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Space Environments and Effects: Trapped Proton Model

S.L Huston
The Boeing Company, Huntington Beach, California

Prepared for Marshall Space Flight Center
Under Contract NAS8-98218
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The Space Environments and Effects Program
managed at the Marshall Space Flight Center

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1 Introduction

Both piloted and robotic space missions require accurate models of the Earth's trapped energetic proton environment. For piloted missions, the concern is mainly total dose to the astronauts, particularly in long-duration missions and during extra-vehicular activity (EVA). As astronomical and remote sensing detectors become more sensitive, the proton flux can induce unwanted backgrounds in these instruments. Observing sessions on the Hubble Space Telescope, for example, are planned so that measurements are avoided during passes through the South Atlantic Anomaly (SAA). All spacecraft are potentially susceptible to single event effects (SEE), which affect electronic systems and can cause system failure. In the future, solar orbital transfer vehicles (SOTVs) may take months to spiral up to geosynchronous orbit, and solar cells will be subject to degradation from trapped particles.

Accurate flux predictions are required to predict dose rate and total dose, as well as SEE rates. Accuracy in the flux predictions in turn requires the ability to model the variations over the solar cycle. Geographic accuracy is required for scheduling EVAs and observing sessions.

Given these requirements for accuracy, the current U.S. model AP-8 [1] is increasingly being recognized as inadequate. Although it contains separate models for solar minimum and maximum conditions, AP-8 does not model the variation through the solar cycle. It also does not address the long-term variations due to the secular variation in the Earth's magnetic field [2,3]. The model can be used to predict the average proton flux for a given orbit, but it cannot be used to predict the instantaneous flux along an orbit, and thus cannot be used for scheduling observing sessions or EVAs. Finally, recent studies [4-6] have shown that AP-8 does not accurately predict the actual flux.

Recent efforts have resulted in the first truly new trapped radiation models in twenty years. These include the Low Altitude Trapped Radiation Model (LATRM) [7] developed by Boeing under NASA's Space Environments and Effects (SEE) program, and the models developed by the U.S. Air Force Phillips Laboratory using data from the Combined Release and Radiation Effects (CRRES) spacecraft. The LATRM model is the first empirical model to include solar activity variations. The CRRES data provides unprecedented detail in energy and pitch angle over almost all of the Van Allen belts for a relatively brief time period (about one year), and the CRRESPRO model [8] implements the data base in an easy-to-use format. While these models represent significant improvements in our ability to predict the trapped proton environment, they do not currently exist in a form that is easy to use for all aspects of the spacecraft design process.

As a result, NASA has undertaken the development of a new model, called TPM-1 (for Trapped Proton Model, version 1), as the first step towards a replacement of AP-8. This new model combines elements of LATRM and CRRESPRO to obtain a model which covers the full spatial extent of the trapped proton belts, determines the differential proton flux over the range of 1 to 100 MeV, and contains a solar cycle variation at low altitudes.

Section 2 of this report discusses briefly the data sets that went into the model and the features of the model. Section 3 discusses the development of TPM-1, including a discussion of how the models were combined. Section 4 presents some results from the new model, including comparisons with CRRESPRO and AP-8. Finally, Section 5 discusses recommendations for improvement. The Appendix provides instructions for using the new model.

2 Basis of the Model

2.1 CRRESPRO

The Combined Release and Radiation Effects Satellite (CRRES) gathered data from July 1990 to October 1991, using a sophisticated set of particle and field experiments. It was placed in a geosynchronous transfer orbit of 350 km × 35,000 km × 18° inclination. Data from CRRES have revolutionized our understanding of the inner magnetosphere and have been used to develop models of the high energy electron and proton fluxes as well as dose behind several shielding thicknesses [8–10].

One of the crucial observations made during the lifetime of CRRES was the development of a new population of energetic trapped protons which emerged after a storm sudden commencement in March 1991. This new population was observed for many months by CRRES and other spacecraft (including TIROS/NOAA).

The USAF Research Laboratory, AFRL/VSBX (formerly Phillips Laboratory), Hanscom AFB, MA, has used the Proton Telescope instrument (PROTEL) to create a new trapped proton model called CRRESPRO. PROTEL has two detector heads which measure protons from 1 to 100 MeV in 24 energy channels. The detector provides excellent angular resolution. CRRESPRO contains the differential flux for each PROTEL energy channel on a grid in magnetic latitude (λ), L space for both quiet (before March 1991) and active (after March 1991) periods. AFRL has invested considerable effort over the past several years to process this data and to understand the characteristics of the detectors.

Detailed information on PROTEL and CRRESPRO can be found in References [8–10].

2.2 NOAAPRO

The TIROS/NOAA low-altitude weather satellites are placed in circular, sun-synchronous orbits (850 km altitude, 93 degree inclination). In addition to their primary weather monitoring sensors, these spacecraft carry a Space Environment Monitor (SEM) package. The MEPED (Medium Energy Proton and Electron Detector) is that portion of the SEM designed to measure the flux of protons (ions) and electrons mirroring above, and precipitating into, the high-latitude atmosphere. Each MEPED consists of two sensor assemblies: the directional (telescope) particle detectors and the omnidirectional proton detectors. The omnidirectional detectors measure the integral proton flux at energies of 16, 36, and 80 MeV.

During the LATRM study, Boeing performed an extensive analysis of the omnidirectional sensors and revealed features that even the NOAA investigators had not known. For example, we discovered that the P7 channel on NOAA-10 gave anomalous results and could not be used for the new model. We also found that the advertised energy passbands are not correct. The P8 channel is advertised as measuring 80–215 MeV protons; in reality, because of the detector thresholds chosen during the design process, this channel detects protons with energy much greater than 215 MeV. Also because of the detector thresholds chosen, the P6 channel is sensitive to > 1 MeV electrons.

While these detectors are not optimally designed, making it more difficult to interpret the data, the problems are similar to those inherent in any experimental data set, and the TIROS/NOAA data set is still an excellent one. For the P6 channel, CRRES electron data have shown that the > 1 MeV electron flux is low in the regions sampled by the TIROS/NOAA spacecraft, so that contamination by electrons is not expected to be significant.

The LATRM study used data from the omnidirectional detectors to develop a solar activity dependent model of the low-altitude trapped proton flux. The data cover two solar maxima and one solar minimum (and approaching a second minimum), with two periods of recovery of the proton flux.

The LATRM model, developed under the SEE program, is the first empirical model of the low-altitude proton environment which contains a true solar cycle dependence. This model represents a crucial first step in developing a more accurate model of the Earth's trapped radiation environment. It is not, however, sufficient to replace AP-8, since it only provides the integral proton flux for the high-energy part of the proton spectrum over a relatively limited portion of the inner zone.

Details of the NOAA detectors and the LATRM model can be found in [9].

2.3 Features of TPM-1

The new model combines many of the features of CRRESPRO and LATRM. Specifically, the model:

- Covers the geographic region from approximately 300 km altitude to geosynchronous orbit.

- Calculates omnidirectional differential flux in 22 energy channels ranging from 1.5 to 81.5 MeV.

- Contains a continuous variation with solar activity, valid over the time span 1960–2020. The solar cycle variation is driven by the solar 10.7 cm radio flux ($F_{10.7}$). The model contains a data file with historical $F_{10.7}$ data from the year 1960 through August 2001, as well as a projection out to the year 2020.

