Future of the Space Situational Awareness Enterprise - Global Trends

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ABSTRACT

Whereas 50 years ago, the United States and the Soviet Union were the major players in space, now over 80 countries have one or more space-based assets. Over 1,700 active satellites are in Earth orbit—approximately twice as many as there were only a decade ago. Addressing these challenges of growing space activities will become more difficult and costly in the future. Up until recently, the United States was the sole leader in space tracking activity, referred to as space situational awareness (SSA). However, given the growing importance of space in countries around the world, and the prospect of profiting from providing this information, there is growing national and private expertise in SSA globally. In this paper, the authors will present findings from a recent study of factors affecting current and emerging global trends in SSA and Space Traffic Management (STM). The findings will identify external factors driving the foreign governments and private operators towards more independence with respect to SSA capabilities. In addition, global trends in SSA data collection, data processing, SSA products and the oversight, management and coordination of the growing space activities will be discussed. We will also present results from an analytic exercise that evaluated four scenarios of how SSA services might be delivered in the next decade. The scenarios are derived from variations on two dimensions: degree of government control (government vs. private) and degree of internationalization (domestic vs. international).

1. INTRODUCTION

The growth in the number and diversity of the activities and actors in the space environment is driving the need for better space situational awareness (SSA) and to develop approaches to better oversee, coordinate, and manage space activities. At the end of 2017, there were over 1,700 active satellites in space, nearly twice as many as there were 15 years ago[1]. Between 2018 and 2026, there are plans to launch at least another 8,000 satellites, including OneWeb and SpaceX small satellite constellations [2]. Two-thirds of the proposed satellites will be launched by various commercial entities, with the remaining third serving civilian and military agencies in 60 countries [3]. Active satellites comprise less than 10 percent of the objects in space; the rest is composed of debris such as rocket bodies and fragments [4]. The growing population of existing satellites and space debris has created two main challenges for safe space operations; 1) the difficulty of detecting and tracking objects in Earth orbit, and being able to predict their future trajectories, and 2) how to best use the information about future trajectories to detect and prevent collisions between space objects, which could damage or destroy functional satellites, and generate additional orbital debris. Conducting safe and sustainable operations in space in this increasingly congested environment thus depends on accurate and precise awareness of all space objects.

Until recently, the United States Department of Defense (DoD) was the only organization in the world—outside, perhaps, of Russia—to develop high-fidelity space situational awareness (SSA) information [5]. Today, DoD shares varying levels of this information freely with public and private users, domestically and internationally. The DoD system is based on a legacy architecture that was originally designed and optimized for missile warning, not tracking space objects or providing SSA information and services to the public. Furthermore, the system was deployed in the 1960s when there were relatively few objects in space, operating in predictable orbits and engaging in predictable activities. Given the evolving space environment—growth in the number of objects in space, growth in the number and diversity of operators and types of activities in space, and changing satellite technology—there is increasing demand from the public for enhanced, actionable SSA services and information to operate safely in space which is outpacing the current DoD architecture. As a result, foreign governments and commercial entities around the world are increasingly pursuing activities to supplement DoD information, and some have begun efforts to establish independent capabilities and systems.

The growth and diversification of space activities and actors, especially in the commercial space sector, is also driving national and international efforts to develop or improve policies and mechanisms to share SSA data, and to better oversee, coordinate, and manage space activities. As a result, bilateral and multilateral agreements on SSA and space activity more broadly are increasing as traditional and emerging spacefaring nations seek to leverage space for national goals. Despite increasing coordination and collaboration, there are ongoing debates regarding how to refine existing or develop new international frameworks and institutions to address expanding space activity. The complexity of building consensus internationally, as well as the lack of international enforcement mechanisms, has led many countries to focus first on national efforts to develop or refine policy frameworks. Regardless of the challenges associated with building a global approach to address increasing space traffic, efforts to develop technical guidelines, best practices, and standards are underway nationally and internationally which will be critical to establishing a foundation for more binding international policies.

