A00-16273

AIAA 2000-0371

ESA's Space Environment Information System (SPENVIS): A WWW Interface to Models of the Space Environment and its Effects

D. Heynderickx, B. Quaghebeur, and
E. Speelman
Belgisch Instituut voor Ruimte-Aeronomie
Brussels, Belgium

E. Daly
ESA Space Environment and Effects Analysis Section
Noordwijk, The Netherlands

38th Aerospace Sciences Meeting & Exhibit
10-13 January 2000 / Reno, NV

AIAA-2000-0371

ESA'S SPACE ENVIRONMENT INFORMATION SYSTEM (SPENVIS): A WWW INTERFACE TO MODELS OF THE SPACE ENVIRONMENT AND ITS EFFECTS

D. Heynderickx, B. Quaghebeur, E. Speelman
Belgisch Instituut voor Ruimte-Aëronomie
Ringlaan 3
B-1180 Brussels, Belgium

E.J. Daly
ESA Space Environment and Effects Analysis Section
Keplerlaan 1
NL-2200 AG Noordwijk, The Netherlands

ABSTRACT

ESA's SPace ENVironment Information System (SPENVIS) provides standardized access to models of the hazardous space environment through a user-friendly World Wide Web interface. The interface includes parameter input with extensive defaulting, definition of user environments, streamlined production of results (both in graphical and textual form), background information, and on-line help. The system can be accessed at the WWW site
http://www.spenvis.oma.be/spenvis/. Intranet versions are also available, and a new Java based server/client system is in the final stages of development. SPENVIS Has a continuously expanding international user community (over 450 registered users), and its set of models and functionalities is continually increased. SPENVIS Is designed to help spacecraft engineers perform rapid analyses of environmental problems and, with extensive documentation and tutorial information, allows engineers with relatively little familiarity to produce reliable results. It has been developed in response to the increasing pressure for rapid-response tools for system engineering, especially in low-cost commercial and educational programmes.

INTRODUCTION

The planning of space missions requires an analysis of the space environment and its impact on space systems. The space environment includes the following hazardous environments:

- radiation environment due to the radiation belts, solar particles, and cosmic rays;
- the plasma environments of the ionosphere and geomagnetic substorms;
- neutral gaseous environments, including atmospheric atomic oxygen;
- micro-meteoroids and space debris;
- magnetic fields;
- solar emissions.

Empirical or quasi-empirical models of these hazardous environments have been developed by different organizations, often independently of one another. As a consequence, the availability of existing models is not always known to potential users. In addition, the issue of updating models and acquiring up-to-date versions is not straightforward.

The SPace ENVironment Information System (SPENVIS) developed for ESA/ESTEC provides easy access to most of the recent models of the hazardous space environment, in combination with an orbit generator, via an integrated user-friendly World-Wide Web (WWW) interface. The interface includes parameter input with extensive defaulting, definition of user environments, streamlined production of results (both in graphical and textual form), background information and on-line help. The tools are harmonised with the European standard on the space environment, currently under parallel development.

GENERAL FUNCTIONALITY

The SPENVIS system makes full use of the WWW facilities through the following features:

- access via computer networks to a centralized system;
- easy-to-use input facilities making extensive use of default values for the various input parameters, hierarchical structuring of input, and input validation;
- identification of users allowing for the creation of personalized environments, in which previous results and inputs are retained, even when leaving the system;
- automatic and/or user-specified generation of output, both plots and tables, as in-line images or downloadable graphical formats;
- extensive on-line help and links to in-depth documentation.

The URL of the SPENVIS system is `http://www.spenvis.oma.be/spenvis/`.

At the heart of SPENVIS is the project concept. A project is defined as the collective input to and output from the SPENVIS system for a series of related runs. This approach ensures that all the inputs and the outputs of a run are conserved, so that an analysis can be performed over more than one session.