- Contains a model for both quiet (nominal) conditions and active conditions, *e.g.*, after an event such as the one observed by CRRES.

- Can be used to obtain the flux at a particular point in space, or combined with an orbital integration to obtain orbit-averaged energy spectra.

To run the model, the user inputs a point in geographical space, either individually or by reading an ephemeris file, along with the date for which the prediction is to be made. The model returns the differential flux for each of the 22 model energies.

The model is delivered with an orbit generator and a driver routine for integrating the proton flux over an orbit and determining orbit-averaged spectra. A version is also available which operates via the World-Wide Web.

3 Development of the Model

There were several issues associated with combining CRRESPRO and LATRM. This section discusses the basic approach taken in combining the data sets, as well as more specific information on the coordinate system used and how the solar cycle variation was implemented.

A problem which nearly always exists in developing models is that the data going into the model come from very different detectors on different spacecraft in different orbits at mostly different epochs. These differences make it difficult to combine the measurements into a single model. However, the approach of developing individual models first, then combining models, has advantages over the approach of combining raw data from each spacecraft. In this case, we also have data from both spacecraft from the same epoch.

In addition, CRRESPRO uses a bin system in which the flux is considered constant within each L–λ bin. CRRESPRO uses an orbit generator to determine how much time a spacecraft spends in each bin, and then averages the fluxes over the entire orbit. LATRM, on the other hand, is more like the existing AP-8 model in that the user provides the B–L coordinates, and the model provides the flux at that particular point. LATRM provides a continuous variation in flux over the model space. In developing TPM-1, it was decided that the latter approach was preferable, and so CRRESPRO had to be converted to a grid system.

Finally, the LATRM model provides integral fluxes in three broad energy ranges, whereas CRRESPRO provides differential fluxes from a number of well-defined energy channels. In order to provide the same energy resolution as CRRESPRO, we made the assumption that the shapes of the CRRESPRO energy spectra were accurate at low altitude, and that the absolute flux could be scaled based on the NOAA data.

3.1 Basic Approach

In order to develop the TPM-1 model, the following steps were taken:

1. Convert the CRRESPRO data from a binned format to a gridded format, so that the flux is determined at a set of grid points and interpolated in between.

2. Using the TIROS/NOAA data from epoch 1991 (when the CRRESPRO data were taken), scale the CRRESPRO fluxes at low altitude to match the TIROS/NOAA altitude variation. This adjusted data set is stored as the main TPM-1 data file.

3. Determine the solar cycle variation of the TIROS/NOAA data using a curve fitting procedure. The fluxes are then scaled to the 1991 values. The curve fit coefficients for determining the

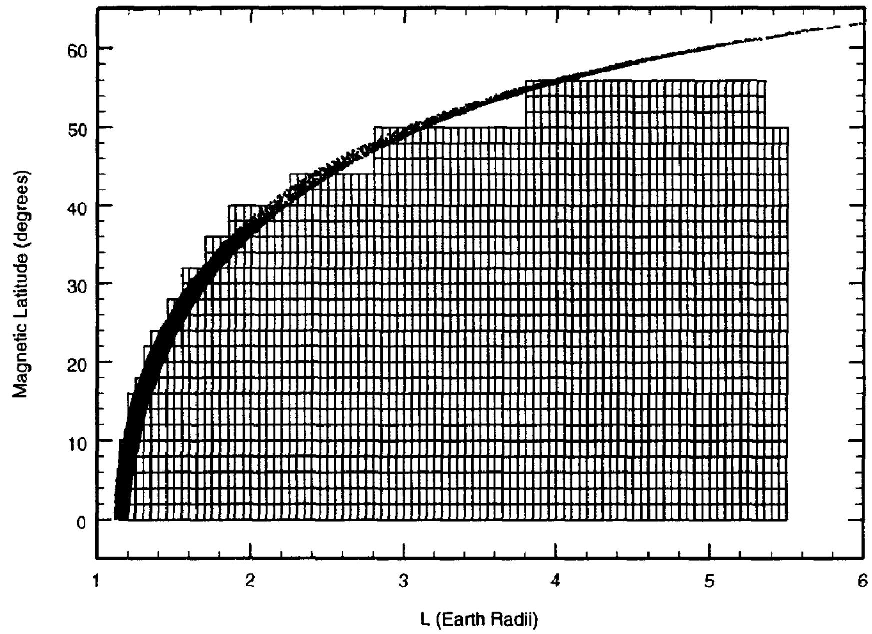

Figure 1. CRRESPRO bins and NOAA satellite coverage in L – λ *space. Solid lines show boundaries of the CRRESPRO bins, and dots show data points for NOAA-10 during the period 1–10 March 1991.*

solar activity scaling factor for a given location and time are stored as the secondary TPM-1 data file.

4. In order to determine the proton flux at a given time and location, the TPM-1 model looks up and interpolates to find what the proton flux would have been in 1991. If the point is in the region where the solar cycle variation is defined, the model then looks up and interpolates to find the curve fit coefficients and determines the solar activity scaling factor. The baseline 1991 flux is then multiplied by the scaling factor to obtain the appropriate proton flux.

3.2 Coordinate Systems

One of the major problems in defining any trapped proton model is in defining an appropriate coordinate system. Although the proton flux at relatively high altitudes (above about 1000 km) is defined by magnetic coordinates, at lower altitudes the flux is a function of both magnetic coordinates and atmospheric density. In addition, finer resolution is required at low altitudes where the flux gradients are very steep. Finally, the traditional *B–L* coordinate system results in a grid in which it is very difficult to represent the lower edge of the radiation belts. Figure 1 shows the CRRESPRO coordinate grid with the TIROS/NOAA coverage superimposed. The upper portion (in *B–L* space) of the CRRESPRO grid approximates roughly the lower portion (in geographic space) of the atmosphere. However, it is not possible to define a uniform orthogonal grid in *B–L* space that will provide sufficient resolution at low altitude without being overly dense at high altitude.

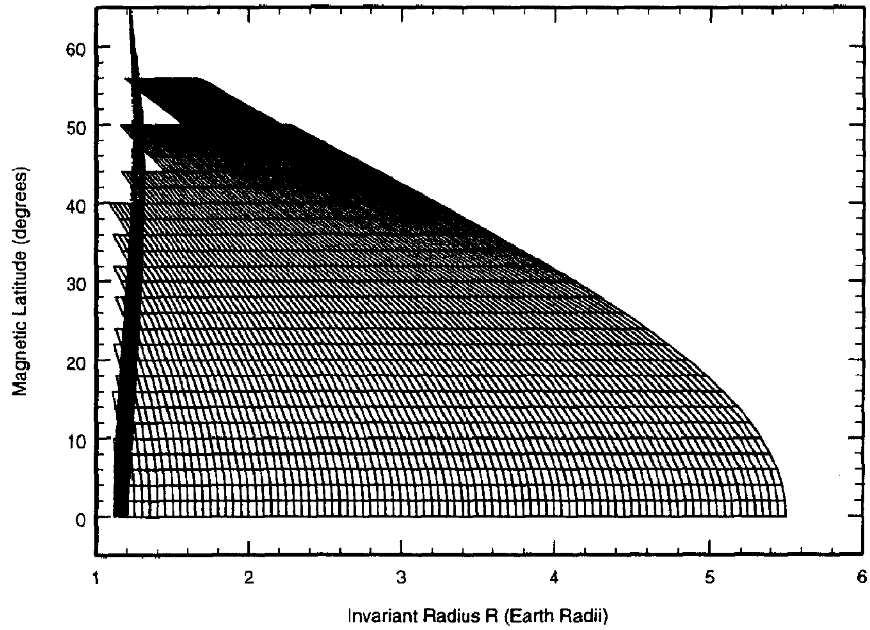

Figure 2 CRRESPRO bins and NOAA satellite coverage in R–λ *space.*

In order to obtain a model grid with sufficient accuracy at low altitudes, we defined a coordinate system based on the magnetic latitude and the invariant radius. Here, the magnetic latitude, λ, is defined by the relation

