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An Overview and Discussion of SPENVIS, ESA's Space Environment Information System, and UNILIB, A Fortran Library of Magnetic Field Utilities

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ABSTRACT

The ESA SPace ENVironment Information System (SPENVIS) provides standardized access to models of the hazardous space environment through a user-friendly 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. It is available on-line at http://www.spenvis.oma.be/spenvis/. Intranet versions are also available. SPENVIS has been operational for about three years, with a continuously expanding user community and set of functions. 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 with the models 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. It is very useful in conjunction with radiation effects and electrostatic charging testing in the context of hardness assurance. 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 types of problem. It has various reporting and graphical utilities, and extensive help facilities. SPENVIS includes models of the radiation environment and effects, including NIEL and internal charging. It also contains an active, integrated version of the ECSS Space Environment Standard, and access to in-flight data. Apart from radiation and plasma environments, SPENVIS includes meteoroid and debris models, atmospheric models (including atomic oxygen), and magnetic field models implemented by means of the UNILIB library.

The UNILIB library implements a series of tools for coordinate transformations, magnetic field computations, magnetic coordinate evaluation, magnetic field line tracing and drift shell tracing. The UNILIB library was originally designed as a tool for the ESA/ESTEC TREND project (Trapped Radiation ENvironment Development) to investigate new coordinates to organise trapped particle fluxes, but can be applied to other fields of magnetospheric research. For instance, UNILIB determines mirror point and footpoint locations and evaluates adiabatic invariants. The UNILIB library is freely accessible from the Web (http://www.magnet.oma.be/unilib/) for downloading in the form of a Fortran object library for different platforms (DecAlpha, SunOS, HPUX and PC/MS-Windows). An interface for the Interactive Data Language (IDL) is included in the distribution. The Web site features extensive documentation including installation instructions, a reference guide, programme examples, and frequently asked questions. A news group has been established at news://news-ae.oma.be/unilib.

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.

In the framework of a separate ESA/ESTEC contract (TREND, Trapped Radiation ENvironment Development, see http://www.magnet.oma.be/trend4/), a Fortran library (UNILIB) of magnetic field routines and utilies has been developed. The magnetic field calculations in SPENVIS use function calls to this library.

Section 2 contains a general overview of the SPENVIS system. The models currently available in SPENVIS are discussed in Section 3, which contains a number of sample plots illustrating the capabilities of the system. Section 4 describes the UNILIB library.

SPENVIS 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/.

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 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.

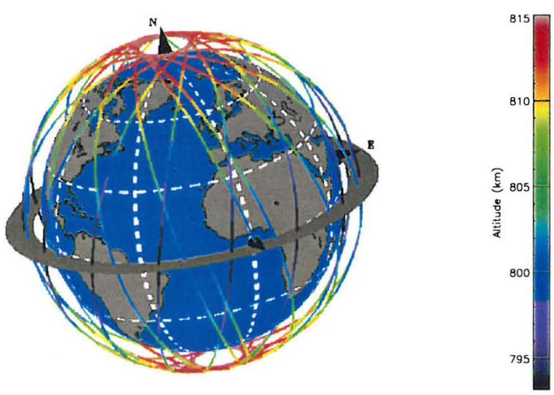

Figure 1. Three dimensional representation of an 800 km heliosynchronous orbit

MODELS IMPLEMENTED IN SPENVIS

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 (Fig. 1 shows a three dimensional representation of a heliosynchronous orbit at 800 km altitude). 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 in the framework of ESA TRP contracts [4] with data sets including SAMPEX [5], CRRES/MEA [6] and AZUR [7], and a model of the low-altitude trapped proton anisotropy [8].
- solar proton models: JPL-85 [9], JPL-91 [10] (see Fig. 2), King [11];
- CREME [12] for cosmic rays.

