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Investigation of the Experimental Data Records of the SHARAD instrument

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1. Introduction

In March 2010 The Mars Reconnaissance Orbiter (MRO) attained the Martian Orbit. On board of this NASA Orbiter is the SHAllow RADar (SHARAD) imager. The data from this radar instrument are available on the website of NASA and are updated every six months.

One of the main goals of the SHARAD is to image the internal stratigraphy of the North Polar Layered Deposits (NPLD) on Mars (Seu et al., 2007). The radar waves are able to penetrate through the ice layers down to a depth of 2 km. Radar reflections from within the deposits show a laterally continuous layering. The reflections from these layers are caused by boundaries between layers that contain different fractions of ice, dust and sand (Phillips et al., 2008).

There are two types of data, processed data and raw data. The processing that has been done is not open. So it is unknown what processing steps are taken to create the processed data.

In 2009 Floris van Lieshout tried to create a 3D model of the North Polar Cap of Mars (Van Lieshout, 2009), combining the processed SHARAD data with topographic data from the MOLA (Mars Orbiter Laser Altimeter) and High Resolution Stereo Camera (HRSC) images. Unfortunately, his goal was not met since the radargrams and the MOLA data did not fit.

In order to solve this problem, a step back had to be made. My goal during this internship was to investigate whether it was possible to create an own processor for the data. After doing this it will be possible to use the data for multiple goals. First of all, we can try to fit them with the MOLA data so that it will be come possible to create a 3D model. Also, the data can be filtered for different frequencies that are transmitted by the SHARAD instrument. The behavior of these different frequencies might provide information about the composition of the layers of the Martian North Pole.

2. Mars North Pole Layered Deposits

The North Pole can be divided into four different units based on their properties and compositions (Nunes and Phillips, 2008), as sketched in figure 1.

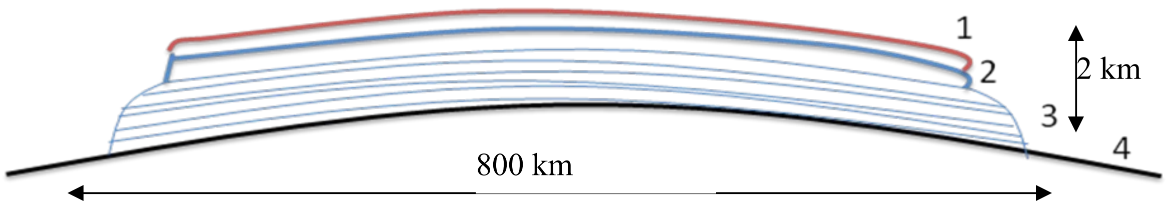

Figure 1: Sketch of the structure of the NPLD.

The numbers in figure correspond to the following layers:

1. *Seasonal frost*
   This is a thin layer of solid CO_2 in winter, and does not exist in summer.
2. *Residual ice*
   This consists of H_2O with a small fraction of dust.
3. *Layered deposits*
   This consists of two units with a constant boundary in between:
   a. Upper layered unit
      Bright and thin continuous horizontal layers with a thickness of around 30 m. Total thickness of this unit can be up to 2 km.
   b. Lower layered unit
      These layers are more rough and vary in thickness from 20 to 50 m. The layers are less lateral uniform.
4. *Preexisting Martian Surface*
   No layering visible.

3. The SHARAD Instrument

The MARSIS on board of the ESA Mars Express (2003) is also a radar sounder, but operates at lower frequencies. Because of this frequency between 2 and 5 MHz the radar waves can penetrate deep into the subsurface of Mars, but the vertical resolution is low.

The SHARAD sounder is developed by the Agenzia Spaziale Italiene and is one of the main instruments on board of the Mars Reconnaissance Orbiter. It operates at a higher frequency than MARSIS and therefore has a better resolution. The SHARAD instrument has a free space resolution of 1/Bandwidth * c/2 = 15 m (Alberti et al., 2007).
Table 1 gives an overview of SHARAD's main characteristics.

