ESA STUDY CONTRACT REPORT

ESA Contract No:	SUBJECT:	CONTRACTOR:
21646/08/NL/NR	Generation of Mars Express / MARSIS Derived Enhanced Ionospheric Calibration Data	The Centre National de la Recherche Scientifique (CNRS)
*** ESA CR( )No:**	**No. of Volumes:** *3* **This is Volume No:** *3* MARSIS derived enhanced ionospheric calibration data	**CONTRACTOR'S REFERENCE:** 3, rue Michel Ange F-75794 Cedex 16 France

ABSTRACT:

A planetary ionosphere is a perturbing environment for radar waves. Unfortunately, it is an unavoidable obstacle along the propagation path of signals emitting by orbiting radar sounders. The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) is an instrument onboard the European Space Agency's Mars Express spacecraft. In order to deeply penetrate the surface, MARSIS operates at MHz frequencies for which the perturbations due the Martian ionosphere can be significant. Therefore, prior to any analyze, MARSIS data need to be corrected from the ionospheric effects.

The MARSIS derived enhanced ionospheric calibration dataset enables to correct the MARSIS signal from the ionospheric distortion. The aim of this document is to provide information on the generation and the description of the parameters forming this derived dataset, and to explain their use when needed.

The work described in this report was done under ESA Contract. Responsibility for the contents resides in the author or organization that prepared it.

Name(s) of author(s):

Cyril Grima / LPG BP 53 - 38041 Grenoble Cedex 9 - France / cyril.grima@obs.ujf-grenoble.fr
Wlodek Kofman / LPG BP 53 - 38041 Grenoble Cedex 9 – France / wlodek.kofman@obs.ujf_grenoble.fr

** NAME OF ESA STUDY MANAGER:	** ESA BUDGET HEADING:
DIV:	
DIRECTORATE:	

* Sections to be completed by ESA
** Information to be provided by ESA Study Manager

Table of contents

1. Introduction

The Mars Advanced Radar for Subsurface and Ionospheric Sounding (MARSIS) is an instrument of the Italian Space Agency (ASI) [*Picardi et al.*, 2005]. It is orbiting onboard the Mars Express (MEX) spacecraft of the European Space Agency (ESA). MARSIS is getting data since its unfolding in the early summer 2005. Its primary science objective is to study the subsurface of Mars at a low-frequency regime to penetrate deep under the soil. The orbit of MEX is highly elliptical with a periapsis of 270 km and an apoapsis of 11600 km, thus always above the ionosphere. The ionosphere is a plasma which disturbs radio waves passing through it. Since MARSIS is an active instrument, it emits its own signal, which is backscattered by surface and subsurface structures before to be collected back. That is, along is propagation path, a MARSIS signal is two times disturbed by the ionosphere.

The impact of the ionosphere on the MARSIS radar signal has been previously described [*Grima and Kofman,* 2008a]. An efficient method to correct the induced distortion of the signal can be applied [*Safaeinili et al.,* 2003; *Mouginot et al.*, 2008; *Grima and Kofman*, 2008b]. The present document describes the enhanced calibration data provided to correct the ionospheric distortion. This data is packed into a Planetary Science Archive (PSA) compliant dataset named 'MARS EXPRESS MARS MARSIS DERIVED SUBSURFACE TEC DATA'. Thereby, this document is somewhat similar to the related Experimenter to Planetary Science Archive Interface Control Document (EAICD) [*RD1*]. Any readers can refer to this later document to get further information about the PSA format and the specifications developed for MEX/MARSIS data. The EAICD provides complete instructions related to the dataset exploitation. Here we will only focus on the basic generation process of the derived calibration data, and the content of the delivered dataset.

