Space Weather risks for space operations and how these risks will be addressed in the ESA SSA Programme

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Space Weather represents a risk for spacecraft and astronauts when in orbit around Earth. Coronal Mass Ejections, Solar Energetic Particles events, Geomagnetic Storms, and other Space Weather phenomena can have a wide range of effects on Spacecraft, from Single Event Effects to total loss of the mission. They can also increase the radiation exposure of astronauts beyond the safe limit. Considering Space Weather and its effects during the design and operations of spacecraft therefore becomes essential. Space Weather is one of the segments that the European Space Agency (ESA) has included in the Space Situational Awareness (SSA) programme. ESA established a list of services that are to be provided during the execution of the programme. In order to better approach the different users, the Space Weather community has been divided into several User Domains, one of which is Spacecraft Operations. In this paper we will discuss how the services that ESA intends to provide to the Spacecraft Operations User Domain address the risks that Space Weather represents. We will discuss the relevant results of the "Provision of Space Weather Segment Precursor Services – Part 1: Definition and Service Consolidation" project (referred to as SN-I).This project has, among its key objectives, the identification of services needed by the community of users interested in Space Weather, and analysing any gaps with the service provision via assets already identified by the Agency. In addition we will discuss the Space Weather-dedicated User Portal and the services provided by it. This Portal will provide access to several ESA owned applications that will be redeployed into a common Data Centre, and to several 'federated' services that will remain hosted at the provisioning organisations. We will also present the architecture of the system and the services that it can provide to the Space Operations User Domain, as well as the concept of 'federation' as it has been implemented in SN-I. Finally the paper will discuss general ideas for the future evolution of the provision of services to the Space Operations user domain and community from the consolidated Space Weather data centre.

I. Introduction

THE European definition of Space Weather is "*the physical and phenomenological state of natural space environments. The associated discipline aims, through observation, monitoring, analysis and modelling, at understanding and predicting the state of the Sun, the interplanetary and planetary environments, and the solar and non-solar driven perturbations that affect them, and also at forecasting and nowcasting the potential impacts on biological and technological systems.*"[1]

The first part of the definition, "the physical and phenomenological state of natural space environments," by using the word "state", shows the transitory nature of the space environment conditions that constitute the Space Weather. It is in these changing conditions that Spacecraft need to operate. It is therefore necessary for the operators to understand the risks that Space Weather can pose to spacecraft and how important having access to forecast and nowcast services is for their activities.

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The Space Environment has negative effects on spacecraft that, though serious, are well known and they are constant over time. This means that they can be properly and fully addressed during the mission design. There are other effects that are dependent on the changing conditions of the space environment –that is Space Weather- that are more difficult to foresee during the design of the spacecraft and it will therefore be up to the operators to deal with the effects once these conditions arise. For example, Single Event Effects (SEE) can increase dramatically during Solar Proton Event (SPE) forcing spacecraft to get into safe mode or even put in risk the overall mission. It is in such situations that the understanding and mainly the predicting of the state of the Sun described in the Space Weather definition become of high importance to spacecraft operators. The European Space Agency (ESA) have compiled a Space Weather Effects Catalogue[2] that summarises the effects that Space Weather can have in different kinds of systems.

In 2008 ESA started the Space Situational Awareness (SSA) preparatory programme whose objective is "to support Europe's independent utilisation of, and access to, space through the provision of timely and accurate information, data and services regarding the space environment, and particularly regarding hazards to infrastructure in orbit and on the ground."[3] This programme has been divided into three segments: Space Weather (SWE), Space Survey & Tracking (SST), and Near Earth objects (NEO) each of which have their own set of projects. In this paper we will discuss what services the SWE segment of SSA have foreseen for the Spacecraft Operators.

RHEA has primed the SWE segment's project "Space Weather Segment Precursor Services – Part 1: Defintiion and Service Consolidation (SN-I)." One of the tasks included in this project is the determination of services requirements for all services that ESA. This task, that implied the writing of strategic roadmaps and the documentation of a requirements specification for the SWE services to be provided within SSA, was lead as well by RHEA. This gives us the necessary insight to discuss these services and to present them to the Space Operations community.

