AF-GEOSPACE: AN UPDATE

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Abstract

The AF-GEOSpace space environment software program was constructed to aid with the design, operation, and simulation of a wide variety of communications, navigation, and surveillance systems. This user-friendly graphics intensive program provides common input data sets, application modules, and graphical visualization tools to all of its models. A wide range of physical domains is addressed including solar disturbance propagation, radiation belt configuration, ionospheric auroral particle precipitation and scintillation. This paper describes upgrades AFRL has made to the SGI/UNIX version of AF-GEOSpace (Fall 1999 release, see http://www-vsbs.plh.af.mil). First, we created an "open" version of AF-GEOSpace and ported it to NT and LINUX platforms. Second, we enabled the execution of dynamic time-dependent simulation models such as the Rice University Magnetospheric Specification Model and the running of static models in dynamic mode, i.e., using time dependent input parameters to generate a time series of environment specifications. Finally, we have simplified the graphical user interface, improved science and application modules, and significantly enhanced graphical performance. The public release of this more portable version of AF-GEOSpace is scheduled for 2001.

Introduction

Space systems experience environmental effects ranging from intermittent communication outages caused by ionospheric scintillation to total satellite system failures caused by energetic magnetospheric particles.[1] The character of these hazards can change within minutes as illustrated by the formation of a second peak in the inner proton radiation belt during March 1991[2]. Motivated by the need to mitigate the impact of these hazards, space environment models are employed during the spacecraft design process and operations and provide environmental simulations for a wide variety of communication, navigation, and surveillance systems operating at altitudes between 100 km and geosynchronous orbit (6.6 Earth Radii).

While our understanding of fundamental heliospheric, magnetospheric, and ionospheric processes is still limited, due in part to the sparse nature of space data sets, a variety of useful empirical, statistical, and theoretical models have been developed. These models deal with topics ranging from solar coronal mass ejections[3] to the Earth's trapped radiation belts[4] to auroral particle precipitation[5]. Some provide detailed dynamic numerical simulations while others only simple static climatologies. There are, for example, models based on large-scale data assimilation[6] as well as those driven by neural networks[7]. Some use parameterized data fits to artificially control dynamic boundary conditions[8] while others strive to self-consistently couple the solar wind, magnetosphere, ionosphere, and thermosphere.[9]

The Air Force Research Laboratory (AFRL) is constantly expanding its space environment modeling capabilities and has integrated a collection of scientific codes and related applications into the computer software program AF-GEOSpace. The program has grown steadily in an effort to address the concerns of the space weather community. While some models may not be considered state-of-the-art, they are included to provide a valuable historical validation baseline and the ability to easily relate output from models covering similar domains, e.g., to directly compare results from the electric radiation belt models CRRESELE and NASAELE. The flexibility to simultaneously view science model results and real-time data with a common set of visualization tools has, for example, allowed AF-GEOSpace to serve AFRL as a development platform for some of the automated visualization products required of the operational community.

