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Verifying Compliance: Constructs to Constrain Counterspace Capabilities

By Benjamin Silverstein

SECURE WORLD FOUNDATION

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About Ben Silverstein

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Executive Summary

Recent security related events in space, including anti-satellite weapons tests, have prompted a wave of discussions about how to best sustain humanity's access to space for future generations. States have engaged in formal debate on space security issues at the highest diplomatic levels, using permanent and ad-hoc forums at the United Nations to exchange perspectives. These engagements have helped clarify the landscape of space security issues, allowing states and observers to identify the most pressing threats as well as sketch pathways toward attenuating risks. Several options for progress on addressing space security issues draw on existing international mechanisms. The expansive record of multi-state agreements provides useful perspectives on what might be politically possible, while an open source accounting of global space sensing capabilities shows clear technical hurdles on the path toward a verifiable space agreement or treaty.

It is unlikely that states can circumvent all of the relevant issues by creatively scoping or designing a treaty or agreement. Each form of restraint has inherent benefits and drawbacks. Thus, some amount of both political progress and technical advancements are necessary for the plausible verification of any space treaty or agreement. For instance, unilateral political commitments that target narrow capabilities are particularly useful as a rapid response tool if domestic constituencies agree on core issues yet there are no plausible international negotiating partners. Formal multinational arms control agreements, like those that address environmental issues, can be diplomatically onerous but are afforded legal status that unilateral political commitments cannot achieve. Arms control or disarmament treaties benefit from strict rules about permissible activities, verification, and enforcement. Verification of any future treaty is of particular interest in the context of modern space security.

This report examines the verification practices of relevant international agreements, including multilateral disarmament treaties, bilateral arms control measures, multinational environmental agreements, and other relevant mechanisms. Several treaties do not include verification processes, but those that do tend to use one or a combination of five core verification practices: national compliance reporting; on site inspections by participating parties; on site inspections by an implementing organization; national technical means of verification (NTM); and international

technical means of verification. These practices are all designed to collect information about participants' behaviors, which inform states' political decisions about enforcement actions in the event that they deem a behavior to be noncompliant with the terms of a treaty. While verification regimes are rarely designed to catch each and every instance of noncompliance, adequate verification complicates cheating by raising the likelihood of detection.

The related literature qualifies how states must apply these five practices when building adequate verification regimes. Verification does not occur in a vacuum - it is a political exercise, and as such it is affected by existing tensions among states. Because verification activities and assessments are generally conducted in a low-trust environment, each party must be able to meaningfully fulfill their verification obligations independently without relying on outside assistance. These historical lessons about collecting and analyzing verification data guide our understanding of states' political and technical needs as they consider restraints on anti-satellite weapons.

The global shortfall in sensing equipment and expertise is a severe hindrance to the verification of any future space security agreement. The types of sensing tools and techniques would vary depending on the scope of the agreement, but the available unclassified information indicates that no state or collection of states is currently well-positioned to conduct a comprehensive verification regime. The lack of capabilities on the global scale hampers prospects for a bilateral or multilateral agreement on the prohibition on the tests of direct ascent anti-satellite missiles, co-orbital anti-satellite capabilities, or for broader restraints on the violent creation of orbital debris.

States would rely on different types of sensors to verify restraints on destructive ASAT activities depending on the scope and nature of the agreement. A ban on destructive DA-ASAT testing, for instance, would require states to monitor missile launches around the world and to have a better understanding of the space environment. Each segment presents challenges: only the United States operates a global missile launch detection architecture, and no state has comprehensive space situational awareness capability. States would have to fill these gaps to verify a ban on destructive DA-ASAT testing. Co-orbital ASAT testing presents other challenges that states could address by codifying stronger communications processes to forestall misperception. These challenges also extend to definitional exercises. For instance, banning destructive co-orbital ASAT testing would require states to differentiate "destroying" from "disabling" a satellite. States would have to expend significant diplomatic capital on creating political definitions to effect a multinational environmental agreement for space debris as well. Negotiating these types of restraints would necessitate agreeing to a ceiling on acceptable levels of debris generation.

The commercial sector will also likely have a large role in effecting any future treaty or agreement on space. This is unusual in the context of international arms control agreements, as third parties infrequently contribute to verification practices. Private space situational awareness and analysis providers are developing advanced tools that rival the capabilities of many states. These technologies have at least two potential impacts that are relevant to verifying a treaty or agreement. First, commercial services could be leveraged to expand access to the types of data and analysis needed to verify an agreement. Second, these services could unduly influence states' behaviors under the treaty system, potentially undermining states' roles as the primary actors. There are few historical touchpoints or experiences from which to draw lessons on navigating the impact of third parties' impact on verification, which lowers expectations that states will develop well-aligned and coherent practices to manage this potential friction.

To capitalize on the recent revitalized interest in addressing space security issues through diplomatic channels, states should consider new political and technical investments that would expand their domestic space situational awareness capabilities. This includes both the collection and analysis of relevant data. These competencies are broadly underdeveloped on a global scale, lagging behind other space related endeavors. A multinational or collective verification network is unlikely to emerge as a viable option, due to economic pressure stemming from industrial constituencies as well as broader funding concerns. With low prospects for an implementing organization to conduct portions of the monitoring and verification mission, states must be in large part self-reliant on domestic competencies to meaningfully participate in verifying others' compliance. Many of these technologies and analytical competencies also support states' nascent or ongoing space activities, meaning that developments that could support verifying compliance with a future treaty or agreement are worthwhile investments for both today and tomorrow.

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Acronyms and Abbreviations

ASAT	Anti-satellite
DA-ASAT	Direct-Ascent Anti-Satellite
SSA	Space Situational Awareness
IMS	Internal Monitoring System
CLRTAP	Convention on Long-Range Transboundary Air Pollution
OST	Outer Space Treaty
UN	United Nations
TCBM	Transparency and Confidence-Building Measures
CTBTO	Comprehensive Test Ban Treaty Organization

1. Refreshing Risk Reduction

States have recently reinvigorated international attention to the threats of offensive space capabilities—some have recently tested direct ascent anti-satellite missiles (DA-ASATs), while others have issued unilateral pledges to not conduct these very same behaviors. The turbulence of state behavior raises the potential for misperception, misinterpretation, and miscalculation. This trifecta of threats reduces expectations that humankind will remain indefinitely able to access and utilize space for the betterment of all.

Civil society, industry, and states themselves have begun to explore ways to reduce the negative impacts of ASATs. States have championed a variety of methods to address space security, socializing voluntary codes of conduct, issuing politically binding commitments, and drafting legally binding treaties—all intended to ensure the safety, security, and sustainability of outer space activities. These approaches showcase differences among states' perspectives and approaches to improving space security and facilitating safe activities in orbit. Perhaps because of these often irreconcilable opinions, these varied efforts have yet to crystalize into global normative expectations for all states' behavior. Nevertheless, states have demonstrated an interest in addressing space security issues at a multilateral level. This warming diplomatic climate, focused in large part on space sustainability, prompts deeper consideration about the principles that might be best suited for any future agreements to support humanity's continued access to space.

Moving from voluntary or political pledges to a binding treaty will require more diplomatic and technical work on several core aspects. The particular areas for improvement depend in great part on the type of treaty states develop (arms control, disarmament, or environmental agreement, for example). Key areas for future work that are consistently present across all types of future multilateral legal instruments include developing a comprehensive monitoring practice and designing ways to use this data to verify states' behaviors are compliant with the terms of any such future agreement. Unsurprisingly, states have shared several distinct perspectives on the prospects for verifying others' compliance. These perspectives can sometimes be irreconcilable. Nevertheless, it is clear that consensus on the issue of verification is essential for any future international agreement.

Verification protocols and practices are often found in agreements that restrain security elements and are cornerstone pieces of many existing bilateral, regional, and multilateral treaties. Other international agreements, like those that address humanitarian issues or the environment, monitor progress but present unique perspectives on the role of verification and how to evaluate compliance. While states have leveraged satellite technologies for verifying compliance with security treaties on Earth, the prospects for monitoring behavior in space requires a different set of technologies and skills. This report assesses the types of behaviors that a future treaty verification regime might aim to monitor and identifies several tools, techniques, and practices that might be applicable to a verifying states' compliance with a future agreement that addresses ASAT capabilities or other salient space security issues.

This report presents a survey of foundational arms control efforts, disarmament treaties, humanitarian protocols, environmental agreements, and other forms of negotiated restraints to identify a plethora of verification practices that could be applied in this context. Further analysis of bilateral, regional, and multilateral agreements is informed by and benefits from interviews with government officials and members of civil society who were instrumental in shaping the final texts of several modern agreements. Their insights into states' perceptions of the circumstances surrounding the negotiations of various agreements provide clarity and context to the findings of this report. Semistructured interviews with leaders from government, industry, and academia conducted for this project provided nuanced perspectives on what types of behaviors might be most ripe for treaty-based restraints and how relevant actors might approach the development of such agreements.

The analysis identifies potential options for a future agreement or treaty, as well as relevant and necessary improvements to monitoring techniques that would enable states to implement each option for verifying compliance with limitations on ASAT capabilities. This analysis charts potential pathways toward ensuring safer space activities as states continue to leverage space technologies in broader geopolitical competition. This includes clarifying the role of states, commercial space situational awareness (SSA) providers, and satellite operators in potential verification regimes. Finally, the report closes with recommendations for investments and multilateral engagements to demonstrate how new or emerging technical concepts might support monitoring and verification activities in the future.

2. What is Verification?

The process of verifying security agreements ebbs and flows between being a political exercise and an intelligence activity. Parties interested in creating a verifiable treaty initiate a political process by scoping core treaty aspects and subsequently negotiating guidelines for the act of verifying that states parties remain in compliance with the terms of the treaty. In parallel to defining treaty-prohibited behavior, states also often use treaty language to establish collateral constraints on activities that could prevent verification. These articles and clauses are not necessarily directly related to the core principles of the treaty; instead, they aim to prevent states party to a treaty from interfering with the verification regimes to support full and effective implementation. This might include prohibitions on interfering with the normal function of "national technical means of verification," a category generally understood to include satellites. Broadly speaking, after signing and ratifying an agreement, parties verify compliance by monitoring other participants, analyzing their findings, deriving a judgment based on this analysis, and resolving any resulting compliance issues.

Valuable verification regimes do much more than just detect violations or questionable activity. In arms control or disarmament agreements, verification has two interlinked but distinct goals: 1) deterring cheating and; 2) detecting violations. Verification regimes aim to alter the decision calculus of a would-be violator, reducing their confidence in getting away with certain activities, and lower the threshold for "undetectable" (and thus undeterrable) violations. Strong verification practices erode a would-be defector's confidence in their ability to evade monitoring practices. While bad actors may still attempt to gain an advantage by cheating, verification practices can be effective by raising the costs of attempting deceit. By raising the costs of circumventing an agreement, a verification regime can lower the benefit of cheating. A state may resign itself to adhering to an agreement if cheating is prohibitively costly.

