POTENTIAL APPLICATION OF AN OPERATIONAL CODE FOR PROTON FLUX PREDICTION. FIRST APPROACH

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ABSTRACT

Large gradual solar energetic particle (SEP) events pose a threat to probe components and space operations, making necessary to develop reliable space weather forecasting models. We present a first version of an engineering code, which provides proton flux profiles at 0.5 MeV and 2 MeV, and the evolution of the cumulative fluence above those energies, for gradual SEP events. These profiles are obtained for spacecraft located at 1.0 AU and 0.4 AU. The code also provides the shock transit time and velocity from the Sun to the spacecraft, and the fluence of the event counted from its onset up to the arrival of the interplanetary shock. The code only considers a limited sample of scenarios, and the resulting profiles still have to be validated by comparing them with observational data. Then, it will be possible to evaluate the applicability of this operational code for space weather forecasting.

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

1. INTRODUCTION

In order to obtain reliable proton flux profiles of SEP events, models must include the contribution of protons accelerated by interplanetary shocks generated by coronal mass ejections (CMEs) [1, 2]. Besides, transport effects on the energetic particles streaming along the interplanetary magnetic field lines (scattering, convection, adiabatic deceleration) must be considered. This last decade our group has been developing a model for SEP events which includes all these effects [3, 4]. We use a $2\frac{1}{2}$-D MHD code to simulate the propagation of the CME-driven shock [5]. This model allows us to determine the evolution of the plasma velocity and magnetic field jumps all along the shock front as the shock propagates out from the Sun, and the location of the cobpoint (i.e., the point of the shock front magnetically connected to the observer and the point where the injection of shock-accelerated protons is taking place). Fig.1 shows an example illustrating aspects of this scenario. Reproducing the proton flux profiles of each SEP event requires several hours of computing time. Therefore, we have built up a database containing synthetic proton flux and cumulative fluence profiles upstream of the shock for 384 interplanetary scenarios (see [6] for details of the model). Intermediate scenarios are fast calculated by interpolation from the flux and fluence profiles of the closest events contained in the database.

2. DATABASE DESCRIPTION

The database contains 288 interplanetary scenarios for a spacecraft located at 1 AU, and 96 for a probe at 0.4 AU, saved in four data arrays, two for fluxes and two for fluences (37 Mb, aproximately). These scenarios include different shock speeds, several observer's locations with respect to the parent solar event, and different conditions for particle transport through the interplanetary medium (i.e., different mean free paths). The parameters selected to define these scenarios have been taken from the range of values used to model real SEP events, assuming averaged conditions for particle transport [4]. We have simulated the propagation of several interplanetary MHD-shocks by considering different initial pulse speeds at the inner boundary of the integration grid [5]: v_s = 750, 900, 1050, 1200, 1350, 1500, 1650 and 1800 km s^{-1}. The same initial pulse width has been assumed in all cases: $\omega = 140°$. As the shape of the particle intesity profiles of SEP events greatly depends on the angular position of the observer with respect to the heliolongitude of the parent solar activity, several angular positions are considered for spacecraft located at 1 AU: W45, W30, W22.5, W15, W00, E15, E22.5, E30 and E45. We have also included the option of three observers located at 0.4 AU in order to study the capability of the

