Cluster virtual observatory for ULF waves
Quick user guide

July 25, 2023

The Cluster virtual observatory for ULF waves (CVO) is an online database of parameters characterizing ULF waves in the Earth's magnetosphere. The parameters are derived from measurements made by the Cluster spacecraft (Escoubet et al., 1997) since the beginning of the mission in 2001. Configuration parameters plots of the Cluster tetrahedron are also available here. The input data is obtained from the ESA *Cluster Science Archive* (CSA). In addition to the plots stored in the database, plots of ULF parameters derived using custom input can be produced via an interactive interface. The stored parameters as well as the parameters corresponding to the plots produced interactively can be downloaded for further analysis.

1 ULF waves parameters archive

A list of the available parameters is given in tables Tab. 1 and Tab. 2. The parameters are stored in the database using the *Hierarchical Data Format* (HDF) standard (Poinot, 2010). The stored parameters can be browsed and downloaded (on a day by day basis) in the section ULF data. To download a larger number of parameters, one may use tools such as lftp of wget pointed at the web root of the database, `http://plasma.spacescience.ro/waves/spectra-data/Fourier`. The path to the data files is `CN/YYYY/ParamName/CN_ParamName_YYYY-MM-DD.hdf`, with the `ParamName` given in the tables. As an example of reading the wave parameters using the IDL HDF interface one can consult the `CVO_hdf_read.pro` we provide in the documentation section of the CVO.

The source data used to compute the parameters is composed of the magnetic field $\mathbf{B}$ measured by the Fuxgate Magnetometer (FGM) (Balogh et al., 1997), the electric field $\mathbf{E}$, measured by the Electric Field and Wave Experiment (EFW) (Gustafsson et al., 1997), and the electron density (derived from the spacecraft potential following Lybekk et al. (2012)).

The parameters in the archive are computed in the time frequency domain using a sliding window of 2048 s with a sliding step of 256 s over 24 h intervals. Before analysis the data is resampled to a sampling rate of one Hz which results in a Nyquist frequency of

0.5 Hz. The resulting parameters are stored as 338×1025 time-frequency arrays. Time resolution is 256 s, frequency resolution is 0.48 mHz.

2 ULF waves parameters plots

For a sub-set of the parameters, plots are provided in `pdf` and `jpg` formats. The plots are organized into six sets of seven parameters each and can be browsed in the section ULF quickplots of the CVO. The available sets are listed bellow:

- Basic parameters
  - Magnetic field time series
  - Magnetic field PSD (sum over PSDs of components)
  - Wave vector azimuth angle (GSE)
  - Wave vector elevation angle (GSE)
  - Spectral matrix eigenvalue ratio (intermediate/minimum)
  - Polarization degree
  - Ellipticity
  - Wave normal angle
- WaveVector direction
  - Magnetic field time series
  - Magnetic field coherent PSD
  - Wave vector direction in SM coordinates (sph)
  - Wave vector direction in GSE
  - Wave vector azimuth angle in SM (sph)
  - Wave vector elevation angle in SM (sph)
  - Ellipticity
  - Wave normal angle
- B MFA
  - Magnetic field time series
  - PSD of the radial component of the magnetic field
  - PSD of the azimuthal component of the magnetic field
  - PSD of the parallel component of the magnetic field
  - Perpendicular power / total power
  - Magnetic field coherence

- Ellipticity
- Wave normal angle

- B-density
  - Magnetic field module and electron density time series
  - PSD of the absolute value of the magnetic field
  - PSD of the electron density variations
  - Coherence between the magnetic field intensity and the electron density
  - Phase difference between the magnetic field intensity and the electron density
  - Polarization degree
  - Ellipticity
  - Wave normal angle
- PoyntingVector direction
  - Magnetic field time series
  - Poynting vector module PSD
  - Poynting vector direction in SM coordinates (sph)
  - Poynting vector direction in GSE
  - Poynting vector azimuth angle in SM (sph)
  - Poynting vector elevation angle in SM (sph)
  - Ellipticity
  - Angle between the Poynting vector and the wave vector
- PoyntingVector MFA
  - Magnetic field time series
  - Magnetic field coherent PSD
  - Electric field PSD (sum over PSDs of components)
  - Radial component of the Poynting vector
  - Azimuthal component of the Poynting vector
  - Parallel component of the Poynting vector
  - Angle between the Poynting vector and the wave vector
  - Angle between the Poynting vector and the magnetic field

