Description

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The data files in this archive contain aggregated and partially processed Solar Energetic Particle (SEP) H and He data derived from space-based measurements.

This Reference Data Set (RDS) may be freely used and modified but any publication or website making use of these data should include the following citation:

SEPEM Reference Data Set version 3.0, European Space Agency (2022).

This work has been carried out as part of successive contracts issued by the European Space Agency (ESA) aimed at building a system for plotting data, building and validating environmental models and derivation of effects pertaining to Solar Energetic Particles (SEPs), all of which were initiatives of the Space Environment and Effects section of ESA based at the European Space Research and Technology Centre (ESTEC) in the Netherlands: <https://space-env.esa.int/>

[Contract Numbers: 20162/06/NL/JD; 4000108377/12/NL/AK; 4000107025/12/NL/AK; 4000115930/15/NL/HK, 4000127129/19/NL/HK, 4000127282/19/NL/IB/gg]

The present Solar Energetic Particle Environment Modelling (SEPEM) system is operated by the Royal Belgian Institute for Space Aeronomy and available for registration and use by registered users here:

<http://sepem.eu/>

Or may alternatively be accessed via the ESA Space Weather Service Network portal:

<https://swe.ssa.esa.int/>

A description of the system and its functionalities is available in a peer-reviewed journal article [Crosby, N., et al. (2015), SEPEM: A tool for statistical modeling the solar energetic particle environment, Space Weather, 13, 406–426, doi:10.1002/2013SW001008].

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Data has been processed from the NOAA Energetic Particles Sensor (EPS) (latterly named Energetic Proton, Electron and Alpha Detector (EPEAD)) and the High Energy Proton and Alpha Particles Detector (HEPAD), part of the Space Environment Monitor (SEM) package on-board GOES and earlier SMS satellites. The original NOAA data is available for download from here:

<https://www.ngdc.noaa.gov/stp/satellite/goes/dataaccess.html>

Data from the EPS(EPEAD) have been cross-calibrated to find the effective (mean) energy of each energy channel using data from the Goddard Medium Energy (GME) instrument on-board the IMP-8 spacecraft:

<http://spdf.gsfc.nasa.gov/imp8_GME/GME_home.html>

A description of this cross-calibration, and necessary corrections for spurious behaviour in the GME measurements, is available in a peer-reviewed research letters article [Sandberg, I., P. Jiggens, D. Heynderickx, and I. A. Daglis (2014), Cross calibration of NOAA GOES solar proton detectors using corrected NASA IMP-8/GME data, Geophys. Res. Lett., 41, doi:10.1002/2014GL060469].

Data from the HEPAD have been assessed in terms of the energy dependence of the geometric factor to derive the bow-tie (mean) energy for each energy channel. A description of this bow-tie analysis is included in the Appendix available in a peer-reviewed journal article [Raukunen, O. et al. (2020), Very high energy proton peak flux model, Journal of Space Weather and Space Climate, 10, 24, doi: 10.1051/swsc/2020024].

The time range for Version 3.0 of the data set is from 1974-07-01 until 2017-12-31.

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RDS v3.0 Data files

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The processed data set is composed of 18 text (.txt) files, for which:

- Caveats have been removed comprised primarily of data spikes which are more abundant in the earlier original data.

- Data gaps have been filled either by other EPS(EPEAD)/HEPAD data of by interpolation where they are short in duration or other data are unavailable.

- Mean energy values are provided for each energy channel (given below)

No further processing was performed on these data, i.e. the channels are the same as in the original files (see the table at the end of this file).

The P2-P7 H channels (P1 was not considered in the analysis) and the A1-A6 He channels into individual files identified by particle species and GOES spacecraft identifier.

