User Guide to the RPC-MIP Science Datasets in the ESA's Planetary Science Archive (PSA)

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Table of Contents

List of Acronyms

DFT	Discrete Fourier Transform
EAICD	Experimenter to (Science) Archive Interface Control Document
ESA	Europeran Space Agency
FFT	Fast Fourier Transform
HK	House Keeping
LAP	LAngmuir Probe
LDL	Long Debye Length
LPC2E	Laboratoire de Physique et Chimie de l'Environnement
MIP	Mutual Impedance Probe
PIU	Plasma Interface Unit
PSA	Planetary Science Archive
RD	Reference Document
RPC	Rosetta Plasma Consortium
SDL	Short Debye Length

Reference Documents

RD1	Rosetta Plasma Consortium users's manual, RO-RPC-UM, issue 2.18, 2011
RD2	Rosetta project – MIP experiment – Onboard data handling, RPC/MIP/RP/13/980317/LPCE, issue 3.4, 2000
RD3	Trotignon J.G. et al, RPC-MIP: The Mutual Impedance Probe of the Rosetta Plasma Consortium, Space Science Reviews, , Volume 128, Issue 1-4, pp 713-728, 2007
RD4	ROSETTA-RPC-MIP to Planetary Science Archive Interface Control Document, RPC-MIP-EAICD, RPC/MIP/OP/14/030247/LPC2E, issue 1.3, 2015

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1 Introduction

The RPC-MIP (Mutual Impedance Probe) of the Rosetta Plasma Consortium is an active sensor that measures the transfer impedance between a transmitter (monopole or dipole) and a receiving dipole. It operates in the frequency range 7-3500 kHz in different frequency bands and different frequency resolutions. In active mode (transmitter ON), it allows to measure the electron plasma density and temperature, and under certain conditions, the plasma bulk velocity. In passive mode (transmitter OFF), the receiving dipole is an e-field antenna that measure one component of the electric field of the plasma natural waves.

This document is provided as a user guide for the RPC-MIP datasets available at the ESA's Planetary Science Archive (http://www.rssd.esa.int/index.php?project=PSA) and explains key science datasets. A complete description of the RPCMIP PSA data products is given in the RPCMIP to PSA Interface Control Document (EAICD).

2 Instrument Description

The RPC-MIP instrument is composed of two main elements:
- a sensor unit and
- an electronics board.

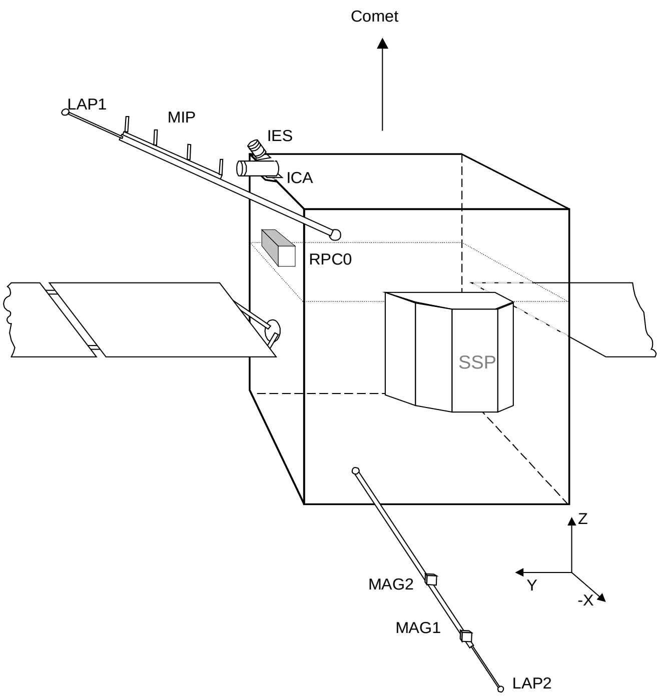

Figure 1: RPC Sensors Layout (deployed).
(Extracted from RD1)