Parameter	*Value*
Across track resolution	100 – 300 m
Along track resolution	1500 – 3000 m
Vertical resolution	15 m in free space
Penetration depth	100's of meters, up to 2 km in ice
Center frequency	20 MHz
Bandwidth	10 MHz
Pulse length	85 μs
Receiving length	135 μs
Pulse Repetition Interval	700.28 Hz
Sampling frequency	26.67 MHz

Table 1: SHARAD main characteristics.

3.1 Transmitted signal

The instrument transmits a linear chirp with a center frequency of 20 MHz and a bandwidth of 10 MHz. The transmitted signals last 85 microseconds and the receiver is opened for 135 microseconds to receive the reflected signal from both the surface and the subsurface layers.

In general the radar transmits signals at a Pulse Repetition Interval of 700.28 Hz, but other PRI's are also possible. This means a signal is transmitted every 1.428 ms.
The Pulse Repetition Interval of a dataset can be read from the Science Data as will be described in section 4.

3.2 Available data

Two types of data are available from the Planetary Data System on the NASA website. The Experimental Data Records (EDR) and the Reduced Data Records (RDR).

The RDR have been processed and can be written into an image or radargram. The processing is done at the SHARAD Operations Centre (SHOC). However, the processing that has been done is not open, so the steps that are taken to create these radargrams are unknown.

For Floris' project 31 footprints over the North Pole were selected. These were selected because they evenly cover the North Pole and the radargrams were relatively clear. Also, these echoes are all received during the night, when the ionosphere has the least influence on the waveform. How to determine if the data is acquired during the night can be found in section 4.2. A list of these footprints can be found in Appendix 1. Figure 2 shows the North Pole of Mars with these footprints.