2. The MARSIS instrument

MARSIS can operate in 2 different sounding modes. The first is a passive mode (receive only) called 'active ionospheric sounding' (AIS) [*Gurnett et al.*, 2005]. It sounds the ionosphere with a quasi-wave tone by swapping 160 frequencies in the range of 0.1 to 5.5 MHz. Of course, for the purpose of this document the ASI mode is not valuable. We will only focused on the second sounding mode, which study the subsurface with the active component of the radar (transmit and receive). MARSIS can use this subsurface sounding mode when the spacecraft is lower than 900 km. This represents 26 minutes of operation by orbit. It uses 4 different frequency bands centered to 1.8, 3, 4, and 5 MHz. Each band is 1 MHz wide. MARSIS operates in two bands simultaneously, in order to get the backscattered echoes as a function of the frequency. The choice of the two operating bands aims to minimize the impact of the ionosphere. It depends on the solar zenith angle (SZA) which is directly linked to the ionosphere activity. The MARSIS signal is emitted at a rate of 127.27 pulses per second. The returned pulses are integrated over 1 s to increase the signal-to-noise ratio (SNR). This final process gives an along-track resolution in the range of 5 to 9 km, varying with MEX altitude and speed. At this time the MARSIS coverage of Mars is almost complete.

3. Data processing

3.1. Reference dataset

The ionospheric correction method *[Mouginot et al.*, 2008; *Grima and Kofman*, 2008b] needs two reference dataset to derive the corrected parameters: 1) MARSIS data [*Picardi et al.*, 2005] uncorrected from ionospheric impact. 2) The Digital Elevation Model (DEM) derived by the laser altimeter MOLA [*Smith et al.*, 2001], in order to get a surface constraint on the true radar echo position.

MARSIS data are the level 1b retrieved from a Jet Propulsion Laboratory server (https://elbrus.jpl.nasa.gov/). Level 1b are the raw data without calibration and range-compression. This data set is preferred than level 2 (calibrated, and range-compressed), in order to avoid any kind of unwanted correction. The range-compression is made using the chirp describing in [RD2].

MOLA DEM has a spatial resolution of 128 pixels/° (~0.468 km at the equator), and a vertical resolution of 1 m. That is well lower than MARSIS characteristics in free space (respectively 10 m and 150 m). MOLA data are retrieved from the PDS Geosciences Node at Washington University in St. Louis (http://pds-geosciences.wustl.edu/).

3.2. Process

The correction process consists in finding the three parameters $[a_1 ; a_2 ; a_3]$ defining the signal distortion $\Delta\varphi$ induced by the ionosphere.

$$\Delta\varphi(f) = \frac{a_1}{f} + \frac{a_2}{f^3} + \frac{a_3}{f^5} \tag{1}$$

where f is the radar frequency of MARSIS. The process has been detailed by *Grima and Kofman* [2008b]. It is summarized step by step in figure 1.