The sensor is mounted on the upper boom (deployed towards the comet facing side in the nominal operation attitude i.e. when pointing nadir) of the Rosetta probe, as illustrated on figure 1. The electrode array is linear and includes one receiving dipole (R1 - R2) and two transmitting monopoles (T1 and T2) supported by a conductive bar, about 1 m in length and 2 cm in diameter. This bar is insulated from the S/C structure, and is kept at a reference potential. The separation between each receiving electrode and the nearest transmitting monopole is 40 cm. The receiving electrodes are located at the ends of the bar in order to maximise the effective length of the antenna for wave measurements, in the passive mode.
Each electrode is made of a small surface conductive cylinder mounted at the tip of a stud and electrically decoupled from this stud with an insulating sheath. The stud is longer than the tip cylinder in order to reduce the perturbing effect of the supporting bar. The overall dimensions of the electrodes and supports are 20 cm in length and 1.1 cm in diameter.
In its active mode, MIP can be operated with different transmitting configurations:

- T1 and T2 can be used as transmitters, independently or conjointly in phase or in phase opposition. Due to its technical principle, this enables to properly analyze plasmas with Debye length lower than a few tens of cm in the so-called Short Debye Length mode.
- To overcome this limit, the Long Debye Length mode has been implemented. In this mode, one of the two Langmuir probes of the LAP instrument (LAP2) is used as a transmitter, enabling plasmas with Debye length up to ~2m to be investigated.

The sensor orientation in the S/C frame is the following (values are in mm):

R1 (X S/C) = -967 R1 (Y S/C) = +1569 R1 (Z S/C) = +3019	R2 (X S/C) = -967 R2 (Y S/C) = +2277 R2 (Z S/C) = +3727
T1 (X S/C) = -967 T1 (Y S/C) = +1852 T1 (Z S/C) = +3302	T2 (X S/C) = -967 T2 (Y S/C) = +1994 T2 (Z S/C) = +3444
LAP2 (X S/C) = -2482 LAP2 (Y S/C) = +780 LAP2 (Z S/C) = -670	

where

- R1 and R2 are the receivers and T1 and T2 are the transmitters of the MIP antenna (from the hinge to the end of the upper boom)
- LAP2 is the transmitter used in LDL mode (fixed at the end of the lower boom)

The orientation of the MIP sensor with respect to the S/C is also given in the SPICE FK kernel ROS_VXX.TF (XX is the version) which can be found on the PSA in the associated Ancillary data associated to the Rosetta mission (SPICE repository).

The RPC-MIP instrument measures the electrical coupling of a transmitting antenna and a receiving antenna, and identifies plasma parameters from the features of the frequency response. No direct contact between the sensor and the plasma is required because the coupling is capacitive only. So, RPC-MIP performance is independent of the chemical composition and photoemissive properties of the probe. It is also immune to contamination by dust and ice deposits. Extremely low energy plasmas can then be explored, an important advantage in a medium where temperatures as low as a few tens of K have been predicted.

In its passive mode, this instrument has also the capability of a plasma wave analyser.

The electronics board is located inside the RPC-0 box. It assumes four functions:

- acquisition of the analog signal from 7 kHz to 3.5 MHz
- data processing using FFT and DFT calculations and some mathematical functions
- a FPGA controls the frequency synthesis and the data storage
- a second FPGA manages the transfer protocol (IEEE 1355) with the PIU who acts as instrument control, spacecraft interface, and power management unit.

3 Scientific objectives

The RPC-MIP measures the electron density and temperature and determines the bulk velocity of the ionised outflowing atmosphere. The investigation of these plasma parameters will contribute to our understanding of the ionisation, thermalisation and expansion of the cometary atmosphere. Observing the variability of the electron density, temperature and drift velocity will provide an additional insight into the scale length of the gas jets and lead to possible correlative studies with the results obtained from Rosetta's particle and optical instruments.

MIP's additional goals include defining the spectral distribution of natural plasma waves in the frequency range from 7 kHz to 3.5 MHz, and monitoring the dust and gas activities. Strong plasma waves were observed in the plasma region upstream of 1P/Halley by Vega 1 and Vega 2, and in the tail of 21P/Giacobini-Zinner by ICE. Nevertheless, no wave measurements were made inside the contact surface, in the close vicinity of the nucleus. Plasma-wave emissions are a very sensitive indicator of outgassing activity. Dust particles impacting spacecraft structures and electric antennas may generate electrostatic impulsive signals that may be detectable with RPC-MIP.

The scientific rationale underpinning the RPC-MIP archive is as follows:

- Maximize the scientific return from the experiment by making available the data to the world-wide scientific community.
- Ensure that the unique data set returned by RPC-MIP is preserved in a stable, long-term archive for scientific analysis beyond the end of the Rosetta mission.
- Provide this archive as a part of the valuable contribution by ESA and the Rosetta science community to the exploration of comets.

