LA-UR-21-22607
Approved for public release; distribution is unlimited.

Title: GPS Energetic Charged Particle Data Product Files (v1.09)

Author(s): Niyazov, Rustam Akhmetovich
Morley, Steven Karl
Hoover, Andrew Scott
Norman, Benjamin

Intended for: Release data for publishing at NOAA website

Issued: 2021-03-17

GPS Energetic Charged Particle Data Product Files (v1.09)

Rustam A. Niyazov, Steven K. Morley, Andrew S. Hoover, Benjamin Norman
ISR-1, MS B241
Los Alamos National Laboratory
Los Alamos, NM 87545
rniyzov@lanl.gov, smorley@lanl.gov, ahoover@lanl.gov, bnorman@lanl.gov
March 12, 2021

Copyright notice for the processed GPS data product files:

Acknowledgement and citation request:

If you use these data products, we would appreciate an acknowledgement of the source. The preferred acknowledgement is: "The CXD team at Los Alamos National Laboratory" rather than any individual's name. The authors of this document are listed as points of contact if you have questions or comments about the data products, the CXD team is much larger. Because the historical GPS data products originate from instruments built and launched over a period of at least 25 years, the list of people who worked on the instruments is very long and has changed with time. The current members of the CXD team are listed at the end of this document. Some of the key papers describing the data set and some of the processing are referred to in this README and we ask that those most relevant to the user's application are cited.

Version 1.09 release notes:

This release improves on the previous dataset in several ways. The data are extended to November of 2020. A general improvement to the flux fitting was realized by switching to a log-likelihood minimization method and other detailed improvements. Some gaps in the previous data were recovered by using improved data processing tools. Some flux fits for ns41 were improved by correctly masking off noisy channels during certain time intervals. Two new satellites are added, ns74 and 75. We are aware of some gaps existing in the data and will attempt to address this in a future release. Note that due to the end of the RBSP mission, ns74 and ns75 data have not been cross-calibrated with RBSP.

Description of the contents of the data product files:

The BDD-IIR instruments are described in [1]. One of the dosimeter sensors in the CXD instruments is described in [2]. These documents (or web links to them) and a few others are in this directory tree. The cross calibration of the CXD electron data with RBSP is described in [3], while the cross-calibration of CXD proton data with GOES is described in [4]. The initial data release was described in [5].

Each row in the data product files contains the data from one time bin from a CXD or BDD instrument along with a variety of products derived from the data. Integration time bin steps are commandable, but 4 minutes is a typical setting. These instruments reside on many (but not all) GPS satellites that are currently in operation.

The data products originate from either BDD-IIR instruments on GPS Block IIR satellites (SVN41 and 48), CXD-IIR instruments on GPS Block IIR and IIR-M satellites (SVN53-61), or CXD-IIF instruments on GPS block IIF satellites (SVN62-73). Although SVN74-75 are in GPS block III, the CXD instrument is of the IIF design. The CXD-IIR instruments on block IIR are identical to those on GPS IIR(M) satellites.

Each data product file contains data products from one GPS satellite for one GPS week. GPS weeks start at 0:00 each Sunday morning (GPS time). GPS time differs from UTC time due to the addition of leap seconds since the start of GPS time. GPS time is counted from 00:00 on 6-Jan-1980 without adding any leap seconds. To get UTC from GPS time, one needs to subtract the total number of leap seconds for the date in question and the number of leap seconds which had been added on 6-Jan-1980 – which was 9 seconds. For example, to convert GPS time on the date of this document (8-Dec-2016) you take the total number of leap seconds added prior to 8-Dec-2016, which is 27. Subtract the 9 seconds which had been added prior to 6-Jan-1980. The difference is 18 seconds. To convert the GPS time to UTC time, subtract 18 seconds from the GPS time. Various software supports conversion between different time systems (e.g., GPS, UTC) including SpacePy [6].

