method to be fine-tuned and eliminate most of the extrapolations in the technique.

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Identification of an Error in the Distribution of the NASA Model AP-8 MIN

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Introduction

THE NASA trapped radiation models AP-8 and AE-8, for protons and electrons, respectively,[1] are widely used to describe the particle fluxes in the Earth's trapped radiation belts. For some years now, the proton models that are available on line at the National Space Science Data Center (NSSDC) have been reduced versions of these models, called AP-8 MIC and AP-8 MAC. The full models AP-8 MIN and AP-8 MAX are only available on specific request.

Recently, we tracked down an error in the previously distributed version of the model AP-8 MIN. This error can be corrected in a straightforward way, so that AP-8 MIN can be reinstated.

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The second section of this paper contains a description of the NASA trapped-particle models. In the third section, we relate how we identified the error in the AP-8 MIN data file and how it can be corrected. The fourth section is devoted to a comparison of the compressed models AP-8 MIC and AP-8 MAC with the full models AP-8 MIN and AP-8 MAX.

Description of the NASA Models AP-8 and AE-8

The proton models[2] AP-8 MIN and AP-8 MAX and the electron models[3] AE-8 MIN and AE-8 MAX are the last in a series of trapped radiation models developed by NASA since the 1960s.[4] They consist of integer arrays of scaled integral particle fluxes as a function of the particle energy E and of the magnetic coordinates B/B_0 and L, where B is the magnetic field at a given location, L is McIlwain's[5] parameter, and $B_0 = M/L^3$, with $M = 0.311653$ Gauss R_E^3, the value of the geomagnetic moment used by McIlwain[5] in his definition of L (L is expressed in units of Earth radii R_E). The logical organization of the model files is described by Vette.[3]

There are two versions of each model, denoted by MIN and MAX, valid for conditions of solar minimum and maximum, respectively. Otherwise, the models are static with epochs 1964 and 1970. AE-8 MIN/MAX and AP-8 MIN should be accessed with Jensen and Cain's[6] geomagnetic field model, which is not time-dependent. For AP-8 MAX one should use the GSFC 12/66 model,[7] updated to 1970. Using other field models may result in considerable errors on the predicted fluxes.[8]

The trapped-radiation models are distributed[1] with a subroutine called TRARA that interpolates between grid points in E, B/B_0, L. Daly and Evans[9] found that with TRARA there are problems when interpolating between L values at low altitude. They derived a new interpolation scheme in terms of the quantity $\varphi = \arcsin[(B - B_0)/(B_c - B_0)]$, where B_c is the magnetic field strength at the atmospheric cutoff. In this way, much smoother flux contours are obtained. All calculations presented here made use of this new interpolation method.

The models originally were distributed in Fortran BLOCK DATA format. Since computer memory was limited at the time of the release of the models, compressed versions of the proton models AP-8 MIN and AP-8 MAX were made available. These versions were denoted by AP-8 MIC and AP-8 MAC and require less than half the storage space of the full versions. The software package RADBELT distributed by the National Space Science Data Center (NSSDC)[1] uses the AP-8 MIC and AP-8 MAC flux maps.

Description and Correction of a Problem in AP-8 MIN

At BIRA/IASB, both AP-8 MIN/MAX and AP-8 MIC/MAC are implemented. Recently, while performing calculations with AP-8 MIN, we found a discrepancy in our copy of this model. Figure 1 shows the integral flux spectrum for $L = 2$, $B/B_0 = 1$, obtained with AP-8 MIN. Clearly, there is a discrepancy in the model around 0.6 MeV. When we repeated our calculations with AP-8 MIC, we found no errors. Upon closer investigation, we found that AP-8 MIC and AP-8 MIN differ substantially in the region bounded by $0.5 \leq E \leq 0.8$ (in MeV) and $1.4 \leq L \leq 2.7$, where the differences in fluxes reach three orders of magnitude.

