LA-UR-19-22539

Contents of GPS Energetic Charged Particle Data Product Files (v1.08)

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15-March-2019

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Version 1.08 Release Notes:

The most recent public release was v1.03. Various intermediate, internal releases were completed as well but not released and so the current version number (v1.08) is reflective of that.

There were two major updates to the dataset for this v1.08 release; a cross-calibration of the proton flux calculation as well as fix to GPS Block IIR electron flux calculations each of which will be briefly described.

Although the previous v1.03 release had proton fluxes available they were not yet cross-calibrated with an additional science mission; this was the major focus of the updated release. The details and procedures of this cross-calibration are described in Carver et al. 2018. The information gathered in that paper is encapsulated here as differential and integral proton fluxes.

After performing a series of validation checks in conjunction with the proton cross-calibration it was noticed that the electron fluxes were impacted by a bug in which the

Block IIR electron fluxes were calculated with the Block IIF detector responses that differ slightly. The calibration of these electron responses was outlined in Morley et al. 2016. This artifact has been rectified in the latest v1.08 release. Only the electron flux values for Block IIR satellites were affected by this and so any other electron data from the v1.03 used previously is still valid.

The remainder of this document is largely identical to the v1.03 release README with the exception that additional data fields were included in the data description table, the proton flux fit equation and description was updated, and a reference to the paper outlining the proton cross-calibration was added.

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 four 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.

Description of the contents of the data product files:

There are no detailed descriptions of most of these instruments in the literature – we will attempt to fix that problem in the future. The BDD 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].

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 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). 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 difference is the number of leap seconds which have been added on 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 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. You can find information about the addition of leap seconds in various places on the web, such as http://tycho.usno.navy.mil/leapsec.html. A description of the conversion of GPS time to UTC can also be found on the web, for example see: http://www.usno.navy.mil/USNO/time/gps/usno-gps-time-transfer. The file name encodes the day the week started (YYMMDD). 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 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 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 table at the end of reference Morley *et al*. [4]

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

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

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 function (see ref. [3]) which generally fits the data better than the single Maxwellian function (particles/(cm^2 sec MeV sr)):

$$\boldsymbol{flux = Mx(par[0], par[1]) + Mx(par[0], par[1]) + Mx(par[0], par[1]) + Gauss(par[6], par[7], par[8])}$$

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

$$\boldsymbol{Gauss(N, P_0, \sigma_P) = N \cdot e^{ln(p/P_0)^2 / 2\sigma_P^2}}$$

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 Gaussian in log(momentum) to describe the cosmic background defined in equations (1) and (2) below:

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

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.

$$\boldsymbol{j_{Bkg}} = \boldsymbol{B} * [\boldsymbol{j_1} + \boldsymbol{f}(\boldsymbol{j_2} - \boldsymbol{j_1})] \tag{2}$$

where the fit parameters $\boldsymbol{B}$ and $\boldsymbol{f}$ are an overall normalization and $\boldsymbol{f}$ 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).

$$\boldsymbol{j_n} = \boldsymbol{A_n}\boldsymbol{e}^{-\left[\log\left[E/E_{0n}\right]\right]^2 / 2\sigma_n} + \boldsymbol{B_n}\boldsymbol{E}^{-C_n} \tag{3}$$

where the five parameters with the n subscript are a 5 parameter fit to the CREME96 [Tylka et al, 1997; Weller et al, 2010; Menderhall el al, 2012] 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.

Parameter	*A*	*E₀*	*σ*	*B*	*C*
Solar Min.	$1.076\ x\ 10^{-4}$	$3.293\ x\ 10^{2}$	1.305	2.441	$3.671\ x\ 10^{-2}$
Solar Max.	$3.286\ x\ 10^{-5}$	$7.463\ x\ 10^{2}$	1.202	2.887	$2.467\ x\ 10^{-2}$

Remaining quantities in the data product files are described in the table below.