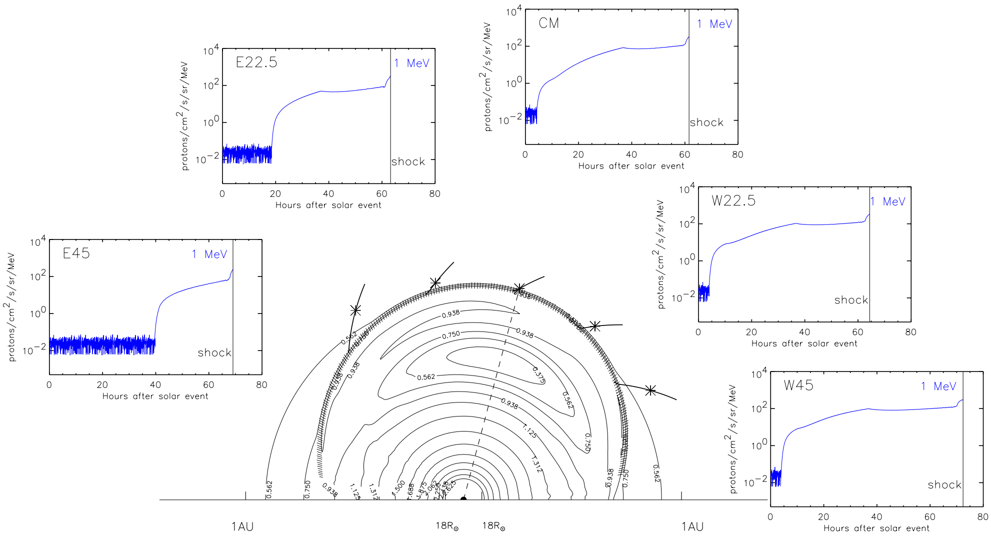

Fig. 1. Snapshot of the simulation of a shock arriving at 1 AU, showing 1 MeV proton flux profiles for observers located at five different angular positions. Vertical lines indicate the time of shock passage at each spacecraft (shown by asterisks in the central panel).

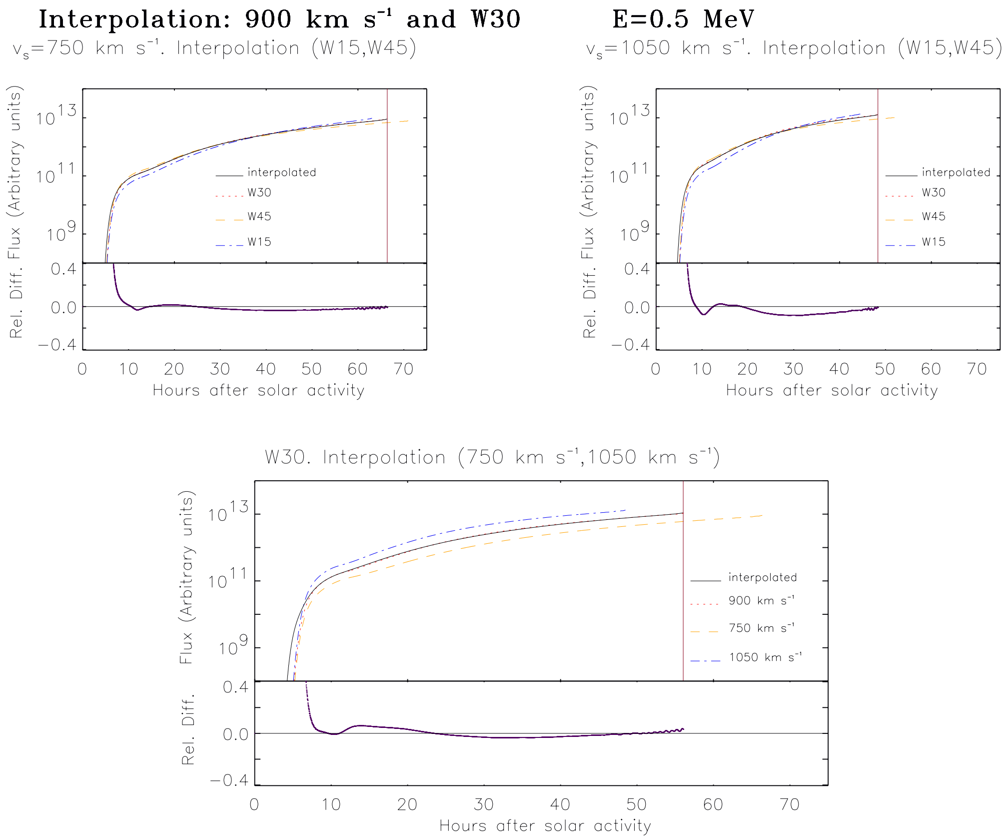

Fig. 2. Interpolation procedure for the SEP event characterized by $v_s = 900$ km s^{-1} and W30. Each plot shows the 0.5 MeV proton flux profiles (top panel) and the relative differences (bottom panel) between interpolated (solid traces) and computed (dotted traces) flux profiles. Vertical solid line indicates the time of the shock passage by the spacecraft of the interpolated event.

