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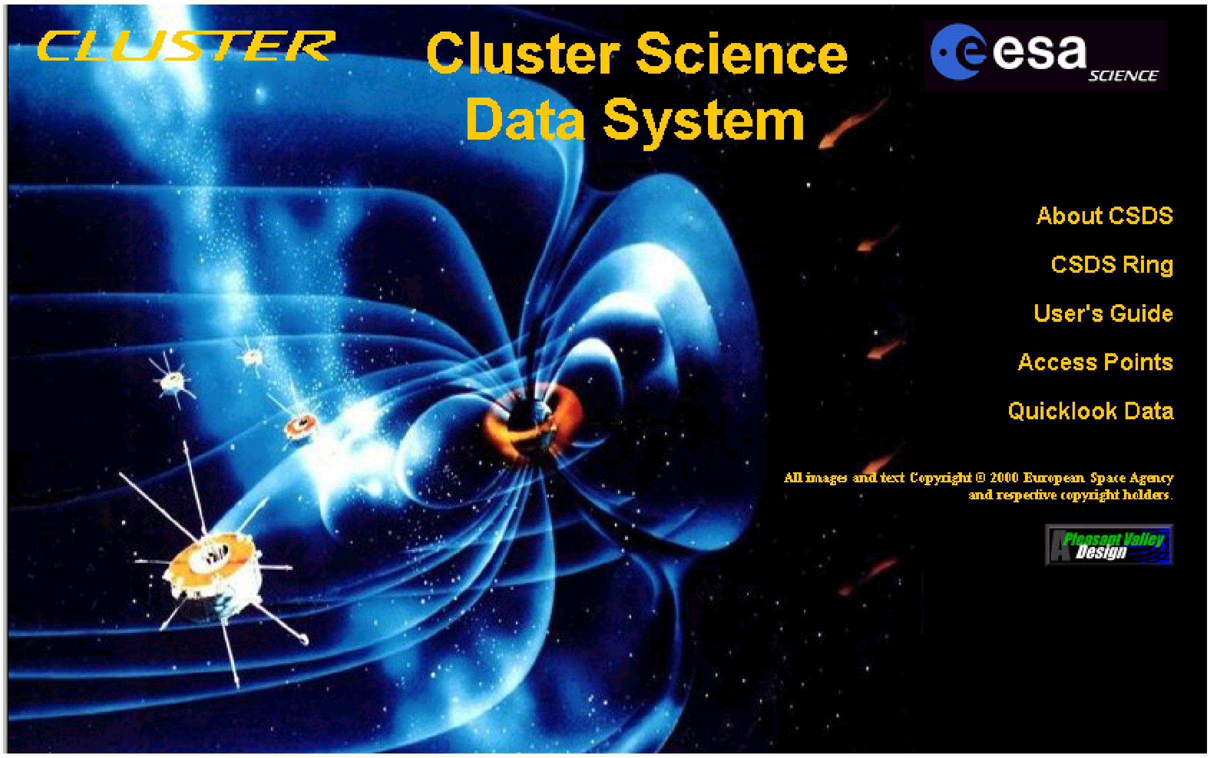
Users Guide to the Cluster Science Data System



The CSDS Home Page is:

http://sci2.estec.esa.nl/cluster/csds/csds.html

Prepared by

Patrick W. Daly

Revised Edition after One Year of Operations

ftp://ftp.estec.esa.nl/pub/csds/task_for/users_guide/csds_guide.html

Dedicated to:

Alan Johnstone
Norbert Sckopke
Berend Wilken
Les Woolliscroft

Our companions along the long, stony road
who never attained the final destination.

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Contents

List of Acronyms **ix**

1 Introduction **1**
1.1 Purpose of this Document . . . 1
1.2 Background . . . 1
1.3 After the Cluster Disaster: Cluster-II . . . 2
1.4 Overview . . . 3
1.5 The Cluster Experiments and Data Centres . . . 4
1.6 The Data Sets . . . 4
1.7 Rules of Use . . . 4

2 The CSDS Parameters **8**
2.1 Status Bytes . . . 8
2.2 Convention on the Definition of a Spin . . . 8
2.3 Convention on the Radius of the Earth . . . 9

3 The Cluster Instruments and their Parameters **16**
3.1 ASPOC . . . 16
3.2 CIS . . . 20
3.3 EDI . . . 24
3.4 FGM . . . 26
3.5 PEACE . . . 28
3.6 RAPID . . . 31
3.7 WEC . . . 35
3.8 DWP . . . 40
3.9 EFW . . . 47
3.10 STAFF . . . 50
3.11 WHISPER . . . 55
3.12 WBD . . . 59
3.13 Auxiliary Data . . . 61

4 Summary Parameter Plots **64**

5 The Role of JSOC **67**
5.1 JSOC Services to PIs . . . 67
5.2 JSOC Services to National Data Centres . . . 69
5.3 JSOC Services to the Wider Community . . . 70

6 Cluster Data Management System—CDMS **72**
6.1 CDMS Services to the National DCs . . . 72
6.2 CDMS Services to the Scientists . . . 73

7 Data Validation **74**
7.1 The Meaning of “Validated Data” . . . 74

8 Online Documentation for CSDS **82**

A Layout of the Summary Plots **84**

B CDMS Usage **90**

C The Size, Elongation and Planarity of the Tetrahedron **97**

D Tetrahedron Quality Factors **99**

References **103**

Index **106**

List of Acronyms

ACDC	Austrian Cluster Data Centre
ACF	Auto-Correlation Function
ADC	Analogue-to-Digital Converter
ASPOC	Active Spacecraft Potential Control (Cluster Exp.)
BM	Burst Mode (Cluster Telemetry Mode)
CCDRC	Chinese Cluster Data and Research Center
CDF	Common Data Format
CDMS	CSDS Data Management System
CD-ROM	Compact disc – read only memory
CETP	Centre d'étude des Environments Terrestre et Planétaires
CFC	Cluster French Centre
CIS	Cluster Ion Spectrometry (Cluster Exp.)
CNES	Centre National d'Études Spatiales, Toulouse, France
CODIF	Composition Distribution Function Analyser (CIS)
Co-I	Co-Investigator
CSDS	Cluster Science Data System
CSDSnet	Network for CSDS
CSSAR	Center for Space Science and Applied Research, Beijing, China
DC	Data Centre
DDID	Data Delivery Interface Document
DPS	Data Processing System
DPU	Data Processing Unit
DSN	Deep Space Network
DWP	Digital Wave Processing Experiment (Cluster Exp.)
EDI	Electron Drift Instrument (Cluster Exp.)
EFW	Electric Field and Waves (Cluster Exp.)
ESA	European Space Agency
ESOC	European Space Operations Centre
ESTEC	European Space Research and Technology Centre, Noordwijk, Netherlands
FFT	Fast Fourier Transform
FGM	Fluxgate Magnetometer (Cluster Exp.)
FGM-PSDS	FGM Processing Support Data Set
FTP	File Transfer Protocol (via Internet)
GCDC	German Cluster Data Centre
GSE	Geocentric Solar Ecliptic coordinate system
GSFC	Goddard Space Flight Center, Greenbelt MA, USA
GSM	Geocentric Solar Magnetic coordinate system
HAR	High Angular Resolution (PEACE mode)
HDC	Hungarian Data Center
HEEA	High-Energy Electron Analyser (PEACE)
HIA	Hot Ion Analyser (CIS)
HK	Housekeeping Data
IBMD	Instrument Baseline Mode Definition (JSOC)
IES	Imaging Electron Spectrometer (RAPID)
IGRF	International Geomagnetic Reference Field
IIMS	Imaging Ion Mass Spectrometer (RAPID)
IMF	Interplanetary Magnetic Field

Internet	The TCP/IP Network
ISTP	International Solar-Terrestrial Physics
IWF	Institut für Weltraumforschung, Graz, Austria
IWG	(CSDS) Implementation Working Group
JSOC	Joint Science Operations Centre
KFKI	Central Research Institute for Physics, Budapest, Hungary
KTH	Kungliga Tekniska Högskolan, Stockholm, Sweden
LAR	Low Angular Resolution (PEACE mode)
LEEA	Low-Energy Electron Analyser (PEACE)
MCP	Microchannel Plate
MLUT	Mode Look-up Table (JSOC)
MPE	Max-Planck-Institut für extraterrestrische Physik, Garching, Germany
MSP	Master Science Plan
MWF	Magnetic Waveform Analyser (STAFF)
NASA	National Aeronautics and Space Administration (USA)
NM	Normal Mode (Cluster Telemetry Mode)
OBDH	Onboard Data Handling
OSTB	One Second Timing Boundary (DWP)
PEACE	Plasma Electron and Current Experiment (Cluster Exp.)
PET	Predicted Event Time (JSOC)
PI	Principal Investigator
PPDB	Prime Parameter Data Base
PSDS	Processing Support Data Set (for FGM)
RAL	Rutherford Appleton Laboratory, Didcot, UK
RAPID	Research with Adaptive Particle Imaging Detectors (Cluster Exp.)
RPA	Retarding Potential Analyser
SDC	Scandanavian Data Centre
SPDB	Summary Parameter Data Base
SPP	Summary Parameter Plots
STAFF	Spatio-Temporal Analysis of Field Fluctuations (Cluster Exp.)
SWT	Science Working Team (Cluster PIs)
TCP/IP	Transmission Control Protocol / Internet Protocol
TLIS	Top Level Instrument Schedule (JSOC)
UKCDC	UK Cluster Data Centre
USCSDC	US Data Center
UTC	Coordinated Univeral Time
WBD	Wide Band Data (Cluster Exp.)
WEC	Wave Experiment Consortium (DWP, EFW, STAFF, WBD, WHISPER)
WECSS	WEC Sample Sync
WHISPER	Waves of High Frequency and Sounder for Probing of the Electron Density by Relaxation (Cluster Exp.)
WWW	World Wide Web

1 Introduction

1.1 Purpose of this Document

This *Users Guide* to the Cluster Science Data System was originally planned as an explanation to the general Cluster community of what one could expect, and not expect, for the electronic data distribution system. It was to describe the various instruments in just enough detail to be able to understand the data sets available and also to list those parameters offered. It was never intended to be manual for an interactive terminal session.

Since this initial goal in the days of Cluster-I many additional questions were raised by people not directly involved in the CSDS development. The answers existed, scattered around endless documentation on dozens of servers, or even on paper in obscure filing cabinets. The *Guide* was then conceived as an ideal medium to collect all the essentials for working with and using CSDS. It was decided to err on having too much rather than too little material.

The major sources of information for Cluster and its data sets are:

Escoubet et al. [1997] *The Cluster and Phoenix Missions*, with detailed descriptions of the instruments and many other aspects of the mission;

Paschmann and Daly [1998] *Analysis Methods for Multi-Spacecraft Data*, a collection of analysis tools aimed at Cluster-like missions;

DDID a detailed description of the data distribution methods and of the formats on the data medium;

Escoubet et al. [2001] a description of the Mission in the special issue of *Annales Geophysicae* containing the first results;

and dozens of other technical reports for all aspects of this project. See the list of references on pages 103–105.

This *Guide* is a distillation of what is relevant and perhaps useful to most users. It is the work of many contributors, as listed on page v. This list should not be considered complete, for many other people have put considerable effort in getting Cluster and CSDS off the ground.

1.2 Background

The Cluster Mission [Escoubet et al., 1997] consists of 4 identical spacecraft equipped with 11 experiments for detailed spatial and temporal studies of various parts of the Earth's magnetosphere. The PIs and Co-Is of these experiments are distributed over many European countries and the United States.

In order to fulfil the purpose of the Cluster Mission, fast and reliable exchange of data sets between these widely scattered experimenters must be achieved. It was recognised very early that such an exchange must be organised long before the launch, and must be well-defined with a functioning infrastructure. To this end, a working group was established to investigate the various possibilities for realising this goal. Its Final Report [CSDS:WG], released in 1990, called for the creation of the Cluster Science Data System (CSDS) as a set of nationally distributed data centres to generate and maintain selected data sets for those experiments most closely associated with each centre.

Consequently, the Cluster Science Working Team (SWT) called into being two bodies to implement the recommendations of the Final Report: a Steering Committee (Steering Committee) consisting of Data

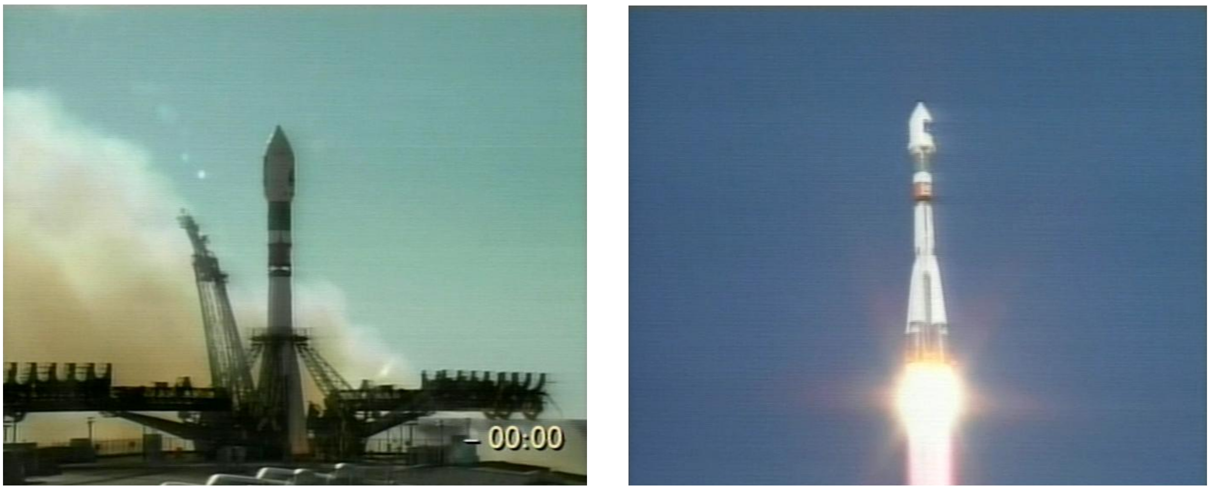

Figure 1: The launch of Cluster 2 and 3 (Samba and Salsa) from Baikonur on a Soyuz rocket, July 16, 2000

Centre and Project managers, and an Implementation Working Group (IWG) for interfacing the various working teams from the Data Centres.

The CSDS has gone through the full process of requirements review, conceptual design review, architectural design review, detailed design review, and finally readiness review. It is now a tested operating system.

It is the purpose of this document to elaborate on the CSDS products, to describe the instruments only in sufficient detail to understand how those products are obtained, and what their limitations are. In contrast to the Data Products Report [Daly, 1994], which was essentially an internal discussion paper, this document is aimed at the external user with possibly little knowledge of the considerations that have led to the final design. It is not meant to provide extensive insight into the Cluster Mission or its experiments, for this is obtainable from other documents [e.g. Escoubet et al., 1997].

1.3 After the Cluster Disaster: Cluster-II

On June 4, 1996, Cluster was launched by the first flight of the Ariane-5 rocket, which exploded about 30 s after lift-off. All four Cluster spacecraft were destroyed.

Immediately afterwards, discussions were started on how the Cluster mission could be "recovered". A two-part plan evolved.

1. For each of the experiments there existed a flight spare. These could be assembled on a still-to-be built spacecraft in relatively short time. This fifth Cluster unit was to be named **Phoenix**.
2. Four Cluster spacecraft should be rebuilt exactly as before and relaunched within the next 3–4 years. By making an exact copy of the previous experiments and vehicles, much development and testing would be avoided.

Work on Phoenix began almost immediately, but with the decision to rebuild all four spacecraft at the end of 1996, the Cluster-II mission was born. Phoenix became incorporated in it as the first of the new quadruplets.

Much of this report was written before the fatal Ariane launch and therefore applies to the original Cluster concept. As for the hardware and software issues, it should be an exact copy of the Cluster-I

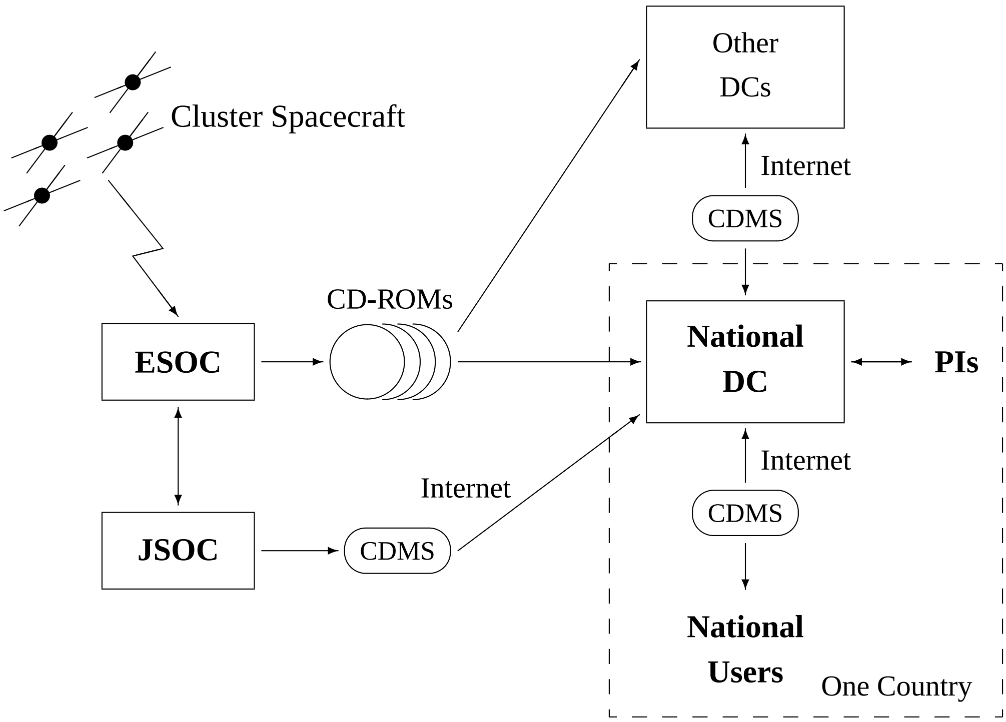

Figure 2: CSDS as a flow diagram showing the transfer of data from the spacecraft to the scientific users.

version. And as for the hardware and software issues, there are indeed many deviations. Thus this work has been revised for Cluster-II.

Nevertheless, we refer only to *Cluster* throughout, making a distinction between Cluster-I and Cluster-II only where there is one. It is the general feeling of the experimenters that there is only one Cluster mission for which we have invested so much of our life's work.

The four Cluster spacecraft were successfully brought into orbit on two Soyuz rockets launched July 16 and August 9, 2000 (Figure 1 on the facing page). They were immediately given the names *Rumba*, *Salsa*, *Samba*, *Tango* for publicity purposes, although most of the scientific community still lovingly refer to them as *One*, *Two*, *Three*, *Four*.

After an extensive commissioning phase for the total of 44 instruments, Cluster was declared functional and the Operating Phase began February 1, 2001.

1.4 Overview

The basic concept of CSDS is illustrated in Figure 2. The data are transmitted to ESOC (via telemetry links with ground-based receivers), where they are transferred onto a hard medium (CD-ROMs) for shipment to the PIs and national Data Centres. In fact, one set of CD-ROMs is sent to every institute with at least on Cluster Co-I.

The national DCs process the raw data from the CD-ROMs by means of software and calibration data provided by the PI, to produce physically meaningful parameters (fields, particle fluxes, temperatures, spectral densities, etc.) for those experiments for which the DC is responsible. The results are stored as Common Data Format (CDF) files. These data sets are then exchanged with the other national DCs so that each one has a full set, which is then made available to the scientific users in that country. In this way, the local users avoid more expensive international network traffic.

The interfacing between the users and the DC, as well as among the DCs themselves, is the CSDS Data Management System (CDMS), a software package that has been developed especially for this purpose. For the science users, this includes a WEB interface to search, browse, visualise, and download the data sets at the DCs. See Section 6 and Appendix B.

JSOC (Section 5) is a body established to coordinate the interactions of the PIs with ESOC. A number of its products (predicted orbit and event files, scientific events catalogue) are also made available to the local users via the national DC.

The DCs and JSOC enjoy the use of the dedicated network CSDSnet. The users must contend with the uncertainties of the public Internet.

1.5 The Cluster Experiments and Data Centres

The 11 Cluster experiments and their PIs are listed in Table 1 on the facing page. Their distribution among the national DCs is illustrated in Table 3.

For the latest information on any experiment, including any possible caveats not contained in this document, see the instrument Web pages given in Table 4.

The Chinese Data Centre CCDRC obtains the full data set by exchange of CD-ROMs with the Austrian ACDC on a monthly basis. The participation of the Chinese in CSDS is an encouragement for international cooperation in the field of space science.

1.6 The Data Sets

There are three data sets and a set of catalogues that have been agreed upon, for different amounts of detail and for distribution to different groups:

Prime Parameter Data Base or PPDB consisting of 65 parameters from all four spacecraft averaged over one spin ($\sim$ 4 seconds); these are to have access restricted to Cluster PIs and Co-Is.

Summary Parameter Data Base or SPDB consisting of 86 parameters but from only one spacecraft and averaged over one minute; auxiliary parameters such as position and spin orientation are also included; these data are available to the general ISTP community.

Summary Parameter Plots are plots of a subset of the Summary Parameters, one minute resolution, 6 hours per page, 4 pages for all the parameters; there are thus 16 pages per day; these plots are distributed electronically as PostScript files, having been produced by the German Data Centre.

Event Catalogues are generated by the Joint Science Operations Centre (JSOC) located at RAL, UK. They provide data concerning predicted and observed scientific events for the Cluster mission, which therefore give the scientists an indication of which time intervals to search with the other data bases. See Section 5.2 on page 69 for details.

1.7 Rules of Use

The CSDS parameters are subject to certain rules regarding their usage. It is not the intention of the Project nor of the PIs that the parameters should be freely available to the entire world, nor that they should be indiscriminately published without prior approval of the appropriate PI. The main reason for

Table 1: The Cluster Experiments

Acronym	Experiment	Principle Investigator	PI Country
ASPOC	Active Spacecraft Potential Control	W. Riedler (retired), K. Torkar	Austria
CIS	Cluster Ion Spectrometry	H. Rème	France
EDI	Electron Drift Instrument	G. Paschmann	Germany
FGM	Fluxgate Magnetometer	A. Balogh	U.K.
PEACE	Plasma Electron and Current Experiment	A. D. Johnstone (deceased), A. N. Fazakerley	U.K.
RAPID	Research with Adaptive Particle Imaging Detectors	B. Wilken (deceased), P. W. Daly	Germany
DWP*	Digital Wave Processing Experiment	L. J. C. Woolliscroft (deceased), H. Alleyne	U.K.
EFW*	Electric Field and Waves	G. Gustafsson (retired), Mats André	Sweden
STAFF*	Spatio-Temporal Analysis of Field Fluctuations	N. Cornilleau-Wehrlin	France
WBD*	Wide Band Data	D. A. Gurnett	U.S.A
WHISPER*	Waves of High Frequency and Sounder for Probing of the Electron Density by Relaxation	P. W. E. Décréau	France

*These experiments are collectively referred to as WEC, the Wave Experiment Consortium

Table 2: Email addresses of the Cluster PIs

Experiment	PI	Email
ASPOC	K. Torkar	Klaus.Torkar@oeaw.ac.at
CIS	K. Rème	Henri.Reme@cesr.fr
EDI	G. Paschmann	gep@mpe.mpg.de
FGM	A. Balogh	a.balogh@ic.ac.uk
PEACE	A. N. Fazakerley	anf@mssl.ucl.ac.uk
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Table 3: The Cluster Science Data Centres

DC Name	Location	Experiments
UKCDC	Rutherford Appleton Laboratory (RAL)	DWP, FGM, PEACE
CFC	Centre National d'Études Spatiales (CNES)	CIS, STAFF, WHISPER
GCDC	Max-Planck-Institut für extraterrestrische Physik (MPE)	EDI, RAPID
ACDC	Institut für Weltraumforschung (IWF)	ASPOC
SDC	Kungliga Tekniska Högskolan (KTH)	EFW
USCSDC	Goddard Space Flight Center (GSFC)	WBD
HDC	Central Research Institute for Physics (KFKI)	Auxiliary parameters
CCDRC	Center for Space Science and Applied Research (CSSAR)	

Table 4: Web Pages for the Cluster Experiments

Experiment	Web Page Address
ASPOC	`http://www.iwf.oeaw.ac.at/english/research/earthnearspace/cluster/aspoc_e.html`
CIS	`http://cis.cesr.fr:8000/CIS_sw_home-en.htm`
EDI	`http://www.mpe-garching.mpg.de/CLUSTER/EDI-Pages/edi_page.html`
FGM	`http://www.sp.ph.ic.ac.uk/Cluster/`
PEACE	`http://www.mssl.ucl.ac.uk/www_plasma/missions/cluster/`
RAPID	`http://www.linmpi.mpg.de/english/projekte/cluster/rapid.html`
DWP	
EFW	`http://cluster.irfu.se/`
STAFF	
WBD	`http://www-pw.physics.uiowa.edu/plasma-wave/istp/cluster/`
WHISPER	`http://lpce.cnrs-orleans.fr`
WEC	`http://www.plasma.kth.se/cluster/wec.html`
Cluster	`http://sci.esa.int/cluster/`
JSOC	`http://jsoc1.bnsc.rl.ac.uk/` (public)
	`http://jsoc1.bnsc.rl.ac.uk/JSOC.html` (restricted)
CSDS	`http://sci2.estec.esa.nl/cluster/csds/csds.html`

this is to guarantee that the PI should have the right of first publication, and that he or she should be able to control improper or incorrect interpretation of the data.

The following statement was agreed upon by the Cluster PIs on February 7, 1995.

1. Prime Parameter Data Base (PPDB): these data sets, generated by software implemented and maintained under PI supervision, validated by PIs, will be the principal means for establishing multi-instrument, coordinated data analysis for the Cluster investigator teams. The data consist of spin-averaged parameters from all instruments on all four Cluster spacecraft as defined, on inputs from the PIs, by the CSDS IWG (Implementation Working Group).

   These data will be accessible to all Cluster Co-Is from CSDS data centres. The access by Co-Is to the PPDB is through agreed procedures between PIs, Co-Is, and the Data Centres.

   The purpose of the PPDB is to establish and carry out coordinated data analysis within the direct Cluster community only. Neither raw data from the PPDB, nor any data derived from the PPDB can be published without the agreement of the PI responsible for the data. It is the responsibility of the PI of each team to ensure that all Co-Is are aware of their obligations under this agreement and that in the event of violation their privileges may be withdrawn.

2. Summary Parameter Data Base (SPDB): these data sets, generated by software implemented and maintained under PI supervision, validated by PIs, will be available to the Cluster investigator teams and to a much wider community, on a best efforts basis, for establishing scientific co-operation with other space missions and with ground based investigators. The data consist of one-minute averaged parameters from all instruments from one of the four Cluster spacecraft as defined, on inputs from the PIs, by the CSDS IWG.

   These data will be accessible and/or distributed from CSDS Data Centres. Access to these data is not restricted; implementation of access and distribution is a responsibility of the Data Centres.

   The purpose of the SPDB is to establish coordinated data analysis between Cluster teams and a wide and diverse scientific community. All recipients of the data and the summary plots will be informed that neither raw data from the SPDB, nor any data derived from the SPDB can be published without the agreement of the PI responsible for the data.

3. FGM Processing Support Data Set (FGM-PSDS): this data set, generated by software implemented and maintained under the supervision of the FGM PI and validated by the FGM PI, will be available in the Data Centres for supporting the generation of the PPDB/SPDB of those investigations which require FGM data for these purposes. These data consist of one-second averaged values of magnetic field vectors from all four spacecraft.

   The FGM-PSDS will not be used for purposes other than the generation of other instruments' PPDB/SPDB, except with the specific agreement of the FGM PI. Data Centres generating the FGM-PSDS will be required to ensure conformance with this agreement.

4. All Cluster data not covered by the categories above, and not held at the CSDS Data Centres will be accessible from the PIs of the different Cluster investigations, or from their designated Co-Is, through data access procedures which will be agreed between the PI and the recipient of the data (including other Cluster PIs and Co-Is) on a case-by-case basis. The recipient of the data will be responsible to ensure that the data use remains within the framework agreed by the PI providing the data.

2 The CSDS Parameters

The parameters that have been selected to be made available via CSDS are listed by experiment in Table 5, pages 11–14.

The contents of this Table have been extracted by computer from the CDF skeleton tables [Allen et al., 1999] that define those files. The following should be noted:

- The full name of any variable includes the spacecraft, data set type, and experiment specification. Thus the low energy electron flux in RAPID has as its full name `J_e_lo__C1_PP_RAP` for the PPDB from spacecraft 1.

  The `Epoch` and `Status` variables, which appear in every data set, are similarly distinguished, e.g., `Epoch__CL_SP_PEA`.

- Whether a parameter is in the PPDB and/or SPDB is indicated by the bullets and circles in the two right-most columns.

- The skeleton files are under document control, which means that no changes can be made without the usual change request and approval by all participants.

  It is for this reason that the Table has been generated by computer, to ensure that the contents of the skeleton files are accurately reflected. Even the descriptive text in the second column is extracted from the files. The current version of each skeleton file is indicated next to each experiment name to guarantee that the correct file has been read.

However, the information in Table 5 is insufficient to give the user, who is not directly involved with the experiments, the necessary background to the measurement. A more detailed description of each instrument and of the parameters delivered by CSDS is given in the rest of this section.

2.1 Status Bytes

One "parameter" common to all the experiments is the status word, allowing the instrument modes or other information to be flagged. This is a byte array, the size of which is variable between the experiments. However, the first byte `Status[0]` has been defined by CSDS to provide a quality flag for the data in the given record. All experiments define this quality flag in the same way, as shown in Table 6 on page 15.

The meanings of all the other bytes in `Status` are defined by each experiment individually.

2.2 Convention on the Definition of a Spin

The definition of the Prime Parameters as given in Sections 1.6 and 1.7 states that they are to be averages over one spin. The Data Products Report [Daly, 1994] defined the spin to be

> the time from one sun pulse, plus *offset*, to the next sun pulse, plus the same *offset*.

