User Guide to the PEACE measurements in the Cluster Active Archive (CAA)

prepared by

A.N. Fazakerley and the PEACE Operations Team

Contents

1 Introduction

This is the User Guide to the PEACE (Plasma Electron And Current Experiment) datasets in the CAA. Its main purpose is to assist users in the usage and interpretation of PEACE CAA data products on thermal electron plasma population; see also Fazakerley et al (2010a). All PEACE datasets available on the CAA are listed in Appendix A.

A significant amount of calibration work has been invested in the absolute determination of the geometrical factor and the time history of the MCP efficiencies in order to provide the users with high-quality distribution functions and electron moments. For further details, see Fazakerley et al. (2010b).

A proper exploitation of the PEACE datasets requires some understanding of the way PEACE has been operated and the various operating modes; these are briefly described in section 3 of this document.

2 Instrument Description

The PEACE instrument consists of two sensors, HEEA (High Energy Electron Analyser) and LEEA (Low Energy Electron Analyser), and a data processing unit, the DPU. The sensors are Top Hat electrostatic analysers. The basic measurement made by PEACE is the number of counted electrons per accumulation time. The satellite spin period, T_{spin}, is measured as the time taken between two detections of the Sun by the spacecraft sun sensor (which is expected to be 4 seconds ±10%). Within the PEACE DPU, the spin period is subdivided into 1024 equal parts, of duration T_{acc}, the PEACE accumulation time. The instrument measurement cycle is thus adjusted to match the spin period so that PEACE collects data from a full 4π solid angle (i.e. provides "all-sky" coverage) during each and every spin. For a nominal 4 second spin, $T_{acc} \sim 3.9$ msec. In reality this is calculated from the duration of the previous spin provided by the spacecraft housekeeping.

The "Top Hat" electrostatic analysers (see Figure 1) are mounted with their 180° field of view fan lying perpendicular rather than tangential to the spacecraft surface (see Figure 2). The 180° detector field of view is divided up into 12 equal parts of angular width 15°. Measurements are made simultaneously in each of these 12 "polar zones". The two sensors are mounted on opposite sides of the spacecraft thus their combined field of view is 360° (not always sampling the same energy at the same time). In combination, the two sensors view the complete 4π solid angular range during half a spacecraft spin.

The LEEA sensor has a geometric factor appropriate for the higher electron fluxes usually found at lower energies (e.g., in the solar wind and magnetosheath). The HEEA sensor has a larger geometric factor, better suited to the lower densities occurring in the outer magnetosphere and magnetotail, which extends the dynamic range of the instrument. The HEEA sensor is usually used to measure higher energies than the LEEA sensor, which extends the energy coverage of the instrument.

The energy range of the instrument is nominally from 0.6 eV to 26,460 eV. The sensors can each be used to make measurements at any of 88 distinct non-zero levels. The first 16 energy levels are equally spaced linearly in the range from 0.6 eV to 9.5 eV. Levels 16 to 87 inclusive are equally spaced logarithmically over the rest of the range. At any given time, each sensor usually samples 60 (or sometimes 30) of these levels in a repeating cycle and hence covers about 70% of the available instrument energy levels (~0.6 eV to ~ 26 keV). For more details of energy coverage, see section 3.2. The sensors are often used together with partially overlapping energy coverage to cover the full range every spacecraft spin.
An Inter-Experiment Link (IEL) is used to share raw magnetic field data between the Fluxgate Magnetometer (FGM) and the PEACE DPU. PEACE uses these data to select the minimum information needed to describe a pitch-angle distribution

(PAD), from the measured 3 dimensional distribution collected by each sensor. In addition the PEACE DPU calculates onboard moment sums (OMS) every spin, using the combined data set from the HEEA and LEEA sensors. The DPU calculates separate sets of OMS data for the energy regions covered by HEEA alone, LEEA alone and by both HEEA and LEEA. In principle these partial moments data can be summed together to provide moments data across the entire measured energy range (though it is necessary to select either HEEA or LEEA or a combination of the two when considering the region of overlapping energy coverage).

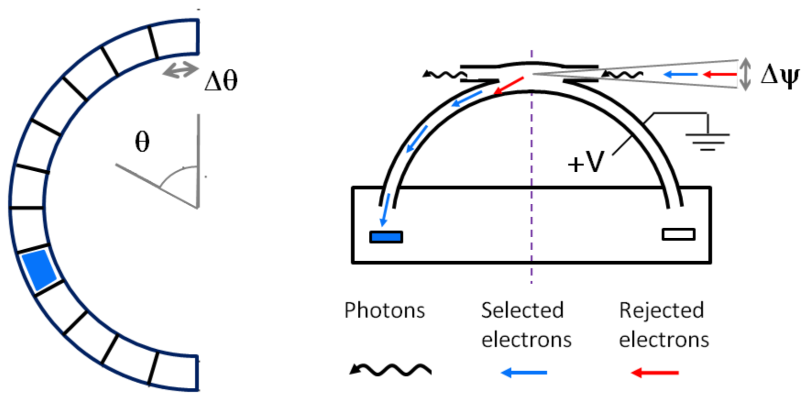


Figure 1. Illustration of the principle of a Top Hat electrostatic analyser, illustrating the PEACE case with simultaneous coverage of a 180° polar angle range in 12 equal parts.

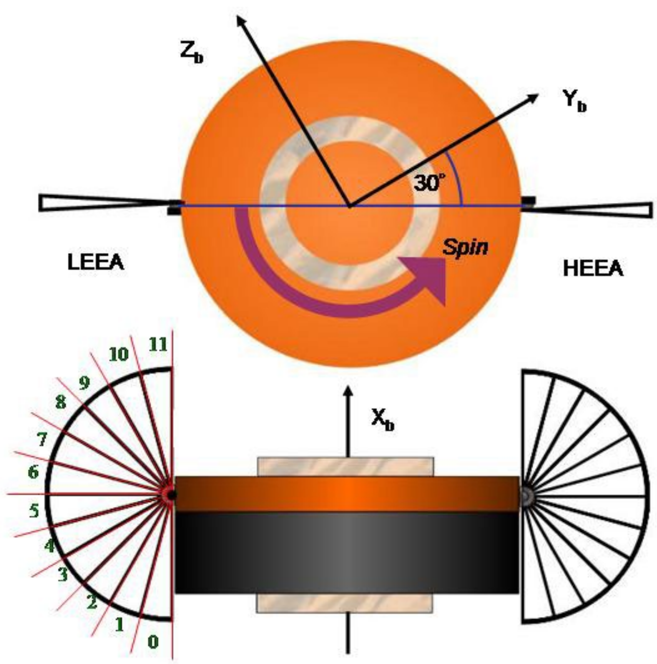


Figure 2. Illustration of the deployment of the two PEACE sensors, HEEA and LEEA, on a Cluster spacecraft, together with labelling of polar zone look directions. The field of view of each sensor is a fan arranged looking radially out from the spacecraft skin rather than tangential to it. The spacecraft are oriented with the spin axis pointing roughly along the negative Z GSE direction.

The full measured 3D distribution is provided in CAA as 3DX, however this is rarely available due to its large size and the spacecraft telemetry constraints. The PEACE DPU also typically performs data compression on the 3DX data from each sensor, making products with the same energy and solid angle coverage, but reduced energy and/or solid angle resolution. A reduced resolution product, 3DR, is routinely produced and is the basis for the onboard moments calculation. See section 3 for details of the availability of different data products.

Appendix E describes various reference frames used for Cluster, and in particular explains in depth the special reference frame used for PEACE 3D data. At times this reference frame is a close approximation to the SR2 coordinate frame, with directional information referring to PEACE look directions. At other times, SR2 is not a valid approximation, as explained in Appendix E.

For a more detailed reference of the experiment, please see Johnstone et al. (1997).

3 Instrument Operations

3.1 PEACE Telemetry Allocations

The telemetry allocations applicable at the time of launch were insufficient to allow PEACE to provide spin-rate 3D distributions routinely, but as the mission progressed there were some opportunities to improve PEACE data rates on some spacecraft, and thus to return 3D data at higher cadence and data resolution (see next section).

The majority of the time, the Cluster spacecraft used the “normal” telemetry rate, but on many orbits a few hours of “burst” mode telemetry was also available. In each case, three options were available, NM1/2/3 and BM1/2/3. NM1 was usually employed in normal telemetry rate. In NM2, CIS received a greater share of telemetry than PEACE, and vice versa in NM3. BM1 or BM2, favouring the particle instruments or the wave instruments respectively, were using in burst telemetry rate. Twice an orbit, short (6 minute) intervals of BM3 were also usually used, in order for some instruments to transmit data stored in internal memory, although PEACE did not do this (incidentally, FGM does not transmit magnetic field measurements made during these BM3 intervals). The CAA provides spacecraft telemetry mode information in the Telemetry Mode (dataset ID: Cx_CT_AUX_TMMODE) files.

Figure 3 presents the history of changes to the PEACE telemetry allocations over the course of the mission. PEACE is unique among the Cluster instruments in being able to automatically adapt to a change in telemetry allocation. The changes shown in the table reflect re-allocations of telemetry, from no-longer operating instruments to PEACE (CIS on C1/2/3 and EDI on C4).

The NM3 mode was used spacecraft C2 after 16 January 2001, shortly before the formal start of science operations (but after instrument commissioning) until mid-November 2001, to the benefit of PEACE (since CIS was not operating). Unused C2 CIS telemetry in NM3 was re-allocated to be shared by RAPID and PEACE in March 2003, and NM3 and NM1 were used on an varying duty cycle from 26 July 2003 through 30 May 2004. Specific times are listed in the RAPID instrument User Guide (Appendix F). The same change to NM3 telemetry allocation was made on C3 in June 2010, after the end of CIS operations, though no corresponding use of NM3 followed.

Later in the mission, C1 CIS was only operated for limited durations per orbit. Accordingly, the C1 spacecraft telemetry mode was NM1 when CIS was operating, but was changed to NM3 for the part of the orbit during which CIS was turned off. This procedure was routinely applied from 29 November 2019 to 19 February 2024. It was no longer needed after C1 CIS stopped operating, since the PEACE NM1 telemetry allocation was increased on 19 March 2024.

Spacecraft	Date	NM1	NM2	NM3	BM1	BM2	BM3
C1234	Launch (2000)	1,257	760	1,770	7,990	1,829	962
C1	07 May 2021	1,257	760	1,770	21,371	1,829	962
	07 Aug 2023	1,257	760	1,770	21,371	5,102	962
	19 Mar 2024	4,021	760	1,770	21,371	5,102	962
C2	25 Nov 2001	4,021	760	1,770	21,371	1,829	962
	06 Mar 2003	4,021	760	2,220	21,371	1,829	962
	02 May 2013	4,021	760	2,220	21,371	5,102	15,691
C3	13 Jun 2010	4,021	760	2,220	21,371	1,829	962
	29 Apr 2013	4,021	760	2,220	21,371	5,102	15,961
C4	21 Mar 2002	2,018	760	1,770	13,381	1,829	962
	30 Apr 2013	2,018	760	1,770	13,381	2,599	18,965

Figure 3. PEACE Telemetry Allocation History. The numbers represent the number of bytes available to PEACE for a nominal 4 second duration spin period.

3.2 Data Product Availability

In NM1, as defined at launch, PEACE typically transmits science data corresponding to onboard-generated moment sums (OMS), onboard-selected pitch angle distributions (PAD), and a further heavily reduced 3D product focussed on low energies, LER, once per 4 second spin, using 1226 bytes from a nominal 1257 bytes allocation. The remaining telemetry allows very infrequent transmission of a reduced resolution 3D distribution data product from both sensors, 3DR. The 3DR cadence is improved in NM3 and BM2, but is not available every spin (or almost every spin) except in cases where CIS TM is reallocated to PEACE, as indicated in Table 4.

In BM1, as defined at launch, the improved telemetry rate allows transmission of 3D data every spin and usually this is more detailed 3D distribution data (3DX or 3DXP) for at least one sensor. In order to provide a continuous 3DR dataset at the CSA, 3DR data are produced during ground data processing from these higher resolution 3D datasets. The enhanced BM1 allocations are so generous that the amount of 3D data that the PEACE instrument transmits becomes limited by internal processes rather than the spacecraft telemetry, so the full measured resolution data products can be transmitted at best once per 3 spins, as indicated in Table 4.

In terms of CAA data products, the restrictions on telemetry allocation mentioned above mean that most of the time there is

- PITCH_SPIN and PITCH_FULL pitch angle data derived from PAD
- 3DR data available at different rates on different spacecraft
- MOMENTS data calculated from the 3DR data

- Onboard moments data: see Preliminary electron parameters (the CSDS Prime Parameter data)

During burst mode intervals, PEACE could provide 3DR data from both sensors every spin with telemetry to spare, so in fact 3DR is provided from one sensor and the more detailed 3DXP from the other. When extra telemetry is available on C2, C3 and C4, the more detailed 3D data can be provided from both sensors. Thus a typical outcome is that

- 3DXP data is available every spin from one sensor (C1) or both sensors (C2, C3, C4)
- 3DR data is available every spin from one sensor (C1)

although there will typically be a slightly reduced energy range for the 3DXP data in the case of C1, to make the product small enough to transmit at spin rate.

Occasionally, other data products are transmitted. For example, during weekly MCP Test operations, the NOI product replaces the PAD product – these test intervals typically last 30 minutes.

Between March 2008 and February 2011 during LEEA-only operations in the solar wind, the contents of the PAD product have often been altered so that extra LEEA data can occupy the part of the PAD telemetry originally intended for the HEEA sensor (which is not produced when HEEA is switched off) with the intention of providing more complete pitch angle measurements from LEEA.

Telemetry Rate bytes/spin	Case	CORE (OMS)	PAD	LER	3DRH & 3DRL	3DXPH & 3DXPL	3DXH or 3DXL	3DXH & 3DXL
		Spins/#	Spins/#	Spins/#	Spins/#	Spins/#	Spins/#	Spins/#
1,257	NM1	1	1	1	> 95			
1,770	NM3	1	1	1	> 5.4			
1,829	BM2	1	1	1	> 4.9			
2,018	New NM1 (C4)	1	1	1	> 3.7			
2,220	New NM3 (C2, C3)	1	1	1	> 3.0			
2,599	New BM2 (C4)	1	1	1	> 2.1			
4,021	New NM1 (C1, C2, C3)	1	1	1	> 1.1			
5,102	New BM2 (C1, C2, C3)	1	1	1	1			
7,990	BM1	1	1	1				
13,381	New BM1 (C4)	1	1	1		1		
13,381	New BM1 (C4)	1	1	1			1	
21,371	New BM1 (C1, C2, C3)	1	1	1				3

Figure 4. PEACE Telemetry Usage Examples. The numbers represent the number of bytes available to PEACE for a nominal 4 second duration spin period.

3.2 Sensor sweep mode selection and energy range coverage

In routine operations, an energy sweep, during which the energy is continuously varied from a high to a low level, over a time interval T_{sweep}, is repeated 16, 32 or 64 times per spin, depending on the selected sweep mode (LAR, MAR or HAR for Low/Medium/High Angular Resolution see Figure 5). During one sweep, the measured energy is reduced by one "step" from energy level *n* to level *n-1* in sweep mode LAR, during each measurement period T_{acc}. The measured energy is reduced by two "steps" during T_{acc}, from energy level *n* to level *n-2* in sweep modes MAR and HAR. As shown in Figure 5, HAR covers half the energy range of MAR. The interval during which the energy selection is reset from low to high energy is called the "flyback" and data collected during this time is discarded (4 accumulation bins in LAR, 2 in MAR and 1 in HAR, per sweep). Notice that LAR-mode observations appear as separated 3DX datasets while MAR and HAR modes are combined in the same 3DX datasets (see Appendix A).

In any sweep mode, a single PEACE sensor always returns 11,520 values per spin (e.g., in MAR 30 energy x 32 azimuth x 12 polar) which correspond to a complete distribution function (this is called 3DX dataset; note that 3DX is not always available at CAA, see 3.1 below). The coordinate system of the 3D data is set by the spacecraft orientation (the spin axis usually points within a few degrees of GSE negative Z) and the start time of a PEACE spin, which is set by a rephased (slightly delayed) sun pulse signal originating from the spacecraft. PEACE needs a regular sun pulse signal in order to operate, so if operating during eclipses, PEACE generates internal sun pulse signals. The time interval between these artificial signals does not usually correspond to the true spacecraft spin rate, which increases during the eclipse in any case. See Appendix C3.

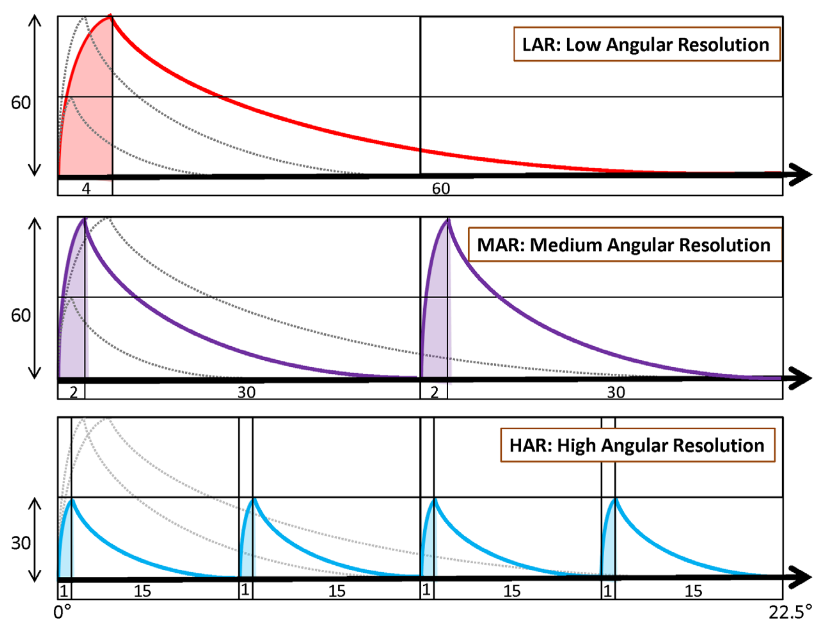


Figure 5. Illustration of the energy sweeps in each of the three sweep models (flybacks shaded). The energy range covered by a sweep is a subset of the 88 possible levels and can be varied by command.

