

CRRES MEDIUM ELECTRON SENSOR A (MEA) AND HIGH ENERGY ELECTRON FLUXMETER (HEEF): CROSS-CALIBRATED DATA SET DESCRIPTION

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Technical Report

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ABSTRACT: A new cross-calibrated data set of energetic electron observations from the Medium Electron Sensor A (MEA) and High Energy Electron Fluxmeter (HEEF) instruments on the CRRES satellite has been completed. This includes cleaning for proton contaminated MEA data and MEA/HEEF data with incomplete pitch angle data, spectral correction of MEA data, and adjustment of HEEF data at high flux levels. Description of the data set contents is provided.

1. INTRODUCTION

This document provides background and description of a cross-calibrated data set of energetic electron observations from the MEA and HEEF instruments on the CRRES satellite. Section 2 summarizes information on the MEA and HEEF instruments and prior data sets. Section 3 reviews the current cross calibration, and section 4 describes the data set contents.

2. BACKGROUND

2.1 Spacecraft

The Combined Release and Radiation Effects Satellite (CRRES) was a joint AFGL/NASA/ONR mission launched on 25 July 1990 and providing data through 11 October 1991. Its orbit was 350 km x 33500 km with an inclination of 18°. The satellite maintained a Sun-pointing spin axis with a spin rate of ~2 rpm. Among its instruments for particle detection were the Medium Electron Sensor A (MEA) and the High Energy Electron Fluxmeter (HEEF), both providing observations of energetic electrons. Both instruments provided pitch-angle resolved observations, using data from the CRRES fluxgate magnetometer. For an overview of CRRES see *Gussenhoven et al.* [1996].

2.2 MEA Instrument

The Medium Electron Sensor A (MEA) is a magnetic-focusing electron spectrometer. Electrons entering the instrument are deflected by a vertical magnetic field, curving to reach one of 17 silicon detectors depending on their energies. MEA observes electrons from 153 keV to 1.582 MeV in 17 differential channels, with an additional channel to provide background measurements. MEA field of view is 1.4-8.2° half-angle, depending on energy, allowing pitch-angle resolved observations given the spin of the CRRES spacecraft. For more information on the MEA instrument see *Vampola et al.* [1992].

The MEA instrument flown on CRRES was originally built as a spare for an instrument flown on OV1-19 in 1969. The MEA was subsequently modified, changing the observed energy range, and eventually recalibrated prior to launch on CRRES. Nominal mid-channel energies for the channels are given in Table 1.

Table 1. Characteristics of CRRES/MEA electron channels [Vampola, 2000].

| Channel (this doc) | Channel (Vampola) | Energy (keV) | E _{min} (keV) | E _{max} (keV) | dE (keV) | GEF (cm ² -sr-keV) | Half Angle (°) |
|-----------------------|----------------------|-----------------|---------------------------|---------------------------|-------------|----------------------------------|-------------------|
| 1 | 0 | 148 | 110 | 188 | 78 | 5.88 | 8.24 |
| 2 | 1 | 214 | 174 | 257 | 83 | 5.68 | 6.37 |
| 3 | 2 | 272 | 230 | 314 | 84 | 5.16 | 5.19 |
| 4 | 3 | 341 | 297 | 384 | 87 | 4.84 | 4.38 |
| 5 | 4 | 417 | 374 | 462 | 88 | 4.59 | 3.78 |
| 6 | 5 | 509 | 465 | 553 | 88 | 4.19 | 3.24 |
| 7 | 6 | 604 | 558 | 649 | 91 | 3.89 | 2.90 |
| 8 | 7 | 692 | 646 | 738 | 92 | 3.58 | 2.63 |
| 9 | 8 | 782 | 735 | 829 | 94 | 3.30 | 2.40 |
| 10 | 9 | 876 | 828 | 923 | 95 | 3.08 | 2.21 |
| 11 | 10 | 976 | 928 | 1024 | 96 | 2.89 | 2.05 |
| 12 | 11 | 1090 | 1042 | 1139 | 97 | 2.66 | 1.88 |
| 13 | 12 | 1178 | 1131 | 1227 | 96 | 2.49 | 1.76 |
| 14 | 13 | 1288 | 1239 | 1337 | 98 | 2.37 | 1.66 |
| 15 | 14 | 1368 | 1322 | 1419 | 97 | 2.23 | 1.56 |
| 16 | 15 | 1472 | 1423 | 1520 | 97 | 2.14 | 1.48 |
| 17 | 17 | 1582 | 1534 | 1633 | 99 | 2.03 | 1.41 |

