Data Description
Cleaned VEX 128 Hz magnetometer data

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1 Introduction

Venus Express was a near copy of the Mars Express spacecraft bus with the addition of a fluxgate magnetometer gradiometer, which consisted of one magnetometer on the body of the spacecraft (inboard) and another on a 1 meter boom (outboard) (*Zhang et al.*, 2006, 2007). There was no pre-existing cleaning method for such a configuration prior to the launch of the mission, thus one needed to be developed. With the assistance of the instrument Principal Investigator (PI), Tielong Zhang, Co-Investigator Christopher Russell and programmer Hannes Leinweber at UCLA developed code to clean the high resolution 128 Hz magnetometer data. Hannes Leinweber is no longer at UCLA and the knowledge of his procedure was not transferred to anyone before his departure. The following section is adapted from the description of his method, which is also available in *Russell et al.* (2013).

2 Data cleaning method

The basic principle of the data cleaning algorithm for the AC signals is that differences between the inboard and the outboard sensors are due to magnetic interference from the spacecraft (Figure 1). The inboard sensor can measure interference that is below the noise level at the outboard sensor. The observed signals at both sites were Fourier analyzed. Since the source of any interference seen by the magnetometers can have a wide range in the relative proximity to the two sensors, the relationship between the signals that are seen
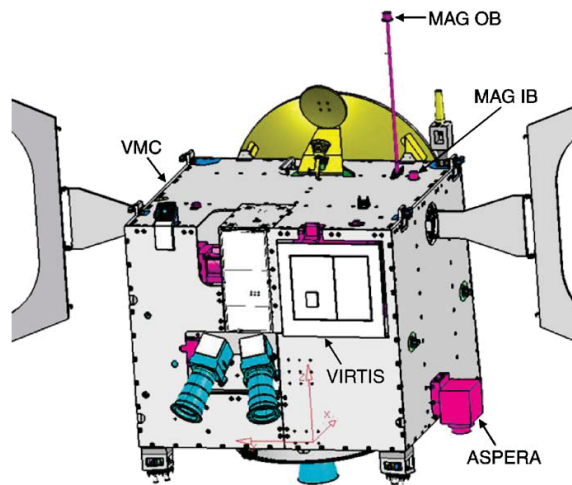

Figure 1: Sketch of the Venus Express spacecraft showing the location of the Venus Mapping Camera (VMC), the Visible and Infrared Mapping Spectrometer (VIRTIS), the ion, neutral and electron energy and mass analyzes (ASPERA), and the two sensors of the magnetometer (*Russell et al.*, 2006, Fig. 11).

at both sites must be examined and the ratio to be used for correcting each one must be determined. If an apparent interfering signal is seen only on the inboard sensor, even more interference can be introduced to the measurements of the outbound sensor by attempting to clean it. Running amplitude spectra of the outboard measurements are used to identify frequency bands in which there is interference. The windowed (Hanning) amplitude spectra are 20 seconds long (segment length) and are shifted by 5 seconds. The threshold for interference is five times the noise level. Inverse Fourier transforms of each of the identified frequency bands are computed for the outboard as well as the difference between the inboard and the outboard sensor. Only the central portion of a segment is used due to edge effects of the windowed inverse Fourier transform. This leads to pairs of inverse transforms for each identified frequency band. The pairs are then matched with running 12 parameter fits to correlate the noise between the two signals. The 12 parameters are equivalent to a matrix and an offset vector. The window length for the fits is 21 points and the shift step is one point. The fit is then subtracted from the outboard sensor. Portions of the overall data set were mirrored at the beginning and at the end of the data set to reduce edge effects of the whole algorithm. The algorithm also removes low frequency content of the outboard sensor. The lower frequencies were restored from a 21-point running average and the zero levels were adjusted according to the independently corrected low-resolution data. The detrended data before this final step are also included in this bundle.

3   Coordinate systems

The data were processed in spacecraft coordinates (SC) and rotated into Venus Solar Orbital (VSO) coordinates afterwards. In VSO coordinates, the X-axis points toward the Sun, the Y-axis points opposite the orbital direction of Venus, and the Z-axis points out of the ecliptic plane, completing the right-handed set. The calibrated 1 Hz data available in the ESA Planetary Science Archive (PSA) are in VSO coordinates. The 1 Hz data were interpolated up to 128 Hz and used to calculate the rotation angles, which were then used to calculate the rotation matrices using Rodrigues' rotation formula (Eq. 1) (*Rodrigues*, 1840).