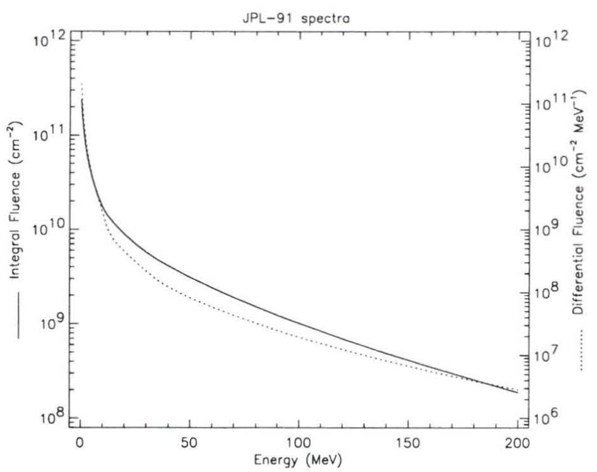

Figure 2. Integral and differential solar proton spectrum for an 800 km heliosynchronous orbit

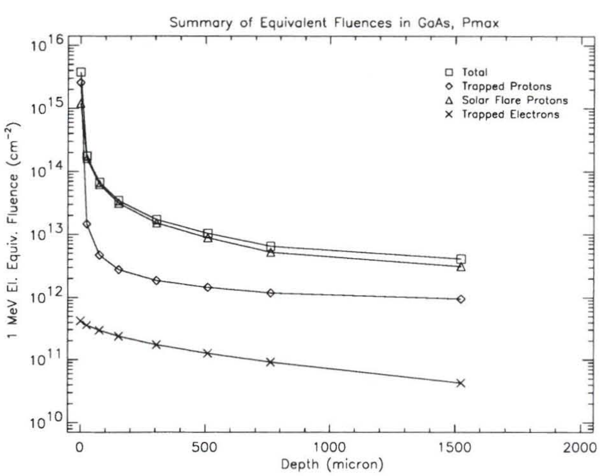

Figure 3. Equivalent fluences in a GaAs solar cell for an 800 km heliosynchronous orbit

The conversion of geographic to magnetic coordinates is done internally without interference from the user, ensuring consistency in the application of magnetic field models, often a source of confusion and error [13]. 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 (see section on magnetic fields).

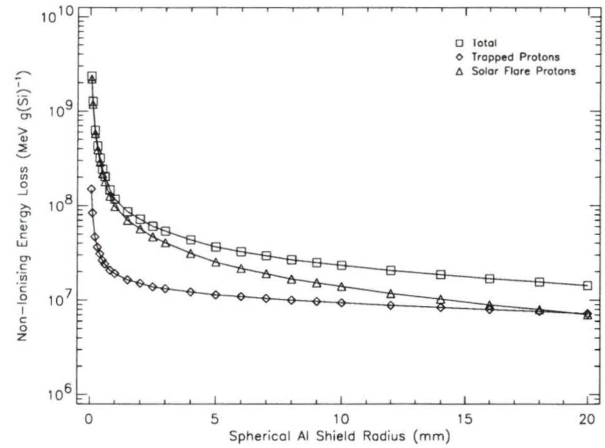

Figure 4. Non-ionising energy loss as a function of Al shield radius for an 800 km heliosynchronous orbit

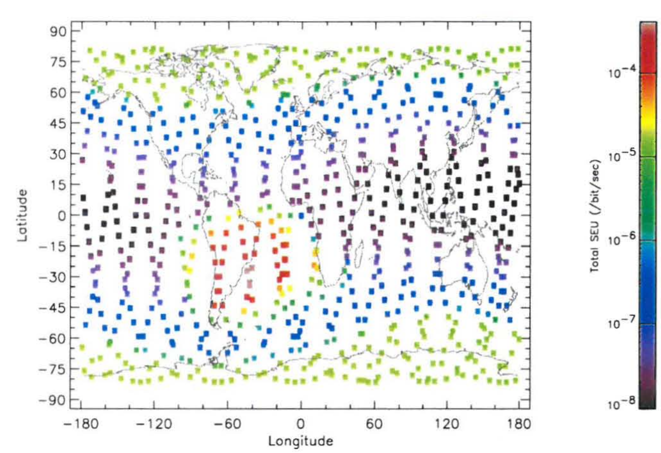

Figure 5. Single event upset rates along an 800 km heliosynchronous orbit

SPENVIS Contains the SHIELDOSE [14] and SHIELDOSE-2 codes for total dose assessment and the EQFRUX [15] and EQFRUXGA codes for solar cell damage-equivalent fluences (1 MeV electron equivalent). Figure 3 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) or non-ionizing dose [16]. 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 4 shows the NIEL of trapped and solar protons for an 800 km heliosynchronous orbit, as a function of Al shield radius.

