Swedish National Interests in Space Situational Awareness

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ABSTRACT

Sweden has committed to broad investments in space infrastructure, with the aim of developing the Esrange space center into a launch facility for low Earth orbit satellites. With its long heritage of launching sounding rockets and its advantageous position north of the Arctic Circle, the target will be to lift smaller satellites, up to about 150 kg in weight, into sun-synchronous orbits.

As a part of this push for an extended space launch capacity, Sweden is undertaking several related activities in order to take up the role as a launching state. The Swedish space legislation is under revision and, in parallel, the needs and requirements for space situational awareness (SSA) is under investigation, with focus on national needs and possible implementations.

The Swedish Defence Research Agency (FOI) has been conducting research activities in SSA for several years, primarily from a national perspective. The purpose of this paper is to review the current space initiatives pursued nationally, in particular in connection to SSA, and discuss what we see as essential national components in SSA going forward. A three-step plan is presented for how a complete SSA system could be implemented, starting with a simple setup – a space object catalogue based on open data – and eventually evolving into a full-scale system including components for data processing, calibration, sensor scheduling, derived user services, and possibly a dedicated national sensor.

1. INTRODUCTION

Sweden is currently pursuing a broad set of space-related initiatives, following the adoption of a new national space strategy in May 2018 [1]. This strategy highlights several important national issues related to space, with the possible establishment of a national capacity for launching satellites as a key element. To further this goal, the Swedish government has committed to an expansion of the Esrange space center, with the aim to gain capacity to launch small satellites into low Earth orbit. Simultaneously with this expansion, the Swedish government has also launched activities to revise the Swedish space legislation and to investigate the needs and possible implementation of a national space situational awareness (SSA).

FOI, the Swedish Defence Research Agency, conducts research activities in both SSA and space policy. The following paper presents our view of the current national development. The first part of the paper gives an overview of the current national initiatives, to provide a larger context and a background for the national SSA needs. The second part outlines the potential paths that we at FOI see for the development of a national SSA capability, and what we believe are important considerations in this process: Which components are vital for a national SSA service, and how can these components best be acquired and implemented? What potential sensor components could be included, and how? It should be recognized, however, that the suggestions and recommendations presented here purely consider the technical aspect – the path forward is by nature a political process, which must take into account the full spectrum of aspects, as an official national policy is established.

Although the paper discusses the implementation of a national SSA service, it is important to note that SSA by nature is reliant on international data sharing. The aim thus not establish national independence, but rather to contribute to international SSA efforts, which in turn would provide the collaboration and information exchange needed to meet the national needs and ensure a national capacity for monitoring objects of specific interest.

2. NATIONAL SPACE INITIATIVES

Sweden has a long heritage in the space sector, with a strong national space industry, a long experience in space research, and a national capacity for launching sounding rockets and balloons. Over the years, Sweden has also developed a string of national satellites, from Viking in 1986, a research satellite that investigated physical processes in the aural region, to PRISMA in 2010, a two-satellite technical demonstrator of formation-flying concepts. A new satellite for atmospheric research, MATS, is scheduled for launch this year. Sweden also has a long history of being an active participant in many international collaborations, primarily within ESA, but also with NASA and other international partners.

In recent years, Sweden has pursued initiatives to expand the national space program. Central to this is the adoption of a new national space strategy in May 2018, which outlines a long-term strategy for the Swedish space sector. The policy builds on the strengths of the Swedish space program and sets a path for a long-term development and growth of the space sector. Many different aspects are covered in the policy. For example, the activities pursued should be of benefit to society. The participation in international efforts aimed toward the peaceful and sustainable use of space should be prioritized, along with the participation in international efforts in SSA. Co-operation between civil and military stakeholders is regarded as an important aspect, where it is vital that both sectors make use of any potential synergies, in order to increase the return on investments and prevent overlapping efforts. National security is given a central role in the policy, where it is stressed that space activities need to be conducted with consideration of national security, taking into account Sweden's foreign and defence policies and making sure that the activities pursued are in line with Sweden's national interests. The strategy also recognizes the need for an improved national SSA. This is particularly important from a national security perspective, but also to enhance the transparency of space activities and reduce the threat from space debris and extreme space weather, as well as to reduce the risk of conflicts in space.