The sensors are usually both operated in the MAR sweep mode. Another relatively common situation has the HAR sweep mode used on one sensor while the other sensor is in MAR mode. The LAR sweep mode is used relatively rarely, usually in situations where high energy resolution spectra are of scientific interest for special studies.

Some examples of how the two sensors may be used to cover the energy range are shown in Figure 6. The sensors are usually set up to ensure full energy coverage of the expected plasma populations, while minimising or avoiding measurements of spacecraft photoelectrons, which are found at and below the energy corresponding to electron acceleration through the spacecraft potential, V_{sc}.

In the solar wind and magnetosheath, and also in the magnetosphere if ASPOC is active, V_{sc} is typically below 10 eV, and the sensors are commonly setup with partially overlapping energy coverage as shown in Figure 6 (left hand side).

In the magnetosphere, and especially the magnetotail lobes and polar cap, V_{sc} may reach several 10's of eV if ASPOC is not active. A HEEA sensor in MAR mode which is set to measure the highest energy (26 keV) and below, reaches down to a lowest energy of about 30 eV. Thus the lowest energies may be contaminated with spacecraft photoelectrons in tenuous plasma environment. In this case, the second sensor may be operated in HAR mode as shown in Figure 6 (right hand side) so that the spacecraft electrons are only seen in the "bottom region" of the combined sensor coverage. This approach improves our ability to get useful onboard moments in such cases, and this approach has been used in the magnetotail starting summer 2003.

Another example of MAR-HAR mode combination uses LEEA in MAR mode at the low end of the instrument range to measure solar wind or magnetosheath, and HEEA in HAR mode at the high energy end of the instrument range to look for escaping magnetospheric electrons or low strahl fluxes.

The instrument measures complete 3D distributions every half spin in the overlapping energy range. Thus, when a key plasma population can be fully covered, sensors are sometimes used with fully overlapping energy coverage, and in principle moments can be determined twice per spin in such a case. Examples include magnetosheath and solar wind measurements in the first two years, and auroral electrons on some occasions in 2008.

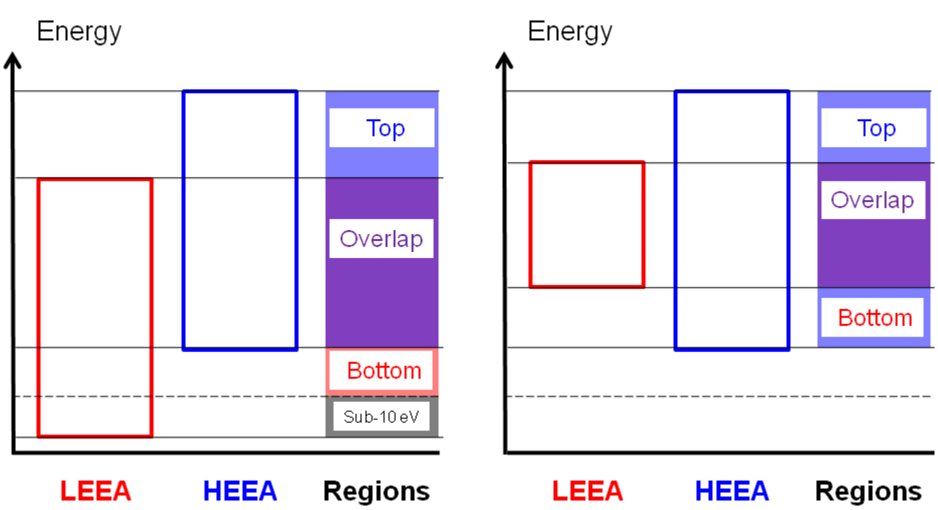


Figure 6. Illustration of coverage of the instrument energy range using the two sensors, HEEA (blue) and LEEA (red), and of terms used in discussing onboard moments. The *bottom region* (red shading) is defined as the group of energies covered by a single sensor in the lower part of the instrument range, but above 10 eV. The *overlap region* (purple shading) is defined

as the group of energies covered by both sensors and the *top region* (blue shading) as the group of energies covered by a single sensor in the upper part of the instrument range. Left: an example with both sensors covering the full sensor range (thus in MAR or LAR mode) in a typical arrangement for a low spacecraft potential situation, such as in the magnetosheath, or in the magnetotail if ASPOC is controlling the spacecraft potential. Right: an example with LEEA in HAR mode and HEEA in MAR, which is mode more appropriate for a moderately high spacecraft potential situation, such as in the magnetotail. Note that these are just two examples and other schemes have also been used during the lifetime of the mission.

3.3 Intervals where PEACE was not operated on one or more spacecraft

PEACE Operations are not supported during thruster firings associated with changes in the spacecraft tetrahedron configuration, or maintaining spin-axis orientation. In fact, particle instruments high voltages are typically turned off 1 hour before planned thrusters firings and remain off for 8 hours afterwards, to avoid any risk of high voltage breakdown due to thruster gases in the instrument.

There are other times when PEACE data will be absent from the CAA due to an instrument having been deliberately turned off, or due to problems with spacecraft data return or with instrument behaviour.

i. The PEACE instruments are normally turned off below L = 6 to minimise the risk of radiation damage to the DPU electronics, and of MCP aging associated with counting high fluxes of penetrating radiation that are sometimes present along the low altitude part of the Cluster orbit. The low L limit was reduced to L = 3.6 from 13 November 2008. A list of exceptions, i.e. operations which WERE carried out below the prevailing low L limit, is provided via links at:
http://www.mssl.ucl.ac.uk/missions/cluster/about_operations/PEACE_ops_history.php.

ii. Payload operations are possible during short or partial eclipses, using spacecraft battery power. In the case of longer eclipses, payload operations are prohibited, not only during the eclipse, but during intervals before and after due to spacecraft-related activities. A list of eclipses and a statement about whether PEACE is operated or not is available in the Caveats files. Although it is difficult to generate moments during eclipses (as the internal sun pulse is not spin synchronized) pitch angle distributions are still reliable (see appendix D).

iii. Concern about MCP aging due to exposure to strong fluxes has led to restricted operations in the magnetosheath and solar wind beginning winter 2002. During winter 2002 (November 10 2002 to February 21 2003) all 4 PEACE instruments were off in these regions, but this policy was amended to a less severe approach thereafter. Thereafter, instrument operations in the magnetosheath and solar wind are restricted to one spacecraft only except during predicted magnetopause and bowshock crossings, and burst mode intervals. The choice of which spacecraft remained on (the "observational" spacecraft) was varied regularly in order to share the exposure to high count rates across the instruments, though over time spacecraft with more rapidly aging MCPs were withdrawn from the procedure, first C3 (15 March 2003), then C4 (6 March 2005) and finally C1 (25 May 2008). Since 19 February 2011 (when LEEA-only operations ceased) all 4 PEACE instruments are left on in the solar wind, with the 3 non-observational spacecraft sampling a limited energy range (34-949 eV) chosen to enable observations of the strahl, while the full solar wind population is sampled by the observational spacecraft (typically 4.7 – 26460 eV). The designated observational spacecraft is usually C2, however between 27 November 2011 and 23 June 2012, C1 was used instead.

iv. Occasionally, anomalous instrument or spacecraft behaviour leads to missing PEACE data. At present, the list of such anomalies is on a password protected link from the URL quoted in (i) above. This information is available in CAA PEACE Caveats files. See Appendix D for summary of typical entries in the daily caveats files.

3.4 Significant long-term instrument issues

The 8 Cluster-PEACE sensors were in good health at the termination of science operations with only two exceptions:

- one of the 12 anodes in the C3 PEACE HEEA sensor (anode 2, using numbering scheme 0-11; anode 3 using CAA numbering scheme as per Appendix E) has not provided data since August 22, 2005, and
- one of the 12 anodes in the C2 PEACE LEEA sensor (anode 1, using numbering scheme 0-11; anode 2 using CAA numbering scheme as per Appendix E) has not provided data since May 15, 2011.

There are consequences for moments data and pitch angle data. There is a loss of accuracy in moments generated with data from those sensors (e.g. density underestimate, incorrect velocity vector) which may be ameliorated in a future set of Moments data. Similarly, PAD data is sometimes affected; there will be incomplete pitch angle distributions from C3 HEEA when the magnetic field is within ~30° degrees of the spin axis direction and from C2 LEEA when the magnetic field is within ~15° degrees of the spin axis direction. Consequently, in-flight calibration of these sensors is also more difficult.

The onboard pitch angle selection process, used in the generation of PAD data from which CAA PITCH_SPIN and PITCH_FULL data are made, was not operating as well as intended in the time interval from commissioning until 11 September 2001. The problem was rectified by uplinking better optimized values onboard calibration values for the magnetic field data for all four spacecraft on that date.

There have been two other intervals during which the onboard pitch angle selection process did not work as intended, and in these cases only Cluster 2 was affected. These intervals are 05-30 April 2002 and 02-24 May 2002, and the problem occurred because the magnetic field vectors received from FGM onboard the spacecraft were corrupted during these intervals (though the FGM data transmitted to ground was of the usual good quality). The PITCH_SPIN and PITCH_FULL products are consequently affected at these times, with only part of the pitch angle range available.

The DPU on Cluster 3 PEACE developed a problem beginning 27 April 2013. Operations resumed in single-processor mode from 22 May 2013 with further testing on 07 June and 14 June outside normal operations intervals. In single processor mode moments (OMS) are not produced onboard, and some 3D data collection options are unavailable. Pitch angle selection onboard does not work correctly. These reductions in onboard performance are partially mitigated by the availability of enhanced PEACE telemetry rates on Cluster 3 from June 2010 (see above), allowing high cadence transmission of 3D data from which moments and pitch angles can be produced on the ground. However, 3D distributions are occasionally transmitted incompletely, giving rise to errors in ground moments data (usually very obvious as spikes in parameters differing from the general trend).

4 Measurement Calibration and Processing Procedures

4.1 PEACE Calibration

Most aspects of the PEACE sensor measurement capability were calibrated during pre-launch activities. In-flight calibration work has been performed for three reasons:

- to confirm absolute sensitivity measurements
- to refine inter-anode calibrations and
- to track MCP sensitivity variations during the mission.

This work has been discussed in the CAA PEACE Calibration Report, by Fazakerley et al (2010b) and Doss et al (2014).

The inter-anode sensitivity corrections arising from in-flight calibration are applicable to data in which the 12 anodes have been grouped together in pairs, namely 3DR and 3
DXP (for details, see 5.1). These corrections are not presently available for 12-zone data like 3DX or PITCH_SPIN and PITCH_FULL. The focus on the 3DR and 3DXP data is due to the fact that these are data from which moments are calculated on the ground, including the CAA Moments data, and that these refined calibrations are necessary for improved determination of all three components of bulk velocity, particularly at times during the mission when the MCP sensitivity is degraded relative to that used in ground calibration work before launch.

The MCP performance in all sensors has degraded to the point that standard calibration techniques are not applicable. An alternative technique based on density comparisons with WHISPER is now used routinely. This approach is discussed in more detail in the CAA PEACE Calibration Report.

4.2 PEACE Data Processing for CAA

The CAA data files for PEACE data contain a number of Mode and Status parameters which are intended to assist the science user. These are produced as part of the data processing work, and discussed in detail in the ICD. Appendix B shows which parameters are available in each dataset.

Mode: (see ICD for a complete list and explanation): this is used to inform the user whether the data in a particular PEACE CAA file come from HEEA, LEEA or both sensors (Mode_Sensor), and for each sensor, what sweep mode was used (Mode_SweepMode); what energy range is covered (Mode_EnergyLevelRange); what MCP voltage level was used (Mode_MCPLevel); what was the parent data product in the PEACE team's own (IDFS) database (Mode_DataOrigin). In the case of 2D and 3D data products, mode data is used to indicate the number of energy, azimuth and polar (or pitch) angles in the parent data set, and also the corresponding dimensions of the CAA file within which it is stored. The detailed timing of the individual measurements during a spin can be derived from this information (see ICD Appendix C for an explanation and worked example).

Status: (see ICD for a complete list and explanation): this is used to provide the user with support information on a record by record basis, using status parameters with self-explanatory names. The primary parameter is the Quality flag, which conforms to the CAA Metadata Dictionary definition, and will be set to show problems or situations where extra care is needed to interpret the data. The other status parameters are used to provide more detailed information both about problems and also indications about the type of validation of the data in the file (for MOMENTS only), which calibration version was used and which version of the PEACE IDFS data file was used to create the CAA file. See Section 6 and Appendix C.

Information on the typical "best case" background count level in 2D and 3D data is provided together with the measurements, in the same units as the actual data. The background level is determined as a typical count rate level measured when no plasma is present (e.g. at higher energies in the magnetotail lobes) of around 0.125 counts/accumulation. There is no attempt to adjust this for data collected at times of penetrating radiation background. There is also no attempt to represent the signature of internal photo-electrons which is present when a sensor is sun-facing (more so in HEEA than LEEA). An example of how this information may be used is given in the companion PEACE Calibration Report, where an energy spectrum which combines PEACE and RAPID data is shown. The background level is plotted to demonstrate that at the highest energies measured by HEEA, the signal is due to the instrument background rather than a real measurement.

For Moments data in particular, it is planned that status information will be provided on the calculation method, the integration limits, and whether or not the energy interval covered by the plasma population was fully captured by PEACE. Future releases of the files may also contain flags warning of time aliasing or of multiple populations being present between the energy integration limits.

The units used for PEACE datasets are listed in the table below.

Unit symbol	Unit text	Units used by PEACE
Cnts	Counts	#
DPF	(Differential) Particle flux	#/cm^2-s-str-keV
DEF	(Differential) Energy flux	keV/cm^2-s-str-keV
PSD	Phase Space Density	s^3/km^6

5 Key Science Measurements and Datasets

For a complete list of datasets and their names, see Appendix A.
For information on a searchable Instrument Mode history file, see Appendix E.
For related information on coordinate systems, see Appendix F.

5.1 General Users

5.1.1 "Moments"

The CAA "Moments" data are electron density, velocity vector, pressure tensor and heat flux vector. The vectors and tensors are provided in GSE coordinates. Velocity and temperature are also provided as components perpendicular and parallel to the magnetic field. The magnetic field data is taken from CSDS FGM PP data, at present. In a possible future release we would ideally use CAA FGM data, but it is considered unlikely that there will be major differences except in very weak field regions. Furthermore:

- $T_\perp$ and $T_{||}$ are determined by projecting the pressure tensor along the magnetic field and dividing by the density and by Boltzmann's constant. $T_\perp$ is the average of the two perpendicular components.
- $\boldsymbol{v}_{||} = (\boldsymbol{v}.\boldsymbol{b})\ \boldsymbol{b}$ and $\boldsymbol{v}_\perp = \boldsymbol{v} - (\boldsymbol{v}.\boldsymbol{b})\ \boldsymbol{b}$. where $\boldsymbol{v}$ is the velocity vector and $\boldsymbol{b}$ is the magnetic field unit vector.

These data are produced on the ground using 3-D data and thus are available at time resolutions which are limited by the rate at which 3-D data can be transmitted. The data source used to generate the moments is always the best available resolution 3-D data; this means mainly 3DR data but in the case 3DX or 3DXP are available these are used instead for the MOMENTS production (see Mode_DataOrigin_HEEA/LEEA). Choices on the best way to combine data from the two sensors can be made in the moments production software; in the first release the moments are made using LEEA data in the energy overlap region. In some situations, use of both sensors together may be a better choice, for example in cases where the distribution changes during a spin as the method can resolve time aliasing errors. If resources allow, the Moments product at CAA may be updated to take advantage of this possibility.

The advantage of these ground-calculated moments is that the best available calibration data is used, a correction can be made for the spacecraft potential measurements (collected by the EFW experiment), and spacecraft electrons can be properly removed. The current release has been generated automatically using default values to control the approach to potential correction and photoelectron removal, and has not been systematically human-validated, so some errors may exist. Specifically, the spacecraft potential, V_{sc}, is set to be 1 V greater than the measured probe-spacecraft potential provided by the electric field experiment (EFW) and the lower energy cutoff for the moments integration is set to reject the energy bin containing the EFW potential and the one above that (which in practice may also contain counts due to spacecraft electrons). Sometimes cold electrons are present which can appear in the same energy bin as the spacecraft photoelectrons, therefore both the cold electrons and spacecraft photoelectrons are removed resulting in underestimated electron densities. Work by the EFW team suggests a more accurate determination of spacecraft potential from the measured potential would be a term that increases linearly above ~10 V (Cully et al., 2007). A further release of Moments data is likely, pending improved calibrations.