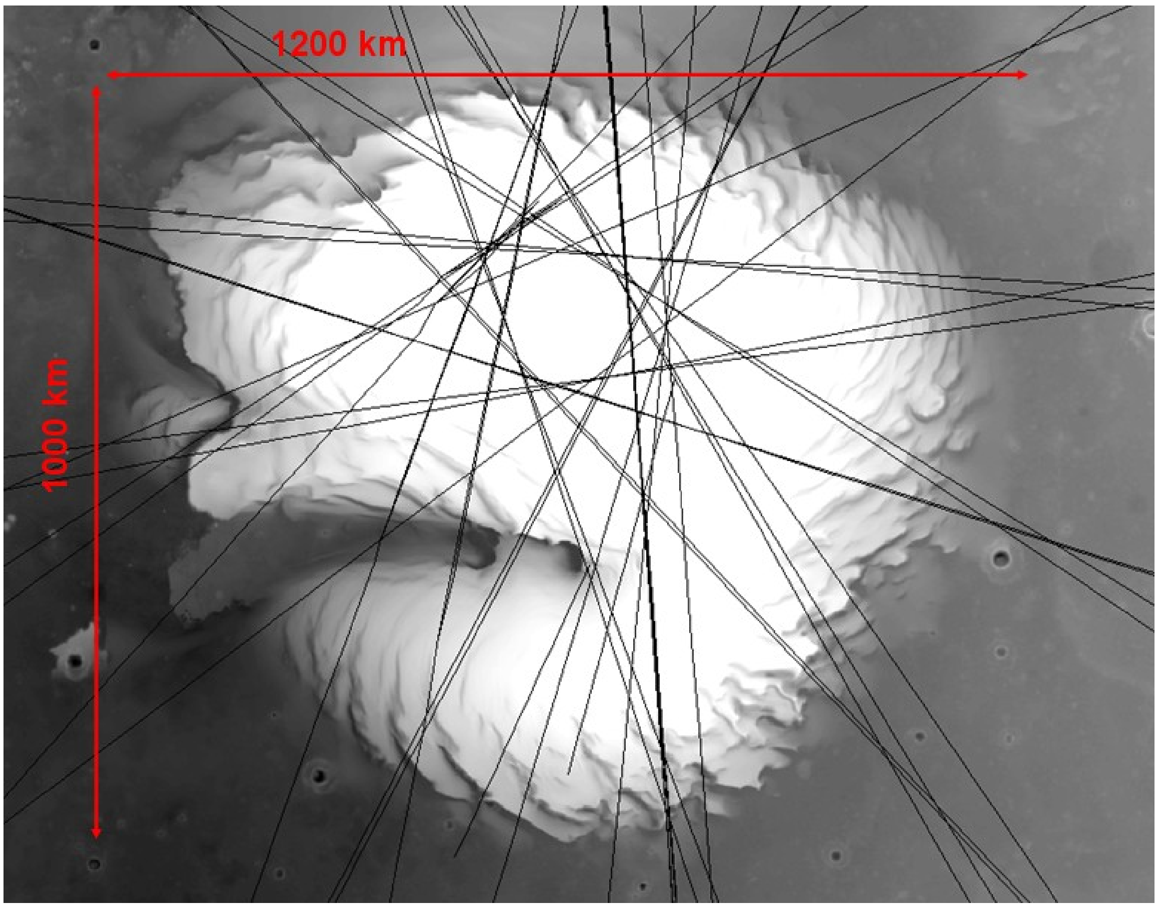

Figure 2: MOLA Topography data of the Mars North Pole with the 31 selected footprints projected on it.

Since the RDR turned out not to be sufficient for creating a 3D model, the accent in this project is on the EDR data. The SHARAD EDR Software Interface Specification (SIS) (Slavney and Orosei, 2008) gives a detailed description of the data product and how it is generated.

For the EDR data some processing is already done on board:

- *Phase compensation*

Due to vertical motion of the spacecraft the position of the echo in time can vary from pulse to pulse. Since the echoes are pre-summed this can cause a degradation of the signal to noise ratio. To prevent this, the waveform oscillation can be brought forward or backward. The phase compensation required is calculated from the Parameter Table (containing the radial and tangential velocity) and the Orbital Data Table (containing information about the topography of Mars).

- *Science Data Acquisition*

The electrical output of the receiver is converted to a digital signal at a sampling frequency of 26.67 MHz.

- *Receiving Window Positioning*

After a signal is transmitted there is some time delay before the receiver is opened. This time delay is not constant but calculated on board. For these differences in time delay the data are corrected.

- *Pre-summing and Data Compression*

The SHARAD instrument can operate in different Subsurface Sounding modes. These modes correspond to the number of echoes that are pre-summed and the bits per sample. The instrument modes in table 2 are included in the selected footprints.

Instrument Mode	Number of pre-summed echoes	Bits per sample	Number of footprints
SS05	4	6	8
SS11	8	6	21
SS19	4	8	2

Table 2: Subsurface Sounding modes of SHARAD instrument.

4. Reading the Experimental Data Records

The experimental data records consist of 38 columns of science data and 38 columns of auxiliary data. The data is read using two M-files by Roberto Orosei, readsharadedrsci.m (for the science data) and readsharadedraux.m (for the auxiliary data).
An own M-file is written to read the data of interest from the footprints of interest: readdata.m.

These reading files have been used to calculate the origin of the pre-summed data and the location of the footprints as can be read below.

4.1 Origin of the data

The instrument has different operation modes corresponding to the number of onboard pre-summed echoes. To find out whether and how much these echoes overlap, the speed of the satellite has to be calculated. This is done by projecting the longitude and latitude on the planet using the polar radius of Mars of 3376.2 km (Mars fact sheet, NASA). This distance is divided by the time that can be calculated using the amount of pulses that have been transmitted and the Pulse Repetition Interval.
The speed of the Mars Reconnaissance Orbiter is just above 3km/s. In the Instrument Mode 'SS19' 4 echoes are pre-summed. At a PRI of 700.28 and a horizontal resolution of 300 meters this means that these pre-summed echoes largely overlap as illustrated in figure 3.