$$\frac{B}{B_0} = \frac{\sqrt{4-3\cos^2\lambda}}{\cos^6\lambda},$$

And the invariant radius R is defined as $R = L\cos^2\lambda$. The resulting mapping of the CRRESPRO grid is shown in Figures 2 and 3; the orthogonal cells are now distorted, particularly at high magnetic latitude. Using this coordinate system, it is possible to define an orthogonal grid with fine spacing at low altitude and coarser spacing at high altitude. However, the TIROS/NOAA data coverage still forms a wavy region in this coordinate system, a manifestation of the Earth's surface. For the TPM-1 model, we introduce a modified invariant radius R_{mod} defined by the relation

$$R_{\mathrm{mod}} = R - \sum_{n=0}^{6} a_n \lambda^n,$$

where the polynomial in λ approximates the surface of the Earth in R–λ space. The resulting R_{mod}– λ system provides a convenient way to obtain fine resolution at low altitudes without requiring excessively small grid spacing at high altitude. The TPM-1 model uses a finer mesh ($\Delta R_{\mathrm{mod}} = 0.005 R_E$) for $R_{\mathrm{mod}} < 0.1\ R_E$ and a coarser mesh ($\Delta R_{\mathrm{mod}} = 0.05 R_E$) at higher altitudes. A constant grid spacing of $\Delta\lambda$=2° is used for the magnetic latitude coordinate.

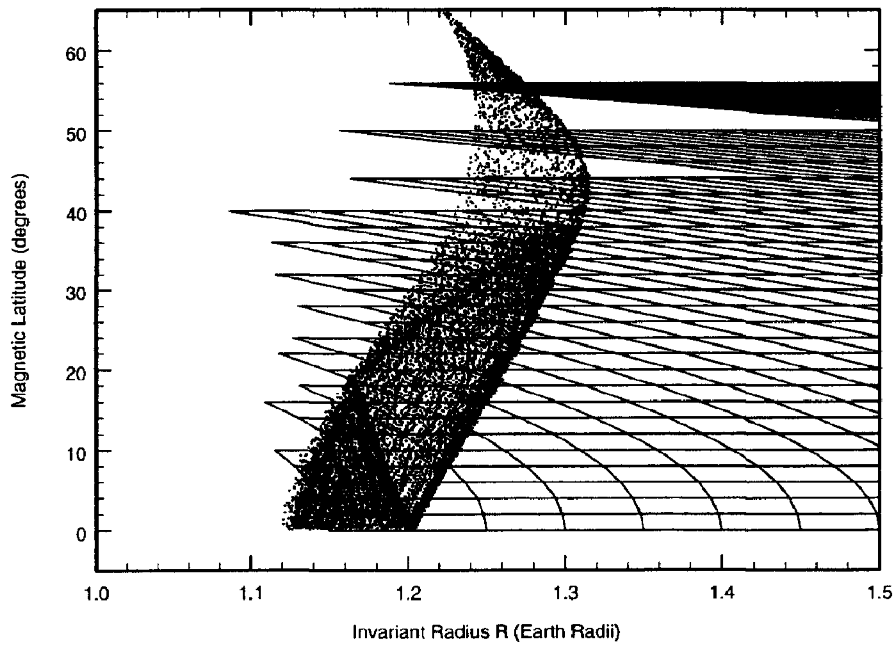

Figure 3. Low-altitude portion of Figure 2.

3.3 Solar Cycle Variations

The model for the variation of the low-altitude proton flux with solar activity is similar to that used in LATRM [7]. The integral proton flux J in a particular energy channel is defined by the relation

$$\ln(J) = b_0 + b_1 F'_{10.7}$$

where $F'_{10.7}$ is the value of $F_{10.7}$ which existed at time $(t-\tau)$, where t is the date at which the measurement is taken, and τ is a phase lag. The parameters τ, b_0, and b_1 are determined using a curve fitting process as described in [7]. The parameters are determined for all values of R_{mod} and λ. Figures 4 – 6 show the variation of the parameters in $R_{mod} - \lambda$ space for the P8 channel (>80 MeV).

In performing the curve fitting and testing the model, we discovered that due to the anomalous behavior of the NOAA-10 P7 channel (>36 MeV) discussed in Section 2.2, fluxes calculated for the P7 channel sometimes were smaller than those for the P8 channel, which is a physical impossibility. We had originally planned to use the TIROS/NOAA data in the 16–36 and 36–80 MeV bands to provide energy-dependent scaling factors, which would provide a more accurate solar cycle variation. Future re-processing of the data may permit the determination of such scaling factors, but as currently implemented the solar cycle dependence is not a function of energy.

3.4 Solar Activity Model

The variation of the solar activity is a critical part of the TPM-1 model. Because the proton flux depends on the past history of the solar activity, it is not sufficient to use a single value of the solar $F_{10.7}$ flux. TPM-1 must be provided with a table of $F_{10.7}$ as a function of time for the time period covered by the analysis. Since many analyses will attempt to predict the proton flux at some future date, it will generally be necessary to provide a prediction of the solar activity.

The file F107.DAT distributed with the TPM-1 model contains historical data from April 1954 through August 2001; it contains a projected history up to January 2020. The remainder of solar cycle 23 after August 2001 is based on the solar cycle prediction issued by the NOAA Space Environment Center on 2002 January 4 (see Reference [11]); it predicts a solar minimum in January 2007. A prediction is also provided for solar cycle 24; this prediction is merely an average of cycles 19 – 22, normalized to an 11-year cycle. The maximum $F_{10.7}$ of this cycle is 200, in March 2011; the minimum is reached in November 2017. Using this file, trapped proton flux predictions are possible covering the period 1960 – 2020. Figure 7 shows the solar cycle variation in the F107.DAT file.

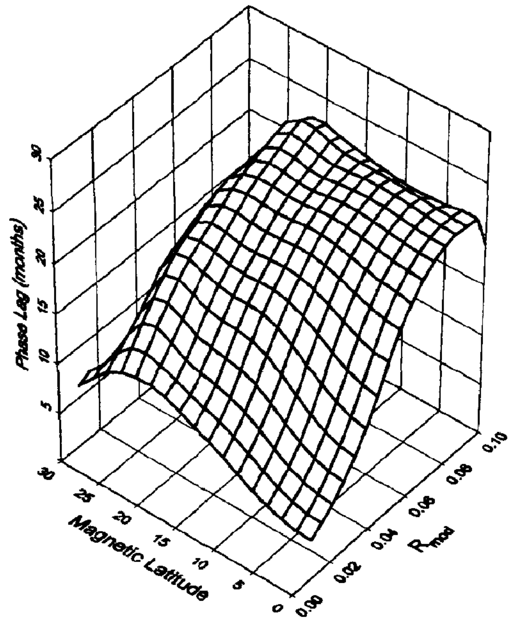

Figure 6. Variation of phase lag with magnetic latitude and R_{mod}.

