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CONSTANT VIGILANCE?

VERIFICATION AND MONITORING FOR SPACE SECURITY

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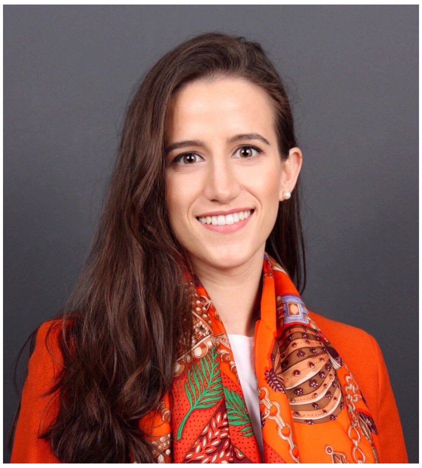
TABLE OF **CONTENTS**

ABOUT THE AUTHORS



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ABBREVIATIONS AND ACRONYMS

ASAT	Anti-satellite
CFSCC	Combined Force Space Component Command
DoD	United States Department of Defense
EU	European Union
EUSST	European Union Space Surveillance and Tracking
GEO	Geostationary orbit
GRAVES	Grand Réseau Adapté à la Veille Spatiale
HCoC	The Hague Code of Conduct against Ballistic Missile Proliferation
INF	Intermediate-Range Nuclear Forces Treaty
ISI	Soviet International Space Inspectorate
ISON	International Scientific Optical Network
JSC	Johnson Space Center
LEO	Low Earth orbit
MoD	Ministry of Defense
NOTAM	Notice to Air Missions / Aviators
NTM	National technical means
OSINT	Open-source intelligence
SKKP	Sistema Kontrolya Kosmicheskogo Prostranstva)
SSA	Space situational awareness
START	Strategic Arms Reduction Treaty
STM	Space traffic management
TCBM	Transparency and confidence-building measures
UNIDIR	United Nations Institute for Disarmament Research
USSPACECOM	United States Space Command

KEY TAKEAWAYS

KEY TAKEAWAYS

- Outer space has become essential to humankind. Space technology enables critical infrastructure and services for billions of people on Earth. Space is also increasingly relevant for military functions, as space systems enable many military services. The military importance of space has prompted several States to develop counterspace capabilities in a manner that creates new forms of threats to space assets and infrastructure. As such, policy options to prohibit or prevent the weaponization of space assets through arms control and disarmament measures at the international level are increasingly important for space security. To facilitate this process, it is useful to understand the options available for monitoring and verifying any future space security obligations.

- There are various definitions of verification. For the purpose of this report, verification is defined as a process of collecting and assessing data with a view to informing judgements on a State's compliance with its treaty obligations. The primary goals of verification are threefold: to detect and deter potential violations of an agreement in a timely manner, thus providing all parties with assurances of compliance; to complicate non-compliance and increase the cost of treaty violations; and to foster mutual transparency and reciprocal confidence among States parties to an agreement.

- Collecting data through monitoring measures is an important component in the verification process. Data can be collected unilaterally, cooperatively or multilaterally and can help to inform judgements around compliance with an agreement. Notably, monitoring does not necessarily require States to accept specific legally binding obligations and can be accomplished through national or other technical means.

- There exist several different possible tools that could theoretically be used in support of verifying obligations related to space security and monitoring activities of States and other stakeholders. Some of these tools are relatively new, others have roots in past proposals or traditional arms control agreements. These components of the verification and monitoring toolbox are not necessarily mutually exclusive; multiple methods working in combination — the so-called 'layered approach'— are more likely to strengthen confidence in compliance with any present or future obligation, and observance of commitments.

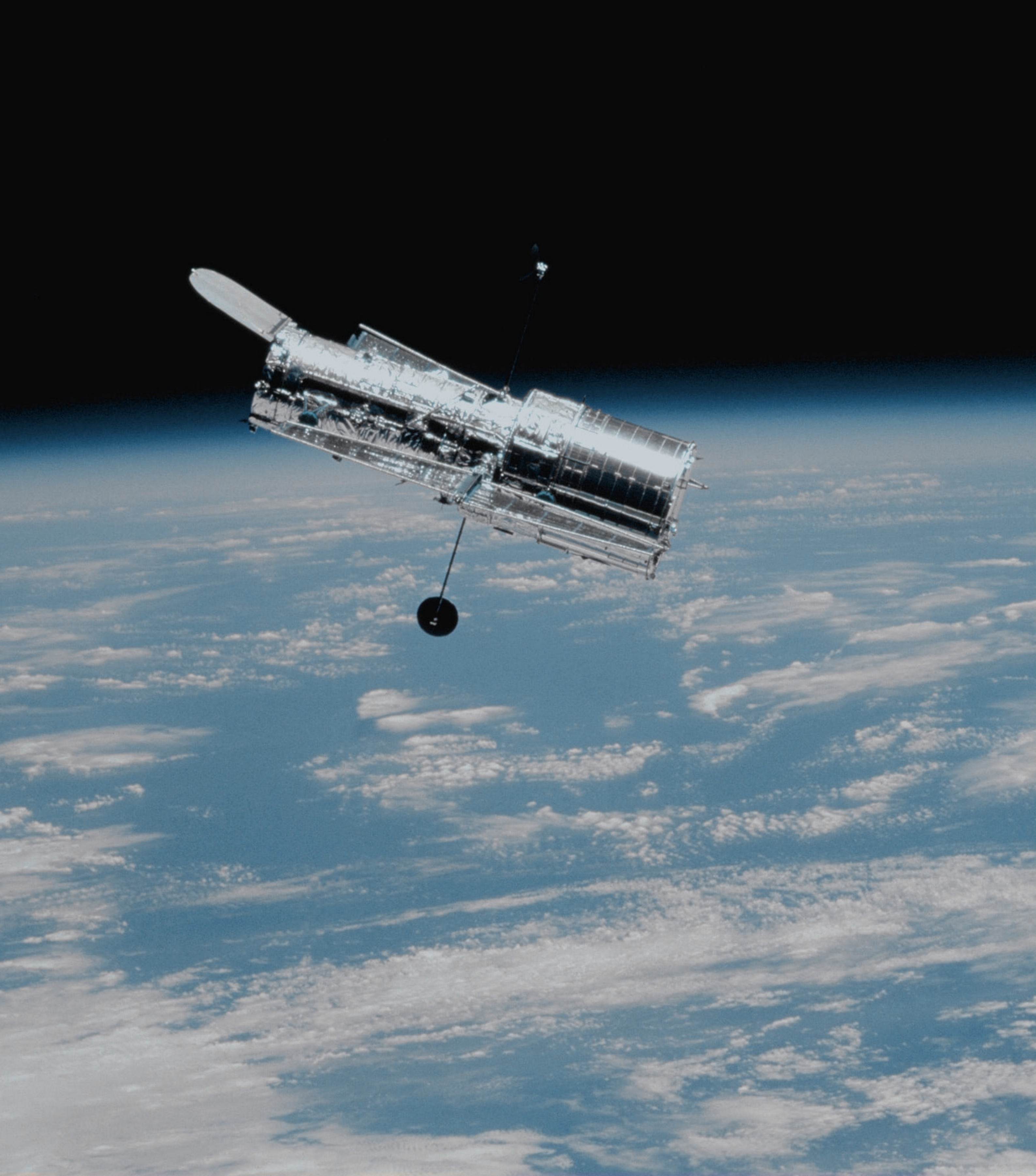
- For example, space situational awareness (SSA) increasingly enables the use of ground- and space-based sensors to track and characterize space objects, compare launch trajectories, and monitor possible radio frequency interference. Such tools could contribute to verification for present or future space measures. Although limitations in SSA remain, the growth in SSA data providers and the enhanced quality of the data itself could improve the verification potential of such tools in the future.

- Verification of space-related obligations is not however limited just to SSA-related technologies. More traditional arms control and disarmament tools, including data exchanges or declarations, the use of Earth observation satellites, or even on-site inspection, could be creatively employed to collect and collate indicators of a State's behaviour and build a better picture of an entity's space-related activities. These traditional approaches could be augmented by new forms of open-source data and methods.

- In addition, there are several indicators that could be derived from a cooperative verification process in which States actively demonstrate their national commitment to using space only for peaceful purposes. This can be achieved through unilateral or collective steps, including the enactment of domestic laws prohibiting the development or production of counterspace capabilities, fostering transparency in national space programmes, or high-level public denunciations of the weaponization of space.

- There is, however, no silver bullet solution for space verification. And the extent to which some potential obligations related to space security could be verified depends fundamentally on the degree of collaboration, the level of intrusiveness and scrutiny that States and stakeholders, particularly from industry, are willing to accept, and the financial costs.

INTRODUCTION



INTRODUCTION

Space technology is more important to humankind than ever before: it enables critical infrastructure and services for billions of people on Earth. Space technology also provides key military services to many States,[1] making outer space a domain of increasing military relevance.[2] In the face of space's ever-increasing importance to humankind, the ongoing development of counterspace capabilities by several States creates new forms of threats to space assets and infrastructure.[3] As such, policy options to reduce or prevent the weaponization of space through arms control, disarmament and wider governance are increasingly important to ensure the security and sustainability of space operations that underpin essential human activities on Earth. For any future measures to be effective, States need to have confidence that other participants comply with any agreed measures. In turn, this often requires a credible verification regime.

To inform policymaking in this area, it is useful to understand the options available for monitoring and verification in space. Of course, specific verification measures will depend on the detail of any treaty, agreement or commitment. States have differing views on what measures should be pursued in efforts to enhance space security, as well as identifying the optimal approach to verification, given the potential implications it has for the effectiveness of an agreement. Irrespective of these differences, some understanding of what is theoretically possible in terms of verification in space remains useful.

