Appendix 1 to AO/1-3306/97/NL/NB

Space Weather Modules and Solar Proton Events Model

STATEMENT OF WORK

ESTEC/WMA/97-163/AH
Issue-3

Contents

1. Introduction

Space missions are becoming steadily more demanding, both in terms of what is expected of payloads through improved performance and higher sensitivity, and in terms of what is expected of spacecraft platforms themselves. High performance microelectronics, CCD and electrostatic sensors, solar cells, and optical systems all suffer interference, e.g. radiation "background", SEU or degradation as a result of energetic particle radiation. Astronaut radiation hazards are an additional concern. The plasma environment, together with energetic electrons, can cause electrostatic charging leading to electrostatic and electromagnetic perturbations, e.g. discharges.

A common characteristic of the charged particle environments (plasma and radiations) is their strong time and spatial variability due to the dynamics of the solar-terrestrial system. Early tools for predicting environmental effects on space systems were based on empirical averaged models of the various components of the environment. Models have improved by taking into account time variations of the environment (e.g. the solar cycle). This opens up the possibility of taking counter-measures against effects, adapted to a specific time period and orbit of a platform. More accurate and flexible tools such as software able to generate maps of percentiles of space environment parameters and of their effects are expected from the development of physics-based simulations of the environment and the building of large and rapidly accessible data bases. The present study is directed toward the latter aspect of the problem.

2. Objectives

The principal objectives of this activity is to establish a new type of engineering analysis method which replaces the traditional role of the empirical model by a data-driven system which can be interrogated to give taylored results in real-time from extensive databases. This makes immediately available, in a suitable format, as much as possible information of the space environment as it has been actually measured by spacecraft detectors.

An example of this is the need for a model of the fluorescence induced by magnetospheric electrons in the keV range in a grazing incidence mirror for X-ray detectors [1]. The standard AE-8 radiation model provides long-term averaged data of the flux for electrons with energy above 40 keV. For the X-ray mirror the energy needed to be considered is as low as 1 keV and the long-term averaged flux is not useful. The relevant information are the percentiles of the distribution of probability of the fluorescence level as a function of the location along the orbit.

The tools to be developed for the study will be capable of providing such an information while the input parameter will be: (1) the orbit specification, (2) the data sets to use, (3) the spectral response function of the mirror as a function of the energy of the particles.

It appears that such an approach is very generic and could be applied for instance to the study of radiation dose deposition behind a shield, simply by modifying the input, i.e., the data set to use and the response function. Also using a response function equal to unity over given locations, time window intervals, or beyond given threshold values can be used for correlation studies of, e.g. operational anomalies, or to generate maps of given environmental parameters. Therefore such a database is also providing a mean to update several kinds of models like radiation maps or solar proton events data base. As an example an updated list of the solar proton events including solar cycle 22 can be produced by specifying the selection criteria for solar flare identification.

Meanwhile solar proton fluence statistics for time period shorter than one year can be produced in real-time by the software.

The software will be a WWW server with an "engineering console" giving access to one or database possibly distributed over several sites. Access and process tools will be provided in order to generate basic functionalities as requested by the applications planned for this study. As a minimum it will be able to generate maps of percentile of environmental parameters from several data sets according to selection criteria (e.g., running averaged time window length, geomagnetic or geographic location, response function).

The data currently used at ESA for space environment analysis will be integrated in a database for this study. However, the database and basic access tools could be based on an already existing programme with its own funding (ESA or other). In this case, the amount and quality of data made available from the contractor side, and the synergy with existing ESA sponsored and contractor activities will be explicitly described in the offer. The magnitude of the work and the amount of the current contract is intended to cover (1) the cost of the integration of the data currently available at ESTEC, (2) the maintenance and the access right for ESA for a period of at least 5 years, (3) the development of the generic analysis tools, (4) the testing of the software by performing some space environment analyses.

3. Work break down structure

The work to be performed under the present contract is broken down in three parts.: (i) core data integration, (ii) development of space environment analysis generic tools, (iii) testing of the software on environment analysis applications.

