crisis, or conflict.

The purchase of the JORN to power the A-OTHR is a generational investment in Canadian defence. By partnering with a like-minded, Commonwealth ally, Ottawa is expanding security partners for the defence of the continent. At the same time, we are upholding our enduring commitment with the US through NORAD to defend North America with our closest and most important ally, showing dedicated commitment. The JORN purchase represents due diligence on Ottawa's part, sourcing a system which has demonstrated its utility in a real-world setting. This shows that Canada is moving at the speed of urgency the international environment and our allies demand, diversifying our security partners and defence industrial base in the process.

The A-OTHR will serve multiple roles. Its primary function, of course, is to provide domain awareness of the air avenues of approach to North America so that NORAD can achieve its aerospace warning, aerospace control, and maritime warning missions. Given the JORN's purported use, the A-OTHR may also serve a dual-purpose role for search and rescue, disaster relief, and drug trafficking – if information and common operating pictures are shared between military and civilian actors.

The A-OTHR can also be used as part of Canada's early-warning contribution to a next-generation missile shield with the United States, as part of the early-warning detection and ability to detect threats before they reach our shores. The data and intelligence the A-OTHR collects will be fed into a system-of-systems that provides greater kinetic and non-kinetic options to decision-makers "left of launch."

Today's threat environment is global. Advanced delivery systems can reach the shores of North America undetected as the North Warning System is not designed to detect the full suite of high-flying, fast, and manoeuvrable aerospace weapon deployed or being developed by our competitors. The deterrence by punishment posture, backed and held credible by US retaliatory strategic forces, limits the range of options available to defend the continent against the full spectrum of threats below the nuclear threshold. The increasing linkages of sea lanes of communication and North America with the North Atlantic and Indo-Pacific means that Canada and the United States have committed to "hardening the shield."[142]

The JORN system has demonstrated its capability to detect air and sea-based threats in the approaches to northern Australia since the late 1960s. Canada will benefit from the established expert collaboration between Australian defence scientists, academic, and industry who are engaged in a consistent process to modernize and upkeep the extensive network based on the Australian continental threat assessments and requirements the Royal Australian Air Force need to defend their avenues of approach. In purchasing the Jindalee system, Canada will field a proven technology to counter Russian and Chinese threats in the air and maritime avenues of approach to North America *through* the Arctic.[143] In tandem with the United States, this will support Canada's enduring mission of jointly defending the continent at the pace the current and anticipated strategic environment demands.

Figure 4: An array field for the JORN, 2025.[144]

Annex

History of the Jindalee Operational Radar Network (JORN): "A Mixture of Technology and Magic"[145]

Phase 1 – Project GEEBUNG

Australia's OTH-R has been developed in six phases. A legacy of the UK Home Chain Radar developed during the Second World War, the first phase dates to 1969 when Australian Defence Science and Technology Organization (DSTO)[146] scientist John Strath advocated for American OTH-R as a solution to Australia's air defence concerns. The defence technology cooperation program, "The Technical Cooperation Program" (TTCP), between Australia, Canada, the US, the UK, and later New Zealand, led to the US sharing technical expertise with Australian scientists to achieve detection of aircraft at long-range with their OTH systems.

After this revelation, Australian Defence approved the exploratory radar Project GEEBUNG in November 1970, seeking to investigate "how well or badly the ionosphere would support OTHR operations in the Australian environment."[147] GEEBUUNG, or Phase 1 of what is now known as the JORN, included the installation of a US-designed transmit site in Mirikata (near Woomera in South Australia) and a US-designed receive site in Broome (near Darby in the North). These sites were supported with Australian-made communications equipment and antennas, where scientists recorded ionospheric activity between the two locations, over 2700 kilometres apart, across a 15-month period.[148] The long distance between transmit and receive sites are to ensure the antennae arrays and frequencies do not interfere with each other.

Strath had cautioned DSTO that there was a small knowledge base in Australia to support the operational requirements of an OTH-R system providing wide-area surveillance of the northern approaches to the country. A line-of-sight (LOS) radar system, widely available at the time, was viewed as a "seemingly intractable problem for a geographically large nation of relatively small population."[149] Following GEEBUNG site visits by American engineers in February 1972, Strath and colleagues worked out a proposal with the US for the "Workhorse" OTH-R system. This would be developed in three stages with correspondingly increasing complexity, capability, and cost should previous trials be successful. This conditional planning was sensitive to fiscal constraints and the lack of technical capability of Australian scientists on OTH-R.[150]

Phase 2 – Project JINDALEE

GEEBUNG's success meant that Phase 2 of what is now the JORN began in 1972, when the radar concept was renamed from Workhorse to Project JINDALEE that July.[151] Meeting notes for the now-defunct Department of Supply refers to Jindalee as an Indigenous word meaning "bare bones," often used as a rallying cry by the engineers to keep costs as low as possible (although contemporary accounts differ over the word's meaning).[152] Phase 2 was split into three stages (A, B, and C) to test the practicality of the system as it was sequentially added on to. Using Australian-made equipment adapted from and modelled after US technology (such as antennas, transmitters, signal processors, cables and software), a small team began to assemble the conceptual radar in remote Alice Springs in the Northern Territory.