To explore the potential for verification for space security further, this report begins with an outline of what is meant by verification and monitoring in the context of legal and normative frameworks pertaining to outer space security. The report then proceeds to examine some of the tools and technologies of relevance to verification in space, drawing from recent technological developments, as well as measures applied in other issue areas that could help to build greater confidence in the actions of others in space. In the final section, the report looks at how these tools could be applied to verify and monitor present and future frameworks related to space security.

[1] "Military uses" of outer space should not necessarily be equated with "aggressive or hostile uses". While the latter goes against the principle of peaceful uses enshrined in the Outer Space Treaty, the former is often understood to fall within the umbrella of legality established by this same principle; Almudena Azcárate Ortega & Hellmut Lagos Koller, *The Open-Ended Working Group on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviours: The Journey so Far, and the Road Ahead*, 48 Air and Space Law Special Issue 19, 22 (2023); Shannon Orr, *Peace and Conflict in Outer Space*, 30 Peace Res. 52, 58 (1998); Bhupendra Jasani & Maria A. Lunderius, *Peaceful Uses of Outer Space-Legal Fiction and Military Reality*, 11 Sec. Dialogue 57, 58 (1980).

[2] It should be noted that the militarization of space is not new, as space has been militarized since the early days of space exploration; *see generally* Bleddyn E. Bowen, Original Sin—Power, Technology And War In Outer Space (2022).

[3] Jessica West & Almudena Azcárate Ortega, *Space Dossier 7—Norms for Outer Space: A Small Step or a Giant Leap for Policymaking?*, UNIDIR, 6 (Mar. 2022), https://doi.org/10.37559/WMD/22/Space/01.

DEFINING VERIFICATION AND MONITORING

DEFINING VERIFICATION AND MONITORING

VERIFICATION

Definitions of verification in the context of arms control and disarmament vary.[4] However, for the purposes of this report, verification is defined as a process of collecting and assessing data with a view to informing judgements on a State's compliance with its treaty obligations.[5]

The primary goal of verification in this sense is not necessarily to detect all violations of any agreement. Rather, the objective is to provide all parties with assurances of compliance, foster mutual transparency and confidence among States party to an agreement and to deter violations by increasing the cost and difficulty of non-compliant activities.[6] However, it is generally expected that an effective verification regime should be able to detect "significant" violations of an agreement[7] "before such activities threaten the core security objectives of the States concerned".[8]

The process of verification typically entails three phases: first, collecting data through monitoring the activities of the parties that are of relevance to an agreement; second, undertaking technical analysis of information derived from monitoring; and third, drawing from the first two steps to reach a judgement as to whether a party is complying with its obligations.[9]

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[4] Some see verification as "nothing but a set of technical measures agreed and implemented by the parties to actual non-proliferation, arms control and disarmament agreements" while others lay greater emphasis on the process suggesting verification is an "iterative and deliberative processes of gathering, analyzing, and assessing information to enable a determination of whether a State Party is in compliance with the provisions of an international treaty or agreement"; see respectively General Assembly, Final Report of the Group of Governmental Experts to Consider the Role of Verification in Advancing Nuclear Disarmament, A/74/90 (15 May 2019), https://undocs.org/en/A/74/90; and International Partnership for Nuclear Disarmament Verification, Working Group 1: Monitoring and Verification Objectives, Deliverable One: A Framework Document with Terms and Definitions, Principles, and Good Practices 14 (Nov. 2017).

[5] This definition has been developed through various sources, including the General Assembly, Final Report of the Group of Governmental Experts to Consider the Role of Verification in Advancing Nuclear Disarmament, A/74/90 (May 15, 2019) *above*; Steve Tulliu & Thomas Schmalberger, *Coming to Terms with Security: A Lexicon for Arms Control, Disarmament and Confidence-Building*, UNIDIR, 185 (3 Jan. 2004), https://unidir.org/publication/coming-terms-security-lexicon-arms-control-disarmament-and-confidence-building; Nuclear Threat Initiative, *Innovating Verification: New Tools & New Actors to Reduce Nuclear Risks*, 5 (July 2014), ; Amy F. Woolf, *Monitoring and Verification in Arms Control, Congressional Research Service* Report R41201 (7 Feb. 2011), https://www.everycrsreport.com/files/20110702_R41201_6c4994e147453fec715eac81ad1c3b8d375d7666.pdf.

[6] Roger G. Harrison, *Space and Verification*, Volume I: Policy Implications (Eisenhower Center for Space and Defense Studies, 2007), https://swfound.org/media/37101/space%20and%20verification%20vol%201%20-%20policy%20implications.pdf.

[7] Ola Dahlman, *Verification: To Detect, To Deter and To Build Confidence, in* 3 Disarmament Forum: Arms Control Verification 3 (Kerstin Vignard ed. July 2010); *See also* Woolf, *supra* note 5, who argues an effective treaty should "deter cheating, to make cheating more complicated and more expensive, or to make its detection more timely."

[8] *See* Dahlman, Ibid.

[9] General Assembly, Report of the Panel of Government Experts on Verification in All Its Aspects, Including the Role of the United Nations in the Field of Verification, A/61/1028 (2007), ¶ 9; *See also* Harrison, *supra* note 6.

MONITORING

Monitoring aims to build a picture of all relevant activities in a State[10] through collecting various forms of data pertaining to States' implementation of an agreement or conformity with guidelines.[11] This can be undertaken unilaterally, i.e. using national technical means (NTM) and other forms of intelligence; cooperatively through some form of agreement to enhance transparency; or multilaterally, something often achieved through the work of international organizations.

Notably in both cooperative and multilateral measures, tools for remote assessment could potentially be augmented through the use of past verification measures and new paradigms of analysis. In terms of the former, on-site activities have formed an important component of several past arms control or disarmament agreements.[12] Regarding the latter, monitoring in multilateral regimes increasingly benefits from reliable open-source tools which present new opportunities (and challenges) for building confidence in compliance.

Monitoring State activities can play a role beyond assisting in the verification process for legally binding agreements by fostering States' adherence to their commitments. Monitoring is therefore an instrument that serves to build confidence and deter violations or irresponsible conduct.

Monitoring data can also include compiling and collating information on a range of actions and activities undertaken by States and other stakeholders that could be suggestive of compliance (or non-compliance). The presence or absence of indicators —illustrative examples of which are laid out in table 1 below— are insufficient to reach a clear-cut judgement as to a State's compliance with any current or future obligations. However, collectively these indicators, which can be enhanced through transparency and confidence-building data and other tools, can help to construct a more detailed picture of a State's behaviour. In turn, this can help to better inform judgements around compliance with any obligation or standard of behaviour.

[10] Pavel Podvig (ed.), Exploring Options for Missile Verification, UNIDIR, 4 (2022), https://doi.org/10.37559/WMD/22/Misver/01.

[11] *See* Tulliu & Schmalberger, *supra* note 5; *See also* Woolf, *supra* note 5.

[12] Space activity monitoring can involve two types of inspections: on-orbit space assets (like satellites) which can be inspected cooperatively or noncooperatively, and the ground segment (including Control Centres) which can be visited either conspicuously or officially. Many States will no doubt be cautious of the idea of intrusive on-site inspections of space assets. However, on-site activity has been an important part of past arms control and disarmament related agreements, including the IAEA safeguards regime and the Chemical Weapons Convention; *See* Harrison, *supra* note 6.

POSSIBLE INDICATORS OF COMPLIANCE AND NON-COMPLIANCE

Possible indicators of compliance	Possible indicators of non-compliance
Comprehensive national licensing process for private operators, with clear requirements and outreach strategies	An absence of licensing procedures and opacity in the interaction between private operators and governments
National export or transfer control legislation and the means to enforce it	Clandestine procurement of dual-use equipment and materials
Domestic laws providing clear guidelines and imposing sanctions	Lack of legal framework and supervision of offensive operations targeting space infrastructure
Measures to enforce legislation	Reluctance to enact and enforce national legislation
Regulatory measures supporting or implementing an obligation	Unduly secretive military or civil space facilities
Transparency in national space programmes and security- and defence-related policies, consistent notification of all launches, transparent space-based defence exercises and simulations	Development, testing and use of counterspace technologies
Sustained measures to promote awareness of an obligation in the scientific and industrial communities	Persistent failure or unwillingness to provide information on space-related activities including launches
Public renunciation or denunciation of the weaponization of space, including high-level speeches and decisions	Rhetoric advocating the weaponization of space or national aspirations to exploit space as a domain for warfighting

Table 1. Possible indicators of compliance and non-compliance

A POLITICAL PROCESS

Regardless of form and function, verification is both a technical and political process. It can draw from objective data, but the determination of another States' compliance is a political judgement that considers multiple factors including, but not necessarily limited to, the results of monitoring and assessment processes.

A degree of political judgement is particularly important in regimes dealing with dual-use technologies, that is, technologies that can have military and security functions as well as civilian and commercial functions. Similarly, dual-purpose assets, which are designed to fulfil a benign objective (such as debris removal or on-orbit servicing), could potentially be repurposed to harm other space objects.[13] The use of these assets, which is increasingly common, blurs the conceptual boundaries of ‘weapons’ and makes control of some space assets through restrictions on hardware difficult. This also complicates efforts to verify space security-related obligations or monitor the observance of norms.

The politics of verification is compounded by two other factors. First, the technological equipment needed to conduct some forms of verification and monitoring is often costly and located in only a small number of select countries —due to either some form of geographical advantage, or to greater economic capacity. This situation is aggravated by the expensive customs fees placed by some States on such assets and limitations in the expertise necessary to collect and assess relevant sources of data. This means that, currently, only a small number of States have the capacity to meaningfully carry out their own space monitoring and verification processes. Moreover, interpretation and evaluation of data is a complex process that is vulnerable to subjectivity. Analysts may be prejudiced when reporting and measuring the data, and employing algorithms to avoid inherent human biases introduces “the risk of replicating and even amplifying human biases”.[14] Likewise, individuals programming the algorithms tracking space activities as well as the automatic analytical processes may unintentionally bias findings. There may also be limitations to data-sharing due to concerns about revealing information on space systems and their capabilities. NTM therefore have a dual-use: on the one hand they can be utilized for verification of compliance with agreements, but also for security and military monitoring, which can even include targeting functions. This may not only limit the willingness of parties to share data for collective verification but also may undermine the preparedness of other parties to accept and trust the data of competitors. Ideally, in such cases, corroboration of data among parties would increase confidence.

