

HOW TO GET SEP FLUX PROFILES AT 0.4 AU AND 1.0 AU

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ABSTRACT

We present a first version of an engineering model which provides proton flux profiles (at 0.5 MeV and 2 MeV) for gradual Solar Energetic Particle (SEP) events. This code is based on a model by Lario et al. (1998), assuming a number of supplementary hypothesis. SEP flux profiles greatly vary depending on the characteristics of the associated CME-driven shock (strength, velocity, large-scale structure, etc.), the heliolongitude of the parent solar activity relative to the observer's position, and the solar wind and interplanetary magnetic field conditions for particle transport. According to these main features we have built up a data base for several scenarios containing synthetic particle flux profiles for spacecraft located at 0.4 AU and 1.0 AU. By interpolating among these simulated scenarios we obtain flux profiles for intermediate events. We improve this code and expand it in order to provide particle event fluences. It will be also necessary to validate it for space weather applications.

Key words: Solar proton events; CME; Interplanetary shocks; Space weather.

ficult. Besides, the computational time required to simulate particle flux profiles makes necessary to develop an operational code for space weather forecasting. The simulation of the evolution of particle injection and propagation, and the details and characteristics of the code to be used in this engineering model have been already described, (Lario 1997). We use an $2\frac{1}{2}$ -D MHD code to simulate the propagation of the CME-driven shock by assuming an initial input shock at $18 R_{\odot}$ from the Sun (Wu et al., 1983). This model allows us to determine the evolution of the plasma velocity and magnetic field jump all along the shock front and as the shock propagates out from the Sun, as well as to fix the position of the cobpoint (the point on the shock front which connects with the observer) where the injection of shock-accelerated particles is assumed. Figure 1 shows an example illustrating several aspects of this scenario. Taking into account the different factors that determine the proton flux of SEP events (Cane et al., 1988; Lario et al., 1998), we have built up a data base containing synthetic proton flux profiles at 0.5 MeV and 2 MeV for 288 different scenarios for spacecraft located at 1.0 AU, and 96 for a probe at 0.4 AU. The parameters which characterize each case as well as the values required for the model are described in the following sections.

1. INTRODUCTION

Large gradual solar energetic particle (SEP) events pose a serious threat to probe components and operations (e.g., Feynmann et al., 2000). To synthesize proton fluxes profiles for these events it is necessary to have information about the associated CME-driven shock close to the Sun, a description of the shock propagation as well as of the injection of shock-accelerated particles and a reliable simulation of the particle transport along the interplanetary magnetic field (IMF) lines. The complexity of these processes makes the simulation of SEP events especially dif-

2. DATA BASE DESCRIPTION

The set of parameters employed to generate this data base have been selected from the range of values used to model real SEP events (Lario et al., 1998), assuming averaged properties for particle transport. One of the most relevant factors that determines the form of the particle intensity profiles is the heliolongitude of the source region with respect to the spacecraft's location. For observers at 1 AU the angular positions considered are: W45, W30, W22.5, W15, W00, E15, E22.5, E30 and E45. In or-