An additional remote beacon site was located 1600 kilometres northwest of the Alice Springs site in Derby to fulfill various “measurement and calibration functions.”[153] The Jindalee Stage A radar and receiving ground stations were activated in October 1976 and quickly detected an aircraft. In December 1977, Stage A successfully detected ships in the waters off northwest Australia.[154] Stage A had a narrow degree of detection and only a simple whip-antenna array. However, its radar waveform generator, the component that generates the intermediate frequency (IF) transmit signal, was Australian-made and kept in future project stages.[155] This experimental radar shut down in December 1978.[156]

Stage B of Phase 2 began in July 1978, when the new advanced radar was constructed next to the decommissioned Stage A systems. Private industry and the RAAF were now involved, and Stage B’s focus was on building a comparatively more capable radar. 20 contractors from Amalgamated Wireless of Australasia (AWA), now BAE Systems Australia (the main contractor of the JORN in 2025), joined the rotating crew of scientists and engineers who would fly in to Alice Springs for a few weeks at a time from Salisbury.[157] This new stage meant a host of technical improvements: the radar could now scan 60 degrees; conduct real-time computation of signals (which demanded an increase in processing power); radar feed displays could now be read and assessed by RAAF operators; a 2.8 kilometre long array with over 1,000 antennae (compared to the 640 metre long Stage A array with 128 antennas); and an expanded Frequency Management System.[158]

Shipping and logistics to the rural and remote Alice Springs site, along with chronic project understaffing, created a 15-month delay by 1981. The additional sensing and computing capabilities brought significant infrastructure demands for new buildings to accommodate crew, power, electrical, air conditioning systems, and the clearing of land.[159] Supplemental radar beacons, which serve radar systems as fixed navigational marks for transmitters,-receivers, transceivers, or transponders, were installed in Darwin and Derby but powered by solar panels.[160]

Project Jindalee’s Stage B antenna arrays were particularly prominent fixtures on the landscape given that both transmit and receiver sites require large installations. Donald Sinnott, the eminent historian on the JORN’s development, recalls the MacMillan couple who set up the Stage B receiver site of 980 array antennas in just 32 days in August 1980. When supervisors from DSTO’s Radar Division visited the site on Mount Everard near Alice Springs that September, they found that supporting pegs had not been driven into the ground as deep as the engineers had specified. Jim MacMillan worked through the night, driving over 1000 pegs a few centimetres further into the ground, receiving approval from the engineers, before packing up his family and moving on from their job later that day.[161] The transmitter site sat at Harts Range, 160 kilometres away. The beacon in Derby was upgraded but moved to a secondary role in favour of a new, more powerful beacon in Darwin.[162]