The IWG has subsequently investigated just how this *offset* is to be realised in as uniform a fashion as possible among all the experiments; the results are summarised in a technical note by Schwartz and Daly [1996].

The overriding criterion is that all instruments should take identical points in time as the spin boundaries. In other words, the spins are to be synchronous among all instruments to avoid time-aliasing during intercomparison. (It is recognised that this goal can only be achieved for each spacecraft separately, since the four spin rates will be independent of one another.) To this end, the Cluster experiments can be classified as follows:

Particle instruments have their data organised by spin, may have spin-averaged moments calculated onboard, or deliver only spin-summed counts; it is therefore impossible to rebuild the data on arbitrary spin boundaries on the ground; PEACE, CIS, and RAPID belong to this group.

Wave instruments are synchronised by their own internal clock, independently of the sun pulse "clock"; they therefore cannot be aligned temporally with the other experiments; the WEC instruments, particularly STAFF and WHISPER, perform in this manner.

Spin independent instruments acquire data at high temporal resolution, independently of the sun pulse, but such that averaging over any arbitrary spin boundaries can be carried out *a posteriori* on the ground; such experiments are FGM, EDI, and ASPOC.

It is the particle instruments that set the limitations on determining the *offset*, for they must adjust their spin boundaries onboard in order to be synchronised *a priori*. After considering the restrictions of each of these experiments, it was agreed to adopt the value

$$\begin{aligned} offset &= \frac{75}{1024} \times 360^\circ \\ &\approx 26.367^\circ \end{aligned} \tag{1}$$

Note that *offset* is expressed as an angle, since this corresponds to the intuitive feeling for its meaning. In reality, it must be converted to a time delay from the instant of the sun pulse according to the current spin rate. See the technical note [Schwartz and Daly, 1996] for more details on the determination of the precise spin boundaries.

Time Stamping

The time associated with each data record (one-spin averages) in the PPDB is the central time of that spin: i.e., the mid-time between two sun pulses plus *offset*. Precision is to the nearest millisecond.

Definition of a Minute

The SPDB are by definition averages over one minute. Again, a more precise formulation is required to determine exactly how this is to be realised. The conclusion of the IWG is [Daly, 1994; Schwartz and Daly, 1996]:

> The SPDB are to averages of all those measurements made during spins whose middle times lie within the minute boundaries.

The time stamp of each SPDB record is again to be the middle time of the average, i.e., it is always at 30 s after the start of a minute. Thus all SPDB time stamps are of the form *hh:mm:*30.000.

2.3 Convention on the Radius of the Earth

Although the spacecraft positions available from the auxiliary parameters will be given in kilometres (page 14), it is often convenient in magnetospheric studies to express distances in terms of the Earth's radius, R_E. For example, in the Summary Plots on pages 84–87, the radial distances of the spacecraft from the centre of the Earth are quoted in this unit. This is also the standard distance unit in many magnetic field models.

Since there is no universally accepted standard for this dimension, and since many investigators apply slightly differing values for it, it was decided by the CSDS IWG at its meeting in Paris, March 26–27, 1996, to recommend a common value for all CSDS, and hopefully all Cluster, applications. This value is to be

$$1\ \mathrm{R_E} = 6371.2\ \mathrm{km} \tag{2}$$

The justification for recommending this value over others is that it already finds wide usage in the IGRF, in the Tsyganenko models, and in the MAGLIB software library of CNES.

Table 5: The Data Base Parameters

The parameters are present or absent as ● or ○ are indicated in the last two columns.

ASPOC (V2.3)

Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	●	●
Status	ASPOC status		4	●	●
I_ion	Ion Current	μA	4	●	●

CIS (V2.3)

Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	●	●
Status	CIS status		4	●	●
N_p	Proton Density	cm^{-3}	4	●	●
N_O1	O^+ Density	cm^{-3}	4	●	●
N_He1	He^+ Density	cm^{-3}	4	●	●
N_He2	He^{++} Density	cm^{-3}	4	●	●
N_HIA	Hot Ion Density	cm^{-3}	4	●	●
V_p_xyz_gse	Proton Bulk Velocity	km/s	12	●	●
V_HIA_xyz_gse	Hot Ion Bulk Velocity	km/s	12	●	●
T_p_par	Proton Parallel Temperature	MK	4	●	○
T_p_perp	Proton Perp. Temperature	MK	4	●	○
T_HIA_par	Hot Ion Parallel Temperature	MK	4	●	○
T_HIA_perp	Hot Ion Perp. Temperature	MK	4	●	○
V_O1_xyz_gse	O^+ Bulk Velocity	km/s	12	○	●
T_p	Proton Temperature	MK	4	○	●
T_HIA	Hot Ion Temperature	MK	4	○	●

EDI (V2.3)

Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	●	●
Status	EDI status		7	●	●
V_ed_xyz_gse	EDI drift velocity	km/s	12	●	●
E_xyz_gse	EDI electric field	mV/m	12	●	○
Reduced_chi_sq	EDI Reduced Chi-squared		4	●	○

FGM (V2.3)

Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	●	●
Status	FGM status		4	●	●
B_xyz_gse	FGM DC magnetic field	nT	12	●	●
B_nsigma_t	Magnetic variance: summed		4	●	●
B_nsigma_b	Magnetic variance: magnitude		4	●	●

continued . . .

Table 5: The Data Base Parameters (*continued*)

PEACE (V2.3)					
Name	Description	Units	Bytes	PP	SP
`Epoch`	Time tags	ms	8	•	•
`Status`	PEACE status		4	•	•
`N_e_den`	Electron Density	cm^{-3}	4	•	•
`V_e_xyz_gse`	Electron velocity	km/s	12	•	•
`T_e_par`	Parallel electron temperature	MK	4	•	•
`T_e_perp`	Perp electron temperature	MK	4	•	•
`Q_e_par`	Parallel electron heat flux	μJ m^{-2} s^{-1}	4	•	•

RAPID (V2.3)					
Name	Description	Units	Bytes	PP	SP
`Epoch`	Time tags	ms	8	•	•
`Status`	RAPID status		4	•	•
`J_e_lo`	Electron Flux (E>50 keV)	1/(cm^2 s sr)	4	•	•
`J_e_hi`	Electron Flux (E>95 keV)	1/(cm^2 s sr)	4	•	•
`J_p_lo`	Proton Flux (E>27 keV)	1/(cm^2 s sr)	4	•	•
`J_p_hi`	Proton Flux (E>95 keV)	1/(cm^2 s sr)	4	•	•
`J_He_lo`	Helium Flux (E>27 keV)	1/(cm^2 s sr)	4	•	•
`J_He_hi`	Helium Flux (E>177 keV)	1/(cm^2 s sr)	4	•	•
`J_hvy_lo`	Ion Flux (m>4, E>90 keV)	1/(cm^2 s sr)	4	•	•
`J_hvy_hi`	Ion Flux (m>4, E>470 keV)	1/(cm^2 s sr)	4	•	•
`A_e_par`	Field-aligned Elec. Anisotropy		4	•	•
`A_p_par`	Field-aligned Prot. Anisotropy		4	•	•

DWP (V2.3)					
Name	Description	Units	Bytes	PP	SP
`Epoch`	Time tags	ms	8	•	•
`Status`	DWP status		5	•	•
`Status_Acf`	DWP status Acf		4	•	•
`Status_Heea`	DWP status Heea		4	•	•
`Status_B`	DWP status B		4	•	•
`State_wec`	WEC status		5	•	•
`Status_wbd`	WBD status		4	•	•
`Correl_signif`	Particle Correlator Significance	%	4	•	•
`Correl_P`	Particle Correlator Energy Band	eV	4	•	○
`Correl_freq`	Particle Correlator Frequency Band	kHz	4	•	○

continued . . .

Table 5: The Data Base Parameters (*continued*)

EFW (V2.3)					
Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	•	•
Status	EFW status		5	•	•
State_wec	WEC status		5	•	•
E_dusk	Duskward Electric Field	mV/m	4	•	•
E_pow_f1	E-field spectral density	V^2 m^{-2} Hz^{-1}	4	•	•
E_pow_f2*	E-field spectral density	V^2 m^{-2} Hz^{-1}	4	•	•
E_sigma	Electric Field Variation	mV/m	4	•	•
I_probe	Probe Current	μA	4	•	•
U_probe_sc	Probe potential	V	4	•	•

* Burst mode only

STAFF (V2.3)					
Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	•	•
Status	STAFF status		4	•	•
State_wec	WEC status		5	•	•
B_par_f1	Magnetic Field Par to Bo	nT^2 Hz^{-1}	4	•	◦
B_par_f2	Magnetic Field Par to Bo	nT^2 Hz^{-1}	4	•	◦
B_par_f3	Magnetic Field Par to Bo	nT^2 Hz^{-1}	4	•	◦
B_perp_f1	Magnetic Field Perp to Bo	nT^2 Hz^{-1}	4	•	◦
B_perp_f2	Magnetic Field Perp to Bo	nT^2 Hz^{-1}	4	•	◦
B_perp_f3	Magnetic Field Perp to Bo	nT^2 Hz^{-1}	4	•	◦
E_pow_f2†	E-field Spectral Density	V^2 m^{-2} Hz^{-1}	4	•	•
E_pow_f3	E-field Spectral Density	V^2 m^{-2} Hz^{-1}	4	•	•
B_pow_f1	B-field Spectral Density	nT^2 Hz^{-1}	4	◦	•
B_pow_f2	B-field Spectral Density	nT^2 Hz^{-1}	4	◦	•
B_pow_f3	B-field Spectral Density	nT^2 Hz^{-1}	4	◦	•

† Normal mode only

WHISPER (V2.3)					
Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	•	•
Status	WHISPER status		4	•	•
State_wec	WEC status		5	•	•
N_e_res	Electron density	cm^{-3}	4	•	•
N_e_res_qual	Quality of the resonance recognition		2	•	•
E_pow_f4	E-field Spectral Density	V^2 m^{-2} Hz^{-1}	4	•	◦
E_pow_f5	E-field spectral density	V^2 m^{-2} Hz^{-1}	4	•	◦
E_pow_f6	E-field spectral density	V^2 m^{-2} Hz^{-1}	4	•	◦
E_var_ts	Normalized E-field Variance		4	•	◦
E_pow_su	E-field Spectral Density	V^2 m^{-2} Hz^{-1}	4	◦	•

continued . . .

Table 5: The Data Base Parameters (*continued*)

AUXILIARY (V2.3)					
Name	Description	Units	Bytes	PP	SP
Epoch	Time tags	ms	8	○	●
sc_status	Spacecraft status		5	○	●
sc_orbit_num	Orbit number (with phase)		4	○	●
sc_r_xyz_gse	Position of reference sc	km	12	○	●
sc_v_xyz_gse	Velocity of reference sc	km/s	12	○	●
sc_dr1_xyz_gse	Position of sc 1 from ref sc	km	12	○	●
sc_dr2_xyz_gse	Position of sc 2 from ref sc	km	12	○	●
sc_dr3_xyz_gse	Position of sc 3 from ref sc	km	12	○	●
sc_dr4_xyz_gse	Position of sc 4 from ref sc	km	12	○	●
sc_at1_lat	gse Latitude of sc 1 axis	°	4	○	●
sc_at1_long	gse Longitude of sc 1 axis	°	4	○	●
sc_at2_lat	gse Latitude of sc 2 axis	°	4	○	●
sc_at2_long	gse Longitude of sc 2 axis	°	4	○	●
sc_at3_lat	gse Latitude of sc 3 axis	°	4	○	●
sc_at3_long	gse Longitude of sc 3 axis	°	4	○	●
sc_at4_lat	gse Latitude of sc 4 axis	°	4	○	●
sc_at4_long	gse Longitude of sc 4 axis	°	4	○	●
sc_config_QG	Tetrahedron Quality G		4	○	●
sc_config_QR	Tetrahedron Quality R		4	○	●
sc_dr_min	Minimum Distance Between Spacecraft	km	4	○	●
sc_dr_max	Maximum Distance Between Spacecraft	km	4	○	●
gse_gsm	Rotation angle GSE to GSM	°	4	○	●
dipole_tilt	Dipole Tilt in GSM z-x Plane	°	4	○	●
sc_geom_size	Tetrahedron size L	km	4	○	●
sc_geom_elong	Tetrahedron Elongation E		4	○	●
sc_geom_planarity	Tetrahedron Planarity P		4	○	●
sc_geom_E_dir_gse	Direction of Elongation		12	○	●
sc_geom_P_nor_gse	Normal of Planarity		12	○	●
	Total number of data bytes:			431	568

Table 6: CSDS-Reserved Meanings for `Status[0]`

Bits	Value	Interpretation
7–0	0	Bad data
	1	Use with caution
	2	OK
	255	No value (fill)

Table 7: The bit assignments for all status bytes

7	6	5	4	3	2	1	0

Most sig. Least sig.

3 The Cluster Instruments and their Parameters

(For latest information on the instruments, including additional caveats not described here, see the experiment home pages listed in Table 4 on page 6.)

3.1 ASPOC

The Instrument

The ASPOC ion emitter instrument (Active Spacecraft Potential Control) [Riedler et al., 1997; Torkar et al., 2001] controls the electric potential of the spacecraft with respect to the ambient plasma by emitting a variable current of positive ions. In steady state, a spacecraft will charge to an equilibrium potential where all currents, namely photo-electron current caused by sunlight, plasma currents due to the environmental electrons and ions, secondary electron currents caused by the impact of primary electrons and ions, and the ion current generated by ASPOC compensate so that there is no net transfer of charge between the spacecraft and the environment. Without active control, spacecraft potentials along the Cluster orbit would range from a few volts positive in the solar wind and magnetosheath up to about 100 V in the magnetospheric lobes. Near the Cluster perigee and in the near-Earth plasmasheet, small negative potentials are possible. High floating potentials obscure the measurement of the core of the ion-distribution function measured by CIS and contaminate the low-energy portion of the electron spectra measured by PEACE by photo-electrons from the satellite surface, trapped by the positive satellite potential. The primary objective of ASPOC is the reduction of high positive spacecraft potentials to a constant value which is sufficiently low (a few volts) to reduce the above mentioned disturbances significantly.

At the heart of ASPOC are emitters of the liquid metal ion emitter type with indium as charge material. The emission principle is field evaporation and ionisation of the liquid metal covering a needle by applied high voltage. The melting of the indium from the cold state lasts about 15 minutes in a mode called “startup”, after which high voltage is applied and successively increased until the field emission process ignites. The emission current is then electronically controlled, while the extraction voltage adjusts itself within 5–9.5 kV.

The emitters are arranged in two “modules” with four emitters each. The nominal maximum beam current is 50 μA, the nominal lifetime of a single emitter is 4000 hours. Emitters should be operated regularly, and therefore the emitter operation will be cycled at regular intervals of several hours. The emission current of an emitter may be increased to maximum current over a fraction of one minute as a precaution to remove any contamination from the emitter, thereby ensuring that the operating voltage remains within operational limits.

The instrument modes are defined by the method for the emission current control. There are two stand-alone modes involving the setting a current to a fixed value by time-tagged command.

- The default active mode second stand-alone mode fixes the total current of the high voltage unit, including losses inside the lens system (mode ITOT). Experience has shown that the resulting emission of an almost constant ion current fulfils all requirements for spacecraft potential control in the magnetosphere and the solar wind even without on-board feedback from measurements of the spacecraft potential.
- The second stand-alone mode active mode controls the ion emission current to a constant value (mode IION).

Table 8: Specifications for the instrument ASPOC

Mass	1930 g
Size	187 × 157 × 170 mm
Power	
Average	2.4 W
Peak	2.7 W
Telemetry rate	108 bit/s
Design lifetime	32 000 hours at 10 μA
Beam characteristics	
Species	In^+
Atomic mass	113, 115 amu
Energy	5 to 9.5 keV
Current	max. 50 μA, design: 10 μA
Opening angle	15° (half maximum)
Direction	along spin axis

- Two more elaborate operating modes, so-called feedback modes, involve the transmission of such measurements by EFW or PEACE via an inter-experiment link (modes FEFW and FPEA). As this feedback loop could not be tested on the ground, several contingency modes have been implemented in ASPOC to cope with a failure of one of the links. In this case ASPOC will generally return to a stand-alone mode or standby. The feasibility of the active spacecraft potential control loop will finally be determined during the in-orbit commissioning phase.
- In standby mode (STDB) both the emitters and their heaters are turned off.
- In order to reduce the time before emission starts, a “hot standby” mode (HOTS) keeps the indium in a liquid state. This mode can be used to interrupt the ion emission by command, without change of modes or emitters before and after the break. The re-ignition time is reduced to the time required to sweep the high voltage.
- A “test and commissioning” mode (T&C) describes a method to sweep the total ion current in steps lasting 8 or 16 s, and with 2 or 4 μA current increment. This mode will be used regularly within the calibration periods to establish the current-voltage characteristics of the spacecraft.
- Finally, the instrument features a technical mode (TECH) for low-level commanding.

The time resolution of the spacecraft potential data in the inter-experiment link is 4 s (EFW) or one spin period (PEACE). In feedback mode, the ion current is adjusted in the same intervals. In stand-alone mode the current remains constant, with corrections due to varying efficiency of the emitters taking place once per second.

The Parameters

ASPOC provides one parameter, namely the emitted ion current `I_ion`, for both the PPDB and SPDB (Table 5, page 11). The measured quantity is the net current flowing from the emitter into space. A current in the described direction is considered positive. The units are microamperes. The data are

Table 9: ASPOC `Status[1]`, Instrument Mode

Bits	Value	Interpretation
2–0	0	STDB, standby
	1	ITOT, constant total current
	2	IION, constant beam current
	3	FEFW, feedback from EFW
	4	HOTS, hot standby
	5	T&C, test and commissioning
	6	TECH, technical
	7	FPEA, feedback from PEACE
3	0	No startup
	1	Startup in progress
4	0	Backup mode inactive
	1	Backup mode active
7–0	255	Mode undefined

Table 10: ASPOC `Status[2]`, Emitter Selection

Bits	Value	Interpretation
1–0	0–3	Filament number
2	0	Module A
	1	Module B
7–0	255	Mode undefined

sampled every 40 ms. The raw data contain 0.5 s averages, from which the PPDB and SPDB data are obtained.

The ASPOC status word consists of 4 bytes, the first of which is the CSDS-defined data quality flag of Table 6 on page 15. The remaining three bytes are to be interpreted according to Tables 9–11.

Caveats

There are presently no known caveats. However please consult the ASPOC home page given in Table 4 on page 6 for the latest information.

Table 11: ASPOC `Status[3]`, Anomaly

Bits	Value	Interpretation
7–0	0	OK
0	1	No ignition
1	1	No beam current
2	1	EFW data not valid
3	1	PEACE data not valid
4	1	Calculated ion current not valid
5	1	Maximum feedback wait period exceeded

3.2 CIS

The Instrument

The Cluster Ion Spectrometry (CIS) experiment [Rème et al., 1997, 2001] is a comprehensive ionic plasma spectrometry package onboard the four Cluster spacecraft, capable of obtaining full three-dimensional ion distributions with good time resolution (one spacecraft spin) and with mass-per-charge composition determination. Since the scientific objectives cannot be met with a single detector, the CIS package therefore consists of two different instruments, a Hot Ion Analyser (HIA) and a time-of-flight ion Composition Distribution Function (CODIF), plus a sophisticated dual-processor based instrument control and data processing system (DPS), which permits extensive onboard data-processing. Both analysers use symmetric optics resulting in continuous, uniform, and well-characterised phase space coverage.

The CODIF instrument is a high-sensitivity mass-resolving spectrometer with an instantaneous $360° \times 8°$ field-of-view to measure full three-dimensional distribution functions of the major ion species (in as much as they contribute significantly to the total mass density of the plasma), within one spin period of the spacecraft. Typically these include H^+, He^+, He^{++} and O^+, with energies from $\sim$0–40 keV/e and with medium (22.5°) angular resolution. The CODIF instrument combines ion energy-per-charge selection, by deflection in a rotationally symmetric toroidal electrostatic analyser, with a subsequent time-of-flight analysis after post-acceleration to $\sim$15 keV/e. The energy-per-charge analyser is of a rotationally symmetric toroidal type, which is basically similar to the quadrispheric top-hat analysers and has a uniform response over 360° of polar angle. In the time-of-flight section the velocity of the incoming ions is measured. Microchannel plates (MCPs) are used to detect both the ions and the secondary electrons, which are emitted from the carbon foil during the passage of the ions and give the start signal, for the time-of-flight measurement, and the positional information (22.5° resolution).

In order to cover populations ranging from magnetosheath/magnetopause protons to tail lobe ions (consisting of protons and heavier ions), a dynamic range of more than 10^5 is required. CODIF therefore consists of two sections, each with 180° field of view, with geometry factors differing by a factor of $\sim$100. This way, one section will always have counting rates which are statistically meaningful and which at the same time can be handled by the time-of-flight electronics. However, intense ion fluxes can in some cases saturate the CODIF instrument (particularly if data are acquired from the high sensitivity side), but these fluxes are measured with HIA.

The sensor primarily covers the energy range between 0.015 and 40 keV/e. With an additional retarding potential analyser (RPA) device in the aperture system of the sensor, and with pre-acceleration for the energies below 25 eV/e, the range is extended to energies as low as the spacecraft potential. The retarding potential analyser operates only in the RPA mode.

The analyser has a characteristic energy response of about 7.3, and an intrinsic energy resolution of $\Delta E/E \approx 0.14$. The deflection voltage is varied in an exponential sweep. The full energy sweep with 31 contiguous energy channels is performed 32 times per spin. Thus a partial two-dimensional cut through the distribution function in polar angle is obtained every 1/32 of the spacecraft spin (125 ms). The full 4π ion distributions are obtained in one spacecraft spin period. Including the effects of grid transparencies and support posts in the collimator, each 22.5° sector has a respective geometry factor of 2.4×10^{-3} cm$^2 \cdot$ sr $\cdot$ keV $\cdot$ keV^{-1} in the high sensitivity side, and 2.6×10^{-5} cm$^2 \cdot$ sr $\cdot$ keV $\cdot$ keV^{-1} in the low sensitivity side, depending on the flight model.

The Hot Ion Analyser (HIA) instrument does not offer mass resolution but, also having two different sensitivities, increases the dynamic range, and has an angular resolution capability ($5.6° \times 5.6°$) adequate for ion-beam and solar-wind measurements. HIA combines the selection of incoming ions, according to the ion energy-per-charge ratio by deflection in an electrostatic analyser, with a fast imaging particle detection system. This particle imaging is based on MCP electron multipliers and position-encoding discrete anodes.

Basically the analyser design is a symmetrical quadrispherical electrostatic analyser which has a uniform 360° disc-shaped field-of-view and narrow angular resolution capability. The HIA instrument has two 180° field-of-view sections with two different sensitivities, with a 20–30 ratio (depending on the flight model but precisely known from calibrations), corresponding respectively to the “high G” and “low g” sections. The “low g” section allows detection of the solar wind and the required high angular resolution is achieved through the use of 8 sectors, 5.625° each, the remaining 8 sectors having 11.25° resolution. The 180° “high G” section is divided into 16 sectors, 11.25° each. For each sensitivity section a full 4π steradian scan, consisting of 32 energy sweeps, is completed every spin of the spacecraft, i.e., 4 s, giving a full three-dimensional distribution of ions in the energy range ∼5 eV/e–32 keV/e. The geometry factor is $\sim 8.0 \times 10^{-3}\ \mathrm{cm^2 \cdot sr \cdot keV \cdot keV^{-1}}$ for the “high G” half (over 180°), and $\sim 3.5 \times 10^{-4}\ \mathrm{cm^2 \cdot sr \cdot keV \cdot keV^{-1}}$ for the “low g” half, depending on the flight model.

The Parameters

The CIS telemetry comprises onboard calculated moments of the distribution functions, transmitted every spin, and detailed three-dimensional distribution functions, transmitted with a time resolution that is mode dependent. The CSDS CIS parameters are moments of the distribution functions, provided by CODIF (separately for each of the 4 major ion species) and HIA (without mass discrimination). These parameters include density, bulk velocity, parallel and perpendicular temperature, as listed in Table 5 on page 11.

To calculate moments onboard, integrals over the distribution function are approximated by summing products of measured count rates with appropriate energy/angle weighting over the sampled distribution. The moments are then log-compressed to 12 bits. Calibration factor corrections, conversion to physical units, and coordinate transformations are performed on the ground. The parallel and perpendicular temperatures are calculated on the ground from the onboard calculated pressure tensor, either by using the magnetic field direction derived from FGM PSDS data, or by diagonalising the pressure tensor (but with a degraded precision, depending on the anisotropy of the distribution function). The FGM PSDS data are average magnetic field values given at one-second intervals.

CODIF moments are calculated from the analyser half (“high G” or “low g”) that is selected by time-tagged commands, depending on anticipated count rates. Count rate summing is performed over 360° in azimuth (one full spin).

HIA moments are calculated from the analyser “high G” half during magnetospheric modes, and from the “low g” half during solar wind modes. Mode switching is performed by time-tagged commands, but automatic mode switching, based on the distribution of the detected ions, can also be commanded. During magnetospheric modes, count rate summing is performed over 360° in azimuth (one full spin). During solar wind modes, summing is performed over a sector of 45° in azimuth and 45° in elevation, centered on the main solar wind direction.

The mode information for every spin is given in the CIS status word. This is a string of four 1-byte unsigned integers:

`Status[0]` Data quality as defined by CSDS, Table 6 on page 15.

`Status[1]` Gives the CIS Operational Mode:

= 0	solar wind — mode 1
= 1	solar wind/upstreaming ions — mode 2
= 2	solar wind — mode 3
= 3	solar wind/upstreaming ions — mode 4
= 4	solar wind - data compression — mode 1
= 5	solar wind/upstreaming ions — data compression — mode 2
= 6	RPA mode
= 7	PROM operation
= 8	magnetosphere — mode 1
= 9	magnetosphere — mode 2
= 10	magnetosphere — mode 3
= 11	magnetosheath/magnetotail — mode 1
= 12	magnetosheath/magnetotail — mode 2
= 13	magnetosphere — data compression — mode 1
= 14	magnetosheath/magnetotail — data compression — mode 2
= 15	calibration/test mode

`Status[2]` Shows whether the telemetry products of the two CIS detectors, i.e. CODIF and HIA, used for the generation of the CSDS products, were the onboard calculated moments of the distribution function, or were the 3D distribution function, from which the moments were calculated on ground. The following table decodes the values of this byte:

Value (binary)	CODIF T/M	HIA T/M
00	3D distribution	3D distribution
01	3D distribution	onboard moments
10	onboard moments	3D distribution
11	onboard moments	onboard moments

`Status[3]` Shows whether the data coming from each of the two CIS detectors, CODIF and HIA, were collected from the detector-half with the large geometric factor or with the small geometric factor. The following table decodes the values of this byte:

Value (binary)	CODIF sensitivity	HIA sensitivity
00	low g	low g
01	low g	high G
10	high G	low g
11	high G	high G

Caveats

The user of the CIS CSDS parameters needs to be cautious. These parameters are only moments of the distribution functions, that result from summing counting rates. Thus they do not convey information on the detailed structure of the three-dimensional distributions.

Counting statistics are essential for obtaining reliable results. Preliminary information on inadequate counting rates, dead or saturated detectors, is given in the Caveats attribute. Besides instrument sensitivity and calibration, the accuracy of computed moments is mainly affected by the finite energy and angle resolution, and by the finite energy range of the instruments.

An inappropriate choice of an operational mode is not without consequences for the accuracy of the parameters. Solar wind modes in the magnetosphere exclude a large portion of the ion distribution. This is particularly important for HIA moments obtained in the magnetosheath while the instrument is in a solar wind mode. The moments then come from the 45° × 45° centered in the solar wind direction, resulting in largely under-sampled distributions.

CODIF energy sweeping during solar wind modes has a reduced energy range when the high sensitivity side faces the solar wind (45° in azimuth over 360°). This implies that if the data come from the high sensitivity side, the solar wind is then not detected.

Magnetospheric modes in the solar wind result in a probable detector saturation.

The He^{++} data can be contaminated by some H^{+} ions, resulting in over-estimated He^{++} densities.

The CIS calibration values are regularly updated to take into account the detector efficiency evolution. However, as the evaluation of the detector efficiency requires some "time history", necessary for a statistical analysis, there is a hysteresis between the detector efficiency drift and the calibration updates.

Furthermore, an inhomogeneous evolution of the detection efficiency between the different anode sectors can result in a bias in the calculated direction of the bulk plasma flow. This phenomenon has been observed on the CODIF data obtained onboard Spacecraft 3 (Samba), resulting in a degraded accuracy of the V_z component (corrected in September 2001 with onboard software patches).

The CIS instrument is not operational on Spacecraft 2 (Salsa).

Please consult the CIS home page given in Table 4 on page 6 for the latest caveat information.

3.3 EDI

The Instrument

The Electron Drift Instrument (EDI) is an active experiment intended to measure the electron drift velocity [Paschmann et al., 1997, 2001]. The measurements are based on sensing the displacement of a weak beam of electrons after one gyration in the ambient magnetic field. This displacement, referred to as the drift step, is directly proportional to the drift velocity. The drift velocity, in turn, is controlled by the ambient electric field and/or gradients in the magnetic field. By measuring the drift velocity at two different electron energies, one can derive, separately, the electric field and the magnetic field gradient.

To make the measurements, two electron beams are independently swept in the plane perpendicular to the magnetic field **B** while those firing directions and electron times of flight are recorded for which return beams are sensed by the detectors on the opposite side of the spacecraft. The drift step can then be determined from the two beam directions via triangulation, or from the difference in times of flight. The triangulation method is applicable for small drift steps, the time-of-flight technique for large drift steps.

Sweeping the beams in the plane perpendicular to **B** until hits are recorded by the associated detectors, implies that the hits are not usually equidistant in time. Thus the sampling rate of the measurements is not fixed. When measurements at two different electron energies are made, and significant magnetic field gradients are present, it takes at least twice as long to gather the relevant information. Furthermore, the strength of the return signal might not always be sufficient for detection, particularly at times when the ambient electron background is strong. When this happens, there will be gaps in the data. Gaps can also be expected at times when strong wave activity in the ambient medium disrupts the beams.