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 solar protons (shown in Fig. 5 for an 800 km heliosynchronous orbit).

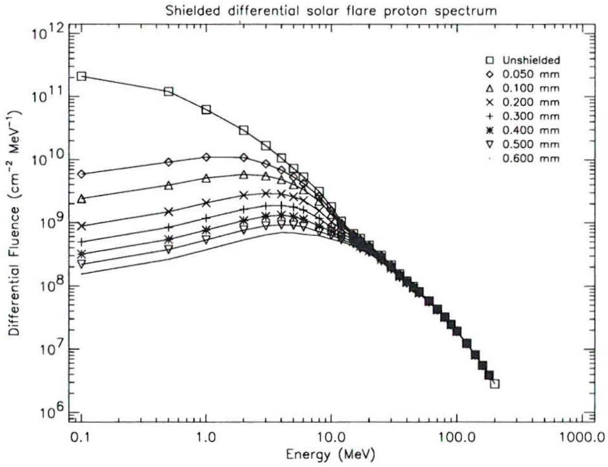

Figure 6. Shielded differential solar proton spectrum for an 800 km heliosynchronous orbit

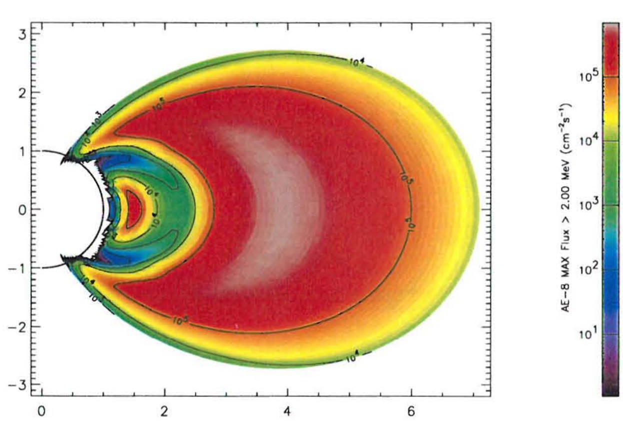

Figure 7. Invariant coordinate map of the AE-8 MAX electron flux >2 MeV

In computing all these parameters, spacecraft or solar cell coverglass shielding is taken into account. Figure 6 shows the shielded differential solar proton spectrum for an 800 km heliosynchronous orbit, for different Al shield radii. In addition, a geometric tool to calculate shielding distributions for simple spacecraft geometries is available. A tool to fold the shielding distribution with ionising and non-ionising dose curves is under development.

The trapped particle models can also be run on a coordinate grid. Figure 7 shows the AE-8 MAX electron flux >2 MeV on an invariant coordinate grid.

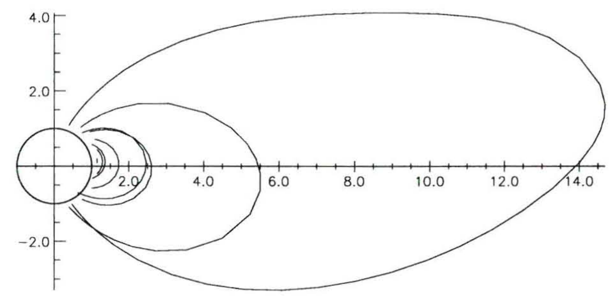

Figure 8. Field line traces for the IGRF95 plus Olson and Pfitzer quiet [17] models