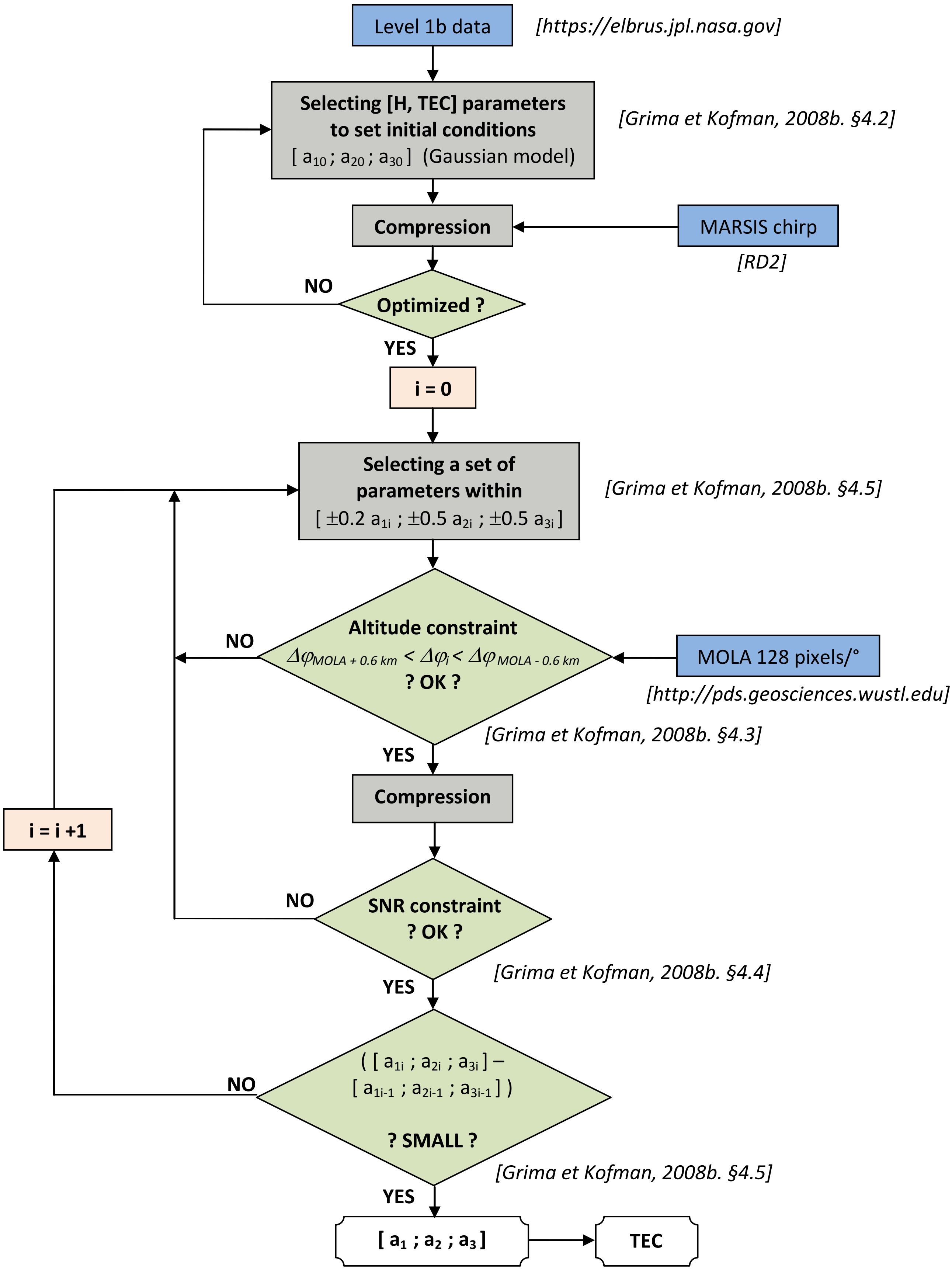

Fig. 1. Data processing executed for each frame.
The results are the parameters *[a_1 ; a_2 ; a_3]* and TEC.

4. Dataset content

4.1. Introduction

The final MARSIS derived enhanced ionospheric calibration dataset will be provided to ESA in a PSA-compliant format with the following identifier:

DATA_SET_NAME = "MARS EXPRESS MARS MARSIS DERIVED SUBSURFACE TEC DATA"
DATA_SET_ID = "MEX-M-MARSIS-5-DDR-SS-TEC"

A set of data files (data product) will be generated by orbit, and then transmitted to ESA. Typically, one data product will be provided for each level 1b orbit. However, the format in which the data will be delivered is not the purpose of this report, since the PSA format conventions and specifications are fully described in the related EAICD document [*RD1*]. It has been preferred to focus on the data itself. Each orbit is composed of several concatenated frames (i.e. radar pulses). For each frame the following parameters will be provided.

4.2. Pulse number

A number is given to identify each frame within a given orbit. The earliest frame in the orbit is number 1, then 2 and so on.

4.3. Ephemeris time

The time of the frame observation. It is given as the seconds elapsed since Jan, 1, 2000, 12:00 UTC. The ephemeris time is get directly from the Level 1b data without any modifications.

4.4. Coordinates (Latitude/longitude)

The subspacecraft coordinate in latitude and longitude in degrees. It is given in a 0-360W coordinate system. The latitude and longitude are get directly from the Level 1b data without any modifications.