2.3 HEEF Instrument

The AFGL High Energy Electron Fluxmeter (HEEF) comprises two solid state detectors (SSDs) and a bismuth germinate (BGO) crystal scintillator with the latter surrounded by an anti-coincidence plastic scintillator. Normally a triple coincidence in the two SSDs and BGO accompanied by anti-coincidence in the plastic scintillator indicates a particle detection, with the energy deposition signature in the SSDs and BGO used to determine particle energy and species (i.e. electron or proton). HEEF observes electrons with energies from 0.6 to 8 MeV. HEEF field of view is ~12° half-angle, accommodating pitch angle-resolved observations given spinning of the CRRES spacecraft. For more information on the HEEF instrument see *Dichter and Hanser* [1992].

The HEEF instrument was extensively calibrated prior to launch. Shortly after launch it was necessary to turn off a heater in the HEEF compartment, with the result that HEEF operating temperatures were significantly different than planned. Since the BGO operation is temperature sensitive, further calibration work on HEEF was completed using on-orbit data and laboratory calibration of a spare unit. In addition, HEEF observations were compared with CRRES Dosimeter observations. Extensive descriptions of both pre- and post-launch calibrations are available [*Dichter et al.*, 1993; *Hanser*, 1995]. Ten differential and eight integral energy channels are defined, but the lowest differential energy channel is unreliable and is not used. Two additional differential channels (0.65 and 0.95 MeV) are derived from differencing pairs of

integral channels. Nominal mid-channel energies for the differential channels are given in Table 2.

Table 2. Characteristics of CRRES/HEEF electron channels [Hanser, 1995].

| Channel (this doc) | Channel (Hanser) | Energy (MeV) | GEF, T=0° C (cm ² -sr-keV) | E, T=0° C (MeV) | GEF, T=-10° C (cm ² -sr-keV) | E, T=-10° C (MeV) |
|-----------------------|---------------------|-----------------|------------------------------------------|--------------------|--------------------------------------------|----------------------|
| 0 | | 0.65 | | | | |
| 1 | | 0.95 | | | | |
| 2 | L1 | 1.60 | 0.1151 | 1.52 | 0.0381 | 1.45 |
| 3 | L2 | 2.00 | 0.230 | 1.96 | 0.0690 | 1.85 |
| 4 | L3 | 2.35 | 0.295 | 2.36 | 0.0802 | 2.23 |
| 5 | L4 | 2.75 | 0.395 | 2.79 | 0.0957 | 2.63 |
| 6 | L5 | 3.15 | 0.448 | 3.23 | 0.0975 | 3.06 |
| 7 | L6 | 3.75 | 1.065 | 3.80 | 0.1981 | 3.59 |
| 8 | L7 | 4.55 | 1.302 | 4.65 | 0.1992 | 4.39 |
| 9 | L8 | 5.75 | 2.410 | 5.83 | 0.2780 | 5.48 |
| 10 | L9 | 7.50 | 2.400 | 7.57 | 0.1949 | 7.13 |

2.4 Prior Data Set Versions

AFRL (formerly AFGL) has released versions of the HEEF and MEA data sets. The MEA data set includes dead-time/foldover and background corrections and was posted to the NASA Space Science Data Center (NSSDC) in September 2000 [Vampola, 2000]. This set was at the 0.512-s instrument resolution but was later processed into one minute averages and posted at Goddard Space Flight Center's CDAWeb in May 2003. The HEEF data set provides one minute averages and includes temperature corrections (addressing the temperature-dependent BGO sensitivity) and dead-time corrections (both described by Hanser [1995]) and was posted to the NSSDC in October 2001 [Brautigam, 2001]. Other versions of these data sets exist, e.g. the MEA data set processed for TREND [Lemaire *et al.*, 1998].