The file name also contains the SVN (Space Vehicle Navstar) number. The data are provided as a self-describing ASCII format, where the metadata are provided in a header using JavaScript Object Notation (JSON). Each line in the header is prefixed with a #, so the header can be recognized and ignored if the metadata is not being used to parse the body of the file. The start column and number of columns ("dimension") for each variable are given in the headers. The actual data are encoded as delimiter separated values (DSV). Specifically, these files use whitespace-delimited ASCII, which is compatible with many CSV (comma separated value) implementations. The JSON-headed ASCII format is also directly supported by software including SpacePy[6] and Autoplot [7].

The first lines give a little information about the software code version that produced the file. It also gives the SVN number -- you can find the translations between the various space vehicle numbering schemes associated with each satellite in a variety of places on the web, but we recommend using the tables given by Morley et al. [5] and Carver et al. [8]

Electron data are initially fit with a single relativistic Maxwellian function to give a temperature and number density:

$$\text{Maxwellian}(n_e,T) = n_e B \frac{p^2}{m_e^2} \exp\left(-\frac{E}{T}\right) \qquad [\text{electrons/cm}^2\text{/s/MeV/sr}]$$

where
n_e = electron_density_fit (cm^{-3})
p = electron momentum (MeV/c)
m_e = electron mass (0.511 MeV)
E = electron kinetic energy (MeV)
B = $c/(4\pi T K_2(m_e/T)\exp(m_e/T)$
c = speed of light ($3\text{x}10^{10}$ cm/sec)
K_2 is a modified Bessel function

For SVN numbers 53 and larger (i.e. all CXDs), electron data are also fit with a more complex functional form (see ref. [3]) which generally fits the data better than the single relativistic Maxwellian (electrons/cm^2/s/MeV/sr):

flux = M_x(par[0],par[1]) + M_x(par[2],par[3]) + M_x(par[4],par[5]) + Gauss(par[6],par[7],par[8])

where $M_x(n_e,T)$ is the Maxwellian function given above, and

$$\text{Gauss}(N,P_0,\sigma_P) = N * exp\left[\frac{\left(\ln\left(\frac{p}{P_0}\right)\right)^2}{2\sigma_p^2}\right].$$

For SVN numbers 53 and larger (i.e. all CXDs), proton data are fit with a combination of an exponential spectrum in momentum which models solar energetic particle events added to a functional form to describe the cosmic ray background defined in equations (1) and (2) below:

$$j_{SEP} = \left[\frac{AN_0}{e^{43.33/r_0}}\right]\left(\frac{E}{p}\right) e^{-\frac{p}{r_0}} \qquad (1)$$

where N_0 is the number density fit, p is the proton momentum (MeV/c), E is total proton energy (MeV), r_0 is the proton momentum fit, 43.33 represents the momentum of a proton with kinetic energy = 1 MeV, and A = 0.046132 is a normalization factor such that the flux is 1000 protons / (cm2 sec sr MeV) at 1 MeV of kinetic energy.

$$j_{bkg} = B * \left[j_1 + f\left(j_2 - j_1\right)\right] \qquad (2)$$

where the fit parameters B and f are an overall normalization and f is a value between 0 and 1 representing some intermediate form of $\boldsymbol{j_n}$ (n representing solar min or max) respectively described in equation (3).

$$j_n = A_n exp\left[-\left[log\left(E/E_{0n}\right)\right]^2 / 2\sigma_n\right] + B_n E^{-C_n} \quad (3)$$

where the five parameters with the n subscript are a 5 parameter fit to the CREME96 simulation of the galactic cosmic ray background at solar min (1) and max (2) at GPS altitude with values given in the table immediately below. See [4] and references therein for details of this proton flux forward model.

Parameter	A	E_0	σ	B	C
Solar Min.	1.076e-4	3.293e2	1.305	2.441	3.671e-2
Solar Max	3.286e-5	7.463e2	1.202	2.887	2.467e-2

Remaining quantities in the data product files are described in the table below (note: the proton_integrated_flux_fit_bkg_sub variable is not included with this release).