Second, some intrusive verification and monitoring methods can be perceived as costly to States and stakeholders. On-site inspections of nuclear facilities have been particularly contentious among stakeholders as it could reveal sensitive or proprietary details.[15] However, on-site inspections, and especially those that occur on short notice, have strong deterrent value. These types of inspections are established in space as well, as stated in article XII of the Outer Space Treaty.

[13] Almudena Azcárate Ortega, *Statement to the Open-Ended Working Group on ‘Reducing space threats through norms, rules and principles of responsible behaviours’ - Topic 3: Current and future space-to-space threats by States to space systems* (14 Sept. 2022), https://documents.unoda.org/wp-content/uploads/2022/09/Azcarate-Ortega-Almudena-OEWG-dual-use-presentation-FINAL.pdf.

[14] Nicol Turner Lee, Paul Resnick & Genie Barton, *Algorithmic Bias Detection and Mitigation: Best Practices and Policies to Reduce Consumer Harms*, Brookings Institution, (2019), https://www.brookings.edu/research/algorithmic-bias-detection-and-mitigation-best-practices-and-policies-to-reduce-consumer-harms/.

[15] George T. Baldwin, *A Systematic Approach for Implementing Managed Access at Sensitive Nuclear Facilities, in* Proceedings of the INMM 41st Annual Meeting, New Orleans, Louisiana, USA (2000).

THE IMPORTANCE OF CALIBRATION AND VALIDATION

The development of verification and monitoring capabilities can be a long and difficult process. For example, the use of sensing technologies requires certain material that needs to be designed, built, and later set up and calibrated precisely. The types of optics and radars used not only necessitate extensive research and development but also significant training of specialists able to manipulate the instruments and gather data for data analysts and experts. These instruments are the result of years of development for each tool and component.[16] Additionally, any sufficient monitoring network must have sensors located in various regions of the world, which requires agreements among States on the implementation of such strategic facilities and their impact on local populations. They also need individual, protected access and global secure networks to be interconnected.[17]

More challenging for any emerging verification regime will be the collective validation of technologies and methodologies by all parties to any agreement. In other regimes there remains a yawning gap between what is technologically possible and what is politically acceptable for verification purposes; bridging this gap requires a social process that builds confidence among parties that the methods and tools used for verification are "scientifically sound, validated, and robust for use".[18] The challenges faced in other regimes will also apply to any space-related initiative. However, successfully bridging the aforementioned gap between technological feasibility and political acceptability not only enables effective verification, but also contributes to confidence-building among the parties involved.

In this regard a balance must be struck between a robust and comprehensive verification and monitoring regime and one that is financially and political viable for States and other stakeholders to any agreement. Put otherwise, the benefits of participation in verification and monitoring regimes must exceed the costs.

[16] *See* Harrison, *supra* note 6, at 3.

[17] Alexandra Stickings, *The Future of EU–US Cooperation in Space Traffic Management and Space Situational Awareness*, Chatham House, 14 (August 2019), https://www.chathamhouse.org/sites/default/files/CHHJ7468-Cooperation-Space-Traffic-WEB-190816.pdf.

[18] James Revill, Alexander Ghionis & Laetitia Cesari Zarkan, *Exploring the Future of WMD Compliance and Enforcement: Workshop Report*, UNIDIR, (15 April 2020), https://www.unidir.org/publication/exploring-future-wmd-compliance-and-enforcement-workshop-report.

A VERIFICATION AND MONITORING TOOLBOX?

A VERIFICATION AND MONITORING TOOLBOX?

Several different tools exist that could be applied in support of verifying obligations related to space security and monitoring activities of States and other stakeholders. Some of these tools are relatively new. Other tools are rooted in Cold War arms control and disarmament processes or past space verification proposals.[19]

Notably, many of the components of the verification and monitoring toolbox are not necessarily mutually exclusive. On the contrary, multiple methods working in combination —the so-called "layered approach"— are likely to strengthen confidence in compliance with any obligation.[20]

This section provides an overview of the state of the art with regard to some key elements of the verification and monitoring toolbox.

SPACE SITUATIONAL AWARENESS

Space situational awareness (SSA) generally refers to "knowledge and characterization of space objects/activities and their environment, including space weather".[21] The concept of SSA emerged during the Cold War when the United States and the Soviet Union developed networks of radars and telescopes for the purposes of ballistic missile warning and tracking human objects in space.[22] The close connection between SSA and early warning capabilities lies in the fact that SSA serves as a central element of early warning systems in space. By accumulating data about space activities, SSA aids in the detection of probable hazards and risks, as well as the early warning of potential threats.

Since the Cold War, a growing array of tools and types of data have been combined to provide rich datasets on space objects. This includes, inter alia, the use of ground- and space-based sensors to track and characterize space objects and to compare launch trajectories "against all other orbital space objects to determine potential on-orbit conjunctions".[23] SSA can further help

[19] For example, the Canadian PAXSAT proposal called for the use of a small satellite constellation equipped with sensors to collect information and determine a satellite's function. *See* Ben Baseley-Walker & Brian Weeden, *Verification in Space: Theories, Realities and Possibilities, in* 3 Disarmament Forum: Arms Control Verification, 42 (Kerstin Vignard ed., July 2010). Another example is the Soviet proposal for an International Space Inspectorate, which sought to verify the non-deployment of weapons of any kind in outer space by carrying out on-site inspections prior to the launching of space objects. *See Soviet Asks Inspection of All Space Programs*, New York Times, 5 (1 April 1988), https://www.nytimes.com/1988/04/01/world/ soviet-asks-inspection-of-all-space-programs.html.

[20] Moriba Jah, "we want to aggregate as many different independent observations to confirm or refute a hypothesis", *in Panel VI – Verification Mechanisms: How Tech Can Aid in Ensuring Compliance with Space Security Regulations*, UNIDIR, *Verification, Technology, and Compliance with Regulations Outer Space Security Conference 2021*, YouTube (28 Sept. 2021), https://www.youtube.com/watch?v=hBUb8EsW7iw.

[21] Notably this differs from the interrelated concept of Space Traffic Management, which "focuses primarily on making decisions based on that information to improve safety of space operations". *See* Emily S. Nightingale et al., *Evaluating Options for Civil Space Situational Awareness (SSA)*, Institute for Defense Analyses, 11, 14 (2016), http://www.jstor.org/stable/resrep22883.5. *See also* Daniel Porras, *Eyes on the Sky – Rethinking Verification in Space*, UNIDIR (2019), https://doi.org/10.37559/WMD/19/Space01.

[22] Louis Leveque, *Space Situational Awareness and Recognized Picture, in* Handbook Of Space Security 699 (Kai-Uwe Schrogl, Peter L. Hays, Jana Robinson, Denis Moura & Christina Giannopapa eds., 2015), https://doi.org/10.1007/978-1-4614-2029-3_46.; *See also* Baseley-Walker and Weeden, *supra* note 19, at 39.

[23] *See* Nightingale et al., *supra* note 21, at 12.

in terms of "re-entry risk analysis", space weather warning and "Radio Frequency Interference Notifications", among other things.[24]

SSA can contribute to verification and monitoring processes through tracking the movement of some, but not all, space objects. SSA can also help to better understand how space assets use the electromagnetic spectrum and the effect their trajectory has on other assets, especially in Earth orbits. Indeed, SSA systems have already played a role in monitoring activities in space, including the detection of anti-satellite (ASAT) testing in near real time.[25] Moving forward, SSA could certainly play a valuable role in aspects of any space verification regime,[26] particularly as the number of actors collecting SSA-relevant data is growing and the technologies underpinning SSA have advanced considerably.[27] At present, SSA is mainly useful for detecting kinetic threats, as well as certain activities that may be of concern such as proximity operations. However, it has limitations in terms of supporting and employing technology to verify the usage and impact of more pervasive and low-threshold counterspace capabilities like cyber and electronic capabilities.

Data-collection entities

There is a growing number of entities collecting SSA-related data. The emergence of multiple actors using multiple sensors has the potential to raise confidence in SSA systems.[28] Some illustrative examples of entities involved in the collection of SSA data are outlined below in table 2.

[24] *Ibid*.

[25] For instance, the U.S. military learned of India's ASAT test almost instantly through its surveillance network. *See* Nivedita Raju, *A Proposal for a Ban on Destructive Anti-Satellite Testing: A Role for the European Union?*, EU Non-Proliferation and Disarmament Consortium – Non-Proliferation and Disarmament Papers No. 74 (April 2021), https://www.sipri.org/sites/default/files/2021-04/eunpdc_no_74.pdf.

[26] Benjamin Silverstein, *Prerequisites for Effective Space Governance: Space Situational Awareness*, Observer Research Foundation (13 Oct. 2021), https://www.orfonline.org/expert-speak/prerequisites.

[27] Porras, *supra* note 21; 18th Space Control Squadron & Combined Force Space Component Command, Spaceflight Safety Handbook for Satellite Operators: 18 SPCS Processes for On-Orbit Conjunction Assessment & Collision Avoidance (1.5th ed., August 2020), https://www.space-track.org/documents/Spaceflight_Safety_Handbook_for_Operators.pdf; U.S. Department of Defense, "Space Track," https://www.space-track.org/documentation#/faq.

[28] *See* James Revill & John Borrie eds., *Science and Technology for WMD Compliance Monitoring and Investigations*, UNIDIR (11 Dec. 2020). https://doi.org/10.37559/WMD/20/WMDCE11.