Verification regimes must also enable timely responses to malfeasance. As all verification regimes are designed to enable enforcement, compliance verification processes must identify cheating in a timely way and must do so for two reasons. First, verification must identify cheating early in the process to prevent participants from reaping military advantage through noncompliance. Second, the observation of noncompliant behavior must be prompt enough to ensure time for harmed participants to seek recourse. These factors remain true independent of the enforcement mechanism, or what compensatory action looks like for a given agreement.

Verification takes a slightly different role in the context of other international agreements that focus on issues outside of military power or strategic stability, such as those that tackle environmental challenges. The distinct goals of environmental agreements inform both the processes and principles of verification. Because the topics addressed by this category of treaties have historically rarely been considered in the context of international strategic security, verifying compliance is often less intrusive – i.e., many environmental treaties rely on states' self-reporting to monitor compliance and progress toward goals.

Verification provides other benefits across arms control, disarmament, and environmental agreements alike. In all of these arrangements, the inherent interstate interaction as part of the treaty verification process can support mutual trust. Regularly practicing verification helps states transparently affirm their commitments to implementing a treaty, and promotes mutual understanding of others' interpretations of, and concerns about, treaty implementation.

3. Limits of Verification

It is valuable to reflect on what verification regimes cannot do. While parties to agreements generally aim to establish the most comprehensive and effective verification process possible, no treaty or agreement is 100% verifiable. Even the most intrusive inspections are not designed to sweep each and every corner for prohibited materials. In some cases, an excruciatingly comprehensive inspection process would still be unable to identify compliance issues or violations due to the potential legitimate civil or otherwise inoffensive applications of treaty-prohibited materials. Some treaties address materials or products that have legitimate treaty-compliant uses which validate manufacturing facilities, such as a state party's chemical or pharmaceutical industry. Thus, states must be satisfied with high, but not necessarily perfect, confidence in a verification regime.

Furthermore, verification tools can only establish what has happened. Verification regimes are not designed to clarify what will happen, why something happened, or to define the intent or motivations of a state party's behavior. With these limits in mind, an adequate verification regime may not aim to detect each instance of noncompliance. In fact, by bombarding participants with evidence of minute infractions, an overactive verification system could perversely threaten the legitimacy and actionability of an agreement. Successful treaties illustrate the benefits of balancing deterring cheating, detecting violations, and ensuring timely recompense.

4. Historical Review

While interest in arms control, disarmament, and other negotiated restraints of security related materiel or behaviors is far from a recent phenomena, coordinated formal verification measures are a relatively modern concept. Treaties designed to balance states' military power in centuries past are often devoid of verification clauses, while more recent efforts to address international security often include substantial annexes devoted to the rules about verifying compliance. Even though verification has grown into a politically acceptable and often necessary activity, some recent agreements stop short of prescribing verification practices. Other agreements charge states parties with the obligation to verify others' compliance.

The verification process outlined in an agreement is generally a factor of both what is technically feasible and what is politically acceptable to the parties. Negotiating partners must consider the technical feasibility of a given practice, as well as the level of trust among participants, the potential for abuse of or exploitative practices, and national security concerns that are often unique to each nation. A survey of international arms control and security negotiations illuminates a breadth of verification techniques. As not all processes are equally fit for purpose, variations between verification regimes are necessary. As such, no single verification template can be used as a one-size-fits-all solution.

The historical record illustrates the viability of many types of verification and compliance measures, including the outright absence of formal verification. As shown in Annex A, common practices over the last century of bilateral and multilateral agreements break down into five general categories:

- National compliance reporting;
- On site inspections by participating parties;
- On site inspections by an implementing organization;
- National technical means of verification; and
- International technical means of verification.

A given verification regime may leverage one or several of the above. Several factors inform what types of verification practices are included in a prospective legally binding agreement. While many nuances combine to affect the design of a verification protocol, some of the more important independent variables include the number of intended participants and the type of cooperation an agreement aims to support. For instance, the verification of a bilateral security treaty likely leverages different principles of verification than a multilateral environmental agreement (MEA).

4.A VERIFYING COMPLIANCE WITH SECURITY ARRANGEMENTS

There are further subtleties within international agreements on security matters. Designing an effective verification regime depends on the type of limitations a treaty or agreement aims to impose on states parties. For instance, some treaties place caps on the numbers of weapons a state may possess, or categorically prohibit the possession of certain types of weapons in their entirety. Other treaties might aim to restrain states' abilities to test new weapons concepts, limit the deployment of concerning systems, or prohibit militaries from employing injurious capabilities.

Different types of verification practices may be better suited to support certain types of restrictions. For instance, verifying the destruction of outlawed materials can be accomplished with on-site inspections, but these types of inspections would be inappropriate and likely inadequate in verifying compliance with a treaty that focuses on the battlefield use of particularly inhumane weapons. The stark differences between how the arms control and humanitarian communities value verification can impact treaty design, especially when a treaty addresses both humanitarian and international security goals. Expert meetings surrounding the negotiation of the 1997 Ottawa Treaty illustrate the gulf between humanitarian and arms control perspectives on verification. Furthermore, the principles and aims of environmental agreements prompt an entirely different type of verification.

4.B VERIFYING COMPLIANCE WITH ENVIRONMENTAL AGREEMENTS

Historic agreements like the 1997 Kyoto Protocol and 1979 Convention on Long-Range Transboundary Air Pollution (CLRTAP) illustrate the need for states parties of an agreement to agree on collection, analysis, and monitoring methods. These MEAs required state parties to standardize the practice of monitoring emissions and estimating pollutants. Follow-on protocols to the CLRTAP reflect that the variety of monitoring practices available to states do not necessarily all produce measurements of equal quality. Thus, it is desirable to achieve standardization by certifying collection practices. The process of standardizing CLRTAP reporting addressed issues as specific as units, parameters, and other factors of reporting. This standardization facilitates implementation by ensuring states parties can report accurate and easily comparable measurements.

4.C THE ABSENCE OF VERIFICATION

History indicates that verification may not even be necessary in some cases. Landmark security agreements such as the 1899 Hague Convention and the 1925 Geneva Protocol, for instance, contain no independent verification mechanisms. While far from ancient history, arms control treaties from that era continue the thread of not requiring verification practices. The 1922 Washington Naval Treaty is one example of a legally binding treaty that omits measures to verify compliance. The practice of legally binding states to obligations without verification protocols directly affects states' behavior in space.

The existing UN treaties on outer space[1] do not provide concrete verification regimes. This may be in part because of the contexts in which states negotiated the agreements. The 1960s ushered in a new era of scientific endeavors, both in space and on Earth. The 1959 Antarctic Treaty illustrates states' understanding of the benefits of preserving these areas of interest for cooperative exploratory endeavors and prohibiting military buildups. States carried this principle through into the 1967 Outer Space Treaty (OST).

The Outer Space Treaty establishes rights and obligations that straddle the line separating transparency and confidence building measures (TCBMs) and verification regimes. For instance, Article XII imposes quasi-verification obligations on states parties. States are instructed to keep "all stations, installations, equipment and space vehicles on the moon and other celestial bodies ... open to representatives of other States Parties to the Treaty on a basis of reciprocity." This clause underwent several revisions after the United States originally proposed it as part of a draft treaty, but it is clearly inspired by the Antarctic Treaty of a few years prior.

The 1959 Antarctic Treaty affords states parties the right to "complete freedom of access at any time" on the continent. States party to the Antarctic Treaty regularly inspect others' facilities. These inspections, among other purposes, are used to verify the absence of military facilities or materiel on the continent. Having been inspired by, and bearing in mind the implementation of, the Antarctic Treaty Article XII of the Outer Space Treaty appears to be the precursor to a verification regime.

However, there is no precedent for states exercising their rights under Article XII of the Outer Space Treaty, in no small part because there are few things to inspect and no humans on the Moon to perform those inspections. Without evidence of what constitutes proper implementation, the international community is left with unanswered questions about the purpose of Article XII. The interpretation of the Article's legal purpose may change if interpreted as a way to safeguard astronaut safety as opposed to a method of verifying the prohibitions of military activities in Article IV. A comprehensive dialogue on verifying compliance with the Outer Space Treaty is predicated on arriving at a well-defined and widely accepted interpretation of the rights and obligations included in the Treaty.

Other treaties, agreements, and conventions promulgate more specific rules and guidance for behavior in space. For instance, the 1979 Moon Agreement doubles down on the obligations of the Outer Space Treaty, but the low rate of ratification showcases states' limited interest in sustaining the principles of non-armament. Agreements such as the 1968 Rescue Agreement and 1972 Liability Convention help clarify important principles, but cannot provide effective,

1 Namely, the 1967 Outer Space Treaty and its progeny, all negotiated at the United Nations Committee on the Peaceful Uses of Outer Space during the 1960s and 70s, https://www.unoosa.org/oosa/oosadoc/data/documents/2017/stspace/stspace61rev.2_0.html

verifiable, or comprehensive restrictions of state's counterspace activities. This is in part because they do not govern relevant state behaviors on Earth. This scope limits the ways that the Outer Space Treaty and associated agreements can restrict state's research on, development, testing, stockpiling, and deployments of ASATs. This gap perpetuates questions about how states could both negotiate and verify compliance with limitations on ASAT capabilities.

More recent examples of politically binding agreements or unilateral reciprocal commitments like the Hague Code of Conduct and U.S. Presidential Nuclear Initiative contain no verification clauses by design. These types of political agreements are unverifiable by design, sometimes in part to bypass arduous negotiations at both multilateral and domestic levels about adopting verification instruments.

This relaxed attitude toward monitoring and verification, however, is changing. Some treaty negotiations, like those between the United States and Soviet Union that resulted in the 1974 Threshold Test Ban Treaty (TTBT), were hampered by intense debates on verification measures. The TTBT also serves as a useful case study to support optimism when facing what some might perceive as intractable problems. In the case of the TTBT, the draft treaty was finalized after decades of work on verification practices. While there is still an appetite for unverifiable political commitments, the viability of future arms control and disarmament treaties may hinge on the states' negotiations of verification practices. Ongoing efforts to address space safety and security illustrate this challenge.

4.D SPACE SPECIFIC AGREEMENTS, DRAFTS, AND OTHER INSTRUMENTS

States perceptions about monitoring, verification, and compliance have clearly shifted over the last century. Recently refreshed perspectives on verification are mixing with sentiments around the world about the adequacy of the existing space security regime. The combination raises difficult questions, namely about how to best ensure that humankind can sustain our collective space activities well into the future in a safe and peaceful outer space environment. Some states have pushed for agreements that either delay negotiating verification practices, or are not verifiable in principle. Others have stated goals to pursue verifiable agreements for space activities that focus on either ASAT capabilities themselves, or the potential deleterious effects such technologies would have on the space environment.