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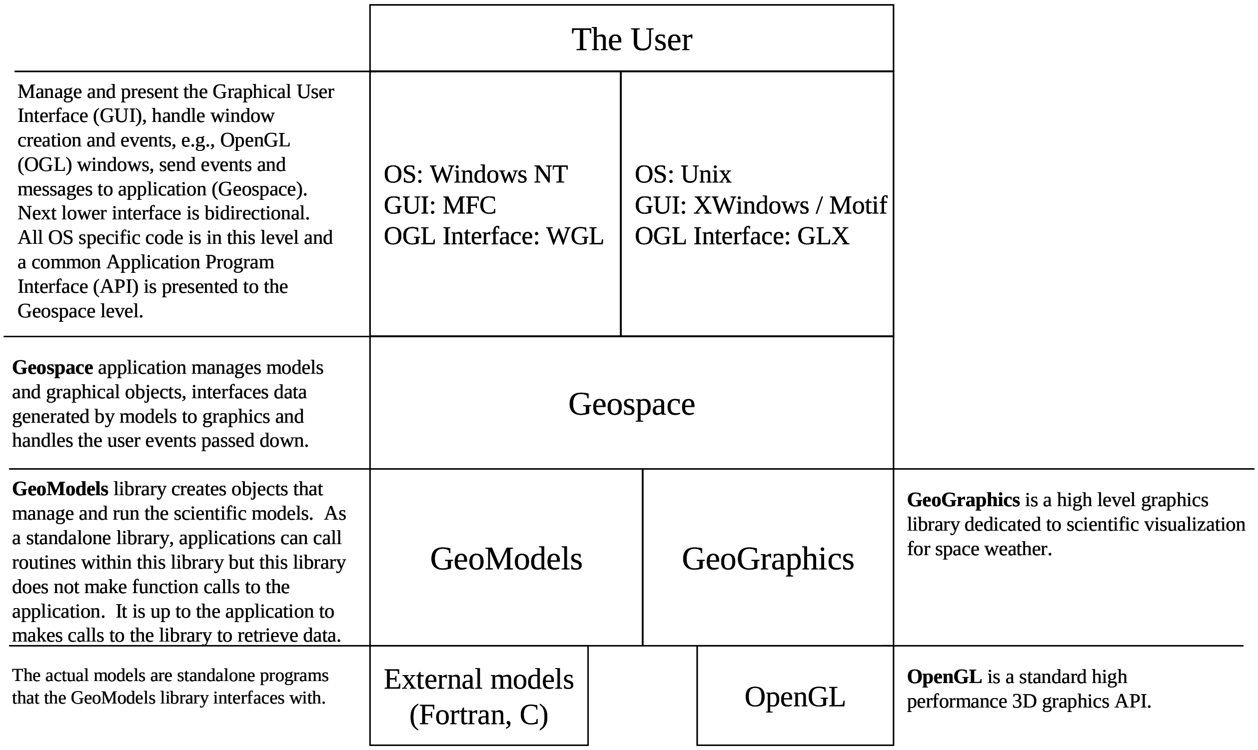

Figure 1. AF-GEOSpace Open Architecture

This paper provides an update on the AF-GEOSpace program. First we highlight its development history, then review its new "open" architecture, and finally, provide a detailed summary of the science, application, and data modules representing the core of its current capabilities.

AF-GEOSPACE

Development Overview

The first public release of AF-GEOSpace (Version 1.21, 1996/Unix on SGI) contained radiation belt particle flux and dose models derived from CRRES satellite data, an aurora model based on DMSP data, an ionospheric model, and ionospheric HF ray tracing capabilities. The last public release of AF-GEOSpace[10] (Version 1.4, 1999/Unix on SGI only) added science modules related to the cosmic ray and solar proton environment, low-Earth orbit radiation dosages, and probability maps of satellite single event effects based on APEX and CRRES satellite data. Also included were application modules for estimating linear energy transfer (LET) and single event upset (SEU) rates in solid-state devices, and modules for visualizing radar fans, communication domes, and satellite detector cones and links. Real-time DMSP data modules were included for displaying auroral particle data and qualitatively identifying enhanced outer zone MeV electron populations. Ionospheric scintillation, solar proton, and shock propagation models were also included. Version 2 (scheduled release on Windows NT and Unix in 2001) includes true dynamic run capabilities to take advantage of models like the MSM[8], and offers new and enhanced graphical and data visualization tools. A simplified graphical user interface reduces the number of actions required to get results on the screen. Just as important, yet hidden from view, is the fact that Version 2 represents a major restructuring of the code to an "open" architecture. This design increases the code's portability as well the ease with which new modules can be integrated.

Code Architecture

AF-GEOSpace Version 2 is an object-oriented code written in C++ with prototype versions running at AFRL on WindowsNT, Windows2000, UNIX, and LINUX systems. Figure 1 illustrates the basics of the open architecture that has allowed AF-GEOSpace to be ported to different platforms. With all models running on a common platform, AF-GEOSpace becomes a vehicle for rapid model prototyping, model validation, environment specification for spacecraft