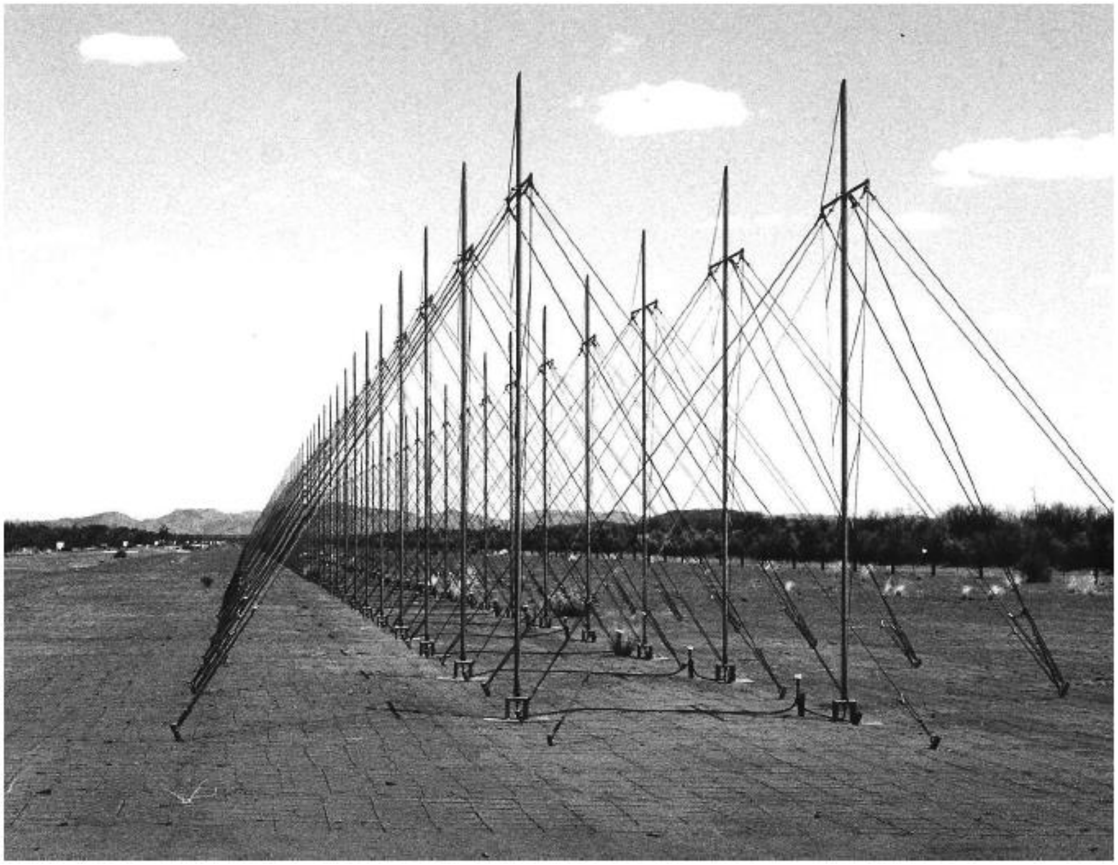

Figure A-1: The Project Jindalee Stage B Receiving Array on Mount Everard near Alice Springs, completed in September 1980. The MacMillan couple set this array up alone in just 32 days.[163]

This chronicle shows the intense support DSTO had from the government, industry, and citizenry for Project JINDALEE's testing. Australians have implicitly understood the advantages to developing Northern approaches early-warning and surveillance systems in defence of the continent. Historians tie this back to the severity of the Bombing of Darwin on 19 February 1942 on the national psyche. The Imperial Japanese attack on the capital of the Northern Territory, its harbour, and nearby airfields exploited the lack of defences on the northern coast with heavy Allied losses of civilians, aircrafts, and ships. It also showcased Darwin's strategic location, as the Japanese sought to cut off Allied counteroffensive capabilities for Tokyo's planned invasion of Timor. The bombing served as a precursor for the more than 200 raids on Northern Australia until June 1944.[164] The commitment to getting the system up and running in a timely fashion, understanding the costs and effortless work of the engineers and tight government leash, combined with the deeply felt history, was felt by all who worked on JINDALEE.

Stage B of Project JINDALEE was effective, with the first detection of aircraft by the new computer system occurring in April 1982. With the project so delayed, this was a concrete and welcome sign of progress. This development was followed by detection of maritime vessels in January 1983 and automatic aircraft tracking by February 1984. Now time for a "convincing demonstration," the RAAF and the Royal Australian Navy (RAN) ran performance trials in April 1984, November 1984 to May 1985, and in July 1986, when Stage B had "substantially achieved its major aim of demonstrating the applicability of OTHR for Australian defence surveillance."[165]

The first six Service Evaluation Trials (JSET) saw RAAF operators control the radar, which had a 90-degree aperture, testing detection of "manoeuvre handling, multiple aircraft, slow speed targets, targets at long-range, small targets and intercept using OTHR data for prepositioning an interceptor." [166] The seventh JSET in July 1986 tested the system for three weeks during Australian winter, with hardware and software upgrades, particularly to the microcomputers to quicken display response time for operators, were made up until November 1986.[167]

By this time, public interest had grown in what the radar could achieve, as many sought an up-close look. Parliamentarians, media, senior Australian defence personnel, and foreign dignitaries "found ways of justifying, and having approved, a visit to the Jindalee sites." Peter Oswald, the lead DSTO Radar Division Station Director provided briefs at "varying levels of technical content and classification," often hosting these visitors in his own home. Oswald and his colleagues worked long hours in the lead up to these tours, fixing and solving software bugs or "beyond-the-call-of-duty efforts" to make certain the project was "well-conceived and well managed."[168]

Stage B, also known as the Jindalee Experimental Facility (JEF), had demonstrated itself to be worthy of detecting and surveilling activity in the northern approaches to the continent. Costing just 30 million Australian dollars, Stage B boasted a "track-while-scan" capability, an advanced automatic frequency allocation system, and a multi-port computer processor to support faster radar signal processing.[169] In the mid-1980s, Australian Defence was under review as its traditional forward defence policy was the cause of inter-service disagreement over strategy, posture, and funding for the continental/national defence.[170] The 1986 Dibb Report and subsequent 1987 "The Defence of Australia" white paper outlined a "strategy of denying aggressors the ability to attack" with a "layered defence of over-the-horizon radar, patrol aircraft and maritime strike aircraft to protect Australia's approaches."[171]