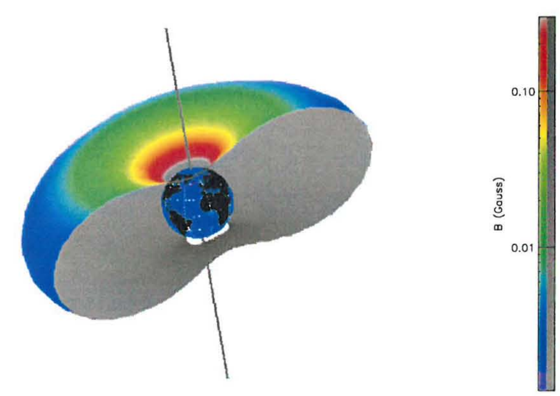

Figure 9. Three dimensional representation of the drift shell L=5,B=0.3

MAGNETIC FIELD

The most commonly used internal and external magnetic field models have been implemented in SPENVIS through the UNILIB library (see section on UNILIB). 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 magnetic field vector components, and the location of the footpoints. In addition, field line traces are plotted (see Fig. 8), and three-dimensional plots of drift shells are available. Figure 9 shows a three dimensional representation of the drift shell (L=5,B=0.3). The mirror point altitudes and the northern footpoints for this drift shell are shown in Figs. 10 and 11, respectively.

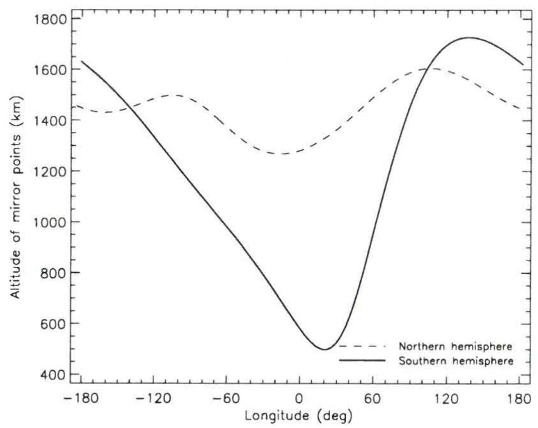

Figure 10. Northern and southern mirror point altitudes for the drift shell shown in Fig. 9

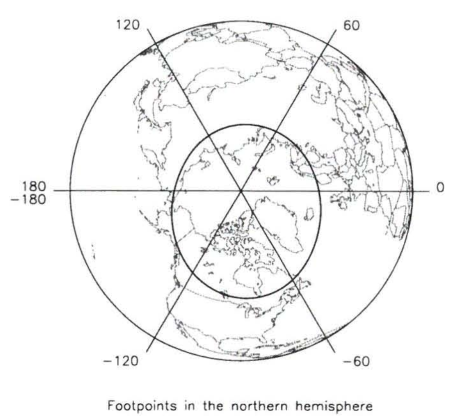

Figure 11. Footpoints in the northern hemisphere for the drift shell shown in Fig. 9

ATMOSPHERE AND IONOSPHERE

The following neutral atmosphere and ionosphere models have been implemented in SPENVIS: MSISE-90 [18], MET [19], DTM78 [20], HWM93 [21], IRI-90 [22]. These models can be evaluated over a grid of points to produce world maps of densities or temperatures (see Figs. 12 and 13), over a coordinate range to produce density profiles, or over a range of one of the model parameters for one geographic point (see Fig. 14). 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. 15).

