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SEPServer advances overview on Solar Energetic Particle events

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Abstract: SEPServer hosts activities related to the scientific analysis of SEP event observations, including data analysis using both data-driven and simulation-based methods. The scientific conclusions of this effort are drawn with the implementation and release to the SEP community of multiple SEP event catalogues based on different spacecraft and instruments, covering a broad timescale from 1975 to 2012 as well as a variety of radial distances from 0.3 to ≈ 5 AU in the heliosphere. SEP events from Helios A & B missions, going back to 1975, at radial distances 0.3–1 AU, together with their Electromagnetic (EM) counterpart from OSRA data are being released for the first time. A catalog covering solar cycle 23 based upon the Solar and Heliospheric Observatory (SOHO)/ Energetic and Relativistic Nuclei and Electron (ERNE) high energy (≈68 MeV) protons at 1 AU with parallel analysis of SOHO/ Electron Proton Helium Instrument (EPHIN) and Advanced Composition Explorer (ACE) / Electron, Proton and Alpha Monitor (EPAM) data, including the relevant EM associations has also been delivered. Furthermore, the first complete Solar TErrestrial RElations Observatory (STEREO) SEP event catalog based on the Low Energy Telescope (LET) protons (6–10 MeV) observations and the Solar Electron Proton Telescope (SEPT) electrons (55–85keV) observations covering the rising phase of solar cycle 24 has been implemented. Moreover, the Cosmic Ray and Solar Particle Investigation (COSPIN) Kiel Electron Telescope (KET) data of 38–125 MeV has been used to identify a new catalog of SEP events observed in and out of the ecliptic plane over solar cycle 23, with simultaneous analysis of electrons recorded by the Heliosphere Instrument for Spectra, Composition and Anisotropy at Low Energies (HISCALE). For selected events simulation based analysis has been applied in order to identify the timing of the injection history and to provide a cross reference to the EM emissions, leading to a comprehensive treatment of these events and to the corresponding testing of the data-driven analysis methods. SEPServer brings together a wealth of SEP data, analysis methods and diverse but at the same time interconnected solar and heliospheric communities. It thus provides an open tool that will advance our understanding of SEP propagation and acceleration, under different conditions, an important element of Space Weather.

1 Introduction

SEPServer is a three year collaborative project funded through the 7th Framework Program of the EU and coordinated by the University of Helsinki. SEPServer project aims to provide a new tool, which greatly facilitates the investigation of solar energetic particle (SEP) events and their origin. This is achieved via an internet server (`http://server.sepserver.eu`) that provides access to high-quality SEP data, related EM observations, state-of-the-art analysis methods and comprehensive catalogues of observed SEP events from 1975 to 2012. The consortium has applied analysis methods to the available SEP and EM data using both data-driven analysis (DDA) methods as well as numerical-simulation based inversion methods developed during the project. Furthermore, the SEPServer online access point (`http://sepserver.eu`) provides educational and outreach material on solar eruptions and the space environment. Throught the three years, SEPServer has managed to collect, assess and provide public access to a number of SEP datasets that had been previously either unavailable or available only through the Principal Investigator (PI) team. SEP experiments included in the SEPServer database come from a number of ESA/NASA missions. In addition to the energetic particle data, SEPServer provides access to a comprehensive set of EM emissions related to the SEP events. It is also, noteworthy that all datasets are accompanied with reports on the assessment of their quality [6].

One of the most important scientific conclusions of SEPServer is the implementation, and release to the SEP community, of multiple SEP event catalogues based on different spacecraft and instruments, covering a broad timescale from 1975 to 2012 as well as a variety of radial distances from 0.3 to ≈ 5 AU in the heliosphere. In particular, SEPServer hosts six catalogues of SEP events based on SOHO/ERNE [6], Ulysses/KET [1], Helios-A & B [2], and STEREO A & B [5].