SPENVIS Is based on internationally recognised standard models and methods in many domains. It uses an ESA-developed orbit generator to produce orbital point files necessary for many different aspects of mission analysis, and can also generate maps and profiles to study the geographical distribution of most model parameters.

The results of a SPENVIS model run are presented in the form of reports and data files that can be downloaded by the user, and as a variety of plot types (line plots, maps and 3-D plots) in different graphics formats (GIF, PS, JPG, VRML, ...).

Extensive help facilities are provided in SPENVIS: context-sensitive help pages provide information on the model parameters and usage, background pages contain in-depth material on the space environment and models, and a user guide and links to other sites are available as well. The help pages are cross-referenced for fast navigation, which is further enhanced by a search engine.

SPENVIS MODELS

Most of the models implemented in SPENVIS require as input a set of points on a spacecraft trajectory or a user-defined set of geographic points. These sets of points are produced by two tools: the orbit generator and the coordinate grid generator. When running the orbit or grid generator, all outputs previously obtained with models that use the respective coordinate tool, are deleted. This is to ensure consistency between results, and to avoid errors in the plotting routines that produce the graphical output. The input parameters for the models are not deleted, so that they can be run again in the same way. The models in SPENVIS have been organised in packages, which are described in the sections below.

Radiation analysis

The radiation tools include:

- radiation belt models: the NASA models AP-8 and AE-8[1], the AFRL models CRRESPRO[2] and CRRESELE[3], and models developed recently[4] (in the framework of ESA TRP contacts) with data sets including SAMPEX[5], CRRES/MEA[6] and AZUR[7], and a model of the low-altitude trapped proton anisotropy.
- solar proton models: JPL-85[8], JPL-91[9] (see Fig. 1), King[10];
- CREME[11] for cosmic rays.

The conversion of geographic to magnetic coordinates is done internally without interference from the user, ensuring consistency in the application of field models, often a source of confusion and error. Internal and external magnetic field models can also be run separately to study the distribution of the magnetic field and related parameters over an orbit or a grid of geographic coordinates, or to generate and visualise magnetic drift shells.

SPENVIS Contains the SHIELDOSE[12] and SHIELDOSE-2 codes for total dose assessment and the EQFRUX[13] and EQFRUXGA codes for solar cell damage-equivalent fluences (1 MeV electron equivalent). Figure 2 shows the equivalent fluences of trapped protons and electrons and solar protons in a GaAs solar cell for an 800 km heliosynchronous orbit. These tools have been augmented by a code for computing the Non-Ionizing Energy Loss (NIEL)[14] or non-ionizing dose. This parameter is gaining importance since it represents the best way to quantify the environment for assessing displacement damage effects such as charge transfer efficiency degradation of CCDs, and is now proposed as a better parameter for solar cell damage assessment. Figure 3 shows the NIEL of trapped and solar protons for an 800 km heliosynchronous orbit, as a function of Al shield radius.

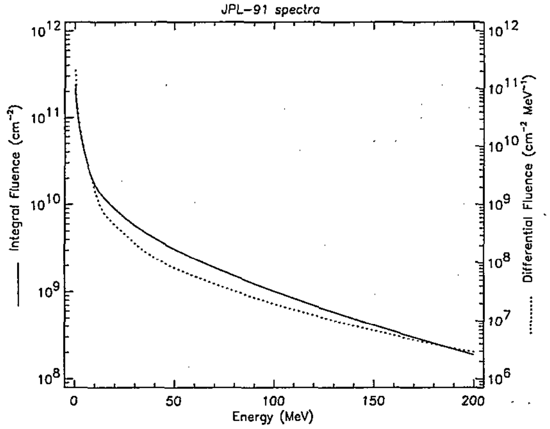

Figure 1. Integral and differential solar proton spectrum for an 800 km heliosynchronous orbit