3. DATA PROCESSING

Starting from the AFRL data sets, we completed a reanalysis and cross-calibration of the two data sets, utilizing the overlap between the MEA and HEEF instruments with channels at 1.6 MeV (these channels are referred to hereafter as MEA-17 and HEEF-2, respectively). Primarily, this data set applied the following data cleaning and corrections to the AFRL MEA/HEEF data sets:

- Removal of proton-contaminated data
- Removal of data missing too many individual pitch-angle values
- Correction of MEA flux values for varying energy spectral slope
- Correction of HEEF flux values to adopt median agreement with MEA
- Merge with K/ Φ /L* values

3.1 Initial Data Set

We started from existing AFRL-produced data sets containing one minute averages of fluxes reported in pitch angle increments of 5° . These data sets were derived from the original 0.512-s resolution data. With the spacecraft rotating at ~ 2 rpm and pitch angle reported over the range $0-90^\circ$, this provides ~ 8 points per pitch angle bin per minute. In the case of HEEF, the AFRL data set included temperature and deadtime corrections. From these we obtained omnidirectional fluxes, applying the reported fluxes uniformly for pitch angle values in each bin:

$$J = 4\pi \int_0^{\pi/2} j(\alpha) \sin(\alpha) d\alpha = 4\pi \sum_{i=1}^{19} j(\alpha) [\cos(\alpha_i) - \cos(\alpha'_i)],$$

with $\alpha_i = [5(i-1)-2.5]^\circ$, $\alpha'_i = [5(i+1)-2.5]^\circ$ (except $\alpha_1 = 0$ and $\alpha'_{19} = 90^\circ$). Figure 1 shows the resulting omnidirectional flux values, HEEF observations vs. MEA observations, before any current data cleaning or corrections.

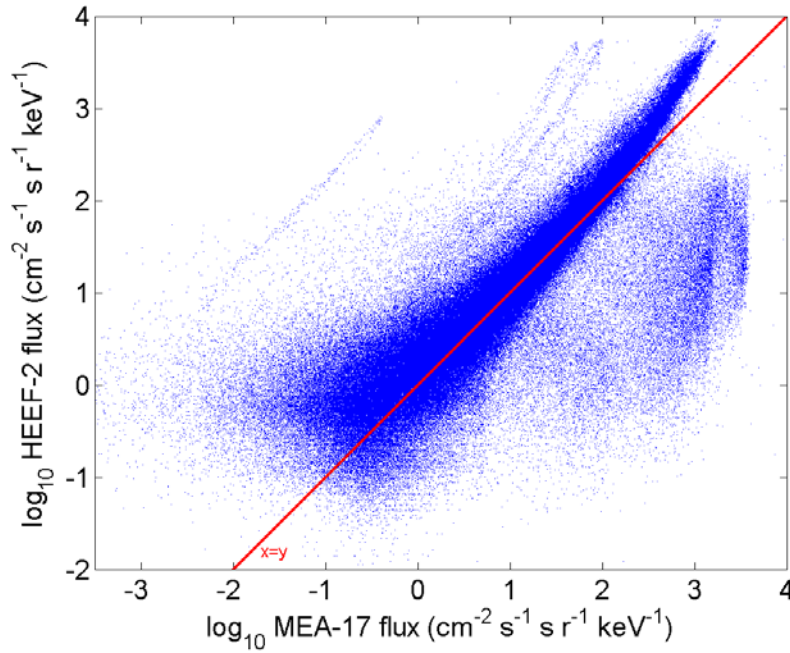


Figure 1: HEEF-2 fluxes vs. MEA-17 fluxes, original omnidirectional data (before cleaning).

3.2 Removal of Proton-Contaminated Data

Most cases with MEA-17 flux much greater than HEEF-2 flux we conclude are due to proton contamination, based on the fact that they occur either when $L < 2-3$, or during the most intense solar proton events of the CRRES mission period. Based on comparison of the two channels, we omit MEA data meeting any of the following criteria:

- $L < 2.0$ and prior to day 82.0 of 1991 (inner proton belt, pre-March 1991 storm);
- $L < 2.9$ and after day 82.0 of 1991 (inner proton belt, post-March 1991 storm);
- From day number 82.85 to 83.00 of 1991 (solar proton event);
- From day number 161.95 to 163.10 of 1991 (solar proton event).

3.3 Removal of Incomplete Observations

Cases with HEEF-2 flux much greater than MEA-17 flux for pitch angle averaged data also resulted from observations with missing pitch angle-resolved data. We elected to drop all flux values for observations with incomplete pitch-angle values. We adopted criteria to filter out cases where pitch angle-resolved data is significantly incomplete:

- HEEF data from day number 236.05 to 236.37;
- HEEF data where the number of zero pitch angle-resolved flux values is greater than 14, and the omnidirectional flux is greater than $10 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}$.
- MEA data where the highest pitch angle resolved flux is greater than $10 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}$, but this value is greater than 10 times the omnidirectional flux value.