The 1987 defence policy stated that Australia had developed "the world's most advanced long-range radar, the Jindalee Over-the-Horizon Radar. A system of up to three new stations is being planned to allow around the clock surveillance of Australia's vast northern approaches."[172] The new radar network was to serve as part of a layered defence system, the first component of an early-warning detection grid allowing for detection of air and maritime long-range strike capabilities far from Australia's shores.[173] Policy-makers gave high priority to the "design and development" of this network to serve as a "basic element of a national system for air defence and airspace control." The white paper also reaffirmed the critical role of DSTO in national defence, describing the JEF as a "good example of how forward looking research on the technology base can lead to the development of important Australian defence capabilities."[174] The JEF at Alice Springs was to also serve as a future "test bed for scientific, engineering, and operational development."[175] With the political announcement, Stage C of Project Jindalee, the operational deployment of the JEF, was renamed to JORN Phase 3. The years-long, grueling effort from scientists, engineers, and labourers to build an Australian-made OTH-R had come to fruition, recognized and endorsed by the political establishment.

Phase 3 – JORN

Numerous naming conventions were changed when Stage C was handed over to the RAAF in 1987. The JEF was transferred from DSTO Radar Division to the DSTO Project Office and renamed Jindalee Facility Alice Springs (JFAS). Its new role was to allow the RAAF to gain deeper operational experience with OTH-R systems and to also serve as a test case for future research.[176] The JFAS was quickly refurbished by BAE Systems for 70 million Australian dollars to account "for the rugged demands of operational life."[177] The upgrades improved signal processing and tracking through replacement of old transmitters, antennae array, and computers which allowed operators see more information faster and with less interference.[178]

Figure A-2: The JFAS Control Centre in Alice Springs following the Phase 2 - Stage 3 (renamed Phase 3) upgrade, completed by BAE Systems Australia in 1990.[179]

Operationally, the RAAF and RAN took over day-to-day duties of the JFAS from DSTO Projects Office in 1990. It was not until 1993 when the JFAS was officially transferred to the Air Force as a fully functioning operational system. The RAAF had created the 1 Radar Surveillance Unit (1RSU) the previous year (now known as No. 1 Remote Sensor Unit since 2015) to run the JFAS' daily operations at Alice Springs. Remote operations testing lasted throughout the decade, with 1RSU moved from the JFAS to the JORN Coordination Centre (JCC) at RAAF Edinburgh near Adelaide, 1200 kilometres away in July 1999.The JCC is now referred to as the Battlespace Surveillance Centre (BSC). [180]

As the JFAS was modernized for operational duty and handed off to the RAAF between 1986-1993, the scoping of the larger JORN project outlined in the 1987 defence white paper, consisting of three radar locations and sites, was underway. Two OTHR sites were selected for the new JORN, with both to be constructed as replicas of the JFAS' technical specifications. Radar 1 (R1) would be constructed in Longreach, Queensland on the east coast to provide 90 degrees of coverage. Radar 2 (R2) was to be constructed in Laverton, Western Australia with 180 degrees of coverage. The JFAS would operate as Radar 3 (R3) with its existing 90 degree coverage. The 3 radar sites working in harmony would close any coverage and surveillance gaps in the northern avenue of approach, with most concentration over the Timor Sea. Their locations provide strategic coverage for optimal situational awareness of the northern avenues of approach to the continent, but also because the JORN's minimum detection range is 1,000 kilometres and so the arrays need to be set far enough away from the approach areas.[181]