4 Instrument Operations

The RPC-MIP in flight operations are controlled by a configuration table sent by telecommand, and setting the operational parameters values.

- SDL/LDL

A relay can be activated by TC to switch between SDL and LDL modes. The frequency range in LDL is fixed to 7-168 kHz with a 7 kHz resolution (24 frequency bins). In SDL mode, the scanned table frequency is chosen among several on board pre-loaded tables with various frequency ranges and resolutions (but with 92 frequency bins).

Details for the available frequency tables for SDL and LDL modes can be found in RD2.

- active modes

Three active modes have been defined for the RPC-MIP instrument: LDL when LAP2 is transmitting, SURVEY and SWEEP when in SDL mode. The SWEEP mode is a sweep over a limited frequency bandwidth, triggered by a SURVEY mode.

- active vs passive mode

In active mode, a transmission signal is injected through one electrode (T1, T2 or LAP2) or the dipole (T1 and T2) at a given frequency. Then, the signal is received on the reception dipole (R1-R2) and Fourier transformed (DFT) with a 7 kHz resolution. A sweep over the selected frequency table allows the computation of the overall response.

In passive mode, when no transmission is applied, the received signal is processed by a FFT over the whole bandwidth (with a maximum frequency resolution of 7 kHz, like in active mode).

- sequence selection

RPC-MIP sequencing is based on the selection of a 32 second sequence (among 7 on board sequences, see RD2 for the detailed description of these sequences) which alternates active and passive acquisitions and transmits in the telemetry all or part of the corresponding information. This results in a set of sub-modes within one sequence. Several sub-modes have been defined to adapt to available telemetry and operating strategies.

- sub-modes

Sub-modes have been defined to limit the information to transmit to the ground:

- FULL, all the computed values are transmitted: 92 modulus values + 28 phase values (centered at the frequency corresponding to the maximum amplitude detected onboard) in SURVEY or SWEEP, 24 modulus values + 24 phase values in LDL, 96 modulus values in PASSIVE
- WINDOW, only the modulus values of a window around the frequency corresponding to the maximum amplitude detected onboard are transmitted (14 values in SURVEY

and SWEEP, 15 values in LDL). In PASSIVE mode, only the first 48 modulus values are transmitted,

- MINMAX (only valid for active modes): two maximums and two minimums of the response are transmitted in the telemetry
- POWER (only valid in passive mode) : the average of the power values in the frequency intervals 7 - 448 kHz (LF part) and 476 - 3584 kHz (HF part) are transmitted

More details about sub-modes and sequences can be found in RD2,
All the parameters of the configuration table are also described in this document. Note that all these parameters can be found in the datasets available in the PSA.

5 RPC-MIP data in the PSA

All the RPC-MIP datasets are given in physical units.
Data processing level number used in MIP naming scheme conforms to CODMAC norm :

3 Calibrated Data: Edited data that are still in units produced by instrument, but that have been corrected so that values are expressed in or are proportional to some physical unit such as radiance. No resampling, so edited data can be reconstructed

5 Derived Data: Derived results, as maps, reports, graphics, etc

The **calibrated** (or 'edited raw') data provided in the PSA for RPC-MIP are:

- **science data** (electric field spectra with modulus and phase and resonance values in active mode, electric field spectra with modulus in passive mode, mean passive power inside a particular frequency bandwidth) for both SDL and LDL modes: contains HK data, amplitudes and frequencies of the electric field spectrum from 7 kHz up to 3.5 MHz in passive mode and HK data, amplitudes, phases and frequencies. A level 3 file contains data from one MIP measurement, i.e. data associated to one configuration table. The time resolution depends on the data, on the telemetry rate and on the on-board operated RPC-MIP sequence (selected by telecommand).

- **house-keeping data** (sequence counters, mean passive power, resonance values, sensor temperature, configuration table): contains HK data concerning the active and passive sweeps: MIP power in Passive mode, resonance power in active mode, resonance frequency in active mode. The time resolution is 32 s.

The **derived** (or 'higher-level') data provided in the PSA for RPC-MIP are: electron density (in m^{-3}) and electron temperature (in K), and under certain conditions the plasma bulk velocity derived from the frequency response.

Note that in the current data set, the derived parameters are not available. When available, this document will provide more information about those parameters.