II. SWE segment services for spacecraft operators

The SSA SWE segment aims at providing services to different users needing information about Space Weather. For this purpose, the users for the segments have been classified into eight domains[4]:

- Spacecraft Design (SCD)
- Spacecraft Operation (SCO)
- Human Space Flight (SCH)
- Launch Operation (LAU)
- Trans-ionospheric radio communications (TIO)
- SSA Surveillance & Tracking (SST)
- Non-space System Operation (NSO)
- General Data Services[*] (GEN)

In this paper we will concentrate in the SCO User Domain (UD). For this User Domain ESA have defined the following services:

- In-orbit environment and effects monitoring
- Post-event Analysis
- In-orbit environment and effects forecast
- Mission analysis

Part of the work conducted in the SN-I project has been to clearly define these services. In order to do so, a service goal statement has been proposed to each of the services. The service goal statements for the SCO UD appear in Table 1.

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[*] General Data Services is not a user domain defined in the SWE website[4] but it was added in the course of the SN-I project

Table 1. Service goal statements for SCO

Service Name	Service goal statement
In-orbit environment and effects monitoring (IEEM)	Provide spacecraft operators with near real-time estimates of the space environment to correlate with spacecraft effects actually experienced.
Post-event Analysis (PEA)	Provide spacecraft operators with access to present and past space environment data to enable the correlation of a particular spacecraft event with space environment conditions.
In-orbit environment and effects forecast (IEFF)	Provide spacecraft operators with forecast of the space environment conditions and their effects on spacecraft in orbit.
Mission analysis (MA)	Provide spacecraft operators with data on the expected space environment conditions and a mission susceptibility assessment in order to enable to perform mission risk analysis.

In addition to the SCO specific services, the GEN data services are transversal to all of the other User Domains. These services with their service goal statements are listed in Table 2.

Table 2: GEN domain data services

Service Name	Service goal statement
SWE data archive (ARV)	Provide access to a long-term database (archive) of all available European space weather data.
Latest data guaranteed service (LST)	Provide to identified customers agreed sets of guaranteed data required as input to the provision of third party services.
SWE nowcast and forecast products (FOR)	Distribute reports and daily and weekly nowcasts and forecasts of agreed set of space weather parameters
Event-based alarms (ALM)	Issue automatically agreed set of space weather alarms as needed (based on subscription). Incorporate relevant data and where feasible rapid model outputs indicating likely consequences.
Virtual SWE modelling system (MOD)	Develop and provide access to an integrated and validated end-to-end space weather modelling and simulation system. Develop visualization tools for displaying the outputs.
Guaranteed data service for 3rd party added value service providers (DS3P)	Make available to third-party space weather service providers (commercial and non-commercial, external to SSA) a guaranteed set of data to be used for the development of customer oriented service products.

The above presented services are the main ones of SWE segment addressed to the Spacecraft Operators. There are in total 37 services distributed in all the user segments but those will not be discussed in this paper.

III. SWE induced risks mitigation with the SSA proposed services

In the Space Weather Effects Catalogue[2] the main Space Weather effects on spacecraft are identified:

- Variations on the atmospheric drag;
- Atomic displacement;
- Dark current increases;
- Surface charging;
- Internal charging;
- Single Event Effects (SEE);
- Orbital elements;
- Electrostatic discharges; and
- Collisions

These effects imply risks for spacecraft when they are exacerbated due to Space Weather activity. They can result in Single Event Upsets (SEU) in on-board computers, unexpected changes of orbit parameters, accelerated degradation of solar cells, electrostatic discharges, etc. Severe Space Weather events can even result on the total loss of the mission as the events of October/November 2003 remind us, when a series of strong Space Weather event led directly to over 70 recorded anomalies including the loss of the JAXA ADEOS-II (Midori-II) mission[5].

