# Status and progress in the Space Surveillance and Tracking Segment of ESA's Space Situational Awareness Programme

**Emmet J. Fletcher**
*European Space Agency, ESAC, Villanueva de la Cañada, Madrid, Spain*
*E-mail: emmet.fletcher@esa.int*

**In November 2008, the European Space Agency (ESA) Council at Ministerial level approved the start of ESA's Space Situational Awareness programme. Between 2009 and 2012 a preparatory phase will run that will develop the architectural design of the system, the governance and data policy and the provision of precursor services in the areas of: Space Surveillance and Tracking, Space Weather and Near Earth Objects.**

**This paper will concentrate on the first of these segments: Space Surveillance and Tracking. It will develop the following main topics: Customer requirements and their integration, the initiation of an integrated catalogue, extension of correlated data to service provision and international cooperation and data fusion**

**The development of the services resulting from these points will be a key driver in the final architecture. This architecture will be proposed at the next Ministerial Council to further develop a full SSA system from 2012 onwards.**

## 1. INTRODUCTION

Space-borne systems have become indispensable components of modern life on a global basis. The growth of infrastructures, civilian, governmental and military, which rely on space-based assets, has been a major feature in the aerospace world and this growth shows no signs of diminishing. This tight interdependency has provoked concern regarding the protection of the space-based segment and the affects that any capability reduction would have on commerce, industry, research and civil defence.

Accurate, timely and comprehensive space situational awareness is instrumental for the protection of all critical European infrastructures in Space and for the secure and safe operation of its Space activities and services, as well as for the protection of the population in the case of re-entry events or possible NEO impact threats[1].

The development of an autonomous SSA capability will also assist Europe to fulfil its responsibilities with regard to the compliance with international treaties and codes-of-conduct, as well as providing an independent resource to the international community to verify third-party compliance with the same international framework.

During the European Space Agency (ESA) ministerial council of November 2008, these concerns were addressed with the creation of a Preparatory Programme (PP) to develop a Space Situational Awareness (SSA) system[23]. The goal of this programme is to provide a solid framework within which a full SSA system can be developed.

The ESA SSA PP was presented to the ESA Member States as an optional programme. To date, thirteen of the eighteen member states have joined the programme, ensuring funding for the lifetime of the PP. The programme has been divided into four main segments as follows:

- Core Element
- Space Weather (including Near-Earth Objects)
- Radar Element
- Pilot Data Element

The Core Element is the heart of the programme and activities carried-out include the development of the SSA Architecture, the definition of robust governance, data and security policies, as well as all activities relating to the Space Surveillance and Tracking (SST) segment.

The Space Weather Element not only incorporates the development of requirements for space weather services, but also incorporates the requirements generated by Near-Earth Object (NEO) services.

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*



| | | |
|---|---|---|
| 1. REPORT DATE<br>**SEP 2010** | 2. REPORT TYPE | 3. DATES COVERED<br>**00-00-2010 to 00-00-2010** |
| 4. TITLE AND SUBTITLE<br>**Status and progress in the Space Surveillance and Tracking Segment of ESA's Space Situational Awareness Programme** | | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**European Space Agency,European Space Astronomy Centre (ESAC),Villanueva de la Canada,Madrid, Spain,** | | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | | 10. SPONSOR/MONITOR'S ACRONYM(S)<br>11. SPONSOR/MONITOR'S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release; distribution unlimited**

13. SUPPLEMENTARY NOTES
**Advanced Maui Optical and Space Surveillance Technologies Conference, 14-17 Sep, Maui, HI. Sponsored in part by AFRL. U.S. Government or Federal Rights License**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **Same as Report (SAR)** | **9** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

Within the Radar Element, research and design related to the development of technologies is carried out that will lead to the design and build of prototype radar sensors – both for surveillance and tracking.

The goal of the Pilot Data Element is to develop the database capabilities both common and specific across the three service segments (SST, SWE and NEO) as well as implementation of strategies for data management and governance.