Figure 1 (WaveVector direction) illustrates all panel types used in the plots database. The top panel (a) always shows the magnetic field time series, with the magnetic field high-pass filtered to eliminate periods longer than 2048 s. To differentiate between the three components, an offset of 5 nT is added to the x component and subtracted from the y component. The three insets on the left show the projections of the spacecraft orbit on the GSE (x,z), (y,z) and (x,y) planes with the starting point marked by a magenta circle. In addition, the magnetospheric regions crossed by the spacecraft and the location of the magnetic foot points when the spacecraft orbit intersects closed field lines are depicted by horizontal coloured bars. The information about the magnetospheric regions and foot points is obtained from the Goddard SSCWeb interface using IGRF internal and Tsyganenko 89C external model (Tsyganenko, 1989) with $K_p = 3$ and is only meant as a rough guide.

Panel (b) shows the PSD of the coherent part of the magnetic field fluctuations in the familiar time-frequency spectrogram representation. The gyrofrequencies of the H, He , O and O_2 computed from the magnetic field smoothed using a boxcar average of 1024 s are plotted on top of the spectrogram with white solid, dotted and again solid and dotted lines, respectively. The position of the spacecraft relative to the GSE (x, y) (equatorial) and (x, z) (noon-midnight meridian plane) planes is marked at the top of this panel by coloured bars as follows: Red if the angle between the position vector and the equatorial plane is less than 10°. Yellow if the angle between the position vector and the noon-midnight meridian plane is less than 10° and the x coordinate is positive (dayside). Green if the angle between the position vector and the noon-midnight meridian plane is less than 10° and the x coordinate is negative (nightside).

The two side by side panels in the third row (c,d) show the direction of the wave vector as scatter plots in the (θ, φ) domain. The time is colour coded. The directions corresponding to 30° cones around the positive and the negative directions of the coordinate system axes are plotted as ellipses for the x and y axes and as horizontal lines for the z axis. The coordinate system used for the left hand side panel (c) is the Local Magnetic Coordinates system (LMC) defined based on the position vector of the spacecraft in the Solar Magnetic (SM) coordinate system (Laundal and Richmond, 2017): The z axis is defined as the geocentric radial direction, the y axis is defined by the cross product of the z axis of the SM coordinate system and the radial direction: $\hat{\mathrm{e}}'_y = \hat{\mathrm{e}}^{\mathrm{SM}}_z \times \hat{\mathrm{e}}'_z / |\hat{\mathrm{e}}^{\mathrm{SM}}_z \times \hat{\mathrm{e}}'_z|$. This axis points eastward in the toroidal direction. The x axis completes the right handed system and points southward in the poloidal direction: $\hat{\mathrm{e}}'_x = \hat{\mathrm{e}}'_y \times \hat{\mathrm{e}}'_z$. The LMC system is useful in the inner magnetosphere where the dipole field dominates. The right hand side panel (d) uses the GSE coordinate system with the x axis pointed towards the Sun and the y axis in the ecliptic plane. To remove from the plot low power fluctuations we discarded the time-frequency cells corresponding to total PSD less than 5×10^{-3} nT^2 Hz^{-1}. We applied this power mask to all parameters derived from the magnetic field, except the other power spectral densities. Moreover, to reduce the noise in the plot we discarded the time-frequency cells corresponding to polarization degree below 70%. Finally, because a low eigenvalue ratio leads to large errors in the determined wave vector direction we also discarded the time-frequency cells corresponding to intermediate to minimum eigenvalue ratios less than 5.

Panels (e,f) show the orientation of the wave vector as given by the azimuth φ and by the elevation θ angles in LMC coordinates. The corresponding frequencies are colour coded. This representation makes it possible to compare the wave vector direction with the mean magnetic field direction at different frequencies. In both panels the mean magnetic field direction is represented with a thick grey line in the background.

Panel (g) shows the wave normal angle, i.e. the angle between the wave vector and the mean magnetic field in a time-frequency representation. Because of the sign uncertainty we reduced the angles to the [0°,90°] interval. For this panel we applied the masks for PSD, polarization degree and eigenvalue ratios with the thresholds mentioned above. Here and in the next panel the gyrofrequencies of H, He, O, and O_2 are plotted with black lines on top of the spectrogram.

Panel (h) shows the waves ellipticity. For this panel we applied the same masks as for the wave normal angle. In addition we masked out the time-frequency cells with near orthogonal propagation ($\alpha_{kB}\geq$80°) because for orthogonal propagation the ellipticity is undefined.

