

MASTER'S THESIS

Processing of the Cluster EFW internal burst data

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Abstract

The internal burst data from the EFW instrument on the Cluster mission have great potential but needs some processing before becoming a part of the Cluster Active Archive (CAA) where all other viable scientific data from the mission are represented. The aim of this thesis is to create a program that that can correct large quantities of the internal burst data, plot the data comparing it to the normal mode data, and save the results. Previously the data have been corrected on a case-to-case base. There is also a detailed description how a new program corrects, plots and saves these plots in a database for the internal burst data. Matlab is used for the data correction and plotting of the results.

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1 Introduction

There are four different state of matter in the universe: solid, liquid, gas and plasma. Almost 99 % of the visible material is in the state of plasma, but even if this is the most common state of matter in the universe, it is hard to find on the Earth. It can for example be found in lightning, auroras and the gas inside fluorescent lights. When looking outside the Earth's atmosphere, plasma can be found in the magnetosphere and in the solar wind [5].

We live on a terrestrial planet with a molten core and a magnetic field. This field comes from the electrical currents that are created inside the planets core, from the movement of the magma (molten rock). Close to the Earth, the magnetic field is quite well represented by a dipole like an ordinary bar magnet, but further out it gets distorted. The Earth's magnetic field is confined by the solar wind into a cavity known as the magnetosphere. The solar wind compresses the Earth's magnetic field on the sunward side of the Earth, but stretches it to a tail on the nightside. It normally extends 60 000 km ($\sim 10 R_e$) towards the Sun and several hundreds of thousands km in the tail. The solar wind is separated from the magnetosphere by a barrier called the magnetopause.

By studying the electric field and plasma densities one can get a better understanding how space plasmas really work; around the Earth, the Sun, and other planets. Several space missions have studied the space environment around Earth and other planets, but Cluster is unique with its four identical spacecraft's that fly in a formation [15]. One has to know what regions the spacecrafts pass through and what processes that can occur in them to better understand the results seen in the collected data. The spacecraft themselves also have to be known, from the instruments that gather the data, to how the data are processed on the spacecraft and the ground. The information about what regions the spacecraft will encounter and the spacecraft itself can be found in sections 2, 3, 4 and 5.

1.1 Aim of the thesis

The main objective of this project was to create a processing pipeline that could gather and correct huge amounts of normal mode and internal burst mode data from the ISDAT server. The ISDAT is a client-server system for scientific data developed for and by the Wave Experiment Consortium on the Cluster satellite. A detailed description of the pipeline can be found in Section 6. When the data have been gathered and corrected, the data have to be plotted and then saved to a designated folder. These plots compare the internal burst and normal mode data to show how the data differ from each other.

Previously this has been done on a case-to-case basis and there has not been a program that can go through large quantities of internal burst data while correcting and saving the results. It should also be able to show where these bursts were gathered and see if they were gathered in completely random places or in specific areas that always have the highest activity.

The outline of this report is as follows: First there is a short description about plasma and the different areas the spacecrafts will encounter on their orbit around the Earth. Then there is a description of the Cluster spacecraft, the EFW instrument and how the internal burst data collection work. The next part is about the program and the specific pieces that have been written to correct the internal burst data and then plot it. Last are the results and discussions about what need to be done more with the internal burst data to further improve the quality. The software is included in appendix

A.

2 Plasma

Plasma is an ionized gas that is created when atoms are divided into their basic components, for example due to high levels of thermal energy or by ionizing radiation. This is not the only way a plasma can survive for long times. In space plasmas, it is very often the case that the plasma is so tenuous that the recombination time becomes much larger than any relevant time scales of the plasma. For example, the recombination time in the solar wind is such that most ions will go through all the solar system without mating with an electron, so most plasma consists of equal number of free electrons and ions, which very often are protons. There is almost the same number of negative and positive particles, which makes the plasma quasineutral. This state of matter exists everywhere in the known universe [21] and it can be described as

“A plasma is a quasineutral gas of charged and neutral particles which exhibits collective behavior.”
(Chen, 2006)[5]

How the plasma moves depends on both local conditions and the state of the plasma far away, this is why one says that plasma has a collective behavior. This effect comes from the Lorentz force such that [7]

$$\mathbf{F} = q(\mathbf{E} + \mathbf{v} \times \mathbf{B}) \quad [2.1]$$

where q is the charge, \mathbf{E} is the electric field, \mathbf{B} is the magnetic field and \mathbf{v} is the particle's velocity.

When charged particles move around, there will be local concentrations of electrons and ions that create an electric field and a magnetic field. The magnetic field has a longer range than the electric field so it can affect the movement of particles in very remote locations. Consider the Coulomb force and its effect on two different plasma regions, A and B, which are separated by a distance r . The Coulomb force between A and B decreases with r^2 except for a specific solid angle where the volume of plasma in B that will affect the plasma in A increases to r^3 , which is a unique effect that can only occur in plasma [5]. In some cases, when the long-range electromagnetic forces are much bigger than the local force from collisions, this effect can be ignored.

Another important parameter is the temperature. If one looks at plasma as a gas with thermal equilibrium that can move in one dimension, the Maxwellian velocity distribution can be written as [5]

$$f(v) = n \left(\frac{m}{2\pi K_B T} \right)^{\frac{1}{2}} e^{-\frac{1}{2} \frac{mv^2}{K_B T}} \quad [2.2]$$

where n is the number of particles in the gas per unit volume (known as the number density or pften just the density), m is the mass of the particles, K_B is the Boltzmann constant, T is the temperature and v is the velocity. To better understand the temperature one should divide it into T_i for the ions and T_e for the electrons. This is because there are almost no collisions between ions and electrons in most plasma we are interested in so they will have their own thermal equilibrium. Even if the temperature in a plasma is very high, the density and hence the heat capacity is very low so it doesn't feel so hot. This can be noted in fluorescent lights where the temperature in the gas is 20000 degrees

but the glass doesn't get hot. Another example is plasma that can be created in a lab where the temperature can become a million degrees but due to the low densities one can overlook the impact this temperature has on the walls.

3 The solar wind

The solar wind mostly consists of electrons and protons that escape from the Sun's gravity due to the pressure difference between the corona and interstellar space (because of the high temperature in the corona and their own high kinetic energy). The solar wind was first discussed in the 1950's after scientists found evidence that variations in the Earth's magnetic field can be traced back to changes in the Sun atmosphere. From the start of the space era, several spacecraft's have measured the solar wind from Mercury's to Saturn's orbit. It travels outward until it reaches the edge of the heliosphere where it mixes with the interstellar wind. The heliosphere is a big bubble that looks a lot like the Earth's magnetosphere and magnetopause and it protects the solar system from galactic cosmic rays in the same way the magnetosphere protects the Earth from the Sun. Close to the Earth there have been several satellites measuring the composition of the solar wind. At 1 AU from the Sun it's still hot and fast, it travels at speeds around 400 km/s and the temperature typically lies between 5,000-150,000 Kelvin. There usually are between 1 and 20 particles per cm^3 , most of them are electrons and protons but there are also heavier elements like helium and hydrogen. Inside the solar wind there is a weak magnetic field (7 nT). The protons carry most of the momentum and energy in the wind and by measuring these quantities close to the Earth one can calculate that the mass loss is negligible in the Sun's mass and energy balance. Because there is almost the same amount of electrons and protons in this plasma, the pressure can be calculated with

$$p_{\text{gas}} = nk_b(T_p + T_e) \quad [3.1]$$

where k_b is the Boltzmann constant, and the two temperatures are for electrons and protons. Using the data collected from different satellites a typical value for this pressure is 30 pPa, though it can vary much. Using the pressure, mass density and the temperatures one can get the sound speed in the plasma according to

$$c_s = \left\{ \frac{\gamma k}{m_p + m_e} (T_p + T_e) \right\}^{\frac{1}{2}} \quad [3.2]$$

where γ is the ratio of specific heat at constant pressure and volume. This gives a sound speed around 60 km/s, which means that the solar wind around the Earth is supersonic. Because there is also a magnetic field present, there will also be hydromagnetic effects in the wind. The magnetic field is exerting a pressure at the Earth that lie around 15 pPa, which indicates that the magnetic pressure is just as important as the particle pressure in the solar wind.

To understand the solar wind one has to know how and where it originates. To simplify matters one can see the solar wind as an extension of the corona, the outermost part of the Sun's atmosphere. The temperature in the corona is almost the same temperature as the Sun's core. Even though it is clear the solar wind originates in the corona there are still several theories how this works.

In one of the theories the solar wind is closely linked to the Sun's magnetic field, which is essentially a magnetic field that's been frozen into the solar plasma. Just like the magma in the center of the Earth, this material rotates. The difference between the Sun and the Earth is the location where the

magnetic field is created. On the Earth the field is created inside the core so which is sufficiently far from the surface for the magnetic field to be approximately dipolar close to the surface, the Sun's magnetic field is created close to the surface in the convection zone so the fieldlines are far from dipolar when they reach the surface. Because the material rotates at different speeds depending on the distance from the equator the magnetic fieldlines becomes entangled. Close to the Sun's equator the magnetic fieldlines are often closed and they look almost like the fieldlines in an ordinary dipole field. Away from the equator the fieldlines become elongated and they close far away from the Sun. There are also open magnetic fieldlines that create coronal holes that generate the fast solar wind. When these open fieldlines reconnect, a stream of charged particles shoots out in both directions from the re-connection point at speeds up to 750 km/s. There are also the slower solar wind that move around 400 km/s that seems to be the product of streamers that are tied to the closed magnetic lines [4].

When the solar wind travels away from the Sun, the particles spiral along the Sun's magnetic fieldlines. When the solar wind travels outward the field lines get elongated until they become open. When the field lines are open the particles can break free from the Sun, which means that the solar wind we experience at Earth mostly originates from the coronal holes. The solar wind can be seen when looking at the dual tail effect on comets. The comet's path creates the first tail while the 2nd tail is created when ions from the comet are accelerated by the solar wind. Depending on where the comet is on its orbit the angle between the two tails change and it can be difficult to see the difference.

Eugene Parker at the University of Chicago presented a theory for the solar wind in 1958 but it wasn't until 1959 the Russian satellite Luna 1 did the first measurements and in 1963 Mariner 2 established that the solar wind was a continuous stream of protons and electrons.

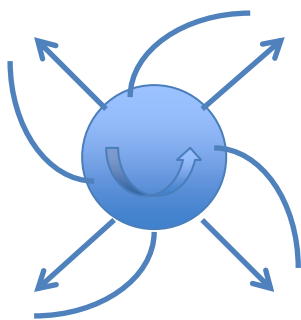


Figure 1, the Parker spiral: When the Sun rotates, the magnetic field lines become bent into a pattern called the Parker spiral (Tribble, 2003). The arrows around the sphere show how the plasma moves away from the Sun and the bent lines show how the magnetic lines bend when the Sun rotates in a counter clock wise direction as shown by the arrow inside the Sun.

Far from the Sun, the solar magnetic field on average forms a spiral pattern, which can be seen Figure 1. The kinetic energy in the solar wind can be described with

$$\frac{1}{2} mnv^2 \tag{3.3}$$

which is a lot bigger than the magnetic field energy

$$\frac{B^2}{2\mu_0}$$

[3.4]

So when the solar wind is expanding radially from the surface of the Sun it drags the magnetic field lines with it. Because the open magnetic field lines are tied to a specific part of the Sun the magnetic field lines get bend when the Sun rotates and it creates a spiral like pattern.

4 The magnetosphere

Near the surface, the Earth's magnetic field is essentially a big dipole field, similar to a field that surround a regular bar magnet. The Earth's field is created when the molten rock inside the core rotates and streams vertically because of convection driven by the vertical temperature gradient: electrical currents are created in this complicated motion that also creates a magnetic field. This motion isn't uniform so over time the polarity of the field starts to change and in 1985 the magnetic north pole was 11 degrees away from the Earth's rotation axis. When the Earth moves through the solar system the solar wind shapes the magnetosphere and it becomes divided into several distinct regions, see Figure 2.