The PP is being developed in two parallel streams. The first is the development of the customer requirements, system needs and architectural design for a full SSA system. The second is the set-up of precursor services for the three service segments. These will be initially based on existing resources, sensors and competencies within Europe, but will be refined as the PP progresses to incorporate more advanced capabilities. More regarding the precursor services for the Space Surveillance and Tracking segment is described later in this paper.

## 2. SPACE SURVEILLANCE AND TRACKING

As a response to the programme declaration[3] a set of services was proposed to address the user needs in the area of SST. These services may address one or many service products and the performance, availability and limitations different across the range of available products. A first iteration produced a number of required services that should be expected from the SST element of the programme. The services identified are illustrated in Fig 1 and are as follows:

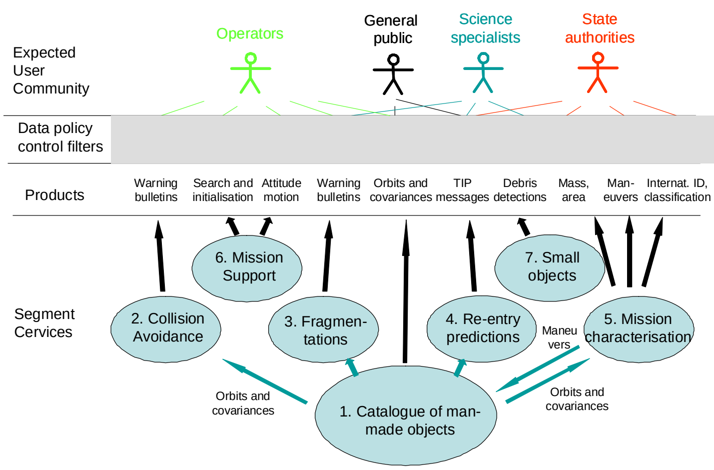


**Fig. 1. Services and expected user communities**

*1: Catalogue of Man-made Objects:* space surveillance and detection of objects, cold start of a catalogue with defined coverage requirements, maintenance of a catalogue with given accuracy constraints
*2: Collision Avoidance:* Conjunction analysis, refinement of the analysis and screening of user provided ephemeredes
*3: Detection and Characterisation of In-Orbit Fragmentations*: Screening of newly detected objects for those correlating from a common originator, identification of the originator objects and characterising the event, issuing warning bulletins
*4: Re-entry Predictions for Risk Objects*: Identification of risk objects that are close to a natural uncontrolled re-entry, prediction of re-entry location and epoch (with uncertainty information), refinement of the analysis in order to achieve the required prediction accuracy
*5: Object and Manoeuvre/Mission Characterisation*: Monitoring of objects to identify active spacecraft, data screening for orbit changes, characterisation of orbit changes
*6: Special Mission Support*: Follow-up of the objects of concerns, highly-accurate orbit determination, observation of object release, Observation of orbit changes,
*7: Characterisation of sub-catalogue debris*: Use of a limited amount of sensor time to characterise the sub-catalogue debris environment, databases with derived statistical information.

Even though diverse outputs will arise, it is expected that these services will be interdependent, with the catalogue being the core of the majority of these activities.

The second iteration was to ensure that the services listed above would meet the requirements of the user communities. A User Representatives Group (URG) was formed from those who would be considered to be future consumers of the products produced by the SST segment of the SSA programme. After consultation, a Customer Requirements Document (CRD) was created which further refined the scope and requirements of the final system[4].

## 3. PERFORMANCE[5]

The required performance of the system in any of the seven services is currently under evaluation. With the cataloguing being the core of all services, the following parameters have been identified as being the key to the overall performance and the main system design (and thus cost) drivers:

- The lower diameter cut-off envelope above which catalogue coverage has to be provided, and the level of coverage above this diameter cut-off
- The accuracy of the orbit information provided
- The overall availability of the information

Guidance for the selection of the associated performance figures are given through the program declaration[3] which mandates that the system is able to detect non-compliance with applicable international treaties and recommendations, support liability assessment and enable the allocation of responsibility for space objects to launching States or Organisations. One of the most predominant international recommendations related to space debris mitigation are the guidelines of the Inter-Agency Space Debris Coordination Committee (IADC)[6]. In this regard, a direct consequence of this request is the necessity to cover all man-made objects in the so-called protected regions. These regions (LEO 0 - 2000km altitude and GEO 35586 - 35986km) have the technical potential to cause a violation (payloads and rocket bodies) as well as causing wide-ranging damage to other systems (mission related objects, evidence for fragmentations). Evidence for fragmentations could be larger debris pieces or the visibility of changes to the parent object (e.g. loss of object) which would allow the exemption of fragments from this requirement.