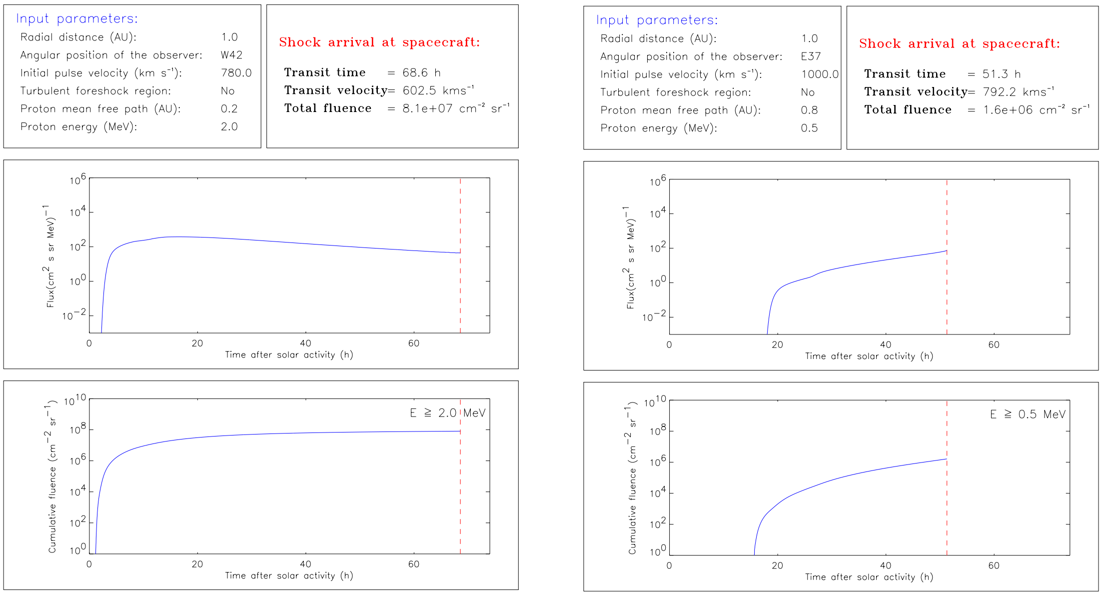

Fig. 3. Examples of a western event at high energy (left) and an eastern event at low energy (right) for a spacecraft located at 1 AU.

code to generate proton flux profiles useful for future planning missions to the inner heliosphere such as Solar Orbiter, and missions to Mercury and Venus. The angular positions with respect to the site of the parent solar activity considered are: W45, W00 and E30.

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; $Q_0 = 1 \cdot 10^{-35}$ (cm^{-6}s^{3}s^{-1}) at 0.5 MeV, $Q_0 = 5 \cdot 10^{-41}$ (cm^{-6}s^{3}s^{-1}) at 2 MeV; and $k = 0.5$, except for western events at high energies ($>$ 2 MeV) where $k = 3.0$. We have chosen this value to reproduce the decaying phase of the 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 $q = 1.5$ [7]. The code offers two possible choices, $\lambda_{\|}$ = 0.2 AU and 0.8 AU at $E = 0.5$ MeV, which is taken as the reference energy. The model allows us to consider the existence of a turbulent foreshock region defined by $\lambda_{\|c}$ = 0.01 AU for 0.5 MeV protons and a given width of 0.1 AU in front of the shock. Proton cumulative fluences for energies above 0.5 MeV and 2 MeV are provided for each scenario . We have numerically integrated the calculated table of fluxes in time, from the onset of the event up to the arrival of the shock, and in energy, for all energies above 0.5 MeV and 2 MeV.