This paper is based on a report written by researchers at the IDA Science and Technology Policy Institute on global trends in SSA and STM [6]. It focuses on SSA technology and policy trends outside the United States but does include an examination of U.S. commercial entities given that private companies conduct work internationally. This study was conducted prior to the United States issued Space Policy Directive-3: National Space Traffic Management Policy [7]. It is likely that international representatives may have approached some aspects of SSA and Space Traffic Management (STM), especially those regarding data sharing and coordination, differently depending on whether their relationships operate through DoD or a United States civil agency. Our discussions did not address this potential shift in the U.S. system. However, because SSA is largely a military function, any shift in the provision of SSA services will entail extensive conversations between the United States and its partners moving forward [6].

2. METHODOLOGY

We first developed a framework that operationalizes the space traffic system, which we used in our discussions with stakeholders (Fig. 1). The framework partitions the space traffic system into six components: 1) Data Collection, which refers to the use of civil, military and commercial sensors, both ground- and space-based; 2) Data Processing, which includes managing the observations to create a database of resident space objects, analyzing the data to create products such as conjunction warnings, and maintaining a data archive; 3) Data Products, such as conjunction or collision warnings that lead to actions such as those taken by operators to avoid collisions; 4) Oversight, Management and Coordination efforts that include regulations, policies, guidelines, standards, and best practices; 5) Data Sharing, which refers to sharing of a range of data products across all stakeholders and occurs during all aspects of the space traffic system; and 6) External Factors, a category that encompasses environmental and operational realities driving changes in both technology and space traffic coordination.