In NM telemetry, one set of firing directions and time of flights are transmitted every 64 ms. In BM1 telemetry, this interval is reduced to 16 ms. These times set the maximum time-resolution of the drift measurements. The time resolution is reduced if no valid measurement occurred in some of the intervals.

The Parameters

The EDI parameters are listed in Table 5 on page 11. Those parameters put into the PPDB are the 3 components of the electron drift velocity and the 3 components of the electric field (cartesian components, GSE coordinates, corrected for spacecraft motion). We also have added a `Reduced_chi_sq` variable which is a floating point scalar.

The exact nature and quality of the data is indicated in the 7 EDI status bytes.

`Status[0]` Data quality as defined by CSDS, Table 6 on page 15.

`Status[1]` Percentage of 1keV beams used in entire spin If 100, only 1keV beams available for analysis in this spin; If 0, then only 0.5keV beams available for analysis in this spin; Else, we're in energy switching mode, but only the 1.0keV beams are used for analysis.

Whenever measurements are made at a single electron energy only, the electric field for the PPDB is computed as if the drift velocity were entirely due to the electric field, even though it could be "contaminated" by magnetic gradient effects. When measurements are made at two electron energies (0.5 and 1.0 keV), the electric field and magnetic gradient are computed, but only the electric field is provided in the PPDB.

`Status[2]` Percentage of Class-A beams used in entire spin where "Class-A" identifies beams of the highest quality.

`Status[3]` Method Papertrail and Ambiguity Flag.

Bits 0-4 reflect the value of the ground software control parameter `pp_method` which determines the logic behind which analysis method (either triangulation or time-of-flight) is used. The three current methods are: triangulation (TRI), poorman's time-of-flight (PMT), and simultaneous time-of-flight (SMT). Various "logic chains" have also been defined in which the most suitable method is chosen depending on various parameters. **The default**: bit 3 is set, meaning `pp_method` = 4, TRI/PMT/SMT examined, Logic Chain 3.

If Bits 5-6 are not set, then method used in the end was Triangulation (TRI)
Bit 5: Set if method used in the end was Poorman's ToF (PMT)
Bit 6: Set if method used in the end was Simultan ToF (SMT)
Bit 7: Not set if there is no 180° ambiguity in drift step
Set if 180° ambiguity exists.

`Status[4]` Percentage of Triangulation outliers.

`Status[5]` Magnitude percentage error.

`Status[6]` Azimuthal error in degrees.

Caveats

From the above description, the following caveats can be identified:

- the measured electron drift velocity cannot always be separated into the electric-field and magnetic-gradient induced parts; in such cases the computed electric fields are subject to contamination by magnetic gradient effects;
- the data quality is variable, and it is therefore mandatory that the status bytes be consulted before interpreting the data;
- the number of samples in the averages is variable.

Please consult the EDI home page given in Table 4 on page 6 for the latest caveat information.

3.4 FGM

The Instrument

Each Cluster spacecraft carries an identical FGM instrument (Fluxgate Magnetometer) to measure the magnetic field [Balogh et al., 1997, 2001]. Each instrument, in turn, consists of two triaxial fluxgate magnetometers and an onboard data processing unit. The magnetometers are similar to many previous instruments flown in Earth-orbit and on other, planetary and interplanetary missions. In order to minimise the magnetic background of the spacecraft, one of the magnetometer sensors (the outboard, or OB sensor) is located at the end of one of the two 5.2 m radial booms of the spacecraft, the other (the inboard, or IB sensor) at 1.5 m inboard from the end of the boom. In flight, either sensor can be designed as the Primary Sensor, for acquiring the main data stream of the magnetic field vectors. In the default configuration, the OB sensor is used as the Primary Sensor. Every sensor has a spare analogue-to-digital converter (ADC) which normally will only be used in the event of failure of the normal ADC.

Five operating ranges are used on the Cluster magnetometers as listed in Table 12. Range switches can

Table 12: FGM Operating Ranges

Nr	Range (nT)	Digital Resolution (nT)
2	-64 to $+63.992$	7.813×10^{-3}
3	-256 to $+255.97$	3.125×10^{-1}
4	-1024 to $+1023.9$	0.125
5	-4096 to $+4095.5$	0.5
7	-65536 to $+65528$	8

occur at any time in a spin period. Range 7 will never be used in flight.

The three components of the magnetic field vector measured by the Primary Sensor are sampled at a constant rate of 201.75 Hz and subsequently digitally filtered to match the transmitted rate, according to the operating modes of the instrument and the telemetry rate allocated to it. The resulting vector rate comprises the FGM instrument mode in CSDS data (Table 13).

Table 13: FGM Vector Rates

Instrument mode	Primary Sensor vector rate (vectors/s)
A or 2	15.519
B or 3	18.341
C or 4	22.416
D	67.249

The Parameters

For CSDS, FGM provides a status word, the three averaged components of the magnetic field vector in the GSE coordinate system and 2 variances (Table 5, page 11). The averaging periods for FGM vectors always conform with CSDS conventions. This applies in particular for the timing of spin periods (see Section 2.2 on page 8). The variances are calculated for each averaging period.

In the status word each of the 4 bytes has a different meaning, the first of which is the CSDS-defined quality flag applied to the FGM data.

`Status[0]` Data quality as defined by CSDS, Table 6 on page 15. The value 1 for "use with caution" is used if either more than 60% of the expected data within the averaging interval were missing or the data had been calibrated using default values only.

`Status[1]` Can have values 0–15, indicating how many data were missing in the averaging interval. The value 0 is for "no data missing", 15 for "more than 90% missing". If all data were missing no record is generated.

`Status[2]` Can be used to determine whether the inboard sensor and/or spare ADC were used at the beginning of the averaging interval. Normally this byte is irrelevant for the CSDS user.

`Status[3]` Contains the range number of the sensor (2–5) at the beginning of the averaging interval. Again this normally will be ignored by the user.

The normalised variance (equivalent to the sum over the component variances) of the total magnetic field σ_t is computed according to

$$\sigma_t = \frac{\langle\, |\,\mathbf{B}\,|^2\,\rangle - |\,\langle\,\mathbf{B}\,\rangle\,|^2}{\langle\, |\,\mathbf{B}\,|^2\,\rangle} \tag{3}$$

and the normalised variance of the magnetic field magnitude σ_b according to

$$\sigma_b = \frac{\langle\, |\,\mathbf{B}\,|^2\,\rangle - \langle\, |\,\mathbf{B}\,|\,\rangle^2}{\langle\, |\,\mathbf{B}\,|^2\,\rangle} \tag{4}$$

where $\langle\ \rangle$ denotes average over time and **B** the magnetic field vector in GSE coordinates. The values of both variances are between 0 and 1, and will be close to zero for small variations over the averaged interval. Note that σ_b is sensitive only to compressional variations.

Caveats

There are presently no known caveats. However please consult the FGM home page given in Table 4 on page 6 for the latest information.

3.5 PEACE

The Instrument

The four PEACE (Plasma Electron and Current Experiment) electron analysers [Johnstone et al., 1997] measure the electron velocity distribution function at the satellite in three dimensions with good time, energy, and angular resolution. Each instrument consists of two sensors mounted on opposite sides of the spacecraft. Each sensor is built to the "top hat" design: with hemispherical electrostatic energy analysers and a semi-annular microchannel plate (MCP) with a position-sensitive readout as the detector. The sensors are mounted unconventionally, with the plane of the field of view containing the spin axis direction but lying perpendicular to the spacecraft body, rather than tangentially. Each sensor separately provides complete 4π solid angle coverage in one spin. The only difference between the sensors is the geometric factor. LEEA is better suited to studying the high fluxes usually found at lower energies, and vice versa. The instrument dynamic range is therefore extended beyond that which a single sensor could provide. In most other respects the sensors are essentially identical and they can be used interchangeably. The Particle Correlator experiment, part of DWP, takes measured counts directly from HEEA.

The instruments have been designed with special care in two areas: they are intended to make high quality measurements of the low energy electron distribution (below 10 eV) and the eight sensors (on the four spacecraft) are to have the best possible relative accuracy.

Good, low energy measurements are facilitated by a design which minimises the amount of direct UV, internally generated photoelectrons and secondary electrons which can reach the MCPs, and by the radial mounting of the sensors on the spacecraft. A sunlit spacecraft immersed in a plasma will usually become electrically charged and will become surrounded by a cloud of low energy photo- electrons originating from the spacecraft surface. Due to acceleration in the electric potential of the charged spacecraft, the measured arrival directions and energies of low energy electrons from the plasma will differ from their natural values (i.e. the values we seek to measure). Also, the sensors will detect both the natural plasma electrons and the photo-electrons originating from the spacecraft. The active spacecraft potential control, provided by ASPOC is intended to hold the spacecraft potential to a small and steady level, which will minimise the distortion of the velocity distribution function of the natural electron population and which will make it easier to characterise the spacecraft photo-electron population so that it can be separated from the plasma electrons during data analysis. The radial field of view (as opposed to tangential) also minimises the time an arriving electron spends in the vicinity of the spacecraft surface where the electric field associated with the charging is strongest.

Careful design and manufacturing work have sought to produce sensors that are identical to within the tolerances set as a design goal, such that relative accuracies of better than 1% are expected in good conditions (e.g., suitable electron flux levels, etc.) that should allow reliable data analysis, combining and comparing data from all four satellites.

The full instrument energy range is divided into 88 different energy levels. Data is accumulated by counting the number of arriving electrons in each anode for intervals of 1/1024th of a spin, known as accumulation bins. Depending on user choice, the energy level is changed either by one step (from level n to level n-1) or two steps (level n to level n-2) during an accumulation bin. The set of consecutive measurements at ever-reducing energies is called a sweep. The lowest 16 steps are approximately linearly spaced and cover the region below 10 eV; the remaining steps are between logarithmically spaced levels (each differs from the next by a factor 1.17) up to the highest energy level at approximately 26.5 keV. A single sensor cannot sample the full energy range. It may sample a range of only 60 levels (or, in another mode, 30 levels). The two sensors together can cover the full energy range in one spin and where their energy ranges overlap there is full 4π solid angle every half spin.

The position sensitive readout in each sensor is divided into 12 equal parts, each seeing a 15° sector in the plane containing the spin axis and the sensors. The satellite spins while the sweep occurs, steadily rotating the field of view around the spin axis. The angle of rotation during a sweep and hence the angular resolution in the spin plane, depends on the sweep duration which may take one of three values. The three sweep modes are called LAR, MAR and HAR.

Standard Operational Mode

In the default standard operational mode, the sweep mode is MAR mode for both sensors. LEEA covers the energy range below about 1.2 keV and HEEA covers the range 34 eV–26.5 keV. The full 4π angular coverage is composed of a grid of 12 polar bins by 32 azimuthal bins; each bin is 15° in polar by 11.25° in azimuth. The data are acquired simultaneously in all 12 polar bins while the azimuthal data are gathered sequentially as the satellite spins. The sweep covers 60 levels in a series of 30 steps, two in each accumulation bin, so that a set of 30 energy bins are generated. Thus the measured data consist of a matrix of (30 energies $\times$ 12 polars $\times$ 32 azimuths, for each sensor).

The default standard operational mode data products transmitted to ground are LEEA and HEEA moment sums (calculated on board), LEEA and HEEA pitch angle distributions and a LEEA three dimensional distribution with heavily reduced angular resolution covering only the energy range below 10 eV (called LER: 8 energies $\times$ 3 polars $\times$ 8 azimuths, for one sensor). When burst mode telemetry is available, a reduced energy and angular resolution three- dimensional distribution (called 3DR-D: 15 energies $\times$ 6 polars $\times$ 16 azimuths, for each sensor) is transmitted. All the above are transmitted once per spin. In addition, in burst mode, a LEEA 3D distribution of full energy and angle resolution, from the energy range below 10 eV, is transmitted at the rate of once per spin. The default mode is intended for use when the spacecraft potential is held well below 10 eV, which is not always true.

Note that PEACE is not operated exclusively in this way during the mission. The energy range coverage of the sensors may be varied; for example they may both be set to cover exactly the same range, so as to provide half spin all-sky coverage over the greatest possible energy range. Quite often the LEEA energy range is selected so that the lowest measured energy is above or near the anticipated spacecraft potential, to avoid unnecessary counting high fluxes of spacecraft electrons (which accelerates detector aging). The sweep rate may be varied. Sweeps lasting half the usual time give doubled azimuthal resolution, but the energy range is halved (this is the HAR mode). Sweeps lasting twice the usual time give one step per accumulation bin, i.e. doubled energy resolution, but halved azimuthal resolution (this is the LAR mode). The sweeps may be stopped to allow measurements at a fixed energy, though this option is not available at energies above 1.8 keVand will rarely be used. In burst mode there are a variety of alternative ways of selecting a subset of the full resolution 3D distribution data for transmission to the ground. The distributions are all partial forms of the measured (30 energies $\times$ 12 polars $\times$ 32 azimuths) distribution, having limited angular or energy coverage, and in some cases halved polar resolution.

The Parameters

The CSDS PEACE parameters (Table 5, page 12) are all derived from a subset of the moment sums calculated onboard. The onboard procedure starts with the full measured resolution data from each sensor, produces the reduced resolution 3DR-D distributions discussed above, removes sub-10 eV data, and calculates the moment sums. The software design assumes that the spacecraft potential is held below 10 Volts (e.g. by ASPOC) and that all spacecraft photoelectrons are confined below 10 eV, so that the counted electrons included in the moments calculation are all from the natural plasma. The LER distribution provides us with an insight into the sub-10 eV population. If the spacecraft potential

Table 14: PEACE CSDS Products

Moment Sums	See Table 5, page 12
Sensors Used	LEEA (Bottom, 10–34 eV; Overlap, 34–1.2 keV)
	HEEA (Overlap, 34–1.2 keV; Top, 1.2–26.5 keV)
Energy Range	10 eV to 26.5 keV in standard mode (MAR)
Phase Space Coverage	
Top Region	7 energy × 6 polar × 16 azimuthal × 1 sensor 3-D dist.
Overlap Region	8 energy × 6 polar × 16 azimuthal × 2 sensor 3-D dist.
Bottom Region	3 energy × 6 polar × 16 azimuthal × 1 sensor 3-D dist.
(Discarded; $<$ 10 eV)	4 energy × 6 polar × 16 azimuthal × 1 sensor 3-D dist.
Time resolution	one per spin outside overlap region, one per half spin in overlap region

does indeed lie below 10 Volts, there will often be a characteristic feature in the measured LER energy spectra, from which the potential may be estimated (EFW provides an alternative indication of spacecraft potential). Assuming that the instrument is in the default standard operational mode, the moment sums are calculated at spin resolution for the "Bottom Region" energy range 10 to 34 eV, and the "Top Region" 1.2 to 26.5 keV, and they are calculated at half spin resolution in the intervening energy range ("Overlap region") where the energy coverage of the two sensors coincides. The spin resolution CSDS prime parameters are produced by combining some or all of the data from the Top, Bottom and Overlap regions. Sums from LEEA or else HEEA could be used in the overlap region. Different choices can be made if desired whenever the CSDS data are reprocessed. The PEACE CSDS software uses the FGM PSDS as the basis for the generation of perpendicular and parallel temperature and parallel heat flux. However, the possibility to estimate the magnetic field direction by diagonalising the pressure tensor also exists, should there be an absence of FGM data.

Table 14 summarises the PEACE CSDS data products.

Caveats

At the time of writing (March 2002) the moments data provided to CSDS are being derived only from HEEA. Thus the minimum measured electron energy is typically about 34 eV as opposed to 10 eV if LEEA is included. This approach is an initial response to the frequently occurring situation that the spacecraft potential does rise above 10 volts. The spacecraft potential is at times above 34 volts, in which case the moments calculations will be include measurements of both plasma and spacecraft electrons and will not accurately describe the plasma population. These cases can usually be recognised as they have particularly high density. The spacecraft potential, when uncontrolled by ASPOC, can often reach such values, particularly in thinner plasmas (e.g., magnetotail lobes, polar cap, etc.) The CSDS Quicklook plots show spacecraft potential from EFW which will further inform the interested reader about which regions characteristically have high spacecraft potential. ASPOC operations do not occur on Spacecraft 1 at all. On about 50% of the orbits there are no ASPOC operations on the other spacecraft, and operations are typically for less than 10 hours at a time when ASPOC is in use.

The PEACE Team are reconsidering their approach to provision of and validation of electron moments data to the CSDS, in the light of the problems with spacecraft potential. The PEACE team will report on the outcome in a future update of this document. Please consult the PEACE home page given in Table 4 on page 6 for further relevant information.

3.6 RAPID

The Instrument

The RAPID spectrometer (Research with Adaptive Particle Imaging Detectors) [Wilken et al., 1997, 2001], is an advanced particle detector for the analysis of suprathermal plasma distributions in the energy range from 20–400 keV for electrons, 40 keV–1500 keV for hydrogen, and 10 keV/nucleon–1500 keV for heavier ions. Novel detector concepts in combination with pin-hole acceptance allow the measurement of angular distributions over a range of 180° in polar angle for electrons and ions. Identification of the ion species is based on a two-dimensional analysis of the particle's velocity and energy. Electrons are identified by the well-known energy-range relationship.

Ions and electrons are detected by two independent sub-instruments, the IIMS (Imaging Ion Mass Spectrometer) for ions and the IES (Imaging Electron Spectrometer) for electrons.

Particles entering the IIMS telescope pass through an entry foil, releasing secondary electrons that are accelerated and detected by a microchannel plate detector. This constitutes the start signal for the time-of-flight analysis. The particle proceeds to a solid-state detector, which emits a signal proportional to the particle's loss of energy within it. Secondary electrons ejected from the surface of the solid-state detector are detected by further microchannel plates, establishing the stop signal. If the particle's energy is sufficiently high, it will pass through the solid-state detector, activating a second back detector. This coincidence signal eliminates the event from further analysis, since the total energy of the particle is thus unknown. The combination of flight time and energy permits the event to be sorted by mass (species) and energy.

The flight path is 34 mm long, the solid-state detector has an area of 75 mm^2 and thickness 300 μm. One such IIMS unit covers a range of 60° in the plane containing the spacecraft spin axis; three such units cover the full 180°. Over one spacecraft rotation the entire unit sphere is scanned.

The ion spectral counts are sorted into 8 energy bins, 12 polar angle segments, 16 azimuthal sectors, and 3 mass ranges. Higher energy and mass precision is obtained with so-called "direct events". However, for the CSDS data sets, only omni-directional fluxes in two energy and three mass ranges are delivered.

The IES system is similarly arranged in three units, each covering 60° in the plane of the spacecraft axis, each subdivided into 20° "pixels". There are thus 9 microstrip solid-state detectors, one for each polar segment. The charge placed on each detector by an incident particle is stored on a capacitor, and is strobed out after a certain integration time (2–50 μs) for further evaluation. The read-out time is 47 μs. The integration time is selected so that the detectors likely have at most one count.

Internally, the electron energy is sorted into 256 bins from which the output energy channels are selected. These are set relative to the location of zero energy (the so-called "pedestal") so that the output channels should all be much the same although the pedestal varies with each strip.

A further complication is the presence of residual charges on the capacitors that lead to a large spike at the pedestal position, the width of which also varies for each strip. In order to monitor the position and width of the pedestal for possible temperature and count-rate dependencies, 2 channels in normal mode and 4 in burst mode are set around the pedestal. This leaves 6 "science" energy channels in normal and 8 in burst mode.

The electron spectral counts are also sorted into 16 azimuthal sectors, but only 9 polar segments. Again, for the CSDS data sets, only omni-directional fluxes in two energy ranges are delivered.

Table 15: Specifications for the RAPID spectrometer

Energy ranges:	Hydrogen	28–1500 keV
	Helium	29–1500
	CNO	92–1500
	Electrons	26–400
Mass range:		1, 4, 12–16, 28–56 amu
Resolution (A/dA):	Oxygen	4
Field-of-view:	IIMS (Ions)	$\pm 3° \times 180°$
	IES (Electrons)	$\pm 17.5° \times 180°$
Geometry factor:	IIMS	2.6×10^{-2} cm$^2 \cdot$ sr
(for 180°)	IES	2.0×10^{-2}

The Parameters

For CSDS, RAPID provides the same set of parameters in both the PPDB and SPDB: omni-directional particle fluxes in two energy ranges for 4 species, plus field-aligned anisotropies for protons and electrons (Table 5, page 12).

The fluxes are integrals of the differential flux $j(E)$ from a lower energy threshold to the maximum upper limit. They should therefore be viewed as a representation of

$$J(E) = \int_E^\infty j(E')\, dE' \tag{5}$$

The units are particles/(cm$^2 \cdot$ sr $\cdot$ s). Giving two integrated fluxes with overlapping rather than adjoining ranges permits an easier comparison of the two when plotted, for the "higher" range will always have a lower value. By contrast, the relative magnitudes of two integrals with adjoining ranges depends both on the energy range widths and on the physically interesting spectral steepness.

The lower energy limits for the RAPID PPDB fluxes cannot be set at any arbitrary value: they must coincide with one of the 8 energy thresholds. For the "lower range" ion fluxes `J_p_lo`, `J_He_lo`, and `J_hvy_lo`, these are the sums of all 8 energy channels, while for the electron flux `J_e_lo` the first channel has been excluded since it can be contaminated by "pedestal" noise. The "higher range" ion fluxes `J_p_hi`, `J_He_hi`, and `J_hvy_hi` are the sums of channels 3–8, while the electrons `J_e_hi` are summed over channels 4–8. See Table 16 for the exact values of the low energy thresholds.

Table 16: Lower limits of the RAPID flux ranges in terms of the external particle energy.

Range	J_p_x	J_He_x	J_hvy_x	J_e_x
`lo`	27 keV	27 keV	90 keV	50
`hi`	95 keV	177 keV	470 keV	95

The field-aligned anisotropies `A_e_par` and `A_p_par` are the normalised differences of the fluxes parallel and anti-parallel to the magnetic field.

$$\varepsilon = \frac{J_\parallel - J_{\text{anti-}\parallel}}{J_\parallel + J_{\text{anti-}\parallel}} \tag{6}$$

RAPID has an inter-experiment link to the FGM experiment on board, allowing it to determine which polar segment and azimuthal sector is closest to the magnetic field. The fluxes in these directions (summed over energy channels 1–4) are used in the above formula. This is an extremely rough estimate; a proper analysis must take into account the entire distribution of flux over the unit sphere, and not just measurements in two directions. It is therefore recommended that only anisotropy values near ± 1.0 and 0.0 should be used to infer the presence and direction of any field-aligned streaming.

The RAPID status word contains four bytes, the first of which is the CSDS-defined quality flag applied to the RAPID data. The remaining bytes yield information on the internal RAPID modes which are primarily of interest only to the RAPID team members. These modes are specified by 5 integers in the form $AB.LMN$, where AB describes the ion (IIMS) part and LMN the electron (IES) instrument.

`Status[0]` Data quality as defined by CSDS, Table 6 on page 15.

`Status[1]` The IIMS mode in the form of $10A + B$;

$A = 0$	instrument off
$= 1$	serial mode; only one sensor on at a time
$= 2$	parallel mode; all 3 sensors on at once
$= 4$	in-flight calibration
$B = 0$	high voltage off
$= 1$	HV on, but set to 0 V
$= 4$	normal operating level
$= 5$	like 4, but with deflection voltage on (neutral particle mode, not for CSDS)

`Status[2]` The IES mode in the form of $100L + 10M + N$;

$L = 0$	normal accumulation mode
$= 1$	in-flight calibration
$M = 0$	instrument off
$= 1$	8 (NM) or 12 (BM) energy channels
$= 2$	not used for Cluster-II
$= 3$	histogram mode, all 256 energy channels
$N = 0$	instrument off
$= 1$–4	specifies integration time (2, 5, 15, 50 μs)

`Status[3]` bits 7–4 (high nibble) indicate 16 steps for the ion deflection voltage with 0 being no deflection. If the deflection is on, RAPID is in its neutral particle mode, and returns only fill values for the CSDS ion parameters;

bits 3–0 (low nibble) = 0 (normal telemetry mode), else 1–3 for burst modes 1–3.

Caveats

The calibration data applied are the most reasonable for a quick and standardised calculation of the particle fluxes. They do not attempt to include cross-calibrations among the spacecraft, since these are extremely complicated, requiring case-by-case analysis. Thus the same geometry factors are applied to all 4 RAPID units. However, the energy thresholds are slightly different, but a spectral analysis correction brings them all to a uniform set of values. Since this correction is applied automatically, it is prone to error.

The restrictions on the interpretation of the anisotropy values have already been mentioned. Furthermore, due to a programming error in the RAPID on-board computer, the magnetic field was incorrectly processed during the first months of operations. This problem was corrected on April 26, 2001 on spacecraft 3, and on May 18, 2001 on the other spacecraft. Up until these times, the anisotropies contain only fill values.

It must be pointed out that the helium and heavy ion fluxes are measured and read out every 4 spins, and not every spin as for protons and electrons. This is consistent with their expected lower count rates. However, since the PPDB deliver data for every spin, it has been decided to fill in the intervening spins with repeated helium and heavy ion data. This accurately reflects the true situation, since the delivered fluxes are indeed averages over these four spins.

Due to another programming bug, the helium and heavy ion fluxes were in fact only measured every 8 spins: every second set of 4-spin data simply repeated the previous measurement. This too was corrected at the same time as the anisotropy bug mentioned above.

During operations it has been discovered that the RAPID DPU can be spontaneously reset, for reasons which are still unclear. This in itself is not harmful, however it does mean that the high voltage supply is turned off (resulting in a loss of ion data) and that the program patches of April 26 and May 18, 2001, are no longer activated. After this was discovered (February 2001) a procedure was built into the standard commanding sequences to regularly correct both these problems. A caveat is written into the CDF files to indicate when this happens.

A more serious problem is the corruption of the new patches when RAPID is temporarily turned off. This corruption becomes noticeable on the next turn-on and results in the immediate deactivation of the patches. The high voltage supply remains on, so ion data are accumulated, however the problems with the anisotropy and helium/heavy ion sampling return. Furthermore, the electron energy thresholds revert to default values that are totally unrealistic, resulting in loss of these data. This situation remains in effect until the patches are manually reloaded by Operations, which can be several days later. Caveats are written to the CDF files to indicate this.

The central ion detector head has been badly hit by sunlight. For details on this and any other caveat information, please consult the RAPID home page given in Table 4 on page 6.

3.7 WEC

The Consortium

The Wave Experiment Consortium (WEC) comprises all of the Cluster wave experiments (DWP, EFW, STAFF, WHISPER and WBD). It was created to coordinate the usage of the wave experiments and so maximise the scientific return. WEC also provides a single interface for the operation of the instruments.

Parameters

General operational details

Within each CDF file containing data from a WEC instrument there is a variable called `State_wec` that contains some brief information regarding the operational mode of the instruments. More detailed information resides in the instrument CDF file. `State_wec` consists of 5 bytes numbered 0–4 that contain data about EFW, STAFF, WHISPER, DWP and WBD respectively. Information is stored in a bit-wise fashion. Tables 17–21 contain information about the contents and interpretation of these words. NOTE: The use of `State_wec[0]` is NOT reserved by CSDS.

Soundings and Sweeps

Within WEC there are two experiments, namely EFW and WHISPER, that may be used in active modes which will disturb the plasma in the vicinity of the spacecraft. The WHISPER transmitter is active for only part of the WEC duty cycle. Depending upon the operational mode this is typically 3/28 or 4/104 seconds (assuming an E-field mode). For the rest of the period, WHISPER is passive. EFW will usually perform one or two sweeps per day although on certain occasions there may be more. These sweeps last around 1.5 seconds.

Information about the use of these modes are coded into the `Status[2]` data word written into the EFW CDF files. The contents and basic interpretation of this word may be found in Table 30 on page 49.

In summary, for a particular sampling interval represented by the CSDS time tag

- WHISPER was actively sounding the plasma during the interval if bit 2 is set to 1, i.e.:

```
if ( ( Status[2] & 4 ) == 0 ) then WHISPER not sounding
if ( ( Status[2] & 4 ) != 0 ) then WHISPER sounding
```

- EFW was carrying out a voltage/current sweep during the interval if bit 1 is set to 1 OR bit 7 is set to 1, i.e.:

```
if (
     ( ( Status[2] & 2 ) != 0 )      /* sweep in progress */
     OR
     ( ( Status[2] & 128 ) != 0 )    /* sweep playback */
   ) then EFW was sweeping
 else
   EFW was not sweeping
```

Table 17: State_wec[0] for EFW

Bits	Value	Interpretation
7	0	EFW working
	1	EFW not working
6	0	Unit 1 in E-field mode
	1	Unit 1 in density mode
5	0	Unit 2 in E-field mode
	1	Unit 2 in density mode
4	0	Unit 3 in E-field mode
	1	Unit 3 in density mode
3	0	Unit 4 in E-field mode
	1	Unit 4 in density mode
2	0	EFW not in interferometric mode
	1	EFW in interferometric mode
1–0	0	EFW in normal sampling mode
	1	EFW in split sampling mode
	2	EFW in HX sampling mode
	3	*Null*

Table 18: `State_wec[1]` for STAFF

Bits	Value	Interpretation
7	0	STAFF SA working
	1	STAFF SA not working
6	0	STAFF MWF working
	1	STAFF MWF not working
5	0	STAFF not in calibration mode
	1	STAFF in calibration mode
4–1	0	STAFF SA in Normal 1 mode
	1	SA in Normal 2e mode
	2	SA in Normal 2b mode
	3	*Illegal*
	4	SA in Emergency mode
	5	SA in Special mode
	6	SA in Normal 1'e mode
	7	SA in Normal 1'b mode
	8	SA in Fast mode 1
	9	SA in Fast mode 3e
	10	SA in Fast mode 3b
	11	*Illegal*
	12	SA in Fast mode 2
	13	Standby
	14	*Illegal*
	15	*Illegal*
0	0	MWF bandwidth 10 Hz
	1	MWF bandwidth 180 Hz

Table 19: State_wec[2] for WHISPER

Bits	Value	Interpretation
7–5	0	Not working
	1	Calibration mode (quiet)
	2	Calibration mode (sounding)
	3	Natural waves
	4	Sounding — normal
	5	Sounding — gliding
	6	Sounding — synchronous
	7	Spare
4(S)	0	Receiving antenna Ez
	1	Receiving antenna Ey
3–2(S)	0	No emission
	1	Pulse level 50 V peak-to-peak
	2	” ” 100 V peak-to-peak
	3	” ” 200 V peak-to-peak
1–0(S)	0	Pulse recurrence 13 ms
	1	” ” 26 ms
	2	” ” 40 ms
	3	other
4–3(N)	0	64 FFT bins used
	1	128 ” ” ”
	2	256 ” ” ”
	3	512 ” ” ”
2–0(N)	0	32 spectra averages
	1	16 ” ”
	2	16 ” ”
	3	8 ” ”
	4	4 ” ”
	5	2 ” ”
	6	64 ” ”
	7	1 ” ”

Table 20: `State_wec[3]` for DWP

Bits	Value	Interpretation
7	0	Correlator working
	1	Correlator disabled
6–3	0–15	Energy level
2	0	Sample clock 25 Hz
	1	Sample clock 450 Hz
1–0	0	Normal mode
	1	Burst mode 1
	2	Burst mode 2
	3	Burst mode 3

Table 21: `State_wec[4]` for WBD

Bits	Value	Interpretation
7	0	WBD working
	1	WBD not working
6–5	0	0 kHz
	1	125 kHz
	2	250 kHz
	3	500 kHz
4–2	0	9.5 kHz 8 bit
	1	9.5 kHz 8 bit
	2	19 kHz 4 bit
	3	19 kHz 8 bit
	4	77 kHz 8 bit
	5	77 kHz 1 bit
	6	77 kHz 4 bit
	7	77 kHz 8 bit

3.8 DWP

The Instrument

The Digital Wave Processing Experiment, DWP, [Woolliscroft et al., 1997] is a component of the Wave Experiment Consortium (WEC). The wide variety of geophysical plasmas that will be investigated by the Cluster mission contain waves with a frequency range from DC to over 100 kHz with both magnetic and electric components. The characteristic duration of these waves extends from a few milliseconds to minutes and a dynamic range of over 90 dB is desired. All of these factors make it essential that the onboard control system for the WEC instruments be flexible so as to make effective use of the limited spacecraft resources of power and telemetry. The DWP instrument employs a novel architecture based on the use of transputers with parallel processing and re-allocatable tasks to provide a high-reliability flexible system.