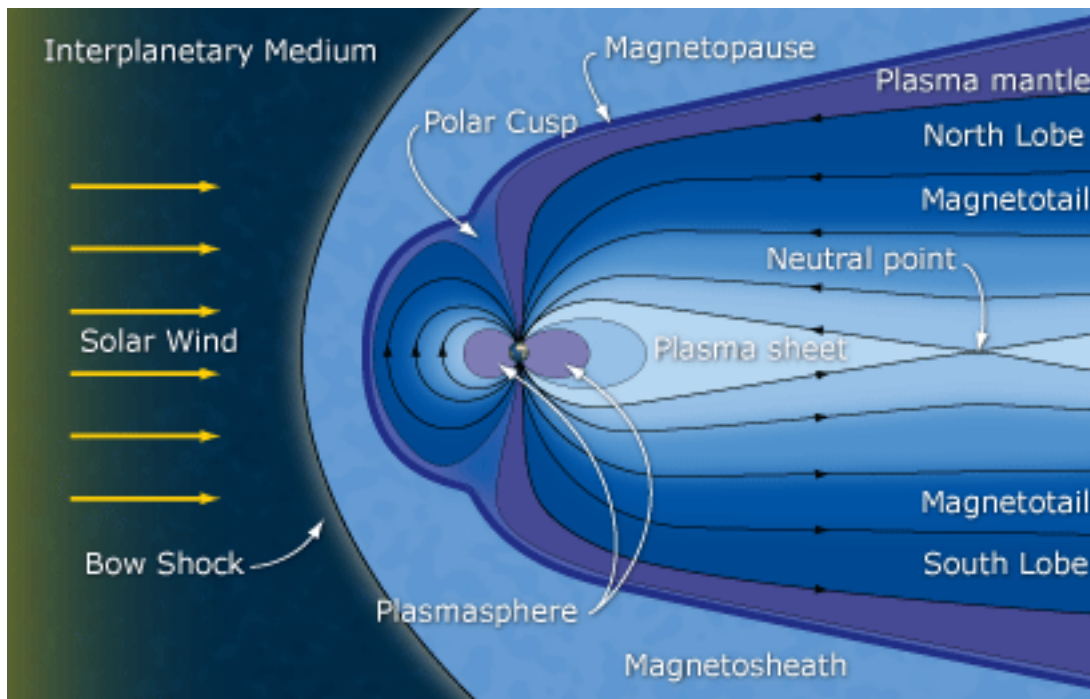


Figure 2: Schematic diagram of the Earth's magnetosphere (ESA, 2007). The magnetosphere is divided into several distinct regions that can be seen in the picture, which are described below.

Close to the Earth, up to a few R_E from its center, the Earth's magnetic field is quite well described by a dipole, around the equator the magnetic field strength is described by:

$$B_e^{\text{dipole}} = \frac{B_0 R_E^3}{r_e^3} \quad [4.1]$$

Where r_e is the distance from the center of the Earth and B_0 is the magnetic strength at the Earth's surface at the equator. In this region and beyond lies the plasmasphere, a part of the magnetosphere that is filled with dense, cold plasma. This area lies close to the Earth and extends to 3-5 R_E , where the plasmapause lie. In the same area, between 1000 km and 6 R_E , the radiation belts and ring currents can be found.

When the Earth moves through the solar system, the solar wind shapes the magnetosphere and it becomes divided into several different areas, see Figure 2. In the sunward direction it's shaped like a

sphere that change size and shape depending on the momentary strength of the solar wind. On the other side of the Earth the field becomes elongated into a cone that is called the magnetotail. This area is then divided into the tail lobes and the plasma sheet.

In front of the magnetosphere a bow shock is created when the solar wind moves past the magnetosphere at supersonic speed.

4.1 The Plasmasphere

The plasmasphere is an extension of the ionosphere and consists of plasma with densities up to 1000 particles per cm^3 [17]. This plasma is bound to the Earth's magnetic field and the particles move along its lines. The size of this region, which actually is more like a torus than a sphere, is set by the strength of the large-scale electric field in the magnetosphere. Close to the Earth the drift motion corresponding can only slightly change the size of the plasmopause [3]. Due to variations in the plasma pressure this sphere isn't completely round, but there is a bulge in the duskward direction, as can be seen in Figure 3 [19].

When looking at Figure 3, the location of the plasmopause, the boundary for the plasmasphere, typically it varies between 3 and 5 R_E . The plasmasphere rotates in an eastward direction around the Earth so it will always be between dusk and midnight when the Earth rotates around the Sun.

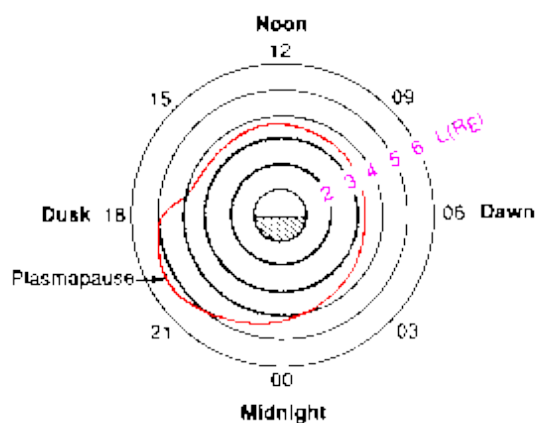


Figure 3: The typical configuration of the plasmasphere in the equatorial plane. Taken from (Rasinkangas, 2008).

4.2 Radiation belts and ring currents

Charged particles inside the magnetosphere move along the magnetic field lines due to the Lorentz force and the most energetic particles create the radiation belts. There are inner and outer belts that lay on different distances from the Earth because of the energy levels of the trapped particles. These particles then bounce between the poles. Because of magnetic mirroring there are more particles around the equator and the further away from the Earth they are. Depending if it's a proton or electron they drift around the Earth in different directions. These belts are also called the van Allen radiation belts after the primary scientist for the Explorer I mission, who first observed the inner radiation belt.

There are several types of currents running through the magnetosphere. In the inner magnetosphere there are ring currents that flow westward around the Earth. The ring current is partly carried by the radiation belt particles, leading to a correlation between the amount of trapped particles and the

strength of the ring current. Almost the entire ring current comes from trapped particles. All particles that are trapped in the radiation belts contribute to the ring current. However, the particles in the radiation belts are all high energy while the ring currents are carried also by particles of lower energy.

4.3 Magnetopause

When the magnetosphere is compressed by the solar wind, the magnetic pressure becomes higher, and the solar wind does not reach further than the point where the magnetic pressure of the geomagnetic field balances the dynamic pressure in the solar wind, hence the magnetopause is created [2]. This is a relatively thin layer of plasma that separates the magnetosphere and the solar wind and it makes sure most particles from the solar wind doesn't get closer to the Earth but some will make it through and some of these particles can be found in the radiation belts. Chapman and Ferraro were the first who discussed this barrier in the 1930's but it wasn't until Explorer 10 and 12 made the first measurements in the early 1960's the existence of the magnetopause was proved.

When the strength of the solar wind changes the size of the magnetosphere changes, a strong wind means a small magnetosphere and vice versa. During coronal mass ejections or other massive events, the compression of the Earth's magnetic field can result in an induction electric field so strong that the electricity supply network on the surface is affected. The magnetopause is considered a barrier but highly energetic particles from the solar wind and galactic radiation still gets through. Inside the magnetosphere the magnetic pressure is dominant while outside in the magnetosheath the thermal and magnetic pressure components of the solar wind dominates. Taken this into account one can derive this equation:

$$\rho_{SW} u_{SW}^2 = \frac{B_{MS}^2}{2\mu_0} \quad [4.2]$$

The left hand side describes the solar wind and the right hand side describes the magnetosphere. For Ampere's law to work the current have to flow in different places on the magnetopause has to flow in different directions and the currents have to follow the momentum equation, where $\mathbf{j} \times \mathbf{B}$ is the force that deflect the particles from the solar wind. When looking at Figure 2, the magnetopause currents close to the Sun flow out of the paper while the currents in the outer sections of the tail flow into the paper and the currents inside the tail flow out of the paper. When a charged particle gets inside the magnetopause, it starts to gyrate until it's out of the barrier again or gets lost into the ionosphere. Because protons are heavier they will travel further into the barrier and most of the current in this area comes from these.

4.4 The magnetotail

The magnetotail is a region of the magnetosphere that is located away from the Sun; this area can be seen in Figure 2. It stretches out far away from the Earth and is a place where the magnetosphere stores magnetic energy, which is injected into the inner magnetosphere by magnetospheric substorms. The tail consists of two lobes, separated by the plasma sheet in which the cross-tail current flows seen in Figure 2. Particles that are diverted from the solar wind can sometimes find their way into the magnetosphere through the tail. These particles usually end up in the radiation belts or they travel into the polar area where they create auroras.

5 The Cluster mission

Since the beginning of the space age there have been several satellites that have been studying the Earth's magnetic field and its interaction with the space around it. To distinguish between the temporal and spatial variations about the regions involved, there was a need for space missions consisting of more than one spacecraft.

The Cluster mission was first proposed to the European Space Agency (ESA) in 1982, but it wasn't until 1996 they were launched with the first prototype of the Ariane-5 rocket. However, due to some technical difficulties with the new rocket, the launch was unsuccessful and the satellites were lost. Because of the amount of time and money that had been used developing the Cluster mission ESA felt that it had to be used again and in 1997 the mission was back as the Cluster II mission. This mission was later renamed the Cluster mission. These satellites were launched in July and August 2000 with two Russian Soyuz rockets due to lower launch costs [13].

The mission consists of 4 identical spacecraft that initially flew in a tetrahedral formation in an elliptical polar orbit with apogee at 119 000 km and perigee at 19 000 km (altitudes). With time, the orbit has evolved, and the perigee is now (April 2011) around 3 000 km above Earth.

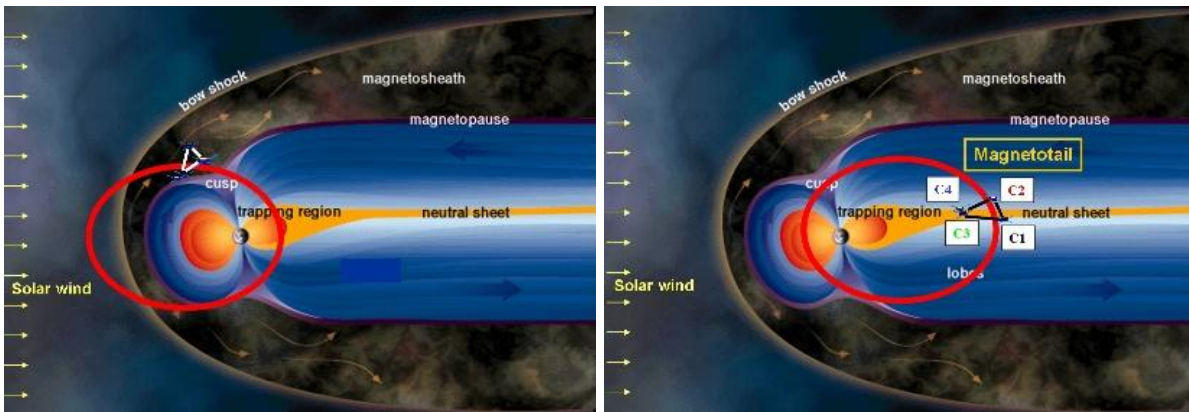


Figure 4: To the left: Original dayside orbit of the spacecrafts. To the right: Original nightside orbit of the spacecrafts [23].

To benefit from the four-spacecraft formation, the distance between the satellites has to be closely monitored and most of the satellites mass consists of fuel for maneuvering. The four spacecraft collect detailed data on small-scale changes in near- Earth space and the interaction between the solar wind and the Earth's atmosphere, which allows scientists to build 3d models of the magnetosphere [10]. There are 12 instruments on every spacecraft and one of them is the Electric Field and Wave instrument (EFW), which was built by a consortium led by The Swedish Institute of Space Physics (IRF). Due to its success the mission has been extended several times and at the moment it is planned to continue until the end of 2014 [6].