The parameters used to produce each plot in the web interface can be viewed by following the link `run params` below the plot. The same information is also saved within the plots themselves and can be viewed for instance using the jhead utility for the `jpg` files or the pdftk for the `pdf` files.

If `audio` is selected instead of one of the sets listed above, then an audified version of the magnetic field data in MFA coordinates is delivered (Alexander et al., 2014). The left channel corresponds to the x_{MFA} (radial) component and the right channel to the y_{MFA} (azimuthal) component of the magnetic field. The 0.05 s resolution data is first band-passed to the (5 mHz,10 Hz) frequency band, and then resampled to compress it by a factor of 1600. One day (24 hours) of magnetic field data becomes 54 s of audio data. The resulted frequency range of the audified data is 8 Hz to 16 kHz. Since the normal human hearing range is from 20 Hz to 20 kHz, only waves with frequencies higher than 12 mHz (periods below 80 s) will be audible. The human peak sensitivity is in the range of 2 kHz to 3 kHz which corresponds to 1 Hz to 2 Hz for the magnetic field data.

Table 1: Parameters derived from a single quantity ($\mathbf{B}$, $\mathbf{E}$, or n). For the definition of the symbols please see Tab. 3.

input	parameter	unit	expression	reference	file name
$\mathbf{B}$	Coherent power	$nT^2\,Hz^{-1}$	$2W(\lambda'_1 + \lambda'_2 - 2\lambda'_3)$	Song and Russell (1999)	coh_power
	PSD of $B_{j\mathrm{GSE}}$	$nT^2\,Hz^{-1}$	$2W\lvert\tilde{B}_j\rvert^2$		B_spec_xGSE
					B_spec_yGSE
					B_spec_zGSE
	PSD of $B_{j\mathrm{MFA}}$	$nT^2\,Hz^{-1}$	$2W\lvert\tilde{B}_j\rvert^2$		B_spec_parallelMFA
					B_spec_perpMFA
					B_spec_azimuthalMFA
					B_spec_radialMFA
	PSD of $\lvert\mathbf{B}\rvert$	$nT^2\,Hz^{-1}$	$2W\widetilde{\lvert\mathbf{B}\rvert}$		B_spec_abs
	RH pol PSD	$nT^2\,Hz^{-1}$	$2WA_+^2$	Kodera et al. (1977)	power_right
	LH pol PSD	$nT^2\,Hz^{-1}$	$2WA_-^2$		power_left
	Linear pol PSD	$nT^2\,Hz^{-1}$	$4WA_+A_-$		power_lin
	Circular pol PSD	$nT^2\,Hz^{-1}$	$2W\lvert A_+^2 - A_-^2\rvert$		power_circ
	Coherency of $\mathbf{B}$	–	$\lvert I_{xy}\rvert^2/(I_{xx}I_{yy})$	Rankin and Kurtz (1970)	coherence
	Polarization degree	–	$1 - 4\det(\mathcal{I})/\operatorname{tr}(\mathcal{I})^2$	Fowler et al. (1967)	polarization
	Ellipticity	–		Arthur et al. (1976)	ellipticity
	Transv. power ratio	–	$\rho_{\text{transversal}}/\rho_{\text{total}}$		compr_ratio
	Eigenvalues	nT^2	λ'_j		eigen_vals0
					eigen_vals1
					eigen_vals2
	Eigenvalues ratio	–	$\lambda'_{\text{intermediate}}/\lambda'_{\text{minim}}$		ev_ratio
	$\mathbf{k}$ direction in GSE	deg	eigenvector $\mathbf{v}'_3$	McPherron et al. (1972)	k_theta_gse
					k_phi_gse
	$\mathbf{k}-\mathbf{B}$ angle	deg	$\arccos(\mathbf{k}\cdot\mathbf{B})$		kb_angle
	$\mathbf{k}-\mathbf{e}_{j\mathrm{LMC}}$ angle	deg	$\arccos(k_{j\mathrm{LMC}})$		alpha_k_radSM
					alpha_k_polSM
					alpha_k_torSM
	Max var dir in GSE	deg	eigenvector $\mathbf{v}'_1$	McPherron et al. (1972)	maxvar_theta_gse
					maxvar_phi_gse
n	PSD of n	$cm^{-6}\,Hz^{-1}$	$2W\lvert\tilde{n}\rvert^2$		dens_psd
$\mathbf{E}$	Total PSD of $\mathbf{E}$	$mV^2\,m^{-2}\,Hz^{-1}$	$2W\operatorname{tr}(\mathcal{S}^E)$		E_spec_total