The user should be aware that this file contains only a "nominal" estimate of solar activity and assumes particular dates for the upcoming solar maxima and minima. In reality, there is a very broad variation in the length of the solar cycle, the rise and fall times of the cycles, and, of course, the intensity of solar maximum. Depending on the application envisioned, the user may

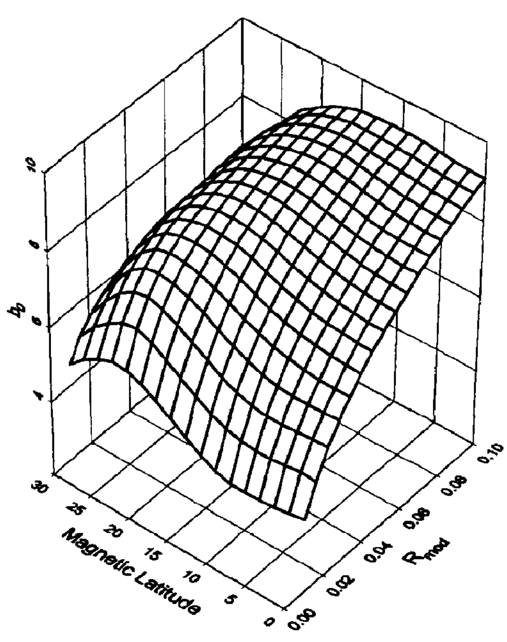

Figure 4. Variation of b_0 *with magnetic latitude and* R_{mod}.

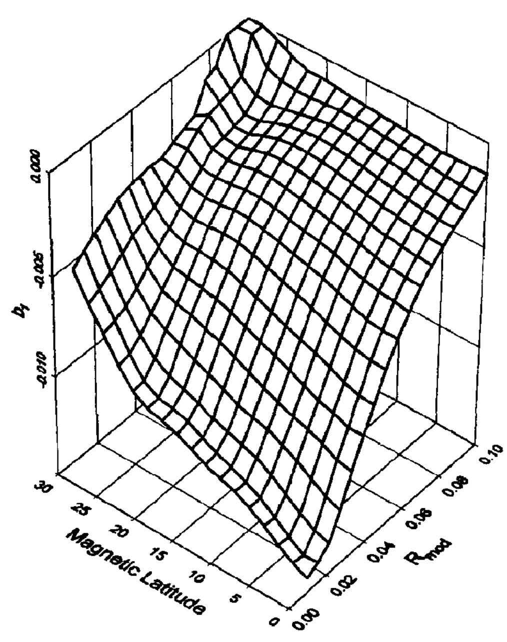

Figure 5. Variation of b_1 *with magnetic latitude and* R_{mod}.

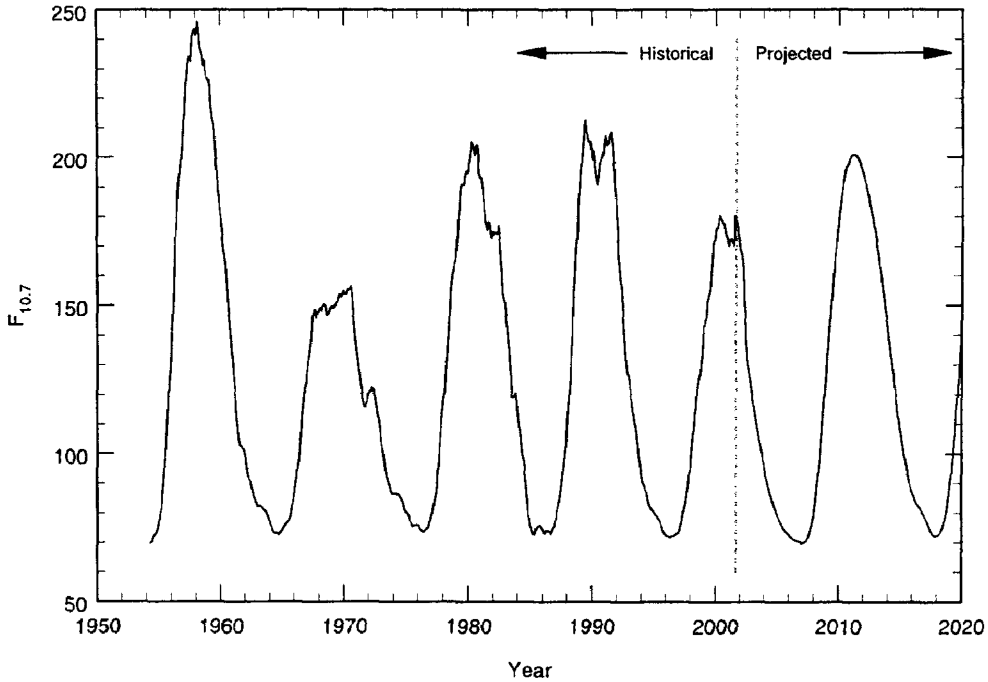

Figure 7. Solar activity variation in F107.DAT.

wish to substitute a different variation to investigate the effect of different solar cycle timing or to ensure that the radiation analysis is conservative. Because it is not possible to know what the ultimate application of the model will be, no solar cycle variation other than the "nominal" one is provided with the TPM-1 model. The user can easily generate a different F107.DAT file with a variation more appropriate for the problem at hand.

4 Results

4.1 Comparison With Other Models

One of the first requirements for TPM-1 was that it duplicate CRRESPRO predictions at high altitudes (where the solar cycle variations are minimal and the flux gradients are not as steep as at low altitude). Figures 8 – 11 show energy spectra predicted by TPM-1 and CRRESPRO for several different orbits. TPM-1 predicts significantly smaller fluxes at low altitudes than does CRRESPRO; this behavior is a result of the steep atmospheric cutoff at low altitudes. TPM-1 models this cutoff more accurately than CRRESPRO by using the TIROS/NOAA data on a much finer grid. As the orbital altitude increases, the atmospheric cutoff becomes less important, and TPM-1 approaches CRRESPRO. Even at high altitudes, there are differences between the two models, however, because of the spectral and spatial smoothing that went into developing TPM-1.

Figures 12 – 16 show comparisons of orbit-averaged energy spectra predicted by TPM-1 and AP-8 for several orbits. The TPM-1 spectra are generally harder than those predicted by AP-8, *i.e.*, TPM-1 shows higher fluxes at high energies.

4.2 Solar Cycle Variations

Figure 17 shows the predicted variation of the proton flux with time for several energies, using the $F_{10.7}$ variation used in F107.DAT. Note that even though the solar activity variation is constant with energy, when the flux is integrated over an orbit, the variation *is* energy dependent. Also note that, because the proton flux is anti-correlated with solar activity, and the value of $F_{10.7}$ at solar minimum is about the same for every solar cycle (around 70), the maximum flux predicted during a solar cycle is fairly constant from cycle to cycle. The difference among cycles is seen mainly in the minimum proton flux during each cycle.