China

The Chinese Purple Mountain Observatory operates multiple telescopes and in 2015 established the Space Debris Monitoring and Application Center, to "track and deal with space debris".[29] Notably, China is developing more powerful telescopes in part "to monitor space debris to ensure the safety of spacecraft during future explorations".[30] Ground stations used by China have been installed within its territory[31] and in South America, particularly in Argentina, based on a contractual relationship between the States for the deployment of large antennas.[32]

The Asia–Pacific Ground-Based Space Object Observation System (APOSOS) Project was approved under the leadership of China in 2011, aiming to establish a linked space observation network using optical trackers for collision avoidance and early warning services for space assets. The initial focus is on objects in low Earth orbit (LEO) and both existing and new facilities in APOSOS member States will be used.[33]

European Union

The European Union (EU) is also investing in SSA activities through space surveillance and tracking (SST) of human-made objects, as part of the EU Space Programme.[34] In this context, since 2015, the European Union has been establishing, developing and operating "a network

[29] *Agency Set to Track, Deal with Space Junk*, Chinese Academy of Science (10 June 2015), https://english.cas.cn/newsroom/archive/news_archive/nu2015/201506/t20150610_148380.shtml.

[30] Jia Liu ed., *Powerful Survey Telescope Due to Be Built by 2022*, Chinese Academy of Science (22 April 2020), https://english.cas.cn/newsroom/cas_media/202004/t20200422_235101.shtml

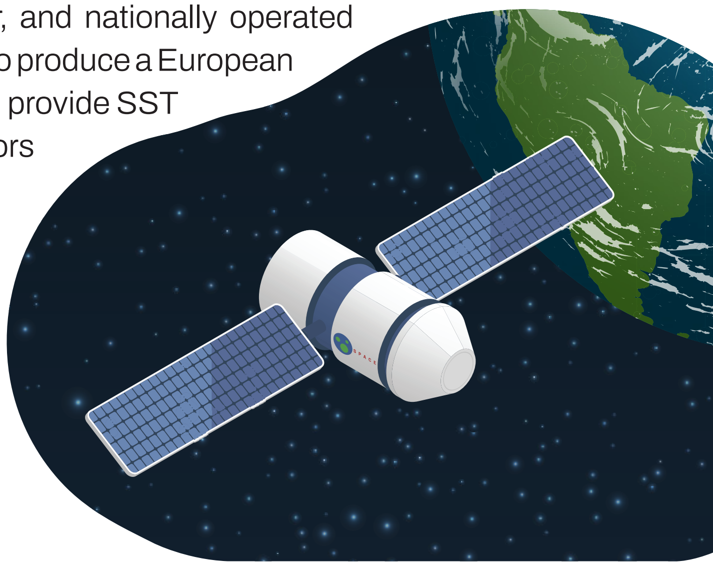
[31] Peter Wood, Alex Stone & Taylor A. Lee, China's Ground Segment Building the Pillars of a Great Space Power, China Aerospace Studies Institute 15 (1 March 2021), https://www.airuniversity.af.edu/CASI/Display/Article/2517757/chinas-ground-segment-building-the-pillars-of-a-great-space-power/.

[32] Cooperation agreement between the Government of the Argentine Republic and the Government of the People's Republic of China on the construction, establishment and operation of a Chinese deep space station in the province of Neuquén, Argentina, within the framework of the Chinese Moon exploration programme (*Acuerdo de cooperación entre el Gobierno de la República Argentina y el Gobierno de la República Popular China sobra la construcción, el establecimiento y la operación de una estación de espacio lejano de China en la provincia del Neuquén, Argentina, en el marco del programa Chino de exploración de la Luna*) (23 April 2014), http://servicios.infoleg.gob.ar/infolegInternet/anexos/240000-244999/243830/ley27123.pdf.

[33] *Ground-Based Space Object Observation Network*, Asia-Pacific Space Cooperation Organization (APSCO), http://www.apsco.int/html/comp1/content/GBSOON/2018-07-05/44-180-1.shtml.

[34] Regulation (EU) 2021/696 of the European Parliament and of the Council of 28 April 2021 establishing the Union Space Programme and the European Union Agency for the Space Programme and repealing Regulations (EU) No 912/2010, (EU) No 1285/2013 and (EU) No 377/2014 and Decision No 541/2014/EU [hereinafter "Regulation (EU) 2021/696"], https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32021R0696; *See also* Regina Peldszus & Pascal Faucher, *European Union Space Surveillance & Tracking (EU SST): State of Play and Perspectives*, 62 Space Policy, (Nov. 2022), https://doi.org/10.1016/j.spacepol.2022.101503.

of ground-based and space-based SST sensors of the Member States, including sensors developed through ESA or the Union private sector, and nationally operated Union sensors, to survey and track space objects and to produce a European catalogue of space objects".[35] EU member States can provide SST services if they own or have access to both SST sensors and human resources to operate them. SST partners share data through a single database, which serves as the foundation for the catalogue and computation of services, such as collision avoidance warning.[36] This initiative is currently carried out by a partnership composed of 15 EU member States represented through their national designated entities.[37]



France

The French Directorate General of Armaments invested in the Space Surveillance System (GRAVES, Grand Réseau Adapté à la Veille Spatiale) of the National Office for Aerospace Studies and Research, which is a fixed radar system that aims to observe moving targets in low Earth orbit. [38]

Russian Federation

The Russian Federation's Space Surveillance System includes the development of the International Scientific Optical Network (ISON) of "more than 50 telescopes located in 17 countries, primarily for GEO [geostationary orbit] observations".[39] The surveillance system is in the process of being augmented and modernized. The military Space Control System (SKKP, Sistema Kontrolya Kosmicheskogo Prostranstva) is a network of ground-based sensors and radars that provide tracking and surveillance of space objects, operated by the Russian Space

[35] Regulation (EU) 2021/696, *Ibid*.

[36] *Frequently asked questions*, EUSST, https://www.eusst.eu/about-us/faq/.

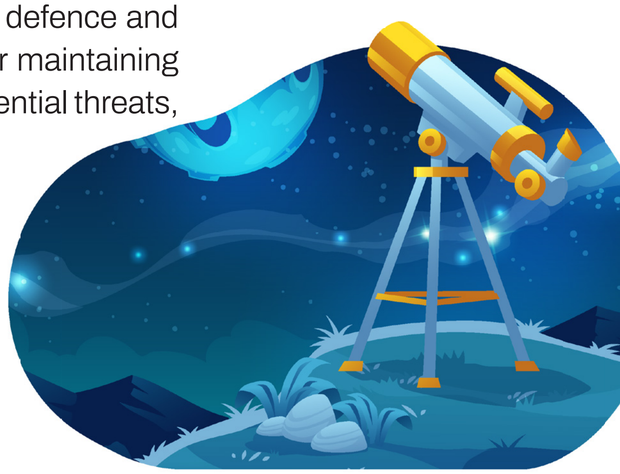
[37] The Space Situational Awareness component of the EU Space Programme consists of Austria, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Latvia, the Netherlands, Poland, Portugal, Romania, Spain, and Sweden. *About Us*, EUSST, https://www.eusst.eu/about-us/; Regulation (EU) 2021/696, *supra* note 34.

[38] *GRAVES, the 1st European Space Surveillance System*, ONERA, (17 June 2019), https://www.onera.fr/en/news/graves-the-1st-european-space-surveillance-system.

[39] Porras, *supra* note 21.

Forces, a branch of the Russian military responsible for the defence and protection of Russia's space assets. The system is used for maintaining situational awareness in space, detecting and identifying potential threats, and enabling rapid response to any emerging challenges.[40]

The Russian Federation is developing a space surveillance network, dubbed "Milky Way" with the objective of monitoring space debris in LEO, particularly small-sized debris, including objects smaller than 10 cm.[41]



United States

The United States has an advanced space surveillance network consisting of "different types of sensors, both ground- and space-based".[42] This State-run system, operated by the U.S. Department of Defense (DoD) tracks more than 23,000 objects larger than 10 cm in diameter.[43] DoD publishes a catalogue of space objects and makes notifications of potential conjunctions. Since 2018, the Department of Commerce was given responsibility for the publicly releasable portion of the DoD catalogue and for administering an open architecture data repository. [44]

Table 2. Illustrative examples of national SSA data-collection entities

In addition to State-operated SSA-related systems, there are several private entities working on SSA and building networks of radars and sensors for monitoring and tracking in multiple orbits —most notably low Earth orbit and geostationary orbit.[45] These networks can be used

[40] I.A. Fadin, S.V. Yanov & O.A. Samokhvalov, *Methods of Validation of the Ballistic Structure of Space Surveillance System Orbital Segment*, translated from Russian, 18 no. 3 Aerospace and Mechanical Engineering 155 (2019), https://journals.ssau.ru/vestnik/article/view/7466/7303; *Russian Space Surveillance System Chief Designer Goryuchkin: Space Debris to Become Critical Problem in Next 10 Years*, Interfax.com, (3 Nov. 2021), https://interfax.com/newsroom/exclusive-interviews/73048/.

[41] *Russia to Launch First Satellite to Monitor Space Junk in 2027*, TASS (28 May 2020), https://tass.com/science/1161437.

[42] Brian Weeden, *Space Situational Awareness Fact Sheet*, Secure World Foundation, 1 (2017), https://swfound.org/media/205874/swf_ssa_fact_sheet.pdf.

[43] Porras, *supra* note 21.