2 SEPServer Catalogues

2.1 SOHO/ERNE

The Energetic and Relativistic Nuclei and Electron (ERNE) experiment onboard Solar and Heliospheric Observatory (SOHO) has been used for the implementation of this catalogue. In particular, the SOHO/ERNE catalogue is based upon the systematic scan of proton intensities (55–80 MeV, or ≈68 MeV) observed from 1996–2012. A total of 143 proton events were identified using data from SOHO/ERNE. For the first 115 events analysis has been performed for SOHO/ERNE, SOHO/EPHIN (Electron Proton and Helium Instrument) and ACE (Advanced Composition Explorer)/EPAM (Electron Proton and Alpha Monitor), resulting to the first comprehensive Catalogue of SEPServer (see [6] for details). Within this catalogue the results of the aforementioned scientific analysis has been tabulated. Onset time determination analysis utilizing two different methods, velocity dispersion analysis (VDA) and time-shifting analysis (TSA), in order to get estimates of the particle release times close to the Sun has been applied. Detailed associations to the electromagnetic (EM) emissions have also been performed and presented.

2.2 Ulysses/KET

The Kiel Electron Telescope (KET) experiment one of five telescopes of the COsmic ray and Solar Particle INvestigation (COSPIN), on board the Ulysses spacecraft has been the basis of this catalogue. In particular, the Ulysses/KET catalogue is based upon the systematic scan of proton intensities at $32 < E < 125$ MeV, while in parallel the highest energy channel ranging from 125 MeV $< E <$ 250 MeV was also scanned, for a time period from 1998-2009 (end of the mission). A total of 40 proton events were identified using data from Ulysses/KET, all of which have been analyzed using proton measurements from Ulysses/KET and electron measurements from Ulysses/HISCALE (Heliosphere Instrument for Spectrum, Composition, and Anisotropy at Low Energies) resulting to the second Catalogue of SEPServer [1]. Within this catalogue the results of the aforementioned scientific analysis has been tabulated. Onset time determination analysis utilizing three different methods, Poisson-CUSUM, the Exponential Fit and the σ method [3], in order to get estimates of the particle release times close to the Sun has been applied. Detailed associations to the electromagnetic (EM) emissions have been performed and presented, based on both Ulysses/URAP (Unified Radio and Plasma Wave

Experiment) and Wind/WAVES. These latter associations provide clear comparisons for events that have been recorded both at 1 AU in the ecliptic plane (i.e. reported from SOHO/ERNE Catalogue) and out of the ecliptic at radial distances > 1 AU and thus greatly facilitate further exploitation of the tabulated results.

2.3 Helios-A & B

The E6 experiment on board both the Helios spacecraft has been used for the production of these two catalogues (Helios-A & Helios B). In particular, the Helios (A or B) catalogues are based upon the systematic scan of proton intensities at 37 MeV, while parallel scanning of the integral proton intensities at 51 MeV and electrons at > 2 MeV took place for a time period from 1975–1982 (for Helios A) and 1977–1980 (for Helios B). A total of 61 events were identified using data from Helios spacecraft, all of which have been analyzed in terms of proton measurements for 51 (Integral channel) and 37 MeV, as well as for electron measurements > 2 MeV, resulting to the third and fourth Catalogues of SEPServer [2]. Within this catalogue the results of the aforementioned scientific analysis has been tabulated. Onset time determination analysis utilizing one method that has proven to work more efficiently for these datasets, the σ method [3], has been applied. Detailed associations to the electromagnetic (EM) emissions have also been performed and presented, based on OSRA available data. It is noteworthy that these Catalogues provide easy access for the first time to SEP events that were recorded in the 70ś at distances close to the Sun ranging from 0.3 to < 1 AU.

2.4 STEREO-A & B

A survey on the STEREO/ Low Energy Telescope (LET) proton intensities within the energy range 6–10 MeV has been performed for each of the two STEREO spacecraft [4]. Furthermore, parallel scanning of the STEREO/SEPT electron intensities in order to pinpoint the presence (or not) of a corresponding electron event has been performed in the energy range of 55–85 keV, for all of the aforementioned proton events, included in our lists. We provide the onset of all events for both protons and electrons, time-shifting analysis for near relativistic electrons which lead to the inferred solar release time and the relevant solar associations to the electromagnetic (EM) emissions have also been performed and presented, based on ARTEMIS, NRH, Wind/WAVES and STEREO/WAVES. Furthermore, associations to hard X-rays recorded by RHESSI are also included in these catalogues, where available. Finally position plots providing the relative location of both STEREO spacecraft with respect to the Earth have been added in the products of the catalogues as well [for an example see the work of [5]].