$$\mathbf{R} = \mathbf{I} + (\sin\theta)\mathbf{K} + (1 - \cos\theta)\mathbf{K}^2 \tag{1}$$

where $\mathbf{R}$ is the rotation matrix, $\mathbf{I}$ is the identity matrix, θ is the angle of rotation, and $\mathbf{K}$ is the antisymmetric matrix such that

$$\mathbf{K}\mathbf{v} = \mathbf{k} \times \mathbf{v} \tag{2}$$

where $\mathbf{k}$ being the vector about which the rotation will be applied and $\mathbf{v}$ is an arbitrary vector. Instead of performing three rotations about the coordinate axes, Rodrigues' rotation formula allows one to rotate a given vector about an arbitrary axis onto another vector. The cleaned 128 Hz data set also includes the data in Radial-East-North coordinates (REN), which are equivalent to spherical coordinates with East being the azimuthal component and North being the negative of the polar component, i.e. the angle increases from the South Pole to the North Pole.

4   Data caveats

This cleaning procedure of the of this data product was an overall success, however, there are some caveats, of which the user should be aware. It is no longer possible to run the code for the cleaning algorithm to regenerate any of the data, so a discussion of any known caveats to the data is included here. A data errata file is also included in this bundle. Graduate student, Richard Hart, utilized the cleaned 128 Hz data set for his thesis work and primarily compiled this data product for submission to PDS. As part of his work, he scanned dynamic spectra of all data that was sampled below 1000 km altitude, ∼30% of the set. The dynamic spectra include the coherence between the two axes perpendicular to the DC field, ellipticity, propagation angle, transverse power and compressional powers. The errata contain periods of unusual behavior that were happened upon while searching for whistler-mode waves. The list contains 52 days, however, it is not intended to be exhaustive; it is intended to provide the user with a significant sample of any known peculiarities within the data. It should be noted that the caveats discussed in this section are a very small portion of the data

4.1 Post-processing correction

In 2019, it was discovered that certain periods of the cleaned data were not in agreement with the lower resolution 1 Hz data set in PSA. It was determined that the incongruity was due to a difference in offsets occurring sporadically throughout the mission, but most frequently in the first two years. As data became available, offsets were received directly from the instrument PI, which were later updated before being submitted to PSA. Because the programmer was no longer available, including knowledge of his procedure, the data were unable to be reprocessed from the raw 128 Hz data in PSA. Instead, a 1 second running average was subtracted from the original cleaned data and the 1 Hz data from PSA were added in to restore the low frequency content, thus ensuring that the cleaned data set has offsets consistent with the publicly available data from the Venus Express mission. If a data gap existed in only one of the data sets, it resulted in a gap in the final reprocessed data set since both were required for the correction. The user is cautioned to proceed with the knowledge that gaps may occur at any time and for any duration. The gaps are not included in the the errata.

4.2 Bursts at 4.5 Hz

On occasion, from 2008 through 2010, the data exhibit short ($\sim$4 seconds), periodic bursts (Figure 2). When these anomalies are present, they occur every 40 seconds. There are 34 days logged in the errata in which this behavior was exhibited. The bursts in the errata all occur above 450 km, between beyond solar zenith angles of 115°, and within 2 hours of local midnight. Noise due to the reaction wheels on the spacecraft has been ruled out because they operate at approximately 40 Hz, as evidenced in Figure 2e. Thrust maneuvers are also an unlikely culprit as the orbital adjustments were not made on days corresponding to the data anomalies. While the signals appear to be artifacts from either the spacecraft or the data cleaning procedure, the source is unknown, so they have been left untouched.

4.3 Full bandwidth circular waves

There are certain periods in which the data exhibit strange harmonic behavior exemplified in Figure 3. This anomalous behavior tends to show significant power at all frequencies in the bandwidth of the instrument (< 64 hz). The signals are circularly polarized, either in the right or left handed sense, and often both simultaneously at different frequencies. They are often propagating at an angle perpendicular to the background field with some exceptions in narrow frequency bands. Again, while these signals appear to be artifacts, the source is unknown, so they are left intact in the data. There are 18 days of such behavior in the errata.

5 Data Sets

The high resolution 128 Hz data were only recorded for 2 minutes about periapsis until the end of 2006, after which the sampling period was extended to 10's of minutes and occasionally full orbits in the last year of the mission (Figure 4). The only set of 128 Hz data in PSA is the raw data. Included in this bundle is a table that lists the data availability for the three sets: cleaned 128 Hz data, raw 128 Hz data, and calibrated 1 Hz data. The table also lists the start and stop times for the corresponding files. Because the cleaned 128 Hz data were not produced from the currently available raw data, the availability of the two sets does not always match. The original raw data that was used to produce the cleaned data is no longer available, but the official raw 128 Hz data is available in PSA at `https://archives.esac.esa.int/psa/ftp/VENUS-EXPRESS/MAG/`.