DWP is responsible for coordinating WEC operations at several levels. At the lowest level, DWP provides electrical signals to synchronise instrument sampling. At higher levels, DWP time tags data in a consistent manner and provides a facility for constructing more complex WEC modes by means of macros.

The processing system within the DWP instrument will also perform particle correlations in order to permit the study of wave/particle interactions. Particle correlation is based on forming autocorrelation functions of the time series of particle detector counts as a function of energy and pitch angle. The basic operations are carried out in DWP resident software using algorithms developed for AMPTE, CRRES, rocket experiments and also from computer simulations.

The DWP particle correlator takes raw electron detection pulses from the PEACE instrument and performs software auto-correlation functions (ACF) that are sorted and summed according to instantaneous PEACE selected electron energy.

The energy level range is partitioned into 15 contiguous energy bins irrespective of the PEACE energy sweeping rate. ACFs have 8 lags including zero lag. As the lag time is 45 μs this corresponds to modulation frequencies up to 11.1 kHz with only low, 1.4 kHz, resolution.

The basic summation period is one spin at normal rate, and 1/32 spin at high data rate. The data rate is limited to transmitting the summed ACF at two selected energies per summation period, plus a third ACF that is stepped in energy once per summation period, through the other 13 levels. Thus in normal mode two selected energies are covered with a time resolution of 4 s, while other energies have a time resolution of 52 s. In high data rate these periods are 0.125 s and 1.625 s, respectively. Note that in normal mode the data corresponds to a range of electron pitch angles, being summed over spins. Assuming that the analysed zone includes the direction parallel to the magnetic field, **B**, then this range in pitch angle is in general, 0° to an angle twice that between the spin axis and the Earth's magnetic field direction. Thus operation in high data rate will be needed to provide the pitch angle dependence of particle modulations. The low data rate mode will obviously operate best when the spin axis is close to **B**.

The particle correlator technique permits the detection of particle flux bursts on time scales short compared with the energy and dwell time and an indication of regions of velocity space in which wave/particle interactions are occurring.

Data-compression techniques are employed in the DWP instrument to optimise the use of available telemetry, a problem particularly severe for wave experiments. This allows more useful information to be transmitted over a given telemetry system than would otherwise be possible and is achieved by removing redundant information from the data. Various data compression methods are implemented within the WEC and DWP. To simplify allocation of telemetry bandwidth, these are restricted to methods providing a fixed degree of compression independent of the variability of the data. The methods are:

- Wideband instrument (WBD)—digital filtering with resampling (page 59)
- STAFF Search Coil (MWF)—differential encoding
- WHISPER—data selection followed by pseudo-logarithmic compression, and
- Correlator—averaging.

The compression obtained (in high-bit-rate mode) are:

Instrument	Raw bit rate	Compressed bit rate
WBD	220 kbit/s	74 kbit/s
STAFF search coil	22 kbit/s	16 kbit/s
WHISPER	≈ 600 kbit/s	4 kbit/s

The design of the DWP permits the transputers to be operated at input clock frequencies of 2.5 or 5 MHz, the lower rate requiring less power. Speed selection is made by hardware command from the OBDH interface.

A variety of interfaces are used to control and obtain data from the instruments of the wave consortium. Interfaces with a relatively low data rate employ registers allocated one of the 16 instrument bus addresses and in some cases an event request line. High-data-rate interfaces use DMA channels.

The peak loading on the kernel processor for transferring data will be about 50%. The average load will be at most half this figure. This leaves time for the other tasks the kernel has to perform.

Wideband data (WBD) has direct connections to the spacecraft data handling system and this is the path that is usually used for data transmission. Unlike the other WEC instruments, sampling and output are not controlled by DWP. It is however, commanded by DWP. WBD data may also be routed to one of the two spacecraft tape recorders through the DWP interface to the spacecraft. To reduce the bit-rate to fit within the WEC science telemetry allocation, DWP reduces the data rate by a factor of three by applying a digital filtering algorithm to this data stream and then resampling it.

DWP time-stamps the WEC data with a time tag relative to the spacecraft onboard time. DWP has an internal clock running at a fixed frequency of 900 Hz. Pulses of this clock are counted by software which derives either a 25 Hz or a 450 Hz signal known as the WEC Sample Sync (WECSS). This controls STAFF Magnetic Waveform Analyser (MWF) and EFW electric field sampling and ensures that sample taking is synchronised to this clock. The WECSS clock is not synchronous with the spacecraft's spin rate.

DWP has direct digital control of STAFF MWF by means of a number of control signals that enable DWP to select the B_x, B_y or B_z field components and to control the analogue-to-digital converter (ADC). DWP reads values of B_x, B_y, and B_z to 16-bit resolution at the frequency of WECSS and assembles the values in a buffer within DWP. By contrast, EFW has its own microprocessor that fills a sampling buffer within EFW and, one per second, outputs a data packet to DWP through a serial interface (uart). To facilitate time correlation of EFW and STAFF MWF data, DWP samples one second's worth of MWF data before outputting it to the spacecraft. Furthermore, DWP controls the start of EFW sampling (by means of the transmission of a synchronisation character) so that EFW and MWF sampling start at the same time and both generate a complete packet of data one second later. DWP ensures that both of these packets carry the same time tag so as to aid subsequent correlative studies.

It can be seen that for EFW and STAFF operations there is a one-second period where sample buffers are being filled before they are output. DWP delays any telecommanded mode changes for EFW and MWF until the sample buffers have been flushed of the samples taken during the last second. This point is termed the One Second Timing Boundary (OSTB), and all WEC instrument mode changes are synchronised to OSTBs to ensure continuous time coverage in known instrument modes.

STAFF and EFW data are stamped with the time of the OSTB at the start of the sampling period. This facilitates time correlation between data from these instruments. WBD and WHISPER data are stamped with the time at which the data packet was received by DWP. From this, and from an understanding of the internal timing within the instrument, it is possible to determine when the samples were actually taken.

An area of DWP memory is allocated as a buffer for WEC macros. The WEC macro buffer can hold a number of command sequences that can be invoked with a single telecommand from the spacecraft. The WEC macros exist for two main reasons:

1. the number of telecommands that can be uplinked to the spacecraft in any orbit is limited; by storing the most commonly used sequences of commands in the macro-buffer, efficient use can be made of the spacecraft telecommanding allocation;
2. commands can be inserted into the macro buffer to enable features such as looping and timed delays to implement automatic WEC instrument mode switching; these permit the construction of more scientifically interesting WEC modes.

To summarise, the WEC macros provide a skeleton for each WEC mode which can be adjusted by additional telecommands transmitted from the spacecraft as may be required for any particular campaign.

The Parameters

The DWP related CDF files produced as part of the UKCDC pipeline data processing activity contain two types of parameters as listed in Table 5 on page 12. The first set are data parameters and relate to data collected by the DWP particle correlator.

`Correl_signif` Percentage significance of most strongly modulated electron component detected.

`Correl_P` Energy band (in eV) of most strongly modulated electron component.

`Correl_freq` Frequency band (in kHz) of most strongly modulated electron component.

The electron modulation significance value `Correl_signif` is calculated by processing the auto-correlation functions which are constructed within DWP using electron count time series provided by the PEACE HEEA sensor. The significance percentage value produced from this processing is either calculated by the Fisher g Test (default scheme) after Fast Fourier Transform of the ACFs or directly on the ACF with the highest amplitude zero lag value. A bit in the CSDS DWP status word determines which scheme has been applied. The `Correl_signif` value returned by processing represents the highest significance value of any of the ACFs processed over the specified time interval. The frequency band (`Correl_freq`) and energy band (`Correl_P`) corresponding to `Correl_signif` are also returned.

The second set are status words, that give information regarding the operational modes of DWP, WEC in general and WBD.

The `Status` variable consists of 6 bytes, the first of which is the CSDS-defined quality flag (Table 6 on page 15) applied to the DWP data. Tables 22–26 provide the key to interpreting the other 5 bytes of the DWP `Status` words.

Table 22: DWP `Status[1]`

Bits	Value	Interpretation
7	0	Correlator statistical significance using Fisher test
	1	Correlator statistical significance using Schuster test
6	0	Correlator in low bit rate
	1	Correlator in high bit rate
5–2	0–15	Count value in correlator time bin (=0 if undersampled)
1	0	Correlator ACF used corresponds to selected energy
	1	Correlator ACF used corresponds to stepping
0	0	HEEA is on
	1	HEEA is disabled

Table 23: DWP `Status[2]`

Bits	Value	Interpretation
7–1	0–127	HEEA energy level Preset value.
0	0	PEACE field direction from FGM = 0
	1	PEACE field direction from Symmetry direction

Table 24: DWP `Status[3]`

Bits	Value	Interpretation
7–4	0–15	HEEA Coarse polar zone number selected for DWP correlator data.
3–0	0–15	HEEA Coarse polar zone number containing field (determined from previous spin).

Table 25: DWP `Status[4]`

Bits	Value	Interpretation
7–2	0–63	azimuthal angle offset for field direction (in units of 5.625°, determined from previous spin)
1–0	0	HEEA sweep mode: PEACE off/ fixed energy mode
	1	HEEA sweep mode: 16 flybacks/ spin
	2	HEEA sweep mode: 32 flybacks/ spin
	3	HEEA sweep mode: 64 flybacks/ spin

Table 26: DWP `Status[5]`

Bits	Value	Interpretation
7–0	0–255	Logarithm value of total counts measured by PEACE HEEA over spin

The State_wec parameter, described on page 35, consists of 5 bytes, providing operational information for each of the 5 WEC instruments. The byte indices 0–4 are assigned to the instruments EFW, STAFF, WHISPER, DWP and WBD respectively. The contents of the DWP byte State_wec[3] are listed in Table 20 on page 39.

The contents of the Status_wbd data word consist of four bytes. Tables 27–29 provide the key to interpreting the values written into the Status_wbd data words. The use of Status_wbd[0] is reserved by CSDS according to Table 6.

Caveats

There are presently no known caveats. Please consult the WEC home page given in Table 4 on page 6 for the latest information.

Table 27: Interpretation of Status_wbd[1]

Bits	Value	Interpretation
7	0	WBD working
	1	WBD not working
6		Not used
5–4	0	0 kHz
	1	125 kHz
	2	250 kHz
	3	500 kHz
3–2	0	LV0
	1	LV1
	2	LV2
	3	LV3
1–0	0	UV0
	1	UV1
	2	UV2
	3	UV3

Table 28: Interpretation of Status_wbd[2]

Bits	Value	Interpretation
7	0	WBD is working
	1	WBD is not working
6	0	HK not via DWP
	1	HK via DWP
5	0	Auto gain select
	1	Manual gain select
4–1	0–15	Digitised gain setting
0	0	Primary
	1	Redundant

Table 29: Interpretation of `Status_wbd[3]`

Bits	Value	Interpretation
7	0	WBD is working
	1	WBD is not working
6		Not used
5	0	VCXO locked
	1	VCXO not locked
4–2	0	9.5 kHz 8 bit
	1	9.5 kHz 8 bit
	2	19 kHz 4 bit
	3	19 kHz 8 bit
	4	77 kHz 8 bit
	5	77 kHz 1 bit
	6	77 kHz 4 bit
	7	77 kHz 8 bit
1–0	0	Ez
	1	By
	2	Bx
	3	Ey

3.9 EFW

The Instrument

The EFW instrument (Electric Field and Waves) [Gustafsson et al., 1997, 2001] is part of the Wave Experiment Consortium (WEC). It consists of four 8 cm diameter spherical probes extended on 42.5 m long wire booms (88 m tip-tip) in the spacecraft spin plane. The probes are used for measuring either electric fields or plasma density variations. In the electric field mode, the probes are actively controlled by a bias current to ensure a high quality measurement. In the density mode, the probes are voltage biased to collect the ambient thermal electron current.

Analog signals from the EFW instrument are fed to STAFF, WHISPER and WBD. Commands to EFW and telemetry from EFW are passed through DWP. In addition, EFW receives (via DWP) signals from FGM and STAFF, and delivers (via DWP) the measured spacecraft potential to ASPOC.

The instrument may sweep the current or voltage of a probe to obtain a current-voltage characteristic useful for both instrument and plasma diagnostics.

Details on how to determine if EFW was sweeping during a particular interval may be found on page 35.

There are a number of signals within the instrument which may be sampled at various frequencies and sent to telemetry. Basically the individual probe current I_i (in density mode) or voltage V_i (in electric field mode) as well as potential differences between probes V_{ij} (in electric field mode) may be sampled at rates between 5 and 36000 s^{-1}. Typically, individual probe signals V_i are sampled at 5 s^{-1}. Potential differences V_{ij} are sampled at 25 s^{-1} in spacecraft normal mode (NM) telemetry speed and at 450 s^{-1} in burst mode (BM).

The Parameters

The CSDS parameters from EFW are two status parameters and six data parameters as listed in Table 5 on page 13, and explained below. All parameters are available both in the PPDB (with spin period time resolution) and in the SPDB (with 1 minute time resolution).

`E_dusk` The electric field component in the spin plane, perpendicular to the GSE x axis, positive towards dusk. Since the spacecraft spin plane is close to the ecliptic plane, the direction of `E_dusk` is very close to the GSE y axis. It is computed by applying a least-squares fit of a sine wave with the spin frequency to the measured data points during one spin, which gives a time resolution of one value per spin for the prime parameter data base. The summary parameter value is a simple average over a number of prime parameter values.

`E_pow_f1` The electric field power spectral density in the spin plane in the frequency band 1–10 Hz. It is computed on ground from raw data sampled at 25 s^{-1} in normal mode and from data sampled at 450 s^{-1} in burst mode.

`E_pow_f2` The electric field power spectral density in the spin plane in the frequency band 10–180 Hz. It is computed on ground from raw data sampled at 450 s^{-1} in burst mode. In normal mode, this parameter is not available from EFW, but computed on board by STAFF (see the description of the STAFF parameters on pages 52–54).

`E_sigma` The standard deviation of the raw data points from the sine wave used for the least-squares fit as described under the `E_dusk` parameter. It is useful for determination of low-frequency noise in the electric field.

I_probe The current to the probe measured when a probe is in the voltage (density) mode. In this mode, which is used only part of the time and generally not on all probes, a fixed (positive) voltage is applied to the probe, and the current measured is proportional to the ambient electron density. The value given in the parameter data bases is the average of the values for all probes in the voltage (density) mode.

U_probe_sc The potential difference between a probe and the satellite body, measured when the probe is in the current (E-field) mode. In this mode, which is the normal mode of operation, a bias current is applied to each probe (to optimise the measurements) and the potential differences between probes are measured to give the electric field. The potential difference between a probe (which is kept near plasma potential) and the satellite is a good indicator of the ambient electron flux, in particular in tenuous plasma. The polarity of the quantity is such that lower plasma density corresponds to a more negative value of U_probe_sc (more positive satellite potential). The value given in the parameter data bases is the average of the values for all probes in the current (E-field) mode.

The State_wec parameter, described on page 35, consists of 5 bytes, providing operational information for each of the 5 WEC instruments. The byte indices 0–4 are assigned to the instruments EFW, STAFF, WHISPER, DWP and WBD respectively. The contents of the EFW byte State_wec[0] are listed in Table 17 on page 36.

The Status parameter consists of 5 bytes, the CSDS-defined quality flag plus 4 bytes for mainly EFW internal use. These are to be interpreted as follows:

Status[0] Data quality as defined by CSDS, Table 6 on page 15.

Status[1] Identical copy of State_wec[0] (see Table 17 on page 36).

Status[2] Interpreted according to Table 30 on the next page.

Status[3] Value of the EFW bias current to those probes in the current (E-field) mode. Interpreting this as an unsigned integer N, the value of the current is $3.82(N - 128)$ nA. A value of 255 indicates that no current value is available.

Status[4] Value of the EFW bias voltage to those probes in the voltage (density) mode. Interpreting this as an unsigned integer N, the value of the voltage is $0.31(N - 128)$ V. A value of 255 indicates that no voltage value is available.

Caveats

The CSDS data are intended for event identification and are not for publication. Some obviously incorrect data have been removed in the validation process, but there may still be occasional data with poor quality in the PPDB and SPDB. Please always contact the EFW PI or the CSDS file validator (information given in the global attributes of each CDF file) for questions on data validity.

The electric field E_dusk has not been corrected for offsets present due to, e.g., photoelectron asymmetries.

The parameter U_probe_sc can be used as an approximate indicator of the electron density, except during periods when ASPOC is operating. Such periods have not been removed from the data. A more (less) negative value of U_probe_sc indicates lower (higher) density.

The operation of WHISPER in the active mode sometimes disturbs the EFW measurements. Such disturbed data have most likely been removed in all quantities except U_probe_sc, where the disturbance is least severe.

Table 30: EFW `Status[2]`

Bits	Value	Interpretation
7	0	No sweep playback
	1	Sweep playback
6	0	No burst playback
	1	Burst playback
5-3	0	Burst state: Off
	1	Burst state: Compiling list
	2	Burst state: Turning On
	3	Burst state: Searching
	4	Burst state: Collecting
	5	Burst state: Closing the file
	6	Burst state: Playback wait
	7	Burst state: Playing back
2	0	Whisper pulses not present
	1	Whisper pulses present
1	0	Sweep not in progress
	1	Sweep in progress
0	0	Spacecraft potential status: data valid
	1	Spacecraft potential status: data invalid

For the PPDB, bits 7, 6, 2 and 1 indicate whether the event in question has occurred at least once during the 4-second time interval covered by the data point. Bits 5-3 and 0 indicate the status at an arbitrary time within the interval. For the SPDB, the status is taken from the last PPDB value in the 1-minute interval covered by the data point.

3.10 STAFF

The Instrument

The STAFF experiment (Spatio-Temporal Analysis of Field Fluctuations) [Cornilleau et al., 1997] is one of the five experiments of the Wave Experiment Consortium (WEC). STAFF uses a three-axis search coil magnetometer to measure magnetic field fluctuations at frequencies up to 4 kHz. The waveform is digitised and telemetered to the ground at low frequencies, while at higher frequencies a digital spectrum analyser calculates the power spectrum and cross-spectrum in near-real time. The spectrum analyser also analyses the two spin-plane components of electric field as measured by the long dipole antennas of the EFW experiment.

The three-axis search coil unit is mounted on a rigid boom with its three mutually orthogonal mechanical axes aligned respectively with the spin axis and the axes of the two EFW spin-plane wire antennas. Each sensor consists of a high permeability core embedded inside two solenoids. The main winding has a very large number of turns mounted in separate sections. The frequency response of the sensor is flattened in the frequency range 40–4000 Hz by a secondary winding used to introduce flux feedback. The secondary winding is also used as a calibration loop on which an external signal can be applied through a calibration network included in the preamplifiers. The measured sensitivity is 3×10^{-3} nT Hz$^{-1/2}$ at 1 Hz and 3×10^{-5} nT Hz$^{-1/2}$ at 100 Hz. The search coils are designed so as to minimise their sensitivity to electric fields. The angles between each magnetic axis and the three mechanical axes have been carefully measured; these angles, at most a few degrees, are known with a precision of 0.1°. The three preamplifiers are mounted inside the spacecraft. The dynamic range of the preamplifiers is about 100 dB, to allow weak signals to be measured in the presence of the large signals induced by the rotation of the spacecraft in the ambient magnetic field. The magnetic preamplifier output is used by:

- the STAFF magnetic waveform unit,
- the STAFF spectrum analyser,
- the WBD experiment,
- the EFW experiment (for the fast event detector), and
- the EDI experiment.

The Magnetic Waveform Unit

The three signals B_x, B_y, and B_z from the search coil preamplifier are passed through 7$^{\text{th}}$ order ant-aliasing filters (i.e., they have an attenuation of 42 dB per octave) with −3 dB cut-off at either 10 Hz or 180 Hz, depending upon the experiment operating mode. The signals are then applied to three sample and hold devices, and digitised by an analogue-to-digital converter, with 16-bit precision to achieve the required dynamic range. The sampling is synchronised by the DWP experiment at either 25 or 450 Hz; this is 2.5 times the filter frequency, so that the rejection of aliased components is at least 40 dB. The output is sent to the DWP experiment. Note that, to facilitate ground data analysis, identical filters are used by the STAFF and the EFW experiments, and the same synchronisation signal is sent to both the STAFF and the EFW experiments. The dynamic range is reduced (by differencing) from 16 to 12 bits inside DWP.

The Spectrum Analyser

The frequency range of 8 to 4000 Hz is divided into three sub-bands, each of covering 3 octaves:

- band A: 8–64 Hz;
- band B: 64–512 Hz;
- band C: 512–4000 Hz.

The “front end” of the analyser is analogue; for each of the three bands and five sensors there are nine automatic gain-controlled (AGC) amplifiers. The gain of these AGC amplifiers is a multiplying factor in the determination of the absolute measurement. The outputs from the 9 amplifiers are multiplexed to a single 8-bit “flash” analogue-to-digital converter, and sampled at 4 times the highest frequency in the band. The AGC gain-control signals are also digitised for inclusion in the telemetry. The digital processing is performed in three distinct steps:

1. De-spin of the spin-plane (B_y, B_z, and E_y, E_z) signals using the onboard sun reference pulse.
2. Determination of the complex Fourier coefficients, using an extension of the Remez exchange algorithm.
3. Calculation and integration of the correlation matrices.

The resulting cross-spectral matrix has its diagonal elements logarithmically compressed into eight bits; the off-diagonal elements are normalised (by the diagonal elements), and coded using four bits (including the sign) for the real and four bits for the imaginary part.

The spectrum analyser determines the complete 5×5 Hermitian cross-spectral matrix of the signals from five input channels, over the frequency range of 8 Hz to 4 kHz. The five auto-spectral power estimates are obtained with:

- a dynamic range of approximately 100 dB,
- an average amplitude resolution of 0.38 dB,

The 10 cross-spectral power estimates are normalised to give the coherence, which is obtained with the following precision:

- the magnitude falls into one of 8 bins with upper limits distributed approximately as $2 - n$, for $n = 0$ to 7 ;
- the phase has a precision which depends upon the magnitude of the coherence: for a signal with magnitude in the highest bin, it is approximately 5° close to 0°, 180°, and ±90°, increasing to about 10° midway between these angles.

The spectral estimates are made at 27 frequencies distributed logarithmically over the range from 8 Hz to 4 kHz, with centre frequencies

$$f_{mn} = 2^{3m} \times 2^{(2n+1)/6} \quad \text{for} \quad 1 \le m \le 3 \quad \text{and} \quad 0 \le n \le 8$$

All channels are sampled quasi-simultaneously, and the integration time, normally the same for all auto and for all cross-spectral channels, can be commanded to values between 125 ms (except at the lowest frequencies) and 4 s. The cross-spectral matrix elements are generally have 4 times less time resolution than the auto-spectra.

The Parameters

The STAFF experiment supplies the following parameters as listed in Table 5 on page 13.

Summary Parameters

Magnetic field: the total power of the magnetic field in three frequency ranges:

1. (1–10 Hz) The parameters are obtained from spectral analysis of the waveform data during ground data processing.
2. (10–180 Hz) Parameters in this range are determined from the onboard spectrum analyser in normal mode, and from spectral analysis of the waveform data in burst mode.
3. (180–4000 Hz) These parameters are always obtained from the onboard spectrum analyser.

The data from the spectrum analyser is obtained by

- summation of the three diagonal components of each 3×3 **B**-field spectral matrix;
- summation over the appropriate range of frequency bands.

Electric field: The power of the spin-plane components (Cluster has no spin-axis electric sensor) of the electric field in the second (in normal mode) and third of the above three frequency ranges. The method of calculation is as for the magnetic field components.

In burst mode the electric field waveform to 180 Hz and hence the parameter `E_pow_f2` comes from the EFW experiment.

`B_pow_f1` The total **B**-field power in the range 1–10 Hz.

`B_pow_f2` The total **B**-field power in the range 10–180 Hz.

`B_pow_f3` The total **B**-field power in the range 180–4000 Hz.

`E_pow_f2` The spin-plane **E**-field power in the range 10–180 Hz.

`E_pow_f3` The spin-plane **E**-field power in the range 180–4000 Hz.

Prime Parameters

The Prime Parameters have the same frequency resolution as the Summary Parameters, but higher time resolution. In addition, for the magnetic field of which all three components are measured, the power is resolved into its components parallel and perpendicular to the measured (FGM) mean magnetic field. This is an indicator of whether the observed waves are compressional (e.g., fast MHD) or not (e.g., Alfvén). Note that for (fictitious) isotropic fluctuations the spin-plane power would be twice the spin-axis power.

`B_par_f1` The $B_{\|}$ power in the range 1–10 Hz.

`B_par_f2` The $B_{\|}$ power in the range 10–180 Hz.

`B_par_f3` The $B_{\|}$ power in the range 180–4000 Hz.

`B_perp_f1` The $B_{\perp}$ power in the range 1–10 Hz.

`B_perp_f2` The $B_{\perp}$ power in the range 10–180 Hz.

`B_perp_f3` The $B_{\perp}$ power in the range 180–4000 Hz.

`E_pow_f2` The spin-plane **E**-field power in the range 10–180 Hz.

Table 31: STAFF SA modes. For a full description see tables III and IV in Cornilleau et al. [1997].

Bit 3	Bit 2	Bit 1	Bit 0	Value	Mode	Components	Frequency Range
0	0	0	0	0	Normal mode 1	$3 \times B + 2 \times E$	8 Hz–4 kHz
0	0	0	1	1	Normal mode 2e	$2 \times E + B_z$	8 Hz–4 kHz
0	0	1	0	2	Normal mode 2b	$3 \times B$	8 Hz–4 kHz
0	0	1	1	3	Illegal	—	—
0	1	0	0	4	Emergency mode	$3 \times B + 2 \times E$	8 Hz–4 kHz
0	1	0	1	5	Special mode	$3 \times B + 2 \times E$	8 Hz–4 kHz
0	1	1	0	6	Normal mode 1'e	$2 \times E + B_z$	8 Hz–4 kHz
0	1	1	1	7	Normal mode 1'b	$3 \times B$	8 Hz–4 kHz
1	0	0	0	8	Fast mode 1	$3 \times B + 2 \times E$	64 Hz–4 kHz
1	0	0	1	9	Fast mode 3e	$2 \times E + B_z$	64 Hz–4 kHz
1	0	1	0	10	Fast mode 3b	$3 \times B$	64 Hz–4 kHz
1	0	1	1	11	Illegal	—	—
1	1	0	0	12	Fast mode 2	$3 \times B + 2 \times E$	64 Hz–4 kHz
1	1	0	1	13	Illegal	—	—
1	1	1	0	14	Illegal	—	—
1	1	1	1	15	Passive	—	—

B_z means the component parallel to the spin axis

`E_pow_f3` The spin-plane **E**-field power in the range 180–4000 Hz.

Status Parameters

There are four bytes of STAFF status words.

`Status[0]` Data quality as defined by CSDS, Table 6 on page 15.

`Status[1]` Bits 0-4 indicate step in calibration (1 to 23), after Cal set to 24 until a DWP reset or a new Cal
- 5 : nothing
- 6 : EFW Z boom pair in density mode
- 7 : EFW Y boom pair in density mode

`Status[2]` Bits 0-3 indicate STAFF-SA mode description (see Table 31)
- 4 : Filter (0 = 10 Hz ; 1 = 180 Hz)
- 5 : Despin (0 = ON)
- 6 : Whisper transmitter active (0 = OFF)
- 7 : Calibration (1 = active)

`Status[3]` Bits 0-3 indicate compression (0 = no compression, 1 = normal compression, 2 = backup compression)
- 4 : EFW sweep in progress

The State_wec parameter, described on page 35, consists of 5 bytes, providing operational information for each of the 5 WEC instruments. The byte indices 0–4 are assigned to the instruments EFW, STAFF, WHISPER, DWP and WBD respectively. The contents of the STAFF byte State_wec[1] are listed in Table 18 on page 37.

Caveats

(Please consult the WEC home page given in Table 4 on page 6 for the latest caveat information.)

1. The STAFF prime parameters do not have the standard CSDS timing which is synchronous with the spacecraft spin clock. The operation of the STAFF digital spectrum analyser is synchronised with the DWP clock.