5.1.2 PITCH_SPIN

A pitch angle of 0° (180°) means that the electrons are moving parallel (anti-parallel) to the magnetic field. PITCH_SPIN is the recommended CAA pitch angle product for routine use and it is usually available every spin. PITCH_SPIN is based on two instantaneous measurements of PAD distribution per spin at two specific azimuths separated by 180º (see Figure 7), so each anode gives measurements for a maximum of two pitch angles during the spin.

PITCH_SPIN contains merged data from both the HEEA and LEEA sensors. It is a two dimensional product, with twelve 15° pitch angle bins (covering 0° to 180° pitch angle) and 44 energy bins (sufficient to cover the full instrument energy range as the measurements from the overlapping HEEA and LEEA energy bins averaged together). The energy bin boundaries are defined in the file on a spin by spin basis. This enables efficient packaging of all data collected in all 3 sweep modes. At energies and pitch angles measured by both HEEA and LEEA, the average of the measured values from the two sensors is used. At other energies, only one or other of the sensors can be the source of the PITCH_SPIN data. The data is provided in spin records, with no sub-spin timing information – for higher time resolution information please refer to PITCH_FULL or PITCH_3D (see below).

The data are derived from onboard selected pitch angle data (PAD) which has been rebinned using ground calibrated magnetic field data, using FGM team software and daily calibration files (used for the PP data production). The magnetic field data is not available at a time cadence as rapid as the individual PEACE measurements, so a higher time resolution dataset is produced by simple interpolation, to produce ~200 magnetic field vectors/second, close to the PEACE cadence (~every Tspin/1024), in the spinning PEACE frame of reference. The magnetic field dataset may be a little less well calibrated than the CAA FGM dataset, but it is not expected that this will usually result in significant errors in the magnetic field direction and in pitch angle rebinning, except perhaps in regions of very weak magnetic field.

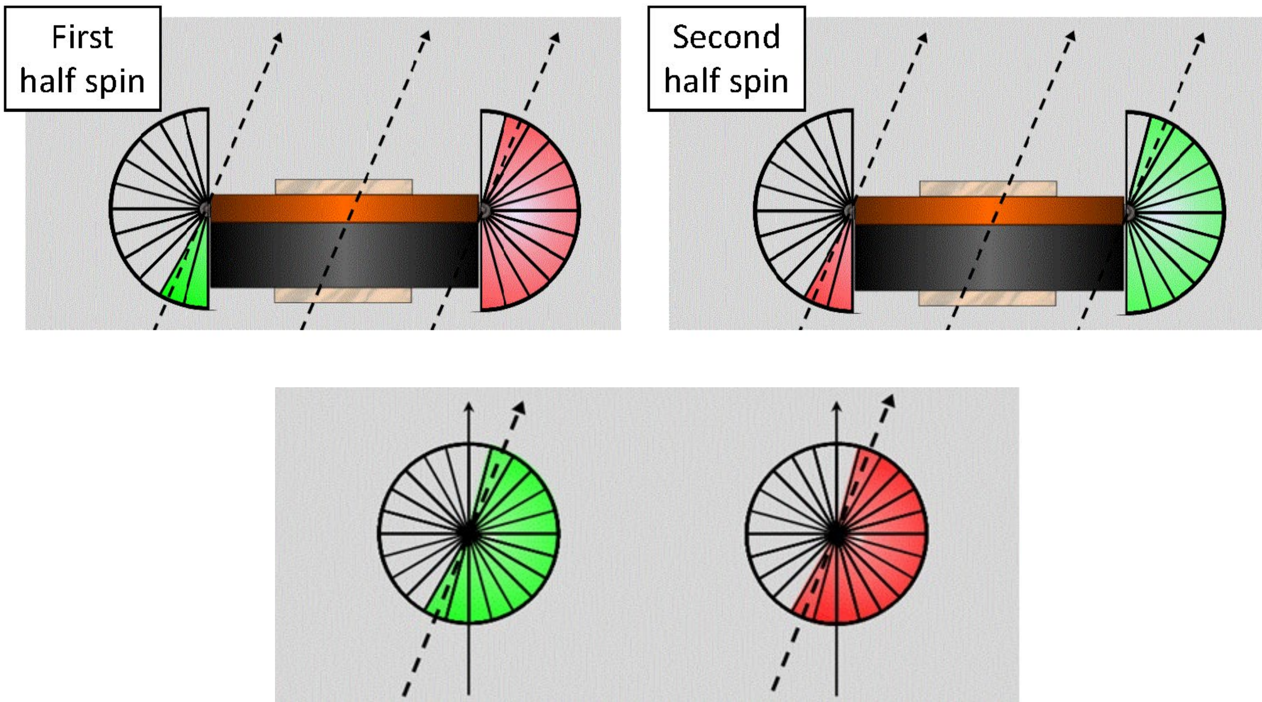


Figure 7. Illustration of formation of PITCH_SPIN using onboard selected pitch angle data from both sensors. The top left and right figures show the two cases each spin in which the magnetic field direction (dashed lines) lies in the plane occupied by the sensor field of view fans (assuming a steady magnetic field). The shading distinguishes each sensor, e.g. HEEA in green and LEEA in red. The lower panel illustrates the combined HEEA data (left) and LEEA data (right) in PITCH_SPIN. Note that data from 13 polar zones collected in each half-spin is rebinned into 12 pitch angle bins using ground calibrated magnetometer data (see Figure 9).
The PEACE Status_PADSelectionQuality flag is used to indicate whether the full pitch angle range is covered in both, one or neither of the two PAD snapshots used to make the PITCH_SPIN data product. For further details, see Appendix C9.

5.1.3 3DR (standard resolution 3D data)

In PEACE 3D data products, as for CIS, the polar and azimuth angles describe the direction from which the detected particle arrived.

As discussed in 3.1, the most commonly available 3D data product is 3DR. It is compressed by a factor 8 relative to 3DX. Unlike the other 3-D data files, the 3DR files have a standard size independent of energy sweep mode. In all sweep modes, adjacent pairs of 3DX polar bins are added together, i.e. the sum of counts in each of the 6 polar zone pairs (0-1, 2-3, …, 10-11). The energy/azimuth compression depends on sweep mode: consecutive groups of 4 energy bins are summed for LAR; consecutive groups of 4 azimuth bins are summed for HAR; pairs of energy bins and pairs of azimuth bins are summed for MAR. The “flyback” information is correspondingly merged.
Occasionally, 3DR is transmitted for only one sensor, and thus there may not always be both 3DRL and 3DRH files.

While 3DR is the default 3-D product, less compressed 3-D data is often sent during burst mode intervals. These 3DX or 3DXP data have been used in ground data processing to make corresponding 3DR data files, in order to give continuity of 3DR file coverage at the request of the CAA. When the source 3DXP file has reduced energy coverage, the corresponding 3DR will have only 13 as opposed to all 15 energy bins.

5.2 Advanced Users: Electron three dimensional distribution data

A variety of 3D data products other than 3DR are occasionally available, usually only for intervals of BM1 telemetry. These offer better energy and solid angle resolution than 3DR. Because of the limited telemetry available, different combinations of modes are used for the two sensors; for details see section 3 and ICD section 3.5.

5.2.1 3DX data (best resolution 3D data)

As noted in section 2, the basic measurement made by each PEACE sensor is of a 3D distribution. This is rarely transmitted without being compressed (e.g. to make 3DR). In the CAA it is provided in 3DX data files when available.

5.2.2 3DXP data (enhanced resolution 3D data)

3DXP is an enhanced resolution 3D product (compared to 3DR) in which the 3DX product is compressed by replacing 12 polar zones with 6 polar zone pairs, containing the sum of counts in each of the 6 polar zone pairs (0-1, 2-3, …, 10-11). This compression is used to reduce the data product size enough that it can be transmitted every spin in BM1. A variant of 3DXP is used on C1 and C3, in which only 13/15 of the measured energy range is transmitted (to keep the data product small enough to allow spin rate transmission together with a 3DR from the other sensor). The 2/15 fraction of the measured energy that is discarded may be from the upper or lower part of the energy range, according to a selection made during instrument commanding 3 weeks prior to the data collection. The aim is to discard the least useful part of the expected distribution, but this is not always successful.

5.2.3 3DXPA data (optimised for most complete onboard pitch angle collection)

In some special operations using BM1 telemetry, the 3DXPA product is returned, in which only two 22.5° wide azimuthal slices of a 3DX distribution containing the magnetic field (as determined onboard) are transmitted. The 3DXPA product is regarded as an enhancement of PAD, as it increases the probability of capturing magnetic field aligned distributions which PAD might fail to capture in time varying magnetic fields. The most useful form of this data product is thus expected to be PITCH_3DXPA (see 5.2.2 below)

*5.2.4 3DX*_LAR data*

The 3DX, 3DXP and 3DXPA products contain data collected when the sensor energy sweep mode is MAR or HAR (see 3.2 above). For reasons of file size optimization, if the sensor energy sweep mode is LAR, the data will be provided in 3DXLAR, 3DXPLAR or 3DXPALAR files.

5.3 Advanced Users: Electron pitch angle data

5.3.1 PITCH_FULL

The PITCH_FULL product provides the rebinned PAD data at sub-spin time resolution from each of the HEEA and LEEA sensors separately in each spin record, in contrast to the merged HEEA and LEEA data in a PITCH_SPIN record. PITCH_FULL is a useful complement to PITCH_SPIN in a rapidly changing plasma environment. In effect, the electron data is collected as two-dimensional pitch angle snapshots, of duration an energy sweep (or two sweeps in HAR mode), collected twice within each spin, at intervals of half a spin (2 seconds). As explained above, a MAR mode energy sweep takes ~ 125 milliseconds.

The PITCH_FULL data for each sensor is organized by pitch angle and energy, and azimuth angle to provide sub-spin timing information. The data can be conceptually divided up into up to four energy regions (top, bottom, HEEA overlap and LEEA overlap; recall Figure 6). For any given snapshot, part of the pitch angle coverage will be provided by LEEA while the remaining part is provided by HEEA (see Figure 7), so that pitch angle coverage will only be complete in the sensor energy overlap region.

A PITCH_FULL snapshot has, for each sensor, twelve 15° pitch angle bins (covering 0° to 180° pitch angle) and 32 energy bins, though usually the energy-pitch angle matrix for a given sensor will only be partially filled with data, for the reasons given above. The data in a single snapshot record from one sensor has an azimuth value 180° apart from that of the other sensor.

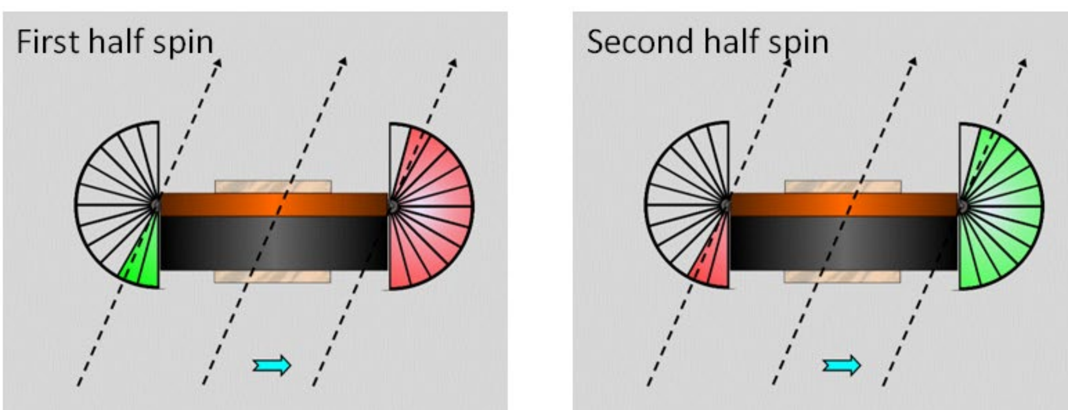


Figure 8. Illustration of pitch angle data organisation for a PITCH_FULL file. Note that data from 13 polar zones collected in each half-spin is rebinned into 12 pitch angle bins (see Figure 9). Data in "azimuth 1" is from LEEA (red) and HEEA (green) at the time the magnetic field crossed the sensors' field of view in the first half spin. Data in "azimuth 2" is similarly organized but collected in the second half spin. The data collected during an individual half spin will only give full pitch angle coverage in the energy overlap region. This data product preserves two "snapshots" of the pitch angle data per spin, typically each snapshot has duration 1/8th second. This high time resolution data is sometimes valuable, but the detailed timing is lost when the pitch angle data is combined to make PITCH_SPIN, hence the need for a PITCH_FULL product.

There are two snapshot records per spin, at azimuths which are 180° apart. The snapshot azimuth angles may vary from spin to spin as the magnetic field direction varies. The leading energy bins are flyback related and contain fill values, which are useful in establishing accurate timing within the spin. As with PITCH_SPIN, the energy bin boundaries can be redefined in the metadata from spin to spin, enabling efficient packaging of all data collected in all 3 sweep modes. The use of 32 energy bins is sufficient to cover the full energy range used by a single sensor.

The Status_PitchAngleCoverage flag is used in PITCH_FULL files to describe the actual pitch angle coverage in each of the two snapshots per spin, for each of the two sensors. For further details see Appendix C10.

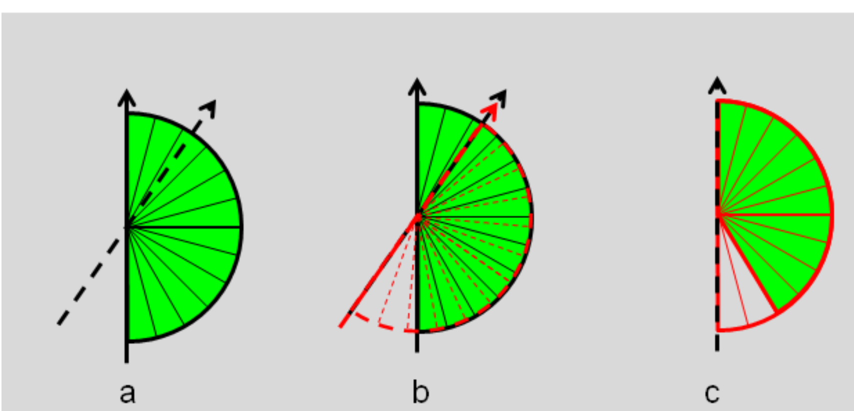
5.3.2 PITCH_3D datasets

For each 3D dataset there is a corresponding pitch angle dataset, thus the PITCH_3D datasets consists of data from a single sensor. For each azimuth the polar zones are replaced by data rebinned into pitch angle bins (see Figure 9). This is useful in a rapidly changing plasma environment, as it captures data at azimuths not available in PITCH_FULL. Where there are 12 polar zone measurements (e.g. 3DX), these are rebinned into 12 pitch angle bins, but if there are only 6 polar zone bins (e.g. 3DR, 3DXP), these are rebinned into 6 pitch angle bins..

Since 3DR is produced on ground from higher resolution 3DX data, PITCH_3DR is correspondingly commonly available Note it has poorer energy and angle resolution than PITCH_FULL.

The initial PITCH_3DR product was produced, in error with 12 pitch angle bins. A corrected PITCH_3DR_v2, with 6 pitch angle bins, has been produced and it will be provided to the CSA before it is closed to new submissions from the instrument teams.

The initially delivered PITCH_3DX data product also contained data that belonged in a separate PITCH_3DXP data product. Similarly the initially delivered PITCH_3DXLAR data product also contained data that belonged in a separate PITCH_3DXPLAR data product. Separate PITCH_3DXP and PITCH_3DXPLAR data products have now been produced and will be provided to the CSA before it is closed to new submissions from the instrument teams. Corresponding PITCH3DXP and PITCH_3DXPLAR files will also be removed from the CSA to ensure consistency



Solid arrow is spin axis and dashed arrow is magnetic field direction
(a) Shows data being collected from each of the 12 polar zones of a PEACE sensor.
(b) Shows a grid of 12 x 15° pitch angle zones superimposed on the sensor look directions (red). Note that two p.a. sectors are not matched to look directions
(c) Shows which p.a. sectors contain data in a PITCH_3D azimuth derived from the 3D azimuth shown in (a)

Figure 9. Illustration of pitch angle coverage from one sensor determined for data collected during a single energy sweep (= a single azimuth) for a PITCH_3DX file.