Secondly, the program declaration[3] requires that the system supports the safe and secure operation of space assets as well as an accurate calculation of risk management (on orbit and during re-entry). This translates into a requirement for the generation of warnings for manoeuvrable spacecraft regarding hazardous conjunctions that would result in catastrophic collisions. Collisions between space objects are “catastrophic” when a certain energy/mass ratio is exceeded. This leads to a disintegration of the colliding objects and thus to a contamination of the environment that has the potential to trigger more catastrophic collisions. This requirement indicates that the system must be able to identify and issue timely warnings of catastrophic collisions involving European manoeuvrable space objects. This has two implications:

1. Objects with the potential to cause catastrophic collisions with European manoeuvrable payloads must be covered by the lower diameter cut-off envelope (which will include a significant share of fragments)
2. The accuracy associated of the orbit information (i.e. the final product after potential refinement actions) must be such that those hazardous conjunctions that would be missed are within reasonable system tolerances.

A ground-based space surveillance system cannot be expected to provide the same performance for all orbital regimes. Therefore the performance requirements over certain regimes can feasibly be relaxed in comparison to others. While Low Earth Orbits (LEO) will, typically, be observed by radar means; in moderate orbital altitudes, comparably small objects can also be covered and their orbits updated regularly. A high performance in detection sensitivity and orbit data accuracy is needed cover the needs for collision avoidance (which are the most demanding in LEO).

The considerations above lead to the definition of separate orbital regions with individual performance requirements, which are analysed below.

The regions are defined in order to reflect the system users' requirements for spacecraft protection, the monitoring of compliance with international ordinances as well the seven user services that were defined previously. Where user requirements allow, regions are limited to the minimum possible extent in order to keep the survey efforts within a manageable level. In addition, for passive optical telescopes, the altitude range in a region should be small in order to reasonably limit the range of possible angular velocities for an optimised detection. Further drivers for the definition of regions are a logical split of observation tasks between sensor types, catalogue size and the actual distribution of the objects. As a result of this the following regions have been defined:

LEO: 0 -2000km

- covers the IADC's definition of the LEO protected region
- covers the major density peaks in spatial density (vis-à-vis the collision avoidance needs)
- contains the majority of cases for LEOP support, Re-entry prediction support and the characterisation of in-orbit fragmentations (more than 80% of all historical detected fragmentation has occurred here)

GEO: 33786 - 37786km

- covers the IADC's definition of the GEO protected region including the graveyard orbits, but also potential disposal orbits of GEO insertion stages as well as the apogees of fresh GTOs
- contains ca. 400 operational payloads - which presents higher density than other areas for manoeuvre detection
- has a small range in inclination and angular velocities that allows for leak-proof surveys and accurate orbit determination results with a focused investment strategy

MEO: 12846km - 33786km

- has a high percentage of operational payloads when compared against the number of inactive satellites or fragmentary debris
- orbits in this region are concentrated in limited inclination bands with altitude boundaries that lend themselves well to optical detection

Gap (Lower MEO): 2000-12846km

- contains a low number of resident objects with a high range of angular velocities. Relatively difficult to acquire with cost-effective ground-based radar.