Relative scatter between HEEF and MEA data is greater at low flux values due to low count statistics. MEA observations tend to exhibit a noise floor around $0.1 \text{ cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}$ (corresponding to $\sim 0.2 \text{ counts s}^{-1}$) whereas HEEF fluxes with value zero are reported.

3.4 Spectral Corrections

Conversion of instrument counts in both MEA and HEEF is sensitive to assumptions regarding energy spectra. In the prior data sets, this conversion assumes a power law spectra $j \sim e^n$ with fixed spectral index n , $n=0$ for MEA [Cayton, 2007] and $n=-6$ for HEEF [Hanser, 1995]. (As noted by Cayton [2007], an alternate MEA data set by Bourdarie uses $n=-3$.)

For MEA, Vampola provides channel geometric factors and nominal energies for integer values of n from -8 to 0 (Figure 2). We adopted an algorithm to correct MEA channel fluxes as follows:

- Determine the power law spectral index for channel k by fitting to fluxes from channels $k+1$ and $k-1$ (or, for the highest and lowest energy channels, from channel k and the adjacent channel);
- Adopt the correction factor from Vampola from the closest tabulated index value;
- Iterate each energy spectra five times (note that results mostly converge on the first iteration);
- Interpolate from the corrected nominal energy back to the standard nominal energy (to provide results for a uniform set of energy values).

We sought to apply a similar process to HEEF data, using reported channel response functions. Figure 3 shows the measured geometric factor (GEF) and hypothetical GEF for the differential channels from Hanser [1995]. Calculations based on these GEFs indicate correction factors ranging from 0.5 to 5 for spectral index values from -10 to 0 depending on the channel. Unfortunately, preliminary results showed that corrections failed to converge to a meaningful result, likely due to differences between the adopted and actual GEF functions. (Another factor is the observed complexity of electron spectra, examined during AE9/AP9 development [Johnston et al, 2013]). Note that the GEF for HEEF channels is temperature dependent, due to the previously mentioned issue with the BGO scintillator. Spectral correction/inversion of the HEEF data would require improved estimates of channel GEFs which was beyond the scope of the current investigation. Consequently we retain the existing spectral assumptions in the HEEF data set, i.e. power-law form with $n=-6$.

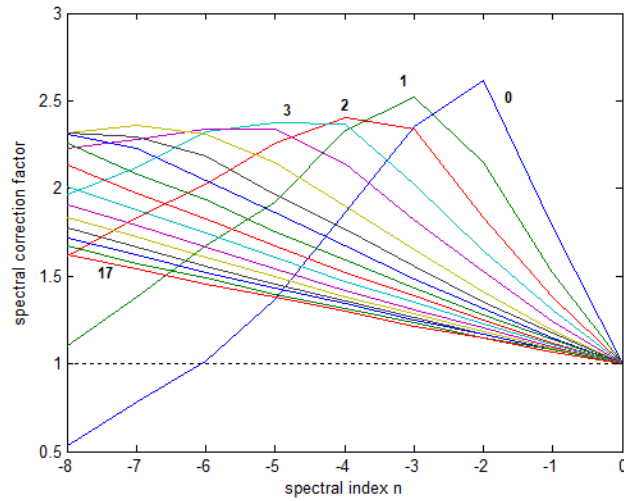


Figure 2: MEA channel spectral correction factors as functions of spectral index, with curves for several channels labeled to show the progression.