Table 2: Parameters derived from multiple quantities. For the definition of the symbols please see Tab. 3.

input	parameter	unit	expression	file name
$\mathbf{B}$,$\mathbf{E}$	Poynting vector components in GSE	mW km^{-2} Hz^{-1}	$2W\Re(\tilde{\mathbf{E}} \times \tilde{\mathbf{B}}^{\star})/(2\mu_0)$	ptg_xGSE
				ptg_yGSE
				ptg_zGSE
	Poynting vector direction in GSE	deg		ptg_theta_gse
				ptg_phi_gse
	Poynting vector magnitude	mW km^{-2} Hz^{-1}		ptg_module
	Poynting vector components in MFA	mW km^{-2} Hz^{-1}		ptg_parallelMFA
				ptg_azimuthalMFA
				ptg_radialMFA
	Poynting vector – LMC axes angles	deg	$\arccos(S_{j\text{LMC}}/\lvert\mathbf{S}\rvert)$	alpha_ptg_radSM
				alpha_ptg_polSM
				alpha_ptg_torSM
	Poynting vector – magnetic field angle	deg	$\arccos(\mathbf{S} \cdot \langle\mathbf{B}\rangle)$	sb_angle
	Poynting vector – wave vector angle	deg	$\arccos(\mathbf{S} \cdot \mathbf{k})$	sk_angle
$\lvert\mathbf{B}\rvert$,n	Magnetic field – density coherence	–	$\lvert G_{Bn}\rvert/(G_{BB}G_{nn})$	bd_coh
	Magnetic field – density phase	deg	$\arg(G_{Bn})$	bd_phase
	Magnetic field – density co-spectrum	cm^{-3} nT Hz^{-1}	$2W\lvert\Re(G_{Bn})\rvert$	bd_cosp
	Magnetic field – density quad-spectrum	cm^{-3} nT Hz^{-1}	$2W\lvert\Im(G_{Bn})\rvert$	bd_quadsp

Table 3: Symbols

symbol	quantity	unit
W	length of analysing window	s
λ'_j	eigenvalues of the real part of the spectral matrix	nT^2
$\mathbf{v}'_j$	eigenvectors of the real part of the spectral matrix	–
$\mathbf{B}$	magnetic field	nT
$\mathbf{k}$	wave vector	km^{-1}
$\mathbf{S}$	Poynting vector	$mW\,km^{-2}\,Hz^{-1}$
A_+	amplitude of the RH polarised wave	nT
A_-	amplitude of the LH polarised wave	nT
$\mathcal{S}$	spectral matrix (in the measurement reference system)	nT^2
$\mathcal{I}$	rank-2 spectral matrix (in the principal component system)	nT^2
$\mathcal{G}$	magnetic field - density cross-spectral matrix	$cm^{-3}\,nT$
n	particle density	cm^{-1}
ρ	power spectral density	$nT^2\,Hz^{-1}$

3 Custom input plots

For detailed wave analysis, an interactive interface is provided. An illustration of this CVO section is given in the Figure 2.

The user can set the following input parameters:

- The spacecraft, the date, and the time interval.
- `input time res`: The time resolution of the magnetic field, electric field and density data used to compute the (cross)spectral matrices from which the waves parameters are derived. Valid range is 0.05 s to 4 s. Default is 1 s. Note that if electric field data is used and `high resolution EFW data` is not checked, or only low resolution EFW data is available, then 4 s resolution will be used. Also, the spacecraft potential used to compute the electron density is only available at 0.2 s resolution.
- `average over 2*n+1 frequencies`: The number of frequencies used to average the spectral matrix. $\langle\mathcal{S}(\omega_i)\rangle = \sum_{j=-n}^{n} \mathcal{S}(\omega_{i+j})$. The default is $n = 2$.
- `high resolution EFW data`: If this option is checked, high resolution (1/25 s) electric field data will be used as input. The electric field data will then be resampled to the `input time res`. If no high resolution is available, then low resolution (4 s) electric field data will be used.
- `E3D from E2D`: The three component electric field is only available from the CSA if the angle between the magnetic field and the spacecraft spin axis is above 15° and the spin axis component of the magnetic field is above 2 nT. If this conditions are not met, the errors in deriving the spin axis component of the electric field