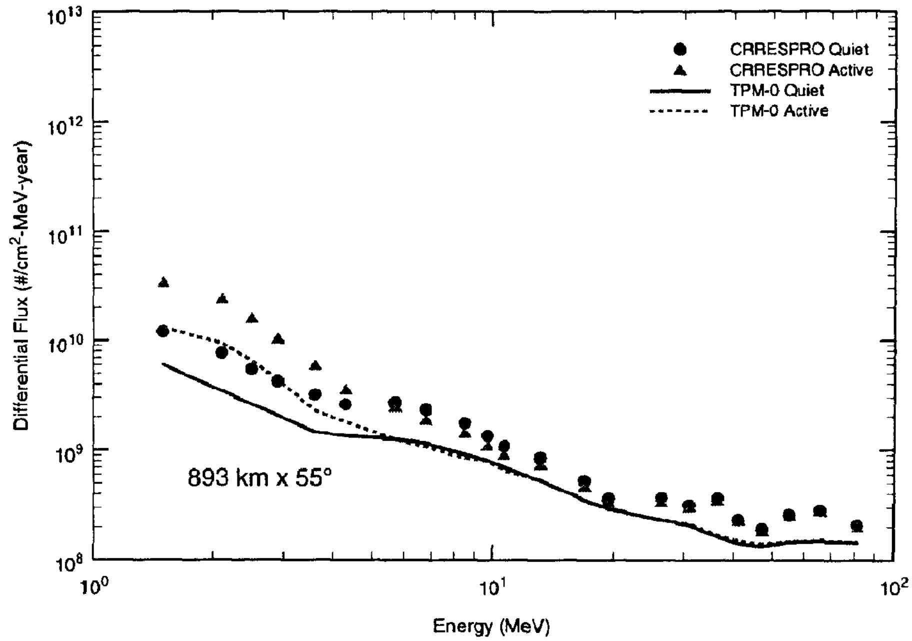

Figure 8. *Comparison of TPM-1 and CRRESPRO energy spectra for a 893 km x 55° orbit.*

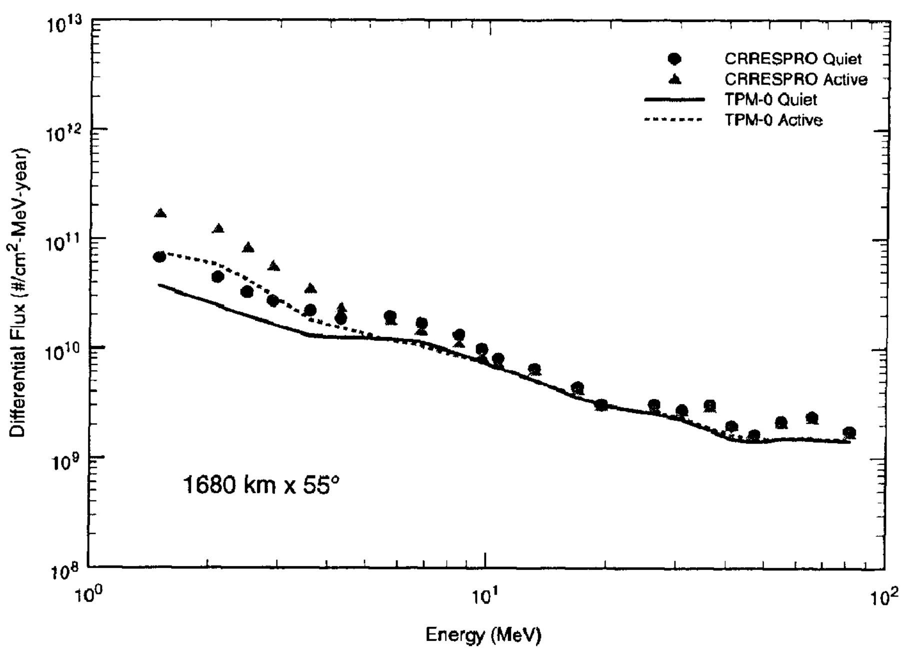

Figure 9. *Comparison of TPM-1 and CRRESPRO energy spectra for a 1680 km x 55° orbit.*

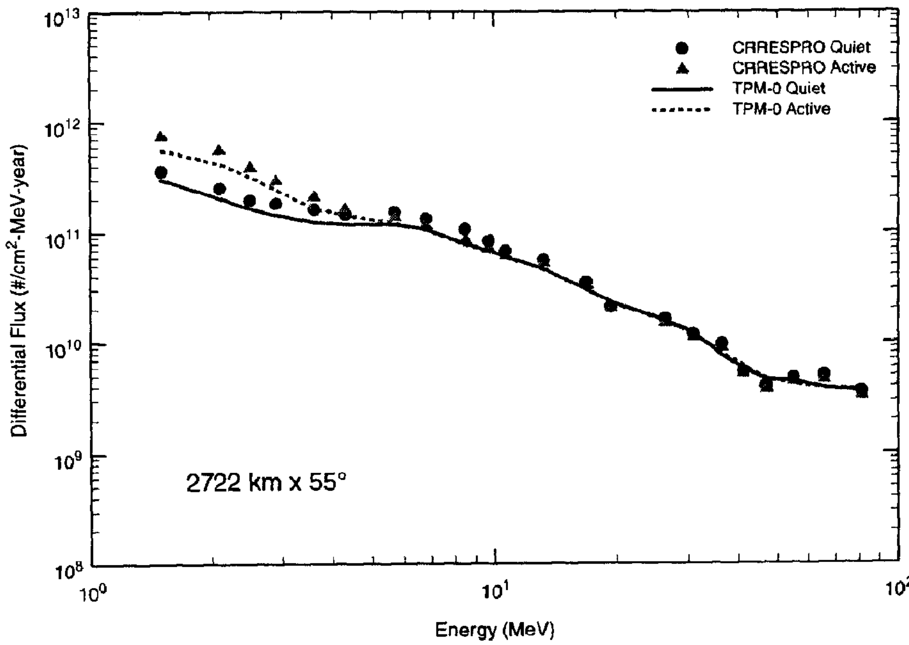

Figure 10. Comparison of TPM-1 and CRRESPRO energy spectra for a 2722 km × 55° orbit.