States have been thus far unable to agree on how to most appropriately supplement existing international space law. Some states have proposed text for new legally binding treaties, while others have championed alternative pathways, such as politically binding commitments or voluntary efforts. The 2008 draft Treaty on the Prevention of the Placement of Weapons in Outer Space, the Threat or Use of Force against Outer Space Objects (PPWT), jointly submitted to the Conference on Disarmament by China and Russia, promotes legally binding provisions that would prohibit states party to the treaty from deploying weapons in orbit or installing them on celestial bodies. The treaty would also prohibit states parties from threatening or using force against outer space objects. However, the draft defers on establishing a verification protocol, suggesting that states take up the issue of monitoring compliance in an additional protocol.

The draft PPWT was partly informed by nearly two decades of incremental work on preventing an arms race in outer space. China had been particularly active on the topic, bringing recommendations to the Conference on Disarmament in 2000 that states "should undertake not to test, deploy or use any weapons, weapon systems or components in outer space" until a new multilateral agreement could be reached. China and Russia continued this incremental work by revising aspects of the treaty, like the definitions of "space weapons". These revisions, however, did not materially improve the prospects that treaty compliance could be effectively verified.

On a similar timeline, the European Union presented an alternative pathway to restraining states' use of ASATs in 2008. The proposed International Code of Conduct provided several contributions intended to improve predictability and safety of space activities. Notably, it included language that would have committed subscribing states to "refrain from any intentional action which will or might bring about, directly or indirectly, the damage or destruction of outer space objects," with caveats excusing actions like those that would reduce debris. Later revisions of the Code expanded and clarified the instances of justifiable exemptions. As the proposed Code would have been a political commitment, it did not provide any verification protocols or mechanisms. The Code struggled to attract political commitments from established or emerging spacefaring states. States have not shown interest in reviving the Code since the last revisions in 2015.

More recent efforts, like the 2022 United States unilateral moratorium on destructive DA-ASAT missile tests, aim to restrain states' counterspace activities. Five months after Russia destroyed one of its own satellites with a ground-launched Nudol missile, Vice President Kamala Harris committed the United States "not to conduct destructive direct-ascent anti-satellite missile testing." The U.S. pledge calls on other states to make similar commitments, and has initiated a cascade of similar pledges from around the world. As of September 2023, 35 countries have adopted a similar commitment. Most of these recently committed anti-ASAT states have no planned, potential, or demonstrated ASAT systems, showing how this type of political act can include aspects of both arms control and non-proliferation, depending on the country undertaking the commitment.

Although adherence to the destructive DA-ASAT missile testing moratorium is currently voluntary, there are several indications that the United States and other countries could leverage its commitment as a first step toward creating a legally binding mechanism to address ASAT activities. In her initial remarks, Vice President Harris presented not just a moratorium on destructive DA-ASAT missile tests but a commitment to work with others around the world to solidify this prohibition as an international norm of behavior. The global wave of successive pledges indicates that there is a global appetite to establish this moratorium as a norm of behavior.

The number of states that have adopted a destructive DA-ASAT missile test moratorium indicates that there might be a growing expectation that all space actors abide by this normative expectation. However, the process by which states establish a standard behavioral expectation is neither clear nor expeditious. Nevertheless, building a norm is one way for states to grow and expand the moratorium against destructive DA-ASAT missile testing. The process of establishing norms of behaviors for space mirrors many of the same steps necessary in establishing internationally legally binding obligations. For instance, states must reconcile domestic stakeholders' perspectives and present a well-aligned national approach in both norm building and treaty negotiations. The same is true for monitoring states' behaviors to ensure each is comporting with its normative, political, legal, or other commitments. The tools used to determine whether a space actor is behaving in accordance with normative expectations in orbit could be used to infer whether a state is complying with its legal obligations.

The United States is angling to develop both the international ambition and substantive content of the moratorium. Shortly after the Vice President's announcement, the United States began to work on a new resolution at the United Nations designed to reduce the risks in outer space. After several rounds of discussions, the United States and over fifty cosponsors introduced a draft resolution to the First Committee of the United Nations as "an urgent, initial measure aimed at preventing damage to the outer space environment." The resolution passed in the General Assembly with overwhelming support, but proven ASAT-capable states (India, China, and Russia) either abstained or voted against the resolution. Nevertheless, the resolution demonstrates not only widespread support for protecting Earth's orbits from wanton debris creation, but also for continued work on reducing the risks of violence in outer space.

The final operative paragraph of the U.S.-sponsored resolution calls on states to "establish and develop further practical steps" such as adopting "additional moratoriums, which could contribute to legally binding instruments." The U.S. delegation continued to clarify the ideal steps on this incremental pathway in other forums, seeding the next steps in their submissions to the "Open-ended working group on reducing space threats through norms, rules and principles of responsible behaviours" (OEWG). To expand the content of new rules or norms against intentionally destroying satellites, the United States recommended that others "consider refraining from any tests, experiments, or other activities that result in satellite break-ups or the intentional destruction of spacecraft or orbital stages." Implementing this type of moratorium would cover a broader amount of capabilities than categorized in the Vice President's commitment.

This process is in its infancy, but the incremental nature is reminiscent of other strategic arms control and nonproliferation efforts. The historical record on issues like nuclear weapons tests provides instructive examples of how iterative processes can contribute to the growth of rules, norms, and treaty law. For instance, there is a clear lineage from the Limited Test Ban Treaty (LTBT) to treaties under consideration today, like the Comprehensive Test Ban Treaty.

The diplomatic path towards widespread nuclear arms control began in 1954, with Indian Prime Minister Jawaharlal Nehru's recommendation of a "stand-still agreement" on nuclear testing in the wake of several large U.S. and Soviet atmospheric nuclear explosions. After winks and nods toward a multilateral moratorium, formal negotiations on a test ban began in earnest in 1958. The Soviet Union had, early in the year, unilaterally suspended their nuclear test program in an attempt to influence the other nuclear powers of the time to adopt a reciprocal pledge. Instead of jumping headlong into an agreement, the United States recommended that first states should discuss how to confirm that such a ban was effective. Expert groups in Geneva investigated the potential for verifying that states were complying with a suspension of nuclear tests. This process already strongly resembles the ongoing experience with negotiated constraints on ASAT capabilities.

After several years of negotiations, states concluded the LTBT, an agreement that arguably focused more on the environmental impacts of nuclear testing than states atomic armaments. The LTBT mandates that states may only test nuclear weapons underground, where the fallout would not escape and contaminate shared environmental resources or neighboring countries. Satisfied with the efforts to drive nuclear testing underground to mitigate environmental impacts, the Soviet Union and United States turned their attention to the size of nuclear tests.

The core of the Threshold Test Ban Treaty (TTBT) took only a little bit longer than a month to draft, and limited both states' nuclear tests to yields of less than 150 kilotons. The proposed treaty initially suffered from verification issues, namely the potential for underground nuclear tests to accidentally surpass the agreed upon limit. Other verification issues were related to technical assessments of blast yield, which varied based on assumptions about the geology and hydrology of specific test sites. The United States and Soviet Union took several years to negotiate new protocols designed to address these issues. Nevertheless, the United States and

Soviet Union committed to a "step-by-step approach" to effectively limit states' abilities to test and validate new types of nuclear weaponry, with an eye to ending testing entirely.

The final step, a Comprehensive Test Ban Treaty, remains just out of reach. However, this ongoing effort to reach a global agreement against all types of nuclear weapons tests illustrates the power of iterative progress at the highest diplomatic level. Several states have already taken one step forward on this path, and may have the tools to verify a variety of limitations on ASAT testing.

5. Verifying for Now and Later

The incremental nature of diplomacy is mirrored in the development of verification techniques. States often follow linear pathways when making technical progress on the tools and systems that could be relevant in verifying adherence to an ASAT test ban. However, recent changes in both technical and regulatory frameworks around the world have opened the door for paradigm shifts and revolutionary progress. Some of these proven and emerging technologies may be able to verify that space actors are complying with certain types of expectations in specific orbits. However, there are clear gaps and areas for improvement.

The political pledge against the testing of destructive DA-ASAT missiles does not contain any steps toward verification. However, this does not mean that a state's adherence to its commitments is left unmonitored by the rest of the world. Historically, states have used a variety of methods to verify that others were complying with their political commitments. Many of these tools are the same or similar to those used to verify formal arms control agreements and treaties, or to address existing national security imperatives.

The United States likely has the capabilities to verify adherence to the current commitment by leveraging its space-based and terrestrial assets to detect both missile launches and satellite breakups. The U.S. Space Based Infrared System (SBIRS) performs an uninterrupted global search for missile launches, providing the U.S. military with constant awareness of launch activities occurring anywhere in the world. Various nodes of the U.S. space surveillance network (SSN) perform the SSA mission to detect, characterize, and track satellites using ground-based and space-based assets. Coupled together, the U.S. missile warning and SSA capabilities can monitor both the Earth and Earth's orbits to inform a compliance verification mission. However, existing gaps in the SSN monitoring capabilities, primarily in the Southern Hemisphere, preclude the sort of unilateral verification that would be necessary to monitor compliance with a broader moratoria covering all types of intentional fragmentation.

Even with gaps, the U.S. prospects for identifying destructive DA-ASAT missile tests are second to none. No other countries operate global missile warning systems, and only a few have high-fidelity SSA capability. Historically, Russia was the other capable actor in this domain but their status as a premier collection and analytical hub has waned. Russia has extensive experience in operating missile launch detection systems, currently operating over a dozen fixed ground-based radars that can detect missile launches about 6,000 kilometers away. Other seaborne, airborne, and space-based systems supplement this capability, further extending the range of Russia's abilities. However, Russia has faced significant challenges over the past two decades related to maintenance and struggled to keep pace with the state of the art in both the terrestrial and space based components. This gives rise to concerns about the potential pending obsolescence of these systems..

Early Russian efforts to build a space-based missile warning system relied on satellites like Kosmos-520, launched in 1972, and the more modern Kosmos-2479, launched in 2012. To replace or supplement these capabilities, Russia recently completed deployments of its Tundra satellites, which operate in highly elliptical orbits designed to maximize the time these satellites can observe the northern hemisphere, specifically the polar region. Thus, these satellites may not be as effective as others for detecting missile launches around the globe. Leading Russian military officials have acknowledged that prior configurations of their missile launch detection satellites were susceptible to coverage gaps. Russia aimed to improve coverage by adding satellites in geostationary orbits, but this program may be delayed or effected by sanctions imposed in the wake of their invasion of Ukraine. These sanctions have not prevented Russia from reaching out to potential partners, though. For instance, Russia and China announced their intent to collaborate on an early warning system to detect missile launches.