6 Recommendations

We provide some recommendations and general information concerning use of PEACE data. The majority of data quality issues which the user should be aware of are flagged using Status parameters (see also the CAA PEACE ICD):

i. **Status_Quality:** This is a standard CAA Status flag, and provides a single parameter summarizing data quality (ranging from "major problems, check caveats" to "excellent data, has received special treatment"). In general it is recommended that users contact the PI prior to planned publication of any data whatever the quality. See Appendix C1

ii. **Status_DatastreamErrors**: Data should not be used for science on rare occasions the PEACE data stream is corrupted. The flag aids users in identifying and ignoring such data. See Appendix C2.

iii. **Status_Eclipse**: Data expressed in geophysical coordinates, such as Moments data, should be considered unreliable during eclipse intervals, since the translation from spacecraft coordinates to geophysical coordinates cannot be made without special efforts that are not made for routinely available CAA PEACE data products. Pitch Angle data are reliable. See Appendix C3.

iv. **Status_ASPOC:** The flag indicates whether or not ASPOC is operating on the relevant spacecraft. In magnetospheric regions where low energy plasma electrons are present, their measurements by PEACE, and associated moments data, are typically improved if ASPOC is operating. See Appendix C4.

v. **Status_FGM:** Pitch angle (PAD) data selection onboard is unreliable when the magnetic field data sent to PEACE onboard is abnormal. Also, in ground data processing, the creation of magnetic field aligned moments and the creation of pitch angle data from 3D data (PITCH_3D*) is not possible if FGM data is missing. This flag indicates rare examples of both problems, to assist the user in recognizing the cause of poor quality pitch angle data, or the unavailability of expected Moments or PITCH_3D*data. In future the flag may indicate the poor pitch angle selection from the start of the mission through to 13 June 2001) due to problems applying calibrations to onboard FGM data. See Appendix C5.

vi. **Status_InterferenceFromEFW**: We recommend that if the user observes perturbations in the Moments data, or sees features in low energy part of the energy-time spectrograms, that they check whether this may be associated with "bias sweeps" by the EFW instrument. Similarly, for any case study where a brief change in electron parameters may appear important to scientific interpretation of the data. See Appendix C6.

vii. **Status_InterferenceFromWHI:** We recommend that if the user observes periodic perturbations in the Moments data, or sees periodic features in low energy part of the energy-time spectrograms, that they check whether this may be associated with "active sounding" by the WHISPER instrument. Similarly, for any case study where a brief change in electron parameters may appear important to scientific interpretation of the data. See Appendices C6 and C7.

viii. **Status_CountStats**: We recommend that the user consider whether Moments data they are using may be from regions with rather low or rather high electron fluxes, in which case the Moments may not be very reliable. Moments data for CAA are calculated from 3DR data. which may be misreported in PEACE telemetry for very high values (particularly for the HEEA sensor). This status flag is only applicable to Moments data and 3DR data. See Appendix C8.

ix. **Status_PADSelectionQuality:** PITCH_SPIN and PITCH_FULL data are based on onboard-selected 2D pitch angle (PAD) data. This flag indicates whether or not the PAD data successfully captured the full 0° to 180° pitch angle range in each of the two half-spins in a spin record. The PAD selection may fail for example if the magnetic field is changing rapidly during the spin. The flag may be useful when compiling statistics (e.g. eliminating spin records with incomplete coverage), or for case studies when the user wishes to check whether full coverage is expected or not. There are a few long time intervals early in the mission when the onboard pitch angle selection process was not working well, which are discussed in section 3.4 above. See Appendix C9.

x. **Status_PitchAngleCoverage:** PITCH_FULL data is based on PAD data which may not always have complete pitch angle coverage. This flag describes the expected pitch angle range in each of the two half-spins of a spin record. If the user is interested in pitch angle coverage within spins, at times not covered by PITCH_FULL, it is recommended that PITCH_3D be examined, although this will not be available if no corresponding 3D data product was available at the time in question. See Appendix C10.

xi. **Status_PenetratingRadiation**: It is recommended that users consider whether penetrating radiation associated with the Earth's radiation belts or with Solar Energetic Particles may produce significant "background noise" count rates in PEACE data they are examining, since Moments data in particular can be misleading in such cases. This flag highlights such situations. Note that in principle, resources-permitting, the PI team may able to produce a "cleaned up" version of the data for users on request, or ultimately for delivery to the CAA. See Appendix C11.

xii. **Status_WarningPartialCoverage:** Users are cautioned that Moments data do not necessarily describe the entire plasma electron population. Moments are determined using the measured data, which are collected from a particular energy range – if the natural plasma distribution does not lie completely within the measured energy range, then the moments provided by the CAA will not properly describe the total electron density, the proper plasma bulk flow velocity, etc. See Appendix C12.

xiii. **Status_WarningTimeAliasing:** Moments data from a single sensor may give incorrect values, if the assumption that the plasma has not changed during the spacecraft spin is not valid. A "time aliasing" status parameter for this situation has not been implemented yet. See Appendix C13 and the ICD for a discussion of how a suitable parameter might be produced in future.

xiv. **Low energy plasma measurements and EFW probe electrons**: The EFW instrument usually emits low energy (a few eV) photo-electrons from the probes at the tips of the wire booms. As these are largely outside the electric potential well associated with the spacecraft, those electrons that travel from the EFW probes to PEACE sensors are accelerated and gain an amount of energy close to that due to acceleration through the full spacecraft potential. Thus they appear in PEACE data as enhanced fluxes in a narrow energy band lying just above the energy range occupied by spacecraft photoelectrons. See for example plots in Appendix C4 and C14. Consequently, it is possible that natural plasma electrons of a similarly low energy may sometimes exist, which will also be accelerated through the spacecraft potential before reaching PEACE. Such electrons would likely typically be masked in the PEACE data by the EFW probe photoelectrons. The situation is sometimes improved when ASPOC is active. The example in Appendix C4 shows low energy plasmasheet electrons that are only apparent when ASPOC is active.

xv. **High spacecraft potential**: In rarefied plasmas, usually the magnetotail lobes, the spacecraft potential can be driven to very high values (100s V) when the EDI instrument emits a high current electron beam. The potential can usually be estimated using the signature of EFW probe photoelectrons mentioned above. In such cases the spacecraft potential estimate from EFW saturates at around 70V and is unreliable. Furthermore, the lower energy component of the lobe plasma electrons are often confined within a single PEACE energy bin near the potential. We recommend that caution is taken when attempting to use PEACE data for science during such intervals; the Moments in particular will be unreliable. See Appendix C14.

xvi. **Minimum Background:** When plotting slices through distribution data using scientific units, it is not usually clear whether part of the plotted curve corresponds to very low count rate data, possibly instrument noise rather than real signals. Thus it is often helpful to overplot a background level curve; the 2D and 3D PEACE data files contain pre-calculated minimum background level data, based on background levels observed in the sensors in orbit (except for a solar-related signal, mainly at low energies, in the sun direction). See Appendix C15.

xvii. **EDI electron gun signature:** When the EDI instrument electron guns are producing a sufficiently high current, it is possible to see the electrons in PEACE data if there is no natural plasma at the relevant energy (usually 1 keV, sometimes 500 eV). The EDI electrons are expected to be at 90° pitch angle and this is what PEACE sees. The user is encouraged to check whether this is a plausible interpretation before seeking a geophysical explanation for such a signature. See Appendix C16.

7 References

Cully, C.M., R.E. Ergun and A.I. Eriksson, Electrostatic structure around spacecraft in tenuous plasmas, J. Geophys. Res., 112, A09211, doi:10.1029/2007JA012269, 2007

Doss, N., Fazakerley, A.N., Mihaljčić, B., Lahiff, A.D., Wilson, R.J., Kataria, D., Rozum, I., Watson, G., and Bogdanova, Y.: In-flight calibration of the Cluster PEACE sensors, Geosci. Instrum. Method. Data Syst. Discuss., 3, 591-626, doi:10.5194/gid-3-591-2014, 2014

Fazakerley, A.N., S.J Schwartz and G.E. Paschmann, Measurement of plasma velocity distributions, Analysis Methods for Multi-spacecraft Data, ISSI-SR-001, 91-124, 1998

Fazakerley, A.N., P.J. Carter, B.K. Hancock and C. Alsop, Cluster PEACE User Manual, 2000.

Fazakerley, A.N., A.D. Lahiff, R.J. Wilson, I. Rozum, C. Anekallu, M. West and H. Bacai, PEACE Data in the Cluster Active Archive, Proceedings of the 1st Cluster Active Archive School, 2010a.

Fazakerley, A.N., A.D. Lahiff, I. Rozum, D. Kataria, H. Bacai, C. Anekallu, M. West and A. Asnes, Cluster-PEACE In-Flight Calibration Status, Proceedings of the 1st Cluster Active Archive School, 2010b.

Johnstone A.D., C. Alsop, S. Burge, P.J. Carter, A.J. Coates, A.J. Coker, A.N. Fazakerley, M. Grande, R.A. Gowen, C. Gurgiolo, B.K. Hancock, B. Narheim, A. Preece, P.H. Sheather, J.D. Winningham, and R.D. Woodliffe, Peace: A Plasma Electron and Current Experiment, Space Sci. Rev. 79, pp. 351-398, 1997.

Paschmann, G.E. , A.N. Fazakerley and S.J Schwartz, Moments of plasma velocity distributions, Analysis Methods for Multi-spacecraft Data, ISSI-SR-001, 125-158, 1998

ESA/ESOC, Cluster Data Delivery Interface Document (DDID) CL-ESC-ID-2001, Issue 3, 19 May 2000

Hapgood, M.A., Coordinate transformations for Cluster, DS-JSO-TN-0008, v1.3, 02 Oct 1997

Schwartz, S.J., Spin timings and offsets for Cluster Prime Parameters, DS-QMW-TN-0007, 22 Jan 1996

Appendix A: Data Sets Recommended to General and Advanced users

A1: The CAA PEACE Science datasets recommended for the general user are

Dataset identifier*	Dataset title
MOMENTS	Electron Moments *(Spin-resolution, HEEA and LEEA)*
PITCH_SPIN	Electron Pitch Angle distribution (made onboard) *(Spin-resolution, HEEA and LEEA combined)*
3DRH, 3DRL	3D distribution *(standard resolution) (HEEA sensor or LEEA sensor)*

*Note: the full dataset name, that is unique for each dataset and that is needed for downloading via the command-line interface is C[n]_CP_PEA_[id]_[unit], where [n] is the spacecraft number, [id] is given in the first column of the tables in this section, and [unit] is the unit in which the dataset is given. Four unit options are available and they are listed in section 4.2.

A2: The CAA PEACE Pitch Angle Science datasets recommended for the advanced user are

Dataset identifier	Dataset title
PITCH_FULL	Electron Pitch Angle distribution (made onboard) *(Sub-spin-resolution, HEEA and LEEA separately)*
PITCH_3DRH, PITCH_3DRL	Electron Pitch Angle distribution (polar sectors replaced by pitch angle bins) *(Sub-spin-resolution) (HEEA sensor or LEEA sensor)*
PITCH_3DXH, PITCH_3DXL	Electron Pitch Angle distribution (polar sectors replaced by pitch angle bins) *(Sub-spin-resolution) (HEEA sensor or LEEA sensor)*
PITCH_3DXLARH, PITCH_3DXLARL	Electron Pitch Angle distribution (polar sectors replaced by pitch angle bins) *(Sub-spin-resolution) (HEEA sensor or LEEA sensor) (LAR mode)*
PITCH_3DXPAH, PITCH_3DXPAL	Electron Pitch Angle distribution (polar sectors replaced by pitch angle bins) *(Sub-spin-resolution) (HEEA sensor or LEEA sensor) (LAR mode)*
PITCH_3DXPALARH, PITCH_3DXPALARL	Electron Pitch Angle distribution (polar sectors replaced by pitch angle bins) *(Sub-spin-resolution) (HEEA sensor or LEEA sensor)*

A3: The CAA PEACE 3D Science datasets recommended for the advanced user are

Dataset identifier	Dataset title
3DXH, 3DXL	3D distribution (best resolution) *(all azimuths , 12 * 15° polar sectors, full energy resolution for MAR or HAR mode)* *(HEEA or LEEA sensor)*
3DXLARH, 3DXLARL	3D distribution (best resolution) *(all azimuths, 12 * 15° polar sectors, full energy resolution for LAR mode)* *(HEEA or LEEA sensor)*
3DXPH, 3DXPL	3D distribution (enhanced resolution) *(all azimuths,6 * 30° polar sectors, full energy resolution for MAR or HAR mode)* *(HEEA or LEEA sensor)*
3DXPLARH, 3DXPLARL	3D distribution (enhanced resolution) *(all azimuths, 6 * 30° polar sectors, full energy resolution for LAR mode)* *(HEEA or LEEA sensor)*
3DXPAH, 3DXPAL	3D distribution (optimised for most complete onboard pitch angle collection) *(only azimuth sectors along magnetic field, 12 * 15° polar sectors, full energy resolution for MAR or HAR mode)* *(HEEA or LEEA sensor)*
3DXPALARH, 3DXPALARL	3D distribution (optimised for most complete onboard pitch angle collection) *(only azimuth sectors along magnetic field, 12 * 15° polar sectors, full energy resolution for LAR mode)* *(HEEA or LEEA sensor)*

Note that on rare occasions a version of 3D distribution in which pairs of neighbouring energy bins were summed was used, reducing energy resolution by half to improve time resolution of the dataset as transmitted from the spacecraft. This is provided in the CSA PEACE 3DX data product. The intention is similar to the summing of pairs of polar bins to produce 3D data at improved cadence that the CSA provides as 3DXP.

A4: The CAA PEACE Ancillary datasets are

Dataset identifier	Dataset title
PADMARH,PADHARH, PADLARH	2D reduced distribution (HEEA sensor) (MAR or HAR or LAR mode)
PADMARL,PADHARL, PADLARL	2D reduced distribution (LEEA sensor) (MAR or HAR or LAR mode)
LERL, LERH	3D reduced distribution trickled back over multiple spins (low-energy only) (HEEA sensor or LEEA sensor)
OMSH,OMSL	Onboard moment sums (HEEA sensor or LEEA sensor)
NOIH,NOIL	MCP test data product (HEEA sensor or LEEA sensor)
PP	Preliminary electron parameters, spin resolution
SP	Preliminary electron parameters, 1 minute resolution

Appendix B: Summary of contents of various Data Products

B1: The Data and Metadata in a CAA PEACE Moments file

CAA/PEACE — Variables in a Moments Data File

MOMENTS files' data are calculated using both HEEA and LEEA data.

Purpose		Items
SPIN RECORD	Spin Data Record Timing	time_tags, time_tags_DeltaLower, time_tags_DeltaUpper
	Which sensor or sensors provided data in the file	Mode_Sensor
	Source sensor for each moments "region"	Mode_TopRegionSensor, Mode_OverlapRegionSensor, Mode_BottomRegionSensor
SENSOR	Source IDFS data product for the dataset & sensor	Mode_DataOrigin
	Sensor behaviour.	Mode_SweepMode, Mode_Preset, Mode_EnergyLevelRange, Mode_EnergyMaxMin, Mode_MCPlevel
DATA	Moments data	Data_Density, Data_Velocity_GSE, Data_Velocity_ComponentParallelToMagField Data_Velocity_ComponentPerpendicularToMagField Data_Pressure_GSE, Data_HeatFlux_GSE Data_Temperature_ComponentParallelToMagField Data_Temperature_ComponentPerpendicularToMagField
QUALITY RECORD LEVEL	Data Quality – overall assessment	Status_Quality
	PEACE specific issues affecting quality	Status_DatastreamErrors, Status_Validation, Status_Eclipse
	Availability of support from other instruments	Status_ASPOC, Status_FGM
	Interference from other instruments	Status_InterferenceFromEFW, Status_InterferenceFromWHI
	Information about how the moments were determined	Status_PenetratingRadiationRemoved, Status_SpacecraftPotential, Status_CalculationMethod, Status_IntegrationLowerLimit Status_IntegrationUpperLimit
	Warning flags	Status_WarningPartialCoverage, Status_WarningTimeAliasing (tbc)
SENSOR QUALITY	Sensor specific issues affecting quality **(Both sensors)**	Status_CountStats, Status_CalibrationVersion, Status_PEACErawData

A definitive set of status flags is planned to be in a separate Status Flags file. A subset have been provided in delivered data files

B2: The Data and Metadata in a CAA PEACE PITCH_SPIN file

CAA/PEACE

Variables in a PITCH_SPIN Data File

PITCH_SPIN files contain merged HEEA and LEEA data.

Purpose		Items
SPIN RECORD	Spin Data Record Timing	time_tags, time_tags_DeltaLower, time_tags_DeltaUpper
	PEACE Sensor Azimuth at Spin Record Time Tag	Angle_SR2phi
	PEACE spin start delay after spacecraft sun pulse	Mode_SunpulseRephaseOffset
	Which sensor or sensors provided data in the file	Mode_Sensor
	Dimensions of the data & how the file is filled	Mode_RealSize, Mode_RealBinNum
	Energy bins (centres, upper/lower limits)	Sweep_Energy, Sweep_Energy_DeltaLower, Sweep_Energy_DeltaUpper
	PitchAngle bins (centres, upper/lower limits)	Sweep_PitchAngle, Sweep_PolarPitchAngle_DeltaLower, Sweep_PitchAngle_DeltaUpper
SENSOR H&LEEA	Source IDFS data product for the dataset & sensor	Mode_DataOrigin,
	Sensor behaviour.	Mode_SweepMode, Mode_Preset, Mode_EnergyLevelRange, Mode_EnergyMaxMin, Mode_MCPlevel
DATA H&LEEA	Electron count rate or PSD or DPF or DEF in each bin (and minimum estimated background)	Data, BackgroundLevel (HEEA and LEEA data are merged)
QUALITY RECORD LEVEL	Data Quality – overall assessment	Status_Quality
	PEACE specific issues affecting quality	Status_DatastreamErrors, Status_Eclipse
	Onboard pitch angle coverage quality	Status_PADSelectionQuality
	Availability of support from other instruments	Status_ASPOC, Status_FGM
	Interference from other instruments	Status_InterferenceFromEFW, Status_InterferenceFromWHI
SENSOR QUALITY	Sensor specific issues affecting quality	Status_CountStats, Status_CalibrationVersion, Status_PEACErawData

A definitive set of status flags is planned to be in a separate Status Flags file. A subset have been provided in delivered data files

B3: The Data and Metadata in a CAA PEACE 3D file

CAA/PEACE

Variables in a 3D Data File

3DR, 3DX, 3DXP, 3DXPA files contain either HEEA or LEEA data.