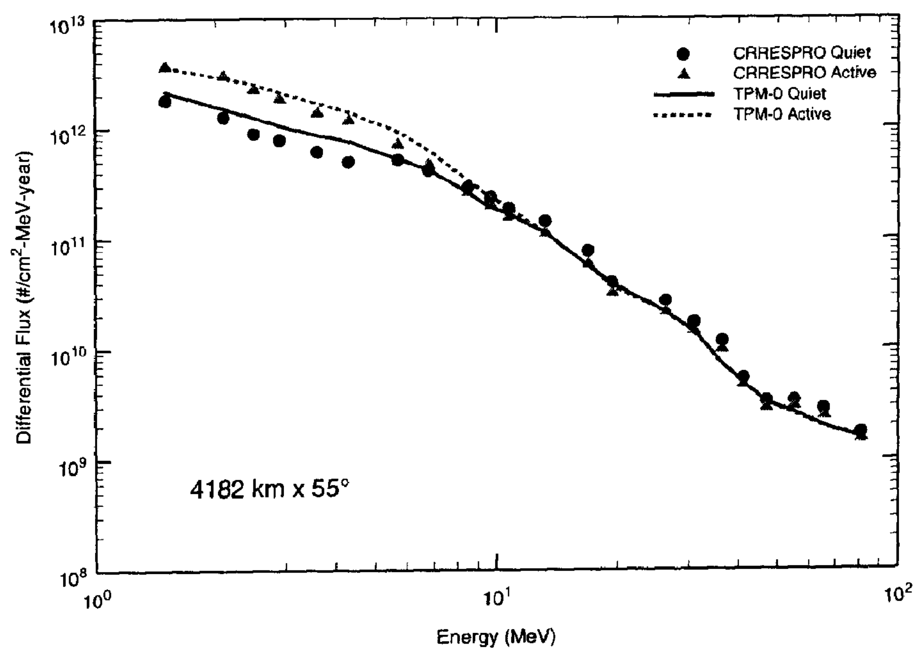

Figure 11. Comparison of TPM-1 and CRRESPRO energy spectra for a 4182 km × 55° orbit.

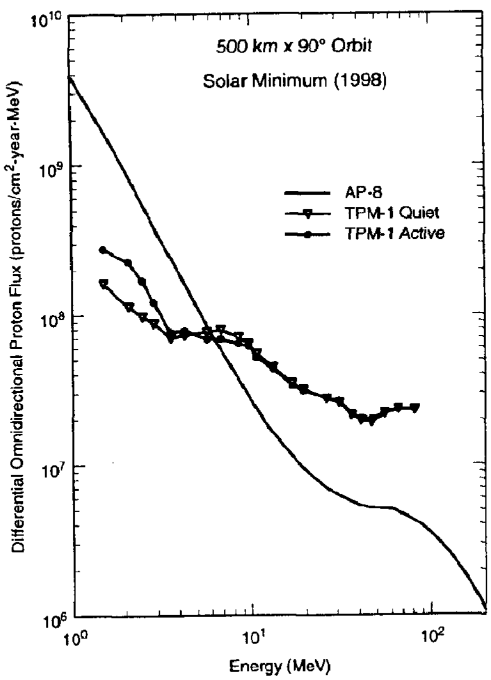

Figure 12. Comparison of energy spectra from TPM-1 and AP-8 for a 500 km × 90° orbit (solar minimum conditions).

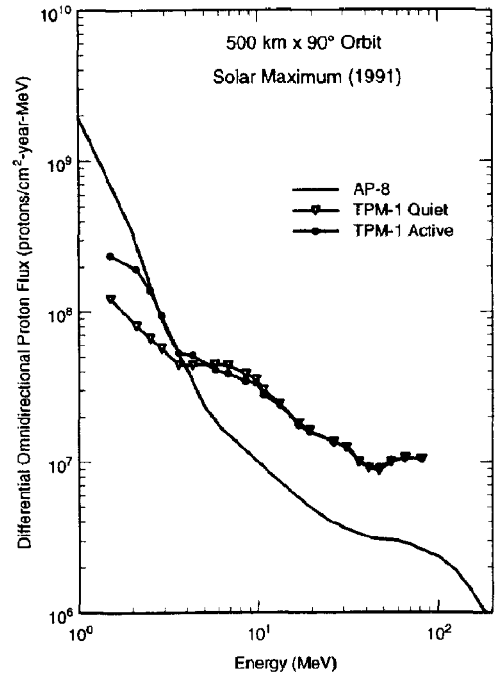

Figure 13. Comparison of energy spectra from TPM-1 and AP-8 for a 500 km × 90° orbit (solar maximum conditions).

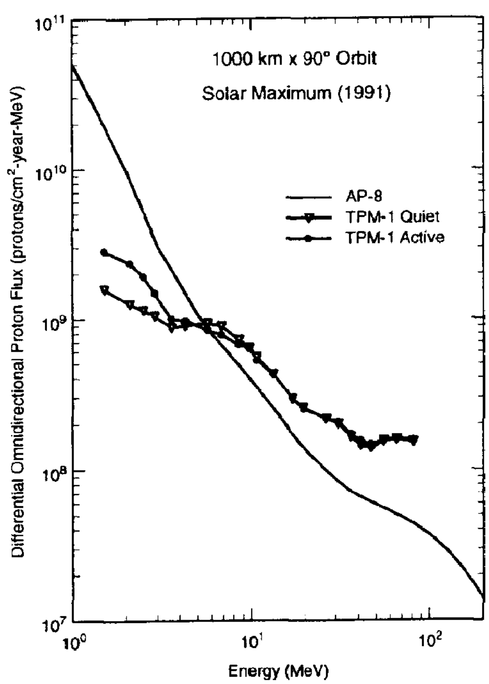

Figure 14. Comparison of energy spectra from TPM-1 and AP-8 for a 1000 km × 90° orbit (solar minimum conditions).

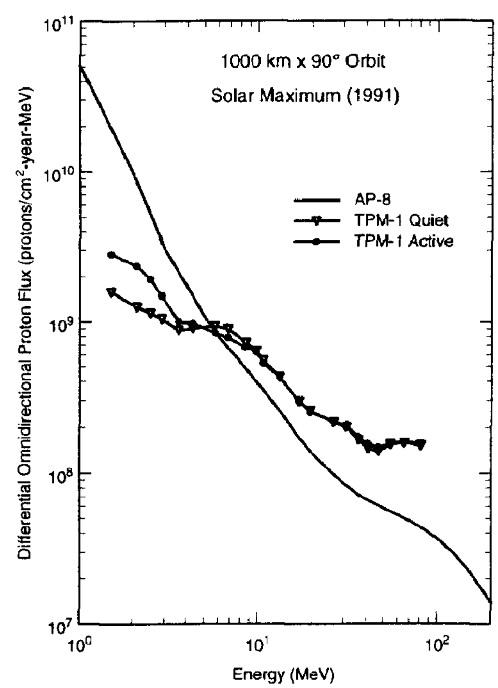

Figure 15. Comparison of energy spectra from TPM-1 and AP-8 for a 500 km × 90° orbit (solar minimum conditions).

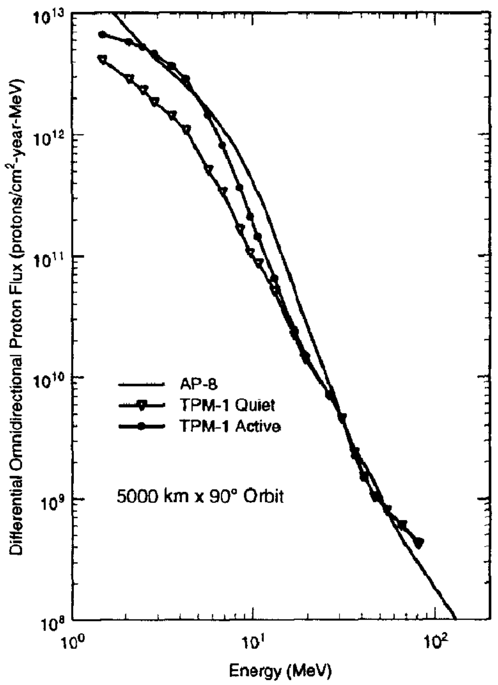

Figure 16. Comparison of energy spectra from TPM-1 and AP-8 for a 5000 km × 90° orbit (solar minimum and maximum are identical).

