THE WAVE EXPERIMENT CONSORTIUM (WEC)

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Abstract. In order to get the maximum scientific return from available resources, the wave experimenters on Cluster established the Wave Experiment Consortium (WEC). The WEC's scientific objectives are described, together with its capability to achieve them in the course of the mission. The five experiments and the interfaces between them are shown in a general block diagram (Figure 1). WEC has organised technical coordination for experiment pre-delivery tests and spacecraft integration, and has also established associated working groups for data analysis and operations in orbit. All science operations aspects of WEC have been worked out in meetings with wide participation of investigators from the five WEC teams.

1. Introduction

The five teams proposing field and wave experiments on the Cluster mission have decided to coordinate their experiment proposals in order to be able to implement modern technology and to optimise the use of limited spacecraft resources. This has led to the formation of the Wave Experiment Consortium (WEC). The five WEC experiments are designed to measure quasi-static electric fields, electric and magnetic fluctuations, and small-scale plasma density structures in the Earth's magnetosphere and the solar wind. These experiments are:

[1] Present WEC Chair.
[2] Previous WEC Chair.
[3] Principal Investigator.
[4] Technical Coordinator.
[5] Technical Coordination Office.
[6] Data Working Group Chair.
[7] Operations Working Group Chair.

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(A) A spherical double-probe electric-field experiment, known as the Electric Field and Wave (EFW) experiment, which will also be used to measure density fluctuations. PI: G. Gustafsson (Swedish Institute of Space Physics, Sweden).

(B) A triaxial search-coil magnetometer and a five-component (2 electric, 3 magnetic) spectrum analyser to perform spatio-temporal analysis of electric and magnetic field fluctuations (STAFF). PI: N. Cornilleau-Wehrlin (CETP/UVSQ, France).

(C) A relaxation sounder for probing eletron density and also used as a natural wave receiver to measure high frequency waves (WHISPER). PI: P. Décréau (LPCE/CNRS, France).

(D) A wide-band receiver system providing wideband waveform data (WBD). PI: D. A. Gurnett (University Iowa, USA)

(E) A digital wave-processing experiment (DWP) charged with on-board control of the WEC instruments and including a particle and wave/particle correlator. PI: H. St. C. Alleyne (University Sheffield, U.K.).

More detailed descriptions of each experiment, in terms of performance and scientific output, are given in companion papers (Gustafsson *et al;* Cornilleau-Wehrlin *et al.*; Décréau *et al*; Gurnett *et al.*; Woolliscroft *et al.*; this issue).

The WEC has benefitted from a close coordination of technical activities, preparation of WEC operations in orbit, data treatments and scientific data analysis.

A Technical Co-ordinator has organised the predelivery tests and spacecraft integration and tests on an engineering model and five flight units (four flight and one spare unit). For these activities, he has been supported by a closely knit team of engineers from all participating laboratories. The detailed operations of the WEC are dealt with by an Operations Working Group, which will be very active during the actual mission; as discussed further in Section 4. A Data Working Group has been working for several years to prepare a common WEC data system. Their prime aim is to develop common tools for the WEC, but also to facilitate data exchange with other Cluster experimenters and with other projects; this activity is described in Section 5. The WEC has a Scientific Board, which comprises the five Principal Investigators, and an elected chairman who serves for a limited period. This Board receives reports from the Working Groups and is the forum for all agreements and decisions, both during the development and later during the in- orbit operational phase.

2. Scientific Objectives of the WEC

The WEC experiments on each of the four Cluster spacecraft are capable of measuring the spin-plane component of the electric field, from dc to several hundred kHz, and the magnetic field vector from 0.1 Hz to ∼4 kHz. Telemetry permits full electric and magnetic wave form sampling, with 25 samples per second and 450 samples per second in respectively normal and burst modes. On-board analysis of magnetic wave-fields can be carried out up to 4 kHz and up to $\sim$500 kHz for electric wave fields. In addition, active sounding of the plasma can be used to determine plasma densities in the range 0.2–80 cm^{-3}, and the electric field probes can be used as a reference to determine the electric potential of the spacecraft, which is a parameter of interest for low-energy ion and electron measurements. Electron densities and their fluctuations can be obtained from spacecraft potential measurements (sensitive down to lobe densities), and by operating electric field probes in 'Langmuir mode' (1–100 cm^{-3}).