The main goal of this mission is to study the magnetosphere, the solar wind and the interaction between them. By having an elliptical orbit it can fly through several interesting areas like the solar wind, the magnetopause, the polar cusp, the magnetotail, and the aurora zone. It's also a part of the Solar Terrestrial Science Programme (STSP), which combines the data from the Solar Heliospheric

Observatory (SOHO) and the Cluster mission to understand all the processes from the interior of the Sun to the Earth's magnetic field.

5.1 The EFW instrument

The EFW instrument is one of the 12 instruments that can be found on the Cluster satellites. A consortium led by IRF in Uppsala constructed this instrument and they are in charge of the instrument and the data collected from it. It is also a part of the Wave Experiment Consortium (WEC) [18], which consists of 6 instruments: Digital Wave Processor (DWP), Electric Fields and Waves (EFW), Spatio-Temporal Analysis of Field Fluctuations (STAFF), Wide-Band Data (WBD), Waves of High Frequency and Sounder for Probing of Electron Density by Relaxation (WHISPER). The DWP coordinates the data from the other four instruments and sends it to the spacecraft before it is transmitted to the ground.

The CAA contain all data and information from the Cluster mission and IRF is responsible for the delivery of the data from the EFW instrument. While most of the EFW products are delivered, the EFW's internal bursts data, which are high-resolution snapshots of the electric field, still need more work before it can be used.

The EFW instrument consists of 5 major parts; four boom units and an electronics box for every spacecraft. These were built by IRF and, see Figure 5.

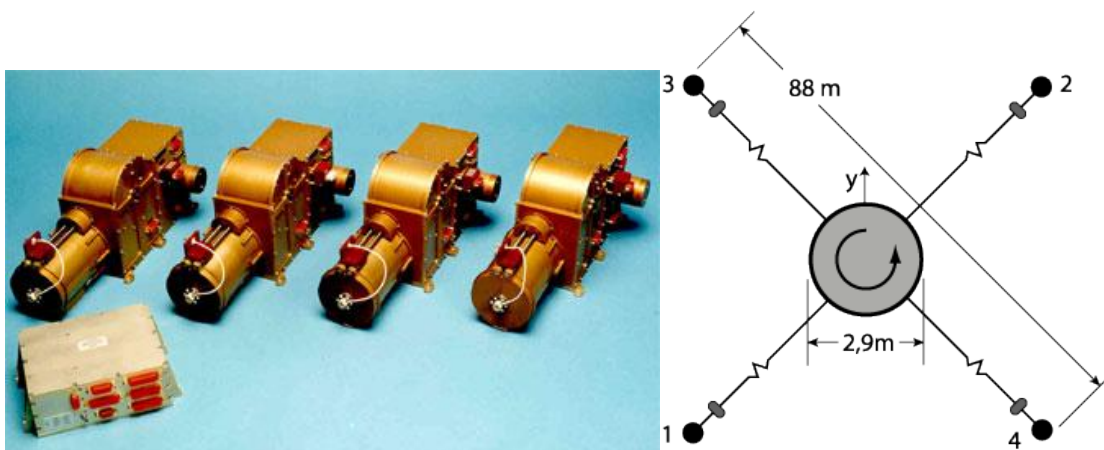


Figure 5: The boom boxes and electronics box from one of the Cluster satellites can be seen to the left. To the right one can see the configuration of the booms when they are fully deployed during normal operation. The satellite in the picture rotates counter-clockwise. [8]

The boom boxes contain a dc motor, 50 m boom wire, a puck shaped pre-amplifier, and an 8 cm spherical probe. These 4 boxes are then mounted on each spacecraft with a 90° angle between them, see Figure 5. After the probes are deployed, the motors make sure all probes end up at the same distance from the spacecraft body. These booms are then kept taut by the rotation of the spacecraft, which is at 15 rpm. The probes are kept away from the spacecraft's body to give more accurate measurements. When the distance between two probes grow, the voltage difference induced by the electric field, which is to be measured, becomes larger and easier to measure. The distance also limits the spacecraft's body influence on the measurements.

To make the booms strong enough to take the strain from the rotation, they had to be reinforced with a Kevlar braid. The booms consist of a cable with 8 conductors for the operation of the pre-amplifier and the sphere and they control the power supply, relay switching, and biasing voltage. The probe

itself is an aluminum sphere of 80 mm diameter coated with a conducting paint that contains graphite (DAG 213).

To make the measurements as correct as possible, the probes have to be protected against photoelectrons from the spacecraft's body and the booms. The spacecraft disturbance can't be helped entirely but the ones coming from the booms are stopped by separating the probe from the boom. After the boom there is a guard, a pre-amplifier puck and a thin wire that is connected to the probe itself. The wire between the probe and the pre-amplifier is 0.3 mm thick and 1.5 m long. It is connected electrically with the probe and even if it's very thin it got a big part of the surface area. Between the pre-amplifier and the boom is a 1.5 m guard, at a negative potential, is placed [23]. They are both connected electrically so they can be given different bias voltage to affect the photoelectron flow to and from the probes. The pre-amplifier and guard voltage follows the sphere with an offset, which can vary between +1.44 and -1.44 V in 256 equal steps for the stub and between +35.6 and -35.6 V in 256 steps for the guard.

This setup is essentially a big voltmeter.

When the probes are in the sunlight, they emit photoelectrons and become positively charged. When the charged becomes large enough, the photoelectrons are attracted back and the probes reach equilibrium, see the figure below. When the probes move into the dark they will become negatively charged because electrons move faster so a bigger number of electrons hits. Because half the probe is sunlit and the other half sits in the shadow, these two effects compete. Escaping photoelectrons try to make the probes positive and the plasmas electrons try to make them negative. If the plasma density is low, as it is in most parts of the Cluster orbit, the first effect dominates so the probes become more positively charged, if the probes are left to reach equilibrium on their own. However, a constant bias current is applied to the probes, as will be discussed below.

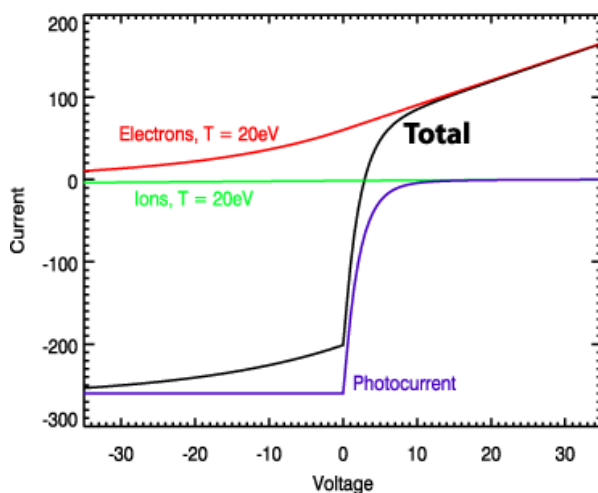


Figure 6: The different currents and how they change when the potential of the probe change (EFW: The Basic Hardware, 2002).

A better description would be: "The three particle populations (plasma ions, plasma electrons, and probe emitted photoelectrons) produce three currents with different dependence on voltage", which can be seen in Figure 6. To find out what the probe potential is, these 3 currents and their effects have to be known.

- The photocurrent: Depends on the sphere's surface material and the illumination from the Sun. The strength of the Sun's illumination depends on the solar cycle so it's a function over time that can vary a lot. This effect is dominating on Cluster because the voltage is normally below 0, as seen in Figure 6.
- The electron current becomes bigger the larger the probes potential is and it depends on the temperature and density of the plasma. When the potential reach about 5 – 10 V, the electron current is the only one that has any effect on the probes.
- The ion current can be neglected in most cases, it works completely opposite the electron current but it's much smaller, due to the lower thermal speed of the ions.

To ensure good voltage measurements, a bias current is sent to the probe. By choosing this bias such that the probe ends up at a point where the curve in Figure 6 is steep, the voltage measured will be as little as possible affected by stray currents (from whatever unknown sources) to the probe, as

$$dV/dI = \left(dI/dV \right)^{-1}$$

is minimal here.

To satisfy the Cluster scientific objectives, the EFW instrument had to be designed to measure (Gustafsson, 1997):

- Instantaneous spin plane components of the quasi-static electric field vector, over a dynamic range of 0.3 to 700 mV/m and with variable time resolution down to 0.1 ms.
- Oscillating electric field in the range 50-8000 Hz and amplitude range 10 mV/m to 1 μ V/m.
- The thermal plasma density, over a dynamic range of 1 - 100 cm^{-3} .
- Plasma density fluctuations over a dynamic range of 1 - 50% with time resolution of 0.1 ms.
- Time delays between signals from up to four different antenna elements on the same spacecraft, with a time resolution of 110 μ s.
- The spacecraft potential, which can give information about electron density in the range 10^{-3} – 10^2 cm^{-3} with time resolution down to 0.2 s.

Each sphere can be operated in voltage or current mode to either obtain the average electric field between the probes or the plasma density. The voltage or current bias of the probes relative to the spacecraft can be stepped both modes for diagnostics and to find out the temperature and density of the plasma.

In electric field mode the probes are operated in pairs. If all probes are working the probes that are opposite each other are used, see Figure 5. If for instance probe 1 is broken, probes that have a 90-degree angle between will be used instead, this is a measure that is only used as a last resort. Thanks to the bias current, the probes sit on almost the same potential as the surrounding plasma and the pre-amplifier is set to high impedance. The electric field can be calculated by measuring the potential difference between the probes. The probes can measure two of the electric field components. The 3rd component can often be derived from the condition of zero parallel field: $\vec{E} \cdot \vec{B} = 0$.

In the Langmuir mode (current mode) the pre-amplifiers impedance is set to low so the probe can be given a bias potential and the resulting current can be measured. The switching between the different modes is done inside the main electronics. The Langmuir mode is useful mainly in high-density plasmas, and is rarely used on Cluster.

The hardware in the EFW instrument can register between two and eight signals depending on what frequency one wants to use. This gives the instrument a chance to investigate a number of different scenarios in the Earth's magnetosphere and its surroundings depending on what the person in charge wants to see. Depending on what data one wants to look at the instrument can be set to collect the data with different filters, sampling rates and data rates. There are four different data rates: 1440, 15040, 22240 and 29440 bits/sec. Then the data are sent through a low-pass filter with 3 dB damping point at: 10, 180, 4000 or 32000 Hz or a band-pass filter at 50-8000 Hz. For normal mode, 1440 Kbit/sec, two electric field components are filtered at 10 Hz, and sampled at 25 samples per second. With the most commonly used burst mode, 15040 bits/sec, two signals are filtered at 180 Hz, and sampled at 450 samples per second. The instrument supports many other combinations, but these are the most commonly used.

In burst mode, data rates of 22240 and 29440 bits/sec can be used to send 3 or 4 signals at 450 samples per second at the expense of telemetry for STAFF and WHISPER. When the low-pass filters are used, the signals from the probes can measure the voltage either relative to the spacecraft or differentially between two probes, most of the time the two probes that are opposite each other. If the signals pass through the band pass filter only the differential between two probes can be measured with an additional gain of 14.

5.2 Scientific Objectives

Having four spacecraft's gives Cluster a perfect opportunity to get the best data ever collected for the Earth's magnetic field and its interaction with the solar wind. This mission can get information at small-, medium-, and large- scale.

5.2.1 Electric fields at small scale

One thing scientists want to study is random events that result in acceleration of plasma, which is one kind of events that should be observed by the internal burst data. When looking in the ISEE database one can see electric- field spikes with amplitude of 100 mV/m that can last for up to 50 ms [15]. With previous missions the properties of the waves were not fully determined but with Cluster all needed parameters can be gathered to evaluate the role of the spikes in different scenarios that can be observed around the Earth, for example, high- energy electron beams that can be seen in bow shocks. These are small random events that happen really fast, which makes them really hard to detect if the data rate isn't high enough. Because of the high data rates the internal burst mode work on, the EFW becomes a perfect tool to see them.

5.3 The internal burst data

The EFW instrument constantly samples both "real time" data and internal burst data, but because the data rate for the internal burst mode is so high the instrument have to save this data on a designated memory chip while it wait to get downloaded to one of the ground stations. That's why the internal burst mode constantly scans and store data to this memory to find the areas with the highest activity.