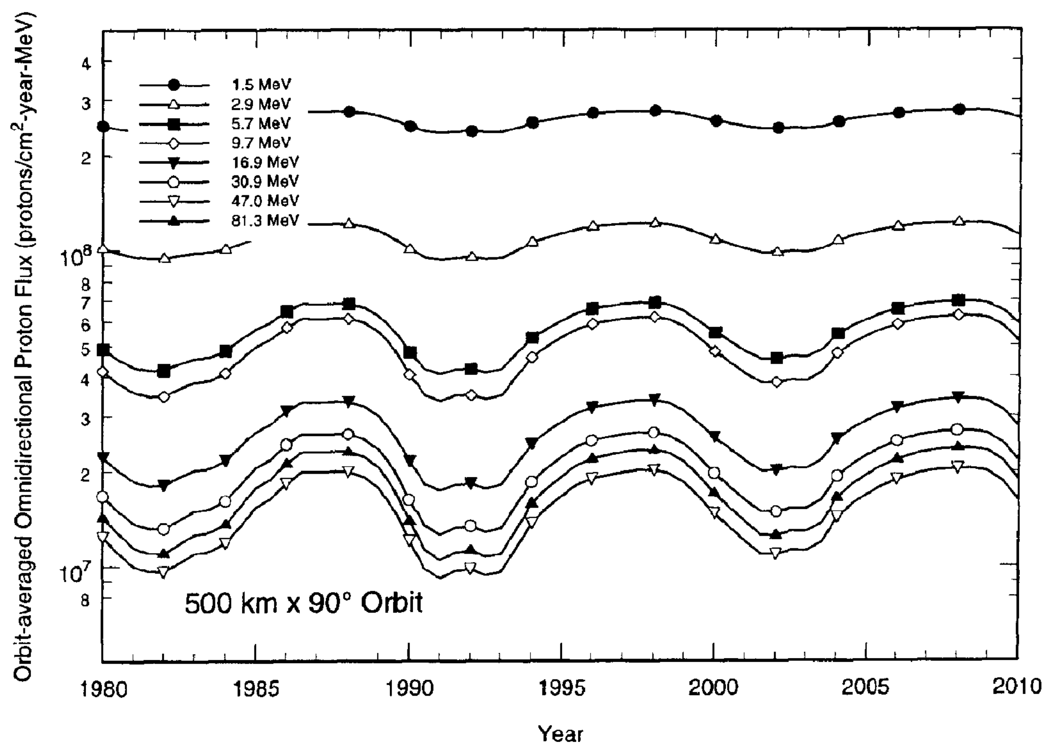

Figure 17. Solar cycle variation of trapped proton flux at several energies.

5 Conclusions

The development of TPM-1 represents a significant advance in the field of trapped proton modeling. It is now possible to predict the trapped proton flux in the energy range 1–100 MeV with good accuracy over several solar cycles. TPM-1:

- Covers the geographic region from approximately 300 km altitude to geosynchronous orbit.
- Calculates omnidirectional differential flux in 22 energy channels ranging from 1.5 to 81.5 MeV.
- Contains a continuous variation with solar activity, valid over the time span 1960–2020. The solar cycle variation is driven by the solar 10.7 cm radio flux ($F_{10.7}$).
- Contains a model for both quiet (nominal) conditions and active conditions, *e.g.*, after an event such as the one observed by CRRES.
- Can be used to obtain the flux at a particular point in space, or combined with an orbital integration to obtain orbit-averaged energy spectra.

At low altitudes, TPM-1 tends to predict harder energy spectra than does the previous AP-8 model. The TPM-1 flux at energies above about 10 MeV is higher than the AP-8 predictions, while the reverse is true below 10 MeV. At higher altitudes, the shapes of the TPM-1 and AP-8 spectra are similar. Orbital integrations show that the proton flux varies over the solar cycle by about a factor of two at higher energies, with the variation decreasing as the energy decreases.

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Appendix A. TPM-1 Operating Instructions

The TPM-1 model is delivered in three different versions:

- As a FORTRAN-callable library which can be linked to the user's driver program.
- A stand-alone version which allows the user to determine orbit-averaged spectra. An orbit generator is included with this version.
- A Web-based version which contains the same orbit generator and flux integrator as the stand-alone version.

In addition, the source code and files required to build the executables have been delivered to NASA.

All versions of the model are written in FORTRAN and were compiled under the Microsoft Windows operating system using the Digital Visual Fortran compiler and Microsoft Developer Studio 97. The executables require Windows 95 or higher to run. The Web-based version is compatible with Microsoft Internet Information Services (IIS). In order to run under a different operating system, the executables would have to be re-built.

All versions of the model require a number of data files to exist in the directory from which the model is run. A number of data files are required for the IGRF magnetic field model; these have file names of DGRFxx.DAT and IGRFxx.DAT. The TPM-1 proton flux data files are named TPM-1.DAT and TPM1B.DAT. Finally the $F_{10.7}$ data are in the file F107.DAT.

A.1. FORTRAN-callable library

The FORTRAN-callable library allows the user to develop a special purpose driver and call the TPM-1 library to determine the proton flux at a given point. In order to call the TPM-1 routines, the subroutine call is of the form

```
      CALL TPM1(XLAT, XLON, ALT, DATE,
     1   NE, E0, DFLUXQ, DFLUXA, IFLUXQ, IFLUXA,
     2   XXL, XXBB0, XXMLAT, XXRMOD, ZFACTOR)
```

The parameters are defined in Table A-1.

The subroutine calls the appropriate magnetic field routines to compute the magnetic coordinates L, B/B_0, magnetic latitude λ, and modified invariant radius R_{mod}. It computes the differential and integral fluxes at each of the 22 energies for both the quiet and active models. It also returns the solar activity scaling factor.

Table A-1. Parameters used in call to SUBROUTINE TPM1.

Variable Name	Type	Input/Output	Meaning
XLAT	REAL*4	Input	Geographic latitude (degrees North)
XLONG	REAL*4	Input	Geographic longitude (degrees East)
ALT	REAL*4	Input	Geographic altitude (km)
DATE	REAL*4	Input	Date in decimal format, e.g., 2002 June 24 = 2002.479
NE		Output	Number of energies output (this is always 22)
E0(22)	REAL*4	Output	Array of energies for which flux is computed (these are set by the model).
DFLUXQ(22)	REAL*4	Output	Array of differential flux at each energy in protons/cm^2-sec-MeV (quiet model)
DFLUXA(22)	REAL*4	Output	Array of differential flux at each energy in protons/cm^2-sec-MeV (active model)
IFLUXQ(22)	REAL*4	Output	Array of integral flux at each energy in protons/cm^2-sec (quiet model)
IFLUXA(22)	REAL*4	Output	Array of integral flux at each energy in protons/cm^2-sec (active model)
XXL	REAL*4	Output	L-value (Earth radii)
XXBB0	REAL*4	Output	B/B_0
XXMLAT	REAL*4	Output	Magnetic latitude (degrees North)
XXRMOD	REAL*4	Output	R_{mod} (Earth radii)
ZFACTOR	REAL*4	Output	Solar activity scaling factor. This is defined to be unity for the year 1991. Generally, it will be greater than 1.