5.1 Instrument calibrations

Data produced on board are already calibrated (active and passive sweeps). At each switching on a calibration sequence is ran. First, an auto-loop process connects directly the transmitted signal to the analogue reception inside the RPC-MIP board in order to automatically check the transmission levels at each frequency. Second, a FFT is processed on given values to verify that FFT calculation is correct

5.2 Determination of the electron density and temperature

The frequency response modulus of the mutual impedance probe exhibits a peak around the electron plasma frequency fpe and an interference pattern that depends on the electron temperature, whenever the magnetic field is weak enough to be neglected. Conversely, when the electron cyclotron frequency fce becomes of the same order of magnitude as the electron plasma frequency fpe, other resonances and anti-resonances are usually observed at harmonics of fce, the upper hybrid frequency fuh, and Bernstein frequencies fqn. Electron plasma density and temperature are derived from these frequency patterns on a case-by-case basis, using results from plasma environment simulations and from a model of the RPC-MIP response (RD3).

6 Archive format and content

A complete description of the archive naming convention, format and content is given in RD4. We only recall here the minimum knowledge needed to a new user to identify the various data files contained in the archive.

6.1 Directories

A data set will be delivered for each **simple mission phase.** Each data set will contain **only one level data processing**.

A RPC-MIP dataset has the following directory structure :

```
            |-AAREADME.TXT
            |-BROWSE--
            |-CATALOG--
            |                         |-MAR-
            |                         |-2004-    |-APR-
            |                         |          …
            |-DATA---CALIBRATED--|               |-DEC-
            |                         |
|-root directory-|                               |    |-JAN-
            |                         |-2005-|-FEB-
            |                         …
            |                         |-DEC-
            |                                    …
            |                                    |    |-JAN-
            |                                    |-2014-|-FEB-
            |                         …
            |                         |-DEC-
            |-
            |-DOCUMENT--
            |-INDEX--
            |-LABEL—
            |-VOLDESC.CAT
```

The DATA directory of each dataset is divided with respect to data level (calibrated or derived) and to years and months.

6.2 RPC-MIP files

Data are given as ASCII files (.TAB) included in the sub-directories of the DATA directory. Each file is associated to a descriptor file (.LBL) which contains a reference to an object describing the content of each column. These objects can be found in the LABEL directory. See RD1 for a more complete description.

Each MIP file contains data from one measurement session (period between instrument ON and instrument OFF). One session can be determined using the time difference between successive (chronologically) data (spectra, configuration tables or HK parameters). If this difference is greater than 100 minutes, then a new session begins and a new file is created.

The filenaming convention is defined in RD1. The following table gives the filename and the LBL file associated to each data of the RPC-MIP instrument.

Physical quantity	Operating mode		Filename	LABEL file
Spectra	Active	SDL	RPCMIPS3WS_ yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_SS_PO.FMT
		LDL	RPCMIPS3WL_.yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_L_PO.FMT
	Passive	SDL	RPCMIPS3ES_ yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_P_PO.FMT

		LDL	RPCMIPS3EL_ yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_P_PO.FMT
Phase	Active	SDL	RPCMIPS3HS_ yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_SS_PH.FMT
		LDL	RPCMIPS3HL_ yymmddhhmn _xxxxx.TAB	MIP_SPECTRUM_L_PH.FMT
HK			RPCMIPSH3XX_ yymmddhhmn _xxxxx.TAB	MIP_CALIBRATED_HK.FMT
Configuration tables			RPCMIPS3XX_ yymmddhhmn _xxxxx.TAB	MIP_CONFIG_TABLE.FMT
Electron density			TBD	
Electron temperature			TBD	

Where yymmddhhmn is the start of observation and xxxxx is the duration (in minutes)

In passive modes the power is coded on-board on 2 bits (0 to 20 db) or 4 bits (0 to 60 dB). This gives integer power steps (2 or 4 dB digitization steps). In active modes the power is coded on 8 bits (0 to 64 dB) giving 0.25 dB digitization steps. However, the power values are always listed as ASCII_REAL with format F7.2 in order to have the same format in different data files.

In passive modes the effective length of antenna is needed in order to obtain the electrical field in appropriate units. However, obtaining the effective length of the antenna is not trivial and is subject to discussion, this length depending on the characteristics of the plasma. That is why the power is given in decibels relative to 0.6 µV.Hz-1/2.