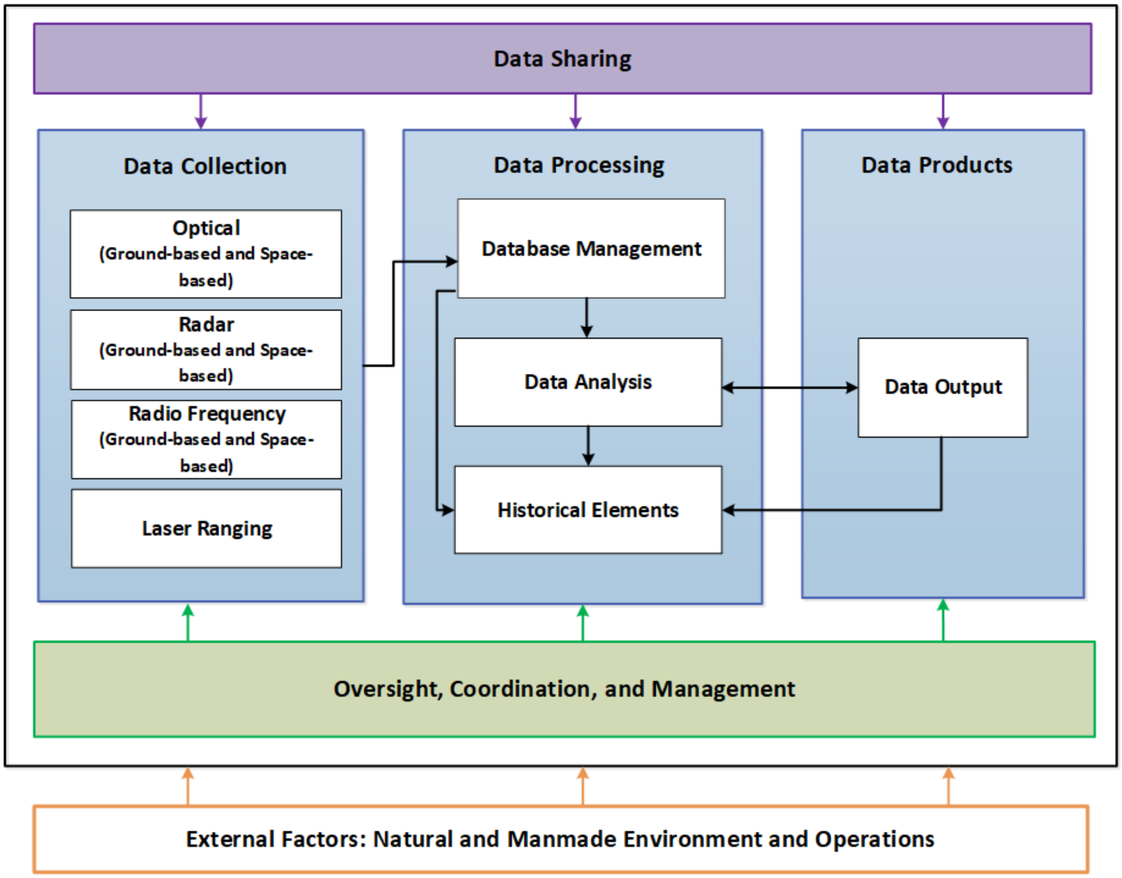

Fig. 1. Analytic Framework for a Space Traffic System

Based on more than 70 unclassified interviews as well as a review of the open source literature, we conducted case studies of the space traffic systems in 18 countries to identify trends in a structured, systematic, and bottom-up manner using this framework (See Fig 2 and 3 for list of countries). The countries were selected on the basis of whether they were major and emerging players (e.g., Russia, China), U.S. allies (e.g., Germany, France), located in geographically strategic vantage points (e.g., Chile, Brazil), and expressed interest in being part of the SSA community (e.g., Poland). Our questions covered topics including: definition of SSA; motivations for doing SSA; investments and roles in SSA; technical capabilities in data collection, processing, and products; domestic and international space policies; and regional and international cooperation on SSA, as well as oversight, management and coordination mechanisms. Lastly, to promote constructive dialogue with stakeholders and examine their assumptions, we developed four archetypical SSA scenarios for the next decade. We presented the scenarios to stakeholders and sought feedback regarding which they viewed as the most likely and the most desirable.[1]

3. FINDINGS

Based on trends in the individual case study countries, STPI identified overarching global trends by each of the six component of the space traffic system. Table 2 itemizes all trends and their implications. The sections below focus on a subset of these trends.

External Factors Driving Changes in Space Traffic System

There is a growing expectation from both government and private operators that the SSA information they rely on be more precise and transparent than it is today. Though this is partly because emerging space activities and

[1] The scenarios were presented and discussed at the AMOS Dialog in 2017, and available for review: http://www.unidir.ch/files/conferences/pdfs/space-situational-awareness-data-sharing-reviewing-old-methods-and-new-capabilities-en-1-1298.pdf

architectures will likely change the ways objects need to be tracked, this is also motivated by operators' growing desire to be more self-reliant regarding their SSA capabilities. While they would like to continue to collaborate with the United States, other governments in our set of case studies and the private sector are seeking to be less dependent on data provided by the U.S. Government, especially given common concerns that the SSA services provided by the United States may become unexpectedly unavailable or no longer provided for free. Furthermore, some countries expressed a desire to be a more equal partner with the United States and make more substantive contributions to the United States and the global SSA enterprise. As a result, there is growing demand for SSA sensors, software, products and services; thus, country-level funding for SSA is increasing, dramatically in some countries such as Australia and Japan, and gradually in others such as Poland and Thailand. Countries are collaborating more and SSA is playing a role in improving even established partnerships. The primary motivation for engaging in SSA activities and, when applicable, pursuing or strengthening their own SSA capabilities, varied across the countries representatives with whom we spoke.