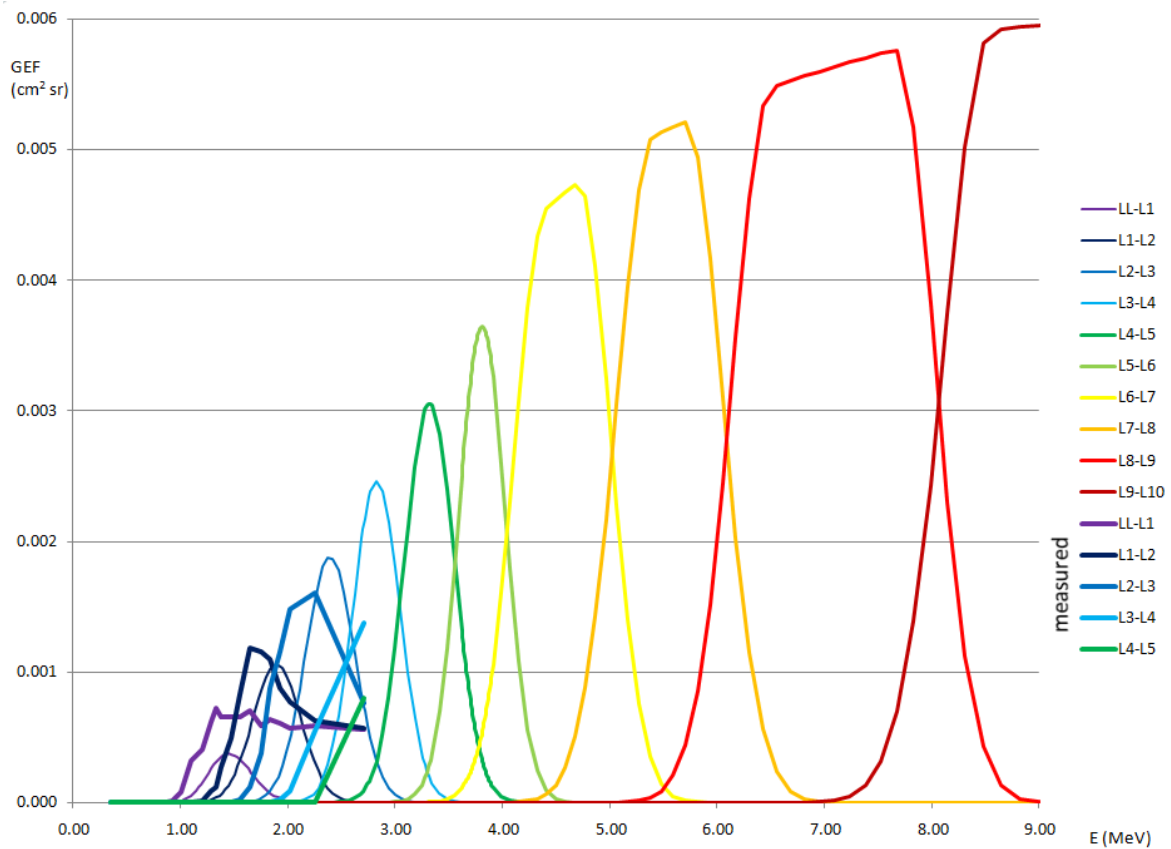


Figure 3: HEEF channel GEF(E), measured (thick lines) up to E=2.8 MeV, and hypothetical (thin lines).

3.5 Cross-Calibration of MEA and HEEF Data

Figures 4 and 5 illustrate the improved agreement between MEA and HEEF following the data cleaning and MEA spectral correction as described above. There remains, however, a significant disagreement between MEA and HEEF at high flux levels, ranging from near agreement at fluxes $\sim 10^2 \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ keV}^{-1}$ and increasing to a factor of 3 higher flux in HEEF when MEA-17 observes fluxes $\sim 10^3 \text{ cm}^{-2} \text{ s}^{-1} \text{ sr}^{-1} \text{ keV}^{-1}$.

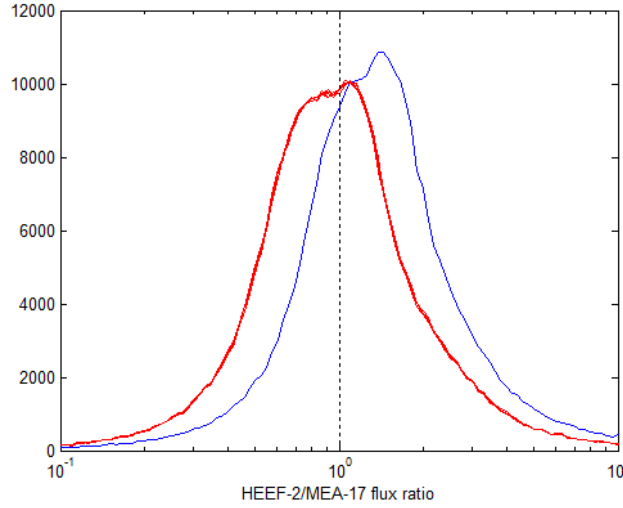


Figure 4: Histogram of HEEF-2/MEA-17 flux ratio values, uncorrected (blue) and after data cleaning and MEA spectral correction (red).