This memory is 1 megabyte and its organized into 16 pages of 64 Kbytes each. These pages can then be assigned to different tasks depending on what the user want. For example, one can use the first two pages to searching for new areas with high activity. The following 12 pages are then used to store the internal burst data and the last two pages can continue the search for even stronger events and if the 2 first pages or 2 last pages find an area with more activity then the saved data, it will the old burst.

Because the internal bursts size they need a lot of bandwidth to get downloaded, so there is only time for the spacecraft's to send the EFW's internal burst data two times per orbit to one of the ground stations. Because of this system at least a few interesting events are saved though the saved events maybe cutoff at the beginning or end due to the finite number of samples possible to save. Even after this is the data very valuable because it's a high-resolution snapshot of the most interesting areas in the spacecraft's orbit.

While in this mode, the probes can provide useful information about the electric field and the spacecraft potential. The potential is normally available at 5 samples per second when science data is collected and 0.2 samples per second when only housekeeping data is available. Because the spacecraft potential varies with the density of the plasma, higher sampling rates are very useful when estimating density in tenuous plasma and identifying boundary transitions.

6 Processing of the internal burst data

The internal burst data have a number of problems, described in detail later, that have been known for years but these have been just removed on a case-to-case bases without a real attempt to make a program that will make sure all the burst data reach the same high quality as the other EFW data available. However, most of the sources to these problems are unknown and they had to be identified and later counteracted with the best possible method.

The goal of the project is to make a program that would process the internal bursts and then plot the results. To figure out how to do this, a lot of data had to be analyzed before the best methods to remove the problems were found. Because there are gathered data from over 10 years of operation, because the data varies a lot the possibility to make a program that can take care of all problems in the amount of time one have during a thesis work is not possible. By taking care of the most pressing problems one can make most of the data viable and the rest of the problems can be handled when they are noticed.

Because the normal mode data doesn't have the same problems as the internal burst data one can assume that the problems only affect the burst data. The problem can be in the codes that collect them from the database or the handling of the data on-board the spacecraft. The making of the program was divided into several smaller pieces so they could be tested separately, starting with the one for removing spikes. Having corrupted data points makes it hard to get a good spin fit and therefore harder to see if the burst data is in the correct order, so correcting the spikes is the first priority.

6.1 Getting information about the burst

The already existing program to gather the information from the database is called "caa_is_get.m". To get the data one need to know start time, stop time, spacecraft number, instrument, field, sensor, filter, type of data, and if the data should be in physical or tm values. By providing as many parameters as possible the program can get the data both faster and more reliably. Previously only half of the parameters were used when the program gathered the data so it had to go through all possible combinations to find the existing data, which is very time consuming. By adding information about the collected internal bursts the data collection can be done in a fraction of the time needed before.

To make this process faster and more reliable, the information about the bursts had to be used. This information for each collected burst is available in the EFW telemetry and has already been gathered in a text file that is available on the homepage [14], where each row represents a different burst. Using a C++ program that interprets the information put this information together.

With these values the data retrieval becomes both faster and more reliable. Because the information in the text document is saved in hexadecimal code, a program had to be written to interpret the different codes and then apply the settings to the data retrieval program that already exists. By using the same principles as the C program that constructs the information on the IRF Uppsala homepage to construct a program in Matlab that does the same task, this was fairly easy to do. The information given for each burst is saved in a hexadecimal system.

6.2 Gathering, calibrating and saving the data from the ISDAT database

After the parameters needed has been gathered and saved, see section 6.1 Getting information about the burst, the internal burst data are collected from the ISDAT database one parameter at a time. First the electric field data are gathered from the ISDAT database in 'tm' values, raw (non-calibrated) data that hasn't been processed or changed in any way. After this is done the time of the data have to be corrected because the clock from the instrument and the satellite itself do not match. Between the instruments and the spacecraft's electronics is the Digital Wave Processor (DWP), which provides an on-board control for the instruments in the WEC. The DWP collects the data from five different instruments, which makes it easier for their teams to cooperate and share data when they use the same protocols, and sends it to the satellite so it can be transferred to the ground [1].

This instrument has an internal clock that is supposed to work at 900 Hz but it's a little bit faster (and also varying slightly between the spacecraft) so when the internal burst data gets a time stamp it is a little bit before the satellites internal clock. To correct the time, the function `c_efw_burst_chkt.m` had to be used. After the time was corrected on the 'tm' data these must be multiplied with a constant so it could be converted from raw data to physical units. The electric field data had to be:

1. Multiplied with the constant $2.12 \cdot 10^{-3}$ so it would be in mV.
2. The time vector for the electric field data is corrected with the function `c_efw_burst_chkt.m`.
3. After this the data is saved in both raw and physical units.

All the normal mode data is ready to be used so there was no need for any calibrations, this data could just be gathered from the ISDAT database. When gathering the normal mode data from the database only the satellite's id and the start time of internal burst could be used from the information gathering in section 6.1 because it's the only parameter that can be used for both internal burst and normal mode data.

If the internal bursts collected also had information about the magnetic field, another part of the program is used to collect the magnetic field data and then correct it. This data had to be corrected in several steps before it can be used, which are done in this order:

1. The data is gathered from the ISDAT database and divided into two; a time- vector and a matrix containing the magnetic data for the x-axis, y-axis and z-axis.
2. The magnetic field data is divided by a factor -7000, which converts the data to nT.
3. The time vector for the burst is corrected with the function `c_efw_burst_chkt.m`.
4. The data matrix and the time vector are put back together to make a matrix with 4 columns.
5. The spikes are removed from the data with the function `rm_ib_spike.m`.
6. Applying a transfer function, `c_efw_burst_bsc_tf.m`, to the data, which despin the data to a DSI reference frame.
7. Using `irf_filt.m` to apply a high- pass filter to the data.

After doing these steps, two sets of magnetic data are available; one that is following the spacecraft's rotating reference frame and the other one is in the de-spun inverse (DSI) reference frame.

6.3 Correct order of the data

Some glitch in the instrument causes the burst data sampled by the EFW instrument to sometimes be stored in the wrong order in the burst memory, so that the data from probe 3 gets saved as probe 1 and vice versa. If this happens there have to be a function that tries to find these errors and correct them. This can be achieved by creating a program that compares the internal burst data to the normal data, so the data will match when they are compared. If the data isn't in the right order, the program will switch the order of the data.

One of the hardest parts of this program was to create a good function to figure out if the data was in the correct order or not. After some research it was concluded that this doesn't happen often and when it happens the collected data couldn't end up in any order. The data is collected by two individual analogue-to-digital converters (ADC), which can only gather specific parameters. For example, the first ADC can only gather data from probe 1 and 3, and the second ADC can only gather data from probe 2 and 4. The user sets what parameters that will be gathered but there is limited number of combinations available, which can be found in the command and telemetry description for the EFW instrument. However it can happen that they collect the wrong pair of parameters, which will make the data end up in the wrong order. For example, the bursts collected from spacecraft 1 at 2000-12-14, should have the parameters V1H, V2H, V3H and V4H. The data from V1H and V2H is supposed to be saved first and V3H and V4H after. If everything goes according to the plan the data will end up in the right order V1H, V2H, V3H, V4H. If there have occurred any problems the 2nd pair can be read first so the order of the data becomes V3H, V4H, V1H, V2H.

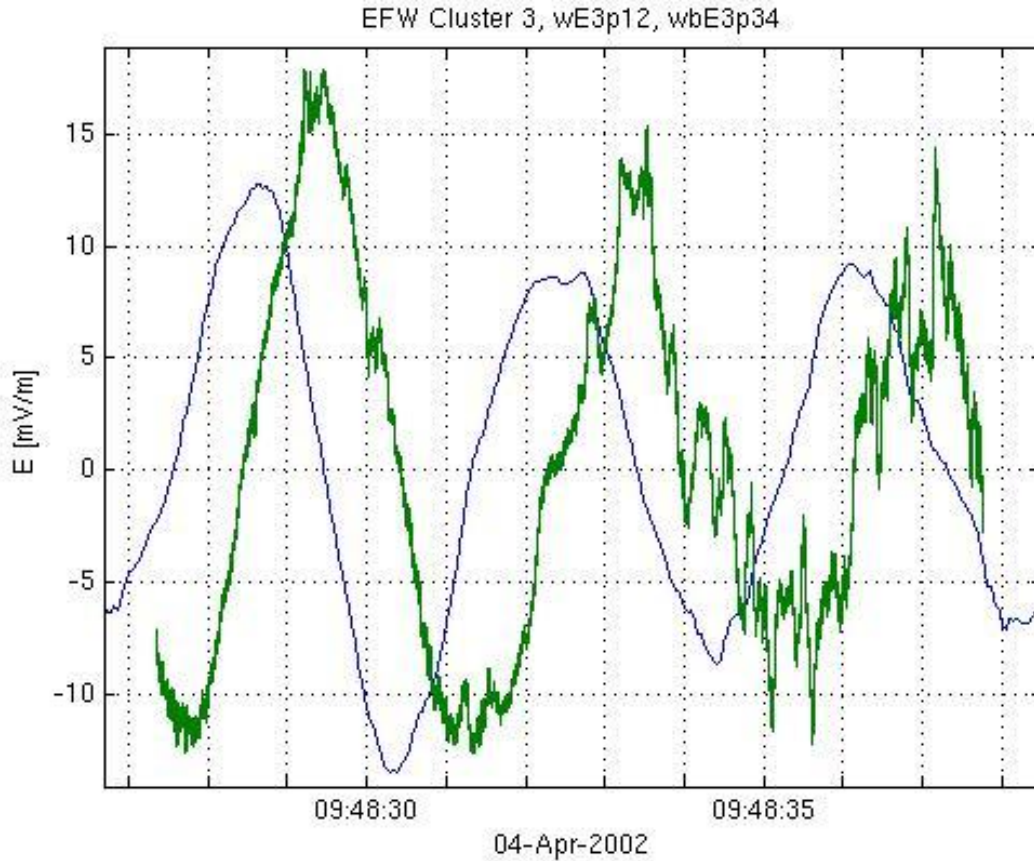


Figure 7: Data collected from cluster satellite 3 April 4th 2002 between 9:48:27 and 9:48:38. This example has been made to illustrate how it looks when data from the normal mode and the internal burst mode does not match. The blue line is the potential between probe 1 and 2 from normal mode data. The green line is the potential between probe 3 and 4 from internal burst data. When the data order in the burst has been shifted, comparing normal mode and burst mode data for the same probe pair will give this kind phase difference.

To find out if the data was corrupted it had to be checked against normal mode data. This is done with the help of a spin fitting code, `c_efw_sfit2.mat` that already exists. However, this function can only compare probe pairs like p12, p34 and p32. To calculate these electric field values from the individual probe potentials the values from two probes are subtracted and then divided by the distance between them, as below.

$$(p1 - p2)/88 \text{ for } p12, p34. (p1 - p2)/66 \text{ for } p32 \quad [6.1]$$

The spin fit function tries to fit the data sets to a sine wave and then one can compare the phase of this sine wave, found as the values of the `atan2` function to see if the data sets are the same data or different. If they match, the data are in the right order and nothing has to be done to it.

The internal burst data are usually 12 seconds long so they consist of 3 spins. There is only need for one spin to see if the data fits or not, but more spins makes the match more reliable. There might not be a fit if there weren't enough spins in the burst data or when the data was too varying to get a good approximation to a known sine curve. If this happens, one has to assume that the data aren't in the correct order, see Figure 7. In this figure one can see that the displacement between the data sets is

around 90 degrees, which suggest that the data will match if the probe pairs that are constructed by using the probes that are opposite each other, wE3p12 (normal mode data) and wbE3p12 (internal burst data). This is the difference between probe 1 and 2 in both internal burst mode and normal mode.

6.4 Spikes

The data gathered from the ISDAT database contains some corrupted data points that look like giant spikes. Where these come from isn't completely understood, however, they are very easy to spot and are clearly not a part of the original data. It appeared to be two different kinds, one that seems to be completely random and another that comes at fixed location. The spikes with a fixed location are largest, see Figure 8, so these had to be removed before other corrupt data points could be seen and removed. To counter these problems, two routines were written.

