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# Satellite Anomaly Analysis and Prediction System

## SAAPS – WP 210 Satellite Anomaly Analysis Module User Requirements Document

ESA/ESTEC Contract 11974/96/NL/JG(SC)

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## Abstract

This document describes the user requirements of the satellite anomaly analysis module. The satellite anomaly analysis module is one component in the Satellite Anomaly Analysis and Prediction System (SAAPS).

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## 1 Introduction

### 1.1 Purpose of the document

The Satellite Anomaly Analysis and Prediction System (SAAPS) contain 3 subsystems: the database and database tools (DBT), the satellite anomaly analysis module (SAAM), and the satellite anomaly prediction module (SAPM). The purpose of this document is to capture the user requirements for the SAAM.

### 1.2 Scope of the software

#### 1.2.1 Introduction to SAAPS

The space plasma and radiation form a hazardous environment to Earth orbiting spacecraft. Spacecraft problems are regularly experienced which in extreme cases lead to a failure or loss of the spacecraft. The anomalous behaviour of spacecraft can partly be explained by technological problems or by the human factor, and partly by the space environment.

SAAPS is intended to be a web-based tool for the analysis and prediction of spacecraft anomalies. Spacecraft engineers shall be able to analyse the space environment data to better understand situations for spacecraft anomalies. Spacecraft operators can use SAAPS for real-time monitoring of the space environment data and to make predictions of future anomalies.

The user of SAAPS shall have access to a database of space weather data, tools for analysing the data, and models for the prediction of spacecraft anomalies. The database shall be updated in real time from various external databases on the Internet. The user shall also have access to online documentation and guidelines of what tools to use for a specific problem.

#### 1.2.2 Satellite anomaly analysis module

With the SAAM it shall be possible to analyse the situation at times of anomalies based on the data in the database. The user can submit a point, or a set of points, in time, which could be the time of an anomaly, and get a summary plot of the parameters in the database at that time. He can select which parameters that he wish to study and the time interval around the event. It shall also be possible to plot the data in geographic or (B,L) coordinate systems, and to retrieve data from the closest space weather satellite. The user can also submit a time series of events and perform statistics on the parameters and correlate them with anomalies in the database. The SAAM can also use the SAPM to conclude which of the pre-existing anomaly prediction models that makes the most accurate predictions of the user anomalies. It shall also be possible to generate new models for predictions.

The type of statistics that shall be available are: linear correlation, superposed epoch analysis, cluster analysis, and pattern search.

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### 1.3 Definitions, acronyms and abbreviations

ACE	Advanced Composition Explorer
DBT	database tool
DB&T	database and database tool
GOES	Geosynchronous Operational Environmental Satellites
IMF	interplanetary magnetic field
IRF	Swedish Institute of Space Physics (Institutet för rymdfysik)
LANL	Los Alamos National Laboratory
NaN	Not a Number
NSSDC	National Space Science Data Center
SAAM	satellite anomaly analysis module
SAAPS	satellite anomaly analysis and prediction system
SAPM	satellite anomaly prediction module
SPEE	study of plasma and energetic electron environment and effects
UL1	user level 1
UL2	user level 2
WDC	World Data Center

### 1.4 References

1. ESA software engineering standards, ESA PSS-05-0 Issue 2, February 1991.
2. Guide to the user requirements definition phase, ESA PSS-05-02 Issue 1, October 1991.
3. Fu, LiMin, Neural networks in computer intelligence, McGraw-Hill, Inc., 1994.

### 1.5 Overview

The structure of this document follows the document template as described in the ESA software engineering standards [1] and user requirements guide [2].

Section 2 describes, in general terms, the user requirements of the SAAM. Then, in Section 3, the requirements are itemised as a number of capability requirements and constraint requirements.

## 2 General description

### 2.1 Product perspective

The SAAM is one module of the SAAPS. The SAAM shall communicate with the DBT to access the database and it shall communicate with the SAPM to access the anomaly prediction models. The SAAPS is a standalone system.

### 2.2 User characteristics

There shall be two levels of user access to SAAPS: user level 1 (UL1) and user level 2 (UL2).

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### 2.2.1 User level 1

At UL1 one shall have full access to the data, source codes, and documentation. This shall only be a hand-full of people that are involved in the development and the maintenance of SAAPS. One such user is the system manager of SAAPS. The system manager should have a good knowledge of computers, web techniques, and Internet. He should have good knowledge in HTML and Java programming. He is also responsible for the extension of the database, which might come as a request from UL2 that wish to add new data. However, all new data that are added must first be agreed by ESA/ESTEC. It is especially new satellite anomaly data that will be added in this way.