The time standards used in the MIP data products are:

- the Orbiter On-Board Time (OOBT, counter having a resolution of 1/65536 sec and based on the spacecraft High Frequency Clock)
- the UTC (from the DDS header time correlated)

6.3 Documents

The DOCUMENT directory contains the following documents:

- RPC-MIP EAICD, Ed. 1, Rev. 2, 04/03/2009
- MIP experiment Onboard Data Handling, Ed. 3, Rev. 4, 20/09/2000,
- MIP/PIU Data Handling Interface, Ed. 3, Rev. 3, 23/05/2001,
- RPC-MIP experiment description, 28/06/2008
- Rosetta plasma consortium users' manual, Ed. 2, Rev. 08, 10/04/2006
- User Guide to the RPC-MIP datasets in the ESA's PSA, RPC-MIP-UG-LPC2E, Ed. 1.0, 04/06/2015 (this document)

- A logbook, containing information on the instrument operations or caveats (one single file for the mission lifetime)

7 Recommendations

7.1 General recommendations on RPC-MIP datasets

RPC-MIP data are usually presented in the form of dynamic spectrograms, in which the electric-field intensity is plotted as a function of time (in the X-axis) and frequency (in the Y-axis) using a colour code. The spectrograms bear important information about explored regions. The characteristic signature of natural or actively triggered waves indicates the nature of the ambient plasma regime and, combined with the spacecraft position, reveals the position of key boundaries encountered during a specific time interval.

It is therefore strongly recommended to first look at these spectrograms. In some cases, RPC-MIP spectra may be corrupted by interferences and/or overflows that make the measurements interpretation intricate. Useful supporting parameters are included in the data file to help the user in the data analysis.

The following example shows the active and passive spectrograms for about 2 hours around the closest approach of Earth Swing-By #3). Values for the electric field power spectral density are expressed in dB and color-coded.

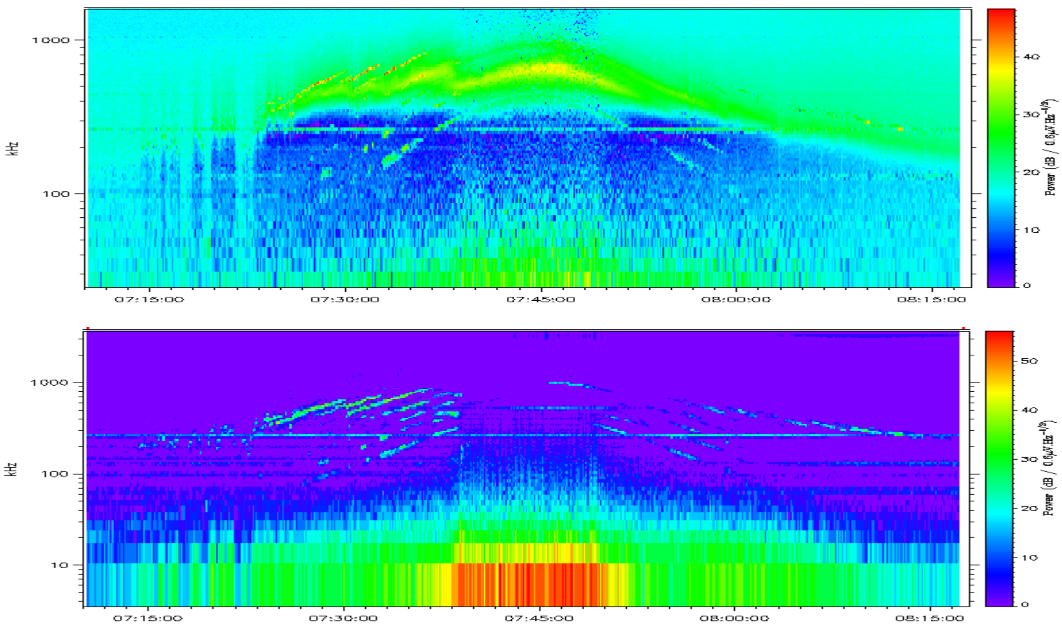

Figure 2: Active (top) and passive (bottom) spectrograms for RPC-MIP on 2009 November 13 (Earth Swing-By 3) between 07:10 and 08:20.