After locating the corrupted data, the program removes these completely from the data set, which create small gaps. Instead of using an interpolation of other data points I choose to remove them so there will be small data gaps instead of corrupted data.

In Figure 8 there is a comparison between raw and processed data. In this example there are some big spikes in the end of the dataset, this varies between different bursts, in some of them there are spikes all over the data set. The spikes that are seen are the ones with set interval and because they are so big they can hide other spikes until they are removed.

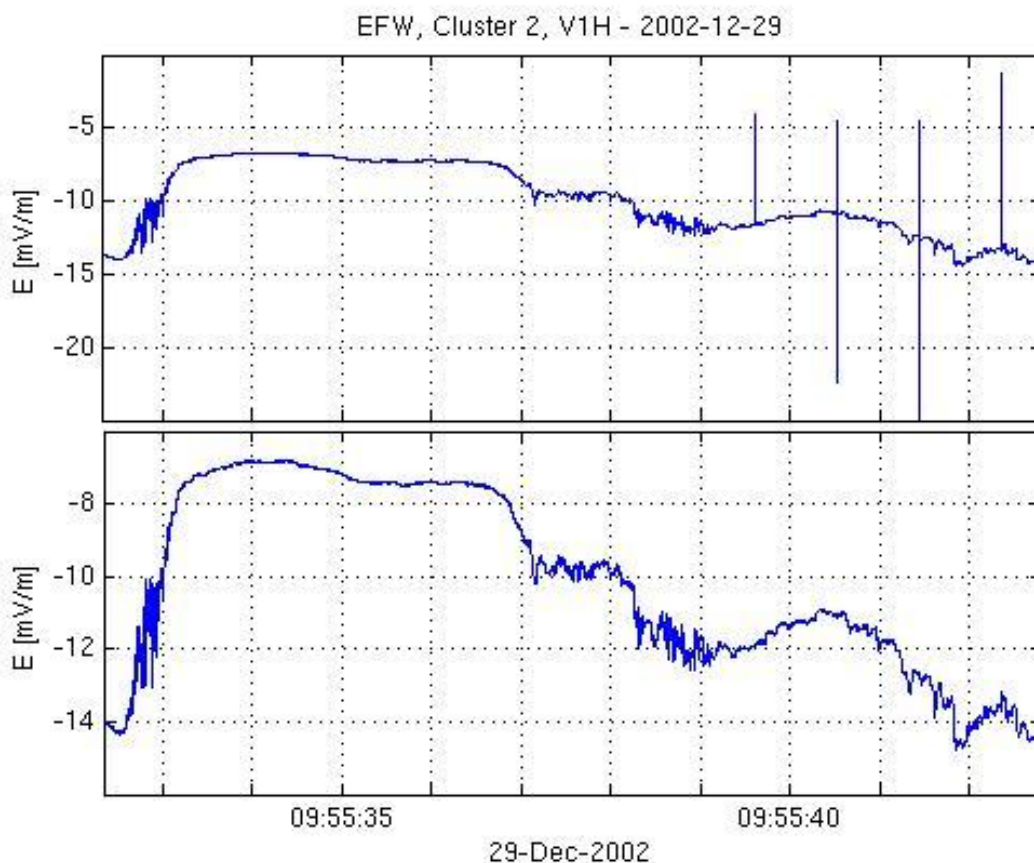


Figure 8: Data collected from the 2nd Cluster satellite, December 29th 2002 between 09:55:33 and 09:55:42. The upper plot shows the data before the spikes have been removed and the lower plot shows the data after the spikes have been removed.

6.4.1 Spikes at fixed locations

After looking at a number of these data sets and calculating the difference between the big spikes with set intervals I could conclude that the interval between the big spikes was 8192 (2^{13}). The

number of corrupted data points every spike consist of seems to be fluctuating between 0 and 5, which are consistent with random events that occur at a set interval.

With a very simple code that identified the first spike, removes 2 data points around it, then jumps 2^{13} points to the next one. This code can be seen in appendix A as a part of the spike removal program.

6.4.2 Random spikes

Random spikes can occur at any point, at any rate and can be caused by single event upsets (SEU), most of these will be corrected by the spacecraft's error detection software but because the internal burst data mostly lie in the burst memory that doesn't have any error detection some will get through. They can also occur during the transportation of the data from the internal memory on the spacecraft to the databanks on Earth. Another possibility is short analog disturbances, short electrical pulses. These points are usually far from the correct data and are therefore easy to spot but harder to remove. To remove these I first divided the data sets into 100 equal pieces and then calculated the standard deviation to see if any points were found that varied with more than 3 times the standard deviation. If any were found they were removed automatically like the spikes with fixed position. Because of this I later had to normalize the size of all data sets so that I could calculate the difference between 2 probes and conclude if the data were in the right order or not, see appendix A. the program that do this only works if the data sets have the same size, otherwise there will be an error when it tries to match the time axis to each other.

When all spikes have been removed, the data are saved.

6.5 Finishing the program

After all the major pieces were put together, there still were a few problems that had to be corrected. The first one was that several functions used the same variable names, which had to be changed. Because the program consists of several different pieces the data get saved several times so one can compare the data between the steps and see what has been done to it. This gives a better overview of the information that can be good in some cases. In the end of the program two routines were added so that the data could be plotted, both the actual data and the position of the gathered bursts. The existing plotting program didn't have a routine for plotting the magnetic field data for the internal burst magnetic field data, this one had to be integrated in the function Summaryplot.m.

There was also a problem with the data when there were gaps in the useful data from the electrical field data from the EFW instrument. These data gaps occur when the WHISPER instrument sends out strong pulses that overwhelm the electric field data recorded by the EFW instrument. The WHISPER instrument sends out signals into the plasma and records the reflected signal. These were already removed from the normal mode data but they were still there for the internal burst data. There is an existing program remove_problems that takes care of all unwanted data by going through a list of known problems; however, the WHISPER component had to be added for the electric field data. This was added to the function GetData.m.

To remove the WHISPER pulses the program checks a signal once a second to see if the WHISPER instrument is active. If the instrument is active, the data for that second is removed from the data set. Because it only checks once every second it sometimes leaves a little of the whisper pulses but most of the time these remnants are small enough they won't be noticeable. If they are still seen, they can just be ignored because they are always seen close to a gap in the data and are therefore really easy to distinguish from the real data.

Both the magnetic and electric internal burst data had to be corrected with the function c_efw_invert_tf. This function takes care of the analogue filter response time that made the internal burst data a little off compared to the normal mode data, as these are already corrected for this delay. To do this one had to use the information about the filters that was gathered in section 6.1 Getting information about the burst. Depending on what filter was used because the delay varies between filters.

There was also a variable added for the GetData.m function called 'dibscburst'. This function uses the internal burst magnetic field data, if it exists, to create de-spun magnetic field data so it can be plotted by the function.

6.6 Making of the plots

One of the main goals of this project was to build up a database with internal burst plots that shows the difference between normal mode data and internal burst data. To do this, the data have to be plotted and then saved to a specific folder.

Before the plots can be made, the data already collected have to be used to calculate the spacecraft potential, the electrical field, the magnetic field and the angle between the spacecraft's spin plane and the magnetic field. This data is collected with the function GetData.m. After the data is collected the function summaryplot.m is used to make the plots. This program sets all labels that can be seen in Figure 9. When the program makes this plot it can contain between 4 and 6 different plots depending of the collected internal burst data content.

In the title of the plots there is information of the burst that was collected. In the example seen in Figure 9, the data is collected from the EFW instrument at spacecraft 2 at 2002-12-29. There were 8 components collected; SCX, BP12, SCZ, SCY, V1H, V2H, V3H and V4H. In this example, six plots were created.

These plots are shown on a single page that is saved in a specific folder that is set by the user. On the bottom of the page is information about the satellite's position in GSE coordinates when the internal burst was collected. There are four different components of the position; the GSE X, Y and Z coordinates and the geocentric distance, R. These are then shown in Earth radius [$1 R_e = 6371.2 \text{ km}$].

The program also creates a list of the satellite positions when the internal bursts are collected. This data is then plotted in two different plots, shown in two different reference frames. The results from this can be seen in Figure 10.

The first coordinate system is the Geocentric Solar Ecliptic (GSE) coordinate system. In this system the x- axis always point towards the Sun while the z- axis is pointed towards the ecliptic pole. The y- axes supplements the other two and are pointing towards the dusk of the Earth.

The other coordinate system is the Geocentric Solar Magnetospheric (GSM) coordinate system. In this system the x- axis also point towards the Sun but the z- axis is the projection of the dipole axis of the Earth on the GSE yz plane and the y- axis still supplements the other two.

6.6 Complete program

When all of these steps have been made the program saves the plot in a specific folder, which can be set by the user. One of these plots can be seen in Figure 9.

This plot is from 2002-12-29 and the collected burst had 8 components; SCX, BP12, SCZ, SCY, V1H, V2H, V3H and V4H. BP12 is a band-pass filtered signal basically resulting from passing the high-pass filtered voltage between probes 1 and 2 through a diode rectifier and a low-pass filter and cannot be meaningfully calibrated into physical units, but is used onboard for triggering bursts. We do not consider it here. This burst was collected when the spacecraft was 13 R_E away from the Earth in the sunward direction, which is at the brink of the magnetosphere. First it's inside the magnetosphere then it passes into the magnetosheath and then backs into the magnetosphere again (in reality, it is the magnetopause moving back and forth). It enters the magnetosheath when the magnetic strength becomes almost 0. When it passes between the magnetosphere and the magnetosheath, one can see a rise in electrical activity, which is evidence of Chapman- Ferraro currents that run along the magnetopause.

The upper panel is always the spacecraft potential. This potential is derived from the available probes. Most of the times these are probe 1-4 but due to some technical difficulties some of these do not work on several spacecraft and in some cases only the differentials between probes are recorded. At the moment of writing this report only the fourth spacecraft has all four probes remaining in operation. The normal mode data (blue line) is also compared to the internal burst data (green line) to see the difference. Here one can see that the internal burst data are sampled at much higher rate.

The second panel is the magnetic field data from the STAFF instrument. There are four different curves showing the magnetic field; the x (blue line), y (green line), z (red line) components and the total magnetic field strength (turquoise line) that are in despun inverse (DSI) coordinate system, which is a good approximation to GSE. The x axis always points in the direction of the spin plane which is as close as possible towards the Sun, the z axis point upwards (towards the north ecliptic pole) from the spin plane and the y axis complete the coordinate system.

The next two panels are usually the electric field data, in the x and y direction. Depending on the content of the data, there are either one or two panels. Most of the plots have 2 panels but the other configuration does occur when there isn't enough data to separate the result into separate panels, one for the x component and one for the y component of the electric field. The normal mode data (blue line) is compared to internal burst data (green line). These plots are also shown in the DSI coordinate system. Sometimes there are gaps in the data. These were filled with data corrupted by WHISPER transmissions or by artificial spikes. These were removed and can be read about in section 6.2 *Gathering, calibrating and saving the data from the ISDAT database.*

The next panel shows the angle between the satellite's spin plane and the magnetic field. When looking at Figure 8 one can see that the angle change from positive to negative when the spacecraft crosses the magnetopause and it gradually returns to normal when it moves back into the magnetosphere.