Purpose		Items
SPIN RECORD	Spin Data Record Timing	time_tags, time_tags_DeltaLower, time_tags_DeltaUpper
	PEACE Sensor Azimuth at Spin Record Time Tag	Angle_SR2phi
	PEACE spin start delay after spacecraft sun pulse	Mode_SunpulseRephaseOffset
	Which sensor or sensors provided data in the file	Mode_Sensor
	Dimensions of the data & how the file is filled	Mode_RealSize, Mode_RealBinNum
SENSOR	Source IDFS data product for the dataset & sensor	Mode_DataOrigin,
	Sensor behaviour.	Mode_SweepMode, Mode_Preset, Mode_EnergyLevelRange, Mode_EnergyMaxMin, Mode_MCPlevel
	Energy bins (centres, upper/lower limits)	Sweep_Energy, Sweep_Energy_DeltaLower, Sweep_Energy_DeltaUpper
	Polar bins (centres, upper/lower limits)	Sweep_Polar, Sweep_Polar_DeltaLower, Sweep_Polar_DeltaUpper
	Azimuth bins (centres, upper/lower limits)	Sweep_Azimuth, Sweep_Azimuth_DeltaLower, Sweep_Azimuth_DeltaUpper
DATA	Electron count rate or PSD or DPF or DEF in each bin (and minimum estimated background)	Data, BackgroundLevel
QUALITY RECORD LEVEL	Data Quality – overall assessment	Status_Quality
	PEACE specific issues affecting quality	Status_DatastreamErrors, Status_Eclipse
	Availability of support from other instruments	Status_ASPOC
	Interference from other instruments	Status_InterferenceFromEFW, Status_InterferenceFromWHI
SENSOR QUALITY	Sensor specific issues affecting quality	Status_CountStats, Status_CalibrationVersion, Status_PEACErawData

A definitive set of status flags is planned to be in a separate Status Flags file. A subset have been provided in delivered data files

B4: The Data and Metadata in a CAA PEACE PITCH_FULL file

CAA/PEACE

Variables in a PITCH_FULL Data File

PITCH_FULL files contain both HEEA and LEEA data.

Purpose		Items
SPIN RECORD	Spin Data Record Timing	time_tags, time_tags_DeltaLower, time_tags_DeltaUpper
	PEACE Sensor Azimuth at Spin Record Time Tag	Angle_SR2phi
	PEACE spin start delay after spacecraft sun pulse	Mode_SunpulseRephaseOffset
	Which sensor or sensors provided data in the file	Mode_Sensor
SENSOR **(Both sensors)**	Source IDFS data product for the dataset & sensor	Mode_DataOrigin,
	Dimensions of the data & how the file is filled	Mode_RealSize, Mode_RealBinNum
	Sensor behaviour.	Mode_SweepMode, Mode_Preset, Mode_EnergyLevelRange, Mode_EnergyMaxMin, Mode_MCPlevel
	Energy bins (centres, upper/lower limits)	Sweep_Energy, Sweep_Energy_DeltaLower, Sweep_Energy_DeltaUpper
	PitchAngle bins (centres, upper/lower limits)	Sweep_PitchAngle, Sweep_PolarPitchAngle_DeltaLower, Sweep_PitchAngle_DeltaUpper
	Azimuth bins (centres, upper/lower limits)	Sweep_Azimuth, Sweep_Azimuth_DeltaLower, Sweep_Azimuth_DeltaUpper
DATA	Electron count rate or PSD or DPF or DEF in each bin (and minimum estimated background)	Data, BackgroundLevel
QUALITY RECORD LEVEL	Data Quality – overall assessment	Status_Quality
	PEACE specific issues affecting quality	Status_DatastreamErrors, Status_Eclipse
	Onboard pitch angle coverage quality	Status_PADSelectionQuality Status_PitchAngleCoverage
	Availability of support from other instruments	Status_ASPOC, Status_FGM
	Interference from other instruments	Status_InterferenceFromEFW, Status_InterferenceFromWHI
SENSOR QUALITY	Sensor specific issues affecting quality **(Both Sensors)**	Status_CountStats, Status_CalibrationVersion, Status_PEACErawData

A definitive set of status flags is planned to be in a separate Status Flags file. A subset have been provided in delivered data files

B5: The Data and Metadata in a CAA PEACE PITCH_3D* file

CAA/PEACE

Variables in a PITCH_3D* Data File

PITCH_3D files contain either HEEA or LEEA data.

Purpose		Items
SPIN RECORD	Spin Data Record Timing	time_tags, time_tags_DeltaLower, time_tags_DeltaUpper
	PEACE Sensor Azimuth at Spin Record Time Tag	Angle_SR2phi
	PEACE spin start delay after spacecraft sun pulse	Mode_SunpulseRephaseOffset
	Which sensor or sensors provided data in the file	Mode_Sensor
	Dimensions of the data & how the file is filled	Mode_RealSize, Mode_RealBinNum
SENSOR	Source IDFS data product for the dataset & sensor	Mode_DataOrigin,
	Sensor behaviour.	Mode_SweepMode, Mode_Preset, Mode_EnergyLevelRange, Mode_EnergyMaxMin, Mode_MCPlevel
	Energy bins (centres, upper/lower limits)	Sweep_Energy, Sweep_Energy_DeltaLower, Sweep_Energy_DeltaUpper
	PitchAngle bins (centres, upper/lower limits)	Sweep_PitchAngle, Sweep_PolarPitchAngle_DeltaLower, Sweep_PitchAngle_DeltaUpper
	Azimuth bins (centres, upper/lower limits)	Sweep_Azimuth, Sweep_Azimuth_DeltaLower, Sweep_Azimuth_DeltaUpper
DATA	Electron count rate or PSD or DPF or DEF in each bin (and minimum estimated background)	Data, BackgroundLevel
QUALITY RECORD LEVEL	Data Quality – overall assessment	Status_Quality
	PEACE specific issues affecting quality	Status_DatastreamErrors, Status_Eclipse
	Availability of support from other instruments	Status_ASPOC, Status_FGM
	Interference from other instruments	Status_InterferenceFromEFW, Status_InterferenceFromWHI
SENSOR QUALITY	Sensor specific issues affecting quality	Status_CountStats, Status_CalibrationVersion, Status_PEACErawData

A definitive set of status flags is planned to be in a separate Status Flags file. A subset have been provided in delivered data files

Appendix C: Status Parameter Examples

This appendix provides details and examples about selected status flags.

A value of "-1" is used when the status flag cannot be determined for any reason.

Initial plans were to have all status flags delivered within data files, however this has only partially been achieved. Instead, the PEACE team intends to deliver a separate Flags file data product with the complete set of status flags, and a definitive Quality Flag in it (that will supercede the Quality flag in already delivered data files).

The Flags file is also referred to in the PEACE ICD section 3.4.7.7.

C1: Status_Quality: Provides a single parameter summarizing data quality

The PEACE Status_Quality flag conforms to the CAA Metadata Dictionary definition as follows:

Status_Quality	Definition
0	Not applicable
1	Major problems, check caveats
2	Minor problems, check caveats
3	Good data
4	Excellent data, has received special treatment

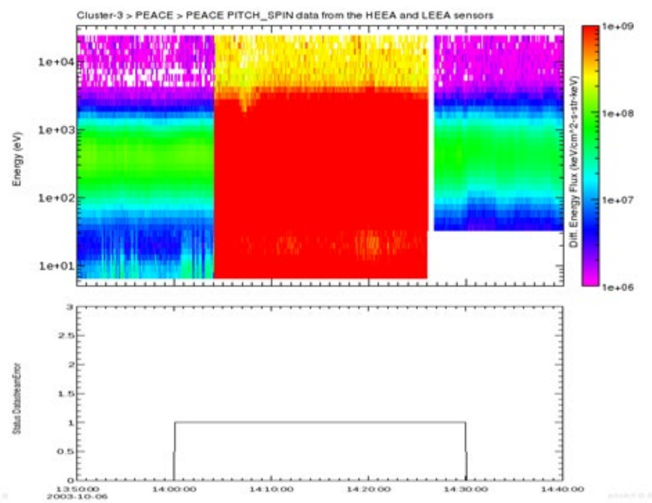
It is recommended that users contact the PI prior to planned publication of any data whatever the quality.

C2: Status_DatastreamErrors: Identifies rare errors in the PEACE datastream (e.g. bad telemetry).

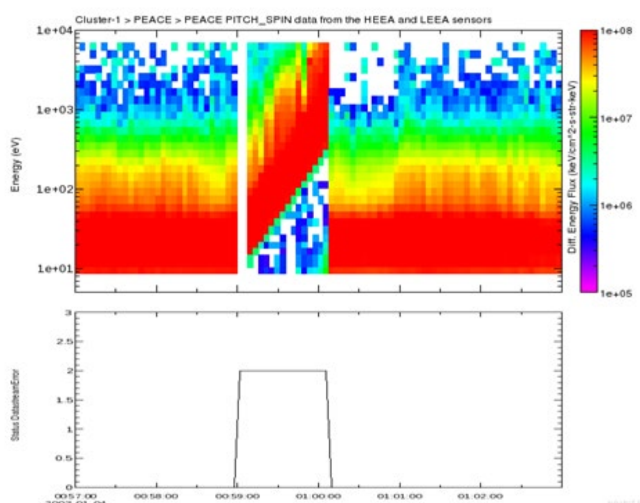
It is recommended that data flagged with 1 or 2 should not be used for scientific work.

Flag values are
0 - no known data stream errors
1 - Error in data transfer from a PEACE sensor to the DPU
2 - DPU re-synchronisation - a process that takes 16 spins

Example of flag = 1 (Cluster 3: 06 October 2003: problem interval ~14:00-14:30 UT)



Example of flag = 2 (Cluster 1: 04 January 2003: problem interval ~00:59-01:00 UT)



C3: Status_Eclipse: Identifies PEACE operation during eclipses; moments are unreliable

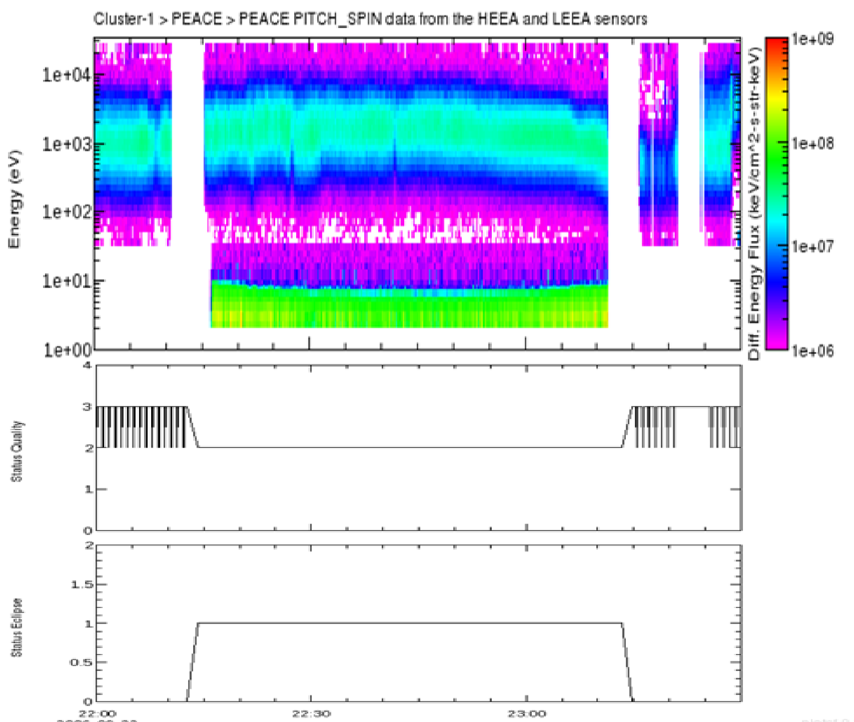
Flag values are
0 - normal operations
1 - eclipse operations

Note that during eclipses, if it is operating, PEACE uses an internal clock to replace the absent "sun pulse". This clock does not track the spacecraft spin period, which varies during the eclipse due to the cooling and contraction of the wire booms.

Routinely produced Moments data in geophysical coordinates should be considered unreliable for two reasons. 3D data usually will not provide exact 360° (spin plane) coverage as the internal clock will usually differ from the true spacecraft rotation rate. The transformation of moments data from spacecraft coordinates to geophysical coordinates cannot be carried out correctly.

Pitch angle data Is reliable, since determination of pitch angles can be executed in the spacecraft coordinate system.

Example of flag = 1 (Cluster 1: 22 September 2006: problem interval ~22:15-23:15 UT)



C4: Status_ASPOC: Identifies PEACE operation supported by ASPOC; moments are enhanced

We provide a flag to indicate when ASPOC is active to help users verify that this is the case, or to search PEACE CAA files for such events. Note that ASPOC was never operated on spacecraft 1, and is not operated on any spacecraft after June 2008.

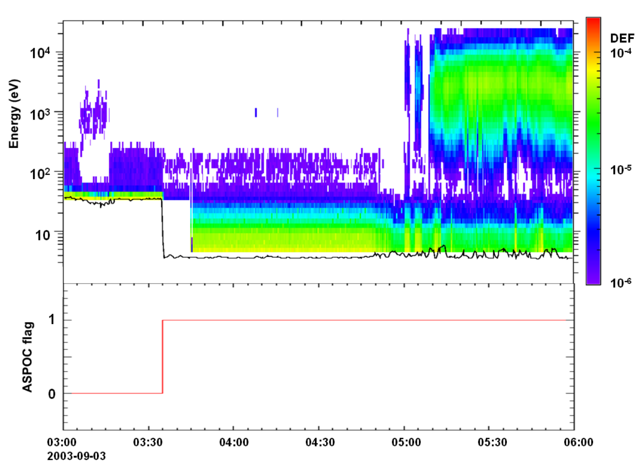
Flag values are
0 - ASPOC is not operating on this spacecraft
1 - ASPOC is operating on this spacecraft

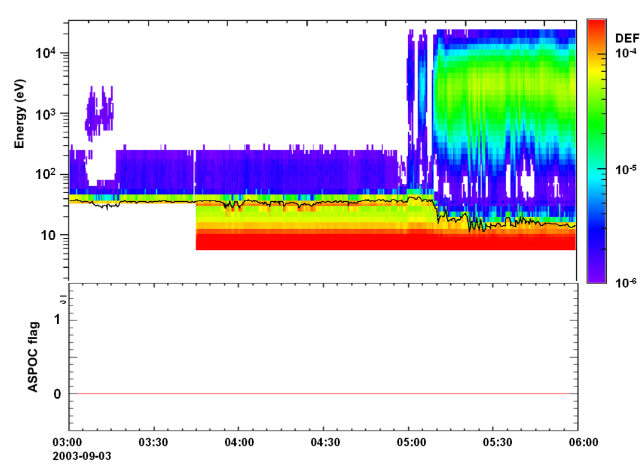
When ASPOC is operating, the balance of currents between the plasma and the spacecraft is affected, and the spacecraft potential may be rendered less positive than otherwise. This may make little difference when there is a large flux of plasma electrons (e.g. magnetosheath, solar wind) but tends to reduce the spacecraft potential significantly when the spacecraft is in the magnetosphere. In particular this improves the ability of PEACE to measure the flux of low energy plasma electrons, leading to more accurate PEACE moments.

Example of ASPOC flag: 03 September 2003: interval 03:00-06:00 UT, passage from magnetotail lobe to plasmasheet

Right hand figure: Cluster 4 ASPOC is off throughout. Black trace shows spacecraft potential from EFW. Orange line under the black trace are EFW probe photoelectrons.

Left hand figure: Cluster 3 ASPOC turns on at 03:35 (red trace changes from 0 to 1), PEACE changes energy coverage few minutes later. Low energy electrons (measured energies between ~5 and 30 eV) in the lobe are revealed, and the persistence of a low energy electron population in the plasmasheet is also evident.





C5: Status_FGM: Identifies intervals of problem FGM data which affect PEACE pitch angle data

The original Status_FGM parameter indicated whether or not FGM data were available in CSDS Prime Parameter files as these were used to produce magnetic field aligned temperature and heat flux parameters in the Moments data. The flag is in the process of being updated to reflect CAA FGM data availability and also occasional issues with FGM data onboard the spacecraft.

Flag values are to be
0 - No problems with CAA FGM data
1 - No CAA FGM data available (derived from FGM CAA gap files)
2 - Period when the FGM team performed a short in-flight calibration, so that the FGM data transmitted to PEACE onboard the spacecraft is unreliable
3 - Period when the FGM data transmitted to PEACE onboard the spacecraft was unreliable due to a temporary problem in the FGM instrument

The ability to calculate pitch angle data on the ground, from PAD data or from 3D data, relies on the availability of FGM data. Similarly the ability to produce magnetic field aligned Moments data. Rare occasions when FGM data is not available (and PEACE data is available) Is tracked using Flag = 1.

The selection of data for incorporation into the PAD data product relies on good quality FGM data provided to PEACE onboard the spacecraft, which is usually available. Flags 2 and 3 indicate situations when the FGM data is known to be unreliable so that PAD data is expected not to cover the full pitch angle range (see also Appendices C9 and C10). These flags are thus relevant to PITCH_SPIN and PITCH_FULL.