4.5. Local true solar time

The angle between the meridian passing through the sub-spacecraft point, and the meridian passing through the sub-solar point of mars. Expressed on a 24-hours clock (decimal units). 12h corresponds to an angle of 0 degree, while 0h corresponds to an angle of 180 degrees. The local true solar time is retrieved from the SPICE data provided by the Navigation and Ancillary Information Facility (NAIF) [http://naif.jpl.nasa.gov/naif/]

4.6. Mars Solar Orbital (MSO) coordinates

The spacecraft rectangular coordinates in the MSO reference frame in kilometers. The MSO reference frame has his +X axis pointing from the center of Mars toward the Sun. The +Y axis points opposite to the orbital motion of Mars. +Z axis completes the right-hand coordinates system. Originally, Level 1b data only provides rectangular coordinates of the spacecraft in the IAU2000 coordinate system (+x axis points to the longitude and latitude 0, +Z axis points toward the North Pole). The conversion into the MSO reference frame is made thanks to the following rotation matrix:

$$\begin{bmatrix} x_{MSO} \\ y_{MSO} \\ x_{MSO} \end{bmatrix} = \begin{bmatrix} x_{IAU} \\ y_{IAU} \\ z_{IAU} \end{bmatrix} \begin{bmatrix} \cos\theta\sin\varphi & \sin\varphi & -\sin\theta\cos\varphi \\ -\cos\theta\sin\varphi & \cos\varphi & \sin\theta\sin\varphi \\ \sin\theta & 0 & \cos\theta \end{bmatrix} \quad (2)$$

Where $[x_{IAU},y_{IAU},z_{IAU}]$ and $[x_{MAO},y_{MSO},z_{MSO}]$ are the space craft coordinates in the IAU2000 and MSO system respectively. θ and φ are the latitude and longitude of the sub-solar point expressed in the IAU2000 system. The subsolar point coordinates are retrieved from the SPICE data provided by the NAIF.

4.7. Sun Zenith Angle (SZA)

Angle between the zenith and the apparent position of the sun. 0° corresponds to the subsolar point. 90° corresponds to the terminator. The SZA is get directly from the Level 1b data without any modifications.

4.8. Total Electron Content (TEC)

The Total Electron Content is computed following the process in 3.2. It is given in electron per squared meters.

4.9. Correction parameters a_1, a_2, and a_3

The corrected parameters a_1, a_2, and a_3 are computed following the process in 3.2. They are given in s^{-1}, s^{-3}, and s^{-5} respectively.

4.10. Data quality indicator

The signal to noise ratio (SNR) of a frame affects the quality of the derived ionospheric parameters. We defined an arbitrary SNR threshold of 15 dB below which a frame can be considered unusable. Figure 2 shows that a net radar signal has an SNR above this value, while Figure 3 attests of a consistent TEC. The SNR is computed by doing the ratio between the brightest echo within a frame, with the average power of the noise.

Instead of the SNR, a data quality indicator named “flag” will be provided. A value of 1 means the SNR is greater than 15 dB (good data), while a value of 0 means the SNR is lower (bad data).