We found the same error in a copy of the AP-8 MIN map we received from A. Vampola (private communication), and also in a new copy that we requested from NSSDC. On visual inspection, we noticed that two lines in the seven-column data file were misplaced, i.e. lines 842–843 were placed after line 798 (the corrupted section of the data file is reproduced in Fig. 2). Line 798 is located in the energy block for 0.6 MeV and contains the beginning of the data block for $L = 1.4$ [the problem with AP-8 MIN was also traced to this region in E and L by H. Evans (private communication)]. Consequently, the wrong values for the increment in B/B_0 are read in this L block. In addition, the value 115 is now read as the length of the next L block, and 263 for the length of the block after that. By an outrageous coincidence, the next value read after the 378 erroneous ones actually falls on the beginning of the L block for $L = 2.7$, at line number 855. Since lines 842–843 have been passed by now, the rest of the file is read correctly. Without this coincidence, the error could have spread through the whole of the remainder of the model

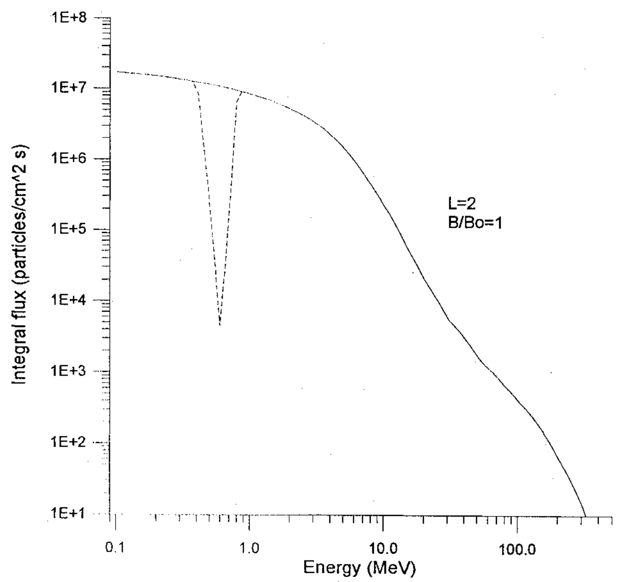

Fig. 1 Integral flux spectrum for $L = 2$, $B/B_0 = 1$, obtained with the corrupted AP-8 MIN (dashed line) and the corrected AP-8 MIN (solid line).

32767	0	1657[a]	60	**3**	0	0	*785*
3	2301	0	**11**	2334	1970	17	*786*
⋮							
18	16	16	9	10	10	10	*797*
24[b]	2867	5300	210	253	297	287	*798*
2161	2415	2598	2410	2095	1750	1257	*842*
843	639	332	268	231	210	203	*843*
288	231	196	(115[c])	88	67	54	*799*
47	31	26	25	25	25	23	*800*
25	26	26	**26**	3072	5850	230	*801*
257	289	312	316	332	333	300	*802*
⋮							
419	475	524	562	616	623	578	*814*
548	517	445	380	334	297	(263[c])	*815*
225	178	158	100	80	62	61	*816*
56	59	66	66	**31**	3891	6979	*817*
348	409	482	580	664	752	853	*818*
⋮							
121	120	113	113	124	**34**	4915	*840*
7817	399	520	723	983	1310	1753	*841*
198	198	202	212	217	218	219	*844*
214	212	214	220	**34**	5120	7922	*845*
408	546	790	1081	1511	2015	2419	*846*
⋮							
256	256	260	(**35**[d])	5529	8079	437	*855*

Fig. 2 Seven-column presentation of the affected region in the corrupted AP-8 MIN model file. The last column gives the line numbers. The entries in boldface are the beginnings of L blocks. The encircled entries are the numbers read and interpreted as beginnings of L blocks after the (framed) corrupted section. The L blocks are "resynchronized" at the third encircled entry in line 855. a: Beginning of the energy block for 0.6 MeV. b: Beginning of the block $L = 1.4$. c: Beginning of the two erroneously identified L blocks. d: Resynchronization with the real L blocks occurs here.

range. Even though the actual error is limited to one energy value in the model file, fluxes calculated for other energies around 0.6 MeV are contaminated by the interpolation procedure.

Simply moving the two misplaced lines to their correct locations removes the discrepancy in AP-8 MIN. Indeed, the flux spectrum for $L = 2$, $B/B_0 = 1$, calculated with the corrected model AP-8 MIN, decreases monotonically, as can be seen in Fig. 1. Also, there is no discrepancy between the corrected AP-8 MIN and AP-8 MIC around 0.6 MeV.