Following its release, several initiatives related to issues prioritized in the national strategy have since been launched. In April 2020, the Swedish National Space Agency (SNSA) was given the task to investigate the potential foreign, defence and security policy effects that would be associated with satellite launches at Esrange, should it acquire satellite launch capacity. In addition, the SNSA together with the Swedish Space Corporation (SSC) have presented an analysis of the potential business opportunities for launching small satellites. In this analysis, they concluded that there are plausible options for the SSC to extend their business portfolio with this type of service, that the risks involved are manageable, and that there are potential partners that may be able to assist in the process, for example with the required rocket technology.

Later in the same year, in October 2020, the Swedish government announced an investment of 90 million SEK (approximately equivalent to 10.5 Million USD), intended for the development of the Esrange space center into a spaceport capable of lifting small satellites (up to 150 kg) into low Earth orbit. The ambition from SSC is to launch the first satellite in 2022, with hopes of becoming the first European-based spaceport. The investment is foreseen to have positive effects on both Swedish space industry and space research, providing conditions for innovation and leading to positive co-investments both nationally and regionally around Esrange.

There are, however, several additional components that need to be in place in order for Sweden to take on the responsibilities of a launching state. The foremost components include a national space legislation that clearly defines the legal requirements, obligations and opportunities for space activities, and a national SSA service that can monitor satellite operations and space debris, support collision avoidance manoeuvers, contribute to international transparency and confidence building measures, etc.

The current space legislation, which came into force in 1983, is limited in its scope. An overhaul of the national space legislation was initiated in September 2020, and the report is due in the fall of 2021. The revision of the space legislation is meant to facilitate private investments in the space industry while at the same time taking into consideration the national commitments and requirements on space activities. This overhaul includes, for example, evaluations of:

- The need for a clearly defined set of legal requirements for space activities.
- The need for the space legislation to include components related to the protection of the space environment and prevention of space debris.
- Sweden's international commitments and the need for regulations related to national security.

In a review of the potential foreign, defence and security policy effects that would be associated with satellite launches from Esrange, the SNSA raised the need of a national SSA service. A follow-up investigation on the implementation of such system was initiated in December 2020. This investigation aims to establish what the operational requirements associated with the national needs are, how the required functionality can be acquired, and at what cost. The assignment thus raises several important questions for an emerging launching state: What are the SSA requirements associated with a launch capacity? How can a national SSA service best be acquired and implemented, depending on the level of ambition? What solutions are available? The following chapters present our view on some of these issues, and they review some of the options available to date. In particular, a concept for incremental implementation is presented, which is meant to facilitate the acquisition of a national SSA service. Although the analysis is based on Swedish prerequisites, the overall approach and many of the conclusions should be of interest for other states going through similar a process.

3. NATIONAL SSA - REQUIREMENTS

With the present investments in the Esrange spaceport, Sweden will soon acquire the capacity to launch small satellites into orbit. However, this new capability also puts new requirements on Sweden as a space nation to take up the responsibilities of a launching state, as well as on the launch provider, SSC.

In addition to the requirements that originate from a satellite launch capacity, there are also other national stakeholders with interests in SSA, both civil and military, as society is becoming more and more dependent on space-based services. These needs may in part be separate, as they depend on whether the actors are users of or actively controlling space resources or services. From the perspective of the launch provider, SSC, there will be a need to handle launch and early orbit phase activities in a safe manner. Similar requirements will come from satellite operators who may need updated orbit parameters and collision predictions in order to manage their satellites in a safe manner, conduct station keeping manoeuvres, and to avoid collisions with satellites and space debris. From the perspective of the national space agency, there will be a need to keep track of launched objects, for example to verify that they are controlled in a responsible way and are not performing harmful or dangerous manoeuvres in their orbit environment. There are also SSA interest from the Swedish Armed Forces, whose needs are primarily focused toward space security, as well as from the research community and civil society, for example regarding space debris. A national SSA service would also contribute to international stability as a data source for confidence and transparency-building measures.

For Space Weather services the needs from the interested parties is to keep an updated prediction of any possible critical community service interruption, for example, navigation, electrical power distribution, communication or radar services such as flight radar. There may also be potential interests in near-Earth object (NEO) monitoring, however, there are currently no plans for dedicated NEO activities on a national level. A solution for NEO that may be more preferable is to include an expert function in national SSA that has the necessary connections to ESA and NASA, in order to provide national advice in case of NEO events.