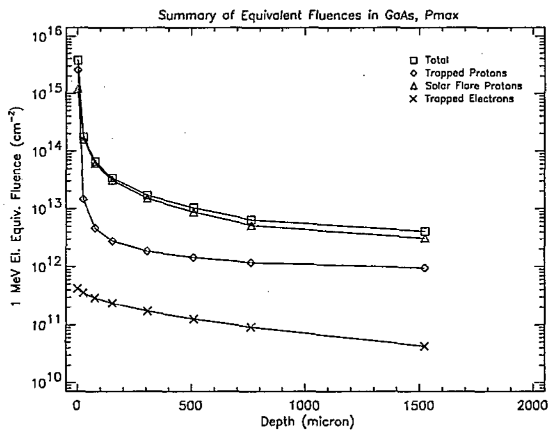

Figure 2. Equivalent fluences in a GaAs solar cell for an 800 km heliosynchronous orbit

In conjunction with CREME and the trapped and solar proton models, the user can compute single event upset rates from cosmic and solar ions and trapped and

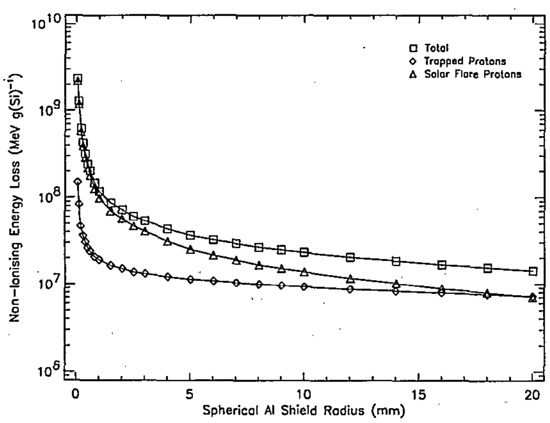

Figure 3. Non-ionising energy loss as a function of Al shield radius for an 800 km heliosynchronous orbit

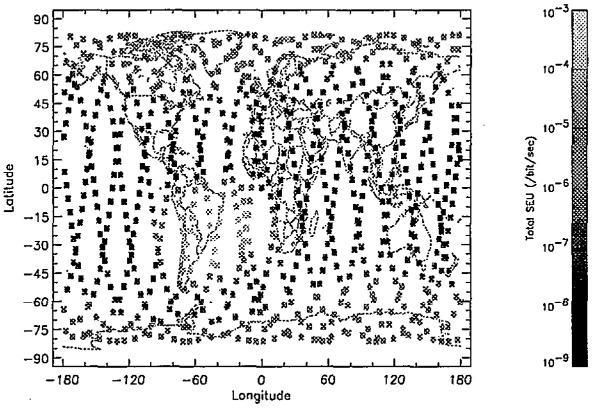

Figure 4. Single event upset rates along an 800 km heliosynchronous orbit

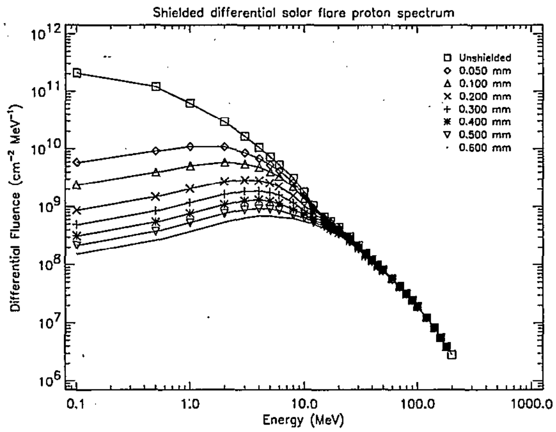

Figure 5. Shielded differential solar proton spectrum for an 800 km heliosynchronous orbit

solar protons (shown in Fig. 4 for an 800 km heliosynchronous orbit). In computing all these parameters, spacecraft or solar cell coverglass shielding is taken into account. Figure 5 shows the shielded differential solar proton spectrum for an 800 km heliosynchronous orbit, for different Al shield radii. A geometric tool to calculate shielding distributions for simple spacecraft geometries is currently under development.