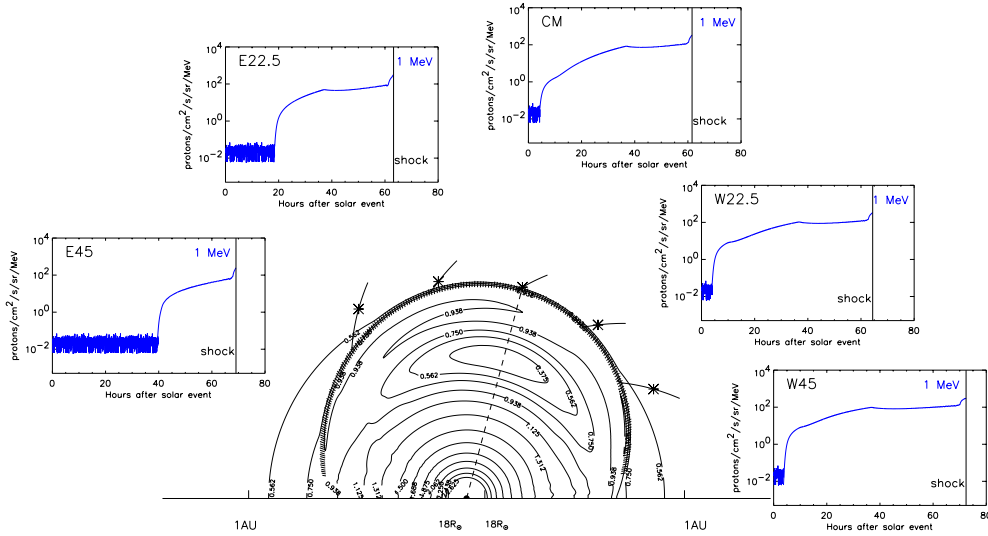


Figure 1. Snapshot of the simulation of a shock arriving at 1 AU, showing 1 MeV proton flux profiles for observers located at five different angular positions. Vertical lines indicate the time of shock passage at each spacecraft (shown by asterisks in the central panel).

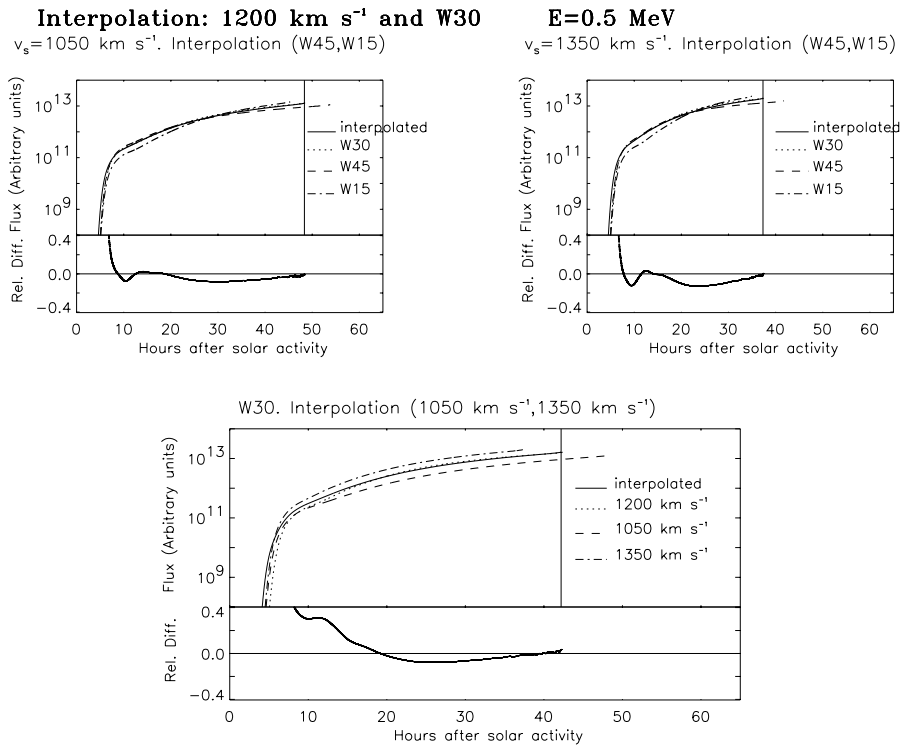


Figure 2. Interpolation procedure for the SEP event characterized by $v_s = 1200 \text{ km s}^{-1}$ and W30. Each plot shows the 0.5 MeV proton flux profiles (top panels) and the relative differences (bottom panels) between interpolated (solid traces) and computed (dotted traces) flux profiles. Vertical solid line indicates the time of the shock passage by the spacecraft of the interpolated event.