The fluxgate magnetometer on Cluster (FGM) will measure the magnetic field from dc to several tens of Hz and will overlap with the WEC search coil magnetometer in the range 0.1 to $\sim$10 Hz. A close cooperation with FGM is essential for most of the scientific objectives outlined in the following. The Cluster tetrahedron, with typical dimensions from a few hundred to a few thousand km, makes it possible to obtain information about spatial scales in this range. Although small-scale structures have been identified on numerous earlier missions – in the solar wind and in the magnetosphere – only with Cluster will it be possible to obtain three-dimensional plasma physics data and to distinguish temporal from spatial variations.

Regions of particular interest are the solar wind, the bow shock, the magnetopause, the cusp and the magnetospheric boundary layers. The crossing of auroral field lines near perigee (5–6 R_E), at different local times with a more elongated Cluster tetradedron, will permit new field and wave measurements and their comparison with ground observations.

Given these possibilities for new observations, the scientific objectives of the WEC are:

(1) To determine power conversion $\mathbf{J} \cdot \mathbf{E}$ for structures (e.g., magnetopause) where $\mathbf{J}$ has a component perpendicular to $\mathbf{B}$. $\mathbf{J}$ will be calculated from four-point measurements of the fluxgate magnetometer (FGM) complemented by STAFF data.

(2) To obtain three-dimensional information on the Poynting flux.

(3) To calculate shear flows and charge separation from div $\mathbf{E}$.

(4) To unambiguously determine the parameters which characterise plasma turbulences (distribution of $\mathbf{k}$-vectors) and small-scale field-aligned current structures (geometry, current density, etc.). This can be achieved by studying interspacecraft correlations of field fluctuations.

(5) To carry out four-point wave/particle interaction studies, via correlations performed on-board between wave and particle measurements.

(6) To identify source locations for the wave vectors measured at various spacecraft positions.

(7) To establish the role of high-frequency waves and to study their fine structure and its bearing on nonlinear wave/particle interactions. This will be done by using wideband data.

(8) To measure plasma density structures varying in time and space.

(9) To measure the spacecraft potential.

3. Technical Organisation of the WEC

3.1. Interfaces between WEC instruments and the spacecraft

Figure 1 is the general block diagram of the WEC showing the interfaces between the five experiments. The five sensors: three magnetic serach coils (STAFF) and two electric double-probe antennas (EFW) can be seen on the left. The electronic units (centre) include:

(i) The magnetic waveform unit, the calibration unit and the spectrum analyser (two electric and three magnetic components) belonging to STAFF.

(ii) The wide-band receiver from WBD, which can process any of four components (two electric and two magnetic).

(iii) The EFW electronic unit is microprocessor-controlled and has the added capacity of being able to store selected events in a separate burst memory.

(iv) The sounder receiver and transmitter.

The DWP experiment, shown on the right of Figure 1 contains a data processing unit which is the main interface with the spacecraft for data transmission. It also operates the experiments' ON/OFF commands and the selection of the modes of operation, either via time-tagged orders received from the ground stations, or via software. Although the WBD high-speed data can be routed via DWP and stored on-board, most of the time WBD does not utilise the DWP; instead, the WBD information is sent, via spacecraft systems, directly to the NASA Deep Space Network. In addition to data formatting and packaging, control of experiments etc., the DPU has specific capabilities, such as compaction and selection of data, and wave/particle correlations. The spacecraft potential measurements are sent to three Cluster experiments from the WEC, as indicated.

3.2. Dynamic ranges for electric and magnetic measurements

Figure 2(a) shows respectively the noise level and the highest measurable level (dashed lines) for different electric field measurements as a function of frequency, compared with the expected levels for several kinds of waves (solid lines). The noise level is an estimate based on flight data from experiments on GEOS-1/GEOS-2 and ISEE-1 similar to the WEC. The capability of EFW/STAFF to observe large signals in the 1–10 Hz and 0–180 Hz filter bandwidths is also indicated; in reality there will be one or more near monochromatic waves to be observed. The WHISPER dynamic range is close to that of the WBD, but limited to the frequency range 2–80 kHz.