The SWE-related services proposed by ESA in the SSA programme are transversal to typically most or all of these risks. The Precursor services will initially be based on the re-use of a small number of mature assets, but in parallel the full Service Development Roadmaps have been derived for the future system. For the Roadmaps, the full assets set available to the ESA SSA system has been critically reviewed, and the optimal set of assets proposed for each of the 37 Services so that all Service Requirements can be met. Where development work will be needed, this is clearly identified, and a strategic plan for undertaking the development and deployment activities within the timeframe of the SSA programme is presented. For some more specific services in other User Domains, the number of assets identified and number of development steps can be rather small. For the four services within the SCO domain, however, this will not be the case, since the numbers of both potential assets and service requirements are large. The final services made available to the SCO user community in the future SSA system will be complex and powerful tools allowing spacecraft operators to comprehensively reconstruct and forecast the space environment and its recorded and potential impacts on systems operating within it.

IV. The Space Weather-dedicated User Portal and the services provided by it

Over several years ESA have addressed several of the risks mentioned above. As a result of many projects in different areas, ESA have either developed or sponsored the developed of many information systems capable of providing information to mitigate the risks. An important objective of the SSA programme is to create a consolidated infrastructure that will be able to provide many of the services from a centralised ESA-controlled location.

In order to achieve this consolidation, an important part of the SN-I project was to create a preliminary system based on the deployment of several ESA owned applications into a common data centre hosted at the Euro Space Center in Red. The work implied porting the applications into a common operating system baseline and deploying it into the data centre. Additionally they were integrated into a web portal so they can all be presented under a single interface to the users. These applications are:

- Space Environment Data System (SEDAT);
- Space Environment Information System (SPENVIS);
- Open Data Interface (ODI);
- Ionosphere Monitoring Facility (IONMON);
- Space Weather European Network (SWENET); and
- European Impact Detector Database (EDID).

The applications allow providing occasionally fully, or more generally partially, some of the SCO services mentioned above. As outlined in Section III, the initial SCO services will be provided using only these redeployed assets, but as the system evolves they will be augmented by additional assets following some development and/or deployment activities. This process will continue in each case until all service requirements are met and the service can be considered to be fully operations-ready.

During the preparatory phase of the programme the applications have been redeployed "as is." This means that there is no consolidated architecture and some replication, mainly on the level of data bases, might exist. Figure 1 shows the high level architecture of the infrastructure deployed during the SN-I project to host the redeployed applications and start with the service provisioning via web to the SWE users community.

In Figure 1 it can be seen that each of the applications have been deployed into their own virtual machine. All of the virtual machines use the same OS baseline –which meant that all of the applications that came from different platforms had to be ported into this new common baseline. EDID and SWENET that use their own databases have been deployed with their respective databases included in the same virtual machine. Additionally a unique web portal was developed to provide a single point of access to all users including a single sign on functionality.

Users will be able to access the system via their web browsers using a user and password that will grant them access to the systems that they have registered to work with. Additionally user support is assured by the SWE Service Coordination Centre (SSCC) which will handle user registration, incident management, and first line user support. For scientific and engineering queries the SSCC will count with the support of Expert Service Centres (ESC).