[44] Space Policy Directive-3, National Space Traffic Management Policy (18 June 2018) https://trumpwhitehouse.archives.gov/presidential-actions/space-policy-directive-3-national-space-traffic-management-policy/

[45] Regina Peldszus in *Panel VI – Verification Mechanisms: How Tech Can Aid in Ensuring Compliance with Space Security Regulations, UNIDIR, Verification, Technology, and Compliance with Regulations Outer Space Security Conference 2021*, YouTube (28 Sept. 2021), https://www.youtube.com/watch?v=hBUb8EsW7iw; Dan Ceperley & Doug Hendrix in *Seeing Space Security: The Role of Space Situational Awareness for Verification of Future Space Arms control*, UNIDIR & Secure World Foundation, *Seeing Space Security: The Role of SSA for Verification of Future Space Arms Control* (10 Nov. 2020), https://unidir.org/events/space-security-awareness-and-verification.

to track newly launched satellites, monitor conjunctions at different speeds and altitudes, and determine what new objects are created in space as a result of conjunctions.[46] These surveillance networks are augmented by a big data pipeline capable of processing data in real time, and these companies offer their services to different governments, satellite operators and commercial companies to enable them to make informed decisions in space.[47]

Some in the international community have highlighted the benefits that SSA data-sharing could have for the purposes of monitoring, and there are certain groups of satellite operators that have formed associations to foster information-exchange and mutual understanding. These organizations share data among participating satellite operators, which is combined with open-source data to provide timely and accurate collision warnings to community members.[48] Some commercial satellite operators share their data broadly, outside of any association or industry groups.[49] The existence of multiple actors collecting relevant data contributes to demystifying the space environment and making space activities more transparent and more accessible.

These new tools and technologies are not designed for verification and monitoring as such. Yet they can aid the process of verifying certain types of space activities related to space security. And through such systems, greater confidence in compliance with certain obligations could be achieved. For example, SSA data could theoretically help to verify a prohibition on anti-satellite tests —particularly those that are kinetic and destructive in nature. Behaviours relating to the use of on-orbit servicing vehicles —to prevent their repurposing into objects to harm other space assets— can also be monitored using existing SSA technology.[50] The utility of these systems could be further enhanced with improvements in computational power and potentially augmented by new techniques.[51]

Current limitations and requirements

While there are more actors and more information available than ever before, there are nonetheless limits to the value of SSA as a standalone measure for monitoring activities in space, yet alone verification. Politically, States and commercial operators may be reticent to share their data freely. The collection and sharing of data in the examples above are done on a voluntary basis. In other cases, commercial entities can be hesitant to share business-related information that might reduce a competitive advantage. Similarly, States may be disinclined to share information that could potentially impact their national security.

[46] Ceperley & Hendrix, *ibid*.

[47] *See* Porras, *supra* note 21.

[48] Mark Dickinson, *A Space Data Association Focus: The Current State of Space Situational Awareness (SSA)*, SatMagazine, (January 2019), http://www.satmagazine.com/story.php?number=1895054050; *Space Briefing Book: Space Situational Awareness*, Space Foundation (2019), https://www.spacefoundation.org/space_brief/space-situational-awareness/#:~:text=There%20are%20tens%20of%20thousands,be%20at%20any%20given%20time.

[49] An example of this is Planet. *See* https://ephemerides.planet-labs.com.

[50] *See* Porras, *supra* note 21.

[51] Bhavya Lal, Asha Balakrishnan, Becaja M. Caldwell, Reina S. Buenconsejo & Sara A. Carioscia, *Global Trends in Space Situational Awareness (SSA) and Space Traffic Management (STM)*, Institute for Defense Analyses (2018), https://www.ida.org/-/media/feature/publications/g/gl/global-trends-in-space-situational-awareness-ssa-and-space-traffic-management-stm/d-9074.ashx.

There are also several technical challenges. First, current SSA practices "cannot maintain continuous supervision of all orbiting objects".[52] Micro-satellites and other small space assets are extremely difficult to monitor. Moreover, with the recent deployment of large satellite constellations, monitoring individual space objects' exact altitude, trajectory and function has become significantly more challenging and complex as the focus shifts from a single system to a system of systems, composed of a multitude of assets.

Secondly, continuously monitoring all space activities from a State's territory is fraught with challenges, which necessitates cooperation with other actors. Some State systems may have limited mandates which can hamper the characterization of space objects, however, private entities are forging ahead with new technologies for more precise monitoring.[53] Even with the advances of private industry, some States still have very limited or non-existent capacity to undertake any form of verification. This creates inconsistencies in access to verification-related technologies that can impinge upon confidence in monitoring or verification of data.

Third, many sources of data could potentially be spoofed. And even when accurate, interpretation of SSA data can prove challenging.[54] Different collectors of SSA data apply different methods (which are often "black boxed") and sometimes result in different data outputs.[55] This means that SSA data from different providers will not necessarily be interoperable or consistent as there is no single incontrovertible source of data on the location of space objects. Such discrepancies in SSA data can undermine efforts to monitor space activities and build confidence in compliance with any future obligations and feed into differences in political judgements about another's compliance with any obligation.

As such, the use of SSA in any verification initiative will require a frank assessment of the technological limits as well as technical cooperation to develop shared standards, validated methods, and to work towards interoperable SSA datasets. This entails a sustained technical dialogue between States and those collecting SSA data to ensure data is accurate and consistent.[56]

The use of SSA data in verification is therefore challenging and complex. These challenges however are not insurmountable, with the necessary political will. Experiences with other complex verification regimes suggest that complex global cooperation is technically possible.

[52] Silverstein, *supra* note 26.

[53] Regina Peldszus in Seeing Space Security: The Role of Space Situational Awareness for Verification of Future Space Arms Control, UNIDIR & Secure World Foundation, (10 Nov. 2020), https://unidir.org/events/space-security-awareness-and-verification.

[54] Jah, *supra* note 20.

[55] As a representative of the Russian Federation remarked during the first substantive session of the OEWG, "systems to track activities in space do not collect data in a uniform and inter-compatible manner". In line with this, the representative highlighted that "since there are these different systems, it gives rise to the issue of ensuring that the data are comprehensive first of all. Secondly, that they are reliable. Third, that they are applicable and that they are timely as well". 9th Meeting, 1st Session Open-ended Working Group on Reducing Space Threats Through Norms, Rules and Principles of Responsible Behaviours, UN Web TV, 49:40 (13 May 2022), https://media.un.org/en/asset/k1n/k1ns2jxdj6; *See also* Lal et al., *supra* note 51.

[56] Curtis Hernandez in Panel VI – Verification Mechanisms: How Tech Can Aid in Ensuring Compliance with Space Security Regulations, UNIDIR, Verification, Technology, and Compliance with Regulations Outer Space Security Conference 2021, YouTube (28 Sept. 2021), https://www.youtube.com/watch?v=hBUb8EsW7iw; *See also* Silverstein, *supra* note 26.

Moreover, a cooperative SSA framework for verification and monitoring has been proposed by several members of the international community and is seen as a measure that could have a positive impact in enhancing and ensuring space security.[57]

DATA EXCHANGE (INCLUDING TCBMS)

Important as SSA is, verification and monitoring of space-related obligations can also be augmented through other means that could theoretically be applied in support of space verification, including data exchanges or other forms of reporting provided by States party to an agreement.[58]

In several past arms control and disarmament arrangements, exchanges of data on location, number, characteristics and status of treaty-limited equipment, and the schedule and details of restricted activities,[59] have served as important components of cooperative monitoring regimes.[60] For example, under the New START agreement, the United States and Russian Federation shared telemetric information about the numbers and locations of their strategic forces as a means to augment NTMs.[61]

To some extent, data-exchange is already happening on space issues. States Parties of the Convention on Registration of Objects Launched into Outer Space[62] are obliged to maintain national registries[63] and also to provide the Secretary-General with information on their space objects[64] for inclusion on the United Nations Register.[65] Not all States adhere to this obligation for all their space objects.[66] Nonetheless information included in the UN Register could aid

[57] Report of the Secretary-General A/76/77, on reducing space threats through norms, rules and principles of responsible behaviours, ¶ 18(g) (13 July 2021), [hereinafter "Report of the Secretary-General A/76/77"], https://undocs.org/en/A/76/77.

[58] *See* Tulliu & Schmalberger, *supra* note 5.

[59] Amy F. Woolf, The New START Treaty: Central Limits and Key Provisions, Congressional Research Service Report R41219, 4 (2 Feb. 2022), https://crsreports.congress.gov/product/pdf/R/R41219.

[60] For example, START included an "extensive data exchange detailing the numbers and locations of affected weapons"; see Woolf, *supra* note 5; Moreover, States Parties to the Chemical Weapons Convention are obliged to amongst other things "declare all relevant military and civilian facilities"; Organization for the Prohibition of Chemical Weapons, Determining Declarable Industrial Facilities, Guidelines for National Authorities, https://www.opcw.org/resources/declarations/determining-declarable-industrial-facilities.

[61] Art. IX New START (Treaty between the United States of America and the Russian Federation on Measures for the Further Reduction and Limitation of Strategic Offensive Arms, entered into force Feb. 5, 2011). In practice, the United States and the Russian Federation have proceeded to such an information exchange only once each year. However, it provided some reciprocal transparency into the capacities of their mutual systems. See Fact Sheet, U.S. State Department, Bureau of Verification, Compliance and Implementation, Telemetry (8 April 2010), https://2009-2017.state.gov/t/avc/rls/139904.htm.

[62] Convention on Registration of Objects Launched into Outer Space, Jan. 14, 1975, 1023 UNTS 15 [hereinafter "Registration Convention"].

[63] Art. II.1 Registration Convention: "When a space object is launched into Earth orbit or beyond, the launching State shall register the space object by means of an entry in an appropriate registry which it shall maintain. Each launching State shall inform the Secretary- General of the United Nations of the establishment of such a registry". Art. II.3 Registration Convention: "The contents of each registry and the conditions under which it is maintained shall be determined by the State of registry concerned".

[64] Art. IV.1 Registration Convention: "1. Each State of registry shall furnish to the Secretary-General of the United Nations, as soon as practicable, the following information concerning each space object carried on its registry: Name of launching State or States; An appropriate designator of the space object or its registration number; Date and territory or location of launch; Basic orbital parameters, including: Nodal period; Inclination; Apogee; Perigee; General function of the space object".

[65] *United Nations Register of Objects Launched into Outer Space*, United Nations Office for Outer Space Affairs, https://www.unoosa.org/oosa/en/spaceobjectregister/index.html.