For its own part, Chinese leadership has recently charged the People's Liberation Army Air Force to focus on expanding its strategic early warning capabilities for ballistic missile launch detection. This new undertaking builds on a longstanding effort to establish a comprehensive missile warning system. China's capabilities leverage ground-based radars, such as the Long Range Phased Array systems that scan eastern horizons for missile launches. Other deployments of these types of radar systems may serve two roles by monitoring India and tracking space objects. More recently, China appears to have developed an initial space-based missile warning system, although the details and coverage are still largely unknown.

Elsewhere in Asia, countries operate missile launch detection or missile warning tools as part of larger missile defense systems, but generally deploy them in response to theater or regional threats. For instance, the Green Pine radar system, developed by Israel Aerospace Industries, is deployed in several countries, including India and South Korea.

In addition to ground-based radars, South Korea plans to launch a small network of satellites to detect North Korean missile launches, with the intent to operate a full early warning system by the 2030s. Similarly, Japan uses a suite of satellite and terrestrial radar systems to detect North Korean missile launches. South Korea and Japan are exploring how to seamlessly join their efforts to monitor the shared threat of North Korean missile launches, showing the potential for collaborative and rapid data exchange.

This regional focus is evident in Europe as well. Europe's reinvigorated attention to missile warning has seen the continent cooperatively improve missile detection capabilities. In response to the last decade of Russian missile activities and threats to continental territorial integrity, the European Union is improving its early warning system to detect missile launches, which may include space-based components in the future. Other efforts include studying the feasibility of using space-based sensors as a first layer to detect missile launches. Prior initiatives under the European Phased Adaptive Approach saw deployments of U.S. sensors in several European countries.

States are not the only actors that can detect rocket and missile launches around the world. The Preparatory Commission for the Comprehensive Nuclear-Test-Ban Treaty Organization, a multinational organization, operates a large network of sensor arrays that collect very low frequency acoustic waves called infrasound. The network is capable of "hearing" rocket launches and transmitting the data to a central analytical cell as part of the International Monitoring System (IMS). Independent analysts have used information collected by the IMS to detect rocket launches, a technique that shows promise for the future.

Nevertheless, sensing and attributing missile launches is only one part of verifying that states who have pledged to not conduct destructive DA-ASAT missile tests are living up to their commitments. The other half of this verification process relies on a comprehensive awareness of the orbital environment.

Investments in SSA are increasing around the world. States, multinational cooperatives, and commercial actors alike are responding to the growing number of space objects and the burgeoning community of satellite operators by improving their sensing and analytical capabilities to better understand the current and future state of Earth's orbit. Broad trends in satellite operations have challenged the efficacy of traditional methods of SSA collection and have advanced the state of the art in both sensing and analysis. New paradigms in satellite design like megaconstellations as well as the growing debris population mean that effective SSA networks must now sense and catalog many more objects than in years past. This explosion in the population of orbital objects complicates SSA missions and exacerbates the need for comprehensive and communal understanding of the orbital environment.

States around the world have developed foundational SSA sensing systems and analysis cells. Some of these systems are nationally-oriented, but collective efforts have become more prevalent recently. With many different concurrent efforts ongoing around the world, there is no "standard" practice to SSA collection and analysis. National SSA systems are designed to address the pressing strategic issues of a particular state, but these sovereign matters are not always aligned with the needs of the commercial space community. An industrial SSA service market is emerging to meet the needs of satellite owners and operators that are not satisfied by national systems. These contemporary changes among relevant public and private actors have complicated coherent global SSA service delivery.

While the gap between excellent and emerging SSA providers is closing, the United States remains the global leader in providing SSA data and analyses. The Department of Defense traditionally managed the state's SSA mission, operating a variety of sensors to monitor space objects, including the terrestrial Space Fence and the in-space Geosynchronous Space Situational Awareness Program (GSSAP). Through its collection, analysis, and dissemination practices, the Department of Defense established itself as the premier entity for both military and civil SSA services. The 18th Space Defense Squadron, a component of the U.S. Space Force, continues to execute SSA programs as they relate to the broader national security missions, but recent changes have shifted the institutional responsibility for civil SSA to the Department of Commerce.

Like the United States, Russia's SSA capabilities originated during the Cold War and involve a large network of ground-based radars and telescopes to track objects in space. Since the breakup of the Soviet Union, these tracking facilities have mostly been limited to the Asian continent. A recent effort known as the International Scientific Optical Network (ISON) overcomes this restriction by combining data from optical telescopes deployed across over a dozen facilities both within and outside of Russia. An overwhelming majority of these facilities are in the northern hemisphere. The Network benefits from data provided by several other sensors from partner organizations outside the network. Many of the advanced analytics focus on satellites in geosynchronous orbit (GEO) or middle Earth orbits (MEO). Russia intends to improve its ability to monitor the space environment, with plans to nearly double the number of telescopes used for SSA collection and to deploy satellites capable of monitoring the space environment. It is unclear how the ongoing war in Ukraine has and will continue to affect Russian SSA capabilities, including the states' ability to maintain partnerships and collaborations.

Europe continues to work on its own SSA efforts. The European Union Space Programme (EUSPA) consolidates European surveillance and tracking tools, having absorbed the programmatic responsibility from the EU's Satellite Centre. The new-look EU Space Surveillance and Tracking (EUSST) network also expanded from seven to fifteen participating member states (Austria, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Spain and Sweden), who now contribute to the network of ground-based lasers, radars, and optical telescopes that identify and track satellites and debris. Several of the sensors are located outside of Europe, providing geographic diversity to the data. The EUSST provides services based on the data collected by this network, including providing collision risk assessments to subscribing users and publishing some data for broader consumption.

China is a relative newcomer in developing SSA capabilities but has rapidly progressed over the last few decades. China operates an extensive indigenous ground-based SSA collection network that mainly leverages missile warning radars. Beijing has expanded its pursuit of comprehensive SSA by developing space sensing and data collection systems that are more advanced than fixed sites on Earth. China has expanded their capabilities by launching a small fleet of satellite tracking ships that navigate the Pacific and Indian oceans and use onboard sensors to monitor a variety of space objects including satellites in Earth's orbits as well as lunar and martian probes. State-sponsored researchers have also explored cutting edge concepts in SSA, such as retrograde orbits that would allow satellites to monitor objects in geostationary orbits with more timely results. These SSA-specific systems support China's efforts to protect their satellites from space debris. This network also includes Chinese-operated facilities abroad and other sites that China leases.

Additionally, China leads a multinational effort as part of the Asia Pacific Space Cooperation Organization (APSCO) that joins several states together in a collective SSA program. Within APSCO, the Asia-Pacific Ground-Based Space Object Observation System (APOSOS) leverages optical telescopes in several countries, including non-Asian states like Peru. Geographic breadth is a prerequisite for persistent custody of space objects outside of the geostationary belt, and APSCO benefits from having a geographically diverse membership. APSCO is developing other projects like the Asia-Pacific Space Sciences Observatories to focus specifically on space debris. At least one node in this system is scheduled to be deployed in each APSCO member state by 2025. Since no APSCO member state could indigenously collect a comprehensive SSA database, APSCO's cooperative model could help create an actionable understanding of the space environment for countries without significant capability of their own.

Elsewhere, states have developed SSA networks without the formality of an international organization and have also explored new techniques such as SSA payloads hosted on other satellites. Recognizing the value of geographic diversity, South Korea incorporates data from optical telescopes located in Mongolia, Morocco, Israel, and the United States as part of its Optical Wide-field patroL Network (OWL-Net). Japan is working toward developing an in-space sensing capability as part of their Quasi-Zenith Satellite System. These diverse approaches to sensing and measuring space objects showcases the breadth of options for tracking satellites and recording behavioral patterns.

Established SSA efforts and networks are still broadly geographically isolated to the northern hemisphere. Some of the more advanced SSA systems leverage sensors in the southern hemisphere, but no organization has complete coverage of Earth's orbits. Australia is one of the most important recent contributors to SSA as a result of its unique location in the southern hemisphere, leveraging several telescopes and sensors spread across the continent and participating in partnerships to ensure that data collected in the southern hemisphere is available to others. Australia has recently committed to enlarging their contribution to civil SSA practices, as well as fostering a stronger commercial SSA sector.

The growing global commercial SSA industry is emerging as a valuable contributor to space safety and sustainability efforts. Commercial SSA services reflect the broader trends in space; commercial interests have emerged to take on and, in some cases, surpass what was once only achievable by sovereign actors. For example, Exoanalytic Solutions leverages a network of more than 250 optical telescopes to provide global continuous coverage of the geosynchronous orbital region. LeoLabs operates a network of seven globally-distributed radars that can track thousands of objects in low Earth orbit and plans to add many more sites to improve coverage. HEO Robotics uses satellites to collect imagery of other space objects. These and other commercial actors provide SSA services tailored to clients' needs, for instance, addressing acute conjunction risks and designing mitigation plans based on mission parameters. Existing SSA providers use a variety of collection techniques, and several emerging commercial actors plan to bring other more exotic techniques to market. This emerging cadre of commercial actors provides another intriguing avenue for collecting, analyzing, and disseminating analyses of space object behavior.

All of these civil, military, and commercial SSA capabilities could feasibly contribute to a treaty or agreement that would limit the uses of ASAT weapons. The design of a future observation regime to monitor and verify compliance would, of course, hinge largely on the types of behaviors a treaty or agreement aimed to prohibit. Put another way, current SSA collection and analysis systems could enable a range of restrictions on the uses of ASAT capabilities. Nevertheless, these tools and techniques have their limits and may struggle to verify compliance with regimes prohibiting certain types of hostile, dangerous, or distasteful behaviors. Future advances in SSA technologies could expand the range of verification possibilities.

The global trends in SSA related activities show a rapid growth in unique sensors and analytical hubs. New actors, more advanced sensors, and novel collection paradigms are certainly welcome. However, it is unclear that all of this activity is providing satellite operators and interested partners with a more clear understanding of the space environment. This is especially poignant in the case of conjunction analysis, essentially the process by which operators understand the probability of a collision in orbit. While some data is shared globally, each analytical hub generally brings data from their own sensors and proprietary analytic techniques to the table. There is no global requirement for standard sensor calibration, introducing concerns about accuracy. Furthermore, there is no standard form of analysis, and these calculations often occur in black boxes (behind closed doors, or otherwise lacking transparency). Thus, models may produce dramatically different results about the probability of a conjunction and subsequent risks of collision in orbit. Without clarity on the assumptions of an analytic model, it is impossible to reconcile divergent analyses. This has distinct impacts on the potential for a future verification regime.

6. Verifying Future Restraints

Technologies that could be used to determine whether states are acting in accordance with their political commitments and legal obligations are maturing and proliferating around the globe. A future agreement limiting the uses of ASATs or restraining hostile behavior in space could leverage these sensors and analytic techniques for verification purposes. The level of formality and organization of these verification tools may open new possibilities for the types of negotiated restraint.