The rapid changes in the space environment with a high launch rate of new satellites and a continued increase in space debris requires a fast handling and response time on the national SSA provider, for example regarding the incorporation of new functions or requirements. This in itself sets requirements on how the SSA service is designed and implemented, in terms of flexibility and agility.

4. NATIONAL SSA – STRATEGIES FOR ACQUISITION AND IMPLEMENTATION

It is well recognized that the efforts involved in establishing a complete SSA service is a global undertaking that needs to be handled through international collaborations – one country cannot undertake this task alone. For Sweden, the European Space Surveillance and Tracking (EU SST) programme provides a natural opportunity for access to a complete SST service, but it would in turn require a dedicated national sensor that can contribute sensor data to the programme. However, in order to use such a resource efficiently, it is important that the needs and use-cases are fully understood before acquisition. There are also several other vital components that need to be considered, for example calibration, scheduling, and data processing. A reasonable implementation strategy would therefore be to acquire new functions stepwise, with an operational national SST sensor as an end target.

What follows is an outline of an incremental system design that will facilitate the deployment, and allow for a step-wise development of a national SSA service. This implementation strategy starts with a system based on openly-available SSA data (Level 1), and from there adds third-party components (Level 2) before finally evolving into a full-scale SSA, including the components required to support a national sensor (Level 3).

Evolving requirements

One of the benefits with an incremental solution is that it allows users to gain experience already before the system is complete, and to test and evaluate the service continuously. As they gain understanding of their respective use-cases, this will help set relevant and useful requirements on the system and provide better understanding for prioritized features.

The space environment is changing rapidly, with new technology coming into play, and larger satellite constellations and an evolving debris population leading to increased risks for collisions. For these reasons, we can expect that also the national SSA needs will evolve with time. An important condition is therefore to maintain a flexible solution that can be adjusted and extended in order to meet new requirements, both from users active within the space domain as well as from other parts of society. There are still many users that are not fully aware of the dependencies they have on space services, and who may not at present consider or recognize space as a domain of concern. However, there may be a need for these users to have knowledge of the status of services, so that they can make contingency plans in case of a space service failure.

In addition to the initial work involved in developing a national SSA service, national users and stakeholders will also need to conduct regular meetings in order to identify new requirements and prioritize development. This activity is also important for new users in order to become familiar with the SSA service and to understand both the opportunities and the hazards that may be associated with space systems. To handle these different requirements, it is clear that the SSA service will not be limited to a set of common use-cases for all users. There may be some features that are useful only for particular users, for example support during launch and early operations, and other functions which may be restricted to a limited number of users that have the needs and clearance to access that particular information. For this reason, it makes sense to develop the system around a core that covers common user needs, with additional functionality outside that are tailored to the unique needs of specific users. However, the goal should be to keep everything that is of common interest in the core functionality, in order to facilitate sharing of information. For that purpose, it is important to find a working method to avoid problems with non-compatible solutions and overlapping development efforts.

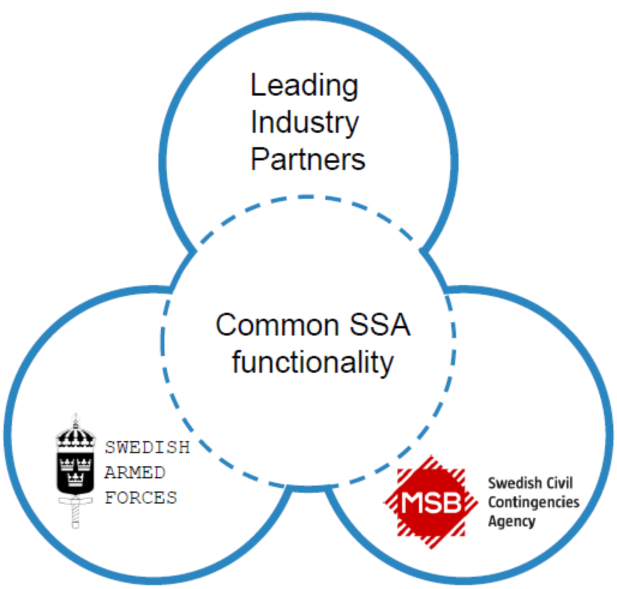

Figure 1. Illustration of the modularity concept. Common SSA functions are illustrated by the dashed circle in the centre, as the union of services offered to different agencies and companies. Specific user needs outside of the common functionality are represented by blue circles, in this case the Swedish Armed Forces together with the Swedish Civil Contingencies Agency and Industry. The complete SSA functionality is thus represented by the whole area, outlined in blue.