The library is called TPM1LIB.LIB, and is located in the TPM1LIB directory. Also included in the directory is the source code for the TPM1EPH driver (described in the next section), which can be used as an example for calling the TPM1LIB library.

A.2. Stand-Alone Version

The stand-alone version of the model runs in a DOS window. It consists of two parts. The first part is an orbit generator, ORBIT.EXE, which accepts the user's orbital parameters, as well as the date desired, and generates an orbital trajectory. It generates an ASCII output file which summarized the orbital data, as well as a binary file with the full ephemeris.

The binary file is then used as the input to the flux integration code, TPM1EPH.EXE. This program reads the ephemeris file, and at each point determines the trapped proton flux. Once the entire file has been read, the program prints out the orbit-averaged proton flux for each energy.

In order to run both programs, the user should open a DOS window, change to the directory where the program is located, and type

```
>ORBIT
```

The orbit generator will prompt for a name for the analysis. The name entered will form the basis for all the output files generated during the analysis. The program will then prompt for the starting date (year, month, day) and time (hour, minute, sec), and for the length of time to propagate the orbit. Once this information has been entered, the program will prompt for the orbital elements. Note that the program uses "solar elements," such as those used in CRRESPRO, rather than the more traditional elements. In the solar element system, the user enters the local time of the orbit's apogee and the local time of the orbit's maximum latitude. In general, this system is easier for most users to visualize than elements using the Right Ascension of the Ascending Node and the Argument of Perigee. The other elements required are the altitudes of apogee and perigee and the inclination. Once the elements have been entered, the program prompts to make sure the user has entered the correct elements. Once they have been accepted, the program generates the ephemeris.

ORBIT creates two output files, with names based on the name the user entered at the beginning; these files will have names x.DAT and x.EPH. The x.EPH file is a binary file with the complete ephemeris data. The x.DAT file is an ASCII file which summarizes the orbit data.

Once the ephemeris has been generated, the user will run TPM1EPH. The program will prompt for the base name entered above, and then will run without further input. It generates two output files, x.OUT and x.EPH. The file x.OUT contains the orbital information and lists the orbit-averaged differential fluxes as a function of energy. The file x.EPH is a detailed output file, which lists the instantaneous flux as a function of energy for each trajectory point where a non-zero flux was found.

A.3. Web-Based Version

The Web-based version of the model is very easy to use by virtue of its graphical user interface. The web page is shown in Figure A-1. The user simply enters the date and time for the analysis, the orbital elements, and a file base name, then clicks on the "Generate Ephemeris" button. The program will calculate the ephemeris and display the results. In order to return to the model execution page, the user must use the browser's "Back" button. To compute the proton flux, it is really only necessary to click on the "Submit" button in the "Run TPM-1" section; the file base name will automatically be entered. The program will execute the TPM-1 orbital integration program and display the results. Once again, in order to return to the model execution page, the user should use the browser's "back" button.

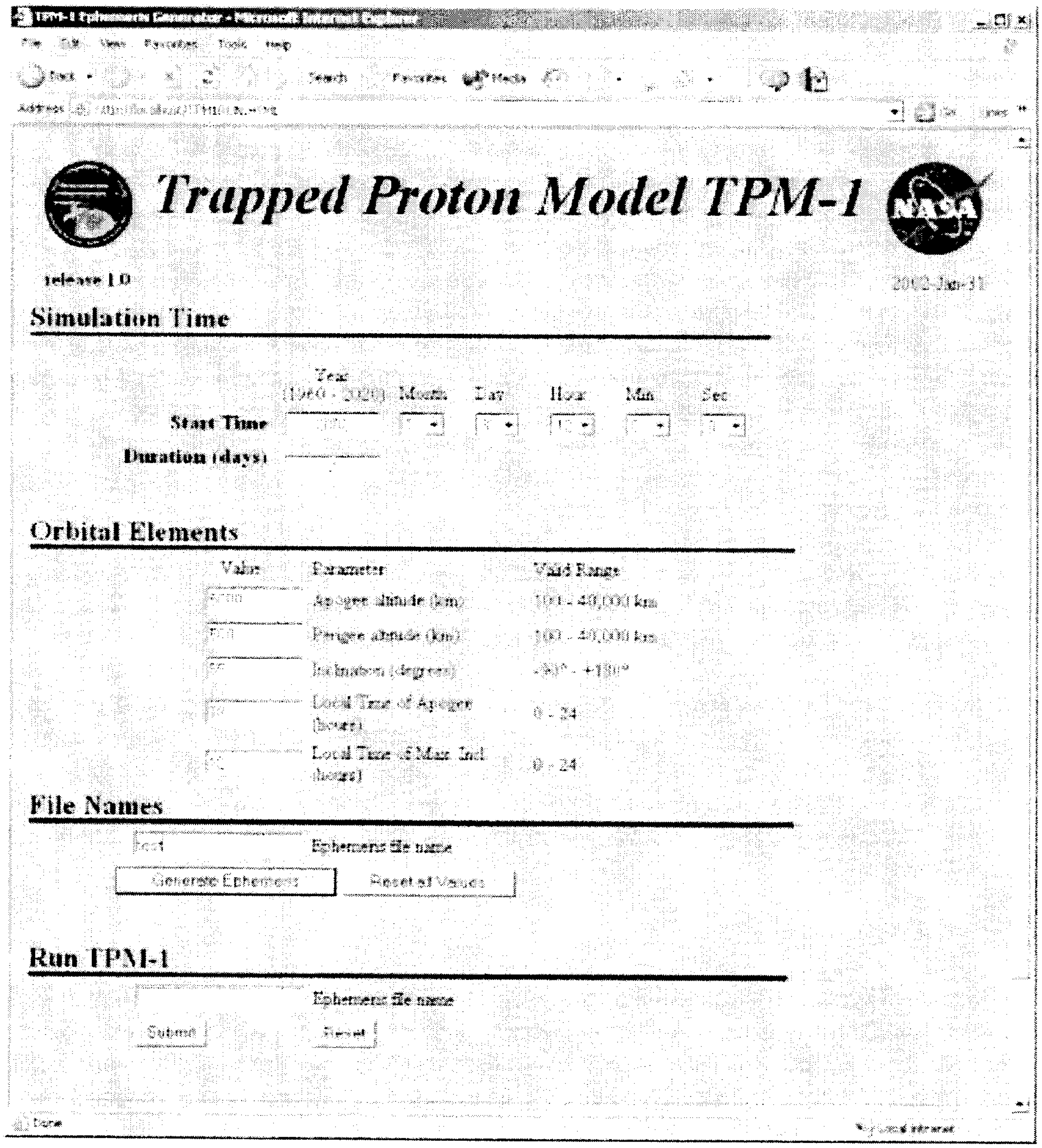

Figure A- 1. TPM-1 Web-based execution page.

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An improved model of the Earth's trapped proton environment has been developed. This model, designated Trapped Proton Model version 1 (TPM–1), determines the omnidirectional flux of protons with energy between 1 and 100 MeV throughout near-Earth space. The model also incorporates a true solar cycle dependence. The model consists of several data files and computer software to read them. There are three versions of the model: a FORTRAN-Callable library, a stand-alone model, and a Web-based model.

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