[66] *Ibid*.: To date, over 85 per cent of all satellites, probes, landers, crewed spacecraft and space station flight elements launched into Earth orbit or beyond have been registered with the Secretary-General.

verification and monitoring efforts as it allows space actors to use sensors and capabilities to determine whether or not a space asset is being used for purposes consistent with those stated in the Register.[67] Even though the Registration Convention only requires very minimal disclosure of information, States are free to be as detailed as they want. The more specific the disclosure of a satellite's function is, the more effective verification potentially could be.

It is also notable that proposals have been put forward —by both States and experts in the field of space security— to catalogue space objects in a manner that provides more detailed information than that found in the UN Register. For example, resolution 62/101 on "Recommendations on enhancing the practice of States and international intergovernmental organizations in registering space objects"[68] encouraged States to provide "any useful information relating to the function of the space object in addition to the general function requested by the Registration Convention". Additionally, the resolution recommended that States provide information on the geostationary orbit location, changes of status in operations, approximate date of decay or re-entry, and the date and physical conditions of moving a space object to a disposal orbit. The recommendations of this resolution have been echoed by some States in several other forums and documents.[69]

Some experts have also proposed the submission of additional information on matters such as "physical properties (e.g. shape, mass, material composition, orientation, surface properties) or data about its mission (e.g. orbital trajectory, operational radio frequencies, anticipated lifespan)",[70] which could help to build a shared understanding of space assets. This information could be stored in a repository as a unique profile, and when an object is detected, measurements are taken and linked to the profile.[71]

As is the case with the proposal of increasing the information to be submitted to the UN Register established under the Registration Convention, the proposal of having a repository of data has also been undertaken by States or State-run organizations,[72] as well as by non-State

[67] Gilles Doucet, *A Proposed Transparency Measure as a Step Toward Space Arms Control*, *in* War And Peace In Outer Space: Law, Policy, And Ethics 247 (Cassandra Steer & Matthew Hersch eds., 2020).

[68] General Assembly resolution 62/101, Recommendations on Enhancing the Practice of States and International Intergovernmental Organizations in Registering Space Objects, A/RES/62/101 (10 Jan. 2008), https://digitallibrary.un.org/record/614200.

[69] *See for example* Group of Governmental Experts on transparency and confidence-building measures in outer space activities, General Assembly, Seventy-eighth session, General and Complete Disarmament: Transparency and Confidence-building Measures in Outer Space Activities, Item 99 (c), A/68/189 (29 July 2013), https://digitallibrary.un.org/record/755155?ln=en; *See also* Report of the Secretary-General A/76/77, *supra* note 57.

[70] Porras, *supra* note 21. Each of these spacecraft, as well as its technical and performance description relevant to ascertaining potential ASAT capability, should be submitted to the Secretary-General for inclusion in the United Nations Register, *see also* Brian G. Chow, *Space Arms Control: A Hybrid Approach*, 12 no. 2 Strategic Studies Quarterly 107 (2018), http://www.jstor.org/stable/26430818.

[71] *Ibid*.

[72] In 2000, the idea of creating a space object catalogue was proposed by the Space Council of the Russian Academy of Sciences (RAS). See V.M. Agapov, *Space Objects Data Catalogue*, 3rd European Conference on Space Debris, (March 2001), https://conference.sdo.esoc.esa.int/proceedings/sdc3/paper/19/SDC3-paper19.pdf. ESA's Space Debris Office also carries out tracking of objects in space with the help of the data provided by the Database and Information System for the Characterization of Objects in Space (DISCOS), which maintains reference information for launches, launch vehicles, and spacecraft. This data includes physical attributes, mission objectives, and object registration details. Orbital data history, fragmentations, and re-entry events are stored for all trackable objects, of which there are more than 40,000 entries. *See* Frazer Mclean, *DISCOS 3: An Improved Data Model for ESA's Database and Information System Characterising Objects in Space*, 7th European Conference on Space Debris (2017). *See also* Harrison, *supra* note 6.

actors and experts.[73] However, States are not always keen to disclose more information than they have to, as there are national security concerns attached to the sharing and disclosing of certain information, such as details on the components of space objects, descriptions of all their payloads, system configurations and manoeuvres over time.[74]

Nonetheless, with sufficient appetite, further data-exchange in the space realm could provide a useful tool for building a baseline of knowledge around activities and facilities of relevance to specific obligations. Such data could then be scrutinized to determine, for example, the consistency of a space asset with its specific purpose or the extent to which a facility appears to be operating in accordance with its declared purposes.[75]

Ongoing data exchanges and notifications

There could also be considerable value to verification, as well as safety and security in space from ongoing exchanges of information.[76] Currently, when certain trajectories are unknown or unexpected changes occur, operators communicate through notifications or direct email exchange on a voluntary basis.[77] However, because of the absence of a coherent framework to proceed with such communications and to provide some form of early warning mechanism, stakeholders can overlook such communications. This can have significant consequences — for example, missed communications nearly resulted in a collision between ESA's Aeolus and SpaceX's Starlink 44 in 2019.[78]

Sustained monitoring of a space object, to assess the extent to which it appears to fulfil its intended function, can also be achieved through the use of radio telemetry. Telemetry allows operators to monitor the activity and performance of their satellites through a series of sensors and monitors built into satellites. The data from these sensors is then compiled and transmitted back to operators.[79] The use of telemetry for the purposes of treaty verification is not a new concept. As noted above, telemetric data exchanges on particular intercontinental and submarine-launched ballistic missiles were already carried out under New START.[80]

[73] Jonathan McDowell's Object Catalogues, https://planet4589.org/space/gcat/web/cat/cats.html; the Astronomical Institute of the University of Bern conducts search campaigns for space debris in GEO. See Reto Musci, Thomas Schildknecht, Tim Flohrer & Gerhard Beutler, *Concept for a Catalogue of Space Debris in GEO*, 4th European Conference on Space Debris, (April 2005).

[74] Bhavya Lal, *Evaluating Options for Civil Space Situational Awareness (SSA)*, presented at the Advanced Maui Optical and Space Surveillance Technologies Conference (AMOS) (2017).

[75] *See* Dahlman, *supra* note 7.

[76] Proposals for information exchange already exist. A few examples include The Hague Code of Conduct against Ballistic Missile Proliferation, https://www.hcoc.at/what-is-hcoc/text-of-the-hcoc.html; Group of Governmental Experts on Transparency and Confidence-Building Measures in Outer Space Activities, U.N. GAOR, 68th Sess. U.N. Doc A/68/189* ¶¶ 36–45 (29 Jul. 2013), https://digitallibrary.un.org/record/755155; Russian-Chinese notification agreement on ballistic missiles and space launch vehicles, *see China, Russia Extend Notification Agreement for Ballistic Missile, Carrier Rocket Launches*, Xinhua (15 Dec. 2020), www.xinhuanet.com/english/2020-12/15/c_139591997.htm.

[77] Alex Cacioni, *Risk of Collision: An Operator Perspective*, paper presented at the SpaceOps Conferences, (2018).

[78] *Predicted Near Miss between Aeolus and Starlink 44, European Space Agency*, (3 Sept. 2019), https://www.esa.int/ESA_Multimedia/Images/2019/09/Predicted_near_miss_between_Aeolus_and_Starlink_44.

[79] Doucet, *supra* note 67.

[80] Protocol on Telemetric Information Relating to the Treaty Between the United States of America and the Union of Soviet Socialist Republics on the Reduction and Limitation of Strategic Offensive Arms, December 30, 1991; Richard L. Bernard, *Telemetry Intelligence (TELINT) During the Cold War*, National Security Agency, Center for Cryptologic History, 9 (2016).

Limits of data-exchange

Of course, there are limits to data exchanges. Some declared information may be difficult to verify independently, and any information exchanged may be either unwittingly or unscrupulously subject to gaps or omissions. Moreover, in some cases operators may be unwilling to share certain details such as number of payloads, transponders, backup systems, antennas, etc. Furthermore, information on physical properties of dual-use and dual-purpose space assets provides only a limited degree of confidence in the function or intended use of any asset in the fast-moving context of space security. And States are unlikely to gain confidence in the actions of another based on assumptions around specific types of space objects.[81] This is particularly notable in the case of dual-purpose space objects, as they could potentially be repurposed for counterspace applications.

Yet for all its limitations, data exchanges could still contribute, in combination with other measures, to verification and monitoring in space as well as fulfilling a wider need for greater communication between States and stakeholders on their operations in outer space.

REMOTE MONITORING

Verification and monitoring for the purposes of space security require supervision of all components of space systems, not just those located in orbit.[82] Moreover, counterspace capabilities able to target assets in outer space would be launched from Earth, thus making it important to monitor activities on Earth.[83] Fortunately, in addition to tracking activities in space, satellite technology has also been used extensively for monitoring activities on Earth, including activities of great importance to the verification of arms control and disarmament agreements.[84]

Such remote sensing technology has existed for several decades. Although in the past this technology was accessible only to those States that could afford it, currently there are hundreds of commercial satellites designed for the purpose of Earth observation with data offered at competitive rates.[85] With more entities involved in Earth observation, "no single State has a monopoly on the data"[86] and past limitations on access to Earth observation data in certain areas are also partially ameliorated.[87] Moreover, the evolution of technology means that more

[81] Frank R. Cleminson & Pericles Gasparini Alves, *Chapter 7 Space Weapons Verification: A Brief Appraisal, in* Verification of Disarmament or Limitation of Armaments: Instruments, Negotiations, Proposals 177 (Serge Sur ed., UNIDIR, 1992).

[82] Open-ended Working Group on Reducing Space Threats through Norms, Rules and Principles of Responsible Behaviours, Threats to the Security of Space Activities and Systems, UNIDIR (12 Sep. 2022), UN Doc A/AC.294/2022/WP.16 [hereinafter "Threats Working Paper"], *https://documents.unoda.org/wp-content/uploads/2022/08/20220817_A_AC294_2022_WP16_E_UNIDIR.pdf*.

[83] *Ibid*.