Level 1 – Open data

As a first step, we suggest the development of an SSA system based on openly available data and services, for example from spacetrack.org, possibly with the addition of data and/or services from other commercial providers. This solution, illustrated in Figure 2, would constitute a relatively straightforward implementation that could support many of the basic requirements. The implementation of such a system would also give experience in catalogue handling, an understanding of the data formats, and the possibility of developing user-services based on the open data set. This solution would quickly enable users to access data and services.

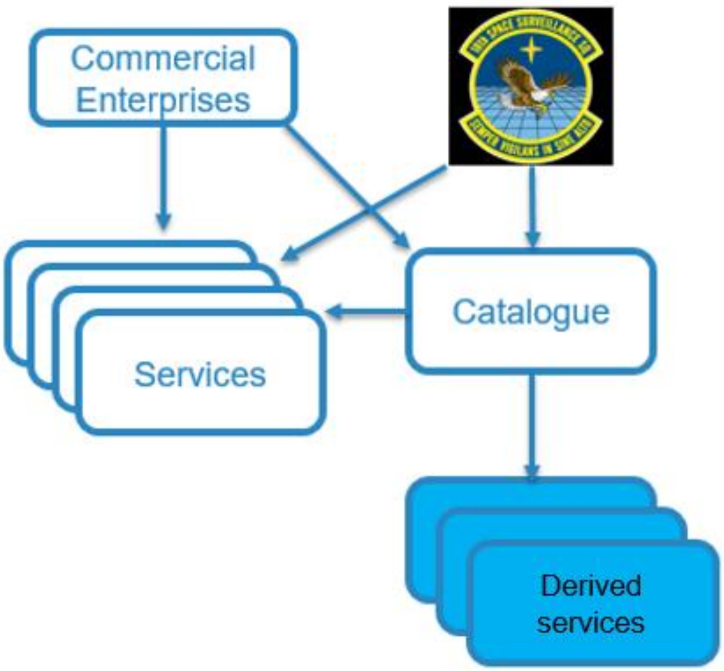

Figure 2. An illustration of the core components of the Level 1 SSA solution, based on openly available data. This system could either be based on data and services solely from spactrack.com, or in a combination with commercial data and services. To allow national expertise to grow, the system should allow for the development of specific national services.

Level 2 – Third-party sensor

In the second iteration, one or several third-party sensors are added to the system, in order to gain experience in how additional data sources can be handled and integrated into the SSA system, including components such as sensor planning, data processing, and incorporating the data into the national SSA database. These additions are illustrated in Figure 3. Further to the services available in the Level 1 design, this solution also adds the opportunity to conduct specific measurements of objects of interest, in order to gain better information of their status and orbital information, and it would also enable verification and validation of the open SSA data.

Level 3 – National sensor

In the final level, one or more national sensors are added to the system, as illustrated in Figure 4. With the lessons learned from the Level 2 design regarding sensor planning and data processing, many of the components required to run a sensor should already be in place. As the location of the sensor will determine which objects are observable (and how often), there may still be need for external data and information to keep the object catalogue up to date. Commercial sensor data might still be of interest as complementary information to the data from national sensor; however, the possibility of joining international partnerships, such as the EU SST, would also increase.