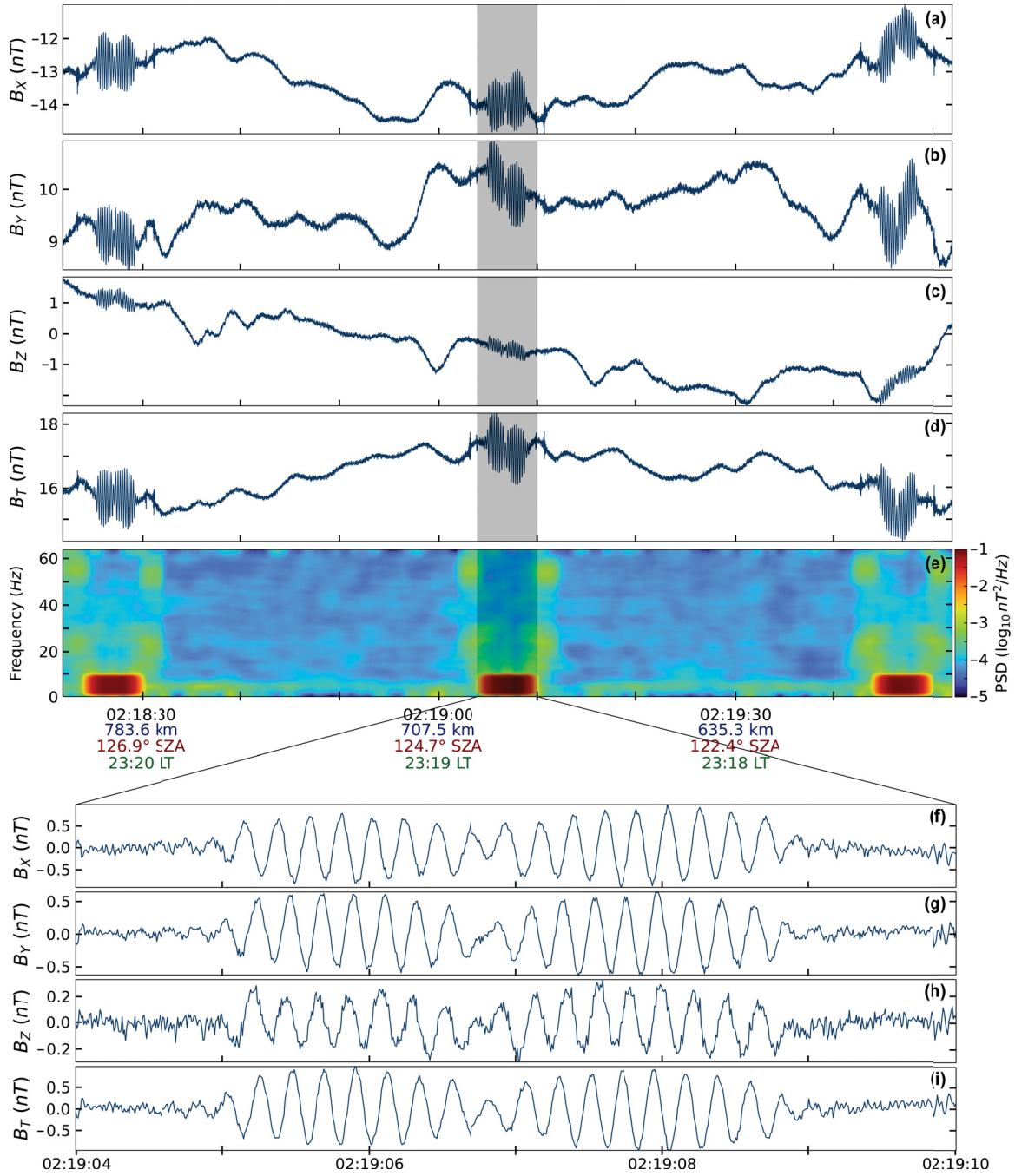| ESA PSA Raw 128 Hz DATA_SET_ID:	ESA PSA Calibrated 1 Hz DATA_SET_ID:
VEX-V-Y-MAG-2-V1.0,	VEX-V-Y-MAG-3-V1.0,
VEX-V-Y-MAG-2-EXT1-V1.0,	VEX-V-Y-MAG-3-EXT1-V1.0,
VEX-V-Y-MAG-2-EXT2-V1.0,	VEX-V-Y-MAG-3-EXT2-V1.0,
VEX-V-Y-MAG-2-EXT3-V1.0,	VEX-V-Y-MAG-3-EXT3-V1.0,
VEX-V-Y-MAG-2-EXT4-V1.0.	VEX-V-Y-MAG-3-EXT4-V1.0.