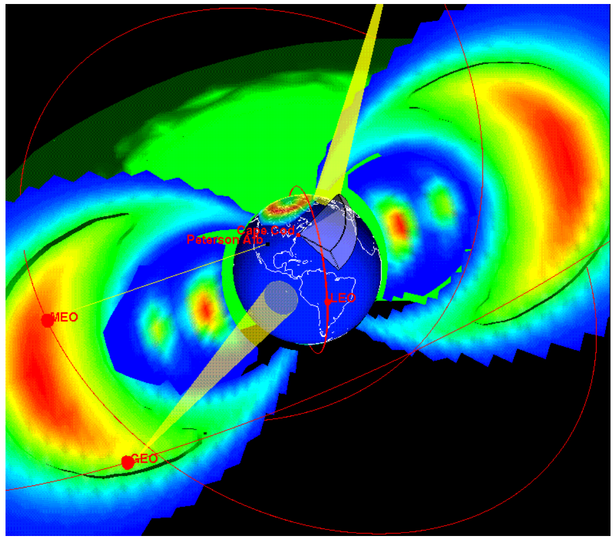

Figure 2. Near-Earth space environment in

design, mission planning, and anomaly resolution. In short, AF-GEOSpace becomes the backbone for an integrated space environment model.

The software is divided into five explicit module classes to simplify the integration of new algorithms and increase portability. *Science Modules* control individual science models and produce output data sets on user-specified grids. *Application Modules* typically manipulate these data sets, e.g., by integrating dose calculated by a radiation belt model or tracing HF rays through a model ionosphere. They also provide capabilities like orbit generation and magnetic field line tracing. *Data Modules* read and assist with the analysis of user generated as well as DMSP related data sets. *Graphics Modules* control the one, two, and three-dimensional windows and enable display features such as isocontours, plane slices, magnetic field lines, line plots, axes, the Earth, stars, and satellites. *Worksheet Modules* provide transformations between the GEOC, GSM, SM, and GEI systems in spherical, cylindrical, and Cartesian coordinates and also provide calendar system conversion tools. This separation of modules by function permits the use of common global input data sets by all science, application, and data modules, and the use of all graphical visualization tools by all of the models. A sample of this coordinated approach is shown in Figure 2 where the Earth's radiation belts and aurora are shown along with a projected radar fan, satellite orbits and associated communication links and instrument detector cones. A data archive covering 1932 to 2000 includes common indices such as *Kp*, *Dst*, and Bartol Sunspot Number as well as DMSP derived auroral boundaries (FTP scripts enable automated updates of some common parameters). These data enable the user to run models over a wide variety of activity levels and space weather events. This dynamic run capability allows the user to animate results in all dimensions, e.g., simultaneously view a satellite's path through a generated data set in 3-D, a 2-D projection on Earth of data slaved to a satellite's altitude, and a 1-D plot of the time history of data values encountered by the satellite.

Science, Application, and Data Modules

The following summarize the science and application module content of Version 2 (*in Version 1.4 only).

APEXRAD: The Advanced Photovoltaic and Electronics Experiment (APEX) radiation dose model[11] specifies the location and intensity of the radiation dose rate behind four different thicknesses of aluminum shielding for five geomagnetic activity levels as specified by Ap15. It covers the Low Earth Orbit (LEO) altitude region (360-2400 km) and was developed to supplement the CRRESRAD model (see below) which has limited resolution in the LEO regime. A related application module determines expected accumulated yearly doses.

AURORA: Auroral precipitation models[12, 13] specify the location and intensity of electron number and energy flux, ion number and energy flux, Pederson and Hall conductivities, and the equatorward boundary at 110 km altitude. This module also provides the capability to map these quantities up magnetic field lines into the 3-D magnetospheric grid.

BFIELD-APP: A variety of internal and external magnetic field models are provided in this application module for the purposes of generating gridded data sets, field lines, and flux tubes.

CHIME: The CRRES/SPACERAD Heavy Ion Model of the Environment[14] (CHIME) specifies the location and intensity of galactic cosmic rays, solar energetic particle fluxes, and anomalous cosmic ray fluxes.

CRRESELE and **CRRESPRO**: The Combined Radiation and Release Effects Satellite (CRRES) models[15, 16] specify the location and intensity of omnidirectional electron and proton fluxes over the energy ranges 0.5-6.6 MeV and 1-100 MeV, respectively, for a range of geomagnetic activity levels. A related application module gives expected integral and differential fluence for user prescribed orbits.

CRRESRAD: The CRRES space radiation dose model[17] specifies the location and intensity of the radiation dose rate behind four different thicknesses of aluminum shielding for active and quiet geophysical activity levels. A related application module determines expected dose accumulation for user prescribed orbits.