The trapped particle models can also be run on a coordinate grid. Figure 6 shows the AE-8 MAX electron flux > 2 MeV on an invariant coordinate grid.

Magnetic field

The most commonly used internal and external magnetic field models have been implemented in SPENVIS. The magnetic field models can be evaluated over a spacecraft trajectory or a coordinate grid. The output from the SPENVIS implementation of the models contains the (B, L) coordinates, the invariant coordinates (R, Λ), magnetic longitude and latitude, the

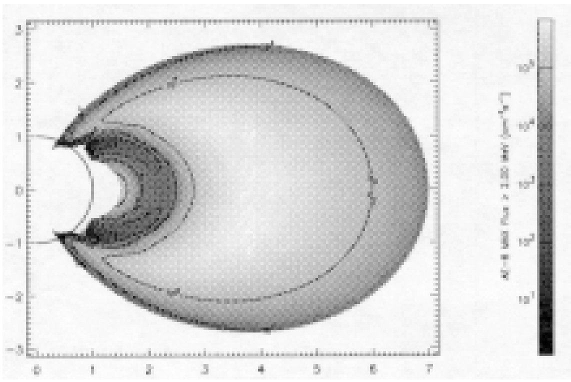

Figure 6. Invariant coordinate map of the AE-8 MAX electron flux > 2 MeV

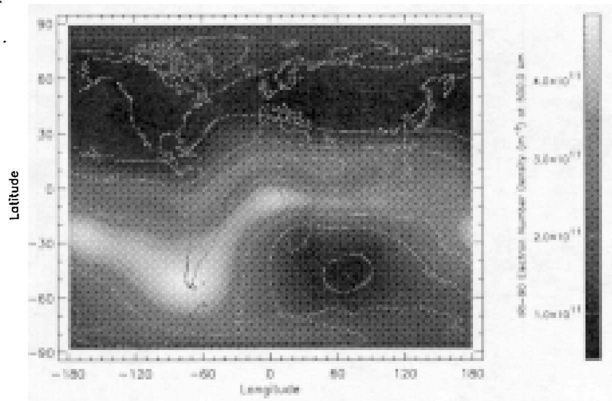

Figure 8. IRI-90 Electron number density at 500 km altitude

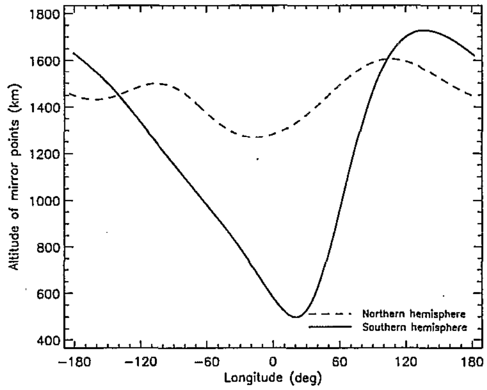

Figure 7. Northern and Southern mirror point altitudes for the drift shell $L = 5, B = 0.3$

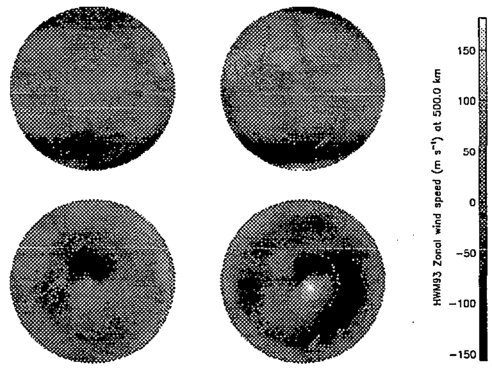

Figure 9. Representation of the HMW-93 zonal wind speed at 500 km altitude

magnetic field vector components, and the location of the footpoints. In addition, field line traces are plotted, and three-dimensional plots of drift shells are available. Figure 7 shows the mirror point altitudes for the drift shell $L = 5$, $B = 0.3$. The magnetic field models and related utilities have been implemented using the UNILIB subroutine library developed by BIRA/IASB (available at http://www.magnet.oma.be/home/unilib/).