The last panel only exists if there are magnetic data for the internal burst. If there is magnetic field data the x (blue line), y (green line), z (red line) components are plotted after the data have been corrected as described in section 6.2 *Gathering, calibrating and saving the data from the ISDAT database.*

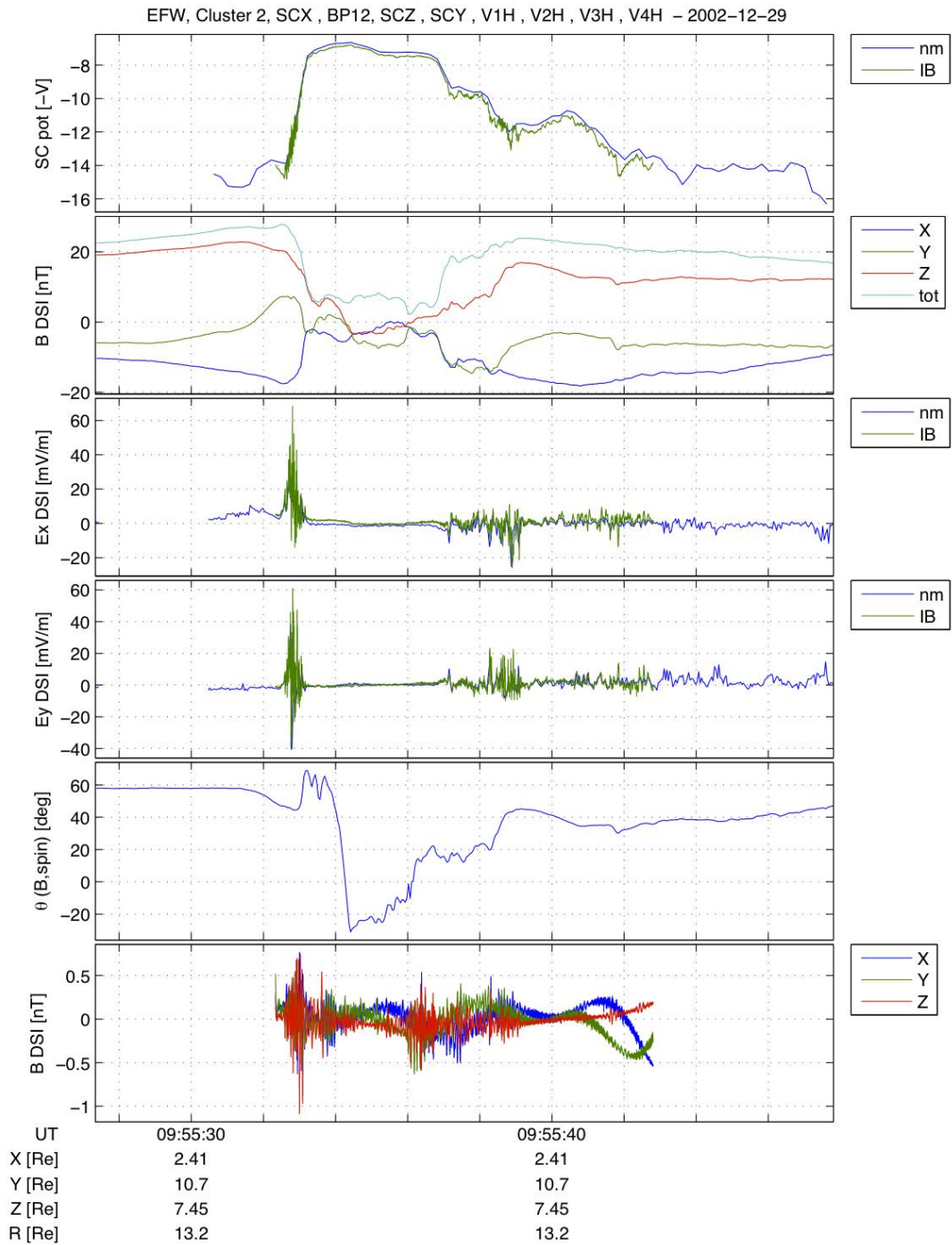


Figure 9: The EFW internal burst summary for spacecraft 2 taken 2002-12-29 between 09:55:28 - 09:55:48. As seen in the title, this burst has 8 components.

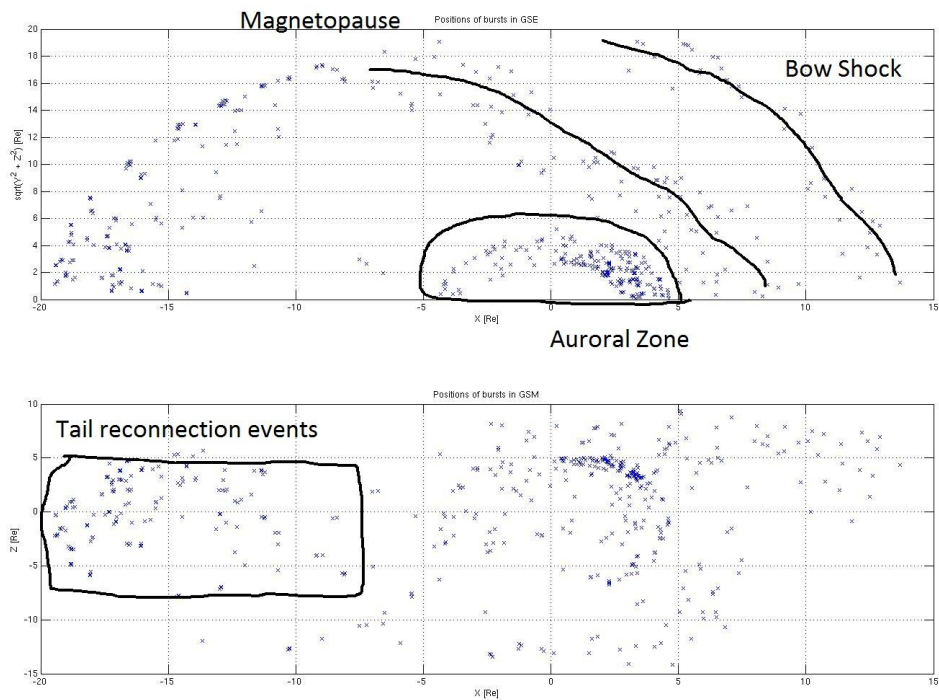


Figure 10: The position of the satellites while they are collecting the internal bursts during 2002. The upper plot shows the position in the coordinate system while the lower one shows the same information but in the GSM coordinate system. In both plots, the Sun can be found to the right.

The other plot that is made with this program is the one with the spacecraft's position, in both GSM and GSE coordinates.

The plot in the GSE system shows the X and $\sqrt{Y^2 + Z^2}$ components in Earth radii [Re] away from the Earth. Here one can see that many of the collected bursts were collected in the inner magnetosphere, between 3 and 5 Re from the Earth in both axis. The others taken towards the Sun is along the magnetopause and the bow shock while the ones taken in the tail are spread out.

The plot in GSM shows the X and Z components in Re. Here one can observe that the positions recorded in the tail are between $Z=+5$ and $Z=-5$ Earth, around the neutral sheet, see Figure 2. Most of the points in the inner magnetosphere are gathered in the northern hemisphere towards the Sun, corresponding to the auroral zone, the cusp, and the polar cap regions.

6.7 Using the program

To use this program one has to have access to IRF's Matlab programs, the data from the Cluster mission and the list over already collected internal bursts that also have the information about frequency, number of parameters and what these parameters are.

If these things are available the program is very easy to use, one just has check in the list_hex.txt and find where on the list the interval one wants to process is located. For example, I want to get the plots for 2002. The first burst for 2002 are at row 744 and the last is at row 1850. So to run the program for the entire year I just have to write:

```
caa_get_bursts(744,1850)
```


7 Results

With the help of the program described in this paper most of the bursts can be downloaded and safely used for scientific research, however, there still remain problems that haven't been solved yet. This program take away the most pressing issues but there still are random events in the data that makes the data collected with this program almost useless. For example, when some of the bursts occur there are no normal data so the program won't work because there is nothing to compare the burst data to and there isn't enough to plot. More time has to be used to manually search through larger quantities of data to find all errors.

There also occur that the internal burst data have information from probe 2, 3 and 4 while the normal mode data only have data from probe 3 and 4. Because of this there will be more information for the burst data and therefore both the spacecraft's potential and the X and Y component of the electrical field doesn't match. Or there can be data on probe 2, 3 and 4 for both internal burst and normal data, but when the program wants to calculate the differential between probe 3 and 2 this can only be done for the internal burst data and not normal mode for satellite 2. This is because the 10 Hz filter for the normal mode data is broken and therefore this component can't be produced.

8 Discussions

The main goal of this project was the processing of the Cluster EFW internal burst data. Due to the large size of the database and the limited time period available there wasn't enough time to go through the entire database and find all errors so there is a need to work more on the program to make sure it will work with as much data as possible. Nevertheless, a program has been created which successfully and automatically can collect a large number of EFW internal bursts, correct their time stamps, remove artificial spikes from the data, correct for possible disorder in the data quantities, save the data and plot overview plots of the data.

In theory it felt like it should have been easy to correct the problems with the internal burst data, however, the problem became a lot harder due to the variations in the data and from the fact that over the years the spacecraft's have started to lose some of the probes so the data is incomplete. The collected data can also vary a lot because the spacecraft's fly through several different regions where the conditions are very different. This made it very hard to make one program to process all data.

The spikes were a problem that I never really understood why it happens. The interval between the spikes is too precise to be a random event but there is no proof it's an implemented design in the data retrieval software. This can come from an error in the software when it combines the data from the different data pages before the data is sent or it can be a problem when the ground station retrieves it and combines the different data packages. Because I don't have the information about what protocols are used onboard the spacecraft and when the data is sent and retrieved, which makes this a problem I can't find a proper explanation to without going far outside this particular thesis. However, the exact nature of the spikes origin is not needed to remove them efficiently enough for this task.

The internal burst data is stored onboard the spacecrafts for long periods of time depending on when the burst was registered and when the next available download window occurred. This can lead to a number of problems when the memory module is radiated, however, the SEU error rate lie between 10^{-12} errors per bit and day if the components used are of the highest quality or 10^{-5} errors per bit and day if one uses commercial grade components. Taking into account the size of the memory and maximum waiting time of 24 hours there can only be 60 errors at the most, which is highly unlikely [21]. This can explain the random errors found in the data but not the spikes that come with a set interval. So they probably occur due to some programming error in either the EFW software or in the software that send the data to the Earth.

There are also a number of problems that can be traced back to the fact that the data from the EFW instrument is sent through another instrument to the spacecraft's computer. Because of this arrangement the EFW instrument doesn't have access to the spacecraft's internal clock directly and has to rely on the DWP clock that supposed to be at 900 MHz but it's a little higher instead which leads to errors in the time codes of the internal burst data that grow over time from a few ms to over a minute later. However, as part of the EFW telemetry records the reading of the DWP clock every 32 s, this can easily be corrected for and is really not a problem.

The data is collected by two analogue-to-digital converters that can sample at rates up to 36 000 samples per second when it uses the internal burst mode. When more than two different parameters are sampled there will be a time difference of $1/36000$ second between some of the information but they will be saved with the same time stamps. This isn't a big time different but I feel it should be acknowledged as a source of possible errors.

When looking at the produced plots one can see that the quality of the plots varies between different spacecraft. This can be explained by the fact that they are not completely identical anymore due to several failures. Without the data from all 4 probes the information is less complete.

The function that checks the order of the data from the internal burst uses a spin-fit. This function tries to fit the data to a sine curve, if it works one use the data collected to calculate the angle. If the angle of the normal data and the internal burst data is the same, the data fits. The thing is, even if the data seem to fit, some of the corresponding plots still look wrong. This is probably not the best method of checking if the data fits or not, so here is one point in the program that can be adjusted for the better. I haven't done it in this paper because I haven't found a better method and the problem isn't that big because most of the data are in the right order.