### 2.2.2 User level 2

At UL2 we shall find the users that are interested in the SAAPS as a tool, and at least two groups can be identified: spacecraft engineers and spacecraft operators. The access to SAAPS at UL2 shall be via a web browser.

If a user wish to add new anomaly data he must be registered to SAAPS. The registration can be made the first time the user submits data, and after approval by ESA/ESTEC he shall obtain a user id and password for future use. The user id shall be related to the coding scheme to ensure confidentiality.

### 2.2.3 The SAAM user

Anyone potentially interested in studying spacecraft anomalies can use SAAM, but the tools shall be developed with the spacecraft engineers and operators in mind. The SAAM user shall be able to run all the different models and tools from a web browser. If he also contribute with satellite anomaly data he shall be able to perform a more detailed analysis on his own data. Typically, he would be interested to deduce whether an anomaly was space weather related, get the typical space weather conditions for different anomaly sets, and correlate anomaly sets against each other. The predictions models in the SAPM shall also be available to the SAAM user. This gives the possibility to examine what model gives the best agreement with a certain anomaly set. This is especially useful for the spacecraft operator that wish to run SAAPS for real time predictions.

## 2.3 General capabilities

### 2.3.1 ~~Summary plots~~Plotting function

With the ~~summary plots~~plotting function the user can produce plots of all the parameters in the database and of predicted anomalies based on the different prediction models. From the web page the user thus selects one or several of the parameters in the database, one or several of the prediction models, and the time period. The summary plot will be useful for single event studies to get an overall view of the space weather conditions. The data shall be presented either as time series plots, or as geographic or (B,L) plots.

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### 2.3.2 ~~Data gaps~~Filters

Most of the data in the database will have occasional data gaps that have to be treated before any further analysis can be made. Here, a linear filter can be used to interpolate missing values. Other possibilities include statistical methods and neural networks.

Generally, the different parameters in the database will have different time resolution. To be able to calculate correlations between parameters the time resolution must be the same. The linear filter can be used to average high-resolution data to match the resolution of another parameter.

### 2.3.3 Statistics

The user shall also be able to perform various statistics on the parameters in the database. The statistics that shall be included are: linear correlation, superposed epoch analysis, cluster analysis, and pattern search. The statistics function shall, when needed, interact with the linear filters to provide a contiguous time series of uniform time resolution.

To perform superposed epoch analysis the user must submit a list of events, which could be a list of anomaly events. The parameters to be considered and the time interval around the event are then selected and plots of the results shall be presented.

The user can also do correlation studies between the parameters. Two or several parameters are selected to calculate the correlation matrix. The time period and possible time shifts between the parameters can also be chosen.

Various types of cluster analysis shall be provided. The simplest form of cluster analysis for a two-dimensional problem is simply to plot one parameter versus the other, and graphically locate possible clusters. Other types of cluster techniques shall be studied, and possibly included in SAAM, and two examples can be k-means clustering and self-organised maps [3]. This study will be part of the technical note of WP 220.

Pattern definition and search algorithms shall be provided for the time series data. The pattern definition can be provided from a single event case or superposed epoch analysis. Providing upper and lower limits for the pattern, other similar patterns can be found that lies within the bounds. Again, more sophisticated methods, such as neural networks can be used, and it will be examined in the technical note of WP 220.

### 2.3.4 Guidelines

Guidelines on how to proceed with the further analysis shall be automatically generated and provided to the user. Assume that the user has a small set of anomaly events (<10), that makes it difficult to perform any statistics, he could then be encouraged to plot the anomaly data in different coordinate systems and/or as a function of local time. He could then continue to look at various parameters and prediction models and compare with the anomaly events. On the other hand, if the user has a large set of anomalies, then he can proceed with the statistical methods.



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### 2.3.5 Estimate best anomaly prediction model

There will be several different models for the prediction of satellite anomalies in the SAPM. Currently, a neural network model is used to forecast satellite anomalies based on daily sums of Kp. Other models shall be developed (WP300) for predictions on different time scales and using other input data from the SAAPS database. Using the SAAM the user shall be able to determine the best model for his satellites from his own experience of satellite anomalies. The user should thus submit a list of anomaly and no-anomaly events and then the best prediction models shall be suggested.

## 2.4 General constraints

The database contains reported satellite anomalies that are to be treated as confidential information. Therefore, it shall only be possible for UL2 to retrieve summary information of the anomalies that will not reveal the origin of the data. UL1 shall have full access to the data.