The key aspects of any future verification regime hinge on what types of behavior these regimes aim to monitor. The tools and analyses needed to verify compliance with a ban on destructive DA-ASATs missile tests are likely very different from those required to verify states' compliance with restraints on co-orbital ASAT testing. Some of these differences are nuanced, while others are more pronounced. Nevertheless, the current and foreseeable suite of sensing technologies provides a reasonable menu of options for verifying a variety of behaviors. Determining the most suitable tools and processes should, of course, be subordinate to a determination of what types of commitments could most effectively reduce the risks of misperception, misinterpretation, and miscalculation in space.

Effective verification regimes must also account for the number of parties involved in an agreement. Across the history of legally binding agreements, verification practices for bilateral treaties are often different from the types of monitoring involved in verifying compliance with multilateral agreements. With these aspects in mind, verification must be tailored to the specific prohibitions and parties. There is no one-size-fits-all solution.

Current SSA monitoring and analysis techniques are likely able to perform some, but not all, of the verification activities necessary to effect a broad prohibition on the use of ASAT weapons. Existing SSA sensors are simply not designed to detect some types of ASAT or counterspace capabilities. While more advanced states may be able to use classified systems to determine adversarial use of electronic interference, directed energy weapons, or other difficult-to-observe tools, these types of systems cannot be counted on for use in a verification regime for several reasons. For instance, states may be unwilling to disclose their sources and methods, or reluctant to admit that their systems were successfully degraded by an adversary. Therefore, current SSA systems are best suited for determining compliance with broadly observable events, such as rocket launches, on-orbit maneuvers, and satellite fragmentations. It is unlikely that emerging or exotic concepts in SSA sensing would meaningfully expand this potential body of work.

A treaty restricting these types of observable events could take many forms, each with specific verification requirements. A disarmament or ASAT nonproliferation treaty is unlikely, in no small part due to the political issues related to the intertwined nature of DA-ASAT systems and ballistic missile defense (BMD) technology. The United States is unwilling to give up its antiballistic missile capabilities, even though the tactical systems that contribute to the BMD mission have been proven as effective ASAT tools. Instead, a test ban or other use-case-specific treaty is likely to be more viable. Using states' extant political commitments as a template for a legally binding treaty is one of the most logical jumping off points.

6.A VERIFYING A BAN ON DESTRUCTIVE DA-ASAT MISSILE TESTING

As an example of what a treaty and associated verification steps might look like in practice, consider the tasks of verifying state compliance with a commitment to not conduct destructive DA-ASAT missile tests. Such verification would require states to monitor two key activities: missile launches and satellite fragmentations. States party to such an agreement would need to both detect missile launches from anywhere in the world and credibly attribute a missile to a launching state. Building a verification regime to accomplish these two tasks would require significant technical advancements in monitoring, as well as overcoming political hurdles and friction related to sharing data.

Foundationally, the paucity of missile launch detection capabilities poses challenges to the plausibility and efficacy of a future treaty. While some states have the capability to detect missile launches originating from neighboring territories, the lack of global coverage makes it unlikely that states would enter a bilateral agreement with treaty partners from other regions. Furthermore, many of these missile launch detection systems are focused on ground-based launch systems. Some non-traditional DA-ASAT missile launch techniques, both conceptual and proven, could evade these detection systems. As states are likely not going to target foreign satellites in destructive DA-ASAT missile tests, the target of a missile in many cases would reveal a missile's origin. However, targeting large pieces of debris or other objects that lack clear provenance could further complicate attributing tests. Advancements in missile launch detection capabilities or national technical means of verification would improve this outlook.

The deficit of states that can survey the entire globe as part of a missile launch detection mission may also affect a multilateral agreement. This scarcity of capabilities could lead to an imbalanced monitoring process, in which the majority of the treaty signatories would be reliant on one or a few states for monitoring all states parties' adherence. This essentially unilateral verification practice could degrade the efficacy of the verification process for several reasons. First, relying on only a few states to monitor many other states' compliance with a multilateral agreement may lead to the politicization of the verification process. For instance, a capable state may weigh the benefits of making evidence of noncompliance public against the risks of revealing sources and methods and conclude that it is not in its best interest to release the related intelligence. Even if a state were to release exquisite, high quality and trusted evidence, the absence of analytical expertise in other countries would likely preclude independent review or adequate corroboration. In another case, a state may wait to release data and, in doing so, prevent any prompt enforcement actions. Similarly to the bilateral case, improvements to states' missile launch detection and monitoring capabilities could reduce the risks of overreliance on one party for verification. The emergence of multilateral and institutional efforts to monitor global missile launches may remedy this imbalance.

The second phase of verifying a destructive DA-ASAT missile test ban would require a monitoring regime to have a robust space sensing capability. This system could take one of two paths. Building on the missile launch detection capability, a comprehensive missile tracking system could continue to track missiles and any associated payloads as they enter and move through space. Determining that the missile did not make contact with a satellite in space would be evidence that it was not a destructive DA-ASAT test. Another paradigm would be to detect the destruction of a satellite target, and work backwards to determine the kill vehicle's origin, thus identifying the non-compliant party.

Currently, no single actor can provide a comprehensive understanding of the satellite population in Earth's orbit. Even if all SSA capabilities were seamlessly combined, the global SSA capacity fails to provide clear and unambiguous data about each object in orbit. These challenges are evident in the broader push for space safety, particularly as it relates to conjunction avoidance and preventing collisions between satellites. Discrete observations sometimes differ based on the type of sensing tool used and not all data is comparable. Based on a variety of differences in algorithms, databases, and more, analytical forecasts of satellites' locations do not always result in compatible results. Consequently, verifying compliance with a treaty banning destructive DA-ASAT missile testing would have to overcome those challenges. Careful and intentional treaty design could help move beyond these issues.

Effectively monitoring compliance with a destructive DA-ASAT missile test ban hinges on complete coverage of Earth's orbits. However—and unlike space traffic management processes—this may not require states to agree on the absolute truth about a satellite's location, only that it exists in one or many pieces. Any verification regime for a destructive DA-ASAT missile test ban would inevitably rely on post hoc (after the fact) evidence to prove that a missile destroyed a satellite. With this in mind, an adequate verification regime may require complete coverage of the near-space environment, but not necessarily require any given system to maintain unceasing custody of each and every satellite. A mosaic of SSA sensors may be enough to provide effective verification that a missile did not destroy a satellite. Ideally, such a monitoring system would ensure that there are no breaks in coverage, but states may be amenable to a system with brief gaps between the borders of SSA systems' coverage.

This mosaic-style monitoring system overcomes certain challenges, such as the need for widespread redundancies or wholesale consolidation of SSA systems under a singular organization, but would raise other concerns related to communication and data access among treaty participants. It is conceivable that such a monitoring system would feature zones of coverage in which all the data was provided by sensors controlled by one actor. Broader development of sensing capabilities could overcome this challenge, but there are unclear incentives for states to forgo other national priorities in pursuit of building sensing equipment to support treaty verification. This potential quasi-unilateral monitoring situation highlights the need for improved communication and trust among monitoring cells.

Without a clear technical solution, states might be best served in the short term to resolve this particular risk through political avenues. For instance, a treaty could design an implementation organization that would receive information from all participating systems and serve as a clearing house. States may oppose such a system due to the national security implications of the SSA data or out of concern that its domestic commercial SSA industry would be negatively affected. Another approach would be to allow states to submit "challenge requests" for data on a case-by-case basis through the treaty's implementing organization. This arrangement may overcome some of the concerns related to a more general SSA data repository, but would likely be a more time-intensive process and could delay enforcement actions. Furthermore, this style of monitoring would inherently advantage states with comparatively more sophisticated national SSA systems, as they would not be so reliant on a data request process.

6.B VERIFYING A BAN ON DESTRUCTIVE CO-ORBITAL ASAT TESTING

As another example, states may wish to introduce a treaty initiative to address a broader range of threats to space systems, including the use of co-orbital weapons against satellites. A treaty prohibiting the destructive testing of co-orbital weapons would foundationally rely on a complete accounting of space objects and prompt cataloging of additional satellites launched into orbit after the treaty enters into force. Existing convention obligates states to contribute to a space object registry, but states' compliance with this duty is irregular. The current regime has been unable to create high levels of cooperative transparency among states as it relates to placing objects in orbit. Revisions to the current legal framework for international communication about launching satellites could close some of these gaps, but analysis shows that advanced spacefaring states are among the most lax about compliance with existing rules, reducing expectations that there is political will for a more stringent reporting framework. States are likely to continue this habit of low compliance, in part due to states' unwillingness to discuss classified payloads. It is unlikely that states would agree to levy penalties for their current and expected future behavior.

Non cooperative sensing, as part of a broader SSA system, could address the gaps left by the bureaucratic paper trail, and facilitate the necessary improvements toward the required level of transparency. First and foremost, complete and continuous supervision of space objects is mandatory for the success of a treaty limiting co-orbital testing of any sort, and would be an integral part of a verification regime. This process necessitates advancements across the entire SSA lifecycle: sensing, characterizing, tracking, and assessing the future state of an object. This data is the critical foundation of conjunction analyses, which would be the necessary next step in verifying compliance.

Second, a verification regime must empower states to use available SSA data and conjunction analyses to conclude whether a collision was inadvertent or malign. Many conjunction analysts conduct their work in black boxes, leaving end users with little to no clarity about the assumptions that influence the final results. Thus, it can be impossible to determine the root cause of variance among conjunction analyses. This is particularly concerning in cases in which incongruent results make it more difficult to determine what is an operational accident, what is a false alarm, and what is an intentionally hostile behavior.. These technical aspects are compounded by political challenges that raise barriers on the pathway toward an effective verification regime for a treaty addressing co-orbital ASATs. With this in mind, a multilateral treaty is perhaps not the most appropriate way to align the wide variety of analytical practices - a global technical forum is likely more suited to take up this issue.

Political avenues could build processes to address other concerns, though. Taking cues from existing treaties, agreements, or arrangements that require notifications, a treaty could obligate states to announce or otherwise notify an implementation organization about activities that could be misconstrued as destructive co-orbital activities. This might include in-space servicing or active debris removal. While not necessarily a true verification regime, and assuming high levels of compliance, this notification practice would cut down on the number of incidents of interest. It would not, however, eliminate concerns about unplanned conjunctions.

While notifications or announcements could reduce the haystack, this political practice cannot clarify intent in the case of satellite maneuvers not related to covered rendezvous and proximity operations (RPOs) such as on-orbit servicing, in-space manufacturing, or debris remediation practices. No monitoring regime can, or should attempt to, determine an actor's intent. The process of assigning intent remains a political judgment. A ban on destructive testing of co-orbital ASATs could be constructed to sidestep this invariably contentious process by focusing solely on debris created by destructive RPO activities. Adjudicating whether an activity created debris is agnostic to the state party's intentions. Some RPO activities necessarily create debris, but do not destroy the servicer or satellite receiving service. States would thus have to agree to a definition of "destroyed," and build the verification regime to fit this new term. It is plausible that any definition would require more precise monitoring and verification practices than what are currently available.