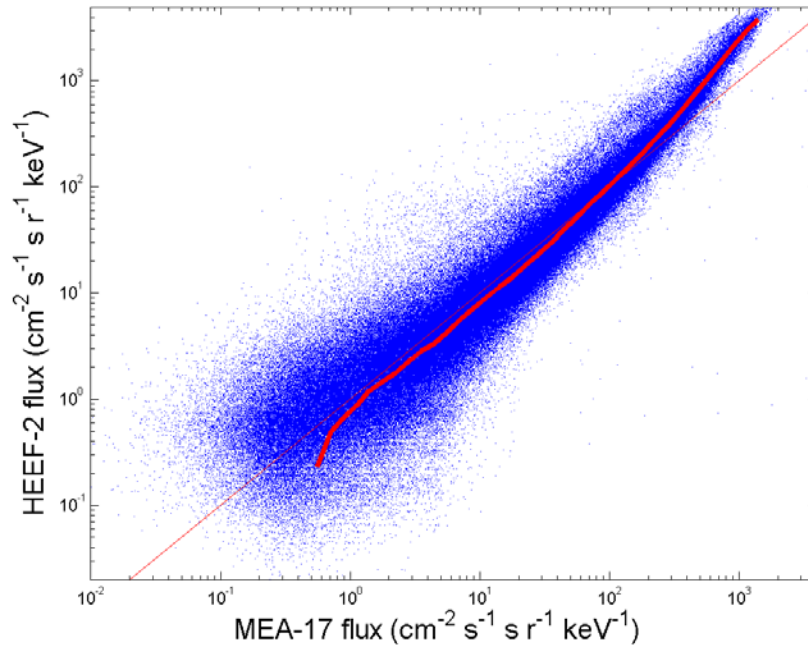


Figure 5: HEEF-2 vs. MEA-17 flux values, after data cleaning and MEA spectral correction. *Thick red line shows median trend with MEA flux.*

Our investigation suggests that this may result from the deadtime correction in the HEEF data set. Based on this, we adopted the MEA observations as standard and used an empirical correction factor as a function of the MEA-17 flux value. Figure 6 shows this correction as a function of flux observed in the HEEF-2 (1.6 MeV) channel. Based on the hypothesis that this is an issue with the deadtime correction, this correction factor based on channel 2 is also applied identically to the simultaneous observations in channels 3-10. However, this issue could be revisited.

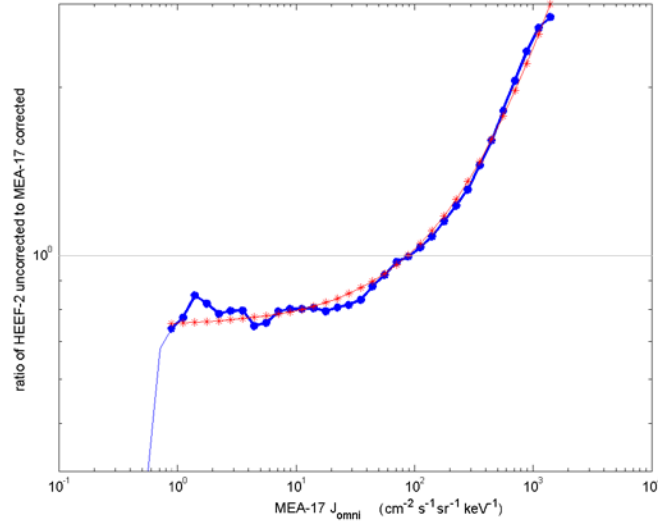


Figure 6: Median HEEF-2/MEA-17 flux ratio as a function of MEA-17 flux (blue), and adopted empirical correction factor (red).

Figure 7 illustrates the final results by plotting HEEF-2 fluxes vs. MEA-17 fluxes for the data set after all data cleaning and corrections.