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```

case 0,
    switch fff
        case 0,
            output=[450 8];
        case 1,
            output=[900 8];
        case 2,
            output=[2250 8];
        case 3,
            output=[4500 8];
        case 4,
            output=[9000 4];
        case 7,
            output=[25000 2];
        otherwise
            output=[0];
    end
end

```

case 1

```

if fff==5
    output=[18000 2];
else
    'bad';
end

```

case 2

```

switch fff
    case 4
        output=[9000 8];
    case 5
        output=[18000 2];
    otherwise
        output=[0];
end

```

case 3

```

switch fff
    case 0

```



```

        output=[450 16];
    case 1
        output=[900 16];
    case 2
        output=[2250 16];
    case 3
        output=[4500 16];
    case 4
        output=[9000 8];
    case 5
        output=[18000 4];
    case 6
        output=[36000 2];
    otherwise
        output=[0];
    end

end

i=1;
iii=2;
ii=54;
vars=zeros(output(1,2),4);

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%%
%%      Getting information about the burst data
%%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%

```

```

while data(ii)~=63

    adc0 = bitand(data(ii),15);
    adc1 = bitand(data(ii),240);
    adc1 = bitshift(adc1,-4);
    adc1 = bitor(bitand(adc0,8),bitand(adc1,7));

    switch adc0

        case 0

            vars(i,:) = 'V1L ';

        case 1

            vars(i,:) = 'V1M ';

        case 2

            vars(i,:) = 'V1H ';

        case 3

            vars(i,:) = 'V1U ';

        case 4

            vars(i,:) = 'V3L ';

```

```

case 5
    vars(i,:) = 'V3M ';
case 6
    vars(i,:) = 'V3H ';
case 7
    vars(i,:) = 'V3U ';
case 8
    vars(i,:) = 'V12M';
case 9
    vars(i,:) = 'V43H';
case 10
    vars(i,:) = 'SCX ';
case 11
    vars(i,:) = 'SCZ ';
otherwise
    vars(i,:) = 'BAD ';
end
switch adcl
case 0
    vars(iii,:) = 'V2L ';
case 1
    vars(iii,:) = 'V2M ';
case 2
    vars(iii,:) = 'V2H ';
case 3
    vars(iii,:) = 'V2U ';
case 4
    vars(iii,:) = 'V4L ';
case 5
    vars(iii,:) = 'V4M ';
case 6
    vars(iii,:) = 'V4H ';
case 7
    vars(iii,:) = 'V4U ';
case 8
    vars(iii,:) = 'V43M';
case 9
    vars(iii,:) = 'V12H';
case 10

```



```

( start_time>=toepoch([2001 04 20 03 00 00]) &&
start_time<toepoch([2001 04 23 15 00 00])) || ...
( start_time>=toepoch([2001 04 24 00 00 00]) &&
start_time<toepoch([2001 04 24 15 00 00])) )
% The bias current is a bit too large
% on p3 and p4 on C1&2 in April 2001.
% Ignore p3, p4 and p34 and only use p1, p2 and p12.
% Use only complete 3-hour intervals to keep it simple.
probe_list = [1 2];
irf_log('dsrc',sprintf('Too high bias current on p3&p4
sc%d',cl_id));
end
case 3
if start_time>toepoch([2002 07 29 09 06 59])
% p1 failure
probe_list = 2:4;
irf_log('dsrc',sprintf('p1 is BAD on sc%d',cl_id));
end
end
pl = [12,34];
switch cl_id
case 1
if start_time>toepoch([2009 10 14 07 00 00]) || ...
(start_time>toepoch([2009 04 19 00 00 00]) &&
start_time<toepoch([2009 05 07 00 00 00]))
pl = 32;
irf_log('dsrc',sprintf('          !Only p32 exists on
sc%d',cl_id));
elseif (start_time>toepoch([2003 9 29 00 27 0]) || ...
(start_time>toepoch([2003 3 27 03 50 0]) &&
start_time<toepoch([2003 3 28 04 55 0]) ||...
(start_time>toepoch([2003 4 08 01 25 0]) &&
start_time<toepoch([2003 4 09 02 25 0]) ||...
(start_time>toepoch([2003 5 25 15 25 0]) &&
start_time<toepoch([2003 6 08 22 10 0]) )
pl = [32, 34];
irf_log('dsrc',sprintf('          !Using p32 on sc%d',cl_id));
elseif start_time>toepoch([2001 12 28 03 00 00])
pl = 34;
irf_log('dsrc',sprintf('          !Only p34 exists on
sc%d',cl_id));
elseif (start_time>=toepoch([2001 04 12 03 00 00]) &&
start_time<toepoch([2001 04 12 06 00 00])) || ...
( start_time>=toepoch([2001 04 14 06 00 00]) &&
start_time<toepoch([2001 04 16 15 00 00])) || ...
( start_time>=toepoch([2001 04 18 03 00 00]) &&
start_time<toepoch([2001 04 20 09 00 00])) || ...
( start_time>=toepoch([2001 04 21 21 00 00]) &&
start_time<toepoch([2001 04 22 03 00 00])) || ...
( start_time>=toepoch([2001 04 23 09 00 00]) &&
start_time<toepoch([2001 04 23 15 00 00]))
% The bias current is a bit too large
% on p3 and p4 on C1&2 in April 2001.
% Ignore p3, p4 and p34 and only use p1, p2 and p12.
% Use only complete 3-hour intervals to keep it simple.
pl = 12;
irf_log('dsrc',sprintf('          !Too high bias current on
p34 for sc%d',cl_id));
end
case 2
if start_time>toepoch([2007 11 24 15 40 0])
pl = [32, 34];
irf_log('dsrc',sprintf('          !Using p32 on sc%d',cl_id));
elseif start_time>toepoch([2007 05 13 03 23 48])
pl = 34;
irf_log('dsrc',sprintf('          !Only p34 exists on
sc%d',cl_id));
elseif (start_time>=toepoch([2001 04 09 21 00 00]) &&
start_time<toepoch([2001 04 10 06 00 00])) || ...
( start_time>=toepoch([2001 04 10 09 00 00]) &&
start_time<toepoch([2001 04 19 15 00 00])) || ...
( start_time>=toepoch([2001 04 20 03 00 00]) &&
start_time<toepoch([2001 04 23 15 00 00])) || ...
( start_time>=toepoch([2001 04 24 00 00 00]) &&
start_time<toepoch([2001 04 24 15 00 00]))
pl = 12;

```

```

        irf_log('dsrc',sprintf('                !Too high bias current on
p34 for sc%d',cl_id));
    end
    case 3
        if start_time>toepoch([2003 9 29 00 27 0]) || ...
            (start_time>toepoch([2003 3 27 03 50 0]) &&
start_time<toepoch([2003 3 28 04 55 0])) ||...
            (start_time>toepoch([2003 4 08 01 25 0]) &&
start_time<toepoch([2003 4 09 02 25 0])) ||...
            (start_time>toepoch([2003 5 25 15 25 0]) &&
start_time<toepoch([2003 6 08 22 10 0]))
            pl = [32, 34];
            irf_log('dsrc',sprintf('                !Using p32 on sc%d',cl_id));
        elseif start_time>toepoch([2002 07 29 09 06 59])
            pl = 34;
            irf_log('dsrc',sprintf('                !Only p34 exists on
sc%d',cl_id));
        end
    end
    %%%%%%%%%%% END PROBE MAGIC %%%%%%%%%%%
    probes=[];
    for out = 1:s
        if vars(out,4)==32
            filt=vars(out,3);
            if vars(out,3)==72 % H
                filter = '4kHz';
                field = 'E';
                instrument = 'efw';
                if s==8 & out>4
                    probe = out-4;
                    sen = irf_ssub('p?',out-4);
                else
                    probe = out;
                    sen = irf_ssub('p?',out);
                end
                [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
                start_satt = c_efw_burst_chkt('db:9',filename);
                if isempty(start_satt)
                    irf_log('dsrc','burst start time was not corrected')
                else
                    err_t = t(1) - start_satt;
                    irf_log('dsrc',['burst start time was corrected by ' ...
num2str(err_t) ' sec'])
                    t = t - err_t;
                end
                d_phys=data*0.00212;
                data_phys = [t d_phys];
            elseif vars(out,3)==85 % U
                filter = '32kHz';
                field = 'E';
                instrument = 'efw';
                probe = vars1(out,2);
                sen = irf_ssub('p?',probe);
                [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
                start_satt = c_efw_burst_chkt('db:9',filename);
                if isempty(start_satt)
                    irf_log('dsrc','burst start time was not corrected')
                else
                    err_t = t(1) - start_satt;
                    irf_log('dsrc',['burst start time was corrected by ' ...
num2str(err_t) ' sec'])
                    t = t - err_t;
                end
                d_phys=data*0.00212;
                data_phys = [t d_phys];
            elseif vars(out,3)==77 % M
                filter = '180Hz';

                field = 'E';

                instrument = 'efw';

                if s==8 & out>4

```

```

        probe = out-4

        sen = irf_ssub('p?',out-4);

    else

        probe = out

        sen = irf_ssub('p?',out)

    end
    [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
    start_satt = c_efw_burst_chkt('db:9',filename);
    if isempty(start_satt)
        irf_log('dsrc','burst start time was not corrected')
    else
        err_t = t(1) - start_satt;
        irf_log('dsrc',['burst start time was corrected by ' ...
            num2str(err_t) ' sec'])
        t = t - err_t;
    end
    d_phys=data*0.00212;
    data_phys = [t d_phys];
elseif vars(out,3)==76 % L

    filter = '10Hz';

    field = 'E';

    instrument = 'efw';probe_nr

    if s==8 & out>4

        probe = out-4;

        sen = irf_ssub('p?',out-4);

    else

        probe = out;

        sen = irf_ssub('p?',out);

    end

    [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
    start_satt = c_efw_burst_chkt('db:9',filename);
    if isempty(start_satt)
        irf_log('dsrc','burst start time was not corrected')
    else
        err_t = t(1) - start_satt;
        irf_log('dsrc',['burst start time was corrected by ' ...
            num2str(err_t) ' sec'])
        t = t - err_t;
    end
    d_phys=data*0.00212;
    data_phys = [t d_phys];
else
    % BP12
    continue

end

else
    filt=vars(out,4);
    if vars(out,4)==72

        filter = '8kHz';

        field = 'E';

        instrument = 'efw';

        if vars1(out,2:3)=='43'
            sen = irf_ssub('p?',34)
        end
    end
end

```

```

        probe = 34;
    else
        sen = irf_ssub('p?',vars1(out,2:3))
        probe = 12;
    end
    [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst');
    start_satt = c_efw_burst_chkt('db:9',filename);
    if isempty(start_satt)
        irf_log('dsrc','burst start time was not corrected')
    else
        err_t = t(1) - start_satt;
        irf_log('dsrc',['burst start time was corrected by ' ...
            num2str(err_t) ' sec'])
        t = t - err_t;
    end
    d_phys=data*0.00212;
    data_phys = [t d_phys];
elseif vars(out,4)==85

    filter = '32kHz';

    field = 'E';

    instrument = 'efw';

    probe = out;
    if vars1(out,2:3)==43
        sen = irf_ssub('p?',34)
    else
        sen = irf_ssub('p?',vars1(out,2:3))
    end
    [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
    start_satt = c_efw_burst_chkt('db:9',filename);
    if isempty(start_satt)
        irf_log('dsrc','burst start time was not corrected')
    else
        err_t = t(1) - start_satt;
        irf_log('dsrc',['burst start time was corrected by ' ...
            num2str(err_t) ' sec'])
        t = t - err_t;
    end
    d_phys=data*0.00212;
    data_phys = [t d_phys];
elseif vars(out,4)==77
    continue
    filter = '180Hz';

    field = 'E';

    instrument = 'efw';

    probe = out;

    sen = irf_ssub('p?',vars1(out,2:3));
    if vars1(out,2:3)==43
        sen = irf_ssub('p?',34)
    else
        sen = irf_ssub('p?',vars1(out,2:3))
    end
    [t,data] = caa_is_get('db:9',st-
B_DELTA,B_DT,cl_id,instrument,field,sen,filter,'burst','tm');
    start_satt = c_efw_burst_chkt('db:9',filename);
    if isempty(start_satt)
        irf_log('dsrc','burst start time was not corrected')
    else
        err_t = t(1) - start_satt;
        irf_log('dsrc',['burst start time was corrected by ' ...
            num2str(err_t) ' sec'])
        t = t - err_t;
    end
    d_phys=data*0.00212;
    data_phys = [t d_phys];
elseif vars(out,4)==76

    filter = '10Hz';

```



```

ff=0;

if cc2(1)==4
    if exist(irf_ssub('wE?p!',cl_id,12))~=0
        name1=(irf_ssub('wE?p!',cl_id,12));
        tt1=eval(irf_ssub('wE?p!',cl_id,12)); % (t1(:,2)-t2(:,2))/88;
        name11 = irf_ssub('PP?!p$',filter,cl_id,1);
        t1=eval(name11); %name11 = irf_ssub('tm?!p$',filter,cl_id,bla(iii,1));
%irf_ssub('SSS2.wE?p!',cl_id,probe(iii,1));
        name22 = irf_ssub('PP?!p$',filter,cl_id,2);
        t2=eval(name22); %name22 = irf_ssub('tm?!p$',filter,cl_id,bla(iii,2));
    else
        name1=(irf_ssub('wE?p!',cl_id,12));
        name11 = irf_ssub('PP?!p$',filter,cl_id,3);
        tt1=eval(irf_ssub('wE?p!',cl_id,34)); % (t1(:,2)-t2(:,2))/88;
        t1=eval(name11); %name11 = irf_ssub('tm?!p$',filter,cl_id,bla(iii,1));
%irf_ssub('SSS2.wE?p!',cl_id,probe(iii,1));
        name22 = irf_ssub('PP?!p$',filter,cl_id,4);
        t2=eval(name22); %name22 = irf_ssub('tm?!p$',filter,cl_id,bla(iii,2));
    end

    aal=c_phase(tt1(:,1),pha);

    sp1=c_efw_sfit2(12,3,10,20,tt1(:,1),tt1(:,2),aal(:,1),aal(:,2),1,output(1,1));

    distance=88;

    tt2=(t1(:,2)-t2(:,2))/distance;

    aa2=c_phase(t2(:,1),pha);

    sp2=c_efw_sfit2(12,3,10,20,t2(:,1),tt2,aa2(:,1),aa2(:,2),1,output(1,1));