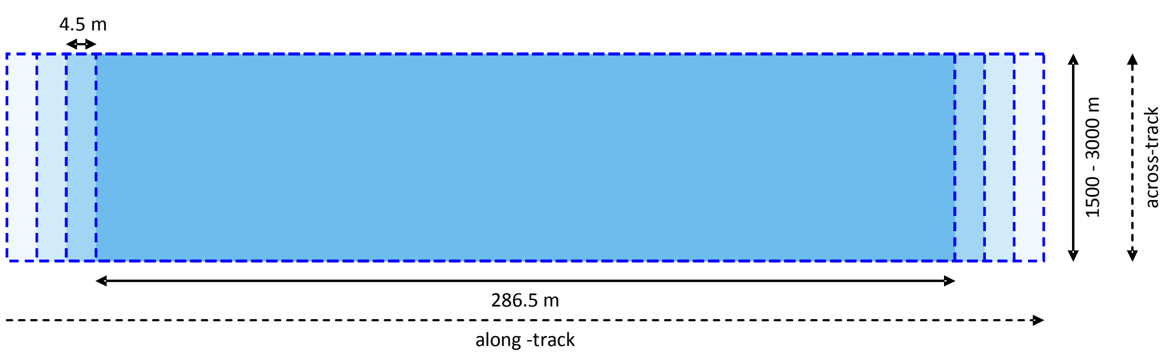

Figure 3: Origin of the pre-summed data.

4.2 Time of acquired data

As explained in section 3.2 it is preferable to use data that is acquired during the night. To determine whether that is the case the 'Solar_Zenith_Angle'-column can be read from the auxiliary data. This column contains the angle between the zenith at the sub-spacecraft point and the vector from this point to the sun.
An angle over 90 degrees means that the sun is below the horizon, and the data is acquired during the night.

4.3 Misfit length of data

The length of the received data has been investigated in two ways. First the 'TLP'-column was read from the Science Data. This column contains the Spacecraft position along its ground track.
The second way the length of the data was measured was by reading the longitude and latitude from the auxiliary data file. For each footprint the longitude and latitude were read 1000 times. These positions were projected on the planet and then the length of the great circle (the shortest distance between two points on the surface of a sphere) through all these positions was calculated using greatcircle.m.

There was a significant misfit between these two ways. The difference can be read from the table 3.

Footprint	TLP distance (km)	Longitude latitude distance (km)	Difference (%)
0444101	397.7	413.9	+4.1
0488901	515.4	528.6	+2.6

Table 3: Calculated length of footprints.

This difference in location data suggests that the exact location of the radar data is unknown. This of course will cause problems when creating a 3D model, for example misfits at the intersections of the radargrams.

5. The echo data

The column that is most interesting is of course the column that contains the received echoes. Since the M-file `readsharadedrsci.m` did not work for reading the echo samples, the following commands (provided by Roberto Orosei) were used:

```
fid = fopen( 'EdrSciFile', 'r' );
echo = fread( fid, 'bit6=>int8', 'ieee-be' );
fclose( fid );

echo = int8( reshape( echo, 3848, [] ) );
echo = int8( echo( 249 : end, : ) );
```

Reading the echo samples without doing any processing does not show any pattern. Figure 4 gives an example of a signal that is read without processing for one trace location.

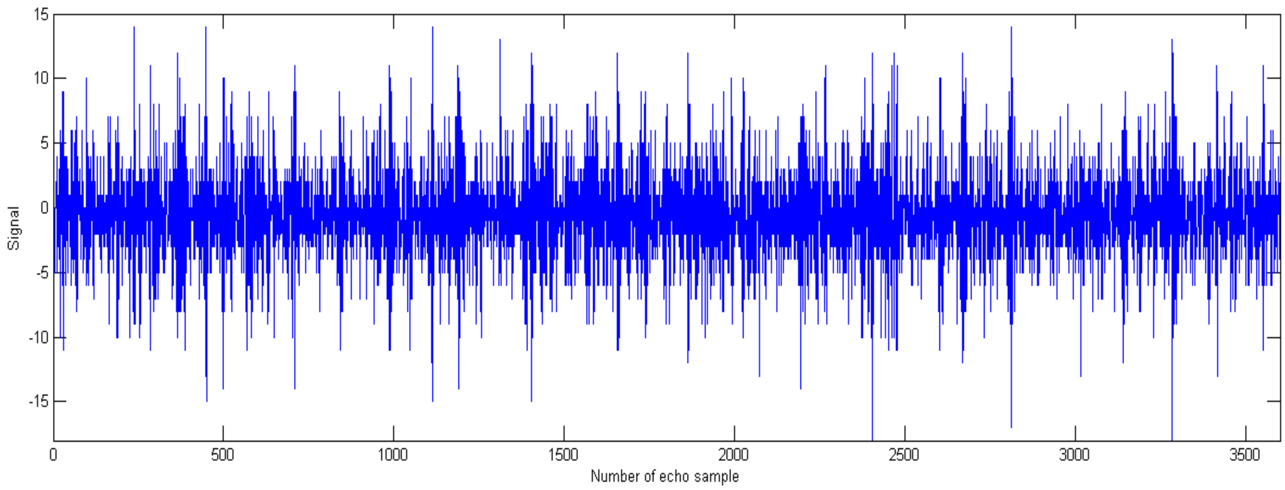

Figure 4: Unprocessed signal for 1 trace.