   The summary parameters are the average of all those instrument measurements made during STAFF 4 s periods whose middle times lie within the minute boundaries. The difference from the standard CSDS definition is negligible for all practical purposes.

2. As already mentioned, the summary parameter and prime parameter E_pow_f2 is supplied by STAFF only when the satellites are in normal mode.

   In burst mode both STAFF and EFW measure the waveform to 180 Hz, and the onboard spectrum analyser is not used to determine the spectrum in the band 10–180 Hz. The parameters B_pow_f2, E_pow_f2, B_par_f2, and B_perp_f2 are determined from the waveform measurements which, in the case of the electric field, come from EFW. Thus in normal mode the parameter E_pow_f2 is supplied by STAFF, while in burst mode it is replaced by the parameter of the same name from the EFW experiment.

3.11 WHISPER

The Instrument

The WHISPER instrument (Waves of High Frequency and Sounder for Probing of the Electron Density by Relaxation) [Décréau et al., 1997, 2001], an element of the Wave Experiment Consortium (WEC), has two main functions:

- to provide the total electron density using a relaxation sounder in the range 0.1–80 e cm−3;
- to provide a survey of the natural wave electric field in the frequency range 2–80 kHz.

The relaxation sounder is an active wave experiment, first flown in the terrestrial magnetosphere on board the GEOS 1-2, ISEE 1, and Viking satellites, as well as on Ulysses in the solar wind and Jovian magnetosphere. The principle of the instrument is similar to that of a radar: an emitter sends a train of pulses in the plasma over a frequency range which contains the electron plasma frequency. When the pulse frequency matches one of the characteristic frequencies of the plasma (F_p the plasma frequency, F_{uh} the upper hybrid frequency, nF_{ce}, the harmonics of the electron gyrofrequency, and the so-called F_q which are the frequencies of the zero-group velocity of the Bernstein modes) a strong resonance is observed by the receiver. The processing of the set of observed resonances in a sounder spectrum determines the plasma frequency from which the total electron density N_e is derived:

$$F_p \text{ (kHz)} \approx 9\sqrt{N_e \text{ (e cm}-3)} \qquad (7)$$

Although the WHISPER sounder has evolved from similar instruments flown on past satellites, the specific constraints of the Cluster project required considering a different technology. The transmission of pulses is still organised by stepping the frequency as on earlier relaxation sounders, but the WHISPER receiver analyses the signal by FFT performed over the full frequency range, whereas previous instruments used a swept frequency analyser.

In sounding modes, the frequency range of the emitter is explored with a maximum of 83 steps each of bandwidth 980 Hz. The signal is received through the 100 m tip-to-tip sphere antennas of the EFW experiment and analysed by a 512-bin FFT, over the range 0–81 kHz. This provides a bin separation of 162 Hz, with a dynamic range of 66 dB. An active wave spectrum is reconstructed by selection, at each step, of the frequency bins in the 980 Hz bandwidth covered by the central frequency of the pulse. It is compressed and sent to the telemetry by the WEC-DWP. The software can also process the natural signal detected in the previous spectrum a few tens of a millisecond before the actual stimulation, and reconstructs the natural wave spectrum.

In natural wave modes, the emitter is off, and the waves are studied with different times and frequency resolutions in the range 2–80 kHz. Four FFT dimensions are available (512, 256, 128, 64 bins with a frequency resolution of 162, 324, 648 and 1296 Hz respectively). Different WHISPER sounding and natural waves modes as well as DWP data selection and compression schemes are implemented to cope with the available resources on board, scientific interests, and WEC modes of operations.

Details on how to determine if WHISPER was active during a particular interval may be found on page 35.

The Parameters

For CSDS, WHISPER provides two types of parameters as shown in Table 5, page 13: the electron density and plasma wave spectral density integrated over the frequency range, plus the status of operations.

N_e_res The electron density is derived using a dedicated algorithm performed routinely on ground on the set of observed resonances for each active spectrum. This algorithm is based on the identification of the resonance of maximum power in the reconstructed active spectrum, which is assumed to be placed at the plasma frequency. The frequency of the resonance of maximum power is however not always placed at the plasma frequency. It can be placed at another resonant frequency: F_{uh}, one of the nF_{ce}, one of the F_q frequencies; this happens when the plasma is significantly magnetised: F_p/F_{ce} is low. In such a case, the falsely identified plasma frequency resonance is usually larger than the actual one, but not too far from it. It can also be placed at a frequency which has no connection whatsoever with the plasma frequency. This happens when either natural emissions or spurious lines (internal to the WHISPER instrument, or created by EDI) are of higher amplitude than the characteristic resonance, or when no resonance is present in the 4 kHz–80 kHz frequency band. The latter case can eventually be detected from a signal to noise test, or by comparison of the "plasma resonance" frequency with one of the known EDI spurious lines. The former case can be detected by the value of the ratio between the identified plasma resonance frequency and the gyrofrequency deduced from the magnetic field value provided by FGM. Those different pieces of information are used to construct the parameter N_e_res_qual.

N_e_res_qual This parameter is aimed at providing a first idea about the likelihood of the measured N_e_res as derived by the crude recognition algorithm used, rather than quantifying the level of uncertainty linked to this value. The value of the tens figure is linked to the signal over noise ratio, the detailed definition of which varies according to the plasma regime, rated with F_p/F_{ce} value. No good mark (> 40) can be given in case of high magnetised plasmas. The value of the unity figure is linked to the F_p/F_{ce} factor (higher value for high F_p/F_{ce}). Moreover, the N_e_res_qual parameter is put to 0 when the identified plasma frequency resonance is close to a gyrofrequency or an EDI spurious line, however only when we have good reasons to think that this fact is a serious problem.

The other WHISPER CSDS parameters provide a rough estimate of the plasma wave activity in the range 2–80 kHz. Each transmitted spectrum is the result of onboard averaging over 1 to 64 individual spectra. The number of spectra considered for averaging is provided in the byte State_wec[2] (Table 19 on page 38). Each E_pow_*xx* parameter is the integral of the spectral density power of these calibrated transmitted spectra over the given frequency range:

$$\texttt{E\_pow\_}xx\ (\mathrm{V}^2\ \mathrm{m}^{-2}\ \mathrm{Hz}^{-1}) = \sum_{\nu(\mathrm{min})}^{\nu(\mathrm{max})} {B_i}^2 \tag{8}$$

$$\text{where } B_i = \text{spectral density of bin } i$$

with:

E_pow_f4 = spectral density for the range 2–10 kHz
E_pow_f5 = spectral density for the range 10–20 kHz
E_pow_f6 = spectral density for the range 20–80 kHz
E_pow_su = spectral density for the range 4–80 kHz (SPDB only)

Note: depending on the FFT dimension used, the exact range covered by the available frequency bins can differ from the above:

FFT 64: 5.2–76.8 kHz
FFT 128: 2.6–78.8 kHz
FFT 256: 2.0–79.8 kHz
FFT 512: 2.0–79.9 kHz

The corresponding operation status is identified in State_wec[2].

The E_var_ts (PPDB only) provides an estimate of the electric field power variability, by computing the standard deviation in the range 2–80 kHz during the 4 s of a spin.

$$\texttt{E\_var\_ts} = \sqrt{\sum_n \xi^2/n - \left(\sum_n \xi/n\right)^2} \tag{9}$$

with ξ the energy integrated on board over the range 2–80 kHz, and n the number of samples obtained during the 4 s spin (typically one sample every 13.3 ms).

There are four bytes in the WHISPER Status word that give additional information, the first of which is the CSDS-defined quality flag.

Status[0] Data quality as defined by CSDS, Table 6 on page 15.

Status[1] determines the mode of operations:
- 0 = contingency mode 1
- 1 = unused
- 2 = sounding mode
- 3 = calibration mode 2
- 4 = natural wave mode
- 5 = calibration mode 1
- 6 = dump mode
- 7 = contingency mode 2

Status[2] = 0 for WHISPER processing; = 1 for DWP processing

Status[3] = number of telemetry blocks used to compute the PPDB/SPDB

Note: because WHISPER runs both active and passive measurement in duty cycle, more than one mode of operation can occur during an SPDB or even a PPDB time interval. The status word for WHISPER is selected from the telemetry block which is the closest to the middle of the PPDB/SPDB time interval, with a greater priority for the active mode information.

The State_wec parameter, described on page 35, consists of 5 bytes, providing operational information for each of the 5 WEC instruments. The byte indices 0–4 are assigned to the instruments EFW, STAFF, WHISPER, DWP and WBD respectively. The contents of the WHISPER byte State_wec[2] are listed in Table 19 on page 38. The significance of bits in the range 0–4 changes depending on the mode of operation which is coded into bits 7–5. For sounding modes (S), bits 7-5 are set to a value of either 4, 5, or 6. For these modes, bits 4–0 should be interpreted using lines in the Table with an (S) in the first column. For a natural wave mode, bits 7–5 contain the number 3 and are interpreted using the entries in Table 19 labelled (N).

Caveats

The WHISPER sounders operate on a duty cycle, so the electron density is sampled on neither a continuous nor a constant basis. This duty cycle covers situations from continuous active modes with one sounding occurring typically every 1–3 seconds, to natural mode operation only when no sounding is performed, and hence no density is provided for long periods. When many density values are available during a PPDB/SPDB interval, the averaged value is provided. When no value is available during such a time interval, the fill value (no data) is given. For example, in the typical WEC normal mode, a double sounding occurs over 3 s every 52 s. Thus, for PPDB, a density value, averaged over 2 spectra, is available followed by 6 fill values. For the SPDB, 2 averaged values are available 52 s apart. They are averaged for the SPDB slot.

3.12 WBD

The Instrument

The Wide Band Data instrumentation (WBD) [Gurnett et al., 1997] is part of the WEC consortium of wave experiments and consists of a digital wideband receiver which can provide electric or magnetic field waveforms over a wide range of frequencies up to 577 kHz. WBD receiver operating characteristics are summarised in Table 32

The wideband technique involves transmitting band-limited waveforms directly to the ground using a high-rate data link. The primary advantage of this approach is that continuous waveforms are available for detailed high-resolution frequency-time analysis.

The instrument processes signals from one of four sensors which can be chosen via command. The four selectable inputs consist of two electric antennas (E_y, E_z) provided by the EFW investigation, and two magnetic search coils (B_x, B_y) provided by the STAFF investigation. Primarily, WBD will utilise the electric antennas.

The input frequency range of the wideband receiver can be shifted by a frequency converter to any one of four ranges (0, 125 ,250, or 500 kHz), where the conversion frequency determines the lower edge of the frequency range to be received.

The bandwidth of the WBD instrument's output waveform is determined by one of three bandpass filters (9.5, 19, or 77 kHz) selected in combination with a given output mode. The output waveform is sampled by an 8-bit analogue-to-digital converter which provides the sampling resolution and data output rates listed in Table 33. For sample rates where the bit rate exceeds the spacecraft telemetry data rate (220 kbit/s), the digitised wideband data are buffered by the format generator and read out at a reduced average bit rate of 220 kbits/sec. The format generator organises the digitised waveform data into a 1096-byte output frame, which includes appropriate timing and status information.

The WBD instrument utilises two separate telemetry acquisition modes for transferring frames of digitised data to the spacecraft data handling system. The primary mode (TDA 8) supports real-time acquisition of WBD data by the NASA DSN. The second data mode (TDA 5.2) supports burst data acquisition through the WEC DWP onto an onboard Solid State Recorder. In this second mode, DWP reduces the WBD data rate (and bandwidth) by a factor of 3 via digital filtering.

The Parameters

By agreement, WBD does not provide a science data product for inclusion in the PPDB or SPDB. However, WBD instrument status is included in both as part of the DWP parameters (Section 3.8 on page 44 and Tables 27–29). Also, since WBD is a low duty cycle experiment (∼4% orbit coverage per spacecraft), an indicator showing when WBD real time data were acquired is included in the summary parameters.

Caveats

There are presently no known caveats. Please consult the WEC home page given in Table 4 on page 6 for the latest information.

Table 32: WBD Instrument Parameters

Sensors	Two electric field components (E_y, E_z); two magnetic field components (B_x, B_y)
Conversion Frequencies	0, 125 kHz, 250 kHz, 500 kHz
Bandpass Filter Ranges	1 kHz to 77 kHz 50 Hz to 19 kHz 50 Hz to 9.5 kHz
Frequency Resolution	Determined by FFT
Time Resolution	10–20 ms (per FFT spectrum)
Gain Select	5 dB steps, 16 levels, dynamic range 75 dB, automatic ranging or set by command
ADC	1-bit, 4-bit, or 8-bit resolution for a selection of sample rates
Sensitivity	4×10^{-18} V^2 m^{-2} Hz^{-1} (baseband) 1.5×10^{-17} V^2 m^{-2} Hz^{-1} (frequency conversion)
Dynamic Range	≈ 100 dB

Table 33: WBD Output Modes

Mode	Bandwidth	Sample Rate	Bits/ Sample	Duty Cycle (%)
0*	0.050–9.5 kHz	27.4 kHz	8	100
1	0.050–9.5 kHz	27.4 kHz	8	100
2	0.050–19 kHz	54.9 kHz	4	100
3	0.050–19 kHz	54.9 kHz	8	50
4	1–77 kHz	219.5 kHz	8	12.5
5	1–77 kHz	219.5 kHz	1	100
6	1–77 kHz	219.5 kHz	4	25
7†	1–77 kHz	219.5 kHz	8	12.5

* Default mode

† Repeat of mode 4, but also toggles the primary and redundant OBDH interfaces.

3.13 Auxiliary Data

In addition to the measured scientific parameters, there are a number of quantities that are essential for the full analysis of the data: the spacecraft positions, velocities, and attitude (direction of the spin axis). These are indeed provided by ESOC with the raw data, but to make them available to the CSDS user without such access, they are treated as a separate pseudo-instrument processed by the Hungarian Data Centre.

In fact, since the original auxiliary data are expressed as vectors in a coordinate system that is not particularly useful to magnetospheric studies (geocentric inertial equatorial relative to vernal equinox of J2000.0), it makes sense to convert them to the usual GSE or GSM systems at this point, guaranteeing a consistent conversion for all users. Furthermore, a few derived parameters are also included to indicate some information about the shape and size of the geometric figure defined by the 4 spacecraft at its apices.

A description of the "raw" auxiliary data as provided on the CD-ROMs can be found in the Data Delivery Interface Document [DDID, Appendix H].

Coordinate Systems

An overview of the coordinate systems used in space physics and the transformations between them has been given by Hapgood [1992, 1997b], along with a description of the role of precession [Hapgood, 1995]. The specific transformations needed for Cluster are explained by Hapgood [1997a].

The Geocentric Solar Ecliptic (GSE) system is defined such that the x axis is directed towards the sun while the y axis lies in the ecliptic plane in the direction opposite to the Earth's velocity around the sun; the z axis completes the right-hand system ($z = x \times y$) which places it essentially along the ecliptic north pole. The origin is located at the centre of the Earth. The GSE system is not inertial, making a full rotation about the z axis in one year.

The Geocentric Solar Magnetic (GSM) system differs from GSE by a rotation about the x axis such that the terrestrial magnetic dipole lies in the $+zx$ plane. That is, the GSM z axis is the projection of the magnetic dipole onto the GSE yz plane. In addition to the annual rotation, this coordinate system exhibits a diurnal wobble. Since the magnetic dipole is usually taken from a geomagnetic model, there can be disagreements between investigators according to which one they use. It is for this reason that CSDS has adopted the method used by JSOC for determining the magnetic north pole. The coefficients of IGRF2000 model are included when predicting the actual location of the drifting pole [Hapgood, 1992, 1997b, a].

The Parameters

The CSDS auxiliary data are listed in Table 5 on page 14. All the vector quantities are given in the GSE coordinate system, since this is considered more "stable" than GSM. The rotation angle between the two is also given, enabling a straight-forward and unambiguous conversion.

Position (in km) is specified by the absolute coordinates of one reference spacecraft (`sc_r_xyz_gse`) plus the relative locations of all 4 with respect to it (`sc_dr`n`_xyz_gse`, $n = 1, 4$). The rationale for this is that, since the separations are much smaller than the distance from the Earth, any one spacecraft is representative of all as far as the global location of the fleet is concerned. On the

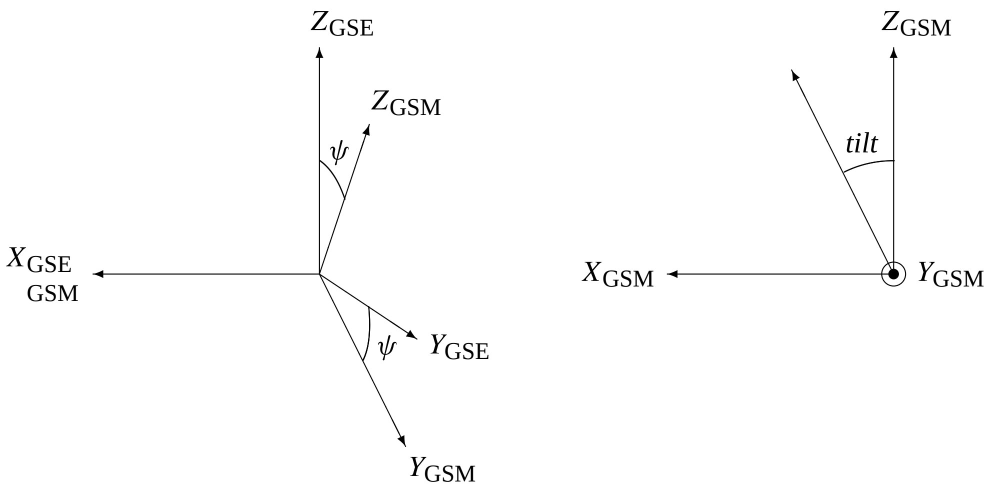

Figure 3: The GSE/GSM conversion angle ψ and the dipole tilt angle.

other hand, the relative locations are important for considerations of the geometric figure, which do not involve the overall position.

Which spacecraft is the reference one is not fixed in advance in case any problems should arise with it. Its number is listed in the `Reference_SC` global attribute of the auxiliary data CDF file.

Velocity (in km/s) is given simply as the absolute value for the reference spacecraft (`sc_v_xyz_gse`). As for global position, one spacecraft is representative of all; however, in this case the relative velocities among the spacecraft themselves are uninteresting.

Attitude is the orientation of the spacecraft spin axes, expressed as angular coordinates, in degrees, in the GSE system. For each spacecraft, the "longitude" (sc_at*n*_long) and "latitude" (sc_at*n*_lat) are given. This terminology has been selected in the hope that it is less ambiguous than "azimuth" and "elevation" angles. A latitude of 0° indicates that the axis lies in the xy plane; a longitude of 0° means that it is located in the $+xz$ plane; 90°, in the $+yz$ plane.

It is the positive spin axis, in the sense of right-hand rotation, that is given. This may be considered synonymous with the spacecraft-fixed X axis.

Geometry of the figure formed by the 4 spacecraft is best expressed by the parameters *elongation* E (`sc_geom_elong`), *planarity* P (`sc_geom_planarity`) together with the *characteristic size* L (`sc_geom_size`). How these are defined and derived as well as how they may be used is explained by Robert et al. [1998]; a brief description is presented here in Appendix C on page 97.

The directions of the elongation and the normal to the planarity are also provided as unit vectors in the GSE coordinate system, as parameters `sc_geom_E_dir_gse` and `sc_geom_P_nor_gse`.

Configuration parameters `sc_config_QG` and `sc_config_QR` are an older attempt to quantify the geometry of the tetrahedron. It is expected that the geometry parameters above will be used exclusively for this purpose. Nevertheless, they are provided for reasons of history and completeness. Their description is given in Appendix D on page 99.

The scale of the tetrahedron is indicated by `sc_dr_min` and `sc_dr_max`, the minimum and maximum sides of the tetrahedron, that is, the minimum and maximum spacecraft separations.

GSM conversion is specified by the rotation angle `gse_gsm`, in degrees. If this angle is positive, the

GSM z axis is on the dusk side (towards $+y$) in the GSE system. Or, letting ψ be this angle,

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix}_{\text{GSM}} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\psi & -\sin\psi \\ 0 & \sin\psi & \cos\psi \end{pmatrix} \cdot \begin{pmatrix} x \\ y \\ z \end{pmatrix}_{\text{GSE}}$$

The additional angle `dipole_tilt` indicates the inclination of the magnetic dipole towards the sun from the GSM z axis. (Recall that the dipole is in the zx plane in this system.)

Both these angles are illustrated in Figure 3.

Status Words

The spacecraft status word `sc_status` consists of 5 bytes, the first of which is the CSDS-reserved quality flag. The remaining bytes present some information about each of the 4 spacecraft in the form of a set of three integers I, J, K for each spacecraft.

`sc_status[0]` Data quality as defined by CSDS, Table 6 on page 15.

`sc_status[`n`]` Status on spacecraft n in form $100I + 10J + K$:

I	= 0	no spacecraft manoeuvre within this minute
	= 1	some manoeuvre occurred
J	= 0	no eclipse within this minute
	= 1	penumbral eclipse occurred
	= 2	total eclipse occurred
K	= 0	no science data
	= 1–3	normal telemetry modes 1–3
	= 4	programmable normal mode
	= 5	not used
	= 6–8	burst modes 1–3
	= 9	programmable burst mode

Status word = 255 for no data (fill value).

4 Summary Parameter Plots

The Summary Parameter Plotss (SPPs) are to serve two purposes:

- to provide a “roadmap” through the plasma regimes encountered and, this way, to facilitate selecting periods of interest for detailed study, and
- to give a quick overview on data from all the experiments as well as on the data availability and telemetry mode employed on Cluster spacecraft.

In accordance with these purposes and with the basic rules laid down in the CSDS Requirements Document [URD:CSDS], the Summary Parameter Plots

- display only a subset of the Summary Parameters,
- do not provide a high (lateral or vertical) resolution,
- have a fixed UTC range (6 hours, coinciding with the day quarters),
- have a fixed layout (4 pages per UTC interval, see below),
- and have fixed ordinate ranges that are to accommodate parameters from all the regions covered; thus logarithmic scales are employed for most parameters.

The layout was drafted during several meetings of the IWG and was finalised after discussions with and approval by the Cluster PI groups and the SWT.

SPPs are produced by the German Cluster Data Centre on behalf of the entire CSDS, who make them available to all the other DCs for distribution to their national users. Both the transfer to the other DCs and the subsequent distribution are realised by the CSDS Data Management System (Section 6).

GCDC will produce SPPs for every quarter day of Cluster operations beyond the Commissioning Phase: either the four standard pages or a one-page graphical message of non-availability.

Since the mean UTC coverage by data acquisitions is of the order of 50% (at least during the first year of operation), there will be many 6-hour intervals for which no “science data” exist. In that case, one of the following three situations will arise:

1. There are no science data, but auxiliary data exist. This is the most likely case, since the auxiliary data base may be fed with *predicted* orbit/attitude information which always exists. A modified Configuration Page will be issued (Figure A5 on page 88) that shows the spacecraft configuration plus an appropriate printed message, whereas the other three standard pages will be suppressed.
2. At least one science data SPDB CDF file exists but there are no data (neither science nor auxiliary) in the current 6-hour interval. This leads to Figure A6 on page 89.
3. In the most unlikely case that not a single SPDB CDF file exists for a given day, four Figures A7 on page 89 will be issued (one for each quarter day).

As soon as one valid (non-fill) data point from at least one of the Cluster instruments exists for a given 6-hour interval, all four standard pages are plotted.

If a CDF input file does not exist at the time of the plot production, panels representing input from that file display the message

[function] XXX not (yet) available.

When an input file exists but no valid data fall into the plot time interval, such panels stay empty.

On the four standard pages (Figures A1–A4, pages 84–87) parameters are grouped under certain headings:

Overview this page combines magnetic field data and basic plasma parameters such as density, temperature and bulk speed;

Composition this page shows partial densities of various ion species as well as ion and electron fluxes in several energy bands;

Fields this page displays the DC and AC electric fields and plasma wave activity as well as the ASPOC ion current and the EFW probe potential;

Configuration this page displays the most relevant auxiliary parameters.

To facilitate cross-referencing among the four pages, the magnetic-field magnitude panel is shown at the top of each page. Also, in order to make the individual pages as self-contained as possible, a number of panels from the *Overview* page are repeated on others.

At the bottom of each page, the spacecraft position is given in terms of the geocentric distance, R, elevation angle from the ecliptic plane, LAT, and azimuth in this plane converted to local time, LT. The *Configuration* page shows in addition the spacecraft orbital speed, $V_{S/C}$. Each page also carries annotations at the bottom that refer to peculiarities of that page.

The parameter labels given on the left-hand side of the plots do not agree with the parameter *names* listed in Table 5 but are closely related. Thus, for the directly reproduced parameters, this relation is easy to establish with the help of the parameter origins indicated at the panel centres of Figures A1–A4. Similarly, the origin of the derived parameters is fairly easy to recognise.

All vectors are represented not by their cartesian components but by their magnitude and two direction angles: λ, the elevation from the ecliptic plane and ϕ the azimuth angle in this plane, with $\phi = 0°$ pointing towards the Sun and $\phi = 90°$ pointing towards dusk. For very high elevation angles, $|\lambda| > 85°$, plotting of the azimuth trace is suppressed because these values become meaningless and the trace is likely to be very erratic.

Except for E_{dusk} on the *Fields* page (see below), *all* directional information, including the spacecraft position, is given in GSE coordinates (Section 3.13 on page 61).

The panel ranges follow closely the default ranges specified, but in some cases not precisely so (mostly for technical reasons). If a parameter trace strays off the allotted range it does not disappear but is represented by a horizontal line “just inside” the panel boundary so as to make the direction of the excursion visible.

In order to accommodate as much information as possible on only four pages, some of the panels are exceedingly narrow. To enhance the readability of the respective functions, the area under those curves will be grey-shaded. This applies to the $q(n_{\mathrm{e,\,res}})$ panel on the *Overview* page and to all the wave intensity panels on the *Fields* page, whose absolute levels will be difficult to judge from these plots whereas their relative variations should be visible.

Specific Comments

Overview Page

The reliability of the parameter $n_{\mathrm{e,\,res}}$ depends crucially on the plasma environment and cannot be judged without knowledge of its quality, $q\,(n_{\mathrm{e,\,res}})$ which is plotted underneath and varies between 0 and 100%. See the WHISPER text on page 56 for more detail.

The block of ion parameters from CIS in the lower part of the figure displays data from either the HIA or the CODIF part of that experiment (see the CIS text on page 20); and in a narrow region of overlap both inputs will be plotted.

The source instrument will be indicated by shading of the upper and/or lower part of the narrow $i\,$(HIA)/ $p\,$(CODIF) panel shown underneath the density trace. The data source selection is based on the following algorithm:

- If CIS operates in one of its “magnetospheric” modes and $n_{\mathrm{CODIF}} \leq 20\ \mathrm{cm}^{-3}$, then CODIF data will be shown;
- If CIS operates in one of its “magnetospheric” modes and $n_{\mathrm{HIA}} \geq 15\ \mathrm{cm}^{-3}$, or whenever CIS operates in one of its “solar wind” modes, then HIA data will be shown.

If, in some of the overlap regions, the two curves of a CIS panel do not coincide, this is to be taken as a warning that possibly neither parameter is accurate enough to represent *the* plasma density etc. in this environment (and that more detailed investigations are needed).

Fields page

The P_{E}(10–180) panel will display data from either EFW or STAFF. For operational reasons, the intervals of EFW input will be well separated from the STAFF intervals most of the time, but some short stretches of simultaneous data provision may occur. The data source may be identified from the rim of the shaded area which is solid (STAFF) or dotted (EFW) but this distinction is not always very legible—nor was it ever meant to be, since the display of the respective wave activity is the sole purpose of this panel.

E_{dusk} is the only directional information *not* given in GSE coordinates. It is the spacecraft spin plane component pointing towards dusk. However, if the spacecraft attitude is nominal, there will be very little deviation from the GSE y-component.

5 The Role of JSOC

The Joint Science Operations Centre (JSOC) has been developed under contract to ESA as part of the Cluster Science Data System (CSDS). Its purpose, at the highest level, is to support the Cluster Project Scientist in coordinating the complex multi-spacecraft and multi- instrument science operations of the Cluster mission.

JSOC forms an integral part of the Cluster operational ground segment and its services are divided into four areas:

Commanding This provides the day-to-day operational interface for payload commanding between the Cluster Science Working Team (SWT), the PI community and the European Space Operations Centre (ESOC). These activities are entirely internal to the Cluster Project and are fully described elsewhere in project-specific documentation. Some products for the PIs and some for the wider community are generated here.

Planning This provides mission planning information to support the SWT and the commanding activities described above. Products are supplied to the PIs and some products to the wider Cluster community.

Monitoring This provides a daily monitoring of mission progress and instrument performance on behalf of the SWT and the PIs. Products are entirely internal to the Cluster Project and are even specific to the appropriate PI.

Information Dissemination This provides dissemination of some of the products (some of which are specific to the PIs) from the other parts of JSOC and encompasses two mechanisms:

- a World Wide Web (WWW) interface for the majority of products;
- a special interface to the Cluster National Data Centres for some of the JSOC planning data base tables.

5.1 JSOC Services to PIs

As mentioned above, JSOC provides specific operational services for, and support of, its interfaces with the SWT, the PIs and ESOC for the purpose of constructing a coordinated payload command schedule which accurately, and safely, embodies the scientific objectives set by the SWT and the PIs themselves. These Project internal products and services are excluded from the descriptions offered here. What is described here are the products specifically generated for PIs which are made available by the Information Dissemination sub-system. PIs also have access to the products and services described in Sections 5.2 and 5.3.

All of these products and services are accessed through the WWW server at JSOC with the PI using an adequate browser (Netscape or Internet Explorer) at their own site. JSOC does not supply WWW browsers or any helper/viewer applications. The JSOC WWW address has been made available to the Cluster community but is only available beyond that in a controlled manner.

A total of six classes of products are available exclusively for the PI from the JSOC server and require username/password authentication to gain access.