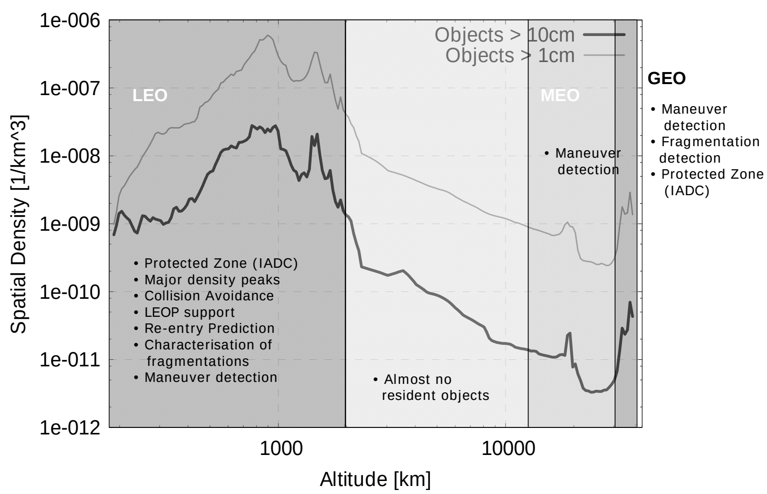


**Fig. 2 Orbit Regions**

The second major system design driver is the required accuracy that the orbit information shall be provided with. Accuracy of orbit information always needs to be looked as a function of time. Depending on the orbit type and the initial covariance, hence the uncertainty estimate for the state at orbit determination epoch, the orbit accuracy evolves over time. Most applications (in particular collision avoidance) require the orbit information to be accurate for a period of a few days, which corresponds to the time to plan, verify, implement, upload and execute a manoeuvre. For this reason, the concept of the so-called accuracy envelope has been introduced. It foresees a limit for the 1-sigma error in the three OCRF positional and the three OCRF velocity components (i.e. the envelope).

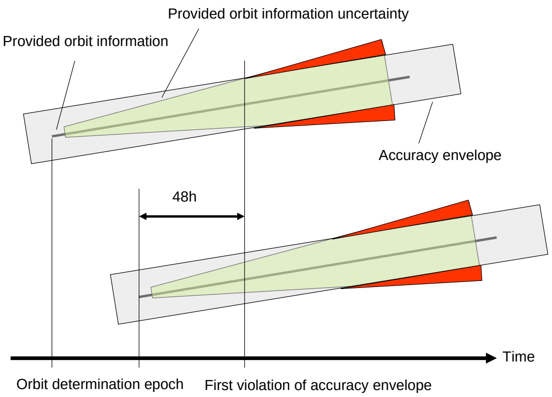


**Fig. 3 The accuracy envelope**

The orbit information is expected to come with its own 1-sigma uncertainty estimates for the same parameters. The user will be notified once the uncertainty estimates violate the envelope. The segment is expected to provide a new data set at least 48h before the envelope is violated for the first time (see Fig 3).

This concept gives the system designers the necessary room to trade-off between frequent updates of refreshed but less accurate orbit information, or rare updates of very precise data (with corresponding long validity). What remains to be defined is the accuracy envelope itself. Again, collision avoidance seems to be the most demanding service for this.

## 4. SYSTEM DESIGN

For further development, the customer requirements need to be converted into a system design that addresses these. In order to address this, contracts were issued to industry in order to complete this. These activities were divided into two main parts.

*Part 1:* To address the use of telescopes to cover Low Earth Orbit/Medium Earth Orbit regimes as a supplement to the use of surveillance and tracking radar operating in the same regimes. As discussed previously, even though optical systems have traditionally been used for high-altitude (> 12,000 km), the cost/result trade-off benefits were considered such that investigation was warranted to see if optical systems could reduce the power requirements for any future radar detection system.

This activity was divided into two parallel contracts in order to investigate two separate design strategies. The outcome and details of these designs is beyond the scope of this paper, but initial results are intriguing and the final results are expected to be delivered to the Agency before Q4 2010.

*Part 2:* Its main objective is to perform system engineering activities for the SSA system in order to produce the system requirements and a functional and physical architecture, to analyse the performance of the system, documenting and justifying the result of the analysis and the trade-offs made. The activity will also elaborate a number of solutions for the implementation of the SSA system that make use of ESA and ESA’s Member States SST, SWE and NEO existing assets. Finally, the activity will produce a cost estimate for each alternative solution envisaged for the implementation of the SSA system.