There is trend towards functional modularization of the SSA system: it is becoming more segmented such that different actors and organizations can service each part (data collection, data processing and the creation of data products) of the system. This is a significant departure from the current SSA system, in which the DoD performs all three parts; now, organizations providing sensor data do not need to process it, and organizations processing data or fusing different sources of data together do not need to be the ones collecting. This trend—which enables organizations, particularly in the private sector, to operate independently and innovate new products or services—is already occurring, particularly in private firms in Europe or the United States. In many cases, investors are funding certain aspects of the system (e.g., data collection companies), and firms are offering products and services on a subset of system. Experience in other industries that grew out of government investment (e.g., computing) has also shown that entrance of the private sector is a precursor not only to falling cost and greater innovation, but also to growing democratization. However, the case studies indicate that globally SSA activities will likely remain dominated by national security-oriented organizations, even as they collaborate with their civil and commercial space counterparts, domestically and internationally; as a result, SSA will likely be slower to democratize than other sectors.

Data Collection, Processing and SSA Products

This functional modularization has enabled each segment to evolve somewhat independently. There are many new sensors for data collection in new locations: countries and companies are already repurposing existing sensors (e.g., those used in the scientific research community for astronomy and atmospheric science research), which can be utilized for SSA for a modest investment, and are seeking "signals of opportunity" to repurpose even further. Newly added sensors include all types—optical, radar, and radiofrequency (RF)—ground-based and space-based. The fact that the cost of these sensors is falling, primarily for optical but also potentially for radar, is beneficial for private sector entities, which rely on private investment to enter into the marketplace. When located in geographically dispersed areas, more sensors, even if they are not as precise, allow for more persistence—the ability to see more assets more frequently. The expansion of sensors could allow data to become more of a commodity, with the value-add remaining in software systems, though the need for exquisite data for certain applications will always remain.

On the processing front, the number of systems for creating catalogs and producing more actionable SSA products is growing. Open source software with the potential to enable faster rates of innovation does exist, although most software appears to be proprietary and owned by governments and individual private companies. While most of the development is in the United States, there are pockets of activity in France and Spain, among other countries. Harnessing capabilities from the mainstream IT community, organizations are applying machine learning and artificial intelligence techniques to process data expected to come from the growing number and diverse phenomenologies of sensors (e.g., combining data from optical and radar sensors to create new insights not feasible with just one type of sensor). There is growing use of large amounts of data to compensate for physics-based models in algorithms (e.g., the effect of solar weather), which enables the user to predict orbits at similar levels of accuracy as those allowed by more sophisticated models. As a result, both countries and companies are increasing data processing capabilities.

These data collection and data processing trends—both on the quantity and quality front—would allow for increasingly more (e.g., covariance information) and better (e.g., smaller error ellipses) SSA information in the coming years. With the private sector entering the market, it is also likely that the cost of SSA products could substantially decrease, possibly enabling other countries to leap-frog closer to the expertise level of the United States without dedicating the same investment of time and funding. Ultimately, while the U.S. Government may continue to have the more exquisite SSA information in the world (especially when Space Fence comes online), it will not be the only source of SSA information and other nations will likely close the gap with relative ease. Fig. 3. shows the analysis coupling countries' interest level in seeking collaboration with their level of technical capabilities and expertise developed in this study.

Interviewees and representatives from the U.S. Government all agreed that SSA information needs to be shared in order to ensure safe operations in space. Data sharing agreements with the United States are growing, but there is increasing collaboration between other countries as well, both bi- and multilateral. In some cases, the partnerships, including formal efforts such as the European Union-Space Surveillance and Tracking project (EU-SST) or Chinese Asia-Pacific Ground-based Optical Space Objects Observation System (APOSOS) as well as individual agreements, do not involve the United States. Many countries are also placing sensors in other parts of the world, particularly in southern hemisphere countries, in exchange for capacity-building in the broader space sector.