The STAFF search coil noise level (dashed lines) and expected magnetic wave spectral amplitudes (solid lines) are presented in Figure 2(b). Notice that the max-

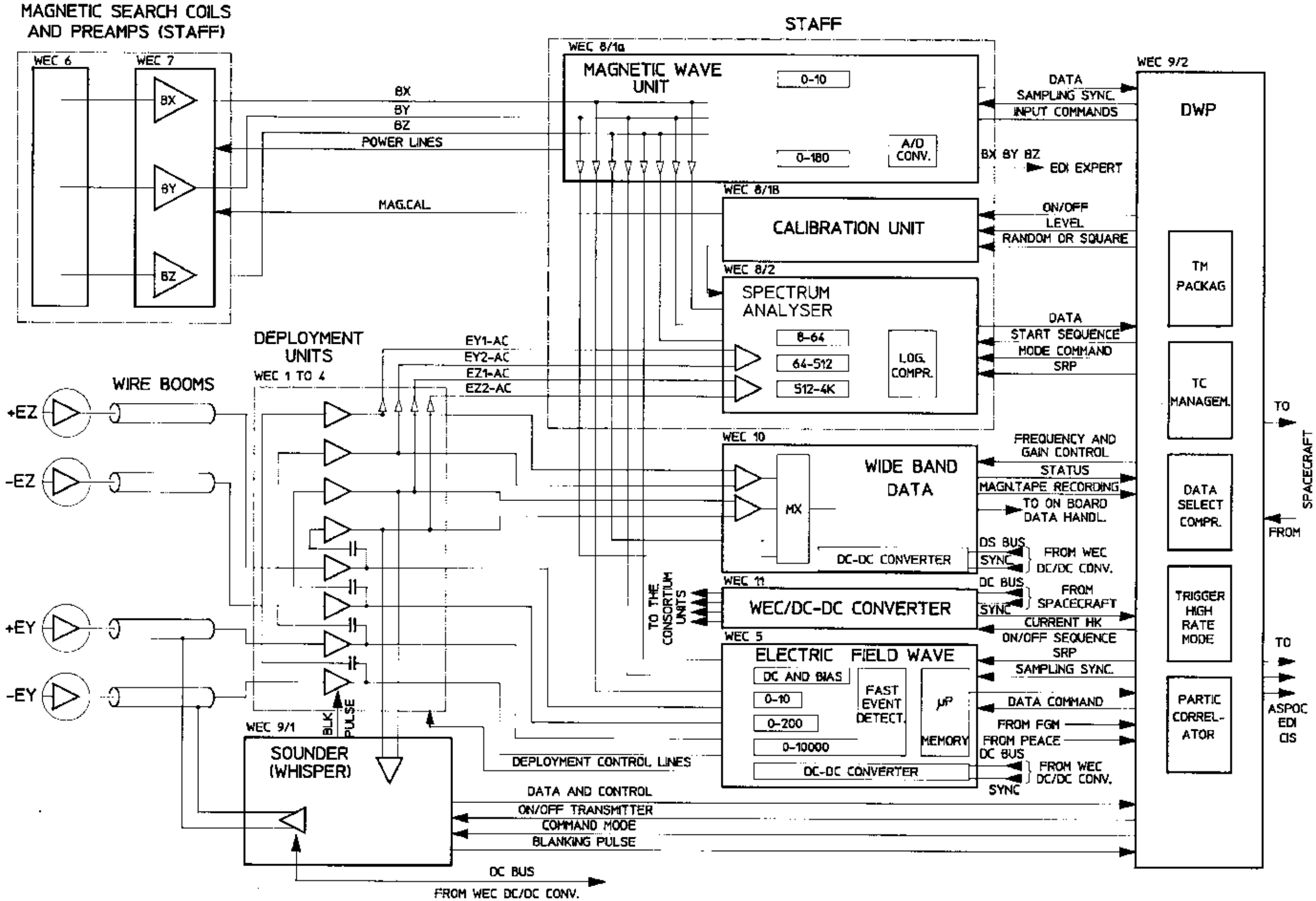

Figure 1. Block diagram of the five experiments which have been combined to form the Wave Experiment Consortium (WEC).