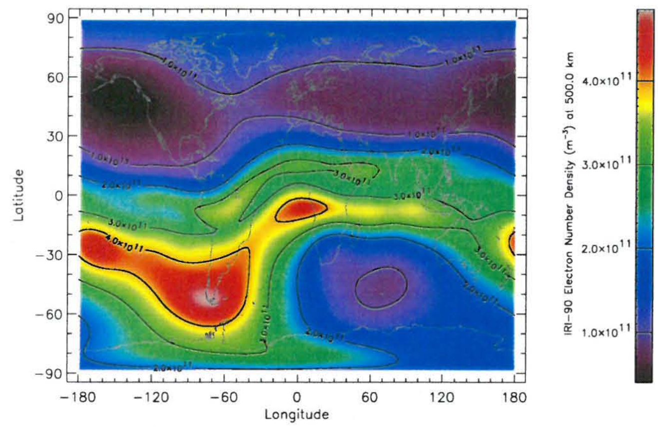

Figure 12. IRI-90 Electron density at 500 km altitude

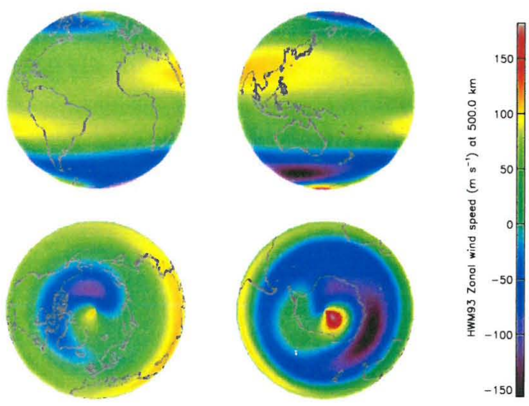

Figure 13. Representation of the HWM-93 zonal wind speed at 500 km altitude

SPACECRAFT CHARGING

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 DICTAT [23] 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.

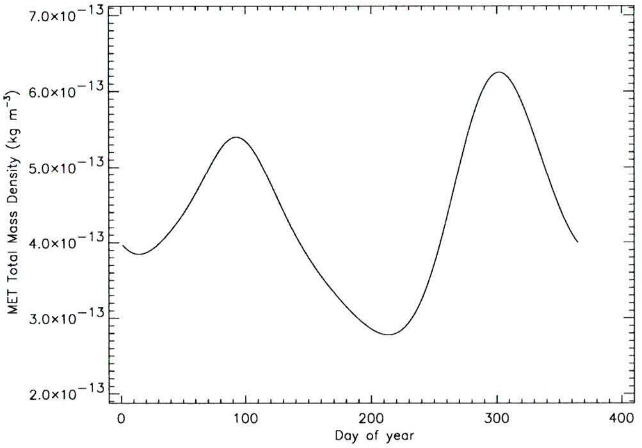

Figure 14. MET Total mass density at 500 km as a function of day number

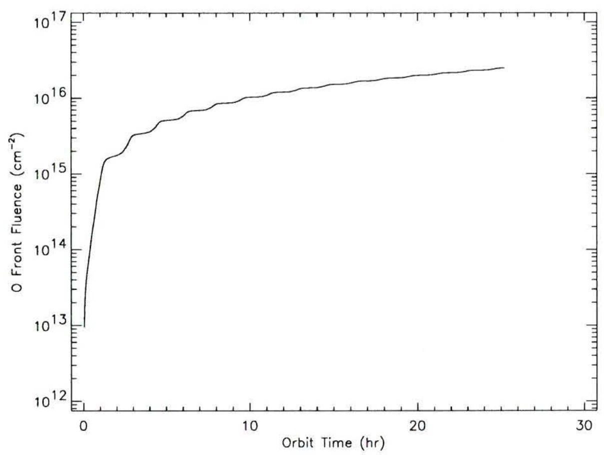

Figure 15. MSISE-90 Atomic oxygen fluence on a plate perpendicular to the spacecraft velocity vector for an 800 km heliosynchronous orbit

While the standard tool for spacecraft charging assessment is the 3-D NASCAP code [24], SPENVIS has implemented the DERA EQUIPOT [25] 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 [26], for assessment of the current collection and the floating potential of solar arrays in LEO (see Fig. 16).

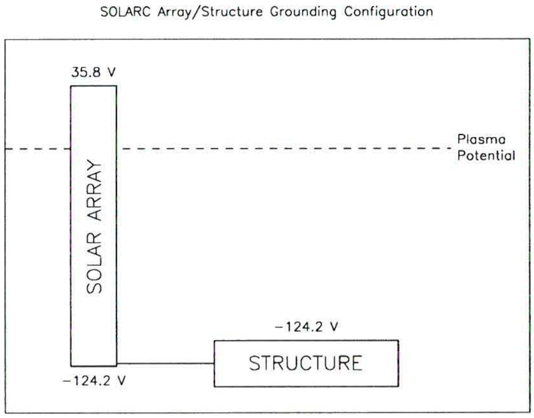

Figure 16. SOLARC Solar array/structure grounding configuration

The system features access to data from surface charging events on the CRRES and the Gorizont spacecraft, in the form of spectrograms and double Maxwellian fit parameters (see Fig. 17).