Figure 2: Example of 4.5 Hz bursts in the data on 2009-09-15. When the anomalies are present, they occur every 40 seconds. (*a*–*d*) The magnetic field components in VSO coordinates and the field strength. (*e*) The power spectral density of the field strength from 0 to 64 Hz. (*f*–*i*) The respective waveforms of the shaded interval in *a*–*d*. Frequencies below 0.5 Hz have been removed.
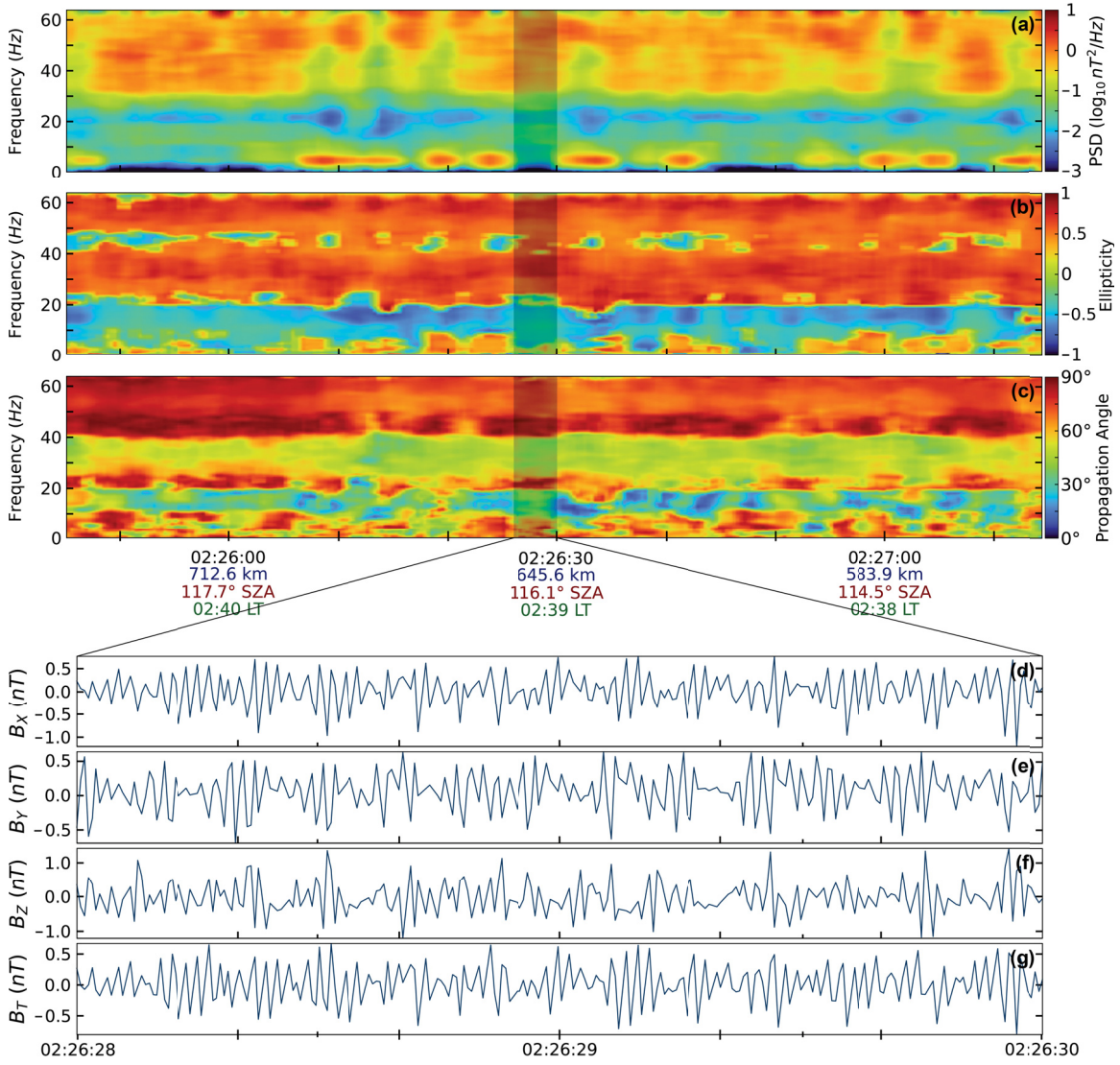
Figure 3: Example of full bandwidth wave exhibiting circular polarity and field alignment on 2011-01-08. (*a*) The power spectral density of the field strength from 0 to 64 Hz. (*b*) The ellipticity from left-hand (−1) to right-hand (+1) circular polarization. (*c*) The propagation angle relative to the background magnetic field. (*d–g*) The waveforms of B_X, B_Y, B_Z, and B_T from the shaded interval in *a–c*. Frequencies below 0.5 Hz have been removed.
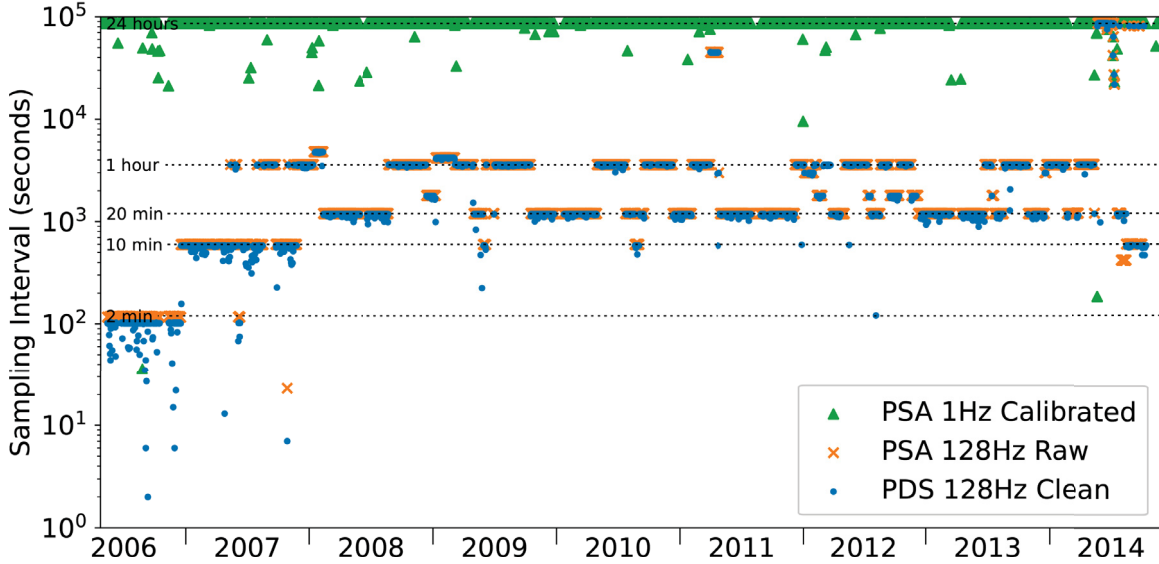
Figure 4: Sampling intervals for each available day of data for each of the three data sets referenced in this document. Each value is the difference between the first and the last times of that particular day.