2.5 Future Improvements & Additions to the Catalogues

2.5.1 Ulysses/KET Catalogue

During the scanning of the data for the implementation of the Ulysses/KET catalog it was made clear that a handful of events (actually 15) have great potential for further exploitation by the scientific community, since those extend to higher energies ($125 < E < 250$ MeV) and thus impose a significant space weather threat. Therefore for these events it is foreseen that the SEPServer consortium will deliver plots and onset times from COSPIN/LET experiment as well as VDA based on the onset times of both COSPIN/KET and LET (for details on such work see [1]).

2.5.2 Simulation-based analysis of selected events

A selection of the events in the ERNE catalogue was performed with the aim of identifying a set of well-observed events for simulation-based analysis. The selection was made based on the conditions of the interplanetary medium, the size of the event relative to the pre-event background intensities and the directional coverage of the observations. The result was a sample of 11 near-relativistic electron events observed during quiet interplanetary conditions (no ICMEs were observed within two days before and after the onset of the event), showing a peak intensity at least an order of magnitude larger than the pre-event background, and with a large directional coverage, that guaranties that the observations contain enough information for a well-constrained inversion. These events are being

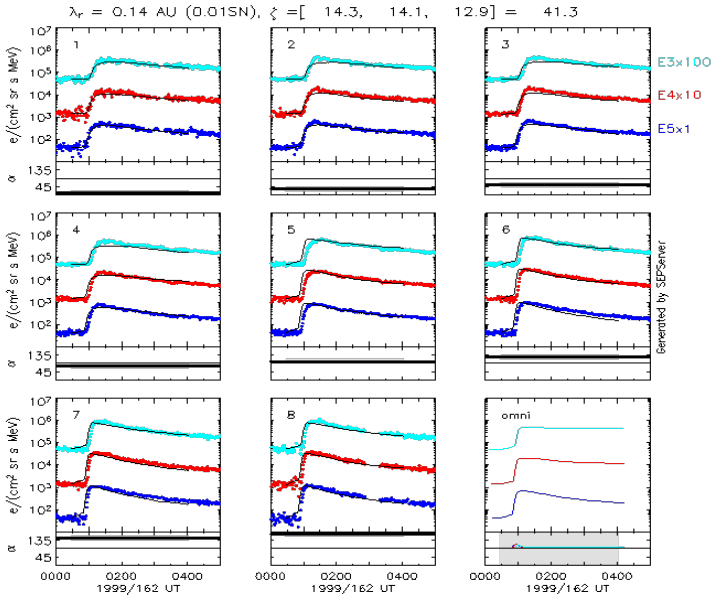

Figure 1: Best fit obtained for the 1999 June 11 event (DOY 162) assuming an electron radial mean free path of the electrons of 0.14 AU. Each panel shows the intensities observed in three energy channels (E3: 50-82 keV, E4: 82-135 keV, E5: 135-230 keV) in eight different pitch-angle (α) bins. Last panel shows the omni-directional intensities and the evolution of the mean pitch-angle.

inverted using the software SEPinversion developed within SEPServer. The results will be made available online through the ERNE catalogue. These include three types of plots for each event: the best fit of the directional intensities observed either by the ACE or Wind spacecraft (see Fig. 1), the background-subtracted directional intensities together with the Green's functions providing a response at the spacecraft location according to the inversion methodology, and the best fit injection profile with the electromagnetic emissions associated with the event.

3 Results

SEPServer brings together a wealth of SEP data, analysis methods and diverse but at the same time interconnected solar and heliospheric communities. It is an open tool that will advance our understanding of SEP propagation and acceleration, under different conditions and the featured catalogues of SEPServer greatly facilitate the in depth analysis of a large set of readily available SEP events.

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