3.1 Integration of the core data in a database

The data available and currently used for charged particle environment analysis at ESTEC were collected with the following instruments:IMP (via OMNIWEB),GOES (via NOAA), Meteosat/SEM 2, ISEE-1 and ISEE-2, REM on STRV and MIR, CRRES/MEA, AZUR/EI-88, SAMPEX/PET, and UARS/HEPS.

They basically consist of flux values of ions or electrons for given energy ranges, dates and locations. Some of them include directional information as well. The contractor shall put these data ("core data" hereafter) in a format that has to be agreed by ESA. In the following, these data combined with the part of contractors data that will be accessible to ESTEC at the end of the contract will be named "Space Environment Data" or SEDAT. Basic functionalities, i.e., updating routines, access and visualisation tools are also required.

3.2 Development of space environment analysis generic tools

The contractor shall develop process tools able to operate on the SEDAT database for space environment analysis activity. Such tools shall at least be able to generate the probability distribution functions and the corresponding percentiles of any environmental parameter in the database or of any function of environmental parameters (e.g., a detector response function) as a function of spatial coordinates. In addition an orbit generator and a magnetic field model (e.g. Tsyganenko model [2]) will be integrated such that the distribution function could be computed and parametrized as a function of magnetic coordinate, geographic coordinate and orbital coordinates of any mission.

The user interface shall be a WWW browser.

3.3 Application of the software

In order to demonstrate the capability of the software, the contractor shall undertake four basic space environment analysis tasks based on this software, two for an interplanetary environment and two for the magnetospheric environment.

A significant test of the new capability of the software shall be the solar proton fluence prediction which tradionally relies on "a priori" models of the statistical distribution of events. Therefore a dedicated study of the comparison with the prediction of the JPL-91 model [3] and a solar proton radiation analysis will be undertaken. Other, magnetospheric, applications will be a correlation study of a set of spacecraft anomalies with the space environment and the computation of the occurrence of fluorescence induced noise background in a detector.

4. Work Packages description

The detailed requirements are given below. For work packages WP101, 103, 301, 302, 303 and 304, Technical Notes shall be produced, describing the background and methods used, and reporting the results. All documents shall also be produced in HTML format.

4.1 Integration of the core data in a database

WP 101: User Requirements Documents

The contractor shall produce the URD for the database to be created with the core data, possibly integrated in an existing database at the contractor's premises. The data that will be used include as a minimum the ones produced by the following instruments:

IMP (via OMNIWEB),GOES (via NOAA), Meteosat/SEM 2,ISEE-1 and ISEE-2, REM on STRV and MIR, CRRES/MEA, AZUR/EI-88, SAMPEX/PET, and UARS/HEPS.

The two first data sets are in the public domain and can be freely accessed or purchased at a relatively low cost. The other seven data sets have been purchased by ESA for other studies and could be made available by ESA to the contractor. At this stage of the study the contractor can update his proposal to modify the amount of data belonging to the data sets that will be integrated. Such a modification will require ESA approval.

The contractor shall also produce the URD for the environment analysis generic tools that will operate on the database. As a minimum the tools shall be able to generate the probability distribution functions and the corresponding percentiles of any environmental parameter in the database or of any function of environmental parameters (e.g., a detector response function) parametrized as a function of spatial coordinates.

The user interface shall be a WWW browser. The user shall be able to interrogate the database by selecting: the sets of data that are thought to be relevant for the analysis,the environmental parameter (e.g., flux in given energy range),the response function (e.g., integrated flux over an energy domain or a time domain, any function to be convoluted with the spectral flux, or a combination of environmental parameters),the type of output requested, i.e., probability distribution function of the value of the flux (or of the response function,) or percentiles of it.additional specification of the output, e.g., distribution over a spatial domain (geographic or geomagnetic coordinates), distribution over orbital position (including orbit averaged), bin sizes or bin numbers, distribution computed over a discrete set of positions or period of times.