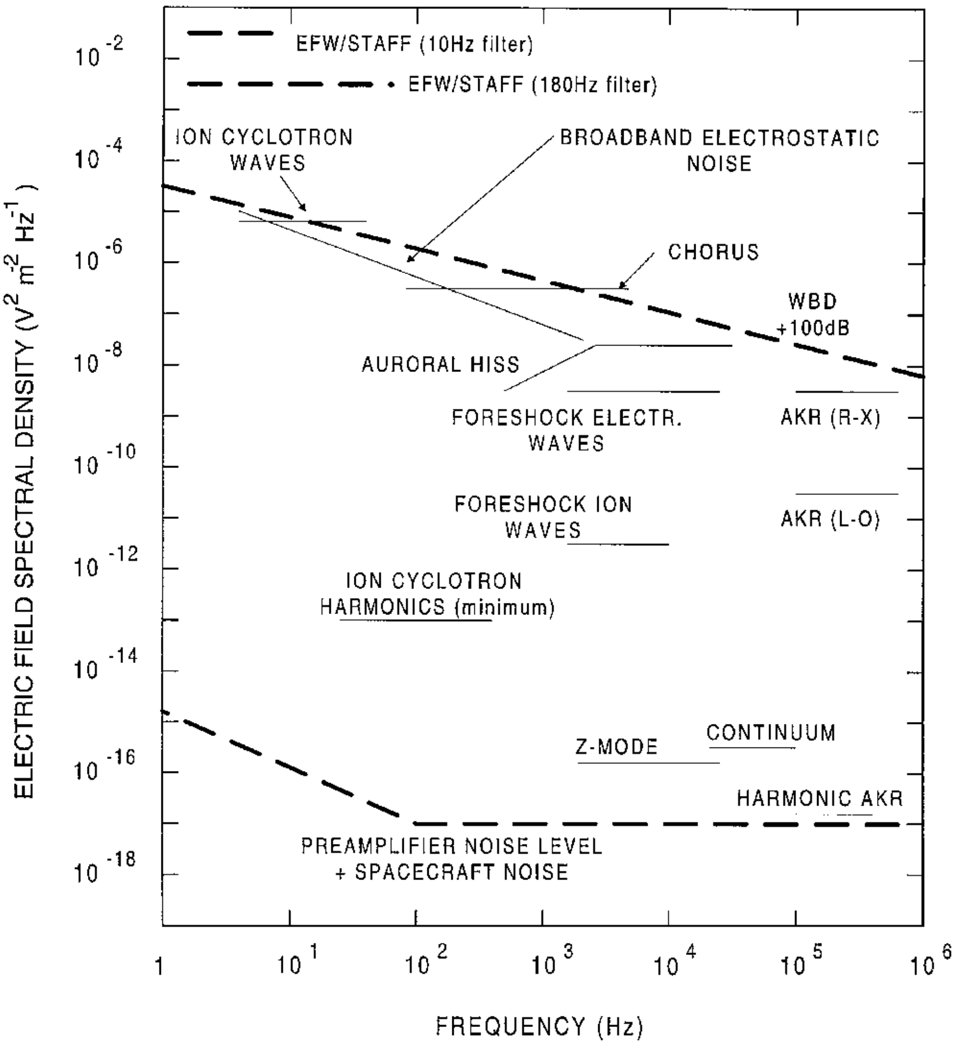

Figure 2a. This figure shows the dynamic range of electric field and wave experiments and the expected levels of signals. The upper three dashed lines show the highest measurable levels for respectively: EFW/STAFF in the 0–10 Hz filter band, EFW/STAFF in the 0–180 Hz band and WBD. The highest measureable level for WHISPER is close to that of WBD, however the upper frequency is 80 kHz. The noise level is well below the expected levels of phenomena to be observed as indicated by solid lines.

imum observable levels are 100 db above the noise, providing a safe coverage of the expected wave phenomena.

The Cluster WEC experiments address particularly well large, low-frequency electric and magnetic wave components, but will also give good coverage of these components up to $\sim$4 kHz. Above this frequency, only the electric component can be measured with good sensitivity.