## 5. ARCHITECTURAL DESIGN

Naturally following on from the system design, the architectural design process must be initiated. As opposed to the system design, which was divided between the three segments (SST, SWE and NEO), the architectural design will be done on a SSA-wide basis, including all the three segments into a single architecture. The purpose of this is to identify and benefit from potential synergies across the three segments and avoid duplication of investments or system tasking.

## 6. SST PRECURSOR SERVICES

As described in the introduction to this paper, the PP is being developed in two levels. The second of these is the installation of precursor services across all three segments. Using existing resources, these precursor services aim to provide a subset of the services given by the full SSA system when developed, but provide various advantages to the programme.

The first of the benefits derived from the creation of precursor services in the SST segment is the ability to provide tangible benefits to European industry before the development of the full system. Within ESA, the capability to provide certain SST services is already well developed, although contained within the ESA infrastructure. Taking these services and providing them to a broader segment of European industry provides visibility of the work that is progressing and an indication of the potential as the full system is developed.

Secondly, the programme has a mandate to federate existing European capabilities. Given that many of these resources are held by academic, commercial, national or international entities, a range of different approaches can be made to utilise the available capacity. Some of these resources operate on a purely research level and hence cannot be expected to provide round-the-clock support, whilst others already have heavy demands placed on them and a careful integration approach must be made to ensure a smooth working relationship.

The precursor services allow different operational concepts to be approached and permit all parties to try and find the most advantageous techniques. As the precursor services are not fully operational, the ability to test these working methods outside of the stresses of a full operational system are advantageous, although operational procedures will be in place in order to replicate the potential environment of a full system.

As with European-sourced facilities, those technologies that need to be developed within the full SSA programme can be tested prior to a full deployment. Such critical technologies as database management, object correlation, orbit determination and conjunction prediction can be tested with representative data from real data sources. Even though a full catalogue would be unfeasible prior to a full-system deployment, the work with sample data will allow proportional validation of these technologies without large up-front financial or time investments.

A fourth benefit is within the realm of governance and data management. As with the precursor services, precursor data centres will be developed in the frame of the PP. It can be reasonably expected that the full system will need to handle data from both civilian and military or sensitive sources. To be able to test any data management, without the need to expose any sensitive data whilst providing a valuable resource will enable to reduce the potential risk involved when progressing to a full system deployment.

To this end, the Space Surveillance Test and validation Centre (SSTC) has been installed at ESA's facilities near Madrid, Spain. The SSTC will provide a test bed for all future services whilst providing a reduced set of services to the European user community.

The services that have been selected are those of collision avoidance and re-entry prediction. These were selected because they can both work on a reduced set of data, whilst the scalability of any system needs to be maintained when adding additional demands on the system (for example, when adding additional sensor feeds or frequencies). Both of these services will require the development of the technologies central to any full system (such as the development of a catalogue or efficient correlation techniques) but a complete data set is not required to test these techniques.

## 7. SST PRECURSOR SERVICES INITIAL DEPLOYMENT

In December 2009, an invitation to tender (ITT)[7] was placed by the Agency to enable the initial deployment of the SST precursor services. This tender, referred to as CO-VI, had four main goals:

1. Transfer the current conjunction prediction system used by the Agency to the SSTC.
2. Create a web-portal to enable system users to obtain and submit data to the system from outside the Agency
3. Validate the interoperability between disparate sensor resources across Europe
4. Design a data model for a future SST catalogue

The Agency currently uses CRASS (Collision Risk Assessment Software) to provide regular collision prediction for Envisat-1 and ERS-2 (both satellites operated by ESA). CRASS has proved to be a reliable tool for this task and hence it was decided to leverage this ‘experienced’ software within the initial deployment of the SSTC.

This deployment has now been made and the delivery of the associated web portal is expected before the end of 2010.