Variable name	type	Dim.	description
decimal_day	double	1	Fractional day, GPS time. A number from 1 (1-Jan 00:00) to 366 (31-Dec 24:00) or 367 in leap years.
Geographic_Latitude	double	1	Geocentric geographic latitude of satellite (deg)
Geographic_Longitude	double	1	Geocentric geographic longitude of satellite (deg)
Rad_Re	double	1	Radius (i.e., magnitude of position vector) in Earth radii
rate_electron_measured	double	11	Measured count rate (Hz) in each of the 11 CXD electron channels
rate_proton_measured	double	5	Measured count rate (Hz) in each of the 5 CXD proton channels (P1-P5)
LEP_thresh	double	1	LEP threshold in E1 channels (0 means low, 1 means high)
collection_interval	double	1	dosimeter collection period (seconds)
year	int	1	year (e.g. 2015)
decimal_year	double	1	decimal year = year + (decimal_day-1.0)/(days in year)
svn_number	int	1	SVN number of satellite
dropped_data	int	1	if =1 it means something is wrong with the data record, do not use it
b_coord_radius	double	1	radius from Earth's dipole axis (Earth radii)
b_coord_height	double	1	height above the Earth's dipole equatorial plane (Earth radii)
magnetic_longitude	double	1	Magnetic longitude (degrees)
L_shell	double	1	L_shell (Earth radii) – currently this is the same as L_LGM_T89IGRF. Which field models this uses may change in a future release.

L_LGM_TS04IGRF	double	1	LANLGeoMag McIlwain L calculation, TS04 External Field, IGRF Internal Field.
L_LGM_OP77IGRF	double	1	LANLGeoMag McIlwain L calculation, OP77 External Field, IGRF Internal Field
L_LGM_T89CDIP	double	1	LANLGeoMag McIlwain L calculation, T89 External Field, Centered Dipole Internal Field
L_LGM_T89IGRF	double	1	LANLGeoMag McIlwain L calculation, T89 External Field, IGRF Internal Field
bfield_ratio	double	1	Bsatellite/Bequator
local_time	double	1	magnetic local time (0-24 hours)
utc_lgm	double	1	Fractional day, UTC (0-24 hours)
b_satellite	double	1	B field at satellite (gauss)
b_equator	double	1	B field at equator (on this field line) (gauss)
istat_Lgm	int	1	Flag indicating input data quality used in LANLGeoMag magnetic field model calculations. 0 is definitive data, 1 is defaults used. -1 is fill (variable not currently used).
electron_background	double	11	estimated background count rate in electron channels E1-E11 (Hz)
proton_background	double	5	estimated background count rate in proton channels P1-P5 (Hz)
proton_activity	int	1	=1 if there is significant proton activity
proton_temperature_fit	double	1	characteristic momentum -- R_0 in the expression given above (MeV/c)
proton_density_fit	double	1	proton number density fit (cm^{-3})
electron_temperature_fit	double	1	electron temperature from an initial relativisticMaxwellian fit (MeV)
electron_density_fit	double	1	electron number density fit (cm^{-3})
model_counts_electron_fit_pf	double	11	E1-E11 count rates due to proton background based on proton flux fit
model_counts_proton_fit_pf	double	5	P1-P5 count rate evaluated from proton fit (using proton_temperature_fit, proton_density_fit)
model_counts_electron_fit	double	11	E1-E11 count rates evaluated from the 9-parameter electron flux forward model
model_counts_proton_fit	double	5	P1-P5 count rates evaluated from forward model -- currently not filled (all -1's)
proton_integrated_flux_fit	double	6	integral of proton flux (based on fit) above 10, 20, 30, 50, 60, and 100 MeV (proton kinetic energy) – in $cm^{-2}sec^{-1}sr^{-1}$
proton_flux_fit	double	31	Differential proton flux at 31 energies ($cm^{-2}sec^{-1}sr^{-1}MeV^{-1}$)
proton_flux_fit_energy	double	31	energies for the fluxes in proton_flux_fit (MeV)
proton_fluence_fit	double	6	integral proton fluence at the six energies of the proton_integrated_flux_fit above ($cm^{-2}sr^{-1}$)