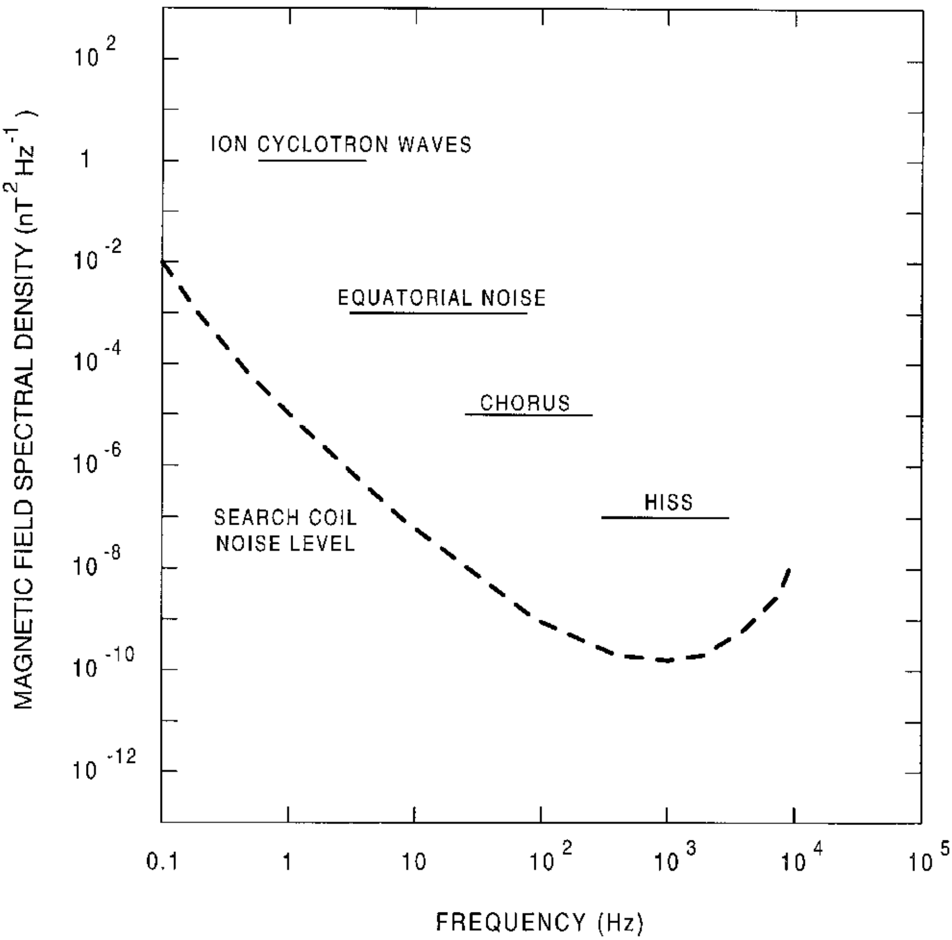

Figure 2b. Magnetic wave measurements have a dynamic range of 100 db above the search coil noise level indicated. This will provide good coverage of the expected signals indicated by solid lines.

3.3. Technical Management of the WEC

To cope with the large number of connections between the various WEC instruments, and with the desire of the Cluster Project to have a single interface, the Wave Experiment Consortium Technical Coordination Office (WECTCO) has been set up. The WECTCO is led by B. de la Porte (CETP), A Bouabdellah (CETP), J.A. Thompson (U. of Sheffield), P.N.H. Davies (U. of Sussex), R. Huff (U. of Iowa) and F.X. Sène (LPCE). The WECTCO is responsible for:

– WEC interface with the spacecraft.
– Interfaces between WEC experiments.
– Management of WEC schedule.
– Integration at WEC level.

Table I
Membership and organisation of the WEC operations group

Subgroup	WHISPER	STAFF search coil	STAFF spectrum analyser	EFW	WBD	DWP
Scientific	PI	PI		PI	PI	PI
Commissioning	J. G. Trotignon	C. De Villedary	C. C. Harvey	G. Holmgren	R. Huff	H. St. C. Alleyne
Technical	Ph. Martin	C. De Villedary	C. C. Harvey	A. Lundgren	R. Huff	K. H. Yearby

The WEC Operations Group has a 'duty coordinator' and is chaired by the DWP PI, assisted by B. de la Porte for WEC hardware and power considerations and A. Buckley for use of the correlator, and by other members of subgroups listed below. H. St. C. Alleyne leads the commissioning subgroup and K. H. Yearby the technical subgroup.

– Participation in assembly, integration and verification.
– Ground operations and EGSE.

4. WEC Operations

The WEC was formed to share resources to maximise the payload scientific return. This is particularly important for telemetry: WEC allocations on each spacecraft are

5217 bits s^{-1} in normal bit rate (NBR) and 43.898 kbits s^{-1} in high bit rate (HBR). In general, WBD will transmit real time data (220 kbits s^{-1}) directly to DSN in parallel with other WEC experiments operated in NBR. This sharing of resources means that scheduling of the components of the WEC cannot be done by individual instrument teams working in isolation; and so, the WEC has established a coordinating operations group, the membership of which is shown in Table I.