6.C VERIFYING A SPACE ENVIRONMENTAL AGREEMENT

The dialogue related to restricting state's testing of ASAT capabilities has strong overlaps with the principles of space sustainability and preserving a low-risk orbital environment by attenuating the growth of the orbital debris population. Recommendations to limit debris creating events in space are often framed in relation to harm to the orbital environment. Using this parallel to inform a multilateral treaty on debris invites a different type of verification process, namely one that is focused on international communication related to the amount or degree of pollution or other environmental harm produced over a defined period of time. National reporting processes are often the primary method of sharing this information. These national reports are founded on standardized collection and monitoring practices to ensure fair comparisons and analyses.

Some MEAs focus on measuring states' emissions of specific pollutants. An agreement could treat space debris like terrestrial pollutants, but an adequate sensing and monitoring system would have to track a wide variety of irregular objects, not just uniformly shaped targets like the molecules that pollute the Earth's atmosphere. Furthermore, all pieces of debris do not necessarily have the same risk profiles. Large pieces of debris are among the most dangerous, but even miniscule debris fragments elevate the risks of collisions with operational satellites. Therefore, states must be able to sense and track a variety of orbital pollutants to effectively verify compliance with an MEA-style space debris treaty. Doing so would require political and technical advances.

National reporting on compliance with, or steps toward compliance with, the terms of an MEA is especially important in the context of pollutants because there are few other ways to collect this data. Individual states are the most capable actors for monitoring emissions within their own borders. In contrast, space has no borders. Activities in orbit are free to be seen by any actor who has the capability and good fortune to be looking in the right place at the right time. Without comprehensive coverage of Earth's orbits, it stands to reason that satellite owners are best positioned to monitor their satellites. States' reporting on the debris created by this subset of the total satellite population would require only a slight political step beyond current international obligations, such as states obligations to supervise space activities under Article VI of the OST.

However, there are significant technical challenges to operationalizing such an obligation. Standardizing SSA monitoring and reporting about fragmentation events or other debris production would require states to drastically improve their sensing capabilities. To create a meaningful ceiling of "acceptable" orbital pollution, SSA systems around the world would need to be able to sense even the smallest debris particles that could destroy a satellite. Estimated to number in the millions, even millimeter-sized pieces of orbital detritus raise the risks of a satellite failing in orbit due to collision with debris. Current SSA systems cannot reliably sense or track these objects. Building a sufficient catalog of these pieces of debris would require massive investments to both qualitatively and quantitatively improve sensors. Meaningful improvements to SSA sensing equipment is a tall order for many prospective parties to an agreement.

States' recent pivot toward using commercial data and analyses may hasten these investments. States could buy ready-made products or services from the emerging SSA industry to build a stronger capacity. However, introducing data or analytical services from the commercial sector may not resolve other challenges, namely deriving a coherent baseline upon which to judge state compliance with an MEA. Private sector actors are motivated to differentiate their products and to protect their competitive advantages, leading to several different analyses of debris generating events all happening in separate black boxes. This variety may be useful in certain contexts, but an MEA would have to create a framework to reconcile these diverse analyses.

On a global scale, SSA capabilities would have to align SSA networks to facilitate data exchange. Multilateral exchanges at the Inter-Agency Space Debris Coordination Committee illustrate the differences among major states' modeling of the space debris population. The differences among the models provide an analogous window into the challenges related to both identifying parameters for permissible debris creation and aligning national reports about compliance. In essence, because an MEA cannot limit what it cannot measure, any agreement would struggle to effect meaningful limits on hazardous debris creation without improvements to the global sensitivity baseline across state and commercial SSA sensors.

7. The Role of the Commercial Sector in Verification

Like most space-related endeavors, commercial entities have been investing in SSA capabilities and have experienced remarkable success in providing alternatives to traditional SSA data sources. This has eroded the traditional governmental monopoly on SSA data. The advent of commercial SSA systems has implications for verifying states' compliance with bilateral or multilateral treaties. Commercial companies have made it clear that they are interested in addressing security and sustainability issues, with some clarifying their corporate positions or issuing ethical evaluations of states' space activities. Recent joint statements show a confluence of perspectives among commercial actors from many segments of the space industry.

Primarily, commercial SSA providers would impact states' role as the principal political actors in monitoring and verifying treaty compliance, without necessarily having this role delegated to them by states. This mirrors the challenges and opportunities posed by open source intelligence analysis. On one hand, commercial actors could support states in adjudicating instances of potential ASAT testing. This would be particularly meaningful for states that might not have their own space sensing infrastructure. Commercial SSA capacities are undoubtedly helpful for states in the pursuit of complete coverage of all objects in Earth's orbits. Even the most advanced spacefaring states still engage with the commercial sector for data and services and are exploring ways to ingest more commercial products. More broadly, commercial SSA data could be readily applied to support verifying states' compliance with treaties restricting co-orbital tests, as some states may not have complete custody of space objects based on the geography of their SSA sensors. Commercial SSA services could provide an apolitical, or relatively less politicized, perspective to support states' adjudication of the data.

On the other hand, the commercial sector may unwittingly force states' hands in addressing what might appear to be a compliance issue. A state and a commercial entity may observe the same instance and derive incompatible conclusions even if based on the same or similar data. For instance, if a state technically violated a treaty but did so unintentionally or in a militarily insignificant way, another state party may be willing to let the violation pass without enforcing the treaty. A commercial entity may adjudicate the data and come to a different conclusion about the significance or intent of the violation. Even if commercial entities are reticent to adjudicate instances of noncompliance or furthermore publicly demand official responses to questionable behavior, the public availability of data and analytical findings may itself tacitly pressure a state's leadership to take enforcement actions.

In a bilateral treaty, continued underenforcement may erode the credibility of a state's leadership, predisposing leaders to action even in borderline cases. This type of frivolous enforcement could jeopardize the efficacy of the treaty, depending on the types of enforcement mechanisms available. Multilateral treaties may suffer similar effects if entities who are neither states nor associated with the implementation organization produce evidence of cheating. While commercial SSA entities aim to provide data and services that preclude operational and strategic surprise in space, these same services may introduce political surprise.

The global nature of the SSA industry makes it difficult to identify clear pathways by which states could place guardrails around the commercial sector's impact. State-level regulation could attenuate some of the risks related to the commercial capabilities and the potential for non-state entities to contribute to the political act of treaty verification. However, the global surge in commercial space sensing and SSA services reduces the likelihood that these types of regulation could be effectively aligned. Uneven implementation of regulations on commercial

SSA capacities around the world would open the door for regulatory forum shopping, an undesirable outcome.

The United States experience with commercial remote sensing is an instructive case study that should inform attempts to regulate SSA systems. The original licensing and regulatory regime for commercial satellites using synthetic aperture radar, optical imagery, and other Earth observation equipment was developed during a time when U.S. industry was both relatively new, but clearly the global leader. This dynamic evolved quickly on both fronts: domestic U.S. industry ballooned, and foreign firms developed competitive products. The regulatory environment, designed to protect U.S. national security interests, quickly morphed into a hindrance on U.S. commercial competitiveness. The liberalization of U.S. regulations reflects the fundamental change in global industrial capacity. Essentially, the United States recognized that one state alone could not effectively use regulation to eliminate threats to national security, and that there was no global appetite to synchronize or harmonize regulation. Attempts to reign in potential harms brought about by commercial SSA systems are likely to encounter many of the aspects of the experience with commercial remote sensing.

Other perspectives indicate that the commercial sector may self-restrain or -regulate. While the space industry is booming around the world, states remain a significant, if not the most significant, purchasers of SSA products. Commercial SSA providers that sell data and services to states' civil space agencies, militaries, and intelligence communities might have second thoughts about disclosing certain information or publicizing analyses that would disrupt their relationships with their most valuable clients. Corporate entities would likely be reluctant to breach contracts with governments, but some commercial SSA providers may ostensibly find themselves unrestrained by market forces and contracts. Because commercial space sensing and analysis organizations are not necessarily competing for the business of all states, it is unreasonable to expect a company to be politically restrained by states that are not or are unlikely to ever become customers. Non-commercial private analysts would also likely not feel the same financial pressures that would induce restraint in other organizations. Other capable SSA providers may feel morally compelled to speak up about what they perceive as threatening space behavior.

8. Ways Forward

The recent wave of political commitments to not test destructive DA-ASAT missiles is a positive sign that states around the world are interested in taking steps toward limiting the negative effects of military activities in space. These pledges may perhaps be the first step on the path toward a formal international agreement on reducing grave threats to objects in Earth's orbit and sustaining a low-risk orbital environment for generations to come. A future treaty would have to contend with questions about verifying states parties' compliance. Creating a verification protocol is common practice for modern security treaties and, as outlined above, a new treaty would require states to improve their monitoring capabilities to satisfy the need for verification. However, different treaties would necessitate distinct improvements. States may be more amenable to investing in certain monitoring techniques than others.

Verification remains a core hurdle for all of the concepts explored above. A future agreement, independent of whether it focuses on reducing security threats or sustaining a low-risk orbital environment, is likely to be verified by state-centric monitoring practices. An international organization with the SSA capabilities to tackle the verification challenge, akin to the CTBTO's IMS, is unlikely to appear on the horizon for several reasons. First and foremost, states are likely to prefer to fund their own domestic SSA systems rather than an international collective. Second, states may not be able to use the data or interpret the analyses produced by an international organization due to a lack of domestic technical capacity. Third, the analytical component of an international SSA organization would continue to struggle to fuse data from national systems, restricting the database to only what the organization itself could collect.

Verifying state compliance with treaty obligations would require states to develop specific sensing tools and analytical techniques, depending on the type of activity being monitored. For instance, states could verify compliance with a treaty that prohibits destructive tests of DA-ASAT missiles by building sensors that provide “cradle-to-grave” missile tracking. However, few states face acute security pressures that would necessitate the procurement of such extensive missile tracking systems. Furthermore, these same sensors may not be adequate if applied in the context of verifying compliance with a prohibition of other types of ASAT tests, like co-orbital capabilities. Therefore, improving SSA capabilities appears to be a more amenable option for most state actors. Improvements to SSA sensing and analytical capabilities could also be leveraged toward verifying a future evolution of the treaty, if states were to take an incremental approach to space security treaties.

Verifying the absence of destructive co-orbital testing would require complete and unfailing awareness of all objects in Earth’s orbits. A treaty to limit the environmental impacts of debris-creating space activities would require a related set of sensing tools, but applied to a different set of state obligations. The SSA systems that could be applicable for verifying these treaties are also capable of supporting broader space safety initiatives.