1. Commanding Information, which is found under the *Cluster reports* link in the JSOC home page.

   This contains a series of further entries, one for each of the seven instrument groups (the five wave instruments constitute the WEC group), under each of which are found five plain text reports generated from the JSOC commanding database on a daily basis. These provide each PI with total visibility of:

- The MLUT (Mode Look-up Table) used to translate scientific mode changes into IBMDs.
- The definition of all the IBMDs used by JSOC to implement the scientific mode changes specified by the SWT and PIs.
- The sub-set of the PI command sequences used by JSOC in the definition of the IBMDs and in the generation of the coordinated command schedule.
- The parameter value files used in IBMD parameter name resolution when generating individual instrument schedules.
- The henceforth parameter value files used in IBMD parameter name resolution when generating the coordinated instrument schedule.

In addition, there is a further plain text file which describes the content and layout of the command sequence report.

2. Commissioning Information, which is found under the *Cluster reports* link in the JSOC home page.

   This contains information for the PIs for the JSOC commissioning slots during the Cluster CVP phase at the start of the mission. Each slot lies wholly within a planning period and contains a series of further entries.

   - One or more Predicted Event Time (PET) files for the planning periods used for JSOC commissioning. These are plain text files generated from the JSOC planning database.
   - One or more PDF plot files showing the location of the data acquisition period along the orbit.
   - A plain text file, generated from the JSOC commanding database showing the instrument science modes to be used during the JSOC commissioning.
   - The definition of the MLUT, the IBMDs, and the parameter value files specific to the JSOC commissioning slots.
   - A plain text file describing the JSOC commissioning plan.

3. PI Supplementary Inputs, which are found under the *Cluster reports* link in the JSOC home page.

   This contains a series of further entries, one for each of the seven instrument group under each of which is found a plain text file which specifies PI specific information supplemental to the strategic science input from the SWT. This information is instrument specific and will generally define additional constraints on instrument command schedule construction. In addition, there is a plain text file which specifies the general JSOC rules for commanding.

4. Predicted geometric position, which is found under the *Cluster reports* link in the JSOC home page.

   This is a plain text file containing the predicted geometric position report for each of the Cluster spacecraft. Resolution is at one hour intervals and the position is given in the GSE and the GSM coordinate systems in units of earth radii.

5. Predicted scientific position, which is found under the *Cluster reports* link in the JSOC home page.

This is a plain text file containing the predicted scientific position report for each of the Cluster spacecraft. Resolution is at one hour intervals and the corresponding magnetic local time, invariant latitude and L-shell value are given. Invariant latitude and L-shell value are null (shown as blank) when the spacecraft is outside the magnetosphere.

6. Local JSOC documentation, which is found under the *Additional documents* and tools link in the JSOC home page.

   This contains a further four entries to different categories of internal detailed JSOC documentation. All documentation is predominantly held as PDF files. The four areas are:

   `doc/` This holds the detailed JSOC design and interface documents. However, the definitive version of these files should always be obtained from the ESTEC document server.

   `TN/` This holds the JSOC Technical Notes. However, the definitive version of these files should always be obtained from the ESTEC document server.

   `IN/` This holds JSOC Internal Notes which normally are never made available outside JSOC.

   `esoc/` This holds documents specific to the interface between JSOC and ESOC.

5.2 JSOC Services to National Data Centres

JSOC also provides a service to the Cluster national Data Centres by providing them with regularly updated copies of five of its planning related databases. These tables contain the same type of information made available via JSOC's WWW server to the PI and wider Cluster communities but at full time resolution.

The frequency of the update depends upon the table and the actual mechanism of the transfer. Furthermore, the provision of these tables to the Cluster community is the responsibility of the national DCs and not JSOC, and is mediated through the CSDS Data Management System (CDMS) described in Section 6. Full details of the products and facilities offered by the CDMS and of how these can be effected are to be found in CDMS External Interface Control Document [ICD:CDMS].

These five tables are briefly described below, the definitive tabular descriptions of their contents are to be found in ICD:CDMS.

JPCY (JSOC Predicted Solar Cycle Trends). Contains predictions of the solar wind ram pressure, the standard deviation of the IMF B_z, the sunspot number.

JPGP (JSOC Predicted Geometric Positions Catalogue). This contains the predicted position and velocity of the reference satellite, the separations of the satellites from the reference satellite, the maximum and minimum inter-satellite separation, the Schoenmaeker quality factors, the GSE to GSM rotation angle and the dipole tilt.

JPSE (JSOC Predicted Scientific Events Catalogue). This contains the predicted times and positions (in GSE) of specific scientific events for each Cluster spacecraft. It also contains the predicted orbit and orbit phase, the magnetic local time and the GSM latitude.

JPSP (JSOC Predicted Scientific Positions Catalogue). This contains the predicted invariant latitude and magnetic local time of each satellite.

JSE (JSOC Scientific Events Catalogue). This contains the observed times and positions of the Cluster spacecraft as determined by JSOC from the Prime Parameter Data Base. Its contents are the same as for the JPSE.

5.3 JSOC Services to the Wider Community

JSOC also provides additional products and services for the wider Cluster community which are also accessed through the WWW server at JSOC with the user using an adequate browser at their own site. The JSOC WWW address has been made available to the Cluster community but is only available beyond that in a controlled manner. A total of nine classes of products and services are freely accessible to this wider community from the JSOC server.

DSN visibility which is found under the *Cluster reports* link in the JSOC home page.

This contains a set of PDF files, one for each Cluster planning period, where each PDF file contains three JSOC visibility plots—one for each of the three orbits comprising the planning period—giving the information needed to select periods for DSN downlink of data from the WBD instrument (spacecraft visibility from ESA and DSN ground stations with respect to the data acquisition periods).

BM3 slots which is found under the *Cluster reports* link in the JSOC home page.

This contains a set of PDF files, one for each Cluster planning period, where each PDF file contains three JSOC visibility plots—one for each of the three orbits comprising the planning period—giving the information needed to select periods for burst mode 3 dumps (spacecraft visibility from ESA ground stations with respect to the data acquisition periods).

Predicted Orbits which is found under the *Cluster reports* link in the JSOC home page.

This contains a set of PDF files, one for each Cluster planning period, where each PDF file contains three JSOC visibility plots—one for each of the three orbits comprising the planning period—showing the data acquisition periods and the regions of scientific interest along each orbit.

Predicted Events which is found under the *Cluster reports* link in the JSOC home page.

This contains four further entries:

All events predicted science and orbit events in plain text files.

Bryant plots graphical presentations—in the form of PDF files—of scientific regions through which the spacecraft are predicted to pass.

Deadlines plain text files showing the operational deadlines which the PIs and JSOC must work to.

PET a plain text file which describes the content and layout of the JSOC Predicted Event Times and which contains a further series of entries—one for each planning period—each of which contains an actual PET file.

Predicted STP activity report which is found under the *Cluster reports* link in the JSOC home page.

This contains a plain text file containing predicted solar cycle trends; the predicted monthly solar wind ram pressure and sunspot number.

Scientific events report which is found under the *Cluster reports* link in the JSOC home page.

This contains a plain text file containing the observed scientific events, determined by JSOC from the Prime Parameters.

General information in five further sources under the *Additional documents and tools* link in the JSOC home page. These are:

- The “Master Science Plan” (MSP) for each constellation (at an appropriate time during the mission). This is presented as a plain text file and as a PDF file.
- The set of “Top Level Instrument Schedule” (TLIS) files—one for each planning period of three orbits. These files are the computer-readable version of the MSP as implemented by JSOC. They include any adjustments introduced by JSOC to reflect rules specified by PIs and SWT (e.g., on calibration periods and instrument constraints). These files are the primary input into the JSOC command software.
- The “Satellite Situation Centre Software System” (at NASA/SPDS). This is a WWW link into a set of NASA/GSFC operated pages whose purpose is to support the NASA science program and in particular the ISTP.
- An anonymous FTP link to the public JSOC documentation held at JSOC.
- An anonymous FTP link to the public JSOC documentation held at ESTEC.

Ground-based facilities and space missions which is a link into a set of WWW pages maintained by the Cluster Ground-Based Data Centre which itself contains links to a number of WWW sites concerned with relevant ground-based facilities and other space missions. Of particular importance is the further link to the Ground-Based Data Centre from where one can link into the pages supporting the generation of “Auroral Oval Indices” on demand.

Forum which will be used to support electronic debates on topics of interest to the operations of the Cluster mission.

6 Cluster Data Management System—CDMS

In order for the various data sets at the national DCs to be efficiently exchanged among themselves, and then distributed to the national users, the CSDS Data Management System (CDMS) has been developed as a joint effort by the following establishments:

ESA, with centres ESTEC in Noordwijk, Netherlands

Institutet för Rymdfysik in Uppsala, Sweden

Rutherford Appleton Laboratory (as JSOC) in Didcot, United Kingdom

Queen Mary and Westfield College in London, United Kingdom

The history of this interface has been long and tumultuous. Originally planned as an ambitious multi-mission system for electronic data exchange in the days before the Internet was a household term, it then became a Cluster-specific software package called the *Cluster User Interface*. After JSOC took over its maintenance for Cluster-II, it was adapted to the WWW browsers, no longer requiring a dedicated local client. At this point it was renamed CDMS.

The collaborative efforts of all the CSDS data centres in testing and providing constructive feedback on the system have been highly appreciated by the development team, and have been a most valuable contribution to the system development.

6.1 CDMS Services to the National DCs

As described in Section 1.4, each national DC will generate PPDB and SPDB data as CDF files for their own instruments. These data will then be validated by the responsible PIs before they are made available to the user community. The CDMS permits the PIs to insert validation information into the CDF files (Section 7). Once the CDF files have been validated, the DC will perform two actions, both done with the use of the CDMS:

1. include the CDF files in their own public data base;
2. make the CDF files available for the other data centres for fetching.

At this stage the CDF files are actually available for the scientists that are served by the local DC, but not for those served by the other ones. Therefore, all DCs will use the CDMS software everyday to look up the other DCs, and to pick up the new CDF files that have recently been made available. These files are then copied to the local data base, thus becoming available to the local scientific community. When the German DC is interrogated, the CDMS also transfers any new Summary Parameter Plots files.

As far as the events catalogues are concerned, the CDMS will automatically update the copies stored in the DCs with the newest version, at regular intervals from the master catalogues in JSOC.

The CDMS permits the DCs to manage their own user community. They can register users, and give access rights. The access rights can be given both in terms of data type (PPDB and SPDB), as well as instruments and observation time intervals for the PP data.

Lastly, the CDMS provides utilities to manage the data bases in the national DC (remove data, backup data etc.) and logging of user access.

6.2 CDMS Services to the Scientists

Once the data are in the national DC, they can be accessed by the Cluster scientists by means of a WWW browser. (See Appendix B for a description of it usage.)

The CDMS permits the scientist to:

- Search in the data catalogues to identify data of interest in the PPDB SPDB.

  It is possible to search on observation time intervals, instruments, instrument modes, and other parameters for the CDF files. The result is either a set of files, or a set of data intervals within the files, depending on the wishes of the user.

- Search in the events catalogues to identify events and time periods of interest.

  The basic search keys in these catalogues are event types, event names, and time intervals.

- Fetch PPDB/SPDB CDF files. This function is linked to the search in the data catalogues, in that the files identified during a search can be retrieved. It is possible to retrieve subsets of the files (i.e., rather than retrieving the whole CDF file, a subset of the observation time interval of the file can be specified). The files can be retrieved in compressed form.

- Fetch SPP files. The scientists can fetch any of the available Summary Plot files to their own computer from their local DC.

- Visualise the PPDB/SPDB CDF files. This function covers possibilities for the scientists to plot the science data contained in the CDF files.

  One can select data in terms of spacecraft, instrument, and/or time interval, constraining the selection to the result obtained from a search of the data catalogues.

  – The selected data can be plotted as a simple time plot.
  – One can make multi-panel plots, or have several plots in the same panel.
  – The plots can be printed to a printer or to a PostScript file.

7 Data Validation

7.1 The Meaning of "Validated Data"

It is the desire of every Cluster PI to release only data that have been thoroughly checked against instrumental and systematic errors, and that have been reduced with the best possible, bug-free algorithms and subjected to the most precise and accurate calibration data. The scientific community should be presented only with reliable and useful physical measurements.

On the other hand, it is the goal of CSDS to make a selection of the Cluster data available to all Cluster co-workers for intercomparison purposes on the shortest possible timescale. This stands in contradiction to the legitimate expectation that the data be clean, accurate, and 100% reliable, since the effort to achieve such a standard can be very time consuming.

It is simply not possible to ensure that the high standards for published data be applied to the large quantity of CSDS data within the short time demanded. However, bearing in mind the Rules of Use in Section 1.7 on page 4 and the strict prohibition against the publication of the CSDS data without PI approval, the Cluster PIs agree to the following understanding on the validation of the CSDS data set.

> The CSDS online data are to be of the best quality consistent with the conflicting demands for fast turnaround versus usability and reliability. Each PI will validate his or her data set to guarantee that they are of "reasonable" quality, not to be compared with the "publication" quality normally expected of public data sets. This is fully in conformance with the aims and limitations of the CSDS, as a means of exchanging data for multi-instrument, coordinated data analysis among the Cluster investigator teams.

Furthermore, the user of CSDS data should pay attention to the data quality flag `Status[0]` (Section 2.1 on page 8 and Table 6 on page 15) and should also be aware of and have read the experimenters' caveat files contained in each CDF file. These caveats will contain more detailed warnings and clarifications on the quality and applicability of the data set.

In addition to this general statement on the definition of validated data, the various experiment teams intend to apply various procedures to achieve this aim.

ASPOC

The validation procedure of ASPOC CSDS data is described in DS-IWF-UM-0003, "Validation Procedure Document for the Austrian Cluster Data Centre", Issue 1, Rev. 1, 3 June 1999. Two types of validation are distinguished:

- PI Validation: metadata, science and housekeeping data are checked by the PI team. This is the standard procedure
- Emergency Validation: no checks; files are marked by a major caveat reading "Authorised by Emergency Validation. No checking of metadata or science/housekeeping data". This procedure applies in exceptional cases only; it covers files for which proper validation was impossible within the available time.

The criteria applied in the validation procedures are the following.

Global and variable attributes are checked at sample files in regular intervals for compliance with the specifications.

The **Epoch** variable is checked for increasing time, for being within the date of the file, and for an erroneous offset.

In the case of errors (time stamps out of sequence, duplicate time stamps, time stamps outside file date, offset) an error analysis is made. If the reason is due to a small number of bad time stamps in the raw data, then records with bad time stamps are flagged as "bad data", and a minor caveat is placed reading "file contains entries resulting from raw data with bad time stamps. These entries have been flagged as bad data." In the unlikely case of a major timing error that cannot be resolved within the time period allowed for validation, the original file is validated with a major caveat reading "File contains entries with bad time stamps."

The parameter **ion current** `I_ion` is checked against consistency with command timeline, instrument housekeeping information, and known physical properties of the instrument.

Apart from deviations internal to the instrument and apart from autonomous actions of the software on board the instrument the behaviour of these parameters is predictable. Therefore the value of the parameter is known within a certain range, the permitted bandwidth depending on the instrument mode. In all modes, however, the known features of the on-board software and the known physical limitations of the ion emitters define a well-known pattern. Deviations may be due to:

Instrumental effects of ion emitters. Data showing instrumental effects of the ion emitters are fully valid.

Timing errors. The start and end time of ion emission is checked against the command timeline and housekeeping data. Inconsistencies of the timing point to a failure mode of the emitter, in which case the data are valid, or are indicative of bad time stamps.

Errors in the data acquisition system, e.g. spikes during the first seconds after instrument turn-on or high voltage turn-on. The parameter production software attempts to cope with some of the known effects, but some spikes will remain in the parameters. These records are not flagged or deleted, but there will be a standard caveat referring to this feature. Other errors in the data acquisition system, e.g. due to a temporary malfunction of the instrument processor, or during data transmission, will be covered by a major caveat reading "Due to malfunction of the data acquisition system the parameter `I_ion` may not represent the actual ion current between record ... and ...."

Summarising the specific procedures for ASPOC, validation will be carried out in principle by the PI team. Otherwise a major caveat will be placed. The files contain a standard caveat covering known deficiencies of the instrument (e.g. data glitches immediately after power-on). Bad time stamps will be flagged if possible, and in any case a caveat will be placed. Deviations due to erroneous data acquisition or bad data transmission will result in a caveat.

CIS

The CIS instrument performance is regularly controlled, and caveats are prepared and inserted in the CSDS files. The users are thus strongly encouraged to read these caveats.

CIS CSDS parameters are mainly onboard calculated moments of the distribution functions. Calibration factor corrections, conversion to physical units, and coordinate transformations are performed on ground.

Preliminary information on inadequate counting rates, dead or saturated detectors, is given in the Caveats attribute.

Besides instrument sensitivity and calibration (anode, energy and species dependent), the accuracy of computed moments is mainly affected by the finite energy and angle resolution, by the finite energy range of the instruments, and by the dead- time of the detector response.

Some deviations are expected between HIA and CODIF parameters (different efficiencies as a function of energy).

CIS validation procedures:

1. Most of the SP data will be plotted.
2. Plot certain housekeeping parameters, and check limits.
3. Recover from CNES the ASCII file with all information about in-flight processing incidents.
4. Look at the warnings generated during SP and PP production.
5. Look at the caveat files created automatically from the limits placed on physical parameters.
6. Use all this information to select periods of PP data for plotting.
7. For some intervals high resolution colour spectra of the distribution function will be plotted to check the instrument detector response efficiency and isotropy.
8. Check for long-term tendencies in the detector efficiencies, to update calibration functions.
9. Whenever necessary, the automatically created caveat/attribute files will be edited and warning messages will be added.
10. CIS CSDS parameters validation is performed on data samples, is on a best effort basis, and depends on available manpower. It thus cannot cover all possible effects. The CSDS data quality is not for publication, and the users should contact the PI.

EDI

The validation of EDI data begins with the assignment of the data quality flag, i.e. Status Byte 0. The production software generates a set of quality parameters for each spin interval, including the number of good-quality beams in a spin, the reduced chi-squared of the triangulation analysis, the magnitude and angle errors of the computed drift velocity and the variance of the magnetic field. Based on these parameters the code then either rejects a spin (no output), or outputs the PP-data together with a quality assignment ("good", "caution", or "bad") in Status Byte 0. The reduced chi-squared is output as one of the data words. Some of the other quality parameters are output as 6 more status bytes, defined in Section 3.3 on EDI.

Once it was recognised that most users of the PP-data had no tools to filter the data according to the Status Bytes, we stopped outputting the data flagged as "bad", starting with the May 2001 data. The earlier data include the "bad" data, but this will be fixed with the first reprocessing of the data in the Spring of 2002. For internal use, we keep a separate set of CDF files that include the data flagged as "bad".

To further aid validation, some statistics are compiled in parallel during the production of EDI PP-data. These statistics document the success rate of the analysis program for each hour of the day being processed. In addition, statistics on the values of Status Byte 0, the method used, the quality of the beams used, and the reasons for failure are also compiled.

Once the PP-data are produced, 12-hour plots are generated, separately for the data flagged as "good", as "good" or "caution", and for all data, regardless of the quality assignment. These plots, and the statistics output are the basis for validation.

PEACE

See the PEACE Caveats section on page 30.

RAPID

The RAPID team emphasises that it is more important to get useful data online for comparison purposes than to have the very best final parameters in the CSDS database.

The online RAPID data have been checked by a member of the experiment team to eliminate obvious noise spikes occurring mainly at switch-on and mode changes.

Caveats are written to explain any instrumental or spacecraft problems that could render the data unusable. Such data are normally marked with fill values, and the caveats are intended only to explain the cause of the problem. There are three types of such caveats:

1. those generated automatically by the processing software when a problem has been detected;
2. date-tagged caveats contained in special caveat files prepared by the PI in advance of the data processing;
3. caveats inserted manually by the PI during validation.

For a description of possible problems, see the RAPID caveats on page 33.

DWP

The validation of the CSDS data products generated by the DWP PI software will be carried out in two stages. The first involves the validation of the `State_wec/Status_wbd` variables, the second the validation of the particle correlator related data words.

The validation of the `State_wec/Status_wbd` data words will involve

1. a comparison of the data words with the command logs to validate the times of mode changes and also changes in the instrument setup;
2. a comparison with the output from housekeeping analysis tools to ensure the correct values have been read and coded correctly within the data words. This provides an independent check for the values of the `State_wec/Status_wbd` data words.

The validation of the particle correlator variables consists of checking bit settings in the DWP status word which flag when the average electron count rate is either too low or saturates by becoming too high, this indicates that an ACF acquired within that time interval (and hence the corresponding CSDS particle correlator data variables) may be invalid. The default setting for the data validity is “use with caution” since the percentage significance variable is a statistical measure that the detected modulation is not produced as a random effect (i.e., for proper scientific use the particle correlator data must be compared with the corresponding wave data and PEACE electron data).

EFW

The EFW CSDS database validation is manually performed during the whole mission. It is done by inspection of graphically displayed EFW parameters on a standard format, using the ISDAT software package to access the SPDB and PPDB at the SDC. Validation control files are created manually, after which the formal validation is done using CDMS. The duty of validation lies with the EFW Co-I group at KTH, Stockholm (co-located with the SDC), but may be transferred to another EFW Co-I group in the future.

The turn-around time for validation is 2–3 months after the actual on-board data taking. The reception of data on CD-ROM and subsequent processing takes the order of 3 weeks. After this there is a delay in waiting for up-to-date FGM calibration files, which are used to get as high a quality as possible in the subtraction of the $V \times B$ induced electric field.

The EFW CSDS parameters are preliminary and not for publication. For more information on data quality and the operations of the instrument, please consult the EFW home page listed in Table 4 on page 6.

STAFF

STAFF procedure to validate the CSDS products:

- Prior to the reception of unvalidated products, the monitoring of the instrument is done using DDS data:
  - the in flight calibration is presently checked at CETP, possibly at JSOC in the future, by running a dedicated program. This is done after each execution of the calibration cycle that is programmed at list once per planning period (3 orbits).
    1. it compares to given thresholds the amplitude and phase responses of the STAFF instruments for different level of calibration signals.
    2. the different STAFF SA modes are checked.
    3. a report is sent by JSOC to the PI.
  - key housekeeping parameters are checked very quickly at ESOC and at WEC level (at Sheffield).

  Any report from ESOC or Sheffield is analysed at STAFF level, where all housekeeping parameters are visualised.
- A quality control software running with the production of PPD/SPD at CFC produces summary files for each PPD/SPD file.
  - it calculates for each parameter the average and variance values and checks for the number of missing and out of range values.
  - these files are systematically examined in the PI Institute.
- SPD and samples of PPD are visualised at the PI institute.
- In case of an anomaly being detected during one of the above steps, appropriate actions are taken.
- The PI or her representative (e.g. nominated CoI for a given period of time, say 2 months) will normally validate the products. One full week of availability of the non-validated PPD/SPD is the absolute minimum. (The first operational period has shown that this is feasible).
  - the validation of one week's data should take no more than half a day to the responsible scientist in routine. The first year of data processing has hopefully allowed to identify and correct most of the software bugs and recurrent low quality data.

  - the caveat file can be filled according to the validity of the data.
  - eventually some of the parameters fields, if invalidated, are filled by a dummy value.
- In the absence of validation after a certain delay, the CFC will send the data with the flag “non-validated data”.
- Nevertheless, the validation is done on the best effort basis, and the STAFF PPD/SPD cannot be considered as publication quality data.

WHISPER

The strategy for validation of CSDS Whisper data is to make use of computer tests.

Other tests (visual inspection of CSDS products, of DDS requested files, of science monitoring results) will take place in parallel, but not systematically. They will not be part of the standard validation procedure.

A caveat page and a validity flag will be prepared by the CSDS PI software installed at CFC, and be part of the control file released with the CSDS products. This file can be edited by the PI (or validator in charge) for a period of so many days between the date of PPD production and the date of final release. This provides a way to take account of the “other tests” results.

Two types of parameters are provided by WHISPER: `N_e_res` and `N_e_res_q`, related to the electron density. `E_pow_f4`, `E_pow_f5`, `E_pow_f6`, `E_pow_su` and `E_var_ts`, related to natural wave emissions.

The caveat page will show mainly:

- Information from onboard calibration for the day (Good, Bad, Non available)
- A two-entry cross table:
  - One entry for the type of data (`N_e` or `E_pow`)
  - One entry for the hour in the day.

  This table will be filled by a flag : H, M or L, indicating the level of tests (High, Medium or Low) passed successfully during the corresponding hour by the corresponding type of data.

Computer tests are :

- tests at instrument level. Detection of overflows (saturating signal) during time acquisitions will result in fill in values for the concerned parameter(s) at the concerned time.
- tests at DWP level. Failures of Whisper to DWP transfers, if detected, result in fill in values for the concerned parameter(s) at the concerned time.
- tests at decommutation level. Inconsistencies in block datation and/or size are detected and counted. Similarly for inconsistencies from all redundant information.
- tests on physical values. Inconsistencies between `E_pow` calculated from time samples and `E_pow` calculated from frequency samples are detected and counted.

A flag value H will be affected to data having passed all computer tests. A flag value M when a number of minor inconsistencies have been detected.

A flag value L when the number of minor inconsistencies is over the number above, or when major inconsistencies are detected.

MOREOVER, the `N_e` data type is calculated from an algorithm for resonance recognition, which cannot take account of all level of information available to the experimenter. The reliability of those data at the CSDS level is thus limited in an unknown and unquantifiable manner.

WBD

The WBD data acquired in real time by JPL/DSN (TDA mode 8) is delivered to The University of Iowa by ftp within a few hours after the end of data acquisition. Iowa preprocesses these data in order to bit and frame synchronise them and create a permanent WBD data archive of original, uncalibrated waveforms (8 bit) residing on CD-ROM at Iowa. Duplicate CD-ROMs will be prepared and distributed on a regular basis to the French, British, and Scandinavian Cluster data centres. The preprocessing program was validated by the Cluster WBD Science Data Manager prior to launch using test data products. Because of ongoing and newly-discovered time problems since launch associated with the Cluster OBDH, this preprocessing program is modified from time to time to correct, if possible, for these timing problems. Every time the program is modified, the Cluster WBD Science Data Manager validates the modified program using test data and WBD data obtained since launch. Once the modified preprocessing program has been validated, it is restricted to read and execute only. The preprocessing program checks for bad data flags in the DSN data product, valid ground receive time, a reasonable comparison between the ground receive time and time computed using the onboard time tag, and complete waveform snapshots (1 minor frame or 1096 bytes). In addition to writing the valid and complete waveform snapshots to CD-ROM, the program also creates frequency-time spectrograms which are used by the Cluster WBD Science Data Manager as a means of validating the data before distribution. The program will not do any other type of processing, such as calibrating the data, checking for and discarding interference, etc.

During preprocessing of the TDA mode 8 data, the start and stop times and instrument mode of the WBD data acquired by JPL/DSN will automatically be written into an ASCII file on the Cluster WBD computer server. This file is sent electronically to a CSDS representative at the German Data Centre for inclusion in the SPDB. The start and stop times contained in the file will correspond to those times when valid data have been detected by the preprocessing program. These times will be checked against the JPL/DSN WBD data downlink schedule. Any significant departures from these scheduled downlink intervals will be investigated, first by scanning the original data files received from JPL/DSN, and second by reviewing the JPL/DSN anomaly reports for any problems encountered during data acquisition. No attempt will be made to screen out time periods in which there are interference, constant data dropouts, and the like. The ASCII files of start/stop times will not be released until the data for those time periods have been validated as described in the previous paragraph.

The WBD burst data (TDA Mode 5.2, or BM2) are obtained through a serial interface between WBD and DWP. In this mode WBD data are transferred to DWP, which reduces the data by a factor of three either through digital filtering or duty cycling. The reduced data set is then transferred to the OBDH system for recording and subsequent playback. Once these data have been retrieved from the CDDS Raw Data Medium, a similar validation technique as described in the first paragraph of this subsection will be employed. Note that the BM2 mode of taking WBD data will primarily be invoked only if DSN is unable to achieve the taking of multi-spacecraft WBD data, and only then, at most one time per month per spacecraft for a time span of one hour on each spacecraft, usually simultaneously on all four spacecraft.

Auxiliary Parameters

During the validation procedure of the Auxiliary data, minor caveats will be indicated when:

- some data are missing for a certain time interval (e.g. attitude data are not provided by ESOC during manoeuvres);
- the status word is unreliable for a certain time interval since there was no precise information available on the actual telemetry mode running on any of the satellites.

8 Online Documentation for CSDS

In order to simplify distributing documentation among the CSDS participating organisations, ESTEC has established an FTP file server to act as a central depository for important papers in electronic form. Although originally intended to allow the DCs and other agencies to exchange their controlling documents, it also contains many reports and technical notes of interest to the general CSDS user community. This *Users Guide* is an example of one such document. All the files on the server may be obtained by anonymous FTP transfer by any user in the Internet.

Several of the references in this *Guide* listed on pages 103–105 are to be found on this server. The file names of these documents are given in the reference listing.

One may obtain these documents either by classical FTP, typing everything in as a command line, or with an Internet browser, at the address

`ftp://ftp.estec.esa.nl/pub/csds`

However, the easiest way for the general user to find and download the most relevant documents is to go to the Web page

`ftp://ftp.estec.esa.nl/pub/csds/task_for/csdsdocs.html`

This page, shown in Figure 4 on the next page lists those documents that might be of interest to the CSDS users, sorted by topic, with a direct link to the most current version of that document.

The first two entries are perhaps the most important of all: this *Users Guide* and the book *Analysis Methods for Multi-Spacecraft Data* [Paschmann and Daly, 1998].