Provision of error bars and uncertainty shall be considered. Sets of defaults inputs, e.g., the one to generate radiation analysis in dose-depth curve shall be included in the software. In addition an orbit generator and a magnetic field model (e.g. Tsyganenko model [2]) will be integrated in the software such that the distribution function could be computed as a function of magnetic coordinates, geographic coordinates and orbital coordinates of any mission. Another requirement of the software is that it shall be able to perform the tasks described in work packages WP301, 302, 303 and 304. Basic access routines, display routines and updating routines are also required. Prototyping activities will take place during this work package and will be described in a technical note.

WP 102: Format definition, SRD and ADD for the SEDAT database

Upon approval of the URD documents, the contractor shall produce the Software Requirements Document and the Architecture Design Document for the SEDAT database and the basic access, display and updating tools. This activity includes the study of the best suited format for the data. Some of the core data being also planned to be included in the SPENVIS system [4], the contractor shall discuss and examine with the SPENVIS team the possibility of using the same format and the same structure for the database. If this be finally not the case a clear and motivated justification shall be given.

WP 103: Integration of the core data and development of the SEDAT

Upon approval of the SRD and ADD of WP102, the contractor shall develop the SEDAT and the basic access, display and updating tools. A technical note describing the SEDAT and the User Manual for the SEDAT and the basic tools shall be produced at the end of this work package.

4.2 Environment analysis generic tools

WP 201: SRD and ADD for the environment analysis generic tools

Upon approval of the corresponding URD, produced in WP101, the contractor shall produce the SRD and ADD for the environment analysis generic tools aimed to operate on the SEDAT.
The contractor shall study distributed solution for the data.

WP 202 Development of the environment analysis generic tools

Upon approval of the SRD and ADD of WP201, the contractor shall develop the environment analysis generic tools for the SEDAT and produce the User Manual for them.

4.3 Applications of the software

WP 301: Solar proton events model

A significant test of the new capability of the software will be the solar proton fluence modelling which tradionnally relies on mathematical models of the statistical distribution of events. Therefore a dedicated study of the comparison with the JPL 91 model shall be undertaken in this work package.

The contractor shall produce a test plan to make use of the above software to generate percentile of the solar proton fluences at 1 AU above 1, 10, and 100 MeV for 3 months, 1 year and 2 years missions and compare them with the prediction of the JPL-91 model. It is expected that data from solar cycles 20 to 22 will be used. Prior to this, the JPL-91 model shall therefore be updated using the same procedure as described in reference [3,5,6,7] but including the events of solar cycle 22 in order to update the parameters to fit the log-normal distribution of the amplitude of the events and the Poisson distribution of their occurrence.

The search for solar proton events and the production of their distribution in time shall be attempted using the environment analysis generic tools, however, this is not mandatory. However, the production of the empirical distribution of the integrated fluence of the events shall be generated with the help of the tools developed in WP202.

Upon acceptance of the test plan by ESA the contractor shall perform the tasks agreed and produce a technical note on the result of this study, describing the updated solar proton events model and the comparison with the new data driven model. Problems related to data gaps [8] will be taken into account and discussed.

WP 302: Radiation environment analysis for the cruise phase of an interplanetary mission

The contractor shall produce a test plan to use the software in order to generate the dose-depth curves due to radiation behind a given shielding, including radiation belts and solar proton events, for a given mission orbit that shall be specified by ESA at the beginning of this work package.

Upon acceptance of the test plan by ESA the contractor shall perform the tasks agreed and produce a technical note on the result of this study.

WP 303: Correlation of spacecraft anomalies with environment data

The contractor shall produce a test plan to make use of the database in order to study a set of anomalies experienced by an ESA spacecraft. The anomaly data would be provided by ESA at the beginning of this work package. This will consist of the orbit specification of the spacecraft and the time of the anomalies. The contractor shall perform correlation analyses with relevant sets of data available from SEDAT for this period. The correlation will consist of the generation of the histograms of the value of the investigated environmental parameters for the anomaly date and for the non anomaly date. Departure between the two histograms can be taken as a measure of the correlation [9]. The study shall evaluate what energy range of electrons is most likely involved in the anomaly process and what are the typical time scales of accumulation of the electrons before an anomaly occurs. Example of similar studies are given in [9,10].

Upon acceptance of the test plan by ESA the contractor shall perform the tasks agreed and produce technical note describing the results.