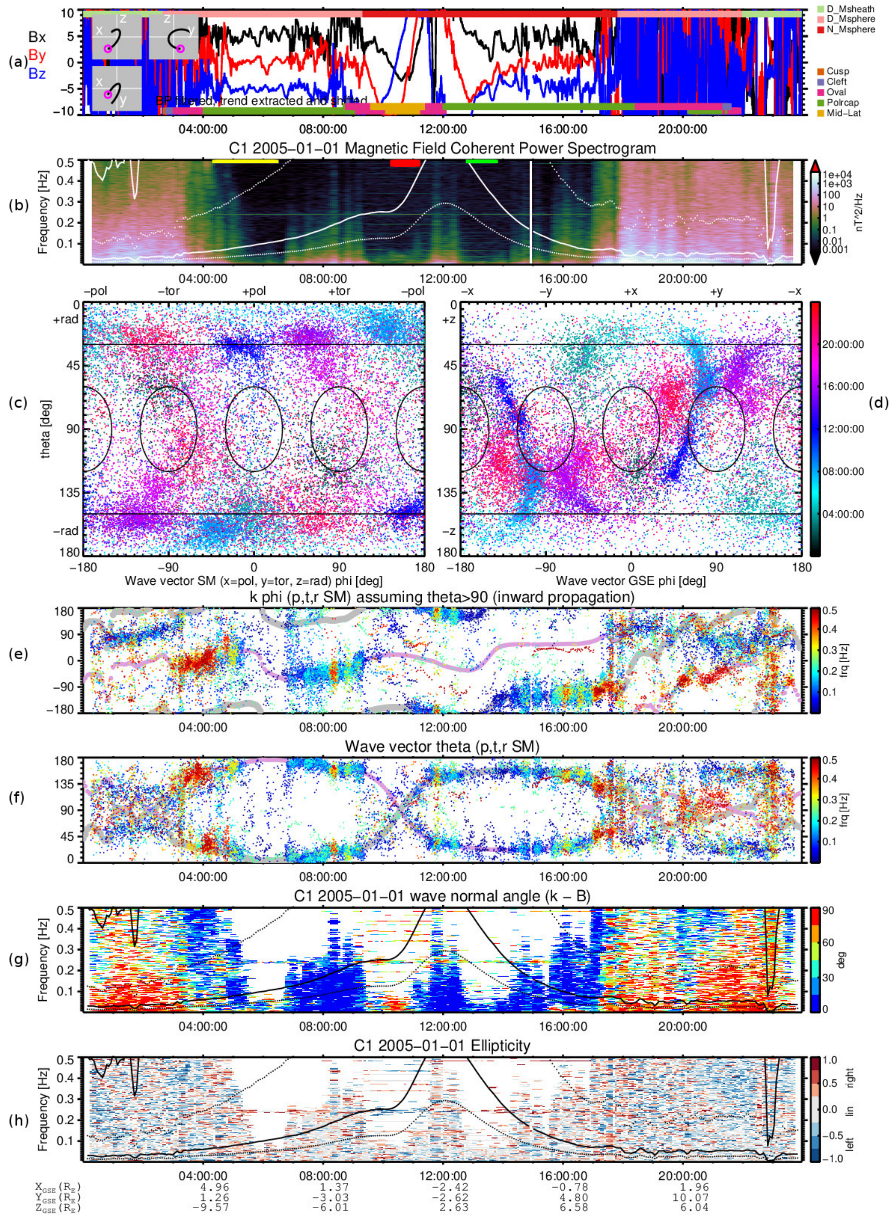

Figure 1: The *wave vector direction* plot set for C1 on 1st Jan 2005. From top to bottom: (a) The GSE components of the magnetic field, high-pass filtered. The insets show the orbit in GSE, the top bar shows the magnetospheric regions, the bottom bars show the magnetic footpoint regions; (b) The coherent power, `coh_power`. The white lines show the gyrofrequencies of H, He, O and O_2. The top bars indicate the sc position (GSE) with respect to the noon-midnight and to the equatorial plane; (c,d) The wave vector orientation in the LMC system and in GSE (`k_phi_gse`, `k_theta_gse`); (e,f) The wave vector orientation in the LMC system. The mean magnetic field is plotted with the thick grey line; (g) The angle between the wave vector and the mean magnetic field, `kb_angle`; (h) The ellipticity, `ellipticity`.