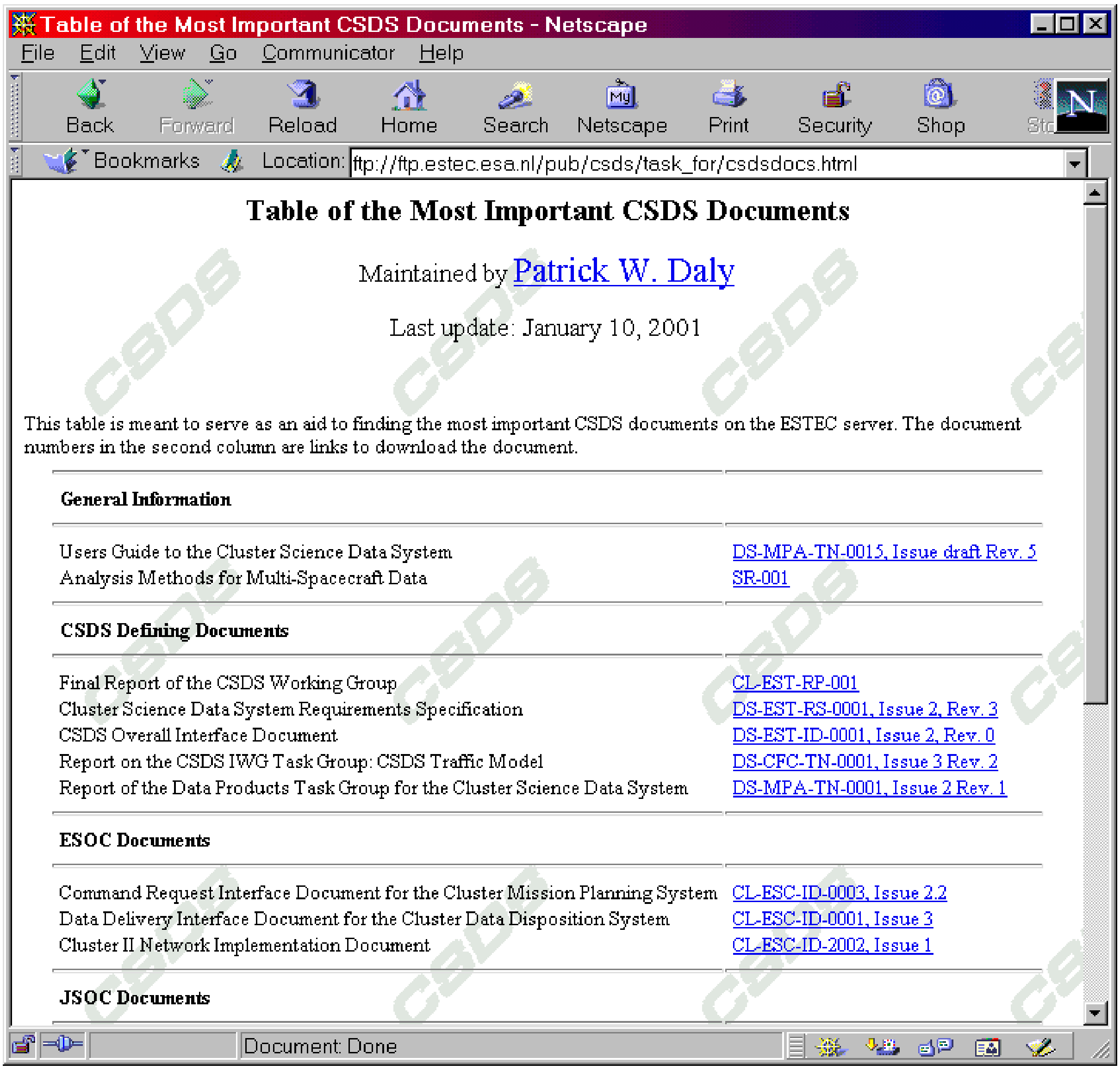

Table of the Most Important CSDS Documents

Maintained by Patrick W. Daly

Last update: January 10, 2001

This table is meant to serve as an aid to finding the most important CSDS documents on the ESTEC server. The document numbers in the second column are links to download the document.

General Information	
Users Guide to the Cluster Science Data System	DS-MPA-TN-0015, Issue draft Rev. 5
Analysis Methods for Multi-Spacecraft Data	SR-001
CSDS Defining Documents	
Final Report of the CSDS Working Group	CL-EST-RP-001
Cluster Science Data System Requirements Specification	DS-EST-RS-0001, Issue 2, Rev. 3
CSDS Overall Interface Document	DS-EST-ID-0001, Issue 2, Rev. 0
Report on the CSDS IWG Task Group: CSDS Traffic Model	DS-CFC-TN-0001, Issue 3 Rev. 2
Report of the Data Products Task Group for the Cluster Science Data System	DS-MPA-TN-0001, Issue 2 Rev. 1
ESOC Documents	
Command Request Interface Document for the Cluster Mission Planning System	CL-ESC-ID-0003, Issue 2.2
Data Delivery Interface Document for the Cluster Data Disposition System	CL-ESC-ID-0001, Issue 3
Cluster II Network Implementation Document	CL-ESC-ID-2002, Issue 1
JSOC Documents	

Figure 4: Web page listing the most relevant CSDS documents, with links

A Layout of the Summary Plots

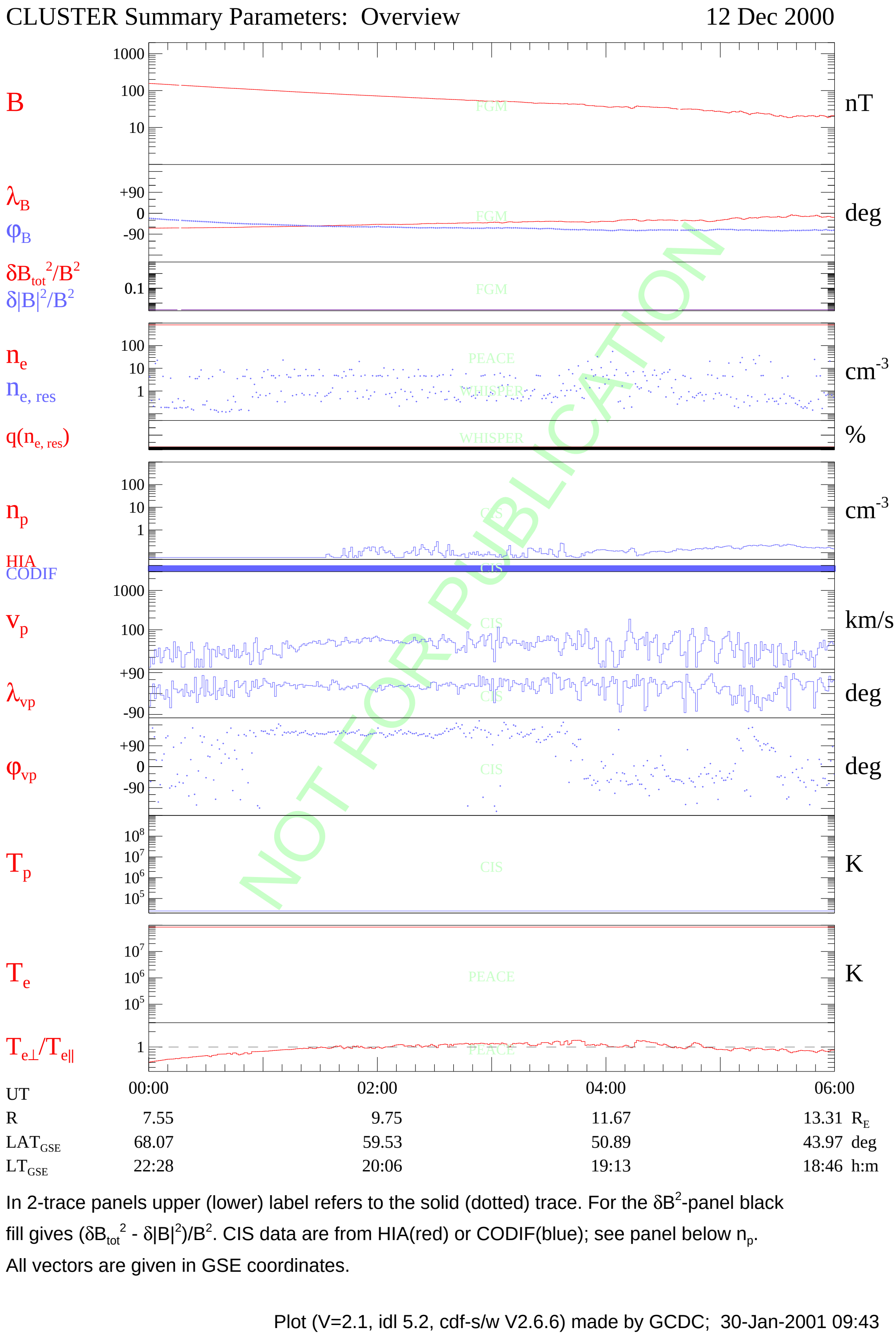

Figure A1: Summary Plot: Overview Page

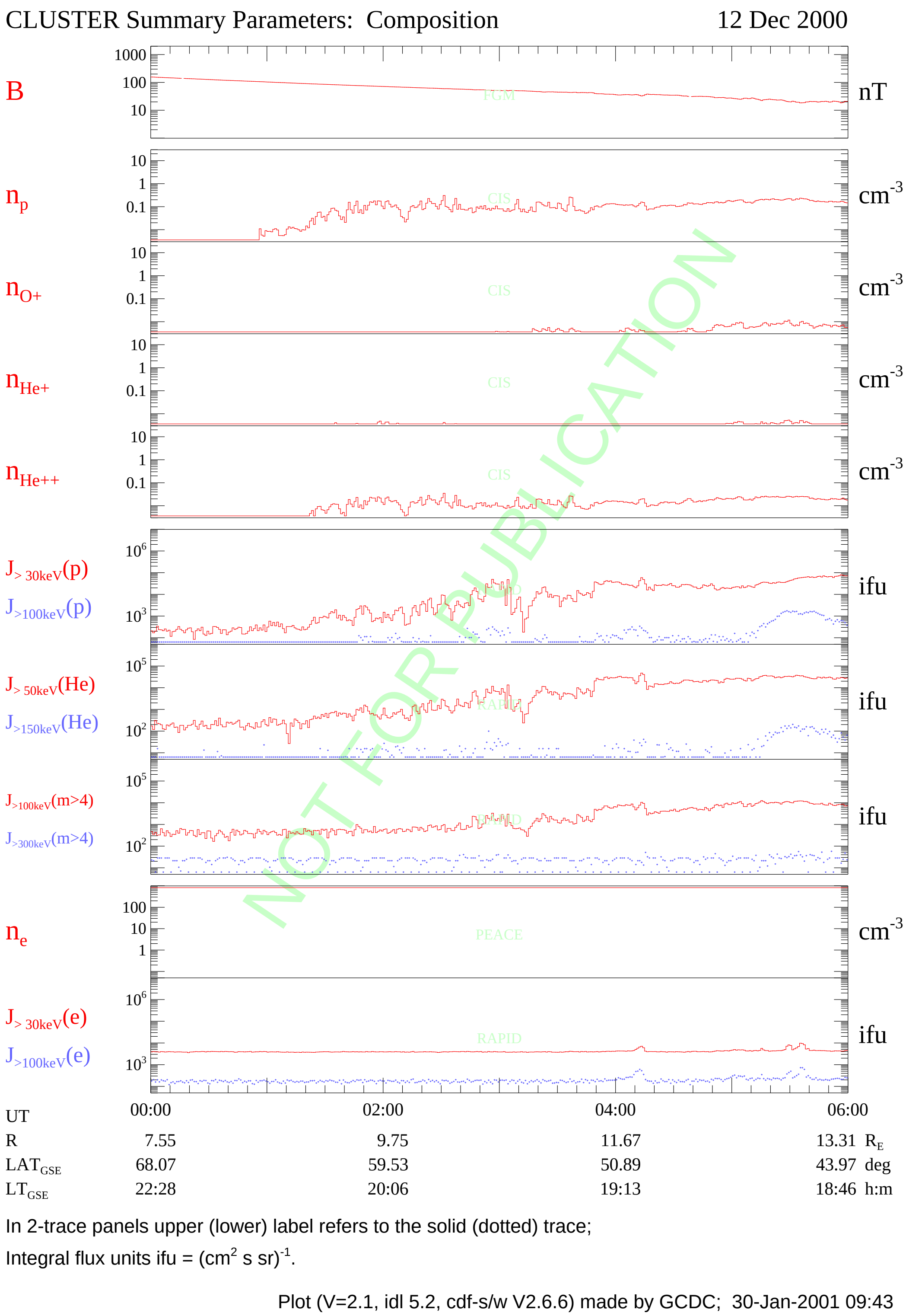

Figure A2: Summary Plot: Composition Page

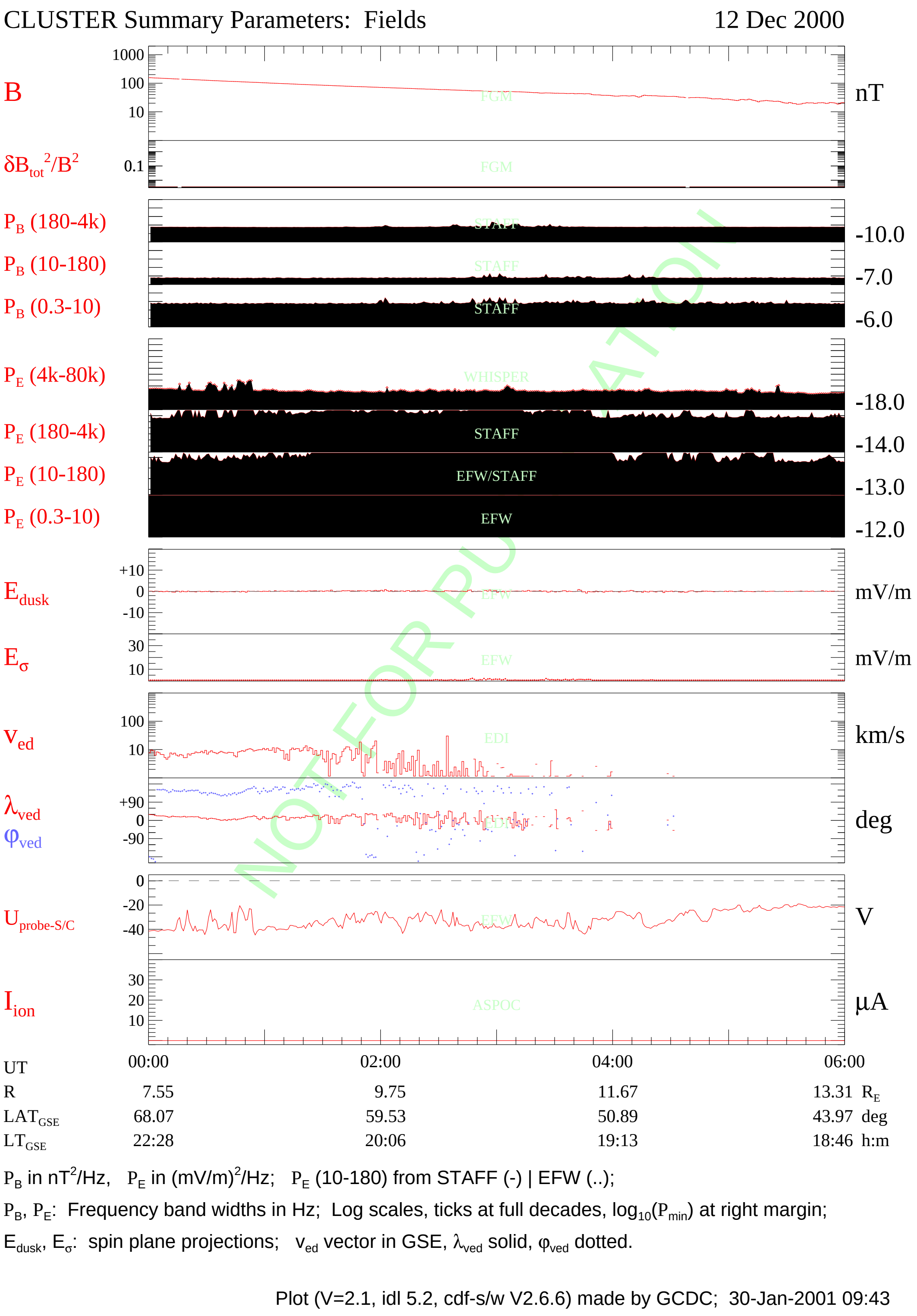

Figure A3: Summary Plot: Fields Page

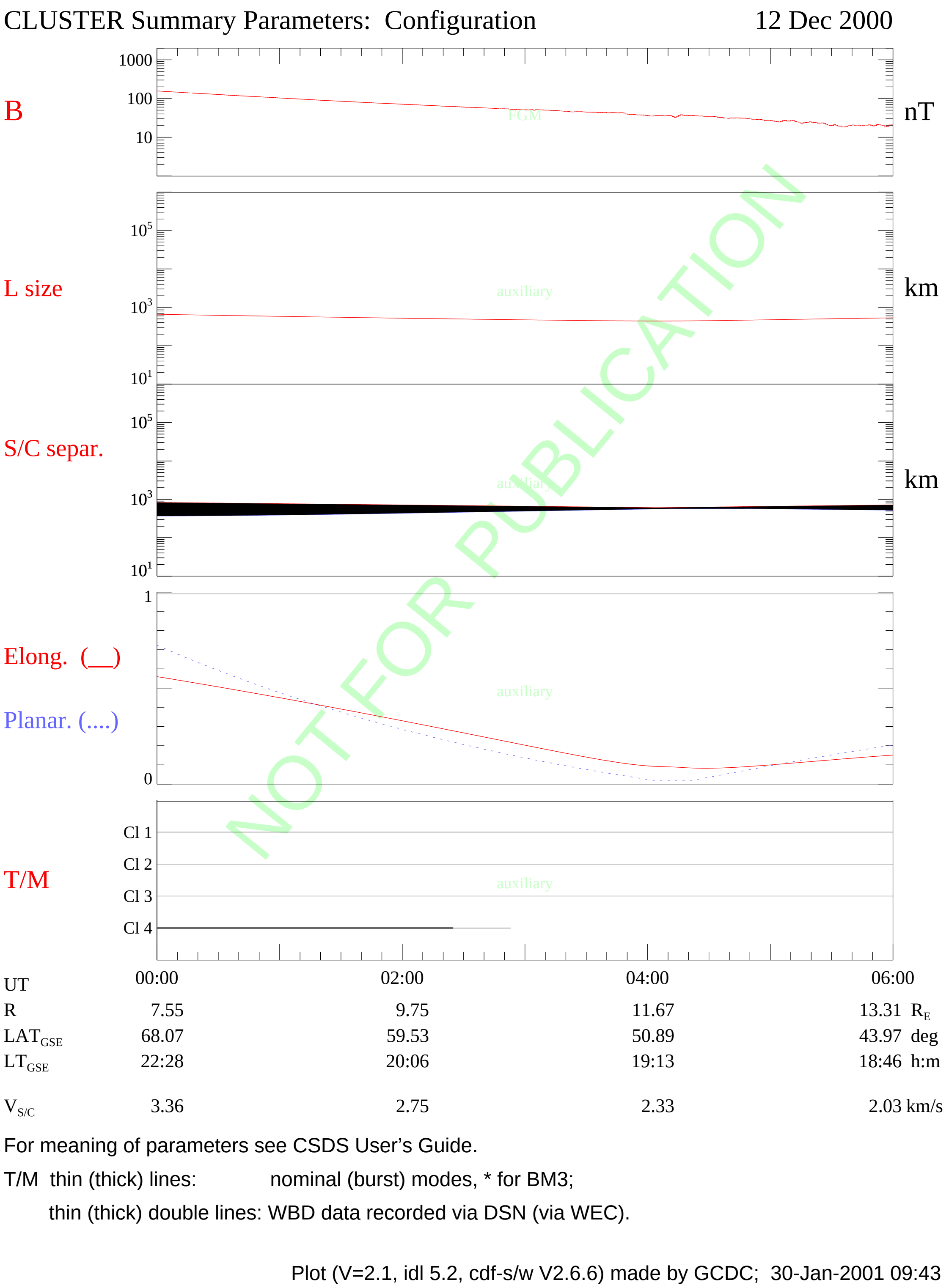

Figure A4: Summary Plot: Spacecraft Page

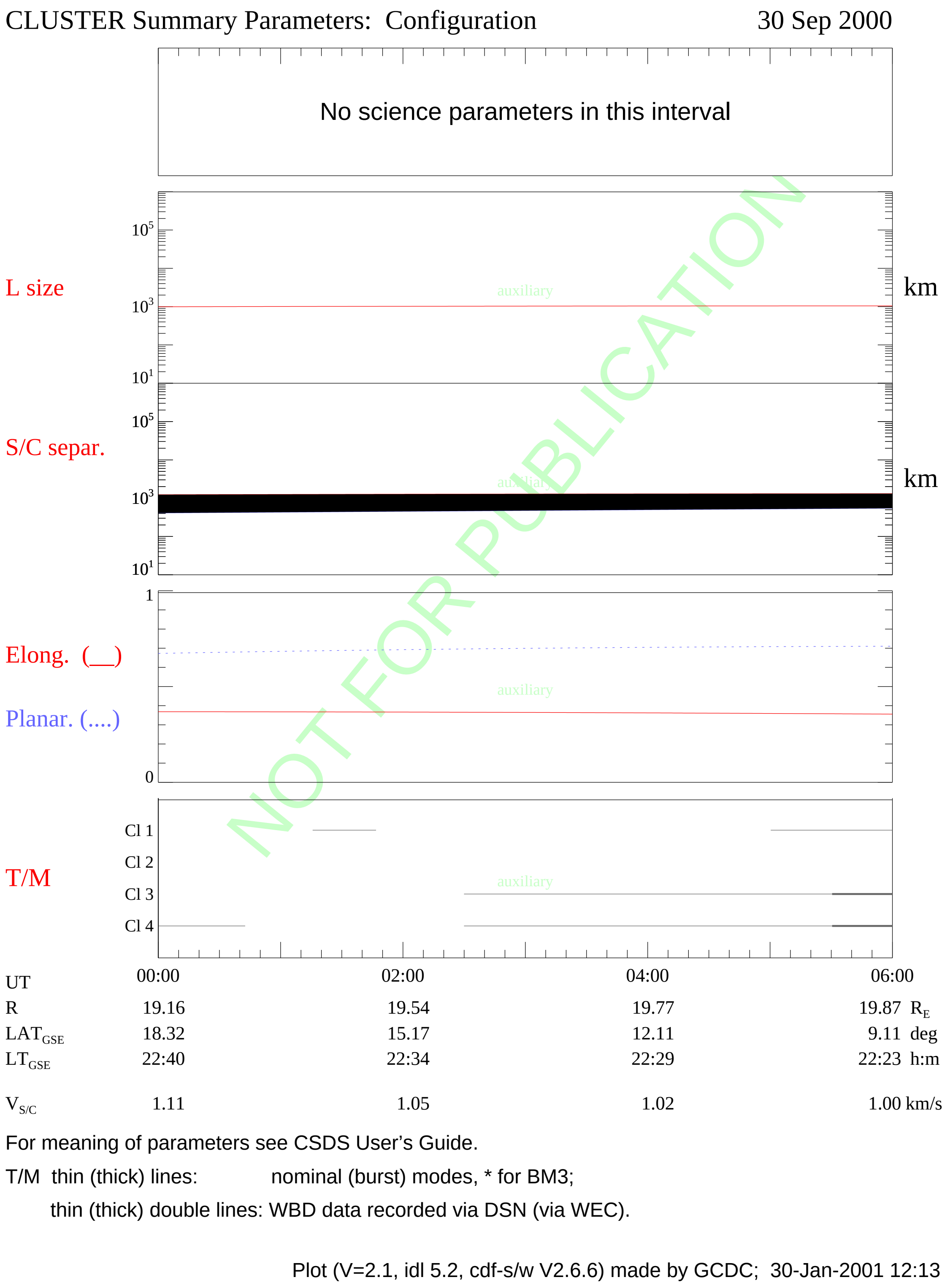

Figure A5: Summary Plot page for an interval without any science data

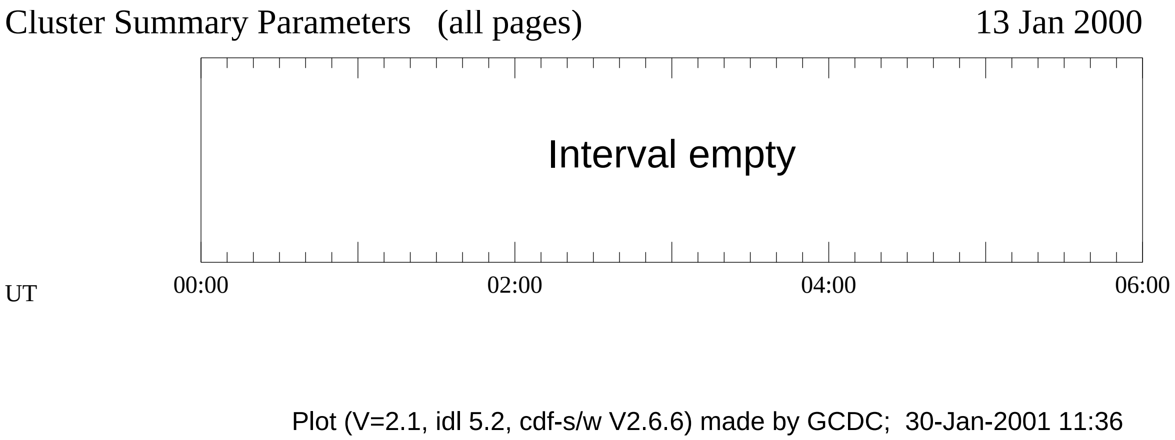

Figure A6: Summary Plot page for an interval containing no data

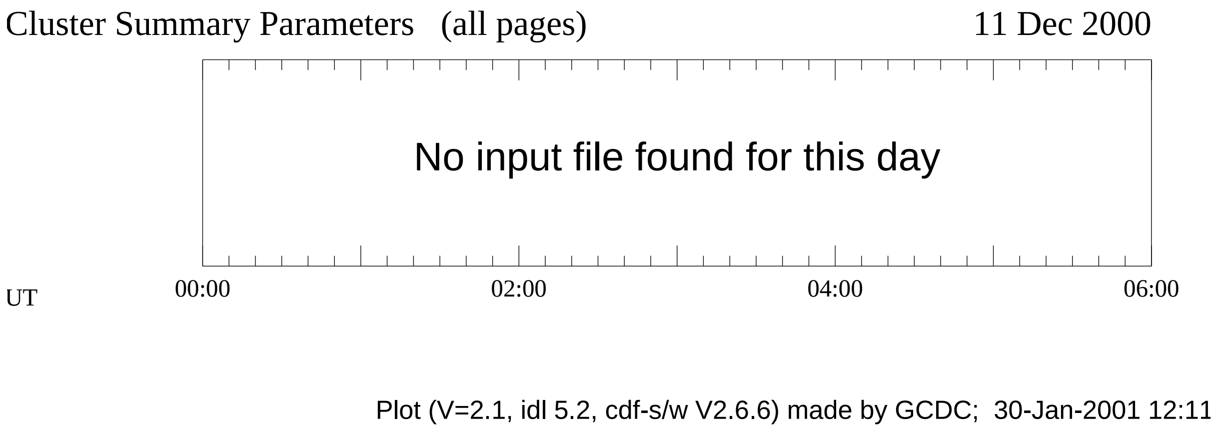

Figure A7: Summary Plot page for an interval for which no CDF files exist

B CDMS Usage

Access to the CDMS should be done via the user's national Data Centre, or through the DC that has been assigned to his or her country. The best way to do this (the first time) is with the CSDS Web page (`http://sci2.estec.esa.nl/cluster/csds/csds.html`), illustrated on the title page of this document. Clicking on the text "CSDS Ring" at the right leads to the page shown in Figure B1 below. At this point, one selects the appropriate DC by clicking on its box.

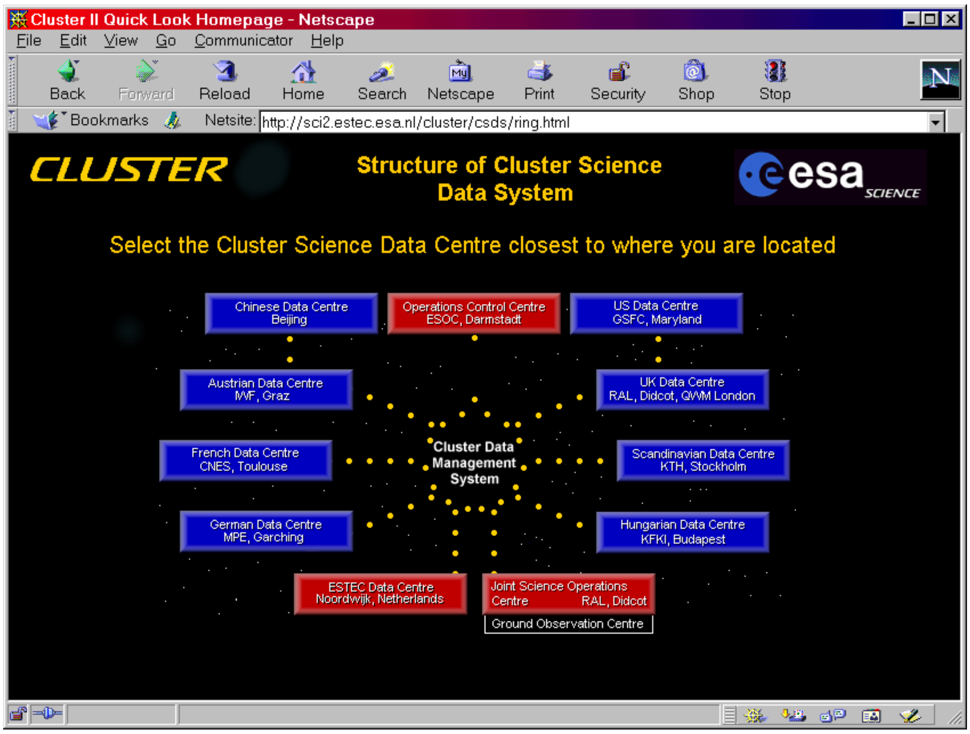

Figure B1: The CSDS Ring: quick entry to the national DCs

For users who are in a country without a national DC, and who are uncertain which DC has been assigned to them, the link under "Access Points" on the CSDS home page offers a list of countries linked to the correct DC.

Logging into the German Data Centre, for example, produces the display in Figure B2. Here one selects the type of data one wants: *proprietary* for the PPDB; *public* for the SPDB; *summary plots*; and *JSOC catalogues*.