If a user (UL2) wish to add data to the database he can not do so directly. Instead he shall fill in a web form that will be sent to the SAAPS system user, and after approval from ESA the system user can update the database.

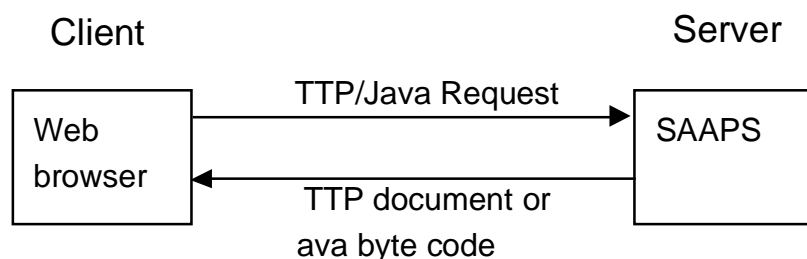
The SAAM shall be operated via a web browser.

## 2.5 Assumptions and dependencies

The SAAM works together with the DBT and the SAPM of SAAPS.

## 2.6 Operational environment

The SAAM shall be platform independent. To fulfil this requirement SAAM shall be written in Java. The module shall be operated via a web browser such as Microsoft Explorer 4 or Netscape Communicator 4 (Figure 1Figure-1). During the contract time the module will be running on a server within the IRF, and at the final presentation be delivered to a server at ESTEC.

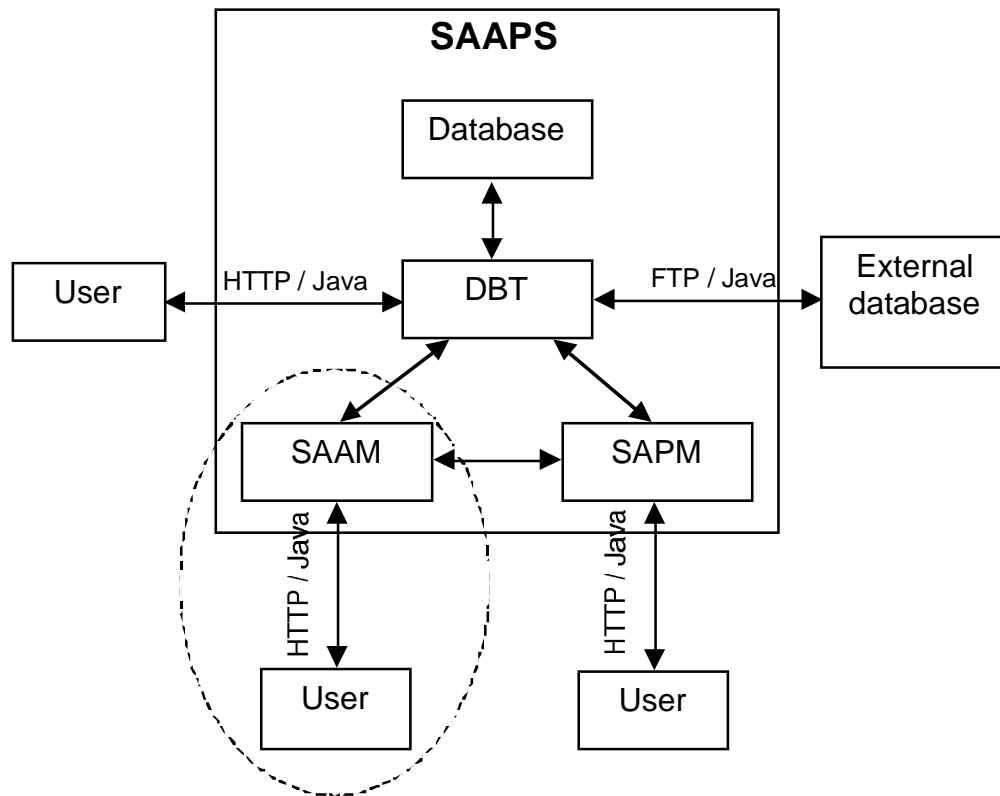


**Figure 1** The figure illustrates the communication between the client (user) and the server.

The SAAPS can be further divided into its subsystems as shown in Figure 3Figure-2. The SAAM will have three interfaces that have: access to the database via the

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database tool (DBT), access to the prediction module ([SAPSAPM](#)), connection to users via a web browser.



**Figure 32** The SAAPS contains the three subsystems: database and database tool (DBT), satellite anomaly analysis module (SAAM), and the satellite anomaly prediction module (SAPM). The encircled region is described in this document.