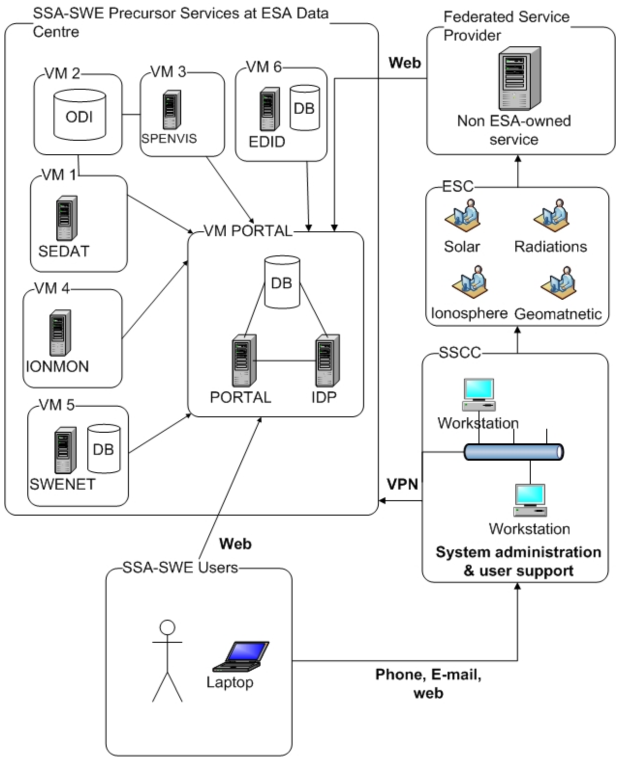

Figure 1. SWE precursor services infrastructure as built in the SN-I project

Services may be available through the SWE infrastructure via a federated approach. Technically this has been defined as presenting a service provided by a third party via the ESA's portal in an iFrame. The third party provider is invited to keep its visual identity to accentuate the character of collaboration between ESA and the service provider.

At the time of writing the system is on final acceptance testing. It is expected to be open to the public during the second quarter 2012.

V. Future evolution of the provision of SWE services

The precursor SCO services will be provided using a limited number of assets which do not address all the service requirements. The full scope of development and deployment activities which will be needed in order to arrive at fully operations-ready services have been identified in the parallel Roadmapping activity. Thus on a service-by-Service basis, a reviewed, prioritised list of key assets and the necessary developmental activities is available. Most of these assets have not been developed via ESA activities, and so the owners and developers will need to be engaged to establish the viability of implementing the Roadmaps as they currently stand, and the impact to the overall system of doing so. It is expected that most non-ESA assets will be federated into the final system, but the actual means of federation will vary from asset to assets and the initial priority order is likely to evolve. This is especially true in the case of the SCO services where we face a large number of service requirements to meet, and a large number of assets for potential re-use.

Technically speaking the portal and associated services could be improved by adopting a consolidated architecture, mainly when it comes to databases. At the moment three different Database Management Systems (DBMS) are used, each of them deployed in the same machine as their associated application sometimes with two different instances of the same DBMS running for two different applications. Significant improvements in performance and security could be achieved by consolidating all the databases into a single DBMS deployed in a secure network.

The offer of services could be expanded by bringing more ESA owned applications to the data centre or by making agreements with organisations to provide services via the federation concept. The latter could be improved by offering different options other than the iFrames used during SN-I.

Appendix A
Acronym List

ALM	Event-based alarms
ARV	SWE Data Archive
DBMS	Database Management System
DS3P	Guaranteed data service for 3rd party added value service providers
EDID	European Impact Detector Database
ESA	European Space Agency
ESC	Expert Service Centre
FOR	SWE nowcast and forecast products
IEEM	In-orbit Environment and Effects Monitoring
IEFF	In-orbit Environment and Effects Forecast
IONMON	Ionosphere Monitoring Facility
GEN	General Data Services
JAXA	Japan Aerospace Exploration Agency
LAU	Launch Operations
LST	Latest data guaranteed service
MA	Mission Analysis
MOD	Virtual SWE modelling system
NASA	National Aeronautics and Space Administration
NEO	Near Earth Objects
NSO	Non-space System Operation
ODI	Open Data Interface
OS	Operating System
PEA	Post-Event Analysis
SCD	Spacecraft Design
SCH	Human Space Flight
SCO	Spacecraft Operation
SEE	Single Event Effects
SEDAT	Space Environment Data System
SEU	Single Event Upsets
SN-I	Space Weather Segment Precursor Services – Part 1: Definition and Service Consolidation.
SSA	Space Situational Awareness
SSCC	SWE Service Coordination Centre
SPE	Solar Proton Event

SPENVIS	Space Environment Information System
SST	Space Survey & Tracking
SWE	Space Weather
SWENET	Space Weather European Network
TIO	Trans-ionospheric radio communications
UD	User Domain
VM	Virtual Machine

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