Figure B2: The CDMS welcome page

> **Note:** access to the PPDB is restricted to the Cluster community; these users have been assigned a username and password by the Data Centre. To obtain this authorisation, send an email to the DC manager whose address appears at the bottom of the welcoming page.

The other data sets are available to the world. However, some DCs request that users register with them anyway (to obtain a username and password) so that they may keep an overview of who is using their services.

Selecting the *proprietary* (PPDB) data, leads the user to the page in Figure B3.

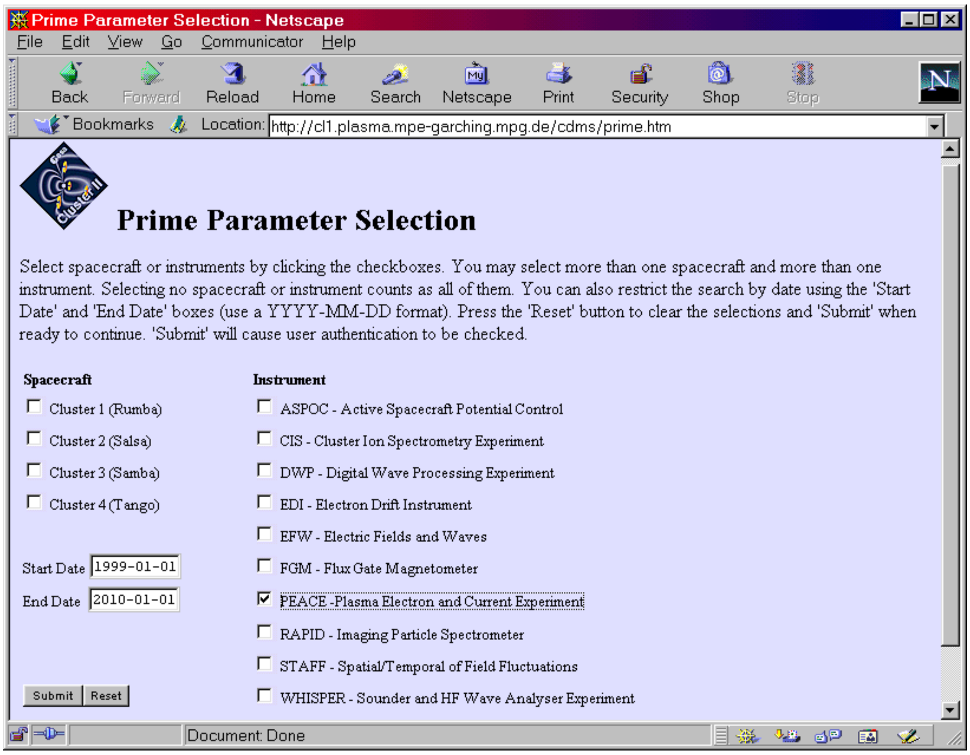

Figure B3: PPDB selection page

Here one selects the experiment and spacecraft that one is interested in, for example, PEACE for all spacecraft (none is the same as all).

After selecting the experiment(s) and spacecraft, and setting the time interval, one presses ***Submit*** to enter the request. The result appears in Figure B4, where all the data files matching the request conditions are listed.

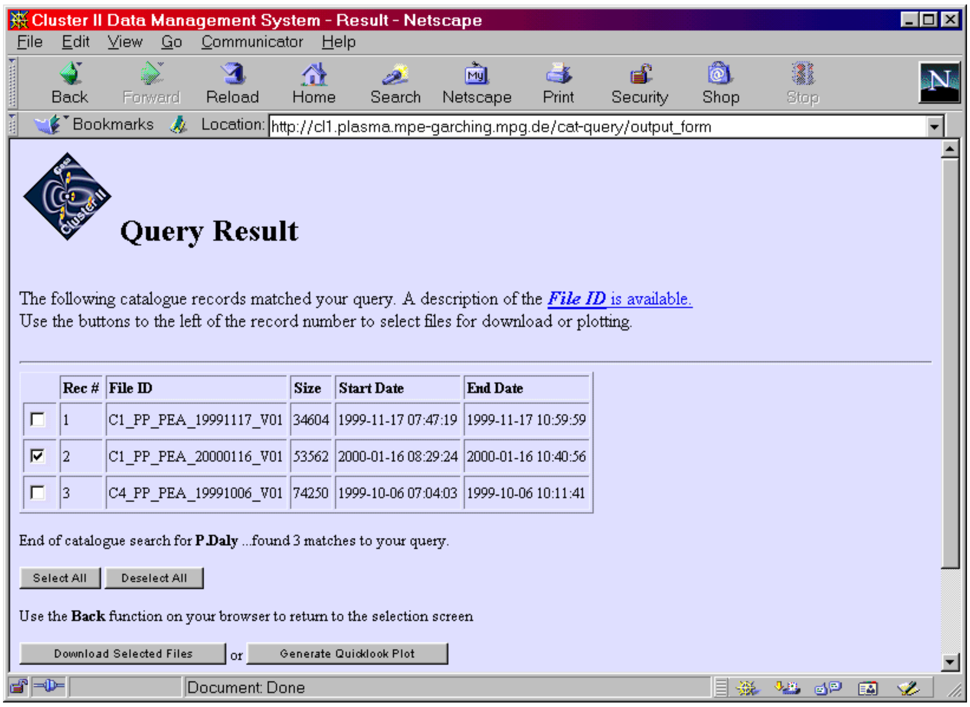

Figure B4: Result of catalogue search

Now one selects the files for downloading to the local computer, or for plotting. Press ***Download Selected Files*** or ***Generate Quicklook Plot*** accordingly. Pressing the latter leads to the page in Figure B5.

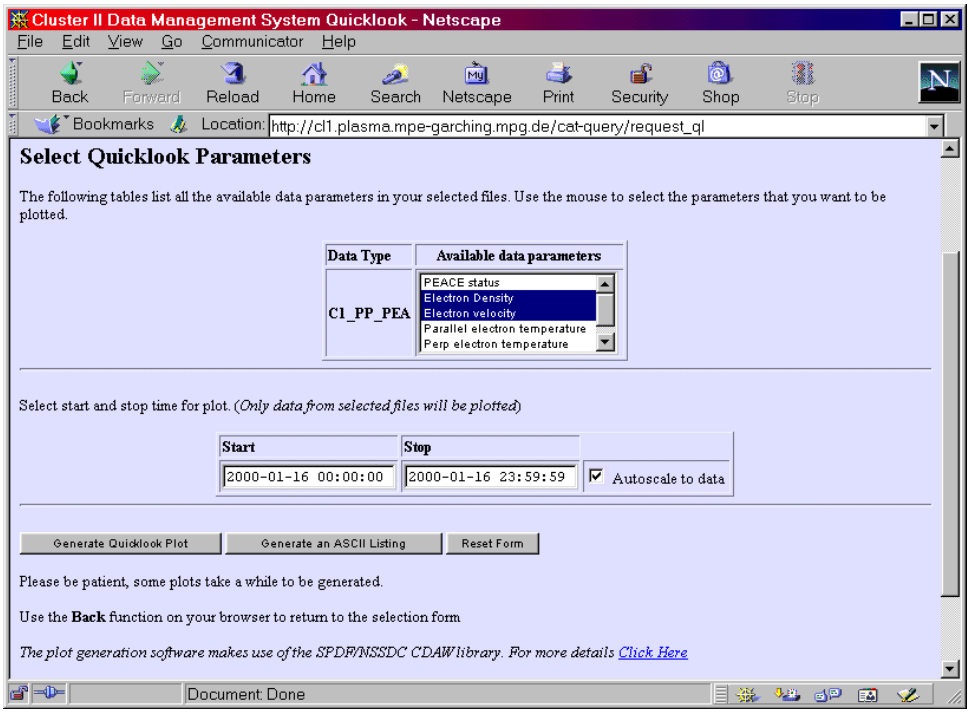

Figure B5: Selection of parameters to plot

One now selects the parameters to plot (here electron density and velocity) and sets the time limits. Then one presses one of the buttons ***Generate an ASCII Listing*** or ***Generate Quicklook Plot***.

The public data sets SPDB and JSOC catalogues can be selected, downloaded, plotted (where meaningful) in similar fashion (Figures B6 and B7).

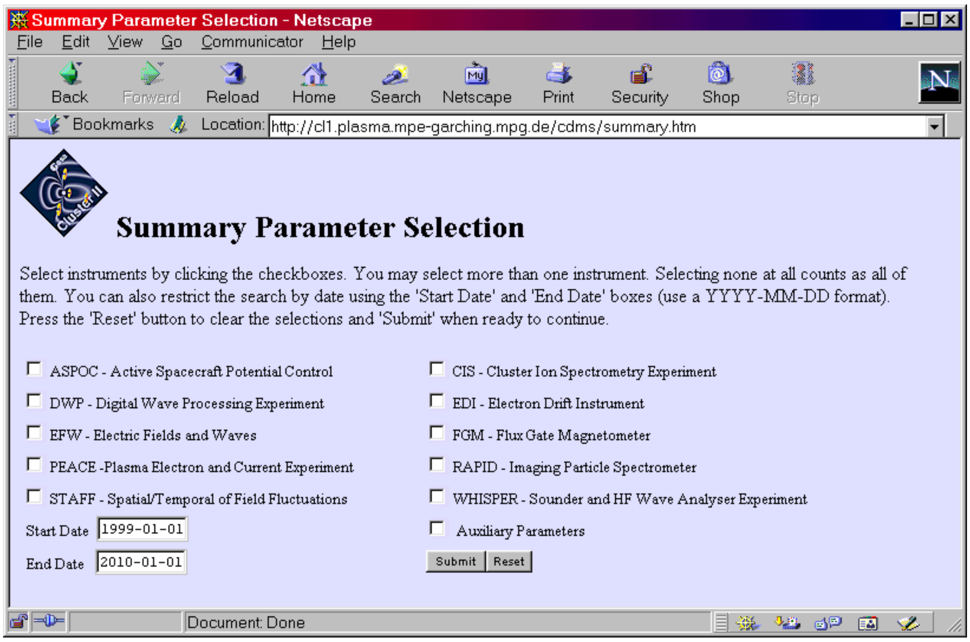

Figure B6: SPDB selection page

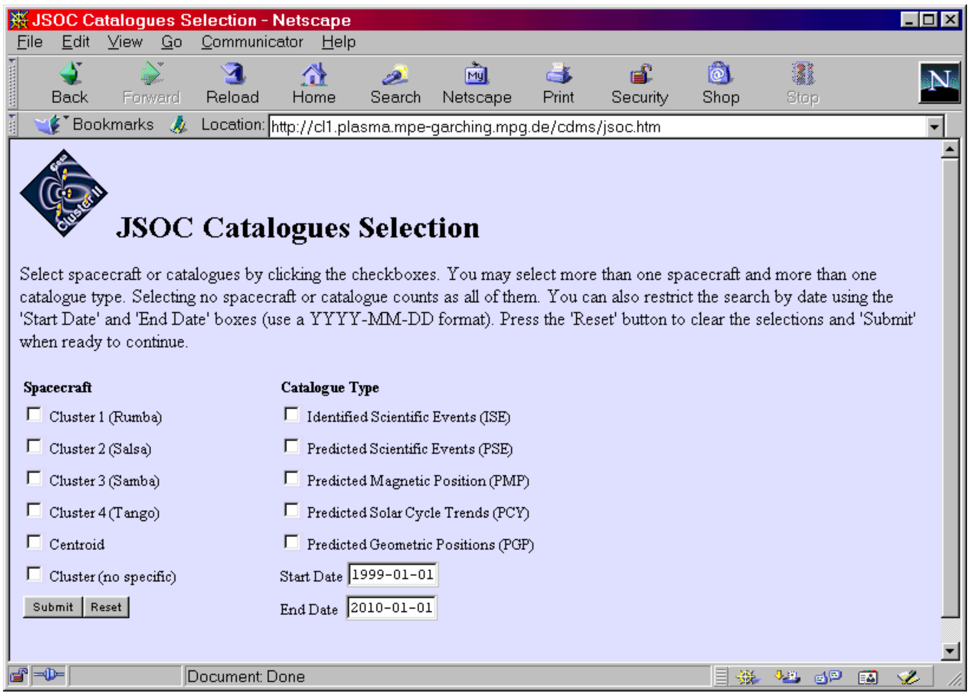

Figure B7: JSOC catalogue selection page

The Summary Plots are available as zipped PostScript files which are not part of the CDMS cataloguing system. Selecting them leads to a list of the available files (Figure B8) which can be manually downloaded to the local machine for unpacking and printing.

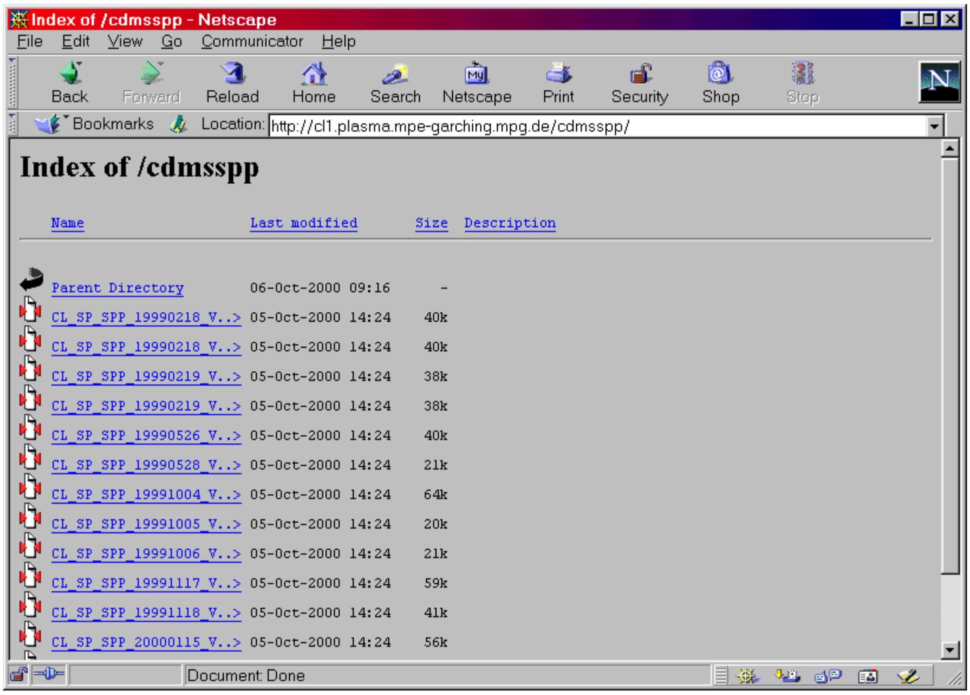

Figure B8: Index of Summary Plots

C The Size, Elongation and Planarity of the Tetrahedron

The auxiliary parameters elongation E, planarity P, and characteristic size L of the tetrahedron, mentioned on page 62, are defined by Robert et al. [1998] in Chapter 13 of the ISSI book [Paschmann and Daly, 1998]. The directions of the axes of elongation and planarity are specified in the Summary Parameter Data Base by their latitude and longitude in the GSE system.

<table>
<tr><th>P \ E</th><th>0</th><th>low</th><th>interme-diate</th><th>large</th><th>1</th></tr>
<tr><td>1</td><td>Circle</td><td colspan="3">Ellipse of increasing eccentricity</td><td rowspan="5">Straight Line</td></tr>
<tr><td>large</td><td rowspan="3">Ellipsoid of increasing oblateness</td><td>Pancake</td><td>Elliptical Pancake</td><td>Knife Blade</td></tr>
<tr><td>interme-diate</td><td>Thick Pancake</td><td>Potatoes</td><td>Flattened Cigar</td></tr>
<tr><td>low</td><td>Pseudo-Sphere</td><td>Short Cigar</td><td>Cigar</td></tr>
<tr><td>0</td><td>Sphere</td><td colspan="3">Ellipsoid of increasing prolateness</td></tr>
</table>

Figure C1: The shape of the polyhedron as a function of E and P

To obtain a feeling for the meaning of these parameters, imagine that a regular polyhedron, for which $E = P = 0$, can be represented by a sphere. Increasing E corresponds to squeezing the sphere so as to form a prolate ellipsoid (cigar-shape), while increasing P corresponds to squashing it to form an oblate ellipsoid (disc-shaped). Whatever the number of spacecraft, E and P lie in the range

$$0 \leq E \leq 1, \quad 0 \leq P \leq 1$$

and the characteristic dimensions of the polyhedron are L (direction of elongation), $(1 - E)L$ (third mutually orthogonal direction), and $(1 - P)(1 - E)L$ (direction of planarity). The shape of the polyhedron as a function of E and P is illustrated in Figure C1 [taken from Robert et al., 1998].

The Summary Parameters Data Base will always provide numerical (i.e., not fill) values for these parameters (except occasionally in the JSOC catalogue when the predicted geometric position (PGP) is unavailable). Therefore it is important to note that some values may not be meaningful:

1. When $P = 0$, the planarity is zero, its direction is undefined, and the corresponding direction cosines are meaningless.
2. When $E = 0$, the elongation is zero, its direction is undefined, and the corresponding direction cosines are meaningless.

3. When $E = 1$, neither the planarity P nor its direction are defined, and the returned values of P and its cosines are meaningless.

Of course, none of the limit conditions will ever occur exactly. But as E or P approach these values so the corresponding direction (and the planarity in the case of $E = 1$) information becomes physically more irrelevant (the values become meaningless, rather than wrong). For a better evaluation of the utility of these parameters, the orbital covariance matrix must be used.

For four spacecraft, the parameters L , E, and P have the following geometrical interpretation:

1. Whatever the shape of the tetrahedron, its volume is $\frac{1}{3}(1 - P)(1 - E)^2 L^3$.
2. When $E = P = 0$ the tetrahedron is regular, the inter-spacecraft separation distance is $\sqrt{2}L$, and the sphere which passes through all four spacecraft has a radius of $\sqrt{3}L/2$.
3. When $P = 1$ the spacecraft are coplanar, and define a quadrilateral which has an area between
   - $\frac{1}{\sqrt{2}}(1 - E)L^2$ in the case of a triangle with two spacecraft coincident, and
   - $(1 - E)L^2$ in the case of a parallelogram.

   When the quadrilateral is "re-entrant" (one of the interior angles is $> 180°$), the area of the triangle defined by the outermost three spacecraft lies within this range; in particular, within this triangle there is a local maximum of $\frac{\sqrt{3}}{2}(1 - E)L^2$ when the fourth spacecraft is located at the common centre of mass.
4. When $E = 1$ the spacecraft are collinear along a line which has a length between
   - L for two pairs of coincident spacecraft, and
   - $\sqrt{2}L$ when two spacecraft are coincident and midway between the other two.

For fewer than four spacecraft, similar expressions apply, but some of the numerical constants have slightly different values.

D Tetrahedron Quality Factors

Four points in space define a *tetrahedron*. If the separations between each pair of points are equal, then it is a *regular* tetrahedron. The four Cluster spacecraft will form a tetrahedron, which in general is not regular. How can we specify the degree to which regularity is achieved?

The 'G' Quality Factor

The parameter proposed by vom Stein, Glassmeier, and Dunlop [1992] is defined as

$$Q_G = \frac{\text{True Vol.}}{\text{Ideal Vol.}} + \frac{\text{True Surf.}}{\text{Ideal Surf.}} + 1 \tag{D1}$$

and takes on values between 1 and 3. It tends to describe the dimensionality of the figure, as listed in Table D1. The *ideal* volume and surface are calculated for a regular tetrahedron with a side length equal to the average of the 6 distances between the 4 points.

The 'R' Quality Factor

In their paper on tetrahedron shape, Robert and Roux [1993] present 17 different parameters, as ratios of various volumes, sizes, areas. Of these, the CSDS community has decided to adopt one as its second quality parameter for the auxiliary data. It is defined as

$$Q_R = \mathcal{N} \cdot \left(\frac{\text{True Vol.}}{\text{Sphere Vol.}} \right)^{\frac{1}{3}} \tag{D2}$$

where the sphere is that circumscribing the tetrahedron (all four points on its surface) and $\mathcal{N}$ is a normalisation factor to make $Q_R = 1$ for a regular tetrahedron. The range of values is between 0 and 1.

Mathematics of a Tetrahedron

Consider four points in space and the figure formed by joining them with lines (Figure D1). The points are numbered 0 to 3, and their vectors are $\mathbf{r}_0$, $\mathbf{r}_1$, $\mathbf{r}_2$, $\mathbf{r}_3$. Without any loss of generality, we may consider only the differences

$$\mathbf{d}_i = \mathbf{r}_i - \mathbf{r}_0$$

in describing the points.

Table D1: Some special values of the G Quality Factor

Q_G	Meaning
1.0	The four points are collinear
2.0	The points all lie in a plane*
3.0	A regular tetrahedron is formed

*A value between 1.0 and 2.0 does not indicate coplanarity.

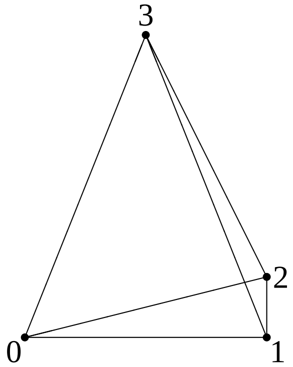

Figure D1: A tetrahedron and its four vertices.

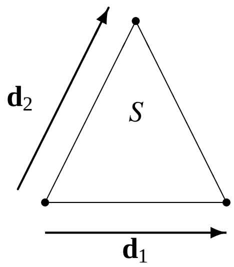

Figure D2: Area S of a triangle.

Area of a Side

The area of a parallelogram bounded by two vectors $\mathbf{d}_1$ and $\mathbf{d}_2$ is given by the magnitude of their cross product; any triangle is half of a parallelogram, so its area is

$$S = \frac{1}{2}\,|\mathbf{d}_1 \times \mathbf{d}_2|$$

where $\mathbf{d}_1$ and $\mathbf{d}_2$ are the vectors for any two sides of the triangle (Figure D2).

For the four sides of the tetrahedron, specify side n to be that one that does not contain point n at any of its vertices. Thus:

$$S_1 = \frac{1}{2}\,|\mathbf{d}_2 \times \mathbf{d}_3| \quad \text{(D3)}$$

$$S_2 = \frac{1}{2}\,|\mathbf{d}_1 \times \mathbf{d}_3| \quad \text{(D4)}$$

$$S_3 = \frac{1}{2}\,|\mathbf{d}_1 \times \mathbf{d}_2| \quad \text{(D5)}$$

$$\begin{aligned} S_0 &= \frac{1}{2}\,|(\mathbf{d}_2 - \mathbf{d}_1) \times (\mathbf{d}_3 - \mathbf{d}_1)| \\ &= \frac{1}{2}\,|\mathbf{d}_1 \times \mathbf{d}_2 + \mathbf{d}_2 \times \mathbf{d}_3 + \mathbf{d}_3 \times \mathbf{d}_1| \end{aligned} \quad \text{(D6)}$$

The total surface S is the sum $\sum_{n=0}^{3} S_n$.

Volume of a Tetrahedron

The volume of a figure bounded by three vectors in space is the triple product of those vectors. Any tetrahedron is 1/6 of such a figure, hence

$$V = \frac{1}{6}\,|\mathbf{d}_1 \cdot \mathbf{d}_2 \times \mathbf{d}_3| \tag{D7}$$

$$= \frac{1}{6}\begin{vmatrix} d_{1x} & d_{1y} & d_{1z} \\ d_{2x} & d_{2y} & d_{2z} \\ d_{3x} & d_{3y} & d_{3z} \end{vmatrix} \tag{D8}$$

Centre of Circumscribed Sphere

To find the circumscribed sphere, we need the point that is equidistant from all four vertices, i.e. we want $\mathbf{r}$ such that

$$\begin{aligned} (\mathbf{r} - \mathbf{r}_n) \cdot (\mathbf{r} - \mathbf{r}_n) &= \rho^2; \quad \forall n = 0, 3 \\ r^2 - 2\mathbf{r} \cdot \mathbf{r}_n + \mathbf{r}_n^2 &= \rho^2 \end{aligned}$$

If we take point 0 as the origin, that is, if we use the $\mathbf{d}_n$ vectors in place of the $\mathbf{r}_n$, then $r^2 = \rho^2$, the sphere radius, and the above 4 equations reduce to

$$2\mathbf{r} \cdot \mathbf{d}_n = d_n^2; \quad n = 1, 3$$

This yields the matrix equation for the centre of the sphere

$$2\begin{pmatrix} d_{1x} & d_{1y} & d_{1z} \\ d_{2x} & d_{2y} & d_{2z} \\ d_{3x} & d_{3y} & d_{3z} \end{pmatrix}\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} d_1^2 \\ d_2^2 \\ d_3^2 \end{pmatrix} \tag{D9}$$

which can be solved for the vector (x, y, z) and the radius of the sphere $\rho^2 = x^2 + y^2 + z^2$. Note that the leftmost matrix in equation D9 is the same as the one whose determinant yields the volume of the tetrahedron (equation D8).

The volume of the circumscribed sphere is then

$$V_\circ = \frac{4}{3}\pi\rho^3\bar{2} \tag{D10}$$

The Regular Tetrahedron

The regular tetrahedron of unit side is the ideal against which the true figure of the four spacecraft is to be measured. We may take

$$\begin{aligned} \mathbf{d}_0 &= (0, 0, 0) \\ \mathbf{d}_1 &= (1, 0, 0) \\ \mathbf{d}_2 &= \left(\frac{1}{2}, \frac{\sqrt{3}}{2}, 0\right) \\ \mathbf{d}_3 &= \left(\frac{1}{2}, \frac{\sqrt{3}}{6}, \frac{\sqrt{6}}{3}\right) \end{aligned}$$

Table D2: Values for regular tetrahedron

Quantity	Value
S_0	$= \sqrt{3}/4$
S	$= \sqrt{3}$
V	$= \sqrt{2}/12$
ρ	$= \sqrt{6}/4$
$V_\circ$	$= \frac{4}{3}\pi \left(\frac{3}{8}\right)^{\frac{3}{2}}$

Values for the regular tetrahedron of unit side length are listed in Table D2.

Calculating the Quality Factors

The quality factors in equations D1 and D2 can now be found with the help of these formulas.

For Q_G, we average the 6 distances between the 4 points to get the side L of the "ideal" regular tetrahedron, with volume $L^3\sqrt{2}/12$ and surface $L^2\sqrt{3}$. The true volume and surface are found from equations D7 and D3–D6.

For Q_R, the radius of the circumscribing sphere is calculated from equation D9. The actual volume of the sphere need not be calculated, for all the factors just go into the normalising $\mathcal{N}$.

$$Q_R = \left(\frac{9\sqrt{3}}{8}V\right)^{\frac{1}{3}} \cdot \rho^{-1}$$

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Index

ACDC, 6
Ariane-5, 2
ASPOC, 5, 16–18
    parameters, 11
    validation, 74
Auxiliary data, 61–63
    parameters, 14
    validation, 81

CCDRC, 6
CDF, 3, 64, 72
    skeleton tables, 8
CDMS, 4, 69, 72–73
    usage, 90–96
CD-ROM, 3, 61
CFC, 6
characteristic size, 62, 97–98
Chinese Data Center, 4
CIS, 5, 20–23
    parameters, 11
    validation, 75
Cluster Science Data Centres, 6
Cluster User Interface, *see* CDMS
Cluster-II, 2, 72
commanding, 67
commissioning, 68
Common Data Format, *see* CDF
Coordinate systems, 61
CSSAR, 6

Data Centres
    CDMS services, 72
    JSOC services, 69
    List of, 6
Dipole tilt angle, 62, 63
Dipole, magnetic, 61
documentation, 82
DWP, 5, 40–44
    parameters, 12
    validation, 77

Earth radius, 9, 10
EDI, 5, 24–25
    parameters, 11
    validation, 76
EFW, 5, 47–48
    parameters, 13
    validation, 77
electronic documentation, 82
elongation parameter, 62, 97–98
email addresses, 5
ESA, 67, 72
ESOC, 3, 67, 69
ESTEC, 69, 71, 72, 82
Event Catalogues, 4, 69, 73
Experiments on Cluster, 5

FGM, 5, 26–27
    parameters, 11
FGM Support Data
    rules, 7
FTP server, 69, 82

GCDC, 6
Ground-based facilities, 71
GSE, 61
GSE/GSM conversion, 62
GSM, 61

HDC, 6

IGRF2000, 61
Internet, 4, 82
IRFU, 72
IWG, 2, 8, 10, 64

JSOC, 4, 67–71

Launch disaster, 2

Magnetic dipole, 61
Master Science Plan, 71
Minute, definition of, 9

NASA, 59, 71
National DCs, 1, 3, *see* Data Centres

online documentation, 82

PDF files, 68–70
PEACE, 5, 28–30
    parameters, 12
    validation, 77
Phoenix, 2
PIs
    Cluster experiments, 5
    email, 5

planarity parameter, 62, 97–98
PostScript, 4, 73
PPDB, 4, 73
  ASPOC, 11
  CIS, 11
  DWP, 12
  EDI, 11
  EFW, 13
  FGM, 11
  PEACE, 12
  RAPID, 12
  rules, 7
  STAFF, 13
  WHISPER, 13
predicted positions, 68, 70

QMW, 72

RAL, 72
RAPID, 5, 31–34
  parameters, 12
  validation, 77
Rules of use, 4
Rumba, 3

Salsa, 3
Samba, 3
SDC, 6
Server, *see* FTP server
Skeleton tables, CDF, 8
SPDB, 73
  ASPOC, 11
  Auxiliary data, 14
  CIS, 11
  DWP, 12
  EDI, 11
  EFW, 13
  FGM, 11
  PEACE, 12
  RAPID, 12
  rules, 7
  STAFF, 13
  WHISPER, 13
Spin, definition of, 8
STAFF, 5, 50–54
  parameters, 13
  validation, 78
`Status[0]`, 8, 15
Steering Committee, CSDS, 1
Summary Parameter Plots, 4, 64–66
SWT, 1, 67

Tango, 3
Tetrahedron quality factors, 99
Time stamping, 9

UKCDC, 6
USCSDC, 6

validation, meaning of, 74

WBD, 5, 59
  validation, 80
Web pages, 6
WEC, 5, 35
WHISPER, 5, 55–58
  parameters, 13
  validation, 79
World Wide Web, 6, 67, 71, 72