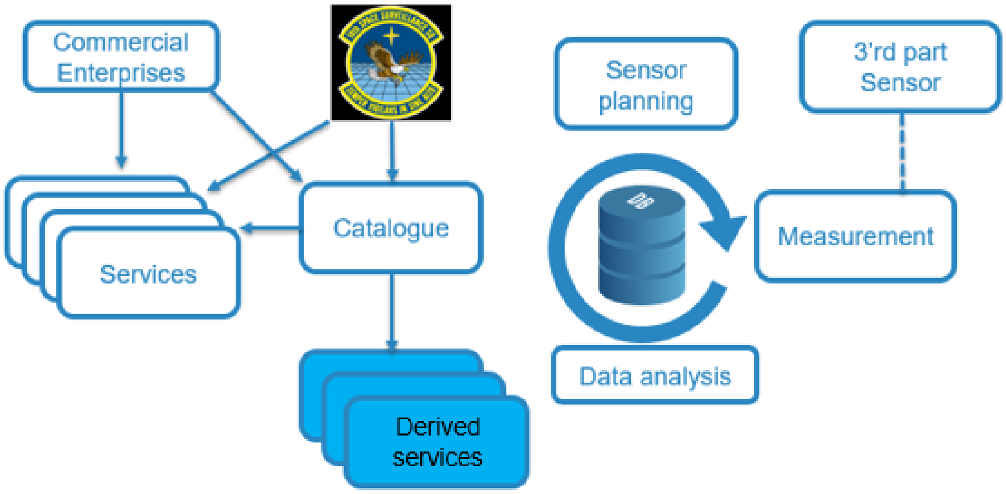

Figure 3: An illustration of the core components of the Level 2 SSA solution. This step builds experience in handling sensor data from external resources. The complete analysis cycle includes scheduling of new observations to keep data up-to-date.

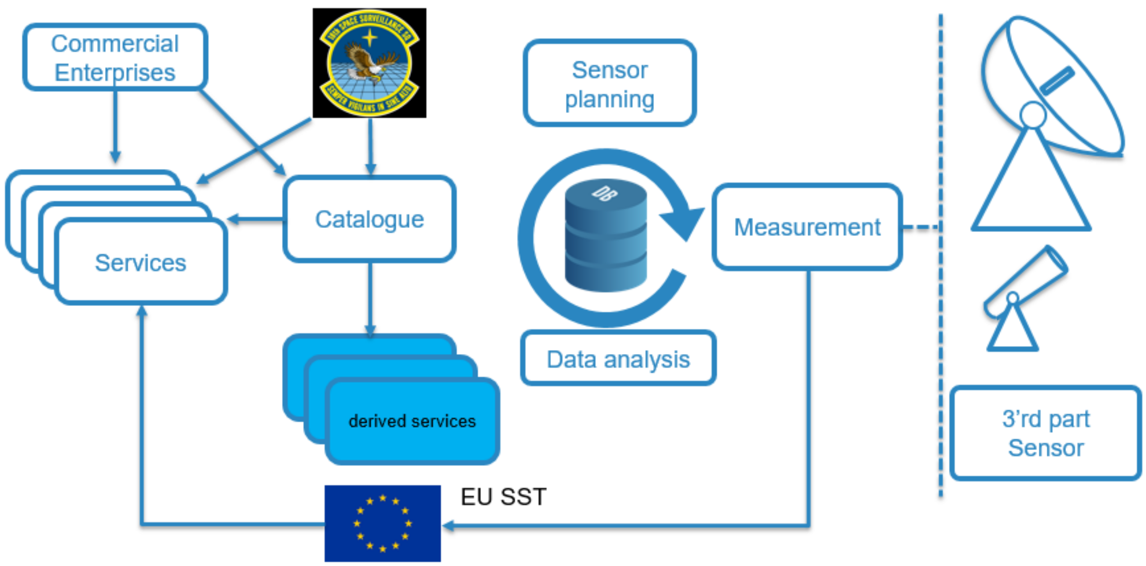

Figure 4. An illustration of the core components of the Level 3 SSA solution. This step includes one or more national sensors together with external data from available resources. The complete analysis cycle would be designed to allow for planning of new observations to keep data up-to-date.

Data processing chain

An additional important aspect is the SSA data-processing chain. The ESA SST Core Software is one possible tool in this process. The software, which is developed under the supervision of the ESA SST User Forum [2], aims to provide a complete SST data processing chain including features ranging from data inclusion from different sensors to derived services such as conjunction analysis and re-entry prediction. The software also allows for the joint development of new functions and services, which adds necessary flexibility to the system. The SST Core Software is thus considered as a plausible alternative for the data processing chain. At FOI, we are currently under way to set up a local test system, in order to evaluate the software properly, both in terms of present functionalities and future opportunities.

National interface
To improve the accessibility to the SSA service, it is preferable that all functions are gathered within a common web portal, even if the different data sources, information and services might be generated and distributed by several different entities, organisations, companies and/or agencies. All information should be accessible through a common interface, and it would be preferable if object data can be accessed by API to allow users to automate and tailor external services. By using secured access, this system could also handle some restricted functions, available only to authorized users.