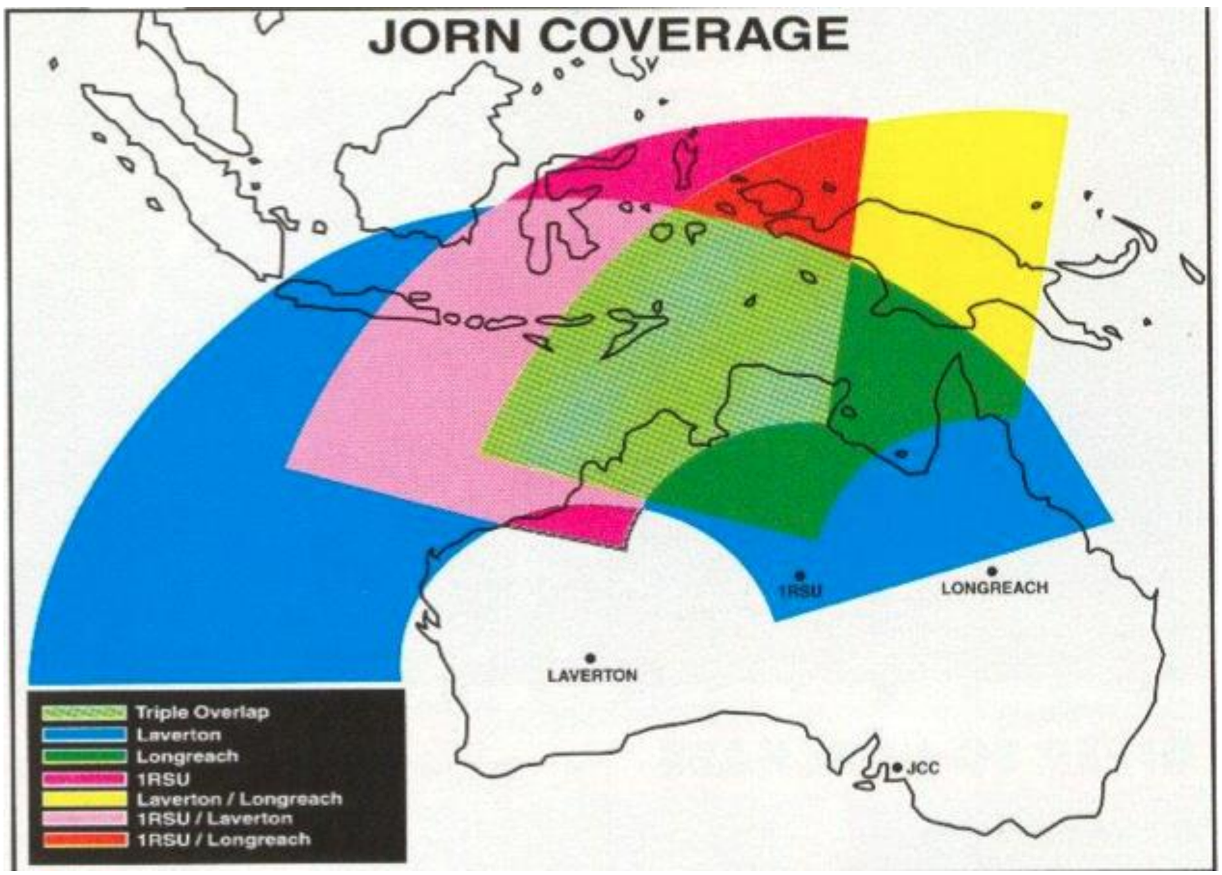

Figure A-3: Locations of the JORN Radar Stations and their corresponding coverage areas, based on a 3,000 kilometre range.[182]

The Phase 3 contract was awarded to prime contractor Telstra in June 1991 for construction of the Longreach and Laverton radar sites by June 1997. BAE Systems Australia and American giant Raytheon had also bid on the $1.1 billion tender. Telstra, a state-owned telecommunications form, was inexperienced in OTH-R development. Alongside sub-contractor Marconi, Phase 3 software and hardware development was less than a third complete by June 1996. The Jindalee Project Office (JPO) within Australian Defence was chastised in a scathing Australian National Audit Office report that summer for its lack of project management experience.[183] Filing for bankruptcy and withdrawing from the project, Telstra was replaced with RLM Systems in February 1997, which was then a joint company with the Australian Tenix Group and US-based Lockheed Martin.[184]

Phase 4 – JORN

Initial testing of the Longreach Radar was conducted in September 1999, where the new station could detect and track targets north of Darwin in the Timor Sea over 2,200 kilometres away.[185] Like the JFAS, R1 and R2 ground stations are comprised of a large, fixed transmitter and receiver antennas (often called arrays).[186] The size of JORN's receive arrays has been described as "daunting," with R1 3 kilometres long, R2 6 kilometres long, and R3 2.8 kilometres in length.[187] Each receive array has two "arms" of equal length. The transmit arrays are approximately 1 kilometre long and located approximately 100 kilometres away from the receive sites to prevent electronic interference. 17 beacons throughout Northern Australia support the JORN, used to measure ionospheric conditions and calibrate radio transmissions.

The JORN has an unclassified operating range of 1,000 to 3,000 kilometres, with the RAAF publicly admitting that the system can operate well beyond that. Depending on ionospheric and weather conditions, radar signals can bounce multiple times before rising over the horizon. Some unofficial reporting suggests the JORN could regularly see Singapore or Hong Kong, but the RAAF described this as "optimistic" in 2000. [188] However, some defence analysts posit the JORN can see far beyond 3,000 kilometres.[189] R1 and R2 also serve a dual-purpose civilian role, used to monitor wave heights and wind directions for weather agencies.[190]

The technical configurations of Longreach and Laverton differed slightly from JFAS, with upgrades to receivers for enhanced signals processing computer algorithms and an automated process of translating tracking data to GPS coordinates. The JFAS station was not originally part of the integrated C^2 of the JORN, but its surveillance and information collection was sent to the JCC at RAAF Edinburgh. After six years of delays, Lockheed Martin Australia and RLM delivered a fully operationally capable three-site JORN to the RAAF in April 2003. Lockheed Martin continued to maintain the Longreach and Laverton sites, while BAE Systems maintained the JFAS. Due to delays, the technical designs of the JORN was based on early 1990s technology.[191]

Phase 5 – JORN

Phase 5 of the JORN began in 2003 when the RAAF received operational control of R1 and R2. The focus of this phase was driven largely by two considerations. The first was to integrate the original Project Jindalee facility at Alice Springs (aka JFAS) into the C^2 structure at RAAF Edinburgh. This would ensure surveillance, intelligence, and sensor information was provided in real-time alongside the Longreach and Laverton systems. The Australian C^2 system is Vigilare, a Boeing produced system that produces the national tactical air picture.[192] The JORN finally incorporated all three radars seventeen years after the concept's original announcement in the 1987 white paper in 2004.