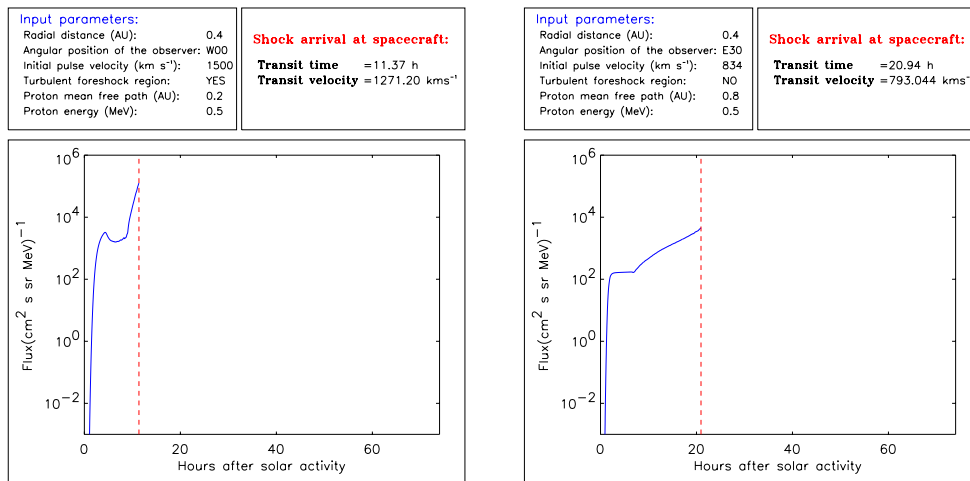


Figure 3. Examples of flux profile at 0.4 AU. Vertical dashed line indicates shock arrival at spacecraft.

der to show that it is possible to obtain SEP proton flux profiles that could be useful for planing missions to heliocentric distances like those that will cover the Solar Orbiter and future missions to Mercury and Venus, we have included the possibility of three other observers located at 0.4 AU. Their angular positions are: W45, W00 and E30 with respect to the site of the parent solar event. To characterize the evolution of the shock we have considered eight different initial shock speeds: $v_s = 750, 900, 1050, 1200, 1350, 1500, 1650$ and 1800 km s^{-1} . We have assumed a fixed initial angular amplitude of the shock in the inner boundary of the integration grid of 140° (Wu et al., 1983).

The evolution of the injection rate of shock-accelerated particles, Q , is given by $\log Q = \log Q_0 + kVR$ where VR is the normalized downstream-to-upstream plasma velocity ratio at the cobpoint; $Q_0 = 1 \cdot 10^{-35} \text{ (cm}^{-6}\text{s}^3\text{s}^{-1}\text{)}$ at 0.5 MeV, $Q_0 = 5 \cdot 10^{-41} \text{ (cm}^{-6}\text{s}^3\text{s}^{-1}\text{)}$ at 2 MeV; and $k = 0.5$, except for western events at high energies ($> 2 \text{ MeV}$) where $k = 3.0$. We have chosen this value to reproduce the decreasing flux profile observed in many western events at high energies. The interplanetary conditions for particle propagation are depicted by means of the proton mean free path; and its energy dependence is given through a quasi-linear rigidity dependence with $q=1.5$ (Jokipii et al., 1966). The code offers two possible choices, $\lambda_{\parallel} = 0.2 \text{ AU}$ and 0.8 AU . The model allows us to consider the existence of a turbulent foreshock region defined by $\lambda_{\parallel c} = 0.01 \text{ AU}$ for 0.5 MeV protons and a given width of 0.1 AU in front of the shock.

3. THE CODE AND RESULTS

The user of this code can select the characteristics of the SEP event to be modelled by specifying: (1) the

spacecraft heliocentric distance (0.4 AU or 1.0 AU); (2) the initial shock velocity (between 750 km s^{-1} and 1800 km s^{-1}); (3) the observer’s angular position with respect to the parent solar activity (from E45 to W45 at 1.0 AU; W45, W00 or E30 at 0.4 AU); (4) the proton mean free path, $\lambda_{\parallel} = 0.2$ or 0.8 AU ; (5) the existence of a turbulent foreshock region (YES/NO) and (6) the energy of the protons to be modelled (0.5 or 2.0 MeV).