SSA sensor options
Third-party sensors are considered useful for gaining knowledge on sensor options and sensor data handling. An initial step in the national implementation would be to include services generated from such external sensors, and then stepwise move toward the inclusion of raw sensor data. Raw sensor data would also require the inclusion of calibration and data-processing procedures, which are natural steps toward an eventual national sensor. This strategy would enable stepwise learning of the different components, and it is likely the easiest and fastest way to establish a national SSA service.

A reasonable long-term ambition would be to set up at least one dedicated SSA sensor nationally. A radar sensor located in the northern part of Sweden would for example have excellent coverage of low Earth orbit satellites with polar or near-polar orbits. Such a sensor would also make a useful contribution to the global SST network. An optical sensor in the same location would not be as practical however, as it would be restricted both by the bright summer nights and a requirement for clear skies.

As Sweden becomes a launching state, it will be of specific importance to keep track of satellites that have been launched under its jurisdiction. One promising solution for increasing the trackability of these satellites is a satellite laser ranging system (SLR) called the miniSLR [3]. This system, presented by Deutsches Zentrum für Luft- und Raumfahrt (DLR), consists of a small ground-based laser combined with passive retroreflector sensors on the spacecraft. If such retroreflectors would be included on all launched objects, this would enable precise orbit measurements with a system much simpler than an ordinary SLR. An advantage with the passive retroreflector is that it does not require any connection to the satellite bus, which means that it will remain functioning regardless of the satellite status, for example if the object fails before it de-orbits. This system could thus be beneficial both for Sweden to keep track of its own launched object, but also as a valuable resource for the satellite operator, as it could generate high precision orbit parameters directly after launch. The drawback with this system, however, is that it would not be able to operate on satellites without retroreflectors, and it also suffers from the same limitations that applies to optical sensors, *i.e.*, a requirement for clear and dark skies.

Other interesting research activities include for example investigations into the use of passive radar sensors or optical all-sky sensors networks to add supporting data to the dedicated SSA sensor systems using data fusion techniques. The new EISCAT-3D incoherent scatter radar, which is due to take its first measurements in 2022, also presents another potential source for high-quality research data. This new radar, which is funded and managed through an international research collaboration, is a state of the art-setup with one core transmitter site in Norway and three geographically distributed receiver stations, positioned in Norway, Sweden and Finland. Although the system has been designed, built and funded with atmospheric and ionospheric research in mind, it is apparent that this radar would make a first-class sensor for SSA-related research, in particular for detecting and tracking small debris objects in low Earth orbit or monitoring debris-generating events such as satellite collisions or explosions. There have been some investigations regarding the feasibility of using EISCAT-3D as an SST sensor [4, 5], and it is clear that if it can be used for space debris tracking for example, it could make a very important contribution to the global SSA network.

5. SUMMARY

In the wake of the national space strategy presented in 2018, the Swedish government has invested in the development of the Esrange space center into a spaceport for low Earth orbit satellites, and they are currently investigating the possible implementation of a national SSA service. This paper presents a three-step approach for how such a system could be implemented. The plan outlined benefits both from a relatively simple implementation in the first step, based on open data and services, while it at the same time offers a path for the eventual inclusion of new functions, data sources, and services. This process would allow users to gain experience and understanding of their SSA needs throughout the implementation process, which in turn can help guide and prioritize the development.

6. REFERENCES

[1] Government communication 2017/18:259. En strategi för svensk rymdverksamhet, 2018.

[2] J. Klug et al. Establishing a Community Approach to SST Core Software through a User Forum, *Proc. 8th European Conference on Space Debris*, ed. T. Flohrer, S. Lemmens, and F. Schmit, ESA Space Debris Office, 2021.

[3] D.Hampf et al., A path towards low-cost, high-accuracy orbital object monitoring, *Proc. 8th European Conference on Space Debris*, ed. T. Flohrer, S. Lemmens, and F. Schmit, ESA Space Debris Office, 2021.

[4] J. Kero et al. EISCAT 3D: The next generation international atmosphere and geospace research radar, *Proc. 1st NEO and Debris Detection Conference*, Ed. T. Flohrer, R. Jehn, and F. Schmitz, ESA Space Safety Programme Office, 2019.

[5] Vierinen, J. et al. Use of EISCAT 3D for observations of space debris, *Proc. 7th European Conference on Space Debris*, Ed. T. Flohrer and F. Schmitz, ESA Space Debris Office, 2017.