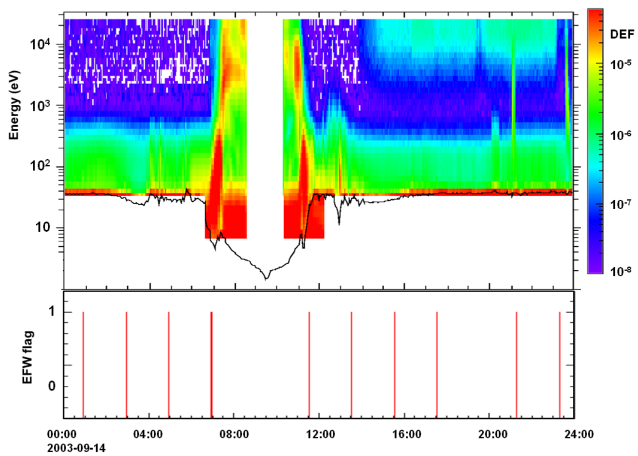
(no plot example is included here, because the Status flag definition is being revised)

C6: Status_EFWInterference: Identifies intervals in which EFW affects PEACE data

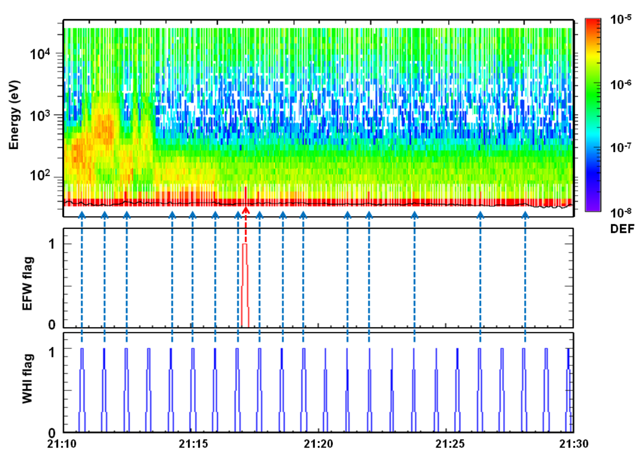
Flag values are
0 - normal operations
1 - the EFW instrument Is performing bias sweep/internal calibration operations

During EFW bias sweeps the spacecraft potential Is briefly disturbed and there is a possibility that PEACE data would be affected, in a similar way to the effects of WHISPER (see Appendix C10).

Example of EFW flag: 14 September 2003 (all day) Cluster 2 data shows ~10 EFW bias sweeps in a day



Example of EFW and WHI flags: 14 September 2003 (21:10-21:30) Cluster 2 data showing low energy plasma perturbations by EFW (red arrow) and by some WHI active mode intervals (blue arrows). See C7 for further information on WHI flags.



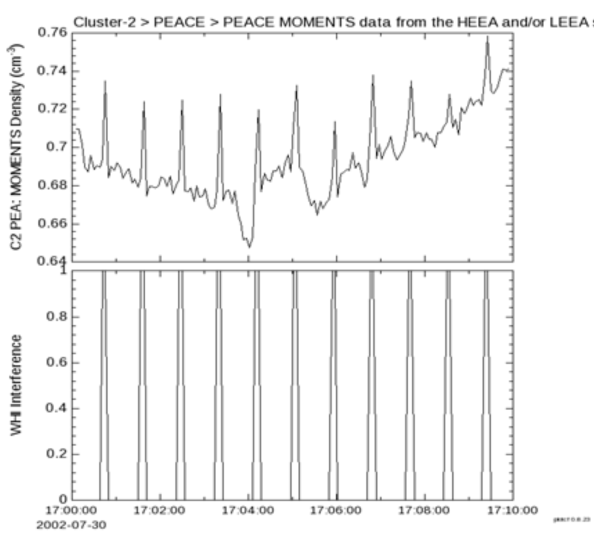
C7: Status_WHIInterference: Identifies intervals in which WHISPER affects PEACE data

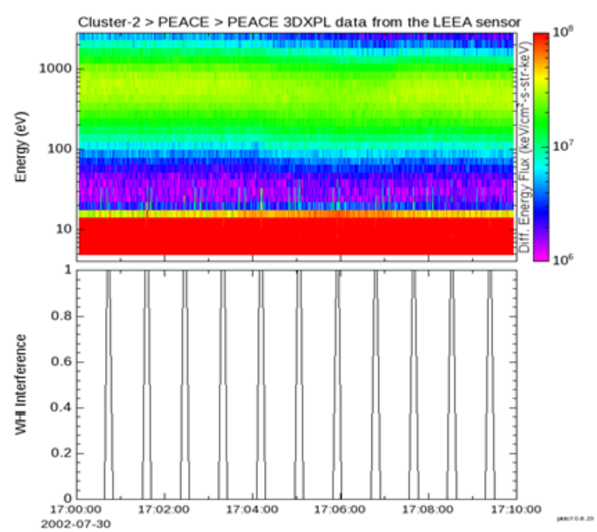
Flag values are
0 - no known interference from WHISPER
1 - the WHISPER instrument is performing active sounding during this spin, possibly producing interference to PEACE

When the WHISPER instrument produces active signals to stimulate plasma resonances, it does so by transmitting by essentially varying the electric field on the long wire booms, which appears to affect the spacecraft potential such that relatively high fluxes of photoelectrons appear at energies above that corresponding to electron acceleration through the prevailing spacecraft potential. If these photoelectrons are at energies covered by PEACE, the Moments data will show enhanced density during the interval of active WHISPER sounding.

Note that PEACE densities are not always affected during WHI active sounding intervals. This flag is provided to allow easy testing of WHI sounding as a possible explanation for density enhancements seen in moment data.

Example of flag = 1 (Cluster 1: 30 July 2002: example interval ~17:00-17:10 UT)





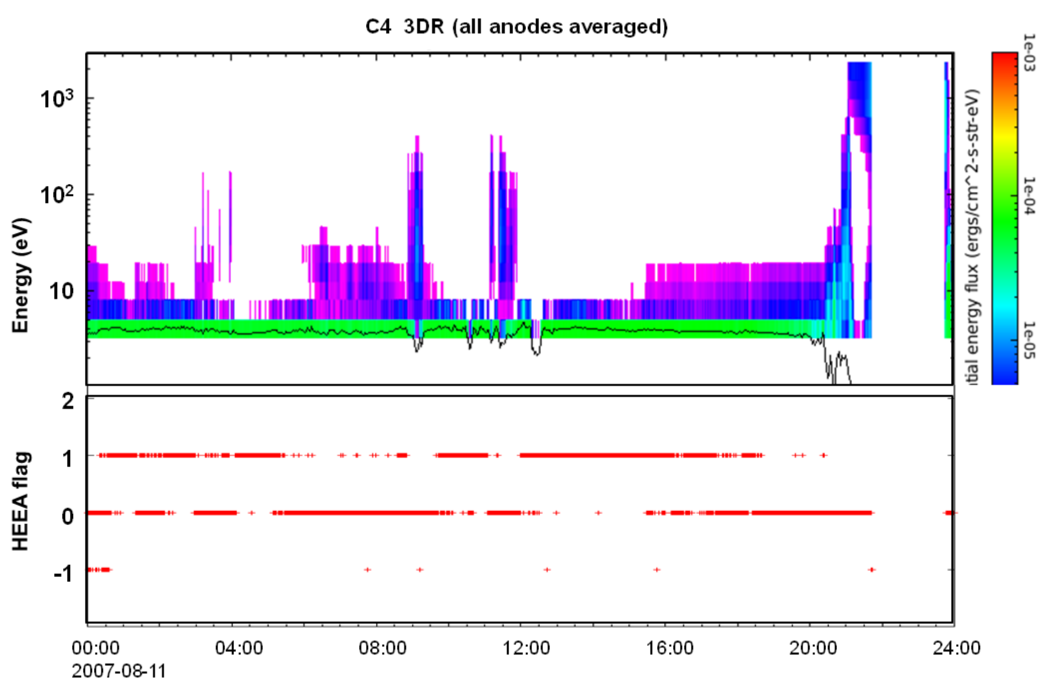
C8: Status_CountStats: Identifies intervals in which low or high count rate data affects PEACE data reliability

Flag values are defined for each of HEEA and LEEA and are defined by
0 - No problems
1 - Caution: low average count rate in the distribution
2 - Caution: possible underestimate of total counts in the distribution
3 - Warning: definite underestimate of total counts in the distribution

A flag value of -1 is set for any record with either missing spacecraft potential support data, or missing PEACE 3DR (or 3DFXR) data.

A flag of 1 is set if the average count rate in the distribution is below 1 count in a 3DR bin after removal of photoelectrons (by discarding the energy bin containing the potential and 2 more above that) and removal of data from sun-facing azimuths. A level of 1 count in a 3DR bin Is equivalent to 1/8 count in a PEACE full resolution accumulation bin, the so-called "background level". Moments data from a sensor with such an average count rate is expected to be inaccurate.

Example of flag = 1 (Cluster 4: 11 Aug 2007: example interval ~00:00-23:59 UT)
Note that for part of the interval the average count rate was close to the threshold, so that the flag alternates between 0 and 1, giving the appearance of simultaneously having both values on our large time duration plot.

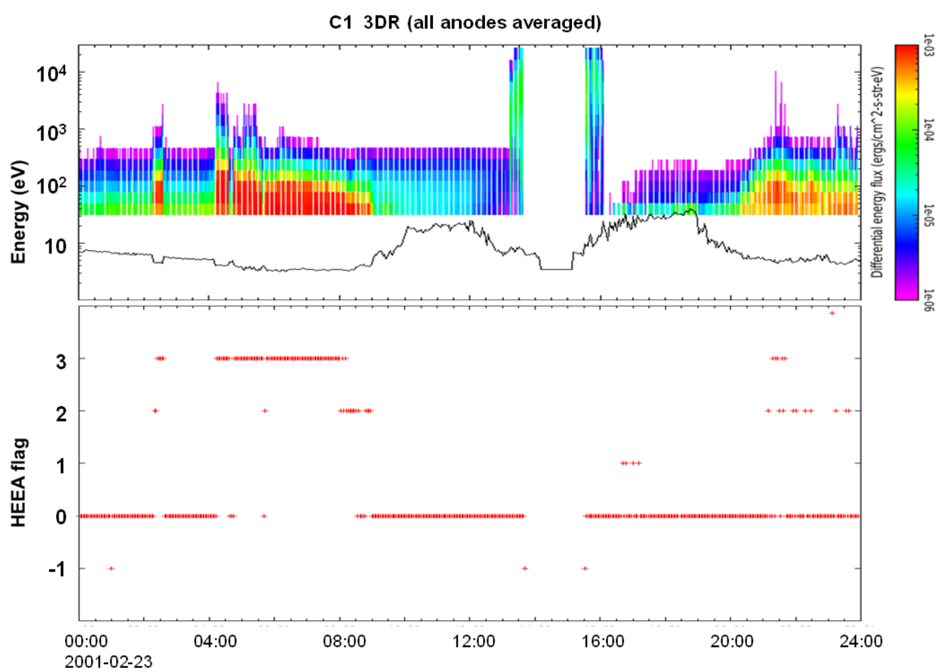


Under conditions of high electron fluxes, the count rates reported from the sensors to the DPU can be very large. The count rates in distributions such as 3DR in which count rates from 8 separate accumulations are combined can be larger still. A data compression error affects 3DR data which leads to under-reporting of high count rates, more often in HEEA data than LEEA data. The specifics are discussed in more detail in the PEACE ICD.

When this under-reporting affects more than 13% of bins in a spin record, the degree of under-reporting of the count rates in these bins (as well as the number of bins) is typically serious enough that the total counts and by extension the Moments data are expected to be seriously in error. This is indicated by setting the flag value to 3.

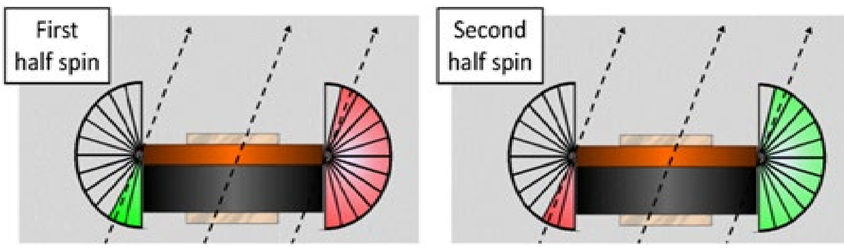
When count rates are under-reported in between 2% and 13% of the bins, the Moments data may still be incorrect in up to ~half of the cases. The need for caution when working with Moments in such cases is indicated by setting the flag to 2.

Example of flags = 2 and 3 (Cluster 4 HEEA: 23 February 2001: example interval ~00:00-23:59 UT)



C9: Status_PADSelectionQuality: Illustration of case of unsuccessful onboard pitch angle selection.

The PITCH_SPIN and PITCH_FULL data products are based on the "PAD" data selected in the PEACE DPU on the spacecraft, using the magnetic field data transferred from the FGM to the PEACE instruments onboard the spacecraft. When successful, the PAD data provides a 2D distribution covering a full 0° to 180° pitch angle range every half spin in the HEEA/LEEA energy overlap region.

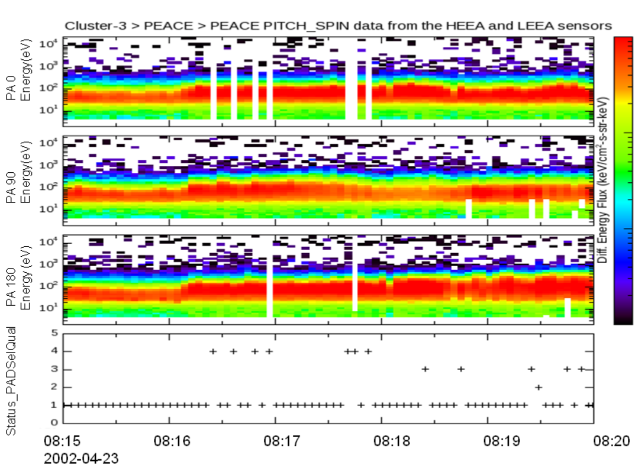


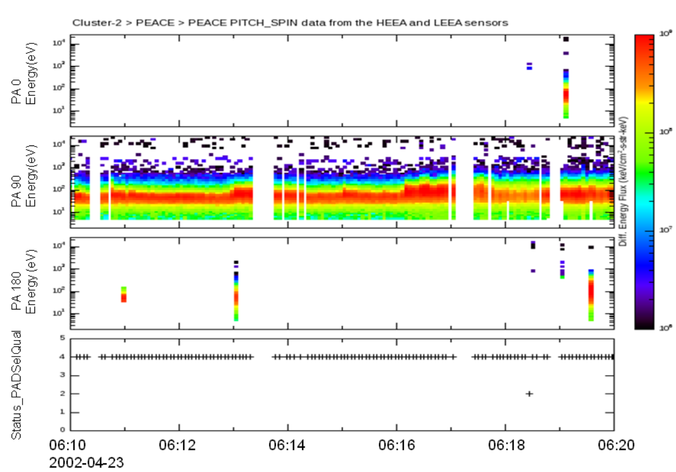
For a variety of reasons, the PAD selection process is not always successful, which may be verified in ground data processing using ground-calibrated high time resolution magnetic field data. This flag indicates whether or not the full pitch angle range is covered in each half spin of the spin record.

Flag values are
1 - 0° to 180° pitch angle coverage in both half-spins - no problems
2 - 0° to 180° pitch angle coverage In the first half-spin only
3 - 0° to 180° pitch angle coverage In the second half-spin only
4 - neither half-spin has complete pitch angle coverage

Below Left: Example of generally good coverage: Flag = 1 (Cluster 3: 23 April 2002: ~08:15-08:20 UT)

Below Right: Example of very bad coverage: Flag = 4 (Cluster 2: 23 April 2002: ~06:10-06:20 UT). In this case there was a problem with the data provided by FGM to PEACE onboard the spacecraft.



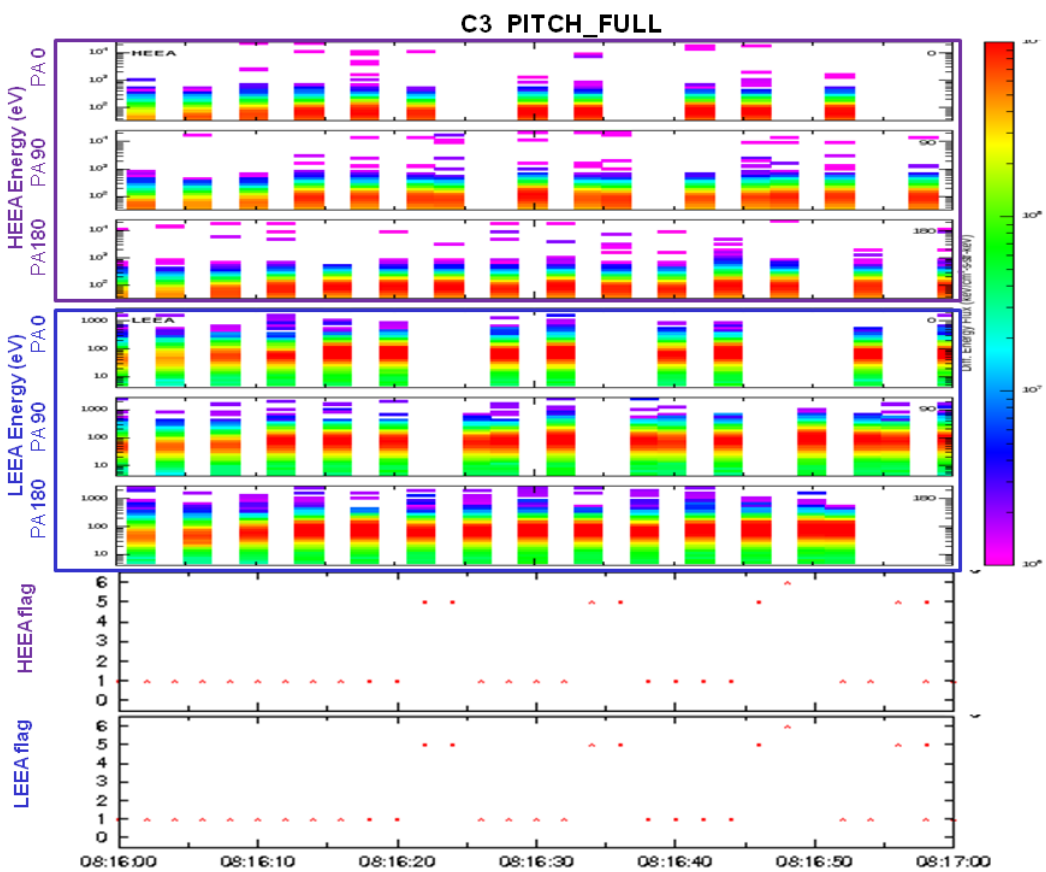


C10: Status_PitchAngleCoverage: Illustration of case of unsuccessful onboard pitch angle selection.