DMSP-SPECTRA*: This data module displays the particle spectra, from the DMSP satellite SSJ/4 sensors[5], which are used to determine auroral precipitation boundaries.

EPHEMERIS: This data module reads and displays generic files representing orbital ephemerides and any corresponding observational data available to or generated by the user.

HEEM*: This data module displays the DMSP High Energy Electron Monitor files, derived from the DMSP satellite SSJ/4 data[5], which are used to identify enhanced outer zone MeV electron populations.

IONSCINT: The High Fidelity Ionospheric Scintillation Simulation Algorithm (IONSCINT) provides disruption maps of trans-ionospheric radio wave (UHF) communications due to equatorial scintillation. It represents statistically realistic climatology as well as the day-to-day variability of equatorial scintillations. An L-Band extension of this module is currently under development at AFRL.

ISPM: The Interplanetary Shock Propagation Model[18] (ISPM) predicts the transit time of interplanetary shocks from the Sun to the Earth and the shock strength upon arrival.

LET-APP: This application calculates the linear energy transfer (LET) spectrum and its associated single event upset (SEU) rate in a microelectronics device resulting from the penetration of energetic space particles. Effects of both cosmic rays and trapped protons are estimated using the CHIME and CRRESPRO science modules described above.

MSM: The Magnetospheric Specification Model (MSM)[8] describes the 100 eV to 100 keV electron, H+, and O+ populations of the inner and middle magnetosphere. MSM responds to changing geophysical conditions on time scales of 15-30 minutes as described by the model inputs, i.e., magnetic indices *Kp* and *Dst*, equatorward boundary of diffuse aurora at midnight, cross-polar cap potential drop and pattern type, solar wind density and velocity, and the IMF.

NASAELE and **NASAPRO**: The NASA AE-8 and AP-8 radiation belt models[19] are used to compute the intensity and location of differential omnidirectional electron flux and proton flux for energy intervals which correspond to the ranges of the CRRES HEEF and PROTEL instruments, respectively. Results can then be compared with those using CRRESELE and CRRESPRO described above.

PIM: The Parameterized Ionospheric Model[20] (PIM) is a global model that generates electron number densities as well as maps of total electron content (TEC), height of E and F2 peaks (HE, HF2), and plasma frequencies at the E and F2 peaks (FoE, FoF2) as a function of a variety of geophysical activity indices.

PPS: The Proton Prediction System[21] (PPS) uses solar optical, radio, and X-ray observations to provide forecasts of the intensity and duration of solar proton events.

RAYTRACE-APP: HF ray traces can be performed through electron number density profiles generated using the PIM science module.

SATEL-APP: Satellite trajectories defined by a variety of types of user-specified orbital elements are calculated. Updates to standard two-line orbital element files can be downloaded via FTP.

SEEMAPS: Normalized flux and dose data for protons with energy > 50 MeV from the APEX and CRRES satellites are used to produce contour maps of the relative probabilities of experiencing Single Event Effects (SEEs) in the Earth's inner radiation belts.[22]

STOA: The Shock Time-of-Arrival Model[23] (STOA) predicts the transit time of interplanetary shocks from the Sun to the Earth. STOA is the predecessor of ISPM.

WBMOD: The WideBand Model[24] (WBMOD) is an RF ionospheric scintillation model specifying S4, SI, and other scintillation parameters between any location on the globe and a satellite above 100 km altitude as a function of geophysical activity indices at any frequency above 100 MHz. A year 2000 update improves high latitude output. A related application module gives 24-hour climatology predictions of the dB fade levels due to ionospheric scintillation effects for specified ground-to-satellite communications links.

Other planned dynamic model installations include the Ionospheric Forecast Model[25], Magnetospheric Specification and Forecast Model[26], and the Parameterized Real-Time Ionospheric Specification Model[27]. In addition, an improved high-resolution neutral density model is under development at AFRL to address drag effects on low orbiting satellites.

Final Comments

The AF-GEOSpace software suite provides the scientific community with a number of empirical, statistical, and physics-based models that address concerns about environmental hazards affecting real-world space systems. Recent improvements to the software have greatly increased its utility and portability. The authors encourage the community to make suggestions regarding the addition of new models and applications. Public release versions of AF-GEOSpace are distributed free of charge by AFRL (please contact the first author).

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