### 3 Specific requirements

The specific requirements are divided into two categories: capability requirements and constraint requirements. The capability requirements describe what the user wants to do and one requirement defines an operation that the software shall be able to perform. The constraint requirements place restrictions on how the user requirements are to be met. Each requirement has a unique identifier with the following fields:

1. **SAAM.**, indicates that this requirement is part of the satellite anomaly analysis module,
2. **CAP.** or **CON.**, capability or constraint requirement,
3. a sequential number.

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### 3.1 Capability requirements

<b>SAAM.CAP.1.</b>	The SAAM shall operate on the data from the SAAPS database.
Source	Section 2.3
Criticality	Mandatory
Verification	Retrieve data from the database.
<b>SAAM.CAP.2.</b>	The SAAM shall have <del>time-series</del> -plotting capabilities for <del>all the parameters in the database</del> <u>two dimensional data</u> .
Source	Section <u>2.3.1</u>
Criticality	Mandatory
Verification	Produce plots <del>of all the parameters</del> .
<b>SAAM.CAP.3.</b>	The SAAM shall have an interface to select which parameters to study.
Source	Section 2.3.1
Criticality	Mandatory
Verification	Select different parameters.
<b>SAAM.CAP.4.</b>	The SAAM shall have an interface to select the time period to study.
Source	Section 2.3.1
Criticality	Mandatory
Verification	Select different periods.
<b><u>SAAM.CAP.5.</u></b>	<u>The SAAM shall have a function to calculate positions in (B,L) coordinate system.</u>
<u>Source</u>	<u>Section 2.3.1</u>
<u>Criticality</u>	<u>Mandatory</u>
<u>Verification</u>	<u>Interpolate data gaps.</u>
<b>SAAM.CAP.6.</b>	The SAAM shall have a function to interpolate data gaps <del>with a linear filter</del> .
Source	Section <del>2.3.2</del> <u>2.3.2</u>
Criticality	Mandatory
Verification	Interpolate data gaps.

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<b>SAAM.CAP.7.</b>	The SAAM shall have a function to calculate the time average of a parameter.
Source	Section <del>2.3.2</del> 2.3.2
Criticality	Mandatory
Verification	Calculate time averages for all parameters in the database.
<b>SAAM.CAP.8.</b>	The SAAM shall have a function to perform superposed epoch analysis.
Source	Section 2.3.3
Criticality	Mandatory
Verification	Calculate superposed epochs for all parameters in the database.
<b>SAAM.CAP.9.</b>	The SAAM shall have a function for calculating the correlation matrix.
Source	Section 2.3.3
Criticality	Mandatory
Verification	Calculate the correlation matrix for all parameters in the database.
<b><u>SAAM.CAP.10.</u></b>	<u>The SAAM shall have a function for cluster analysis.</u>
<u>Source</u>	<u>Section 2.3.3</u>
<u>Criticality</u>	<u>Mandatory</u>
<u>Verification</u>	<u>Submit a anomaly data set and determine best prediction model.</u>
<b><u>SAAM.CAP.11.</u></b>	<u>The SAAM shall have a function for pattern search.</u>
<u>Source</u>	<u>Section 2.3.3</u>
<u>Criticality</u>	<u>Mandatory</u>
<u>Verification</u>	<u>Submit a anomaly data set and determine best prediction model.</u>
<b><u>SAAM.CAP.12.</u></b>	<u>The SAAM shall automatically generate user guidelines for the operation of SAAPS.</u>
<u>Source</u>	<u>Section 2.3.4</u>
<u>Criticality</u>	<u>Mandatory</u>
<u>Verification</u>	<u>Submit a anomaly data set and determine best prediction model.</u>
<b>SAAM.CAP.13.</b>	The SAAM shall have a function for determining the best anomaly prediction model based on user anomaly data set.
Source	Section 2.3.5
Criticality	Mandatory
Verification	Submit <u>an</u> anomaly data set and determine best prediction model.

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### 3.2 Constraint requirements

<b>SAAM.CON.1.</b>	The SAAM shall <u>only</u> be accessible from a web browser.
Source	Section 2.4
Criticality	Mandatory
Verification	Demonstrate with a web browser.
<b>SAAM.CON.2.</b>	The SAAM shall have access to the database via the DBT module.
Source	Section 2.6
Criticality	Mandatory
Verification	Demonstrate with a web browser.
<b>SAAM.CON.3.</b>	The SAAM shall have an interface to the SAPM.
Source	Section 2.3.5
Criticality	Mandatory
Verification	Demonstrate with a web browser.