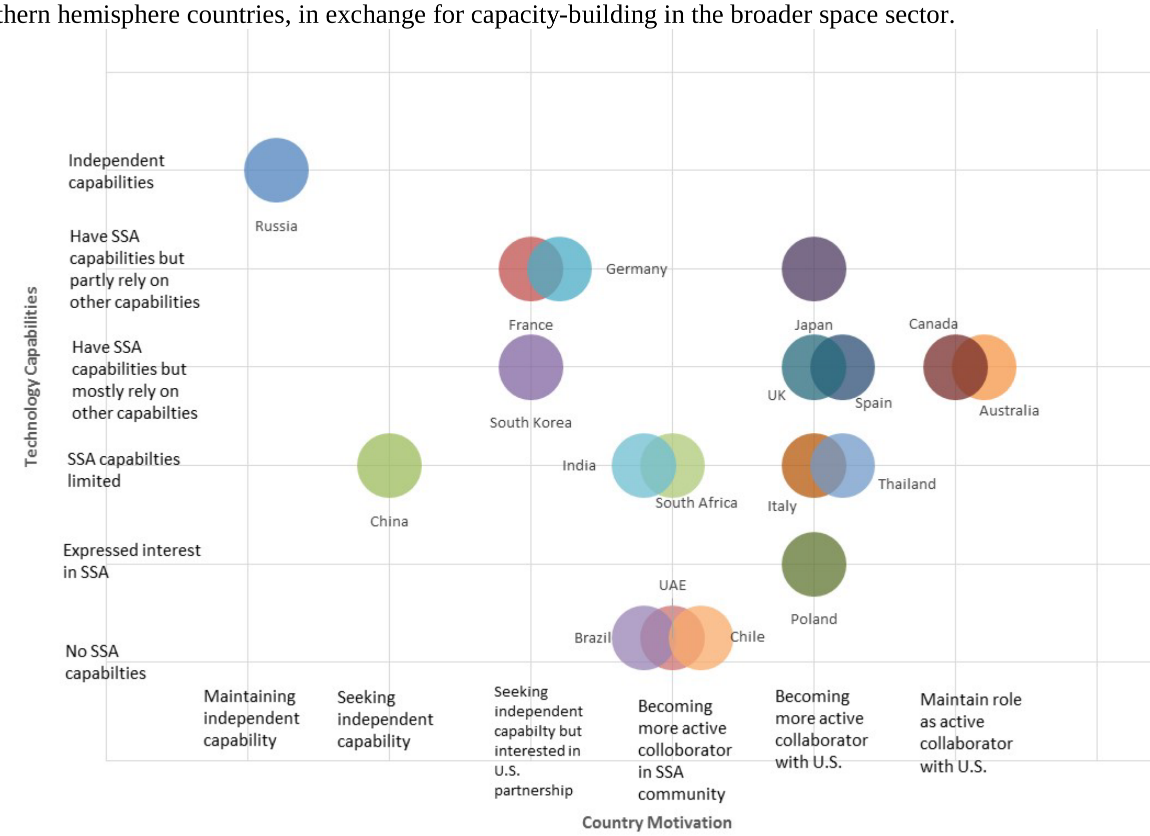

Fig. 3. Country technical capabilities by country motivation and desire for collaboration

Oversight, Management and Coordination

The lack of a standard understanding of the concept of STM across interviewees or literature resulted in the selection of the terms "oversight", "management" and "coordination". Traditional and emerging spacefaring countries have expressed growing interest in contributing to the development of approaches to address the rapidly changing space environment and its potential effects on their space activities. Private sector operators, both U.S. and international, also emphasized the importance of space cooperation. However, undertaking such cooperation will be challenging given the increasing numbers of players, technologies, and activities in space. Issues related to lack of trust and transparency pose challenges to efforts to develop more binding and formal institutions for space traffic management. Additionally, there is no definitive framework on which this international system would be modeled, and the relative roles of governmental and private operators in determining next steps is unclear. For these reasons there is unlikely to be agreement on a binding international STM regime in the next decade unless countries are able to overcome these major complexities and challenges. International efforts will likely continue to focus on developing consensus on non-binding and voluntary mechanisms. At the same time, SSA is seen especially by governments as a critical national security function first, and military organizations and interests are likely to dominate, particularly for the operational part of SSA, presenting additional challenges to collaborating with civil agencies or creating a global regime. Thus, it is expected that spacefaring and emerging space nations will likely address these issues through domestic regulations first, before approaching international agreements; indeed, many countries are revising their official documents to better address changing space activities (Table 1).