7.2 Caveats

7.2.1 Interferences

RPC-MIP suffers from a number of interferences that have been observed since the beginning of the mission. Both passive and active spectrograms are affected by a high level of interference, located at 266 kHz, at 49 kHz-harmonics and 800 kHz. These interferences are believed to be related to the on-board electronics and are steady over the mission lifetime in frequency but may vary in amplitude in part due to the variation of the plasma environment and the antenna temperature.

7.2.2 Data quality

A quality index is given for each data file. Possible values are:

- for CALIBRATED data:

-1	not yet qualified
0	Good quality (number of reliable points > 75%)
1	Acceptable quality (number of reliable points > 50% and < 75%)
2	Bad quality (number of reliable points < 50%)

- for DERIVED data:

-1	not yet qualified
0	Good quality - Unambiguous determination (number of reliable points > 75%)
1	Acceptable quality - Difficulties encountered in the determination (number of reliable points > 50% and < 75%)
2	Bad quality - Possible errors in the determination (number of reliable points < 50%)

The data quality value is indicated in the label file (.LBL) associated with each data file. It is highly recommended to pay special attention to data analysis when encountering every other value than 0.

7.2.3 R2 temperature

A thermistor located in the R2 RPC-MIP electrode provides temperature measurements with a 32 seconds time resolution. Artificial features have been observed since the beginning of the mission, especially at low temperatures. Periodic peaks and squares are observed on the temperature curves, presumably due to on-board electronic device. The reason for these features is currently unknown.

One has to note that the type of features observed (peaks or squares) is dependent on the telemetry rate and on the mode (SDL or LDL) of the RPC-MIP instrument.

Moreover, the temperature value given by the R2 thermistor must be handled with care since, at the comet, surrounding conditions are not necessarily fully compatible with the nominal operating range of the thermistor. This parameter is included in the HK RPC-MIP dataset.

7.2.4 Temperature effect on the preamplifier response

Since the beginning of the mission, it has been observed that the electric field power spectral density is affected at low temperatures, both in passive and active modes. This is due to the influence of the temperature on the preamplifier response, then affecting the overall response of the instrument, over the whole frequency range, and strengthening interferences level.

It may also be observed that the response of MIP is affected by small temperature variations when the antenna is operating well in its operational temperature range, especially since about April-May 2015.

Figure 3 below illustrates the temperature effect on the passive spectrograms obtained by RPC-MIP around 2008 September 04. The color-coded passive spectrogram (top panel) exhibits a higher level of noise and interferences when the temperature is lower (second panel). The last three panels are attitude angles (roll, pitch, yaw) showing the correlation between the probe attitude and the temperature.