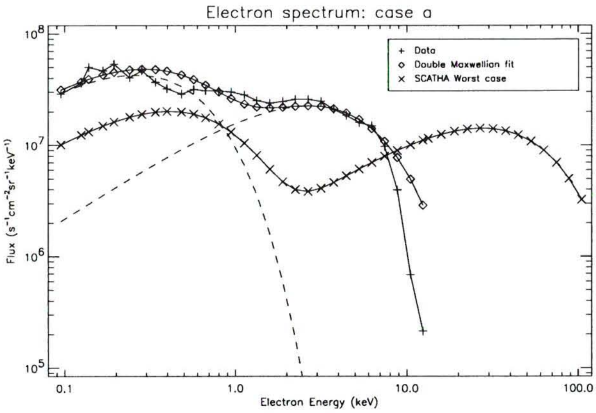

Figure 17. Double Maxwellian fit to a Gorizont/ADIPE electron charging event spectrum

METEOROIDS AND DEBRIS

The Grün [27] meteoroid model and the NASA90 [28] debris model have been added to the system. Figure 18 shows the Grün meteoroid flux at 500 km altitude. The implementation of the NASA96 [29] debris model as well as particle/wall penetration models for damage risk analysis are in progress.

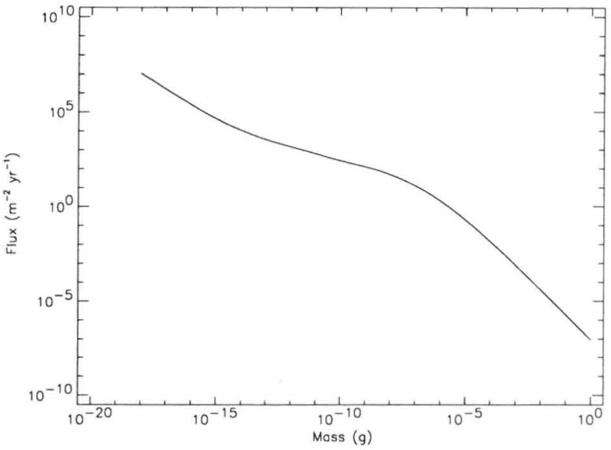

Figure 18. Grün meteroroid flux at 500 km altitude

ACCESS TO SPACE ENVIRONMENT DATA BASES

One of the latest developments is a feature to produce survey plots of satellite data bases, in combination with geomagnetic indices and related parameters. Data from Meteosat, GOES, SAMPEX, UARS, AZUR, CRRES, and ISEE have been implemented, as well as radiation environment data from the REM instruments on MIR and STRV. Figure 19 shows a sample multi-panel plot obtained with the data base interface.