The second consideration was DSTO's research and development program had achieved technological advances in OTHR detection during the Phase 4 buildout. The DSTO's teams had implemented these advancements to the JFAS facility from 1993 to 2003 as the Alice Springs site had been designated a "test bed" developmental system for government engineers during the construction of the new sites. Bringing Longreach and Laverton up to the full capability as Alice Springs would enable greater surveillance and domain awareness in the new C^2 system.[193]

BAE Systems Australia and Lockheed Martin implemented the enhancements and merged all three radar sites into one user interface "to provide consistency for [RAAF] operators." Additionally, a "stare" capability was added so that the radar could "repeatedly observe the same geographic area with high revisit rate to provide operators with improved tracking performance for maneuvering targets." Legacy signals processors were replaced by larger clusters of processors that could be scaled to share large volumes of data and improve range and depth coverage of the radars.[194]

Phase 5 was completed in late 2014, two years behind schedule due to a skilled labour shortage, representative of Australia's small base of knowledgeable technocrats, for $62 million Australian. All three radars are now used to test new technological developments. Improvements were made to the arrays, collecting more data with increased bandwidth and classification of targets by size. The RAAF publicly states that the JORN can see targets as small as a 300-ton boat or jet trainer, but cannot see something like a civilian wooden boat (as an OTHR wave needs to reflect off something metal which has sufficient high-frequency energy to bounce back to the receive site).[195] The upgraded processors in Phase 5 allows the JORN to "dwell" on "tiles" of areas under surveillance faster by scanning larger geographic areas rather than conducting a broad sweep for objects. Phase 5 also achieved cost-saving objectives on the radar's energy consumption, with digitalization of analog computing systems saving approximately $10 million Australian per year. As of 2014, the RAAF did not operate the JORN 24/7 due to the costs and "lack of peacetime need to do so."[196]

Phase 6 – Mid-Life Upgrade

AIR2025 Phase 6 is the codename for the JORN's Mid-Life Upgrade program, which seeks to extend the "world leading over the horizon capability" past 2040.[197] Launched in 2018 and managed by the Chief of the Air Force, the $1.3 billion Australian project seeks to address obsolescence issues with components across the network: the Alice Springs receive station antenna will be retrofitted, personnel will be receive enhanced training and knowledge-building, and the Battlespace Surveillance Centre will be updated with a new user interface and C^2 system at 1RSU at RAAF Base Edinburgh. [198] With DSTO (formerly DSTG before 2015) leading the technological development and BAE Systems Australia and Lockheed Martin contracted to modernize the network, this ten-year project will: improve detection of small, slow, and maneuverable targets; increase real-time surveillance overage; improve target geolocation capability; and reduce operator workload.[199]

To achieve these specifications, modernization includes: the installation of next generation common aperture receivers for high-speed data acquisition, enhancing transmit enhancements through use of state-of-the-art high-power amplifiers, and signal processor upgrades to achieve ten-times increased sensitivity and resolution in both range and on the horizon (also referred to as azimuth) without compromising detection of performance.[200] Adelaide-based Quant X develops and builds sapphire oscillators, some of the world's most advanced clocks, which are being implemented into Phase 6 to achieve accurate time signals. These new components will help to achieve the increased sensitivity and resolution that makes the JORN world-class. BAE Systems Australia state that all JORN technology is designed, developed, and manufactured in Australia.[201]

In October 2023, BAE Systems Australia, DSTG, and the University of Adelaide partnered to open the JORN Open Innovation Network (JOIN) Centre for Advanced Defence Research in High Frequency Technologies (CADR-HF).