While each different treaty would require a specific sensing tool to support a verification regime, the common thread among all options is the need for improvements. At the state level, no one country can support a truly comprehensive verification regime. Furthermore, it is undesirable to rely exclusively on one or few countries to monitor and verify a potential multilateral treaty. Low prospects for an international organization raise the stakes for individual countries to improve their domestic capabilities. Pushing resources toward developing indigenous SSA capabilities primarily for verifying a multilateral treaty will be untenable for many states. Developing analytical capacity is an alternative, yet still meaningful, avenue toward supporting treaty verification. The private sector offers yet another option, but commercially-available data and analyses may erode states’ primacy in verifying multilateral treaties. The full effects of the commercial SSA sector’s involvement are yet to be seen, however.

Notably, few of the technical or political options for verifying a future agreement or treaty address challenges brought on by low levels of ratification. Global SSA systems need to improve to set the stage for any type of verifiable treaties, but states must have the political will. Even if states had access to a perfect treaty monitoring system and ideal verification process, enforcing the treaty on non-signatory states would be a difficult task. Global political will may be stifled by a treaty’s inability to detect violations before they negatively impact the global military balance or the orbital environment, or both. Comprehensive SSA systems satisfy one goal of verification, to deter defection by raising the likelihood of identifying cheating, but verifying a treaty through SSA sensors and analyses of satellite breakups might struggle to satisfy the equally important second goal - to afford states adequate time to react to violations discovered through verification practices. Relying on post-hoc evidence of satellite fragmentations to verify compliance places treaty-abiding states at a deficit in taking political, legal, or military steps to offset the benefits a defector has gained.

In the best case scenario, global compliance with the treaty’s terms could eventually develop into a normative expectation or customary international law. This is a long and complicated process, with plenty of time for a committed opposition to spoil the results. Thus, it is imperative that states interested in attenuating the negative effects of space debris take steps toward developing verifiable treaties, including the technical capabilities and political frameworks that would support verification.

Title	Key Date(s)	Participation	Verification Article, Clause, or Protocol?	Types of Monitoring: National Technical Means	Mutual On-Site Inspections	Implementing Partner Inspections	International Technical Means	National Reporting	Key Monitoring and Verification Practices
Anti-Ballistic Missile Treaty	Entered into Force 1972; Ceased 2002	Bilateral	Yes	✓					States are permitted to use national technical means of verification under Article XII. Furthermore, the Parties are prohibited from both interfering with the normal function of national technical means of verification of the other Party, and deliberately impeding the other Party's use of national technical means of verification through deliberate concealment measures.
Intermediate-Range Nuclear Forces Treaty	Entered into Force 1988; Ceased 2019	Bilateral	Yes	✓	✓				The INF Treaty included an extensive verification regime, endowing Parties with the right to on-site inspections of missile operating bases and support facilities and permitting the use of national technical means of verification. Parties were obligated to expose certain missile sites on request to ensure that national technical means of verification could complete their monitoring mission. The Parties also established a Special Verification Commission to address and resolve compliance concerns.
Treaty between the United States of America and the Russian Federation on Measures for Further Reduction and Limitation of Strategic Offensive Arms (New START)	Entered into Force 2011	Bilateral	Yes	✓	✓			✓	The Treaty provided a detailed verification regime to monitor and confirm both the conversion and elimination of strategic offensive arms. The Treaty provides states with up to ten on-site inspections of sites with deployed and non-deployed strategic systems (Type One) and up to eight inspections of non-deployed strategic systems (Type Two), annually. Type One inspections allow the United States and Russia to count the number of reentry vehicles on a single deployed missile per inspection, while Type Two inspections can be used to verify the conversion or elimination of weapons systems or closure of facilities. States may, during inspections, verify their counterpart's declaration of deployed warheads by observing the other party load warheads onto delivery vehicles. States also committed to rolling notifications on the status of strategic delivery vehicles and launchers, excluding the dispersal of mobile ICBMs and SSBN patrols. Furthermore, New START mandates that states exchange telemetry and establish a database of relevant information. New START also included a commitment to not interfere with the other party's national technical means of verification.
Interim Agreement Between the United States of America and the Union of Soviet Socialist Republics on Certain Measures with Respect to the Limitation of Strategic Offensive Arms (SALT I)	Signed in 1972	Bilateral	Yes	✓					Article V entitles the United States and Soviet Union to use their national technical means to verify the other party's compliance, as well as obligating states to neither interfere with nor deliberately conceal their activities from the other's NTM.
Treaty Between The United States of America and The Union of Soviet Socialist Republics on the Limitation of Strategic Offensive Arms (SALT II)	Signed in 1979	Bilateral	Yes	✓					Though it was never ratified by the participants, SALT II permitted the United States and Soviet Union to verify the other's compliance via national technical means of verification. This suite of technologies includes reconnaissance satellites, among other advanced sensors. The sides agreed not to interfere with each others NTM systems, as well as committing to not deliberately impede NTM verification processes like overhead imagery collection by concealing systems of interest. Furthermore, the sides agreed to not encrypt telemetry from missile tests that would increase transparency about missile tests. To aid the verification process, the Soviet Union accepted a ban on production of certain types of missiles that would have been difficult to distinguish from other Treaty-limited systems.
Treaty Between the United States of America and the Russian Federation on Further Reduction and Limitation of Strategic Offensive Arms (START II)	Signed in 1993	Bilateral	Yes	✓	✓				START II has a variety of verification principles and obligations beyond those contained in prior treaties. Notably, the US and Russia were obligated to ensure that heavy bombers that had been reoriented from nuclear to conventional roles (or those that had been reoriented back to a nuclear role) would be marked with differences that could be observed by NTM and apparent during inspections. Parties were required to exhibit these heavy bombers (at a place of their choosing). Inspections of these bombers shall, per the Treaty, be conducted by no more than ten inspectors and take no longer than two hours. The Treaty created the Bilateral Implementation Commission, which provided the Parties with a forum to both resolve implementation or compliance issues and discuss the viability of future verification efforts.

LEGEND: Bilateral · Minilateral · Regional · Unilateral · Multilateral · Yes · No · N/A

Title	Key Date(s)	Participation	Verification Article, Clause, or Protocol?	Types of Monitoring: National Technical Means	Mutual On-Site Inspections	Implementing Partner Inspections	International Technical Means	National Reporting	Key Monitoring and Verification Practices
Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms (START I)	Entered into Force 1994	Bilateral	Yes	✓	✓			✓	The Treaty allows for the United States and Russia to use NTM, and prohibits interference with the other's NTM systems. It also creates avenues for information exchanges, including telemetry data from missile tests along with the locations of facilities such as production, storage, and basing information that relate to strategic arms systems. Building on the INF, the parties to the Treaty are permitted to continuously monitor facility portals and perimeters, consistent with and building on the INF Treaty. The Treaty allows for certain types of on-site inspections, distinguishing Party's rights to short notice and planned inspections.
Treaty Between the United States of America and the Russian Federation On Strategic Offensive Reductions (Moscow Treaty, or SORT)	Entered into Force 2003	Bilateral	No	✓					The treaty contains no verification clauses but instead leveraged verification practices included in START I. The Treaty allows for the parties to agree on supplemental verification practices in the future. While not a verification practice, SORT also established the Bilateral Implementation Commission to formalize structured conversations between the United States and Russia on compliance matters.
Treaty Between The United States of America and The Union of Soviet Socialist Republics on the Limitation of Underground Nuclear Weapon Tests	Entered into Force 1990	Bilateral	Yes	✓	✓			✓	The Treaty outlines verification methods and practices in a Protocol, adding a series of obligations and permissions in addition to national technical means of verification. These practices include data exchanges and an advanced hydrodynamic yield measurement method. The Protocol also offers states the opportunity to agree on additional verification measures for nuclear tests with certain physical and geological characteristics.
Rush-Bagot Treaty	Entered into Force 1818	Bilateral	No						None
Lisbon Protocol	Signed in 1992	Minilateral	Yes						The Lisbon Protocol extended the provisions of START to the former Soviet states in the aftermath of the Soviet Union's collapse. It contains no additional verification elements.
London Naval Treaty	Signed in 1930	Minilateral	No						None
Washington Naval Treaty	Signed in 1922	Minilateral	No						None
Arms Trade Treaty	Entered into Force 2014	Multilateral	Yes					✓	The Arms Trade Treaty contains no international monitoring or verification mechanisms but requires states to provide the Secretariat with reports on measures undertaken to implement the Treaty. International organizations like Amnesty International observe international arms transfers to monitor compliance.
Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal	Entered into Force 1992	Multilateral	Yes	✓					Article 19 addresses verification, permitting Parties to inform the Secretariat of the Convention and the alleged non-compliant Party. The Convention does not, however, outline a Convention-specific inspection regime. Parties established a fifteen-member Implementation and Compliance Committee in 2002 as a subsidiary to the Conference of Parties to aid the implementation process and compliance. The Committee considers reports from States Parties about implementation difficulties and non-compliance, and subsequently issues advice or recommendations to both the Party(ies) in question and to the Conference of Parties on how to resolve concerns.

LEGEND: Bilateral · Minilateral · Regional · Unilateral · Multilateral · Yes · No · N/A