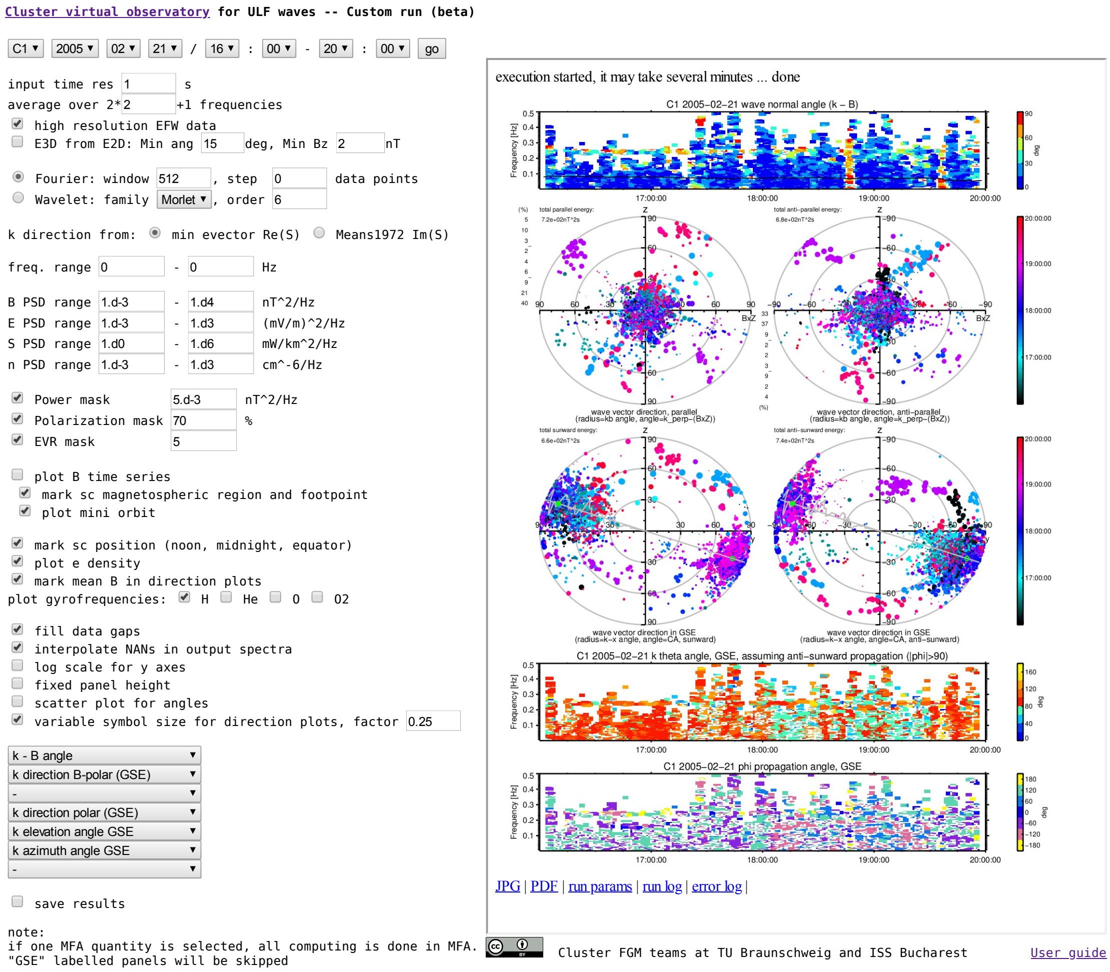

Figure 2: The *Custom run* section of the CVO. This section allows producing plots of wave parameters from user provided input.

are considered too large. Checking this option will circumvent this limitation by prompting the code to compute the third component from the 2D electric field data with the new thresholds defined by the `Min ang` (default 15°) and `Min Bz` (default 2 nT). This option should be used with caution, and before using it for scientific analysis, the EFW team should be consulted.

- `Fourier`: If this option is checked then the (cross)spectral matrices are computed using Fourier analysis with a sliding window of `window` data points (default 2048) and a step of `step` data points (default 1/8 of `window` if set to 0).

- `Wavelet`: If this option is set then the (cross)spectral matrices are computed using wavelet analysis using family `family` (default `Morlet`) of order `order` (default 6).

- `k direction from`: The wave vector direction can be determined either from the eigenvector corresponding to the minimum eigenvalue of the real part of the spectral matrix, or from the imaginary part of the spectral matrix as described by Means (1972). Here one of the two options can be selected. The default is the eigenvector of $\Re(\mathcal{S})$.

- `freq. range`: The minimum and maximum frequencies of the output plots. The default for the minimum frequency is 1/`window`·dt if `Fourier` is selected or 1/interval_length if `Wavelet` is selected. The default for the maximum frequency is the Nyquist limit. The defaults are used if "0" - "0" is selected.