This centre supports talent development, create technological breakthroughs, and "continue Australia's reputation as being a world-leader in the development and export of high frequency technology." Exports of the home-grown technology led to the 2022 export of a multi-mission digital high-frequency receiver system to the United States Navy's Maritime-centric Over the Horizon Radars (MASORs) for $18 million Australian. This enables the USN to identify targets up to 3000 kilometres away.[202]

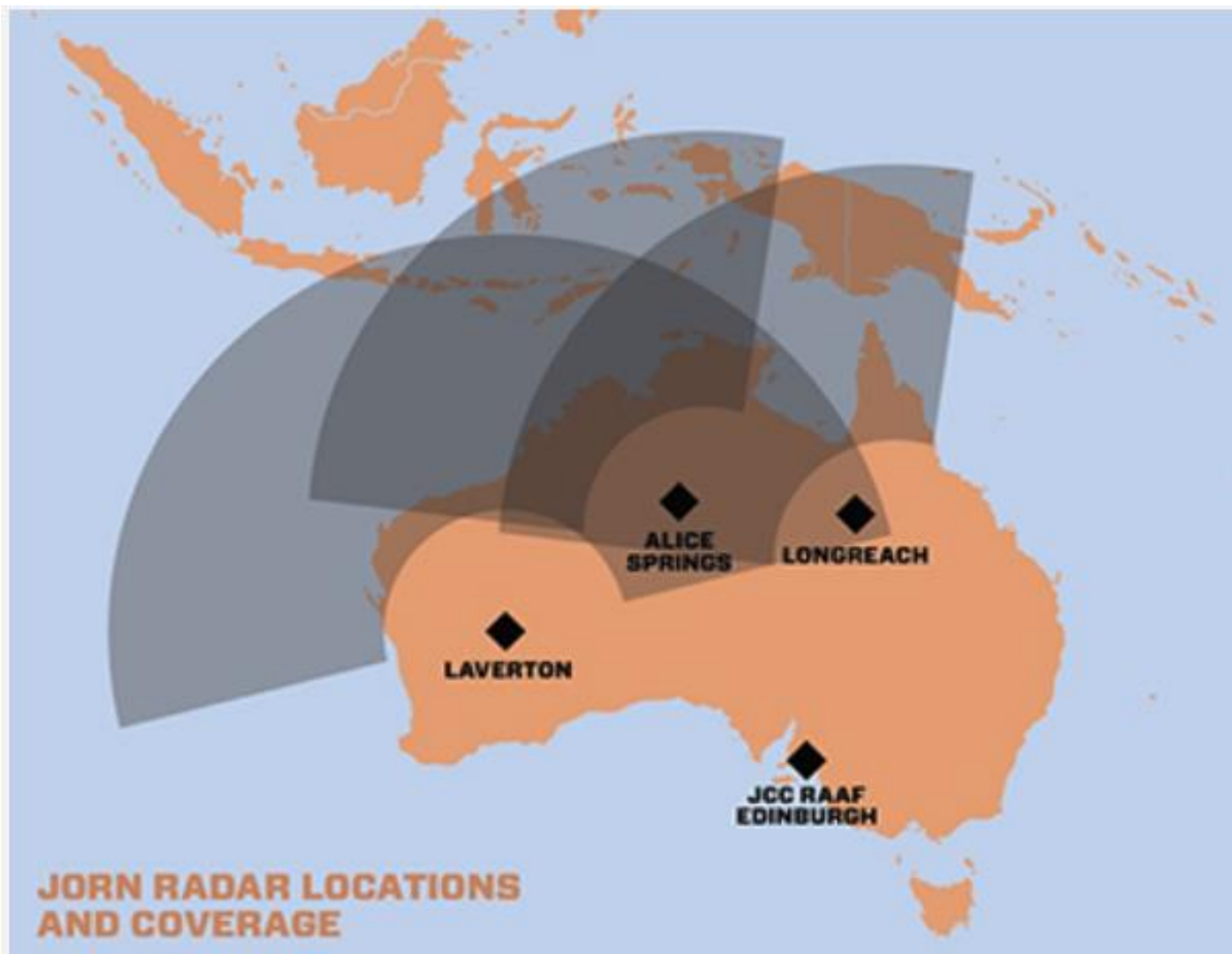

Figure A-4: Installation locations of the JORN and its unclassified, public radar coverage.[203]