Given the wide range of sensors available across Europe, together with their individual origins, the federation of these sensors requires certain hurdles to be crossed. The main one of these regards the standardisation of data when exchanged across the federated network, as well as the fusion of data from different sources. As a baseline, it has been decided that the Consultative Committee for Space Data Systems (CCSDS) standards shall be used for this data exchange. The reasoning behind this is primarily because the CCSDS standards provide a flexible and widely used format to enable the efficient and precise transfer of both tracking data[8] and orbital position data[9]. As the CCSDS standards are commonly known and provide the detail that is needed for the current phase of the project, it is not considered prudent or necessary to create a new standard for this aim.

To test the ability of federated systems to provide data in CCSDS standards, a coordinated tracking campaign will be held during the end of 2010 to track known objects whose precise orbital parameters are readily available. Various sensors will be tasked to simultaneously track these objects. The resulting orbit determination results will then be tested and the resulting data then shared with the sensor operator. The final results of this exercise will provide indication as to the problems faced when attempting to perform sustained tracking or surveillance campaigns, a set of representative tracking data to assist in the development of future orbit determination algorithms and vital feedback to the sensor owners as to what, if any, problems were encountered and recommendations on how these campaigns can be improved.

The final task – to create a data model – will be provided to other areas of the SSA programme when designing the pilot data centres for the precursor services. Since a catalogue forms the heart of any SST system, the proper design of this is vital for future provision of services and the ability to extend the reach of the system as availability of input data and the needs of the user community grow. With a preliminary implementation of a data model, this should reduce the risk associated with the second stage of the precursor services when a precursor catalogue is created.

At the end of this contract, a list of recommendations will be created by the contractor regarding where current gaps in the precursor services design shall be rectified and the lessons learnt from the tracking campaign shall be detailed in to improve the coordination when data is required for orbital objects.

## 8. INTEGRATED CATALOGUE DEVELOPMENT

As indicated in the previously in this paper, the development of an integrated catalogue is at the heart of the majority of the services to be delivered by a full SST system. In the precursor services, it is not expected that a full catalogue will be initiated as a continuous supply of data is not available. However, a representative catalogue can be developed using partial data to enable test and validation activities to occur.

Chapter 3 of this paper refers to the performance factors that must be taken into account in a full SST system. The data representing the results of a system performing with in these requirements must be able to represent the state of the orbital environment in a manner that meets the same requirements. In order to test this, the design of the precursor catalogue must be – to all intents – identical to that of the full system catalogue. What will differ is the data held in the catalogue and the update frequency associated with each catalogued object.

Another factor that affects the design of a catalogue is the specific constraints placed within ESA regarding operational software. These constraints are designed to ensure both the traceability and future lifespan of any software tool used in an operational environment. As the aim is to as closely replicate a potential operational system as near as possible, then these constraints will also be taken into account in the precursor catalogue.

## 9. INTERNATIONAL COOPERATION

ESA has always worked to cooperate actively with its international counterparts. Many science missions have entailed a large degree of interdependency with the US, Russia, Japan, India and other agencies. SSA is no exception to this policy. ESA has received excellent assistance from the US to ensure that its satellites do not contribute to the debris population.

On Jan. 21, 2010, 02:53 UTC, Envisat-1 would have had a close conjunction with a 3.8 ton Chinese CZ-2 2nd stage at a distance of 48m. Due to the slightly eccentric CZ-2 orbit, with a correspondingly low accuracy of its Two-Line Element (TLE) data, the risk potential of the event was only detected by the US JSpOC (Joint Space Operations Center), who have access to precise orbit data and alerted ESA on Jan.18. The highest risk predicted with ESA's means described above using the TLE information was only 1/365096 due to a radial separation of -346m, hence far below any reaction threshold.

Based on 5 passes of the German TIRA radar, ESA established a fly-by geometry at a total distance of 48m, with 15m in radial and 7m in cross-track (see fig 4). This result closely matched the JSpOC forecast. This improved assessment results in a probability of collision exceeding 1 in 80. This was the highest risk that ESA had noted in 15 years of conjunction assessments. At the same time, it was the event with the largest combined masses (8 tons + 3.8 tons), exceeding the Cosmos-2251/Iridium-33 mass (that led to 1,500 tracked catalogue objects) by a factor of 7.6.