As discussed In C9, the PITCH_SPIN and PITCH_FULL data products are based on "PAD" data. Users of PITCH_FULL data may be Interested to know the actual pitch angle coverage achieved In each half-spin, especially when the PAD selection was not fully successful. Hence this status flag.

Flag values are produced for each half spin, taking one of the following values
1 - pitch angle coverage is 0° to 180°
2 - pitch angle coverage is 15° to 165°
3 - pitch angle coverage is 30° to 150°
4 - pitch angle coverage is 45° to 135°
5 - pitch angle coverage is 60° to 120°
6 - pitch angle coverage is 75° to 105°

Example of mixed quality coverage: Flag = 1,5 (Cluster 3: 23 April 2002: ~08:16-08:17 UT)
In this case, flag = 5 occurs when the magnetic field direction crosses the 0°/180° azimuth In PEACE coordinates, a fairly rare special case which leads to a PAD selection error in the onboard software.

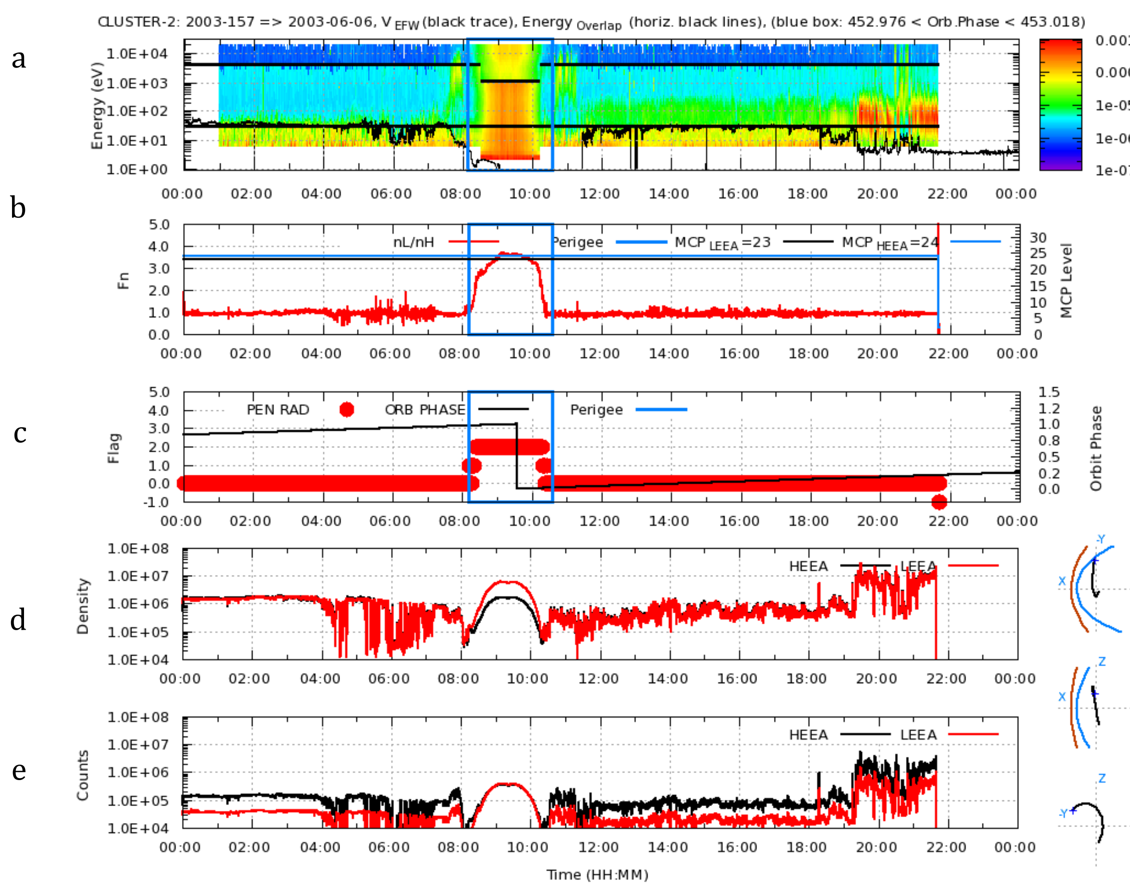


C11: Status_PenetratingRadiation:

Background "noise" due to penetrating radiation associated with trapped radiation belt particles may be seen during some of (not all) the perigee passes during which PEACE is switched on. In addition, radiation associated with Solar Energetic Particle (SEP) events may sometimes affect PEACE, depending on the flux of the specific SEP event, particularly when the spacecraft are outside the magnetosphere. Details of the flag production method are provided in the PEACE ICD.

Flag values are produced for each half spin, taking one of the following values
0 - no penetrating radiation affecting PEACE
1 - Caution: possible penetrating radiation counts
2 - Warning: significant penetrating radiation counts in PEACE data

Example of flag = 2 during a perigee pass (Cluster 1: 06 June 2003: example interval ~08:00-10:10 UT)
The count rates of HEEA and LEEA (panel e) are very similar in the affected interval, dominated by penetrating radiation. Thus the LEEA density exceeds the HEEA density in the overlap region (panel d). The density ratio Fn >3 (panel b) and the Flag is set to 2 (panel c) to reflect a strong background signal.



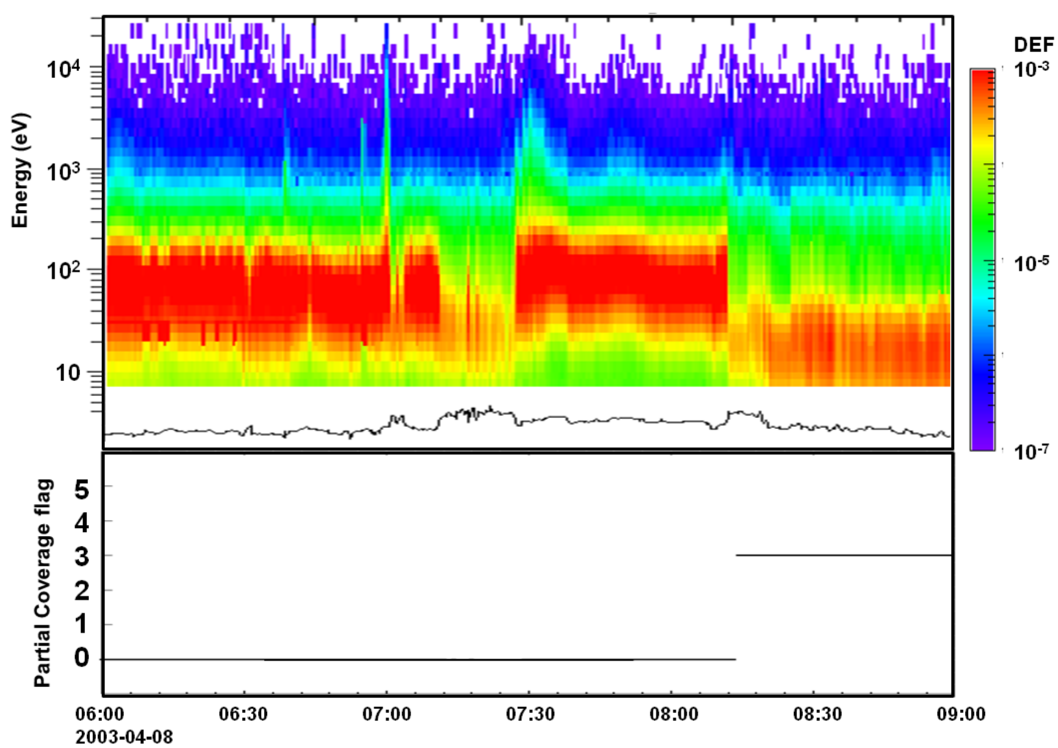
C12: Status_WarningPartialCoverage: measurements are for partial energy coverage of the plasma.

In order to interpret Moments data it is important to know whether or not the PEACE sensors have measured the full energy range spanned by the electron plasma population or populations. For example, if the measured energy covers only a fraction of the electron plasma population, the electron density calculated from the PEACE measurements will not represent the total electron density at the spacecraft location. The effects of partial energy coverage are described In detail in "Analysis Methods for Multi-Spacecraft Data" Chapter 6 (ISSI Scientific Report, 1998).

This flag identifies clear cut cases of "partial coverage", using the flag values given here.

Flag values, based on the combined coverage of the HEEA and LEEA sensors:
0 - full coverage of the plasma
1 - full coverage, caution: check low-energy population
2 - full coverage, caution: poorly resolved lobe population
3 - partial coverage at low energies
4 - partial coverage at high energies
5 - partial coverage at low and high energies
6 - Caution: very low counts - see also Status_CountStats

Example of flag = 3 (Cluster 1: 08 April 2003: problem interval ~08:15-09:50 UT)



C13: Status_WarningTimeAliasing: Affects Moments accuracy

An underlying assumption in the calculation of Moments from PEACE data is that a PEACE sensor can capture a full electron velocity distribution during a spin (duration ~ 4 s). However, if the plasma conditions change during the spin, this assumption is violated and the result of the Moments calculation should be treated with caution.

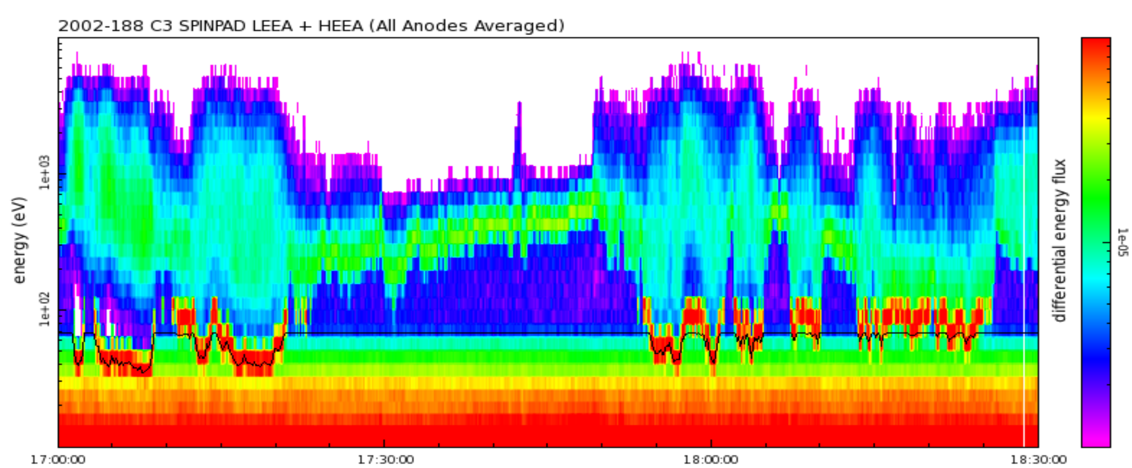
By comparison of HEEA and LEEA moments in the energy overlap region, it may be possible to develop a status flag to warn of such time aliasing, at least in cases where the fluxes are significantly changed between the first and second half-spins. This is further explained in the PEACE ICD.

Alternatively, in such cases, already delivered PEACE CAA Moments data may in future be replaced with data calculated using the average of the moments calculated in the first half spin and then the second half spin (using HEEA and LEEA half spin distributions In each case) which will produce more accurate moments data if the HEEA-LEEA energy overlap region captures the majority of the electron fluxes.

C14: Very high spacecraft potential: Affects Moments accuracy

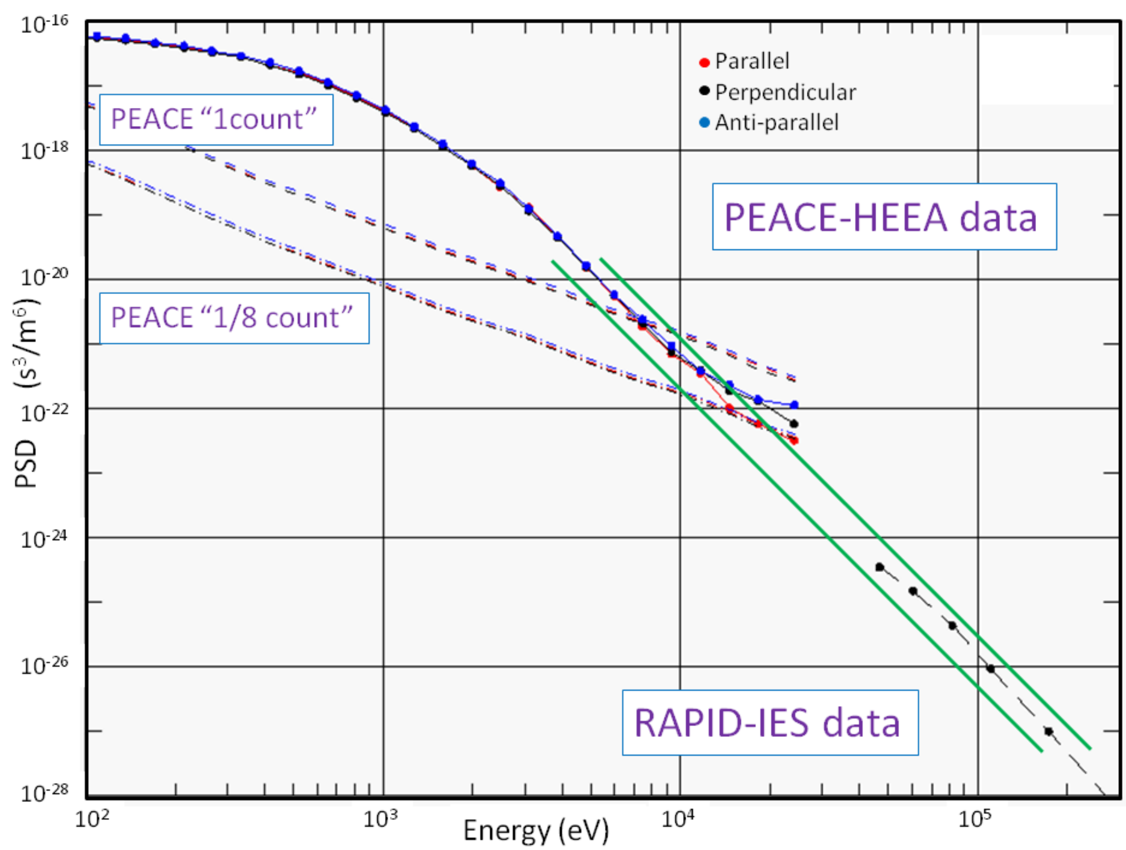
At times of very high spacecraft potential, the EFW spacecraft potential estimate will be unreliable, and analysis of PEACE data will require particular care. Such situations arise when the EDI electron gun current is particularly high in a region of rarefied plasma, typically the magnetotail lobe.

We do not provide a status flag for such cases, but here is an example (Cluster 3: 07 July 2002: problem intervals include ~17:20-17:55 UT). The black trace represents the spacecraft potential estimate from EFW which tracks the EFW probe electrons up to the limiting value of ~70 V. The probe electrons continue to track the spacecraft potential when it rises to a few hundred V.