WP 304: Fluorescence induced noise in an X-ray detectors

The contractor shall produce a test plan to make use of the database in order to compute the noise induced in XMM X-ray detector due to electron scattering through the mirror shells. The input from ESA would be the orbit specification of the spacecraft and the function relating the input spectrum of particles to the noise level (response function). The contractor shall produce as an output the histogram of the occurrence of the noise level as a function of the position along the orbit.

Upon acceptance of the test plan by ESA the contractor shall perform the tasks agreed and produce a technical note on the result of this study and comparing with a previous study that made use of ISEE-2 data only [1].

5. Management

The standard requirements for Management, reporting Meetings and deliverable (Appendix 2 to the contract) shall apply to the present activity, taking into account the following specific requirements, which shall prevail.

5.1 Reporting

Detailed technical notes shall be produced for work packages WP101, 103, 301, 302, 303, and 304. Draft technical notes shall be provided to ESA, allowing for at least a 1-week review period.

5.2 Deliverables

Para. 4.1.1 is not applicable.

Para 4.4 is not applicable.

Computer programs: All software and data bases developed under this contract, together with the associated documentation, shall be delivered.

Delivered software as a source code and associated documentation shall be guaranteed for a six-month period following the date of the provisional acceptance of the software. Further data, documentation, computer output, plots, graphs or drawings acquired or produced during the course of the contract shall be identified and kept available to ESA.

5.3 Commercial evaluation: applicable.

6. Software Development:

All developed software shall conform to ESA Software Engineering standards as defined in the section `Applicable documents'. Programming shall be performed either in ANSI Fortran-77 or Fortran-90 or in C. The target computer system shall be either a DEC-Alpha running the Ultrix operating system, a HP station running HP-UX operating system or a SUN station running Solaris system, or a PC with Windows 95, linked to the Internet networks. The PV-Wave, IDL, HTML analysis and graphics packages may be used in parts of this work agreed with ESA.

Final versions of all developed software shall be installed at ESTEC by the Contractor at the time of the final presentation when a detailed instruction course of 1 day duration shall also be performed. Draft software developed shall be installed at ESTEC by the Contractor at the time of completion of each respective work package, when similar training of 1 day duration shall be given. As part of the software engineering process for each work package, software test plans shall be prepared by the Contractor and approved by ESA.

7. Applicable documents:

"ESA Software Engineering Standards', ESA PSS-05-0 Issue 2, February 1991" with the restriction contained in "Guide to applying the ESA software engineering standards to small software projects, BSSC(96)2 Issue 1, May 1996" shall apply.

8. Reference list

[1] Hilgers, A., Scattering of low energy electrons in X-ray grazing incidence XMM telescopes: environmental input data and mathematical model, ESTEC report EWP 1942, 1997.

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[3] Feynman, J., G. Spitale, and J. Wang, Interplanetary proton fluence model: JPL 1991, JPL memorendum 5217-92-23, 1992.

[4] http://www.spenvis.oma.be/

[5] Feynman, J. G. Spitale, J. Wang,, and S. Gabriel, Interplanetary proton fluence model: JPL 1991, J. Geophys. Res., vol. 98, pp13,281-13,294, 1993.

[6] Feynman, J. G. T. P. Armstrong, L. dao-Gibner, and S. Silverman, New Interplanetary Proton Fluence Model, J. Spacecraft and Rockets, vol. 27, pp 403-410, 1990.

[7] Tranquille, C., and E. J. Daly, ESA Journal, vol. 16, p 275-, 1992.

[8] Evans, H., Severity of solar cycle 22 in terms of solar proton events, internal memorandum, /esa/estec/wma/he/col_cycles/1, Oct 29, 1996.

[9] Lopez Honrubia, F. J., and A. Hilgers, Some Correlation Techniques for Environmentally Induced Anomalies Analysis, Journal of Spacecraft and Rockets, in press, 1997.

[10] Rodgers, D. J. ,E. J. Daly, A. J. Coates and A. D. Johnstone, Correlation of Meteosat-3 Anomalies with Data from the Space Environmental Monitor, European Space Agency, EWP-1620, June 1991.