Variable name	**type**	**Dim.**	**description**
decimal_day	double	1	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	Latitude of satellite (deg)
Geographic_Longitude	double	1	Longitude of satellite (deg)
Rad_Re	double	1	(radius of satellite)/Rearth
rate_electron_measured	double	11	Measured rate (Hz) in each of the 11 CXD electron channels
rate_proton_measured	double	5	Measured 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 but this is intended to be our suggested choice for the L shell calculation in the long run.
L_LGM_TS04IGRF	double	1	LanlGeoMag L-shell McIlwain calculation, TS04 External Field, IGRF Internal Field.
L_LGM_OP77IGRF	double	1	LanlGeoMag L-shell McIlwain calculation, OP77 External Field, IGRF Internal Field (not currently filled)
L_LGM_T89CDIP	double	1	LanlGeoMag L-shell McIlwain calculation, T89 External Field, Centered Dipole Internal Field
L_LGM_T89IGRF	double	1	LanlGeoMag L-shell McIlwain 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	UTC (0-24 hours)
b_sattelite	double	1	B field at satellite (gauss)
b_equator	double	1	B field at equator (on this field line I think) (gauss)
electron_background	double	11	estimated background in electron channels E1-E11 (Hz)
proton_background	double	5	estimated background 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	N_0 parameter in fit to proton flux ((protons/(cm^2 sec sr MeV))
electron_temperature_fit	double	1	electron temperature from a one Maxwellian fit (MeV)
electron_density_fit	double	1	electron number density from a one Maxwellian fit (cm^{-3})
model_counts_electron_fit_pf	double	11	E1-E11 rates due to proton background based on proton flux fit

model_counts_proton_fit_pf	double	5	P1-P5 rate from proton fit (using proton_temperature_fit, proton_density_fit)
model_counts_electron_fit	double	11	E1-E11 rates from the 9-parameter electron flux model
model_counts_proton_fit	double	5	P1-P5 rates from electron background -- 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_integrated_flux_fit_bkg_sub	double	6	Background subtracted integral proton flux (based on fit) above 10, 20, 30, 50, 60, and 100 MeV – 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			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. These are still a work in progress. The parameters are here as placeholders until we finalize the fit function and parameters.

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

Variable name	type	Dim.	Description
decimal_day	double	1	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	Latitude of satellite (deg)
Geographic_Longitude	double	1	Longitude of satellite (deg)
Rad_Re	double	1	(radius of satellite)/Rearth
rate_electron_measured	double	8	Measured rate (Hz) in each of the 8 BDD electron channels (E1-E8)

rate_proton_measured	double	8	Measured rate (Hz) in each of the 8 BDD proton channels (P1-P8)
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) -- I do not clearly understand the origin of the calculation, but it seems to be a dipole field/T-89
bfield_ratio	double	1	Bsatellite/Bequator
local_time	double	1	magnetic local time (0-24 hours)
b_sattelite	double	1	B field at satellite (gauss)
b_equator	double	1	B field at equator (on this field line I think) (gauss)
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)
proton_activity	int	1	=1 if there is significant proton activity
electron_temperature	double	1	electron temperature from a one Maxwellian fit (MeV)
electron_density_fit	double	1	electron number density from a one Maxwellian fit (cm^{-3})
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)
integral_flux_instrument	double	30	(based on 2 parameter Maxwellian 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 2 parameter Maxwellian fit) electron flux at energies electron_diff_flux[i] (particle/(cm^2 sr MeV sec))

References:

[1] Tuszewski *et al,* NIM A482, 653 (2002)

[2] Tuszewski *et al*. (2004), “Bremsstrahlung effects in energetic particle detector,” Space Weather, 2, S10S01, doi:10.1029/2003SW000057, 2004.

[3] S. K. Morley *et al*. (2016), "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.
[4] Morley S.K., J.P. Sullivan, M.R. Carver, R.M. Kippen, R.H.W. Friedel, G.D. Reeves, and M.G. Henderson (2017), "Energetic Particle Data from the Global Positioning System Constellation," Space Weather, 15, doi:10.1002/2017SW001604.
[5] Carver M.R., J.P. Sullivan, S.K. Morley, J.V. Rodriguez (2018), "Cross Calibration of the GPS Constellation CXD Proton Data with GOES EPS," Space Weather, 16, doi: 10.1002/2017SW001750.

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