5.1 Required processing

To process the raw data in a way that useful radargrams can be written a lot of steps have to been taken.

- *Decompression*

The raw echoes must be decompressed to correct for the scaling that has been performed on board. This can be done by determining the kind of scaling applied to the data and apply reverse scaling for this.

- *Azimuth or Doppler processing*

Azimuth processing is necessary to achieve an angular resolution of λ/D (antenna diameter). The received echo signals can be focused back to their original location by applying phase shifts.

- *Ionosphere Correction*

Mars' ionosphere can distort the waveform because its dielectric constant is frequency dependent. Ionosphere effects are not uniform over Mars and much stronger during the day than at night. Therefore night data generally does not need this correction.

- *Calibration*

Interference of spacecraft electronics has to be corrected. Antenna gain can be achieved by observing a flat surface on Mars at different spacecraft altitudes and in different orbits and then scaling the antenna gain with respect to a baseline configuration.

- *Pulse compression*

Vertical resolution is achieved by applying a filter that delay the frequencies such that the frequency transmitted first arrives at the filter output at the same time as the frequency transmitted latest and all frequencies in between. In this way they are all superimposed at one single moment in time.

5.2 Unknown signal

Another issue is that the exact signal of the SHARAD instrument is unknown. It is stated that it is a chirp as described in section 3.1. When taking the fast Fourier transform (using `fft.m`) of a received signal to find the frequencies that are in the signal the frequencies in figure 5 are found. This is not the center frequency and the bandwidth from the described chirp.

The reason for this difference is unknown, but an unknown signal will cause problems when processing the data, since it is impossible to correlate the received signal with the transmitted signal when this signal cannot be described.

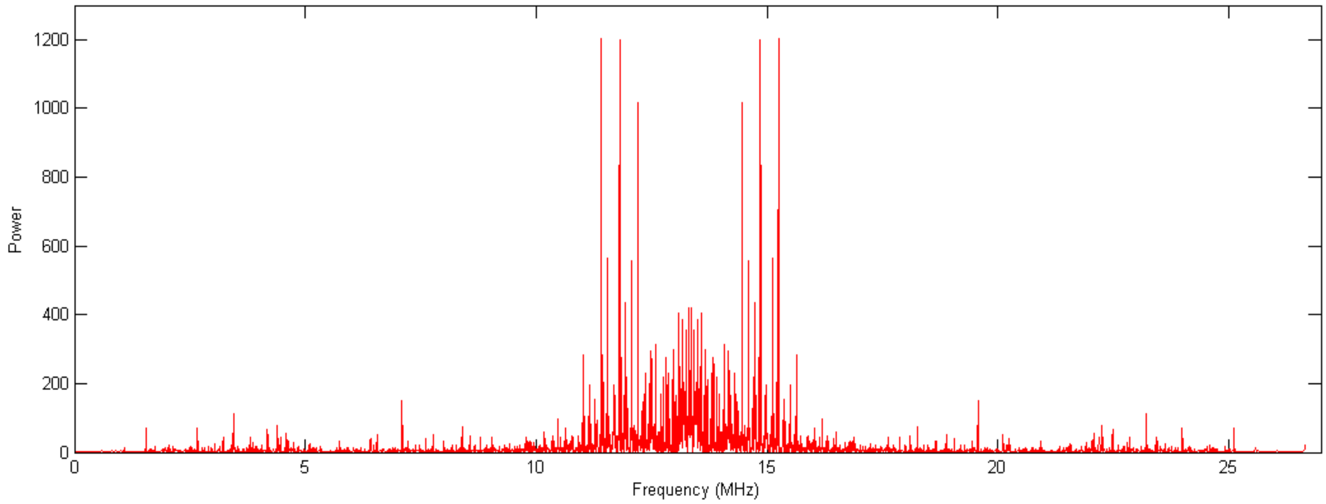

Figure 5: The frequency of one trace.