C15: Cross-checking that data in scientific units is above minimum background

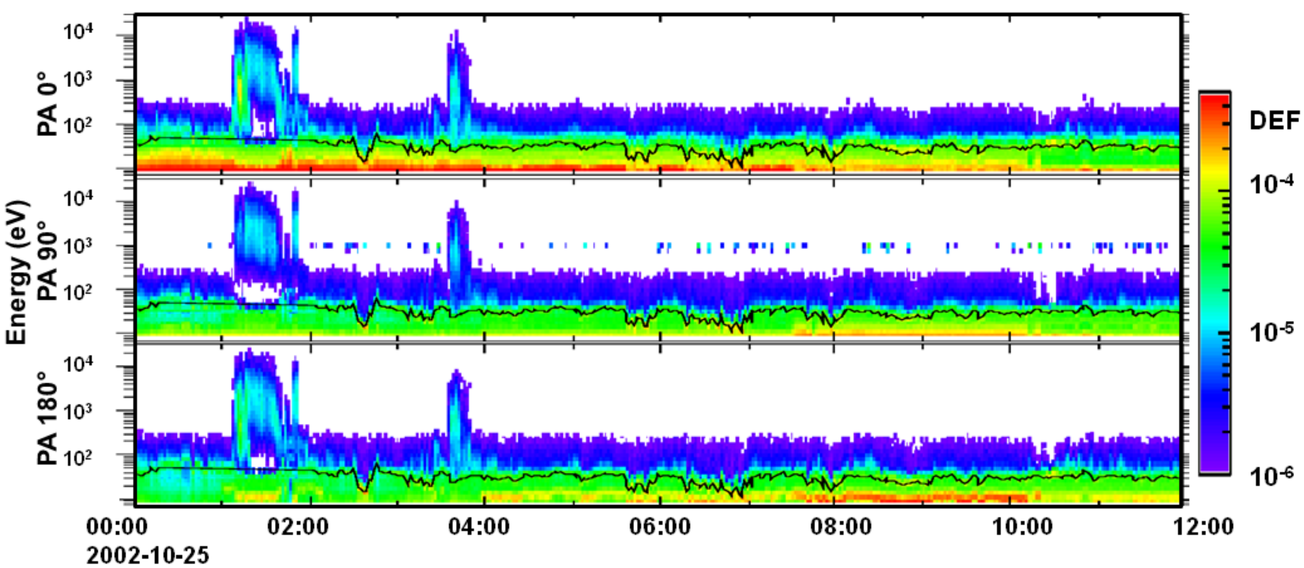
The following example (taken from cross-calibration studies) illustrates the principle of comparing PEACE data expressed in scientific units (phase space density in this case) against the values that would be expected if no plasma signal was present, but a background noise level was contributing to the phase space density in the plot. The example shows the background level associated with an average of 1 count per accumulation and also 1/8 count/accumulation. The latter represents the minimum level of background signature observed In PEACE data, so when the "data" curve starts to overlay this background curve we should not consider the affected data points to be describing the plasma - in this case the three points at highest energy in the PEACE data appear to be predominantly a background signature.



C16: Caution: EDI electron beam signature in PEACE data

The following example (taken from cross-calibration studies) illustrates the principle of comparing PEACE data expressed in scientific units (phase space density in this case) against the values that would be expected if no plasma signal was present, but a background noise level was contributing to the phase space density in the plot. The example shows the background level associated with an average of 1 count per accumulation and also 1/8 count/accumulation. The latter represents the minimum level of background signature observed In PEACE data, so when the "data" curve starts to overlay this background curve we should not consider the affected data points to be describing the plasma - in this case the three points at highest energy in the PEACE data appear to be predominantly a background signature.

Example of EDI beam electrons at 90° pitch angle and 1 keV energy (Cluster 1: 25 October 2002: example interval ~00:00-12:00 UT)



Appendix D: Caveat Files

Summary of situations highlighted In PEACE daily Caveats Files:

D1 Science Data Loss

Science Data Loss: All instruments affected by Spacecraft/Ground Segment Issue

- Spacecraft computer reboot

Science Data Loss: PEACE affected by Spacecraft/Ground Segment Issue or Internal Problem

- Occasional mis-commanding of PEACE
- Spacecraft ADCE switchover causing PEACE to stall, not affecting other instruments
- ESOC decision to turn off PEACE as a precaution

Science Data Loss: PEACE affected by Spacecraft/Ground Segment Issue: Pitch Angle Data still available

- Spacecraft data recorder problem (Cluster 2, June 2007 only)

D2 Caution: Science data

Caution: Science Data: PEACE Onboard Data Handling Problem

- Bit flips. Complements detailed information in the Status_DataStreamErrors parameter.
- Intervals when PEACE onboard software patches were tested

Caution: Science Data: IEL Related PEACE Onboard Data Handling Issues

- Data production in the PEACE DPU was adversely affected when EDI IEL signals were received; the relevant interval is described.
- For a short period in 2002, on Cluster 2, the FGM IEL signal was corrupted. Complements detailed information in the Status_FGM parameter.

Caution: Science Data : PEACE MCP Problem

- Unusual MCP behaviour
- Improper MCP level commanding

Caution: Science Data Problem: Penetrating Radiation Background

- SEP event list (tbc) Complements detailed information in the Status_PenetratingRadiation parameter.

D3 Other Information

Information: Spacecraft Event

- Major thrusters firings
- Battery leaks

Information: PEACE Operational MCP Level Change

- Time extracted from PEACE operations team records.

Information: PEACE Real Time Operations

- Start and end time extracted from PEACE operations team records. Typically refers to real time tesing of MCP performance. Interval not recommended for science.

Information: PEACE Eclipse Operations on One or More Spacecraft

- Start and end time extracted from PEACE PIOR command files, Complements detailed information in the Status_Eclipse parameter.

Appendix E: PEACE Instrument Mode File

This appendix summarises the type of information provided in the Instrument Mode History file. There is one file for each spacecraft. Due to the large variety of Instrument set-ups used during the mission, It Is not straightforward to identify any given instrument mode with a given environment (e.g. solar wind, magnetotail lobe etc) so a different approach has been followed.

For any given interval of steady operations (defined by a start and stop time) the file provides the mode description used internally by the PEACE team.

In addition, for non-PEACE team members, it classifies the relationship of the HEEA and LEEA energy sweeps (in terms of degree of energy overlap, and selected sweep mode for each sensor. For example, times with fully overlapping energy coverage are particularly useful for effectively providing a velocity distribution function measurement every half-spin (~2 seconds), Instead of every spin (~ 4 seconds). Similarly, times with partially overlapping or nested energy coverage may also be of Interest for the same reason, though the half-spin cadence only applies In the band of overlapping energies. Occasions when only one or other sensor Is turned on are also indicated.

It similarly characterises the type of 3D data product available from each of HEEA and LEEA, providing a convenient way to search for occurrences of e.g. 3DX or 3DXP data, with or without reduced energy coverage ("windowing") or the less often used 3DXPA.

It indicates occasions when onboard pitch angle data is not transmitted, which are rare, except for the case of C3 after switching to single processor mode. It does not indicate occasions when the LER product Is not transmitted, as this data product is not expected to be of interest to most CSA users.

For advanced users, there is information on special operations, and also information about the MCP voltage and the activation or otherwise of the grid for each sensor.

Full details are provided in the PEACE ICD section 3.4.7.6.

Appendix F: Coordinate Systems

This appendix illustrates the relationship between different Cluster coordinate systems, and explains the PEACE instrument coordinate system used for the PEACE 3D data products. The figures show the location of the PEACE HEEA and LEEA sensors and also the spacecraft Sun Sensor (SS). These reference systems are formally defined in the DDID and JSOC TN0008 documents.

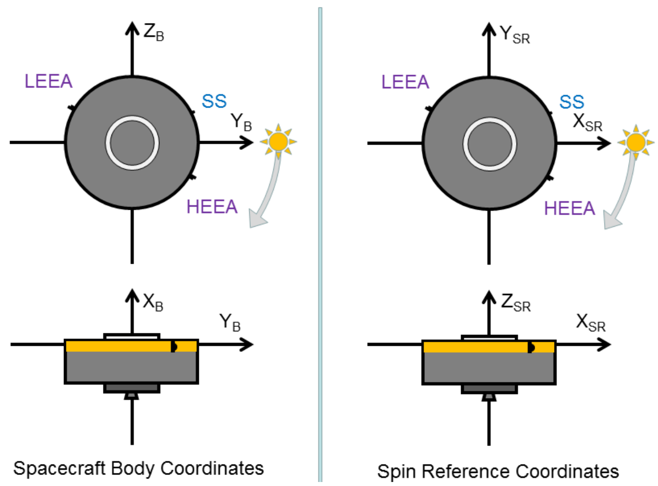
F1 Spinning Coordinate Systems

Spacecraft "Body-Build" Coordinates

- Reference frame locked to the spacecraft body

Spin Reference System

- Spinning reference frame aligned with the maximum principal inertia axis. Typically the spacecraft attitude is deliberately tilted so that the sun direction lies a few degrees out of the X_{SR}-Y_{SR} plane (to avoid shadowing of the EFW probes by the spacecraft).



The apparent motion of the Sun is indicated.

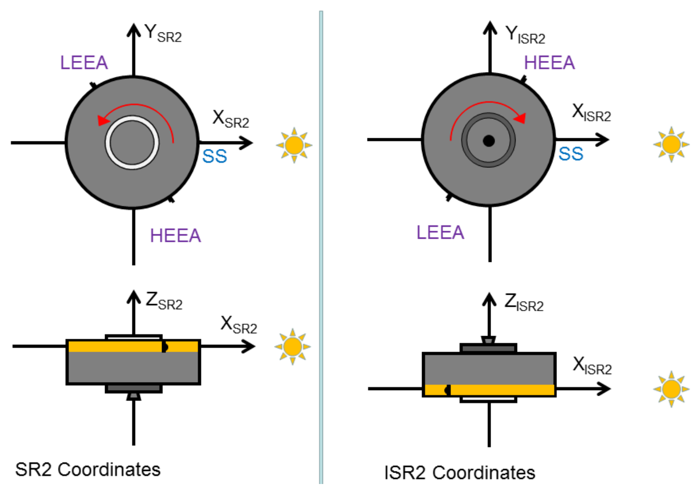
F2 Non-Spinning Coordinate Systems

SR2: Despun version of SR

- X defined so that SS points to the Sun
- Z points close to GSE -Z
- Y completes right handed set

ISR2: Inverted SR2

- X points to the Sun
- Z points close to GSE +Z
- Y completes right handed set



Sense of spacecraft rotation indicated by the red arrow. The apparent position of the Sun is fixed in these reference frames.

F3 PEACE Coordinate System for CAA 3D data

Dependence of PEACE reference frame on PEACE Sun Pulse Offset

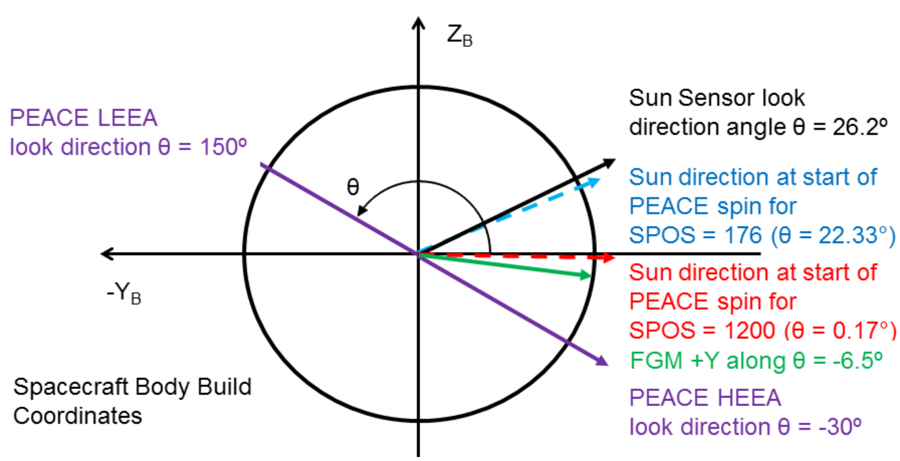
Collection of data during a PEACE “spin” does not begin when the Sun Sensor sees the Sun. Instead it starts after a short delay, so that the energy sweep is not measuring low energy electrons while the sensor is looking directly towards the Sun. The aim is to avoid “seeing” fluxes of photoelectrons generated within the analyser at the time when the fluxes are will be very high.

The delay time is represented by the “SPOS” parameter measured in units of a 1/16th of a PEACE accumulation time. In CAA PEACE files this is given by the parameter “Mode_SunpulseRephaseOffset”. The value should be 1200, in order that PEACE spins are consistent with the CSDS spin timing standard set out in DS-QMW-TN-0007. However, a value of 176 has also been used, as indicated in the table below.

SPOS value	Start time (UT)	PEACE 3D Data Reference Frame
176	launch	SR2_PEA1 ~SR2
1200	16 Aug 2003 23:55	SR2_PEA2 ≠ SR2
176	16 Jun 2004 11:02	SR2_PEA1 ~SR2
1200	04 Sep 2004 13:45	SR2_PEA2 ≠ SR2

On 15 Sep 2003 there were some tests in which the SPOS was altered a few times on spacecraft C3.

The figure (right) shows the Sun direction at the start of a PEACE spin, for SPOS values of 176 and 1200.



If the SPOS value is 176, the PEACE spin starts ~43 ms (for a 4 s spin) after the Sun Sensor sees the Sun, during which ~4° of spacecraft rotation occurs. Thus the PEACE reference frame is ≈ the SR reference frame, and 3D data products collected during a complete spin are approximately in the SR2 frame.

However, when the SPOS value is 1200, the delay is 293 ms (for a 4 s spin) during which ~26° of spacecraft rotation occurs (i.e. a full 3DR azimuth more than when SPOS = 176) in which case it is no longer a good approximation to treat the PEACE 3D data as being in the SR2 frame.

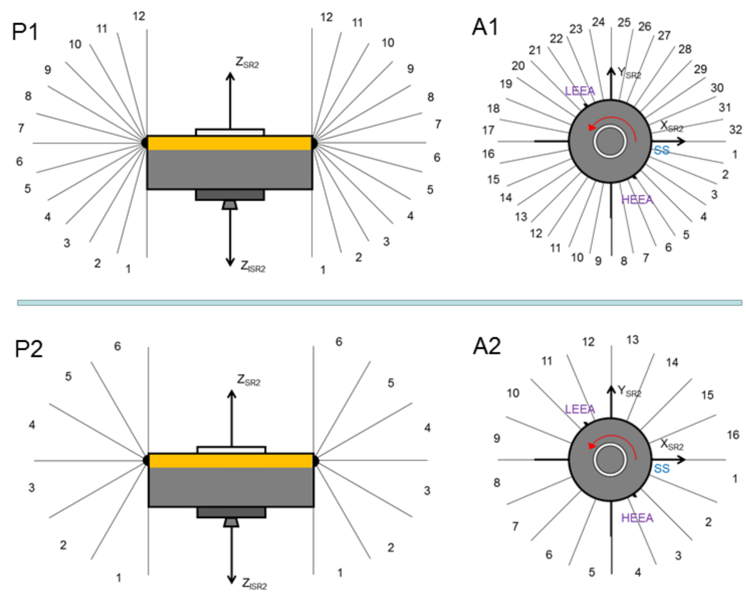
Telemetry constraints mean that 3D data is not necessarily transmitted each and every spin, in which case it is not possible to consider retrospectively reorganising 3D data into "spins" that start at the time that the Sun Sensor sees the Sun.

Azimuth and polar directions

The azimuth and polar directions in CAA PEACE data files refer to the *look directions* of the sensors (and not the flow directions of observed electrons).

The look directions of the 12 anodes of the two PEACE sensors, and their numbering in a CAA PEACE 3DX data file, are shown in the figure to the right, P1, in relation to Z_{SR2} and Z_{ISR2}. The azimuth sector numbering is shown in A1, in relation to the SR2 coordinate system (applicable when the SPOS = 176).

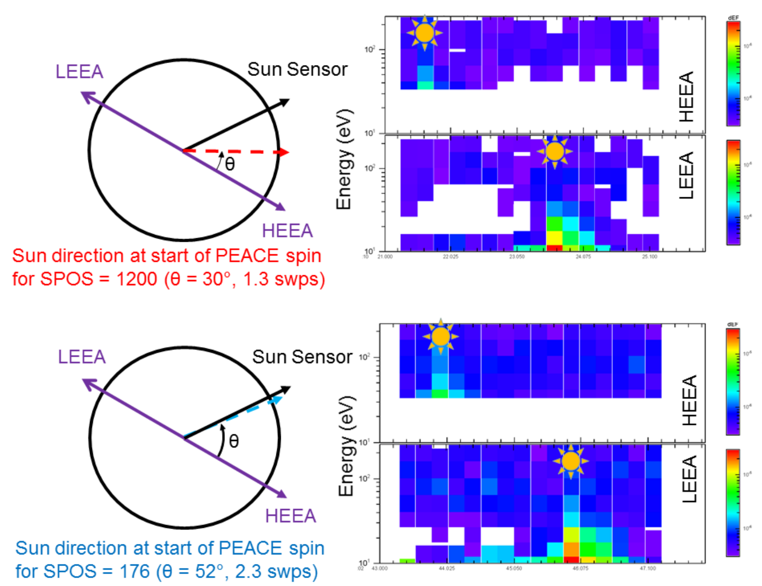
The anode and azimuth numbering for a CAA PEACE 3DR file are shown in P2 and A2. For a CAA PEACE 3DXP file, the appropriate figures are P2 and A1.



Examples for PEACE for SPOS 176, 1200

The figure shows (upper panel) 3DR data summed over all anodes, collected during a single spin of PEACE data with SPOS = 1200, and (lower panel) with SPOS = 176. In each case the HEEA data is shown above the LEEA data.

3DR data contains 16 azimuths, of width 22.5° each, corresponding to the 16 vertical strips in each energy –time spectrogram.



These data are for special cases chosen that there is minimal natural plasma and no spacecraft photoelectrons in the energy range 10-250 eV that is shown. The plots highlight the internal photoelectron fluxes produced when the HEEA and LEEA sensors look sunward (as indicated by the Sun symbol on each spectrogram).

The spectrograms and associated cartoons show that when the SPOS = 176 the Sun is seen in HEEA 3DR azimuth 3 (LEEA 3DR azimuth 11) as expected from figure A2 above.

The figure also illustrates that when the SPOS = 1200, the Sun is seen in HEEA 3DR azimuth 2 (LEEA 3DR azimuth 10). This demonstrates the shift in spin phase of the start of the PEACE spin by 22.5° or one PEACE 2DR azimuth sector.