Table 1. Status of National Policy Frameworks for Space Activities

Country	Space Policy/Strategy/Plan	Space Regulation/Law	SSA Included
Australia	Undergoing revision	Undergoing revision	Yes
Brazil	Undergoing revision	Undergoing revision	Unknown
Canada	Recently revised	No recent revisions	Yes
Chile	Unknown	Unknown	Unknown
China	Recently revised	Recently revised	Yes
France	No recent revisions	No recent revisions	Yes
Germany	No recent revisions	No recent revisions	Yes
Italy	Recently revised	No recent revisions	Yes
India	No recent revisions	Undergoing revision	Unknown
Japan	Recently revised	Recently revised	Yes
Poland	Establishing	Establishing	Yes
Russia	Recently revised	No recent revisions	Yes
S. Africa	No recent revisions	Undergoing revision	Unknown
S. Korea	Recently revised	Undergoing revision	Unknown
Spain	No recent revisions	No recent revisions	Unknown
Thailand	Establishing	Establishing	Yes
UAE	Establishing	Establishing	Unknown
U.K.	Undergoing revision	Recently revised	Yes

Source: STPI Analysis. Explanations and references can be found in [6].

4. CONCLUSIONS

Our overall finding is that in the next decade, while U.S. Government capabilities in SSA may continue to be seen as the gold standard, many other countries would likely develop capabilities that would allow them to become increasingly more self-sufficient and less reliant on the United States. The world is on a path-of-no-return for the proliferation of SSA capabilities, a trend that has significant implications for transparency in space (e.g., more actors will be increasingly able to track others' activities in space). The increasing competence in SSA globally also likely means more vocal participants in decisions of how oversight, management and coordination mechanisms are structured internationally, which will affect the sphere in which the U.S. seeks to demonstrate leadership in space.

Table 2: Summary of Trends in SSA and STM and their Principal Implications

	Observations and Emerging Trends	Implications
External Drivers	There are emerging changes in the space environment—growth in the number of objects in space, growth in the number of operators, diversity of activities, changing satellite technology—all factors that make existing approaches to SSA more challenging.	These changes will necessitate changes in the way SSA (designed for a time when there were few assets doing a small number of things using known technology) would need to be conducted—there will likely be more data from more sources and better fusion capabilities to provide more timely and precise SSA services.
	USG provided data and services are viewed as not being transparent enough, and countries and private sector organizations are increasingly more motivated to aim for greater self-sufficiency or to make more substantial contributions to current efforts.	As a result of growing interest to participate, there is and will continue to be growing investment both in the private sector and other countries to supplement (and supplant) USG data and services.
	Technology changes and other factors have allowed the SSA value chain to undergo "functional modularization“ breaking up the SSA value chain, and allowing more players (including more private firms and academia) to enter the individual links.	A greater number of stakeholders in the system and especially the presence of the private sector can create more innovation in the individual segments; it may also require more coordination and interoperability across segments of the system.
Sensors, Data Processing, Creation of Products	There is a growing number of sensors of all types—primarily optical, but also radar, and active and passive RF (both ground- and space-based). The growth is driven both by new investment and repurposing of old assets used for science applications.	Growth in the amount of data available, together with other advancements such as ability to fuse data from disparate sources, will likely lead to more sophisticated SSA products, with fewer false negatives and positives, more confidence in CAs, lower covariance, etc.
	The sensors are increasingly more capable at comparable costs, and R&D is underway to minimize the limitations of optical systems including daytime imaging, mobile sensing platforms, and space-based sensing.	While exquisite data will always be needed and be available, growth in the amount of data available would likely lead to the commoditization of most SSA data, with value added services in data processing and creation of value-added services. This trend mirrors that seen in EO community.
	There is growth in the number and diversity (e.g., open source) of software/algorithms for processing data and creating SSA products as well as more efficiently operating sensors.	Increased data sharing would likely push for and lead to international standards. The proliferation of sensors has already made it possible for more non USG organizations (including countries) to have independent access to data. As they grow capabilities in data processing, countries would increasingly achieve self-sufficiency, and able to be partners with the United States and each other on a more equal footing.