[84] For example, commercial satellite data has been used to identify possible uranium enrichment sites; whereas emerging satellite capabilities using multispectral bands have been applied to reveal camouflage or signatures of nuclear facility activity, *supra* note 28

[85] *UCS Satellite Database*, Union of Concerned Scientists, https://www.ucsusa.org/resources/satellite-database.

[86] Revill & Borrie, *supra* note 28.

[87] Treaty on Principles Governing the Activities of States in the Exploration and Use of Outer Space, including the Moon and Other Celestial Bodies. (1967), 27 January 1967, 18 UST 2410; 610 UNTS 205; 6 ILM 386 [hereinafter "Outer Space Treaty" or "OST"].; The OST forbids the national appropriation of outer space "by claim of sovereignty, by means of use or occupation, or by any other means". Furthermore, the OST allows and encourages the exploration and use of outer space, "for the benefit and in the interests of all countries, irrespective of their degree of economic or scientific development, and shall be the province of all mankind". It also prohibits discriminatory restrictions on the freedom of exploration and use of outer space. *See* arts. I and II OST.

images of the Earth are taken today than ever before, and such images are of a higher quality than in the past.[88]

Data from Earth observation satellites has been and will be valuable in monitoring activities related to the use of space systems and would be important in informing assessments of compliance with any future treaty obligations. In particular, such data can be useful in monitoring the use of ground stations. Space activities —from launching, to telemetry, tracking and command, manoeuvring on-orbit operations, and re-entry— are inextricably linked to launch platforms, satellite operation centres, and production storage facilities on Earth. The monitoring of such ground-based infrastructure through remote sensing, including newer forms of multispectral remote sensing capable of revealing camouflage or particular activities, is therefore important for the purposes of space security verification.

Limits of Remote Sensing

Remote sensing tools, specifically enabled by satellite data, can provide an image of activities on the ground. However, interpreting that data will depend on the development of methodologies, the availability of adequate, credible data and expertise, and sometimes on the weather conditions, particularly cloud coverage.[89] It will also require resources and international cooperation to mobilize networks of telescopes, sensors and computing capabilities. Remote sensing may also generate concern among States and private sector actors in relation to the preservation of confidential information. Technical advancements in space operations may also affect the value of remote sensing for monitoring and verifying space security agreements. For instance, as in-space manufacturing matures into a viable industry, analyses of Earth observation data may have to contend with indeterminate findings because the sites and activities of interest have moved off the Earth's surface and into space.

ON-SITE ACTIVITIES

Like remote monitoring, on-site activities would focus on verification and monitoring of activities on Earth. Several earlier arms control and disarmament agreements include provisions for on-site activities. For example, in the Chemical Weapons Convention,[90] many hundreds of on-site inspections have been conducted since entry into force. On-site inspections take various forms but are typically undertaken by designated inspectors who can establish the facts regarding a particular facility (and corroborate data generated through declarations). However, there are stringent rules applied to on-site activities.[91]

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[88] Melissa Hanham & Jeffrey Lewis, *Remote Sensing Analysis for Arms Control and Disarmament Verification*, Federation for American Scientists (15 Sept. 2017), https://fas.org/wp-content/uploads/media/Remote-Sensing-Analysis-for-Arms-Control-and-Disarmament-Verification.pdf. *See also* Todd Harrison & Matthew Strohmeyer, *Commercial Space Remote Sensing and Its Role in National Security*, CSIS (2 Feb. 2022).

[89] Igor Moric, *Capabilities of Commercial Satellite Earth Observation Systems and Applications for Nuclear Verification and Monitoring*, 30 Science & Global Security, 22 (January 2022), https://doi.org/10.1080/08929882.2022.2063334.

[90] Convention on the Prohibition of the Development, Production, Stockpiling and Use of Chemical Weapons and on Their Destruction, 13 Jan. 1993, 1974 UNTS 45; 32 ILM 800 (1993); *See also* Dahlman, *supra* note 7.

[91] As is the case with the U.S.-Soviet experience in INF and START, "inspectors did not actually have the ability to wander around a declared site and search for prohibited items or activities." *See* Amy F. Woolf, *Chapter 2: Monitoring Mobile Missiles: Lessons from US–Soviet Arms Control, in* Exploring Options for Missile Verification 21 (Pavel Podvig ed., UNIDIR, 2022), https://doi.org/10.37559/WMD/22/Misver/01.

Some past space security-related proposals have also included provisions for on-site inspection. For instance, the Soviet International Space Inspectorate (ISI) proposal included a provision for a form of on-site inspection. And the Outer Space Treaty provides a route to one form of on-site inspection, albeit not on Earth[92] but "on the Moon and other celestial bodies [which] shall be open to representatives of other States Parties to the Treaty on a basis of reciprocity".[93]

Such verification tools could be useful to consider as part of any more ambitious regime and there is a range of on-site activities that could be considered. For example, inspections of facilities could be employed to determine whether a payload carries nuclear weapons, or to verify the absence of infrastructure associated with military space programmes or counterspace technologies.[94] Interviews with facility personnel as part of an on-site inspection regime could help to establish relevant facts related to a programme[95] or short notice inspections could be agreed to investigate claims of storage of any counterspace systems prohibited under any future agreement.

Similarly, inspection of launch vehicles on site could allow inspectors to assess their size and develop estimates as to payload capacity or whether they would be able to separate in orbit. Following the example set by the now defunct Intermediate-Range Nuclear Forces Treaty (INF) regime, "inspectors could measure and visually inspect the outside of the vehicle and use sensors to collect an image of the items inside the vehicle".[96] To facilitate inspection processes, methods to differentiate space launch vehicles though specific markings could be applied, drawing on practices successfully employed in the START Treaty.[97] Such a step could provide an increased understanding of the activities for which such vehicles and payloads are intended, making verification and monitoring a simpler task once the objects reach their orbital destinations.

One more ambitious step could include the inspection of spacecraft, their integration and test, and actual monitoring of launch during both pre-launch and on-launch stages. This step could empower inspectors to monitor the life cycle of a space asset, from in/near-factory, to the launch site, to in-orbit operations.[98]

Limits of on-site activities

On-site activities are the most intrusive component of verification and monitoring regimes. As such, the prospect of on-site activities would likely create considerable concern among owners

[92] 1 Cologne Commentary On Space Law 210 (Stephan Hobe, Bernhard Schmidt-Tedd, Kai-Uwe Schrogl eds., 2009).
[93] Art. XII OST.
[94] Almudena Azcárate Ortega & Dmitry Stefanovich, *Chapter 4: Space Launch Vehicles and Ballistic Missiles, in* Exploring Options for Missile Verification 43 (Pavel Podvig ed., UNIDIR, 2022), https://doi.org/10.37559/WMD/22/Misver/01.
[95] *General Rules of Verification: Inspection Team and Inspected State Party rights*, Organization for the Prohibition of Chemical Weapons, https://www.opcw.org/chemical-weapons-convention/annexes/verification-annex/part-ii-general-rules-verification.
[96] *See* Woolf, *supra* note 91.
[97] Pavel Podvig & Amy F. Woolf, *Monitoring, Verification, and Compliance Resolution in US–Russian Arms Control*, UNIDIR, 13 (2019), https://doi.org/10.37559/WMD/19/WMDCE5; *See also* U.S. Department of State, *JCIC Coordinated Plenary Statement on Conversion Procedures and the Manner of Accountability for the One Road-Mobile Test Launcher of the RS-24 ICBM Prototype*, Unclassified Annex to U.S. Closing Plenary Statement (5 Dec. 2007), https://2001-2009.state.gov/s/l/2007/112730.htm.
[98] Cleminson & Alves, *supra* note 81.

and operators of space-related assets. Indeed, proposals for on-site verification activities in other issue areas have been met with fierce resistance, including from industry actors concerned over the risk to intellectual property.

Accordingly, procedures and timing for on-site activities as well as measures to ensure the protection of commercially or militarily sensitive information would be required. This would entail careful advance negotiation, including with relevant private sector stakeholders with relevant assets.[99] Due to the growing number of possible facilities, on-site activities could rapidly become resource intensive unless quota systems —as applied in other disarmament regimes— for on-site activities could be agreed. As such, on-site activities should be seen as a last step in a monitoring or verification process.[100]

OPEN-SOURCE DATA

Open-source data, that is, data derived from publicly available information, is not a substitute for more formal verification and monitoring tools. However, open-source tools, particularly those drawing from a growing array of online information, have already augmented the space verification and monitoring toolbox and present opportunities to further build confidence in compliance with space security measures.[101] Easy access to cheap and high quality observation instruments, as discussed above in the sections on SSA and remote sensing, has led to the emergence of an entire community of "space watchers" sharing and assessing public material to delimit a zone of interest and detect patterns and behaviours.[102] Consequently, some space activities can be closely observed from different sides of the world at all times by a multitude of observers.

However, there are a range of other possible open sources that could be applied to space monitoring and verification. In addition to the role of commercial satellite imagery and SSA data (discussed above), the following could contribute to verification and monitoring:

- Public information on the **movement of satellite or other space assets**, including the identification of anomalies with space assets not registered under the United Nations' Registration Convention,[103] and NOTAMs that contextualize information on direct-ascent launches.

- Public information on the **movements of military units or personnel** associated with military space programmes.

- **Patent data** pertaining to specific space technologies in specific institutions, which can be used to better understand the technologies being developed in a particular institute.

[99] Woolf, *supra* note 91, at 24.
[100] *Ibid*.
[101] *See* Pavel Podvig & Decker Eveleth, *Chapter 5: The Role of Open-source Data in Verification in* Exploring Options for Missile Verification 53 (Pavel Podvig ed., UNIDIR, 2022), https://doi.org/10.37559/WMD/22/Misver/01; *see also* Harrison, *supra* note 6.
[102] Clément Renault, Paul Charon & Fabien Laurençon, *Renseigner autrement? Trajectoires de l'Osint dans les services de renseignement*, 186 Hérodote (2022) at 24.
[103] Harrison, *supra* note 6.