6   Data table format

The data file names are of the format fg128HzY{YY}D{DOY}.tab. The VSO and REN coordinate systems are as defined in section 3.

1. **Time** – UTC date and time for the sample record.

2. **BR** – Radial component of magnetic field value in REN coordinates in units of nanotesla.

3. **BE** – East component of magnetic field value in REN coordinates in units of nanotesla.

4. **BN** – North component of magnetic field value in REN coordinates in units of nanotesla.

5. **BT** – Magnetic field magnitude in units of nanotesla.

6. **BX** – X-axis magnetic field value in VSO coordinates in units of nanotesla.

7. **BY** – Y-axis magnetic field value in VSO coordinates in units of nanotesla.

8. **BZ** – X-axis magnetic field value in VSO coordinates in units of nanotesla.

9. **XVSO** – X-axis position in VSO coordinates in units of kilometers.

10. **YVSO** – Y-axis position in VSO coordinates in units of kilometers.

11. **ZVSO** – Z-axis position in VSO coordinates in units of kilometers.

12. **RVSO** – Radial distance of position in VSO coordinates in units of kilometers.

13. **BXSCD** – *Detrended X-axis magnetic field value in SC coordinates in units of nanotesla.

14. **BYSCD** – *Detrended Y-axis magnetic field value in SC coordinates in units of nanotesla.

15. **BZSCD** – *Detrended Z-axis magnetic field value in SC coordinates in units of nanotesla.

*"Detrended" refers to the cleaned data before adding the zero levels and restoring the low frequency portion.

References

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