The file name format is RDS3.0\_<species>\_<detector>\_<spacecraft>.txt. GOES is shortened to ‘G’. There are:

- 7 EPS(EPEAD) H files (note that SMS 1 and 2 and GOES 1 and 2 are given in 2 single files)

- 7 EPS(EPEAD) He files (note that SMS 1 and 2 and GOES 1 and 2 are given in 2 single files)

- 4 HEPAD H files

The file format for both sets is the same with a header line followed by data records (always in 5-minute time resolution):

Column 1 contains the date and time in ISO format (yyyy-mm-dd HH:MM:SS) of the start of a measurement time bin

Columns 2-7(2-4) contain the differential fluxes [cm-2.s-1.sr-1.MeV-1 or cm-2.s-1.sr-1.(MeV/nuc)-1] in scientific notation with 2 decimal places of the H/He channels with channel definitions and effective (mean) energies given below.

All data are comma-separated.

A separate JSON file (metadata.json) provides the channel information and units for FPDO (Flux of Protons Differential in energy and Omnidirectional) and FADO (Flux of Alpha particles Differential in energy and Omnidirectional)

Timespan of data sets

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In order to build a contiguous time series of data, the following datasets were processed with the stated start and end dates (values in parentheses indicate where HEPAD end dates differ from those of EPS):

SMS01 (EPS): 1974-07-01 to 1975-10-31

SMS02 (EPS): 1975-02-01 to 1978-03-31

GOES01 (EPS): 1977-01-01 to 1977-07-31

GOES02 (EPS): 1977-08-01 to 1983-05-19

GOES05 (EPS): 1983-05-20 to 1987-03-24

GOES06 (HEPAD): 1983-05-20 to 1994-12-31

GOES07 (EPS): 1987-03-06 to 1996-08-31

GOES08 (EPS&HEPAD): 1995-01-01 to 2003-06-16 (2003-06-17)

GOES11 (EPS&HEPAD): 2000-07-01 to 2011-02-27 (2010-12-31)

GOES13 (EPEAD&HEPAD): 2010-05-01 to 2017-12-31

The presence of NaNs in files indicate a lack of knowledge regarding the correct flux values. The P4 channel in the GOES01-02 data is corrupted, so this channel is set to NaN in the SEPEM\_H\_GOES01-02.TXT file.

The presence of zeros (0.00E+0) in files indicate background levels although data is unavailable for the given instrument.

All data files are contiguous in time, i.e. there are no data gaps, with only one exception: The GOES11 H and He data contain large gaps before 2003-06-20; the data before that date were kept nonetheless in order to maximise the overlap with GOES08 for comparison studies. Data from GOES12 has been used to in place of GOES11 data in the data files for EPS for the period from 2003-06-01 until 2003-06-21 (until the end of an SEP enhancement where GOES08 data is also missing) noting that background levels were used for the highest 2 energy channels during this period due to missing channels in GOES12 data (the 3rd highest channel is also at background during this period). HEPAD energy channels can also be assumed to be at background.

Data Processing from Original files

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The format of the GOES/SEM data files depends on the processing algorithms used for the individual spacecraft. Up to now, three formats have been used:

- 1974-1985: FITS (precursor spacecraft SMS01-02, GOES01-03, and the pre-1986 portion of the GOES05-06 data)

- 1986-2011: ASCII (GOES05-12)

- 2010-present: netCDF (GOES13-15)

The pre-1986 (binary) FITS files (one per month) contain successive records with 3 channel samples of 1 second each, where the channels vary over successive records. The time histories of the individual channels in each file were averaged over 5-minute intervals and output to new ASCII files in the same format as the 1986-2011 files (A and G files). As a consequence, an extra solar cycle of H, He data has been made available.

Data Availability

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The data files (H and He) were ingested into a MySQL database; all subsequent analysis and processing was performed using the database tools available on the SEPEM server. The resulting individual data sets are accessible following the Heliophysics API (HAPI) specification through ESA’s Open Data Interface (ODI) at:

<https://spitfire.estec.esa.int/hapi/>.