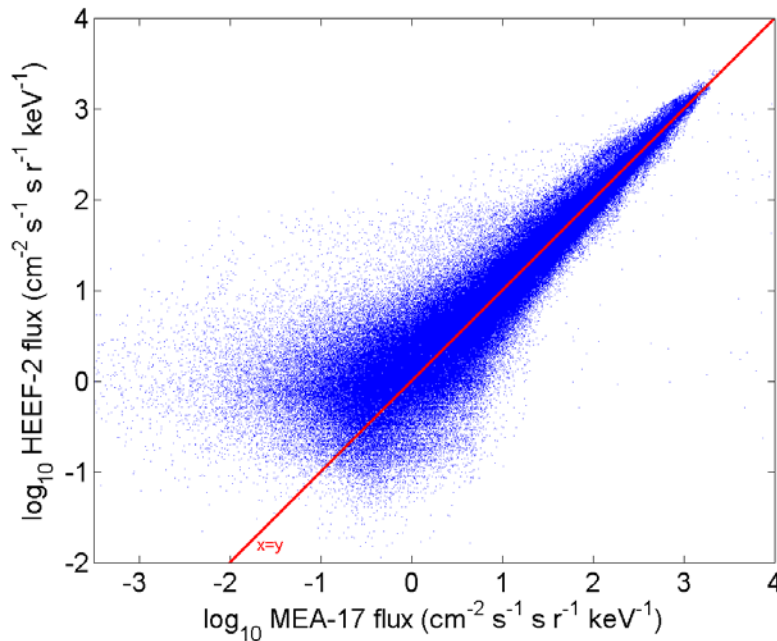


Figure 7: HEEF-2 vs. MEA-17 fluxes, omnidirectional, final data set.

MEA and HEEF data for $h_{\min} \leq 1100$ km was not used in AE9.

4. DATA SET CONTENTS

The cross-calibrated data sets are provided as Common Data Format (.cdf) files and Matlab (.mat) files, with separate files for each day and for MEA and HEEF. File naming convention is:

CRRES_(HEEF or MEA)_(year)_(day of year)_v3.mat
for example: CRRES_HEEF_1991_040_v3.mat.

Each .mat or .cdf file contains twelve arrays of data. The data arrays cover the number of observations N for that day. Each observation is the average of values for observations included in the one minute average (this includes average ephemeris time and coordinates). McIlwain L_m is calculated using fixed $k_0=0.311653 R_E^3$. L^* is calculated from ϕ using $k_0=0.30318 R_E^3$ (for 1990 epoch). Flux arrays include a number of columns C, one for each energy channel of the instrument (17 for MEA or 11 for HEEF). Directional flux values are provided for 19 pitch angle bins, $0^\circ, 5^\circ, \dots 90^\circ$, corresponding to the middle of the pitch angle bin, and omnidirectional flux values are included as well.

Arrays include:

--general--

mjd (N x 1): Modified Julian date for each observation.

eph (N x 11): Ephemeris data for each observation, with columns:

- Year
- Day number of year
- UT (seconds)
- Decimal day of year (UT)
- ECI X (km)
- ECI Y (km)
- ECI Z (km)
- SMLAT ($^\circ$)
- SMLT (hr)
- L_m
- B/B_0

keV (1 x C): nominal energy for differential channels (C=17 for MEA, 11 for HEEF)
(keV)

--for omnidirectional data--

K (N x 1): K for each observation, for particles with 90° local pitch angle ($R_E G^{0.5}$)

L^* (N x 1): L^* for each observation, for particles with 90° local pitch angle

Phi (N x 1): ϕ for each observation, for particles with 90° local pitch angle ($G R_E^2$)

flux (N x C): omnidirectional flux for C differential channels (C=17 for MEA, 11 for HEEF) ($\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}$)

--for directional data--

pa (1 x 19): middle value for local pitch angle bins ($^\circ$)

Kpa (N x 19): K for each observation and each pitch angle bin ($R_E G^{0.5}$)

Lpa (N x 19): L^* for each observation and each pitch angle bin

Phipa (N x 19): ϕ for each observation and each pitch angle bin ($G R_E^2$)

fluxpa (N x C x 19): directional flux for C differential channels (C=17 for MEA, 11 for HEEF) ($\text{cm}^{-2}\text{s}^{-1}\text{sr}^{-1}\text{keV}^{-1}$) and 19 pitch angle bins

Table 3 lists nominal energies for the MEA and HEEF differential channels in the data set.