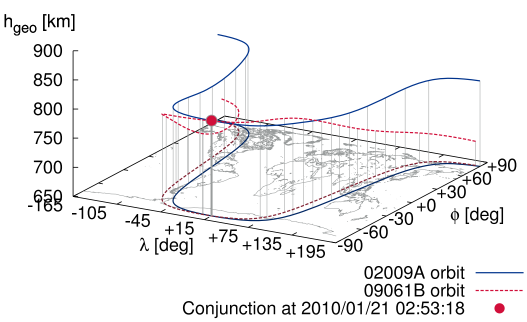


**Fig. 4 Envisat-1, CZ-2 conjunction geometry**

This example of international cooperation, initial alert triggered by the US, follow-up tracking delivered by Germany for a European spacecraft is a template for how the global SSA system should develop in the future. The development of internationally recognised – and used – standards is a central theme for this future cooperation. Fortunately, the CCSDS standards are widely recognised, although work will need to be made in such areas as conjunction warning, where no such standards are currently in place.

Cooperation between sensors is also envisaged. Even though the coordinated tracking campaign for the SSA PP is experimental for a specific aim, the IADC also performs regular coordinated tracking campaigns across the different communities. Extending this further enriches all parties through the improvement of tracking techniques, refining orbit determination algorithms and extending cross-entity communications and protocols.

## 10. CONCLUSION

The development of a European SSA system has a clear roadmap to the creation of a full SSA solution. Beginning from the original programme declaration, the user requirements have been developed and are in the process of being transformed into system requirements and from there into an architectural design. In parallel, the creation of precursor services allows future SST systems to be tested and evaluated using representative data from existing

European assets. The integration of these assets, taking into account their individual characteristics, as well as the standards required to guarantee precision for a future space object catalogue is being dealt with in an incremental manner with a view to replicating the needs and solutions for the full SST system.

International cooperation remains a priority in the baseline design of the system and past experience has show how vital this can be. The mutual development, maintenance and use of internationally recognised standards will ensure the ability of all nations to continue to exploit the near-Earth regime in liberty and safety.

---

[1] Bobrinsky N., Del Monte L. "ESA's Space Situational Awareness Programme", Proceedings of the 2nd CEAS, ISBN 1 85768 2130, Manchester UK, October 26-29, 2009.
[2] European Space Agency Council at Ministerial Level *Resolution on the role of Space in delivering Europe's Global Objectives.* ESA/C-M/CCVI/Res. 1 (Final), The Hague The Netherlands, 26 November 2008.
[3] European Space Agency Council, *Declaration on the Space Situational Awareness (SSA) Preparatory Programme,* ESA/C(2008)192, Att.: ESA/C/SSA-PP/VII/Dec. 1 (Final), Paris France, 8 December 2008
[4] *Space Situational Awareness – Surveillance and Tracking Customer Requirements Document* ESA internal document, SSA-SST-RS-CRD-1001, November 2009.
[5] H. Krag, H. Klinkrad, T. Flohrer, E. Fletcher and N. Bobrinsky, *The European space surveillance system – required performance and design concepts*, Eighth US/Russian Space Surveillance Workshop
Space Surveillance Detecting and Tracking Innovation, Maui, Hawaii. April 18 - 23, 2010
[6] Inter-Agency Space Debris Coordination Committee, IADC Space Debris Mitigation Guidelines, IADC– 02-01, Version 3.3, 15 October 2002.
[7] *Space Surveillance Precursor Services*, SSA-CO-SOW-COVI, Issue 1, 18 December 2009.
[8] *Tracking Data Message (TDM).* CCSDS 503.0-B-1. Consultative Committee for Space Data Systems. Blue Book Issue 1, November 2007
[9] *Orbit Data Message (ODM).* CCSDS 502.0-B-2. Consultative Committee for Space Data Systems. Blue Book Issue 2, November 2009