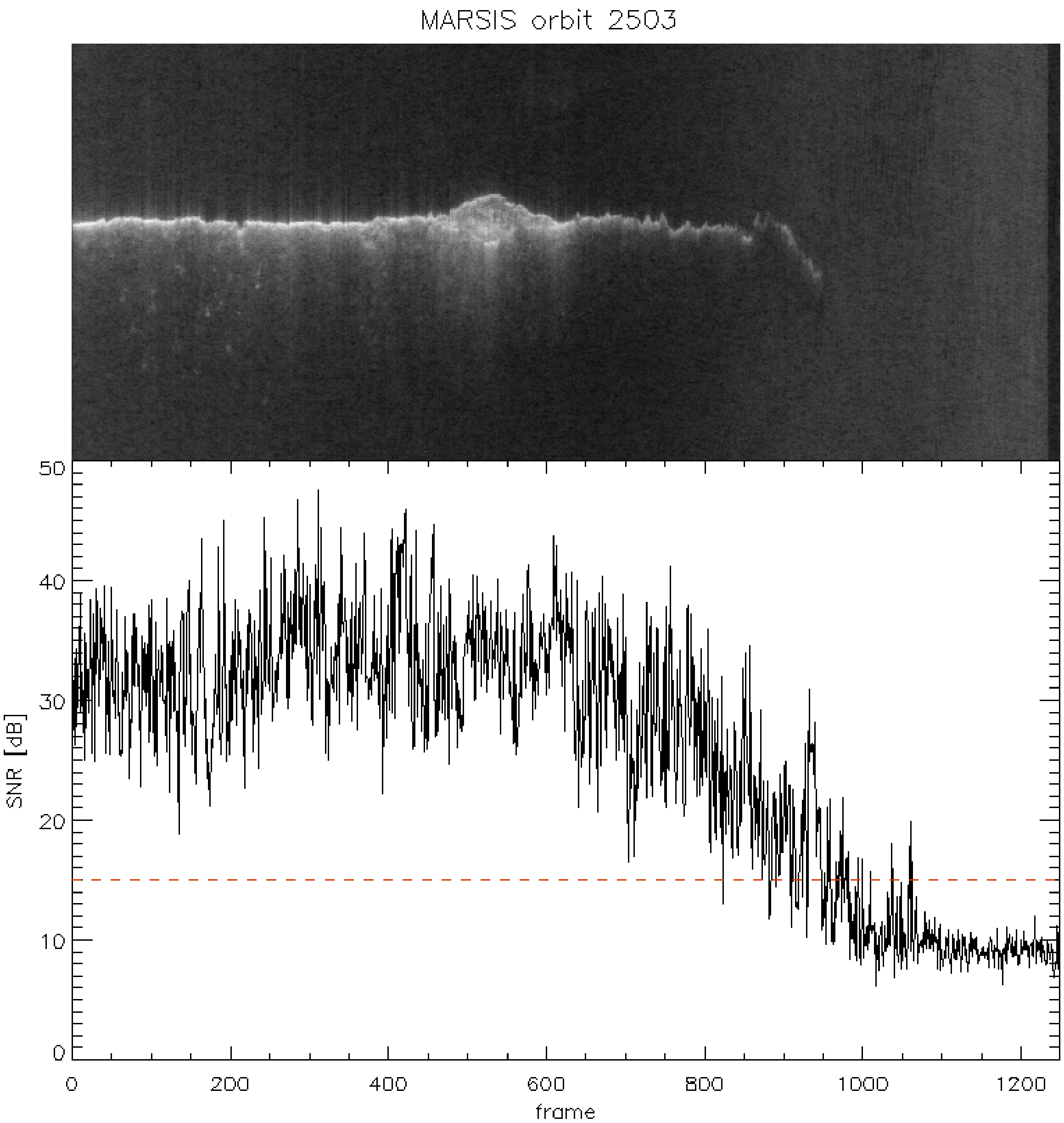

Fig. 2. The signal to noise ratio (down) for the MARSIS orbit 2503 (up). The red-dashed line indicates the defined SNR-threshold of 15 dB. All the frames lower than this value have a “flag” equals to zero.

4.11. Data browsing

To allow a fast check of the data, an image will be provided for each orbit. It is a plot of the computed TEC over the SZA in respect with the MARSIS radargram. Light grey areas on the plot indicate the frame having a "flag" equals to zero (bad SNR).