- `B PSD range`: The range of the power spectral density spectrograms of the magnetic field. The default is 1×10^{-3} nT^2 Hz^{-1} to 1×10^4 nT^2 Hz^{-1}.

- `E PSD range`: The range of the power spectral density spectrograms of the electric field. The default range is 1×10^{-3} (mV/m)^2/Hz to 1×10^3 (mV/m)^2/Hz.

- `S PSD range`: The range of the power spectral density spectrograms of the Poynting vector. The default is 1 mW km^{-2} Hz^{-1} to 1×10^6 mW km^{-2} Hz^{-1}. The minimum value is also used to mask out all Poynting vector related quantities when the Poynting vector module is bellow this value.

- `n PSD range`: The range of the power spectral density spectrograms of the electron density fluctuations. The default is 1×10^{-3} cm^{-6} Hz^{-1} to 1×10^3 cm^{-6} Hz^{-1}.

- `Power mask`: The value below which all quantities involving the magnetic field are masked out. The default is 5×10^{-3} nT^2 Hz^{-1}.

- `Polarization mask`: The value below which all quantities except power spectral densities are masked out. The default is 70 %.

- `EVR mask`: The value of the ratio between intermediate and minimum eigenvalues bellow which the quantities derived using the wave vector direction are masked out. The default is 5.

- `plot B time series`: If this option is checked (default) then the first panel will show the magnetic field vector components in GSE, band-pass filtered to the `freq. range` set above.

- `mark sc position (noon, midnight, equator)`: Mark the noon, midnight and equator in the magnetic field spectrograms as described in section 2.

- `mark sc magnetospheric region and footpoint`: Mark the magnetospheric regions crossed by the spacecraft and by the conjugate footpoint on the ground, as described in section 2.

- `plot mini orbit`: Add the orbit insets to the magnetic field time series plot.

- `plot e density`: Plot the electron density on the magnetic field spectrograms.

- `mark mean B in the direction plots`: If this option is checked then the mean magnetic field direction is marked with a green $\oplus$ symbol and the antiparallel direction is marked with a green $\circ$ symbol on the GSE direction plots. In addition, on the GSE polar direction plots, the mean magnetic field clock angle is marked with a straight grey line and the evolution of the magnetic field clock angle in time is plotted (also) with a grey line. For the later, the radial coordinate is the time and the angular coordinate is the clock angle.

- `plot gyrofrequencies`: Set which gyrofrequencies will be plotted over the spectrograms. The default is the H gyrofrequency.

- `fill data gaps`: If this option is set then prior to computing, the gaps in the input data will be interpolated. At the end, the missing time intervals will be masked out.

- `interpolate NANs in output spectra`: If this option is set, then before plotting, after all processing is done the masked-out values in the final spectrograms will be interpolated if: (1) the number of consecutive gaps is ≤ 1 in time direction and ≤ 5 in frequency direction; (2) The maximum difference between the values at the edge of the gap to be interpolated is less then 45° in case of angles and less then 0.25 for `ellipticity`, `B - density coherence` and `B compression ratio`. Note that this interpolation is not done for the direction plots.

- `log scale for y axes`: If this option is checked then the y-axes of the spectrograms will be set to logarithmic scale.

- `fixed panel height`: If this option is set then all panels will have a fixed default height, irrespective of the number of panels drawn. If not set, then the height of the panels will grow to fill the page.

- `scatter plots for angles`: If set, then the plots for angles will be scatter plots as the panels (e) and (f) in the figure 1. If not, then the more common "spectrogram-like" (x=time, y=frequency, angle value as colour) representation will be used.

- `variable symbol size for direction plots`: If this option is set then the area of each symbol in the "direction" and "scatter" plots will be proportional with the logarithm of the relevant power spectral density (magnetic field for the wave vector direction, and Poynting vector for the Poynting vector direction). The `factor` allows tuning the size of all symbols.

- `save results`: If this option is set then the parameters corresponding to the plotted panels are saved on the server. An additional link named `download results` will appear below the plot. The link points to a tar archive containing the parameters in `hdf` format.

Note that "masking" effectively removes (replaces with NANs) the affected values from processing.