Title	Key Date(s)			Types of Monitoring					Key Monitoring and Verification Practices
		Participation	Verification Article, Clause, or Protocol?	National Technical Means	Mutual On-Site Inspections	Implementing Partner Inspections	International Technical Means	National Reporting	
Biological Weapons Convention	Entered into Force 1975	Multilateral	No						The BWC lacks a verification mechanism, but states explored verification concepts through an Ad Hoc Group of Governmental Experts, VEREX, in 1993. Arts. V & VI allow States Parties to the BWC to address compliance issues through consultation and cooperation on problems related to the objective or application of the BWC. "Any States Party can request a formal consultative meeting of States Parties to consider any problems and suggest ways and means for further clarifying matters considered ambiguous or unresolved. Requests for convening a consultative meeting are addressed to the BWC's three Depositaries (the US, UK, and Russia), who inform States Parties of the request and convene within 30 days an informal meeting of States Parties to discuss the arrangements for the formal consultative meeting, which is convened within 60 days of receipt of the request.
Chemical Weapons Convention	Entered into Force 1997	Multilateral	Yes	✓	✓	✓		✓	Verification Annex OPCW Verification The treaty contains extensive verification clauses. States agreed to establish comprehensive reporting requirements, supported by baseline inspection. Furthermore, the treaty authorizes on-site inspections, and allows states parties to request challenge inspections.
Convention on the Prohibition of the Use, Stockpiling, Production and Transfer of Anti-Personnel Mines and on their Destruction	Entered into Force 2009	Multilateral	No						Articles 7 and 8 lay out foundational aspects that could facilitate compliance through transparency measures, but the convention contains no formal mechanisms, responsibilities, or institutions to conduct a more robust verification mission.
Convention on Certain Conventional Weapons	Entered into Force 1983	Multilateral	No						The Convention on Certain Conventional Weapons does not contain any monitoring or verification measures.
Convention on Cluster Munitions	Entered into Force 2010	Multilateral	No					✓	Article 7 obligates States Parties to report on their implementation status and progress, and Article 8 permits all States Parties to submit Requests for Clarification to the Secretary General about another's compliance.
Convention on long-range transboundary air pollution	Entered into Force 1983	Multilateral	Yes					✓	Through the Convention, Parties agreed to coordinate on data exchanges, consultative processes, and monitoring systems to address air pollution. Article 9 emphasizes the need for national and international monitoring systems. Article 9 also supports the standardization of monitoring procedures so that results can be compared. An Implementation Committee, created by the Executive Body in 1997, reviews cases of potential non-compliance and submits recommendations to the Executive Body, which makes final decisions.
Comprehensive Nuclear Test Ban Treaty	Opened for Signature 1996	Multilateral	Yes			✓	✓		The CTBT proposes a layered verification network in Article 4 of the Treaty and through a Protocol. The Preparatory Commission is responsible for ensuring the verification network is established and practicable as a prerequisite for Treaty implementation. The proposed system leverages the International Monitoring System as a primary method of detecting potential nuclear explosions, through a network of hydroacoustic, seismic, and other sensors. There are currently over 300 active sensors in this network. The International Data Centre distributes raw data and analyses to Member States to facilitate broad understanding of notable events. Finally, if the CTBT enters into force, Member States will have the option to request that the CTBT Organization's On-Site Inspections team conduct fieldwork to investigate IMS-detected events. Member States are not allowed to decline an inspection. Requests for on-site inspections must be based on data collected through the IMS or through national technical means of collection.

LEGEND: Bilateral Minilateral Regional Unilateral Multilateral Yes No N/A

Title	Key Date(s)	Participation	Verification Article, Clause, or Protocol?	Types of Monitoring: National Technical Means	Mutual On-Site Inspections	Implementing Partner Inspections	International Technical Means	National Reporting	Key Monitoring and Verification Practices
Convention on the Prohibition of Military or any Hostile Use of Environmental Modification Techniques (EnMod)	Entered into Force 1978	Multilateral	Yes	✓					Article V(3) implies that states can use their own tools and techniques to verify compliance, and Article V(4) implies that the Security Council has the power to investigate states' compliance.
International Code of Conduct against Ballistic Missile Proliferation (Hague Code of Conduct, or HCOC)	Established 2002	Multilateral	N/A						As the HCOC is not a legally binding measure, there is no verification protocol. There are, however, instructions for states parties to consider inviting international parties to observe space launch facilities.
Kyoto Protocol to the United Nations Framework Convention on Climate Change	Entered into Force 2005	Multilateral	Yes					✓	The Kyoto Protocol bases its monitoring regime existing practices of the United Nations Framework Convention on Climate Change. The Protocol adds to this existing framework by requiring Parties to have national systems for estimating domestic greenhouse gas emissions as well as sinks. Under Article 5 of the Protocol, these national systems shall use an agreed-upon common methodology. Annex I Parties are required to positively demonstrate their compliance by reporting supplemental information. Article 8 creates a review process for these communications and submissions from Annex I Parties, essentially assigning expert review teams to assess the accuracy and validity of information like Parties' accounting of emissions inventories. These review teams are made up of experts nominated by Parties and chosen by the Secretariat.
Montreal Protocol on Substances that Deplete the Ozone Layer	Entered into Force 1989	Multilateral	Yes						Article 8 of the Montreal Protocol obliges States Parties to consider how to determine and address non-compliance. States followed through on this obligation by creating a permanent Implementation Commission. Through this Committee, any Party can report a non-compliant party to the Secretariat.
Agreement Governing the Activities of States on the Moon and Other Celestial Bodies	Opened for Signature 1979	Multilateral	Yes		✓				Article 15 of the Agreement obligates states parties to keep "all space vehicles, equipment, facilities, stations, and installations on the Moon" open to other agreement participants. States interested in inspecting facilities, vehicles, or equipment are instructed to give "reasonable advanced notice" prior to inspections.
Missile Technology Control Regime	Established 1987	Multilateral	N/A						As the MTCR is a collection of informal standards and guidelines, there are no aspects of compliance to formally verify.
Treaty on the Non-Proliferation of Nuclear Weapons (NPT)	Entered into Force 1970	Multilateral	Yes			✓	✓	✓	The NPT has an extremely intricate verification practice, carried out by the International Atomic Energy Agency. Article III mandates that non-nuclear weapons states conclude agreements with the IAEA so that the Agency can execute an extensive monitoring mission. The core aspects of this mission include safeguards placed on their existing nuclear materials, safeguards on materials transferred between states, and inspections of nuclear facilities.
Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies (OST)	Entered into Force 1967	Multilateral	Yes		✓			✓	Article XII allows states to, on the basis of reciprocity, access all stations, installations, equipment and space vehicles on the Moon or other celestial bodies. This may be to inspect facilities that may be the subject of compliance concerns. To a differing extent, Article IX promotes appropriate international consultation to resolve questions about other states parties activities that may cause potentially harmful interference.
Paris Agreement	Entered into Force 2016	Multilateral	Yes					✓	Article 15 of the Paris Agreement establishes a committee of experts to facilitate compliance. This committee builds on the existing verification practices of the UN Framework Convention on Climate Change, and thus verifies compliance by assessing states' self-reporting on greenhouse gas inventories and other related transparency measures.

LEGEND: Bilateral · Minilateral · Regional · Unilateral · Multilateral · Yes · No · N/A

Title	Key Date(s)	Participation	Verification Article, Clause, or Protocol?	Types of Monitoring: National Technical Means	Types of Monitoring: Mutual On-Site Inspections	Types of Monitoring: Implementing Partner Inspections	Types of Monitoring: International Technical Means	Types of Monitoring: National Reporting	Key Monitoring and Verification Practices
Treaty on the Prohibition of the Emplacement of Nuclear Weapons and Other Weapons of Mass Destruction on the Seabed and Ocean Floor and in the Subsoil Thereof	Entered into Force 1972	Multilateral	Yes	✓	✓				Article III provides states with the right to inspect and cooperatively observe the activities of others for the purpose of verifying compliance with the Treaty using their preferred means of inspection, so long as these methods do not interfere with the legitimate activities of other parties and are conducted with due regard for the rights of states under other international law.
Treaty on the Prohibition of Nuclear Weapons	Entered into Force 2021	Multilateral	Yes			✓			"Article 4 mandates that states parties "shall cooperate with the competent international authority ... for the purpose of verifying the irreversible elimination of its nuclear-weapon programme." and that states parties "shall conclude a safeguards agreement with the International Atomic Energy Agency sufficient to provide credible assurance of the non-diversion of declared nuclear material from peaceful nuclear activities and of the absence of undeclared nuclear material or activities in that State Party as a whole." While Article 4 outlines that states must cooperate with a "competent international authority" to verify the irreversible elimination of its nuclear weapons program, but details neither how it should accomplish its mission nor the requirements, essential competencies, or authorities of such a verification organization."
Treaty Banning Nuclear Weapon Tests in the Atmosphere, in Outer Space and Under Water	Entered into Force 1963	Multilateral	No						The Treaty contains no verification protocol.
UN Framework Convention on Climate Change	Entered into Force 1994	Multilateral	Yes					✓	Article 12 requires Parties to self report information related to implementation. Because there are no expectations for each Party to follow exactly the same implementation process, the Convention cannot outline a specific verification, monitoring, or compliance regime. The Thirteenth Conference of Parties addressed this gap, agreeing to support transparency among Parties on the effects of climate change mitigation efforts by tasking technical experts to analyze, consult with Parties, and publish summary reports.
Treaty of Versailles	Entered into Force 1920	Multilateral	Yes			✓			The Paris Peace Conference established the Inter-Allied Commissions to oversee the process of German disarmament. The Commission was empowered to "proceed to any point whatever in German territory" (Article 205), essentially conducting on-site inspections. In addition to overseeing the disarmament of German military forces, the Commission had an arms control function. Article 208 mandates that the German government must notify the Commission of the location of munition depots, armed fortifications, and arms factories or war material production facilities.
Antarctic Treaty	Entered into Force 1961	Regional	Yes	✓	✓				Article VII establishes the rights of all Parties to conduct on-site unannounced inspections of all installations and facilities in Antarctica to monitor compliance with prohibitions on all military activities, including the testing of weapons, the explosion of nuclear materials, and the storage or disposal of radioactive waste.
Treaty on Conventional Forces in Europe	Entered into Force 1992	Regional	Yes	✓	✓			✓	Article XIII mandates that each State Party notify and exchange information with others on the conventional armaments covered by the Treaty. Article XIV designs a strong on-site verification process by which States Parties may verify an inspected party's compliance with numerical limits imposed by the Treaty and the disarmament process. States Parties may follow up with aerial inspections after the on-site inspections are complete. The Treaty protects States Parties' rights to use national or multinational technical means of verification and prohibits interference with these monitoring tools or efforts to impede verification by concealment.

LEGEND: Bilateral · Minilateral · Regional · Unilateral · Multilateral · Yes · No · N/A

Title	Key Date(s)	Participation	Verification Article, Clause, or Protocol?	National Technical Means	Mutual On-Site Inspections	Implementing Partner Inspections	International Technical Means	National Reporting	Key Monitoring and Verification Practices
African Nuclear Weapons Free Zone Treaty	Entered Into Force 2009	Regional	Yes			✓			Article 9 of the Treaty mandates that States Parties conclude safeguards agreements with the IAEA. Annex II obligates States Parties to submit reports on IAEA safeguards compliance to the African Commission on Nuclear Energy.
South Pacific Nuclear Free Zone Treaty of Rarotonga	Entered Into Force 1986	Regional	Yes			✓			Verification is completed through implementing IAEA safeguards.
Treaty for the Prohibition of Nuclear Weapons in Latin America and the Caribbean	Entered Into Force 1969	Regional	Yes			✓			Articles 12-18 outline a verification regime that relies heavily on the involvement of the IAEA. Contracting Parties must negotiate safeguards agreements with the IAEA. The IAEA may also carry out special inspections. Contracting Parties must submit semi-annual reports to both the IAEA and an Agency created by the Treaty, the Agency for the Prohibition of Nuclear Weapons in Latin America and the Caribbean.
Presidential Nuclear Initiative	Issued 1991	Unilateral	N/A						As unilateral political commitments, U.S. President Bush's and Soviet President Gorbachev's nuclear reductions were unverifiable by definition.

LEGEND: Bilateral · Minilateral · Regional · Unilateral · Multilateral · Yes · No · N/A

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