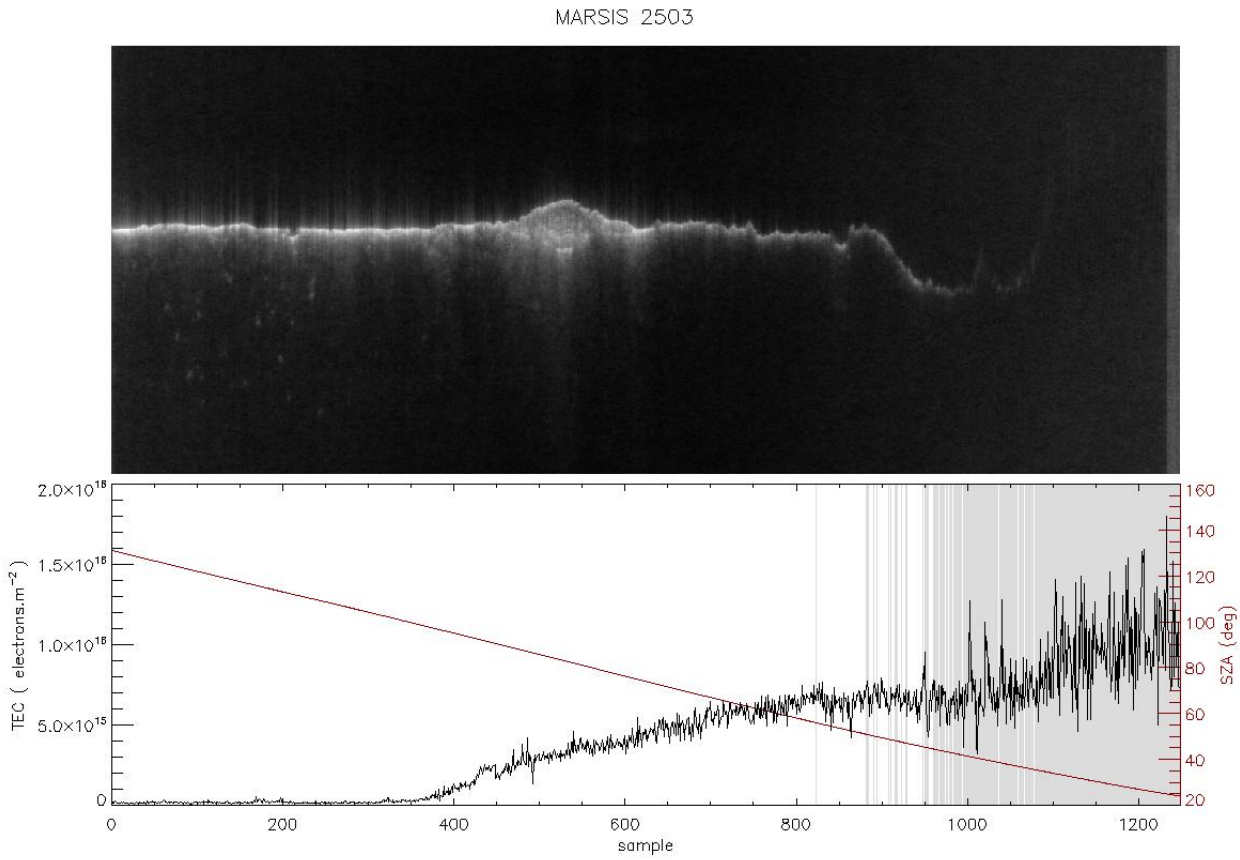

Fig. 3. Example of the plot provided for the orbit 2503 (see text for details).

5. Dataset delivery

The delivery of the data will be discussed soon in more details with ESA. But, typically, the data would be delivered to MARSIS PI (INFOCOM) for internal validation first, via the ASDC server. Then the data would be delivered to the ESA's Planetary Science Archive in a PDS-compliant format, by means of the ESA-provided tool PVV. The MARSIS data coming with the next mission extensions will be also processed and provided by these means, at predefined dates (6-month intervals).

6. References

[RD1] Experimenter to Planetary Science Archive Interface Control Document (EAICD) for the MEX-MARSIS Subsurface (SS) mode: Total Electron Content (TEC) of the ionosphere level 5 derived data. Grima, C., Witasse, O. and Orosei, R. *Mars Express / Planetary Science Archive*, in prep.

[RD2] MARSIS on board processing algorithms, TNO-MAR-0037-ALS, ISSUE 2.

Grima, C., and Kofman, W. 2008a. Ionospheric impact on MARSIS radar signal. *ESA study contract report* No 21646/08/NL/NR, volume 1.

Grima, C., and Kofman, W. 2008b. Correcting the ionospheric impact on MARSIS radar signal. *ESA study contract report* No 21646/08/NL/NR, volume 2.

Mouginot, J., Kofman, W., Safaeinili, A., and Herique, A. 2008. Correction of the Ionospheric distortion on the MARSIS surface sounding echoes. *Planet. Space Sci. 56*, 917-926.

Picardi, G., Plaut, J.J., Biccari, D., et al. 2005. Radar soundings of the subsurface of Mars. *Science* 310, 1925-1928.

Safaeinili, A., Kofman, W., Nouvel, J-F, Herique, A., and Jordan, R.L. 2003. Impact of Mars ionosphere on orbital radar sounder operation and data processing. *Planet. Space Sci. 51*, 505-515.

Smith, D.E., Zuber, M.T., Frey, H.V., et al. 2001. Mars Orbiter Laser Altimeter: Experiment summary after the first year of global mapping of Mars. *J. Geophys. Res.* 106, E10, 23,689-23,722.