More information on ODI is available via the user guide:

<https://spitfire.estec.esa.int/trac/ODI/>

and the client software may be downloaded from:

<https://essr.esa.int/project/odi-open-data-interface-client>

Original energy channels for the individual GOES data files

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H EPS/EPEAD channels (MeV)

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Spacecraft P2 P3 P4 P5 P6 P7

SMS01 4.0-6.0 6.0-10.0 18.0-38.0 40.0-500.0 84.0-150.0 150.0-500.0

SMS02 4.0-6.0 6.0-10.0 18.0-38.0 40.0-500.0 84.0-150.0 150.0-500.0

GOES01 4.0-6.0 6.0-10.0 18.0-38.0 40.0-500.0 84.0-150.0 150.0-500.0

GOES02 4.0-8.0 8.0-16.0 16.0-36.0 36.0-500.0 80.0-215.0 215.0-500.0

GOES05 4.2-8.7 8.7-14.5 15.0-44.0 39.0-82.0 84.0-200.0 110.0-500.0

GOES07 4.2-8.7 8.7-14.5 15.0-44.0 39.0-82.0 84.0-200.0 110.0-500.0

GOES08 4.0-9.0 9.0-15.0 15.0-40.0 40.0-80.0 80.0-165.0 165.0-500.0

GOES11 4.0-9.0 9.0-15.0 15.0-40.0 40.0-80.0 80.0-165.0 165.0-500.0

GOES13 4.2-8.7 8.7-14.5 15.0-40.0 38.0-82.0 84.0-200.0 110.0-900.0

H HEPAD channels (MeV)

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Spacecraft P8 P9 P10

GOES06 330–420 420–510 510–700

GOES08 330–420 420–510 510–700

GOES11 330–420 420–510 510–700

GOES13 330–420 420–510 510–700

He EPS/EPEAD channels (MeV/nuc)

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Spacecraft A1 A2 A3 A4 A5 A6

SMS01 4.0-10.0 10.0-16.0 18.0-56.0 71.0-150.0 167.0-245.0 340.0-392.0

SMS02 4.0-10.0 10.0-16.0 18.0-56.0 71.0-150.0 167.0-245.0 340.0-392.0

GOES01 4.0-10.0 10.0-16.0 18.0-56.0 71.0-150.0 167.0-245.0 340.0-392.0

GOES02 3.2-10.0 10.0-16.0 16.0-60.0 85.0-182.0 156.0-228.0 326.0-412.0

GOES05 3.8- 9.9 9.9-21.3 21.3-61.0 60.0-180.0 160.0-260.0 330.0-500.0

GOES07 3.8- 9.9 9.9-21.3 21.3-61.0 60.0-180.0 160.0-260.0 330.0-500.0

GOES08 4.0-10.0 10.0-21.0 21.0-60.0 60.0-150.0 150.0-250.0 300.0-500.0

GOES11 4.0-10.0 10.0-21.0 21.0-60.0 60.0-150.0 150.0-250.0 300.0-500.0

GOES13 3.8- 9.9 9.9-20.5 20.5-61.0 60.0-160.0 160.0-260.0 330.0-500.0

Effective energies obtained from cross calibration

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H EPS/EPEAD channels (MeV)

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Spacecraft P2 P3 P4 P5 P6 P7

SMS01-02 4.282 6.561 29.59 52.96 150.7 440.8

GOES01-02 4.347 7.233 - 34.20 78.29 278.5

GOES05 6.348 11.01 17.56 46.54 103.8 213.6

GOES07 6.591 11.15 21.54 49.98 102.4 214.4

GOES08 6.214 10.74 18.65 47.82 105.6 152.9

GOES11-13 6.643 12.61 20.55 46.62 103.7 154.6

H HEPAD channels (MeV)

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Spacecraft P8 P9 P10

GOES06 405 473 622

GOES08 406 457 583

GOES11 406 457 583

GOES13 406 457 583

He EPS/EPEAD channels (MeV/nuc)

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Spacecraft A1 A2 A3 A4 A5 A6

SMS01-02 1.558 2.417 5.849 23.76 38.95 75.00

GOES01-02 1.558 2.417 5.849 23.76 38.95 75.00

GOES05 1.664 4.173 8.607 21.13 41.21 79.79

GOES07 1.664 4.173 8.607 21.13 41.21 79.79

GOES08 1.598 3.717 8.680 17.45 39.32 77.79

GOES11 1.598 3.717 8.680 17.45 39.32 77.79

GOES13 1.598 3.717 8.680 17.45 39.32 77.79