The role of this group is to convert the Master Science Plan, which has been agreed by the Cluster Science Working Team, into command sequences which will be merged by the JSOC (Hapgood *et al.*, this issue) with the scientific command requests from the rest of the payload. As such, the operations group performs a task which is rather similar to that of the JSOC for issuing commands. This group is also responsible for the generation of new modes for the WEC and new command sequences for special scientific operations, commissioning plans and for dealing with operations in the event of problems in orbit. The operations group forms the WEC's formal point of contact with the JSOC of the WEC for issuing of commands.

Most normal operations are based on a restricted number of standard WEC modes. This is for the clear reason that it will yield datasets which are readily understood without frequent discontinuities associated with mode changes. However, even within these normal WEC modes there are additional parameters which still need to be defined. These are described more fully in the associated individual WEC instrument papers (Gustafsson *et al.*; Cornilleau-Wehrlin *et al.*;

Table II

Some of the main WEC Operation Modes (simplified). Terms such as 'normal' or 'fast' cover several possibilities and do not have the same meaning in each case. The WBD instrument is capable of many modes but is expected to be operated in NBR-basic or HBR-basic mode much of the time that it is operational.

Name	WHISPER	STAFF	STAFF	EFW	WBD	Correlator
NBR-basic	3 s active, 25 s passive	Normal	Normal	Normal	Normal	On
NBR-low recurrence	4 s active, 100 s passive	Normal	Normal	Normal	Normal	On
NBR-Langmuir	4 s active, 100 s passive	Normal	Normal	Normal (Langmuir)	Normal	On
NBR-spin synchronized	129 spins 516 s active	Normal	Normal	Normal	Normal	Off (on)
NBR-active	104 s active	Normal	Normal	Normal	Normal	On
NBR-WBD	4 s active, 4 × 25 s passive	Normal	Normal	Normal	Many modes	On
HBR-basic	3 s active, 25 s passive	High	Fast	High	Off	Off
HBR-low	4 s active, 4 × 25 s passive	High	Fast	High (Langmuir)	Off	Off
HBR-Langmuir	4 s active, 4 × 25 s passive	High	Fast	High (Langmuir)	Off	Off
HBR-spin synchronized gliding	580 s active	High	Fast	High	Off	Off
HBR-active continuous	185 s active, 13 s passive, 2 s off	High	Fast	High	Off	Off
HBR-EFW	Passive (off)	High (off)	Off	High (many modes)	Off	Off (on)
HBR-WBD	Off	Normal	Normal	Normal	Special mode	Off

Décréau *et al.*; Woolliscroft *et al.*; this issue). Table II gives a summary of the standard WEC modes. The DWP instrument paper (Woolliscroft *et al.*; this issue) gives more details on how these modes correspond to measurement cycles and the use of macro command sequences.

5. WEC Scientific Data Handling

There are essentially three means by which the WEC co-investigators can access the Cluster data: firstly, via the Cluster Science Data System, CSDS; secondly, via