5.3 An own processor

As has been made clear in section 5.1 and 5.2 writing an own processor is a major job and a lot of corrections have to be taken into account.

Due to the amount of time for this project and the limited knowledge on some of the processing steps that have to be taken it will not be possible to create an own processor for the raw data.

6. Conclusions

My goal during this internship was to investigate whether it was possible to create an own processor for the data. As is explained above this is not within reach.

It has been possible to read other information from the raw data, which I did for example for the location and the speed. The location of the footprints shows some misfits, which may be a reason for problems when trying to create a 3D model.

It may still be interesting to filter the data for different frequencies, but this will only be possible if data that is already partly processed (i.e. the steps described in section 5.1 are taken, except for the pulse compression) is provided by scientists that have their own processor.

7. Recommendations

The Jet Propulsion Laboratory in California has created an own processor for the SHARAD data. Yonggyu Gim is the person behind this. It may be possible to get processed data from him including a description of the processing that has been done.

8. Appendices

8.1 Selected footprints

Footprint #	Corresponding data file
1	e_0429202_001_ss11_700_a_s.dat
2	e_0429802_001_ss11_700_a_s.dat
3	e_0434202_001_ss05_700_a_s.dat
4	e_0444101_001_ss19_700_a_s.dat
5	e_0472302_001_ss11_700_a_s.dat
6	e_0478402_001_ss11_700_a_s.dat
7	e_0478602_001_ss11_700_a_s.dat
8	e_0478802_001_ss11_700_a_s.dat
9	e_0479302_001_ss11_700_a_s.dat
10	e_0488901_001_ss19_700_a_s.dat
11	e_0496302_001_ss05_700_a_s.dat
12	e_0498102_001_ss05_700_a_s.dat
13	e_0521602_001_ss11_700_a_s.dat
14	e_0522402_001_ss11_700_a_s.dat
15	e_0557002_001_ss11_700_a_s.dat
16	e_0557402_001_ss11_700_a_s.dat
17	e_0563902_001_ss11_700_a_s.dat
18	e_0580702_001_ss05_700_a_s.dat
19	e_0614102_001_ss11_700_a_s.dat
20	e_0656102_001_ss11_700_a_s.dat
21	e_0656503_001_ss11_700_a_s.dat
22	e_0698602_001_ss11_700_a_s.dat
23	e_0699002_001_ss11_700_a_s.dat
24	e_0699202_001_ss11_700_a_s.dat
25	e_0735302_001_ss11_700_a_s.dat
26	e_0742402_001_ss11_700_a_s.dat
27	e_0765803_001_ss05_700_a_s.dat
28	e_0856202_001_ss05_700_a_s.dat
29	e_0886102_001_ss11_700_a_s.dat
30	e_0893602_001_ss05_700_a_s.dat
31	e_1042502_001_ss05_700_a_s.dat

8.2 M-files

The following M-files are available upon request:

```
fft.m
greatcircle.m
readdata.m
readsharadedraux.m
readsharadedrsci.m
```

9. References

Alberti, G., et al., 2007, The Ground System of the SHAllow RADar (SHARAD) Experiment, Mem. S.A.It. Suppl. v. 11, 57.

NASA, Mars Fact Sheet, http://nssdc.gsfc.nasa.gov/planetary/factsheet/marsfact.html.

NASA, Geosciences Node Data, MRO SHARAD, http://pds-geosciences.wustl.edu/missions/mro/sharad.htm

Nunes, D.C., Phillips, R.J., 2006, Radar subsurface mapping of the polar layered deposits on Mars, Journal of Geophysical Research, v. 111, p. 16.

Seu, R., et al., 2007, SHARAS sounding radar on the Mars Reconnaissance Orbiter, Journal of Geophysical Research, v. 112.

Van Lieshout, F.M.J., 3D modeling of the Martian North Polar Cap, using surface and subsurface images (email for copy)

Slavney, S., Orosei, R., 2008, Shallow Radar Experiment Data Record Software Interface Specification, Version 1.2, http://pds-geosciences.wustl.edu/missions/mro/sharad.htm