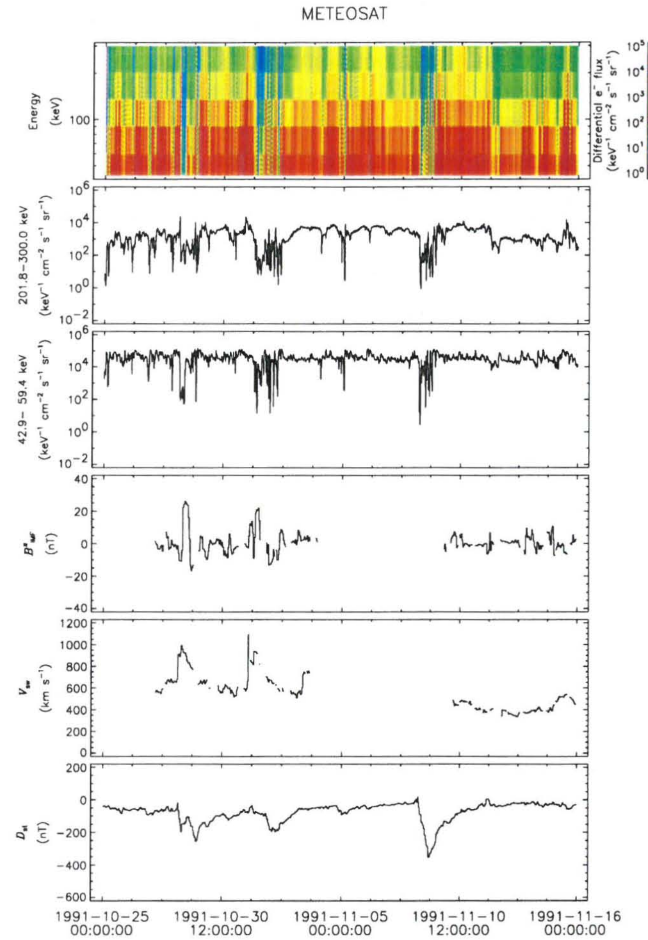

Figure 19. Sample output of the data base interface

INTEGRATION WITH A STANDARD ON THE SPACE ENVIRONMENT

The European Cooperation on Space Standards (ECSS) is a system of harmonized 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 [30], 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.

UNILIB

The UNILIB library has been designed as a tool for the TREND project (Trapped Radiation ENvironment Development), the main objectives of which are to improve the radiation environment models and the software used to predict the radiation experienced by satellites and spacecraft in orbit around the Earth. The UNILIB library is a collection of FORTRAN modules that implements a series of tools for coordinate transformations, magnetic field computation, magnetic coordinate evaluation, magnetic field line and drift shell tracing, etc. These modules can be applied through the use of a FORTRAN programme or by the use of IDL/RSInc external calls for which a specific interface is provided. The library has been developed conform to Standard FORTRAN 77, extended to the use of STRUCTURE and RECORD statements which greatly increase the user friendliness of the library and are supported by most FORTRAN 77 compilers. Machine specific code has been avoided so that the library can be installed on different platforms and operating systems. The UNILIB library is freely accessible from the Web (http://www.magnet.oma.be/unilib/) for downloading in the form of a Fortran object library for the supported platforms (DecAlpha, SunOS, HPUX and PC/MS-Windows). The documentation of the library is provided in the form of HTML pages. It includes a cross-referenced list of all the components of the library with a detailed description of each component. A list of frequently asked questions and some examples are provided as well.

Currently, the library includes most of the common geomagnetic and external magnetic field models: DGRF/IGRF 45-95, Jensen and Cain [31], GSFC 12/66 [32], Mead and Fairfield [33], four Tsyganenko models (1987 short and long [34], 1989c [35] and 1996 [36]), Olson and Pfitzer quiet [17] and dynamic [37], Ostapenko and Maltsev [38].

Inside the UNILIB library, geographic locations are expressed in the Geocentric Equatorial (GEO) coordinate system and vectors are specified by their GEO spherical components. Other coordinate systems and representations can be used by applying conversion routines included in the library. These conversion routines allow transformations between GEO, Geocentric Equatorial Inertial (GEI), Geomagnetic (MAG), Solar Magnetic (SM) and Geocentric Solar Magnetospheric (GSM) coordinates. They allow also conversions between cartesian and spherical representations of coordinates as well as of vector components.

Magnetic field line segments are traced by means of a fourth-order Runge-Kutta integration [39] with a step size proportional to the radius of the field line curvature. The segments are defined by conditions on the magnetic field intensity, e.g. the intensity B_m at a trapped particle mirror point, or on the geographic altitude, e.g. to determine foot points. Parameters like the integral invariant coordinate I [40], the Kaufman K parameter or the McIlwain [41] L parameter can be obtained for each evaluated magnetic field segment. The field line tracing is also used to compute magnetic drift shells defined by a pair of (B_m,I) values: for a number of longitudes, the magnetic field line segments that yield the user-defined (B_m,I) values are sought by iterations. In addition to the drift shell, the library provides information such as the foot print of the drift shell, the mirror point with the lowest altitude, the magnetic flux enclosed by the drift shell and the Roederer [40] L^* shell parameter.

The MSISE-90 [18] atmospheric and IRI-90 [22] ionospheric models are also implemented into the library. These models can be evaluated at any geographical location and be integrated along a field line segment or a drift shell for specific applications.

ACKNOWLEDGMENTS

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