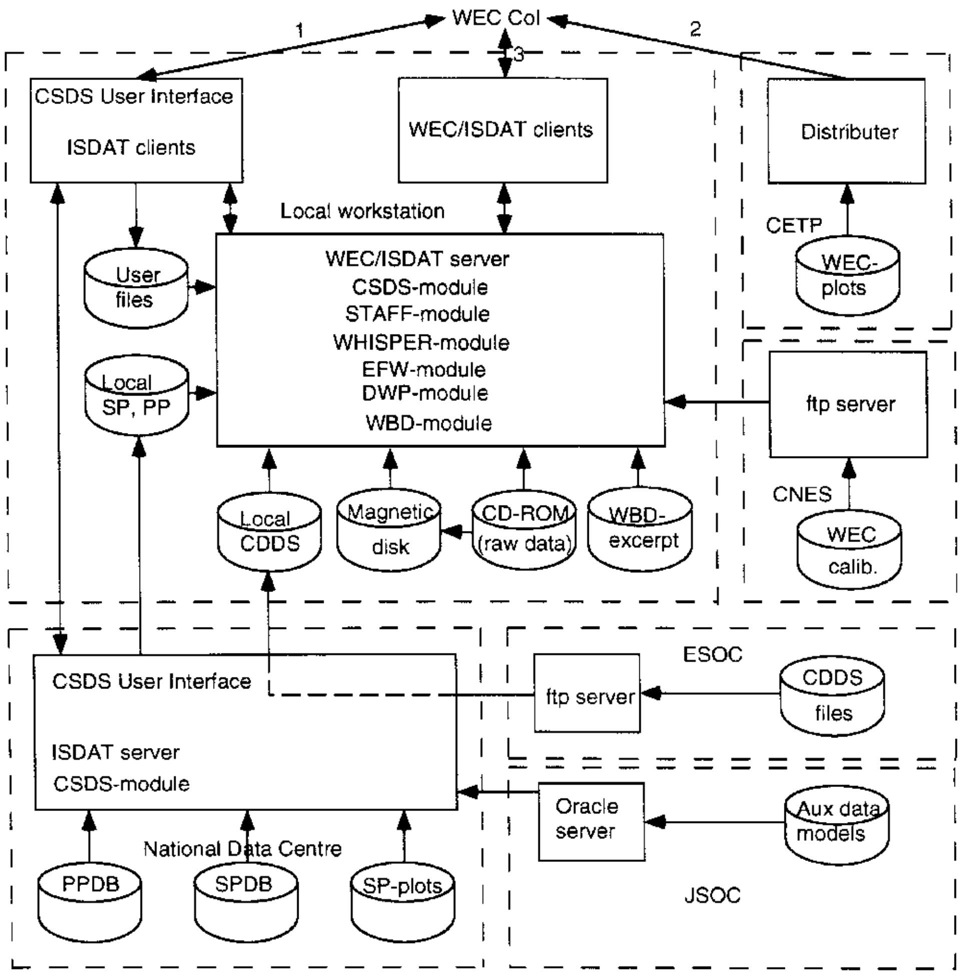

Figure 3. The WEC data handling system.

the WEC Summary Plots; thirdly, via the WEC Interactive Science Data Analysis Tool (WEC/ISDAT). They are all illustrated in Figure 3 and described in more detail below.

5.1. Science data system

CSDS is an undertaking, at Cluster project level, to make Cluster scientific data available to a wide scientific community. The CSDS is described in Schmidt and Escoubet (this issue), here we emphasise the parts that are of particular importance to the WEC data handling, notably the fact that the ISDAT is being used both for the WEC detailed data analysis and as a component of the CSDS.

WEC related CSDS databases are produced at the national data centres in France, U.K., and Sweden and copied to all CSDS national data centres. The CSDS Prime Parameters (PP) and Summary Parameters (SP), residing at the National Data Centres, are accessible via the CSDS User Interface as illustrated by the left path of Figure 3.

The WEC scientists can access the databases via a CSDS User Interface client software package, installed on his local work stations, which is connected to a national data network as shown in Figure 3. By the CSDS User Interface the user can:

– Browse CSDS parameter catalogues.
– Search in scientific data using personal search criteria.
– Analyse, manipulate, display and locally store CSDS parameters.
– Retrieve summary plots.
– Browse catalogues at the Joint Science Operations Centre (JSOC).
– Copy data files to the local work station.
– Analyse and display locally stored CSDS parameters.

Of particular interest in connection with WEC data analysis is that the ISDAT software constitute an integral part of the CSDS user interface. This means that it will be possible to access locally-stored CSDS data files from the WEC software package, and integrate the low time-resolution parameters from all instruments with the WEC full-time resolution data.

5.2. The WEC summary plots

Special WEC summary plots will be prepared by and will be accessible from CETP, Velizy, France, as illustrated on the far right section of Figure 3. They will serve a similar purpose as the CSDS summary plots, but will give more details and be specially designed for the WEC. Dynamic spectra of magnetic and electric field wave components will be produced for the whole frequency range of WEC. The status of WBD data, which is not on the Cluster master CD-ROM, will be provided. The WEC summary plots will also include ‘relative wave parameters’, or comparisons calculated on the basis of WEC measurements on the four spacecraft.

5.3. The WEC/ISDAT system

5.3.1. *The WEC/ISDAT Software Development*

WEC/ISDAT is designed for the detailed, full-time-resolution, scientific data analysis of the WEC data. The software development has been a cooperative effort within the WEC scientific laboratories, based on the ISDAT system that the WEC EFW team has been developing over the last few years.