Notes

*Thank you to Dr. Andrea Charron and Dr. P. Whitney Lackenbauer for their expert feedback and comments.
[1] "Statement of General Terrence J. O'Shaughnessy, United States Air Force Commander, United States Northern Command, and North American Aerospace Defence Command," *Senate Armed Services Committee*, 26 February 2019, 2, https://www.armed-services.senate.gov/imo/media/doc/OShaughnessy_02-26-19.pdf.
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[4] P. Whitney Lackenbauer, "Threats Through, To, and In the Arctic: A Framework for Analysis," *NAADSN Policy Brief,* 23 March 2021, https://www.naadsn.ca/wp-content/uploads/2021/03/Lackenbauer_Threats-Through-To-and-In-the-Arctic.pdf.
[5] Franklin D. Roosevelt, "The Great Communicator": The Master Speech Files, 1898, 1910-1945 File No. 1168 (August 18, 1938), Kingston, Ontario, Canada - Address at Queens University: 4; Roosevelt's initial concerns about the state of Canadian readiness in the Second World War was over the maritime domain, which Germany or Japan could use to block forces and resupply.
[6] Examples could include Joint-Base Elmendorf-Richardson in Alaska, the largest concentration of 5th generation airpower globally, or the seat of American government in Washington, D.C.
[7] Note that the Pinetree Line initially supplemented "permanent" US radar located in the northern continental states. Joseph Jockel, *Canada in NORAD: 1957-2007* (Montreal/Kingston: McGill-Queen's University Press, 2007), 10-11.
[8] Ibid.
[9] Ibid., 10.
[10] Joseph Jockel, *No Boundaries: Canada, the United States, and the Origins of North American Air Defence, 1945-1958* (Vancouver: UBC Press, 1987), 62, 72, 82-83; P. Whitney Lackenbauer and Matthew Farish, "The DEW Line and Military Modernization in the Canadian Arctic," in P. Whitney Lackenbauer and Matthew Farish, *The Distant Early Warning (DEW) Line Coordinating Committee: Minutes and Progress Reports, 1955-63* (Calgary: Documents on Canadian Arctic Sovereignty and Security (DCASS) no. 15, 2019), ix.
[11] Jockel, *Canada in NORAD: 1957-2007,* 11.
[12] Jockel, *No Boundaries Upstairs*, 62.
[13] Jockel, *Canada in NORAD: 1957-2007*, 11.
[14] Jockel, *No Boundaries Upstairs*, 66.
[15] Jeff Noakes with P. Whitney Lackenbauer, "Introduction: Situating the Mid-Canada Line, 1953-1957," in Jeff Noakes and P. Whitney Lackenbauer, *Special Contract: A Story of Defence Communications in Canada* (Antigonish: Arctic Operational Histories no. 6, 2019), xxxi.
[16] Jockel, *No Boundaries Upstairs*, 85. Quote found at: Canada, House of Commons, *Debates*, 18 July 1956, 6118.
[17] Jockel, *Canada in NORAD: 1957-2007*, 11.
[18] Today, satellite tracking systems and the BMEWS are tied into NORAD's Tactical Warning and Attack Assessment and global Area of Operations for missile warning.
[19] The satellite programs have been modernized with the US Space Force Defense Support Program (DSP) and the; satellite tracking systems and the BMEWS are tied into NORAD's Tactical Warning and Attack Assessment and global Area of Operations for missile warning.
[20] Image available for use in the public domain. Found at: "File:Dew line 1960.jpg," *Wikimedia Commons*, https://upload.wikimedia.org/wikipedia/commons/9/97/Dew_line_1960.jpg.
[21] Andrea Charron, "The Case for a Reimagined NWS," *NAADSN Policy Brief*, 18 October 2019, https://www.naadsn.ca/wp-content/uploads/2019/12/policy-brief-19-oct-18-charron-NWS-briefing-note.pdf.
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[27] "US military slams 'unsafe' Russia fighter jet maneuver near Alaska," *Reuters,* 30 September 2024, https://www.reuters.com/world/us/us-military-slams-unsafe-russia-fighter-jet-maneuver-near-alaska-2024-09-30/.
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[36] Charron, "Responding to Hardening the Shield."
[37] O'Shaughnessy and Fesler, "Hardening the Shield," 14; As a defensive command, NORAD only has an area of responsibility for its aerospace warning and control and maritime warning missions in North America and its Air Defense Identification Zones (ADIZ); its missile warning mission has a global area of operations, but given Canada's declination to participate in missile defence in 2005, the intercept and defeat options for missile defence rests with USNORTHCOM. For analysis on the command-and-control implications of NORAD/USNORTHCOM adopting an offensive mandate, and structural changes to the US Unified Command Plan, see: Charron, "Responding to Hardening the Shield."
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[41] For expanded detail on distilling threats *through*, *to*, and *in*, the Arctic, see: Lackenbauer, "Threats Through, To, and In the Arctic: A Framework for Analysis."
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[43] Ibid.
[44] Ibid.
[45] Ibid., 5.
[46] Ibid.
[47] Andrea Charron and James Fergusson, "North America's Imperative: Strengthening Deterrence by Denial," *Strategic Studies Quarterly – Deterrence* (Winter 2021): 42, 44. https://www.airuniversity.af.edu/Portals/10/SSQ/documents/Volume-15_Issue-4/D-Charron.pdf.
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[50] Unclassified threat briefing from NORAD/USNORTHCOM J2 – Intelligence Directorate. Provided to the author at NORAD/NORTHCOM Headquarters in Colorado Springs in May 2025.
[51] Statement of General Gregory M. Guillot, United States Air Force Commander, United States Northern Command, and North American Aerospace Defence Command," 8.
[52] Ibid., 6.
[53] Charron and Fergusson, "North America's Imperative: Strengthening Deterrence by Denial," 55-57.
[54] Lackenbauer, "Threats Through, To, and In the Arctic: A Framework for Analysis."
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