integral_flux_instrument	double	30	(based on 9 parameter fit) integral of electron flux above integral_flux_energy[i] particles/(cm^2 sec)
integral_flux_energy	double	30	energies for the integral of integral_flux_instrument (MeV)
electron_diff_flux_energy	double	15	energies for the fluxes in electron_diff_flux_energy (MeV)
electron_diff_flux	double	15	(based on 9 parameter fit) electron flux at energies electron_diff_flux[i] (particle/(cm^2 sr MeV sec))
efitpars	double	9	Fit parameters for 9 parameter electron fit
pfitpars	double	4	Fit parameters for 4 parameter proton fit.

SVN41 and 48 have slightly different data products, differences are as described in the following table.

Variable name	type	Dim.	Description
L_shell	double	1	L_shell -- dipole field/T-89
diffp	double	1	No longer used
sigmap	double	1	No longer used
electron_background	double	8	estimated background in electron channels E1-E8 (Hz)
proton_background	double	8	estimated background in proton channels P1-P8 (Hz)
model_counts_electron_fit	double	8	E1-E8 rates from the 2-parameter Maxwellian fit to the electron data
dtc_counts_electron	double	8	Dead time corrected electron rates (from data, not fit)
electron_diff_flux_energy	double	15	energies for the fluxes in electron_diff_flux_energy (MeV)
electron_diff_flux	double	15	(based on 2 parameter Maxwellian fit) electron flux at energies electron_diff_flux[i] (particle/(cm^2 sr MeV sec))

References:

[1] M.G. Tuszewski, T.E. Cayton, and J.C. Ingraham, Nucl. Instrum. Methods Phys. Res., A, 482(3), 653-666, doi: 10.1016/S0168-9002(01)01735-1,2002.
[2] M. Tuszewski, T.E. Cayton, J.C. Ingraham, and R.M. Kippen, “Bremsstrahlung effects in energetic particle detector,” Space Weather, 2, S10S01, doi:10.1029/2003SW000057, 2004.
[3] S.K. Morley, J.P. Sullivan, M.G. Henderson, J.B. Blake, and D. N. Baker , “The Global Positioning System constellation as a space weather monitor: Comparison of electron measurements with Van Allen probes data,” Space Weather, 14, 76-92, doi:10.1002/2015SW001339, 2016.
[4] M.R. Carver, J.P. Sullivan, S.K. Morley, J.V. Rodriguez, “Cross Calibration of the GPS Constellation CXD Proton Data With GOES EPS”, Space Weather, 16, 273-288, doi:10.1002/2017SW001750, 2018.
[5] S.K. Morley, J.P. Sullivan, M.R. Carver, R.M. Kippen, R.H.W. Friedel, G.D. Reeves, and M.G. Henderson, "Energetic Particle Data from the Global Positioning System Constellation", Space Weather, 15, 283-289, doi: 10.1002/2017SW001604, 2017.

[6] https://github.com/spacepy/spacepy
[7] http://autoplot.org
[8] M. Carver, S. K. Morley, and A. Stricklan, "GPS Constellation Energetic Particle Measurements," *2020 IEEE Aerospace Conference*, Big Sky, MT, USA, 2020, pp. 1-10, doi: 10.1109/AERO47225.2020.91

Current members of the CXD team:
Steve Armijo, Kerry Boyd, Jonathon Deming (Chief Engineer), Bob Dingler, James Dowd, Jim Distel, Ernst Esch, Adam Esquibel, Orlando Garduno, Jeff George, David Glass, Andrew Hoover (Chief Scientist), Michael Holloway, Ramona Maestas, Nathan Martin (I&T Lead), Rob Merl (Deputy Project Leader), Zach Miller, Steve Morley, Rustam Niyazov, Ben Norman (Project leader), Doug Patrick, Dan Poulson, Penny Salazar, Gina Sandoval, Jon Teague, Melinda Vigil, Howard Watson.