Comparison Between the Full and Compressed Models

The compressed proton models AP-8 MIC and AP-8 MAC are widely used and have generally replaced AP-8 MIN and AP-8 MAX.

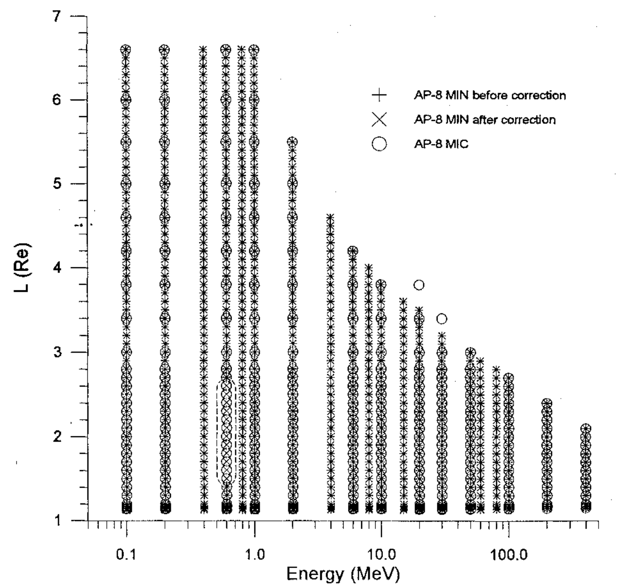

Fig. 3 Coverage in E and L, for $B/B_0 = 1$, for the corrupted AP-8 MIN, the corrected AP-8 MIN, and AP-8 MIC. The area where the distributed AP-8 MIN is corrupted is framed by a dashed line.

Since with modern computer hardware both versions of the models can easily be implemented, we feel there is no reason to adhere to AP-8 MIC and AP-8 MAC, as after all these compressed versions are considerably sparser than the original ones.

Figure 3 shows the difference in coverage of the E, L plane between the corrupted AP-8 MIN, the corrected AP-8 MIN, and AP-8 MIC. The effect of the error in the corrupted AP-8 MIN model file is that part of the L range for $E = 0.6$ MeV, i.e., $1.5 \leq L \leq 2.6$, is not covered. This L range, plus the value $L = 1.4$ in which L block the corruption starts, is completely covered by AP-8 MIC. The model block for these L values at $E = 0.6$ MeV in the corrected AP-8 MIN is identical to the corresponding block in AP-8 MIC.

From Fig. 3, it can be seen that there are no data in AP-8 MIC for $E = 0.4$, 0.8, 4, 8, 15, 60, and 80 MeV. In addition, the closing points for $E = 20$ MeV and $E = 30$ MeV in AP-8 MIC have been shifted to higher L values than in AP-8 MIN, in order to cover the same L range. This shift can lead to differences in the interpolation at the edge of AP-8 MIC.

For $B/B_0 = 1$ the difference between AP-8 MIC and AP-8 MIN (after correction) is small over most of the (E, L) region. However, for $2 \leq E \leq 6$ (in MeV) and $L > 2.5$, the AP-8 MIC fluxes differ significantly (by a factor 2 or more) from the AP-8 MIN values. This difference can be explained by the much sparser coverage in energy by AP-8 MIC in this region (see Fig. 3). A similar, but less pronounced, effect is seen in the other energy bands where AP-8 MIC has no data. It should be kept in mind that the uncertainty on the full models was estimated by Vette[4] at "about a factor of 2."

The difference between AP-8 MAC and AP-8 MAX is completely analogous to the difference between AP-8 MIC and AP-8 MIN. As for the solar minimum model, the main differences are situated in the energy bands where the coverage of AP-8 MAC is sparse. The magnitude of the flux ratios is also comparable to those for the solar-minimum models.

Conclusions

We have shown that there are non-negligible differences between the compressed and full versions of the NASA trapped proton models. Since we found that AP-8 MIN contains no physical errors after all, and the unidentified problems associated with this model can be traced to a simple discrepancy in the model file, we feel there is no reason not to use this model. As far as we know, there have been no problems reported about AP-8 MAX. Therefore, we believe it is advisable to reinstate the complete versions AP-8 MIN and AP-8 MAX. To this effect, we have sent a copy of the corrected AP-8 MIN model file to NSSDC.

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