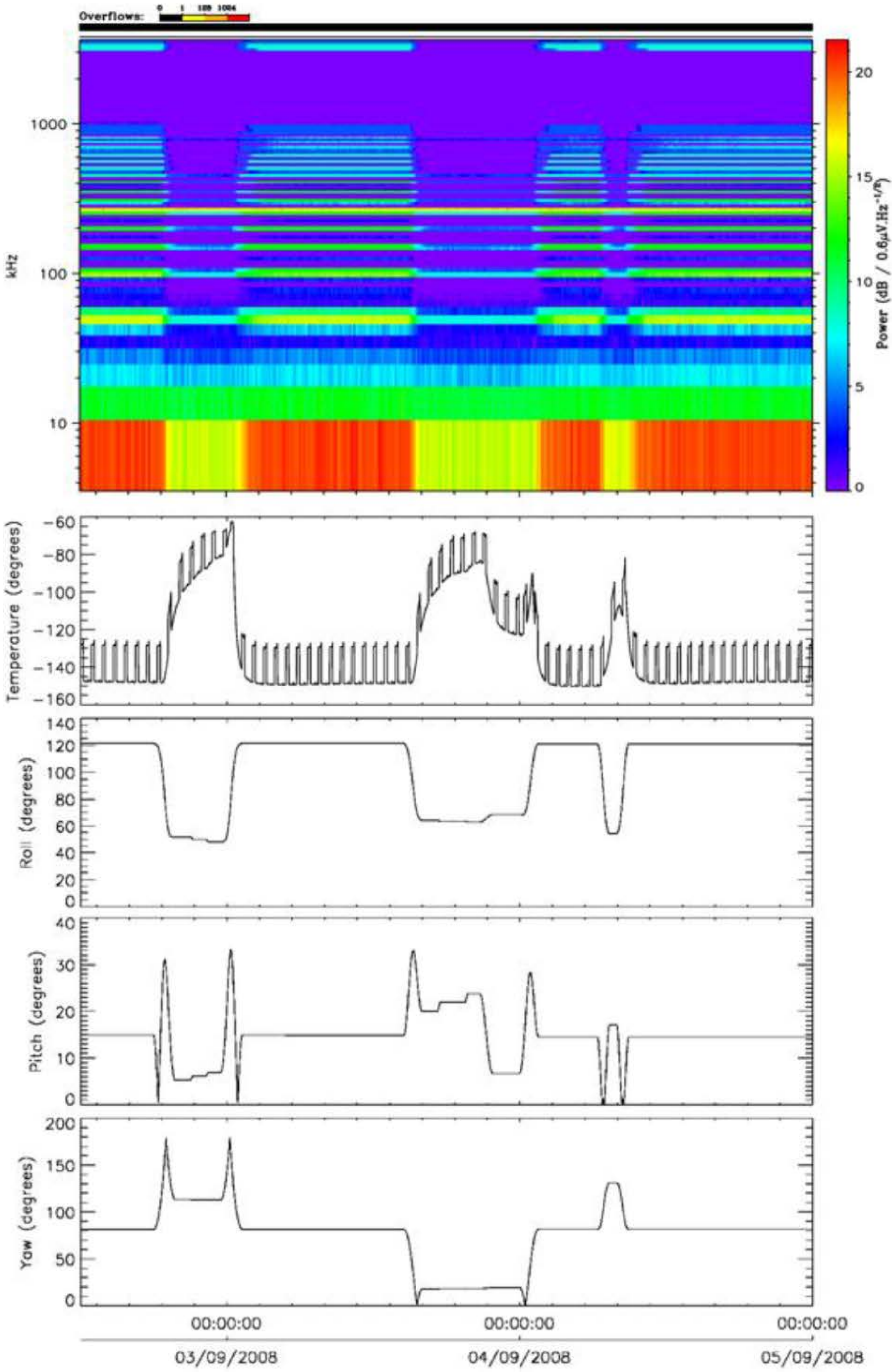

Figure 3: Example of temperature effect. From top to bottom: RPC-MIP E-field passive spectrogram, R2 temperature, roll angle, pitch angle, yaw angle.

The user is invited to check the power spectral temporal variations against temporal variation of the R2 temperature or against orbital positions and attitude variations, available on the PSA server (under the Ancillary Data section)

7.3 Reference systems

The coordinates systems that may be used to analyze the expected MIP data are as follows:

The GSE, GSM, and SM systems are Earth-centered coordinate systems, they are used to study the space ionized environment of the Earth and its interaction with the interplanetary medium (solar wind and its embedded interplanetary magnetic field).

The geocentric solar ecliptic system, GSE, has its X-axis and Y-axis in the ecliptic plane. The X-axis points from the Earth towards the Sun and the Y-axis points towards dusk. The Z-axis is therefore parallel to the ecliptic north pole. Relative to an inertial system this system has a yearly rotation (one Earth's year).

The geocentric solar magnetospheric system, GSM, has its X-axis in common with the GSE, while now the Y-axis is defined to be perpendicular to the Earth's magnetic dipole. In this way, the X-Z plane turns out to contain the dipole axis. It is worth noting that the GSM is then deduced from the GSE by a rotation about the X-axis.

In the solar magnetic coordinates SM the Z-axis is parallel to the north magnetic pole and the Y-axis is perpendicular to the Earth-Sun line towards dusk. The difference between this system and the GSM system is a rotation about the Y-axis. The amount of rotation is the dipole tilt angle.

The MSO is a Mars-centered coordinate system, it is the one actually used to study the space environment of Mars and its interaction with the solar wind.
The X-axis and Y-axis of the Mars solar orbital system, MSO, are in the Mars solar orbital plane. This plane is inclined at 1.9 degree above the ecliptic plane. The X-axis points to the Sun, the Z-axis is the cross-product of the X-axis and Y-axis, and points to the North Mars solar orbital plane. The Y-axis is thus in the Mars solar orbital plane and points towards dusk (opposing planetary motion). Relative to an inertial system this system has a yearly rotation (two Earth's years).

At comet and asteroids, body-centered coordinate systems will also be used. They are similar to theGSE (for the Earth) and MSO (for Mars) systems. The X-axis and Y-axis are in the respective body solar orbital planes. The X-axis points towards the Sun.