	Observations and Emerging Trends	Implications
	Software is increasingly more capable [through the use of tools that enable data fusion, faster processing for large amounts of data, automation]. One particular emerging capability in the open source is combining multiple phenomenologies or sensor types to improve the quality of assessment.	Given growing capabilities both in sensors and software, countries would increasingly achieve self-sufficiency, and be partners with the United States and each other on a more equal footing. (without agreements in place) Assets would be harder to conceal by both governments around the world as well as private operators.
Private Sector	There are a growing number of private sector companies in the United States, but also in Europe, Japan and Australia (with global investors).	As a result of private sector approaches, both end-use (e.g., SSA products) and derived services and products (e.g., sensor data) would continue to improve and get less expensive.
	Their capabilities are improving at a faster rate especially when compared with government-owned sensors and publicly-released government data.	SSA would increasingly be able to be offered as a service (or a hybrid service ownership model).
	Companies are experimenting with mainstream business models (e.g., subscription, value-added risk management), turning SSA into a service rather than a technology capability to acquire.	With expectations of growth in space, SSA is likely to continue to attract investment. However, in other countries, it is unlikely to be led by the commercial sector. Given national security imperatives, most governments would leverage the private sector, but not outsource service provision to the private sector.
	Given national security constraints, many governments are leveraging the private sector (e.g., partnerships, software acquisition) but do not seem willing to outsource service provision to the private sector (see it as an inherently governmental function).	In other sectors, typically the emergence of a private sector has led to the globalization of that sector (e.g., computing). Unclear if that will happen here. However, U.S. companies, having already had a head-start, could dominate global markets.
Oversight, Management and Coordination	There is growing agreement on part of all countries (including the United States) and non-State actors that to ensure proper functioning of space assets and sustainability of space activities, not only is there need to share data but to oversee, manage, and coordinate space activities both domestically and internationally.	SSA is seen especially by governments as a critical national security function first, and military organizations and interests are likely to dominate especially the operational part of SSA, presenting additional challenges to collaborating with civil agencies or creating a global oversight, management and coordination regime.
	There is growing collaboration on space activities and a growing number of data sharing agreements (including for SSA data). In some cases, the partnerships do not involve the United States.	Given lack of trust in international institutions, in the absence of any "wildcards" (such as a major collision in space), will further increase the likelihood that there is no international agreement on an international STM regime in the next decade.

	Observations and Emerging Trends	Implications
	There is growing recognition that with increasing numbers of players, technologies and activities in space, creating a new or revising the existing international oversight, management and coordination regime will be complex.	National governments will likely focus on domestic regime-building (with some countries using measures such as incentives to develop bottom-up safety measures).
Overall Observations and Implications	Because of national security constraints, the field will likely "democratize" slower than analogous domains such as computing, Earth Observation or small satellites have.	
	Private sector capabilities in sensors and software systems will accelerate improvements in the quality of SSA, globally.	
	While there are many different reasons countries are pursuing self-reliance, the world is on a path-of-no-return for the proliferation of SSA capabilities, with support from the private sector; the US government will increasingly be one of many information providers to the world.	
	While U.S. capabilities are likely to be seen as the "gold standard" and will continue to have exquisite capabilities for SSA, using partnerships and engaging the private sector, other countries' will likely be able to produce "good enough" capability.	

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