    [a,b] = size(sp2);

    gg=0;

    i=1;

    while i<a+1

        [c,d]=find(sp1==sp2(i,1));

        ex1=sp1(c,2);

        ex2=sp2(i,2);

        ey1=sp1(c,3);

        ey2=sp2(i,3);

        timevec=fromepoch(sp2(i,1));

        z1=atan2(ey1,ex1);

        z2=atan2(ey2,ex2);

        y=round(abs((z1-z2)/pi)*180)

        if ~isempty(y)

            if isnan(y)==1

                irf_log('proc','NaN');

            elseif 25<y && y<155

                gg=gg+1;

            elseif 205<y && y<335

                gg=gg+1;

            else

                ff=ff+1;

```

```

        irf_log('proc','the data match');
    end

    end

    end

    i=i+1;

end

if ff>gg
    xy=[1 2 3 4]
else
    xy=[3 4 1 2]
end
probe_l=probe_list

else
    probe_l=1:length(pl)
    if length(pl)==2
        xy=[1 2]
    else
        if pl==34
            xy=[1]
        else
            xy=[2]
        end
    end
end
end
save_time=[];

for aa=probe_l

    save_list='';

    save_file = './mEFWburstR11.mat';
    name = bla2(xy(aa,:),:);
    data = eval(name);
    name = bla2(aa,:);
    if vars(aa,4)>60
        eval(irf_ssub(['wb1E?p!=data;' 'save_list=[save_list ' 'wb1E?p!
''];'],' ,cl_id,name(9:end)));
    else

        eval(irf_ssub(['P1?!p$=data;' 'save_list=[save_list ' 'P1?!p$
''];'],' ,filter,cl_id,aa));
    end
    if flag_save==1 && ~isempty(save_list) && ~isempty(save_file)

        irf_log('save',[save_list ' -> ' save_file])

        if exist(save_file,'file')

            eval(['save -append ' save_file ' ' save_list]);

        else

            eval(['save ' save_file ' ' save_list]);

        end

    end

    % prepare the output

    if nargout > 0

        if ~isempty(save_list)

            sl = tokenize(save_list);

            out_data = {sl};

            for i=1:length(sl)

                eval(['out_data{i+1}=' sl{i} ' ;'])
            end
        end
    end
end

```

```

        end

    end

else

    clear out_data

end

save_list='';

save_file = './mEFWburstTM1.mat';
name = bla(xy(aa),:);
data = eval(name);
name = bla(aa,:);
data = eval(name);
if vars(aa,3)<60
    eval(irf_ssub(['wb1E?p!=data;' 'save_list=[save_list 'wb1E?p!
'];'],cl_id,name(9:end)));
else
    eval(irf_ssub(['tm1?!p$=data;' 'save_list=[save_list 'tm1?!p$
'];'],filter,cl_id,name(end)));
end
if flag_save==1 && ~isempty(save_list) && ~isempty(save_file)

    irf_log('save',[save_list ' -> ' save_file])

    if exist(save_file,'file')

        eval(['save -append ' save_file ' ' save_list]);

    else

        eval(['save ' save_file ' ' save_list]);

    end

end

end

% prepare the output

if nargout > 0

    if ~isempty(save_list)

        sl = tokenize(save_list);

        out_data = {sl};

        for i=1:length(sl)

            eval(['out_data{i+1}=' sl{i} ''])

        end

    end

else

    clear out_data

end

end
end

```

```

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
%
% Removing spikes from the data
%
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
test3 = load('mEFWburstR11.mat');
load('mEFWburstR11.mat')
fn3 = fieldnames(test3)
bla3=char(fn3)
cc3=size(bla3)

```

```

for aa=1:cc3(1)
    if vars(aa,4)>60
        name = irf_ssub('wb1E?p!',cl_id,bla3(aa,7:end))
    else
        name = irf_ssub('P1?!p$',filter,cl_id,bla3(aa,end))
    end

    if name(9:end)==12 | name(9:end)==34
        e=eval(name);
    else
        data_phys=eval(name);

        standard=std(eval(name));

        x=1;
        y=2;
        xx=0;

        while abs(data_phys(y,2)-data_phys(x,2))<3*standard(1,2) && y<length(data_phys)
            x=x+1;
            y=y+1;
            xx=xx+1;
        end

        a=data_phys;

        i=1;
        x=x-xx;
        z=x+5

        if z<length(a)
            a(x:z,:)=[];

            while i<round(length(data_phys)/8192)
                x=x+8192-5;
                z=z+8192-5;
                a(x:z,:)=[];
                i=i+1;
            end

            pl=length(a);
            x=round(pl/50)

            i=1;
            k=1;
            d=x;
            e=a;
            f=1;
            g=0;

            while i<(length(a)/x)+1

                if d>pl

```

```

        d=p1
    else
    end

    count=a(k:d,:);

    mu = mean(count);

    sigma = std(count);

    [n,p] = size(count);

    % Create a matrix of mean values by
    % replicating the mu vector for n rows
    MeanMat = repmat(mu,n,1);

    % Create a matrix of standard deviation values by
    % replicating the sigma vector for n rows
    SigmaMat = repmat(sigma,n,1);

    % Create a matrix of zeros and ones, where ones indicate
    % the location of outliers
    outliers = abs(count - MeanMat) > 2*SigmaMat;

    % Calculate the number of outliers in each column
    nout = sum(outliers);

    count(any(outliers,2),:) = [];

    [h,j]=size(count);

    g=g+h;

    e(f:g,:)=count;

    f=f+h;

    k=k+x;

    d=d+x;

    i=i+1;

end
if g<d
    e(g:end,:)=[];
else
end

else

end

if isempty(save_time)==1
    save_time=e;
else
    a=length(e)
    b=length(save_time)

    if a>b
        x=a-b
        e(b+1:b+x,:)=[];
    elseif a<b
        x=b-a
        e(a+1:a+x,:)=e(a-x+1:a,:);
    else

end

end

```



```

end

end

switch filt
case 72
    filt='H'
case 76
    filt='L'
otherwise
    filt='U'
end
e = C_EFW_INVERT_TF(e,filt);
save_list='';

save_file = './mEFWburstR.mat';

data=e;

if vars(aa,4)>60
    eval(irf_ssub(['wbE?p!=data;' 'save_list=[save_list 'wbE?p!
''];'],cl_id,name(7:end)));
else
    eval(irf_ssub(['P?!p$=data;' 'save_list=[save_list 'P?!p$
''];'],filter,cl_id,name(end)));
end
if flag_save==1 && ~isempty(save_list) && ~isempty(save_file)

    irf_log('save',[save_list ' -> ' save_file])

    if exist(save_file,'file')

        eval(['save -append ' save_file ' ' save_list]);

    else

        eval(['save ' save_file ' ' save_list]);

    end

end

end

% prepare the output

if nargout > 0

    if ~isempty(save_list)

        sl = tokenize(save_list);

        out_data = {sl};

        for i=1:length(sl)

            eval(['out_data{i+1}=' sl{i} ''])

        end

    end

else

    clear out_data

end

save_list='';

end

```

```

for v=1:length(vars11)
    cp = ClusterProc;
    getData(cp,cl_id,vars11{v});
end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
% Making summary plots of the data
%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
clf

cp = ClusterProc;
dt2=5;
st_int=st-dt2
st_int2=sp-st+2*dt2
orient tall
summaryPlot(cp,cl_id,'fullb','ib','st',st_int,'dt',st_int2,'vars',vars1)
print('-dpdf',fname);

load('mR.mat');
cordinates=eval(irf_ssub(['R?'],cl_id))
YZ=sqrt(cordinates(1,3)^2+cordinates(1,4))
GSE(cord,:)=cordinates(2,:) YZ
GSM(cord,:)=irf_gse2gsm(cordinates(2,:))
cord=cord+1;
catch
end

end
if ~isempty(GSE)
    orient PORTRAIT
    GSM(:,2:4)=GSM(:,2:4)/6171;
    GSE(:,2:5)=GSE(:,2:5)/6371;
    figure
    subplot(2,1,1);plot(GSE(:,2),GSE(:,5),'x')
    title('Positions of bursts in GSE')
    xlabel('X [Re]')
    ylabel('sqrt(Y^2 + Z^2) [Re]')
    grid on
    subplot(2,1,2);plot(GSM(:,2),GSM(:,4),'x')
    title('Positions of bursts in GSM')
    xlabel('X [Re]')
    ylabel('Z [Re]')
    grid on

save_file = './position.mat';

    data = GSM;

    eval(irf_ssub(['GSM=data;' 'save_list=[save_list ' 'GSM '];'],1));

if flag_save==1 && ~isempty(save_list) && ~isempty(save_file)

    irf_log('save',[save_list ' -> ' save_file])

    if exist(save_file,'file')

        eval(['save -append ' save_file ' ' save_list]);

    else

        eval(['save ' save_file ' ' save_list]);

    end

end

% prepare the output

if nargout > 0

    if ~isempty(save_list)

```

```

        sl = tokenize(save_list);
        out_data = {sl};
        for i=1:length(sl)
            eval(['out_data{i+1}=' sl{i} ';''])
        end
    end
else
    clear out_data
end
save_list='';

save_file = './position.mat';
data = GSE;
eval(irf_ssub(['GSE=data;' 'save_list=[save_list ' 'GSE ''];'],1));
if flag_save==1 && ~isempty(save_list) && ~isempty(save_file)
    irf_log('save',[save_list ' -> ' save_file])
    if exist(save_file,'file')
        eval(['save -append ' save_file ' ' save_list]);
    else
        eval(['save ' save_file ' ' save_list]);
    end
end
end
% prepare the output
if nargout > 0
    if ~isempty(save_list)
        sl = tokenize(save_list);
        out_data = {sl};
        for i=1:length(sl)
            eval(['out_data{i+1}=' sl{i} ';''])
        end
    end
else
    clear out_data
end
save_list='';

else
end

end

%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%%
function dataout = rm_ib_spike(magneticdata)

```

```

% Remove spikes in staff IB data

DT = 0.455; % sec, time window
THR = 5; % data above TRH StDev discarded

dataout = magneticdata;

ndata = length(magneticdata(:,1))
dt2 = ceil(DT*c_eww_fsampl(magneticdata,'ib')/2);

i = 1;
while i < ndata
    i2 = i + dt2*2
    if i2 > ndata % last window
        i = ndata - dt2*2;
        i2 = ndata;
    end
    x = magneticdata(i:i2,2:4);
    y = x;
    iii=length(y)
    x = detrend(x);
    s = std(x);
    for comp=3:-1:1
        ii = find(abs(x(:,comp))>THR*s(comp))
        if ~isempty(ii)
            if ii(end)==iii
                y(ii,:) = y(ii-1,:);
            else
                y(ii,:) = y(ii+1,:);
            end
        end
    end
    dataout(i:i2,2:4) = y;

    i = i2 + 1;
end
end

```