The development team realised at an early stage that a working group would never be able to provide a system that would satisfy all involved co-investigators. On the other hand, it was realised that the WEC team would collectively have a large scientific and technical expertise; a leading principle of the work has therefore been that each group or individual would contribute to the system within their respective fields of expertise. This has led to the active involvement of a majority of WEC laboratories. This work has been carried out to make extensive use of network communication programmes, such as: electronic mail, ftp file transfer, remote login, world wide web etc. A limited number of personal progress meetings have been held.

5.3.2. *The WEC/ISDAT Software Design*

The WEC/ISDAT software design is based on a client/server model. The original development is made for UNIX systems in general, but it is also being ported to Open VMS in conjunction with the implementation in the CSDS User Interface. A guiding principle is to ‘hide’ all instrument-specific technical items, such as de-commutation or calibration in server modules and to use a well defined, general data structure as an interface between the server and the clients. The server is modular in the sense that a local system can be built with an arbitary set of Cluster instrument modules. The modular design can also support the eventual inclusion of non-Cluster instrument modules for inter-project studies. On the client side, a limited number of standard analysis and display clients are provided, but the individual user can also add his personal display and analysis software written either in C or IDL languages. The totality of the Cluster raw data will be distributed to all WEC laboratories. The ISDAT is a flexible system distributed over wide-area networks. It is based on a central workstation with one server at each outside laboratory and clients at co-investigators workstations.

5.3.3. *The WEC/ISDAT Data Flow*

The WEC/ISDAT data flow is illustrated by the middle path in Figure 3. The WEC/ISDAT server will give access to the following databases:

– The locally stored CSDS parameters.

– The locally stored Cluster Data Disposition System (CDDS). These are files which are identical to the final data delivered on CD-ROM, but available immediately after data-taking from ESOC through the national data centres. The amount of data is limited and the CDDS are primarily intended for the PI’s to perform instrument health checks or quick science analysis for mode settings.

– Final science raw data distributed to all WEC co-investigator laboratories from ESOC. WEC/ISDAT can use the CD-ROM directly, but it is anticipated that normally data will first be copied to a magnetic disk for improved performance. Depending on the locally available WEC/ISDAT server modules, the WEC co-investigator can access data from either one or several instruments from the CD-ROM.

– Data from the WBD instrument is distributed separately from the general Cluster CD-ROM. If data is locally or remotely available to the WEC co-investigator and if the WEC/ISDAT server has the WBD-module, then the WBD data is accessible via the WEC/ISDAT software.

– Files generated by the user via the CSDS User Interface.

In order to maintain up to date calibrations, all WEC instrument calibrations are available via an ftp server at CNES as illustrated in Figure 3.

6. Conclusion

The Wave Experiment Consortium (WEC) was established, already at the time of the writing of experiment proposals, to coordinate all activities related to five field and wave experiments on Cluster (STAFF, WHISPER, WBD, EFW, and DWP). These experiments are described in detail in this issue. This coordination resulted in technical solutions which ensured the best possible use of resources and uniformity in the ways in which data were sampled. Testing of the WEC experiments as a block, before integration on the four spacecraft, also contributed to a well organised activity during the lengthy test programme.

Working groups for data analysis and operations of the experiments in orbit are part of the WEC set-up, and a large number of technical and scientific staff have been working for several years to prepare the science data-taking in orbit and the subsequent data analysis.

The ultimate aim of WEC is to have a well organised data output from the five WEC experiments and, within the framework of CSDS, to combine WEC data with other Cluster data sets.

The tools and organisation are in place for carrying out new and exciting science with four-point data sets from Cluster.

Acknowledgements

A large team of engineers from WEC groups have participated in the integration and tests of experiments. Some of these engineers have carried out work on one particular instrument and others have carried out overall WEC tasks during integration and tests or by working within the Operations and Data Working Groups. The WEC would like to express appreciation to the following for their dedication, for doing an excellent job and for keeping up a good team spirit.

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Obs. de Paris, Meudon: Y. de Conchy, C. C. Harvey, F. Wouters.

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SSL, Berkeley: P. Berg, P. Harvey, D. Pankow, R. Ulrich.

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University Oulu: K. Lappalainen.

University Oslo: B. Lybekk, T. Sten.

University Sheffield: H. Aleyne, S. Walker, K. H. Yearby.

University Sussex: A. Buckley, P. N. H. Davies, S. J. Davies.