Atmosphere and ionosphere

The following neutral atmosphere and ionosphere models have been implemented in SPENVIS: MSISE-90[15], MET[16], DTM 78[17], HWM 93[18], IRI-90[19]. These models can be evaluated over a grid of points to produce world maps of densities or temperatures (see Figs. 8 and 9), over a coordinate range to produce density profiles, or over a range of one of the model parameters for one geographic point (see Fig. 10). In addition, number densities can be calculated along a spacecraft trajectory, and particle fluxes and fluences on an oriented surface can be determined (see Fig. 11).

Spacecraft charging

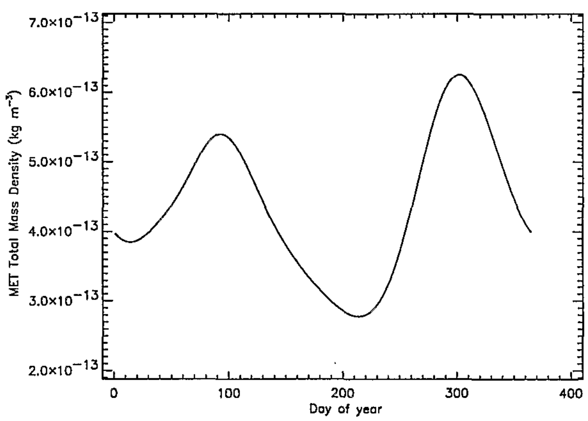

Figure 10. MET Total mass density at 500 km altitude as a function of day number

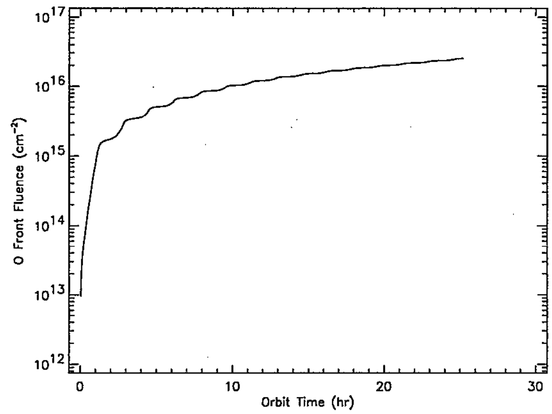

Figure 11. MSISE-90 Atomic oxygen fluence on a plate perpendicular to the spacecraft velocity vector for an 800 km heliosynchronous orbit

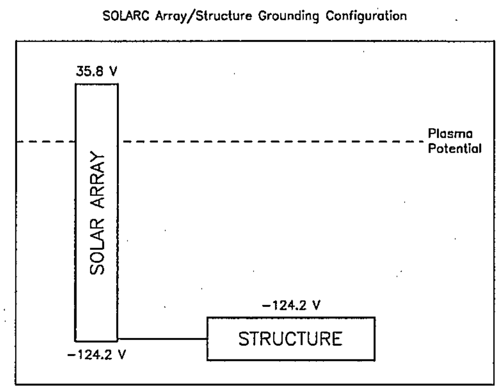

Figure 12. SOLARC Solar array/structure grounding configuration

There has long been a lack of a tool for engineering level evaluation of the internal charging problem. This has recently been addressed by the development of the

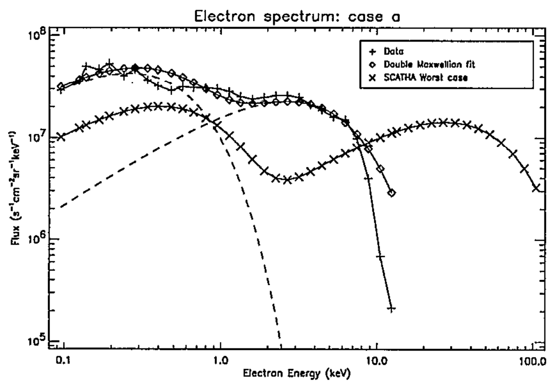

Figure 13. Double Maxwellian fit to Gorizont/ADIPE electron charging event spectrum