Table 3: Nominal energies for MEA and HEEF differential channels

| MEA channel energies (keV) | HEEF channel energies (MeV) |
|-------------------------------|--------------------------------|
| 148 | 0.65 |
| 214 | 0.95 |
| 272 | 1.60 |
| 341 | 2.00 |
| 417 | 2.35 |
| 509 | 2.75 |
| 604 | 3.15 |
| 692 | 3.75 |
| 782 | 4.55 |
| 876 | 5.75 |
| 976 | 7.50 |
| 1090 | |
| 1178 | |
| 1288 | |
| 1368 | |
| 1472 | |
| 1581 | |

Figure 8 shows sample data for day 50 of 1991, with plots against UT for: omnidirectional flux from five MEA channels and four HEEF channels; L_m and B/B_0 ; and SMLAT and SMLT.

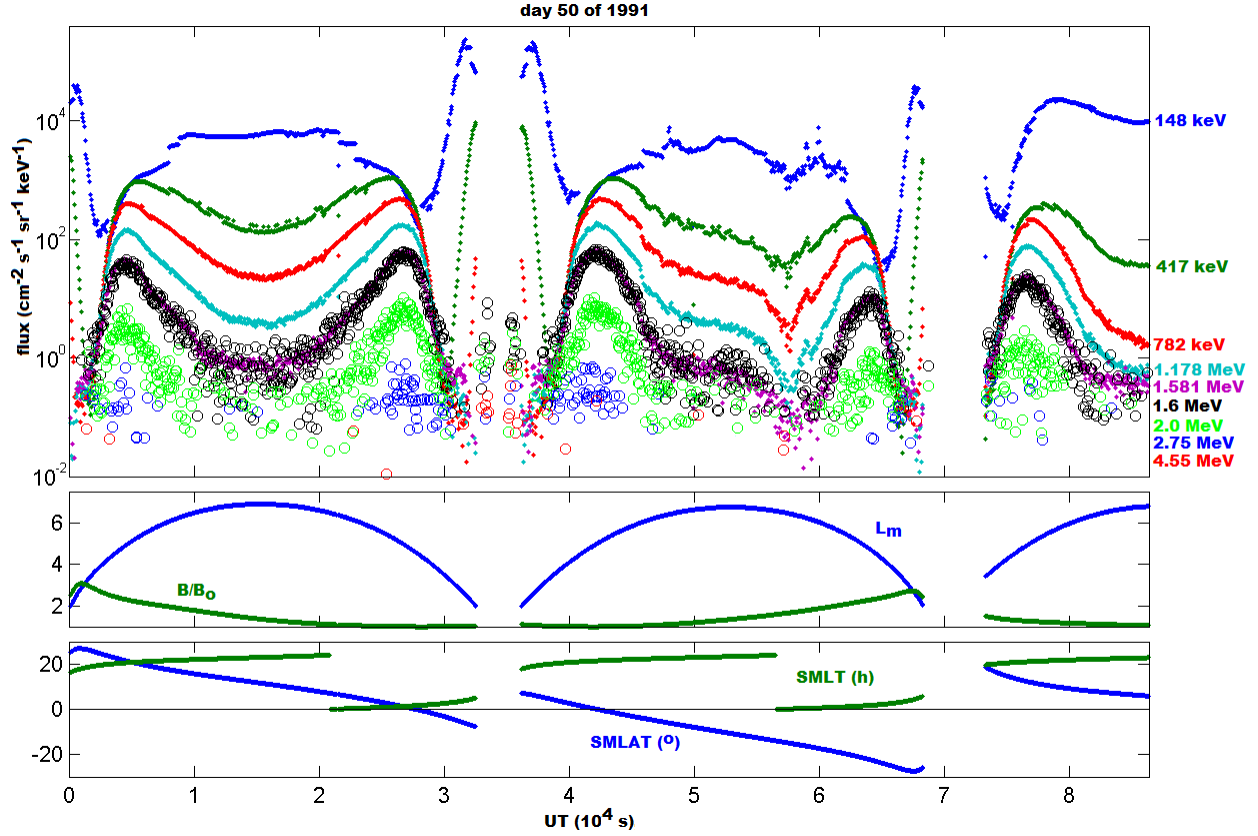


Figure 8: Sample data vs. UT for day 50 of 1991. (top) fluxes from five MEA channels (points) and four HEEF channels (circles); (middle) L_m and B/B_0 ; (bottom) SMLAT and SMLT.

5. CONCLUSION

Versions of the MEA and HEEF data sets as processed for AE9/AP9 are publicly available at the ViRBO web site [Johnston *et al.*, 2011].

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