The following panels can be selected for plotting (refer to Table 1):

- `-`: no panel is plotted. Two consecutive "direction" plots must be separated by this.
- `skip`: no panel is plotted but a vertical space equal to the panel height is inserted
- time - frequency spectrograms:
  - `B coherent power`
  - `B total power`
  - `|B| PSD`
  - `B PSD MFA azimuthal`
  - `B PSD MFA radial`
  - `B PSD MFA parallel`
  - `B PSD MFA perp`
  - `B transversal power ratio (MFA)`
  - `B liniar polarized power`
  - `B circular polarized power`
  - `B circular left polarized power`
  - `B circular right polarized power`
  - `B eigenvalue ratio`
  - `B coherence`
  - `B ellipticity`
  - `B polarization`
  - `k - B angle`
  - `E PSD total`
  - `|S| PSD`
  - `S PSD MFA parallel`
  - `S PSD MFA radial`
  - `S PSD MFA azimuthal`
  - `S - B angle`
  - `S - k angle`
  - `density PSD`
  - `B - density coherence`
  - `B - density phase diff`
  - `B - density cospectrum`
  - `B - density quadspectrum`
- angular plots:
  - `k elevation angle GSE`
  - `k azimuth angle GSE`
  - `S elevation angle GSE`
  - `S azimuth angle GSE`
- direction plots (will produce two side by side double height panels):
  - `k direction (GSE)`: $(\theta_k, \phi_k)_{\mathsf{GSE}}$ and $(\theta_k, \phi_k)_{\mathsf{SM}}$
  - `k direction polar (GSE)`: sunward and antisunward polar plots. The radial coordinate is equal to the angle between the wave vector direction and the x_{GSE} axis. The angular coordinate is equal to the clock angle of the wave vector in the GSE reference.

- `k direction B-polar (GSE)`: parallel and antiparallel to the magnetic field polar plots. The radial coordinate is equal to the angle between the wave vector and the mean magnetic field. The angular coordinate is equal to the angle between the orthogonal to the magnetic field component of the wave vector and the (x_{GSE} - mean magnetic field) plane.
- `S direction (GSE)`: $(\theta_S, \phi_S)_{\mathrm{GSE}}$ and $(\theta_S, \phi_S)_{\mathrm{SM}}$
- `S direction polar (GSE)`: same as `k direction polar (GSE)` but for the Poynting vector instead of the wave vector.
- `S direction B-polar (GSE)`: same as `k direction B-polar (GSE)` but for the Poynting vector instead of the wave vector.

Once the "go" button is pressed, the computation of the wave parameters commences and "execution started" is displayed in the frame at the right. Upon successful completion the plots are displayed in this frame. Due to limited resources of the server, the production of the plots might take a few minutes. If the computation does not complete successfully, the message "run failed, check error_log and run_log" message is displayed instead. Only one instance of the program computing the waves parameters is allowed to run at a given time. Therefore, if the server is already computing wave parameters, the message "Server busy, retry in several minutes" is displayed.

4 Configuration parameters plots

The elongation and the planarity as defined by Robert et al. (1998) are essential in characterising the shape of the spacecraft formation, as shown in Table 4. These parameters are hosted in the Tetrahedron geometry section of the CVO. Available sets are:

- Four years overview

  Mean separation. Position in the elongation-planarity domain is colour coded

- Yearly overview

  Mean separation. Position in the elongation-planarity domain is colour coded

- Monthly plots

  Orbit projections in the GSE and mean separation. Position in the elongation-planarity domain is colour coded

- Daily plots

  Magnetic field, separations, geocentric distances, degeneration, trace in the elongation-planarity domain, barycentre orbit projections in GSE.

The elongation and planarity values are colour coded in the plots. The colour-key is a representation of the (e,p) space, with the origin $(0, 0)$ at the lower left corner, and maximum value $(1, 1)$ at the upper right corner. The red colour near origin indicates a

Table 4: Shapes in the planarity-elongation domain. Adapted from Robert et al. (1998).

planarity \ elongation	0	low	intermediate	large	1
1	circle	ellipse			
large	lenticular	pancake	elongated pancake	knife blade	line
intermediate		thick pancake	potato	flat cigar	
low		egg	short cigar	cigar	
0	sphere	rugby ball			

nearly regular tetrahedron. The yellow colour (large elongation, low planarity) indicates cigar shapes. The green colour indicates shapes resembling a long, flat knife blade. The blue colour indicates nearly circular flattened pancake shaped formations. The grey colour in the centre indicates irregular “potato” shapes. The function chosen to map the (e,p) space to the (r,g,b) space is bijective, therefore one can estimate the shape of the tetrahedron at a given moment in time from the colour of the corresponding line in the plot.

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