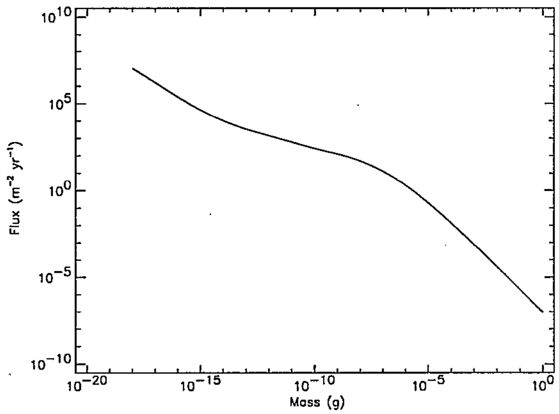

Figure 14. Grün meteoroid flux at 500 km altitude

DICTAT[20] tool by DERA for ESA. Not only is there a lack of analysis tools but also of a method for specifying the hazard, which is addressed by DICTAT. DICTAT calculates the electron current that passes through a conductive shield and becomes deposited inside a dielectric. It has an integrated electron environment model. From the deposited charge, the maximum electric field within the dielectric is found. This field is compared with the breakdown field for that dielectric to see if the material is at risk of an electrostatic discharge. The breakdown field can be a field deduced from beam irradiations, also with the help of the tool.

While the standard tool for spacecraft charging assessment is the 3-D NASCAP code, SPENVIS has implemented the DERA EQUIPOT non-geometrical tool for assessing material susceptibility to charging in typical orbital environments, including polar and GEO environments. While it does not treat geometry explicitly, it does model the charging behaviour of a patch-on-a-sphere model which is useful for investigating differential charging. SPENVIS Also includes SOLARC, for assessment of the current collection and the floating potential of solar arrays in LEO (see Fig. 12).

The system features access to data from surface charging events on CRRES and the Russian Gorizont spacecraft, in the form of spectrograms and double Maxwellian fit parameters (see Fig. 13).

Meteoroids and debris

The Grün[21] meteoroid model and the NASA90[22] and NASA96[23] debris models are currently being added to the system, as well as particle/wall penetration models for damage risk analysis. Figure 14 shows the Grün meteoroid flux at 500 km altitude.

Access to space environment databases

One of the latest developments is a feature to produce survey plots of satellite databases, in combination with geomagnetic indices and related parameters. Data from Meteosat, GOES, SAMPEX, UARS, AZUR, CRRES, and ISEE are being implemented, as well as radiation environment data from the REM instruments on MIR and STRV.

Integration with a standard on the space environment

The European Cooperation on Space Standards (ECSS) is a system of harmonised standards for the management and engineering of space projects. One of the standards is on Space Environment. SPENVIS Has allowed this standard to be made "active" so that it links to SPENVIS utilities when an engineer wishes to make use of a model or method referred to in the standard, and sits alongside the models so that the engineer can consult the standard in an efficient way for information. As further standards are prepared by ECSS in the areas of radiation effects and spacecraft charging, these will be similarly integrated.

Future developments

More models and additional functionalities are continuously added to the system. New candidate models include AFRL's CHIME cosmic ray model[24], a tool for evaluating solar and Earth albedo illumination, MSU's solar flare and cosmic ray models, and possibly a Monte Carlo code to be combined with the geometric shielding analysis. We envisage the extension of the help system to a more general and educational level. We are also looking at the combination of satellite measurements with model estimates in plots and tables.

ACKNOWLEDGEMENTS

The SPENVIS project is funded by ESA/ESTEC/TOS-EMA General Support Technologies Programme Contract No. 11711-WO1.

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