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, $\lambda_{\|}$ = 0.2 or 0.8 AU; (5) the existence of a turbulent foreshock region (YES/NO option) and (6) the energy of the protons to be modelled, 0.5 or 2.0 MeV. The code searches in the database the events with closest characteristics to the user's selection. For intermediate values of initial shock velocity (v_s) and observer's angular position (W), flux and cumulative fluence profiles are calculated performing a linear interpolation from the synthetic flux and fluence profiles of the closest events contained in the data base. 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. Fig.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. Since the interpolation is performed between non-correlative events in the database grid, these relative differences are an upper limit of the diferences obtained when running the code. For observers located at 0.4 AU, interpolation is performed solely with intermediate values of v_s because there are only three angular positions considered.

Once the program has performed the interpolation (when necessary), it normalizes the obtained profiles to physical units: flux in protons/(MeV cm^2 sr s) and fluence protons/(sr cm^2). Fluence values have to be multiplied by the solid angle of the detector to translate its units to protons/cm^2. Next, the code asks the user for displaying either just the flux-time profile, the evolution of the cumulative fluence or both profiles simultaneously. Then the code shows a window with the selected plots and two panels at the top. The left panel shows the list of the pa-

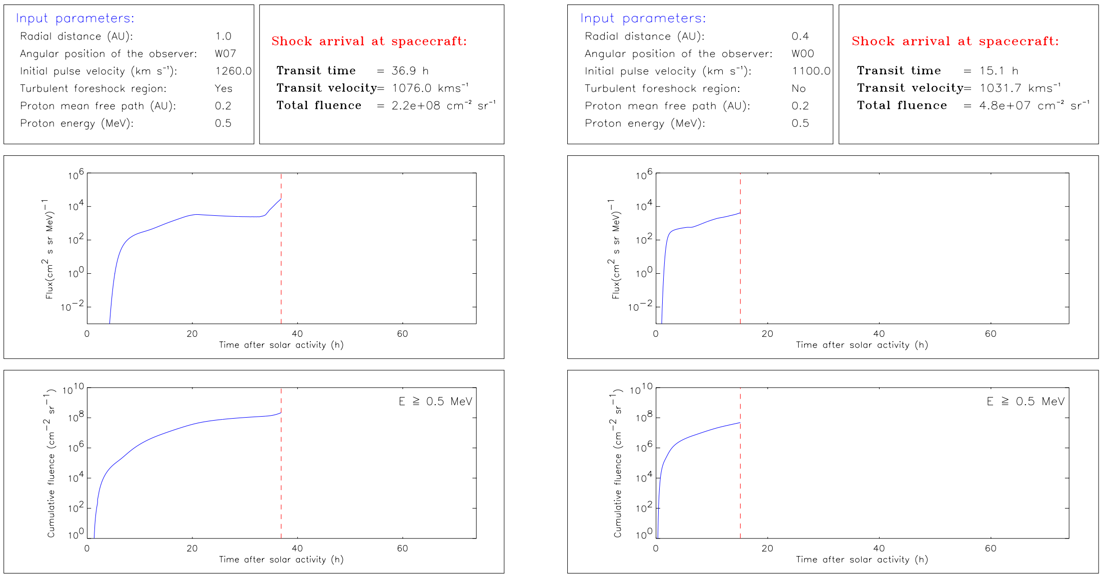

Fig. 4. Examples of a central meridian event at low energy for a spacecraft located at 1 AU (left) and at 0.4 AU (right).

rameters introduced by the user, and the right panel contains the transit time and velocity of the shock from the Sun to the observer and the fluence from the onset of the event to the shock arrival, named as total fluence in Fig.3 and Fig.4. These figures display the flux and cumulative fluence profiles obtained for different events. Dashed vertical lines indicate the time of shock arrival to the spacecraft. The code offers the possibility of saving the display as a JPEG image.

4. CONCLUSIONS

We can obtain rapidly ($<$ 1 min.) proton flux and cumulative fluence 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). We plan to extend the data base grid to consider more scenarios. We have performed a linear interpolation which leads to flux profiles differing on average less than a ten percent when comparing with the computed profiles. It will be necessary to validate the profiles contained in the data base by comparing them with observational data to evaluate the applicability of this code for space weather forecasting. Besides, it is also needed to check in deep the Q(VR) dependence by modelling more real SEP events. We are currently undertaking this work.

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