- **Bibliometric publication data** produced by specific institutions or individuals, which can inform understandings of trends in space technologies in different regions.

- **Global trade data** related to space, as provided in United Nations Comtrade database,[104] which can provide an indicator of trends in the import or export of space-related commodities, including spacecraft and suborbital space launch vehicles.[105]

- **Social media material**, including photos or videos, which can and has been used to identify new military technologies or uncover clandestine activities.

- **Official documents and other official materials**, such as photos or videos, or financial records and budgets that can inadvertently or in some cases deliberately disclose valuable information.

States with existing capabilities might supplement their own information with unofficial sources that could provide data that is informative of the activities of others in space. However, open-source intelligence (OSINT) is unlikely to supplant existing capabilities and its use faces several limitations.[106]

Limitations of OSINT

First, users and producers of open-source data may consciously or unconsciously exhibit bias in the collection and interpretation of data. Second, none of the above tools or sources of data is of significant value as a standalone source of data. Third, yet related to the above, the process of using OSINT is inherently unsystematic, there is no system of global structured coverage of all sources. In light of the above, it should be clear that these tools are of limited value as standalone measures, or if OSINT is collected only by small groups of actors —for OSINT, numbers matter. The plurality of sensors and observers is what provides an accurate perception of a situation in a determined context.

Moreover, while OSINT can help build up a picture of a State or other stakeholder's space-related activities, it can also create new challenges. More data and tools erode the States' monopoly on reaching judgements around compliance. This is arguably a good thing, but opens the door for the emergence of more sophisticated disinformation. On the other hand, the use of relevant and accurate OSINT is useful to precisely identify a space object or a zone of interest and subsequently confine monitoring activities to a specific area, while other observers continue the scrutiny of different zones.

[104] Of particular note could be data related to commodity codes such as *Harmonized System (HS) Codes*, used to identify and track every product that crosses an international border, for example HS 8802 Other aircraft (for example, helicopters, aeroplanes), except unmanned aircraft of heading 8806; and HS 880260 Spacecraft (including satellites) and suborbital and spacecraft launch vehicles.

[105] Notably, HS commodity code 880260 Spacecraft (including satellites) and suborbital and spacecraft launch vehicles.

[106] Lal et al., *supra* note 51.

When it comes to the reliability of the data, the use of digital signatures could be beneficial to retrace all processing steps that an image undergoes, from the sensing to the analysis, in order to mitigate the risk of manipulation. In order to alleviate the sensing mechanism's limitations, data scientists are aggregating the data collected to develop predictive models measuring and hypothesizing scenarios.[107] Six data quality dimensions can aid in accurately interpreting a situation: data timeliness, completeness, uniqueness, consistency, validity and accuracy.[108]

Including commercial platforms, mapping objects in Earth orbit with open-source tools employed for SSA could aid verification efforts. Recently, space-related data has been shared directly on open platforms such as Space Track or AstriaGraph by operators such as Starlink, Planet, the Combined Force Space Component Command (CFSCC), the USSPACECOM, JSC Vimpel, and SeeSat-L, among others.[109] However, these platforms could pose intellectual property issues in the long run as they are stored, processed, organized, and displayed in a particular manner. In addition, they could increase the costs to access SSA information and constitute entry barriers for some operators who would be obliged to either share their information to access the data or pay high fees.

As mentioned above, even though the open sharing of data allows easier access to information that can result in more accurate data to ensure space safety, it also increases the possibility of data manipulation, with a high risk of misuse, omissions, and potential misreading. In this case, the reliability of open-source data could be at stake and should therefore be considered cautiously.

[107] Jah, *supra* note 20.

[108] *Ibid*.

[109] Space-Track, *Frequently Asked Questions* (FAQ), https://www.space-track.org/documentation#faq; AstriaGraph, http://astria.tacc.utexas.edu/AstriaGraph/; Privateer Space, https://www.privateer.com/.

MOVING FORWARD: WHAT OBLIGATIONS AND ACTIVITIES CAN BE VERIFIED AND MONITORED?

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The development of any space verification regime will require clear, specific, and observable space-related obligations.[110] In arms control and disarmament, such obligations are normally found in legally binding agreements. Yet existing agreements related to outer space provide only a limited set of verifiable obligations. The 1967 Outer Space Treaty (OST) provides some examples of space security-related obligations, including the obligation under article IV "not to place in orbit around the Earth any objects carrying nuclear weapons or any other kinds of weapons of mass destruction, install such weapons on celestial bodies, or station such weapons in outer space in any other manner".[111]

This does not necessarily preclude the monitoring of adherence to normative frameworks agreed at the multilateral or bilateral levels, nor does it preclude unilateral steps demonstrating a commitment to using space for peaceful purposes. Through performative transparent acts, national political, institutional and technical arrangements and mechanisms can be leveraged to demonstrate —domestically as well as internationally— a State's commitment to only using space for peaceful purposes.[112]

Indeed, steps such as public renunciations of counterspace capabilities, national reporting on peaceful space policies, and legislative measures prohibiting the development of counterspace assets could help to foster confidence in a State's intentions and behaviours in space.[113] The testing of kinetic ASATs can be used here as an example once more. There is a long history of proposals for prohibiting kinetic ASATs.[114] However, at present there is no consensus on a prohibition of kinetic ASATs and therefore no clearly verifiable obligation established from which to develop the parameters of a verification regime.

Yet, the international community is increasingly aware of the dangers posed by kinetic ASAT testing. The intentional creation of debris is considered by the majority of States to be a significant, growing, and indiscriminate threat to all space objects.[115] In the face of this danger, several States unilaterally chose to commit not to test direct-ascent kinetic ASATs.[116]

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110 "Verification depends on both technical capability and *precision of language in delineating specific* measures". *See* Harrison, *supra* note 6, at 3 and 15; *see also* Woolf, *supra* note 5.

111 Open-ended Working Group on Reducing Space Threats through Norms, Rules and Principles of Responsible Behaviours, *Existing Legal and Regulatory Frameworks Concerning Threats Arising from State Behaviours with Respect to Outer Space*, UNIDIR (3 Feb. 2022), UN Doc A/AC.294/2022/WP.1, https://documents-dds-ny.un.org/doc/UNDOC/GEN/G22/248/57/PDF/G2224857.pdf?OpenElement.

112 *See* Sébastien Philippe & Zia Mian, *Chapter 1: The TPNW and Nuclear Disarmament Verification: Shifting the Paradigm, in* Exploring Options for Missile Verification 5 (Podvig, Pavel ed., UNIDIR, 2022), https://doi.org/10.37559/WMD/22/Misver/01.

113 Harrison, *supra* note 6.

114 The Carter Administration undertook ASAT limitation negotiations with the Soviet Union beginning in 1978. Harrison, *supra* note 6; *see also Russia's Roscosmos to Initiate Talks on Kinetic Kill ASAT Ban*, SpaceWatch Global (12 Dec. 2019), https://spacewatch.global/2019/12/russias-roscosmos-to-initiate-talks-on-kinetic-kill-asat-ban/.

115 Threats Working Paper, *supra* note 82; Report of the Secretary-General A/76/77, *supra* note 57.

116 The United States was the first to unilaterally commit to this measure, and encouraged other States to follow its example. Canada, New Zealand, Japan, Germany, the United Kingdom, South Korea, Australia, Switzerland, France, the Netherlands, Austria, and Italy have joined the commitment so far; *see* Laetitia Cesari, *Une nouvelle étape dans le désarmement spatial : le cas des tests de missiles antisatellites à ascension directe*, Fondation pour la Recherche Stratégique (7 Dec. 2022).

Such unilateral commitments eventually led to the submission and adoption of UN General Assembly resolution 77/41 on “Destructive direct-ascent anti-satellite missile testing”, which urges States to commit not to conduct destructive direct-ascent anti-satellite missile tests.[117]

Even though UNGA resolutions are not legally binding, adherence to such commitments can be monitored. Although by no means should norms and other non-binding mechanisms be seen as a panacea able to address all existing space security concerns, the establishment of monitorable norms and guidelines serves to pave the way towards a more transparent, trusting, and secure space environment that creates new possibilities for legally binding, and verifiable, regulations in the future.[118]

[117] General Assembly resolution 77/41, Destructive Direct-ascent Anti-satellite Missile Testing, A/RES/77/41 (7 Dec. 2022), https://documents-dds-ny.un.org/doc/UNDOC/GEN/N22/738/92/PDF/N2273892.pdf?OpenElement.
[118] West & Azcárate Ortega, *supra* note 3.

CONCLUDING THOUGHTS

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Verification and monitoring instruments can enhance space security significantly by encouraging compliance with legal and normative frameworks. As technology continues to develop, the accuracy and precision of the tools available to carry out verification and monitoring also increase. However, these tools continue to have limitations that cannot be overcome through technological advancement alone. In order for verification and monitoring mechanisms to be effective, they have to be used in combination with one another. Moreover, new technological opportunities will need to be validated for use in verification.

Verification also requires clear obligations that can be assessed realistically. At present, obligations are limited and outer space law is often worded in an ambiguous manner that allows for differing interpretations. Accordingly, States will need to build common understanding around space security-related obligations. However, this should not preclude further exploration of space verification opportunities by both formal and informal processes that focus attention on this topic and open up policy options for States to consider moving forward.

Ultimately, common understanding is at the core of effective verification and monitoring. Instruments to verify and monitor compliance with legal and normative frameworks will always be imperfect. No stakeholder will have access to all information on all space activities of all actors. This is difficult even if multiple stakeholders chose to work together towards it. The feasibility of any verification and monitoring regime will depend fundamentally on the extent to which States see the benefits of their participation as outweighing the costs. Moreover, the effectiveness of verification and monitoring mechanisms, while never perfect, is increased when such tools are used in combination of one another, and is further strengthened through international cooperation, information-sharing, and transparency.

CONSTANT VIGILANCE?

VERIFICATION AND MONITORING FOR SPACE SECURITY

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