For intermediate values of initial shock velocity (v_s) and observer’s angular position (W), flux profiles are calculated performing a linear interpolation from the flux profiles of the closest events contained in the data base. Since three angular positions are only considered for observers located at 0.4 AU, interpolation is performed solely for these events with intermediate values of v_s . We have compared, for a given set of parameters, the interpolated flux with those fluxes derived directly when using the event parameters and running the codes. Figure 2 shows an example of the procedure to obtain the flux profile for a given (v_s, W)-shock. Bottom panel in each plot shows the relative difference between the interpolated and computed flux. It is worthy to note that the relative differences shown in Figure 2 can be considered as an upper limit of the differences obtained when running the code, because the interpolation is performed between non-correlative events in the data base grid.

Once the program has performed the interpolation (when necessary), it produces a graphic display containing the proton flux profile for the SEP event chosen by the user. It also gives the transit time and velocity from the Sun to the spacecraft. Figures 3 and 4 show two examples of flux profiles obtained at 0.4 AU and 1.0 AU, respectively. The vertical dashed lines indicate the time of shock passage by the observer’s location. User’s input parameters defining the characteristics of the SEP event are also displayed.

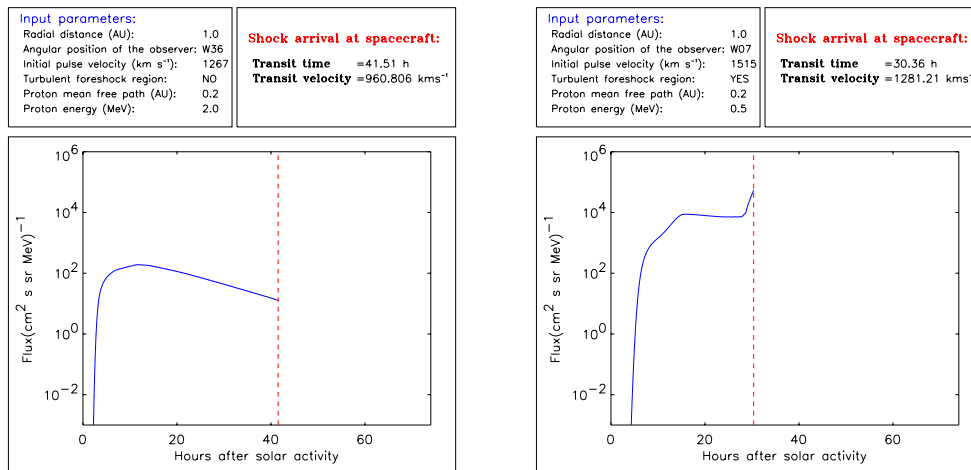


Figure 4. Examples of flux profile at 1.0 AU. Vertical dashed line indicates shock arrival at spacecraft.

4. CONCLUSIONS

Codes like this we are using should permit to quantify the evolution of the injection rate of shock-accelerated particles at the shock front as it expands from the Sun. Thus, it is possible to obtain proton flux profiles for SEP events at the heliocentric distances where the Solar Orbiter will travel. We have presented a first version of an operational model which allows us to obtain on-line synthetic proton flux profiles at 0.4 AU and 1.0 AU, for any shock with initial velocity from 750 km s^{-1} to 1800 km s^{-1} , and for any heliolongitude between E45 and W45 (at 1 AU). Intermediate events are calculated from those contained in the data base by performing a linear interpolation which leads to flux profiles differing on average less than a ten percent when comparing with the computed profiles. Next step will be to validate these profiles by comparing them with observational data, in order to check the applications of this code for space weather forecasting. We are currently working on the incorporation of the SEP event fluences in this data base since they are a key feature for space weather purposes.

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