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Swarm preliminary Plasma dataset User Note

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APPROVAL

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DISTRIBUTION

Name/Organisational Unit

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1 INTRODUCTION

The Preliminary Plasma Dataset has been made available to the Swarm science users thanks to the efforts of the Swarm Electric Field Instrument (EFI) principal investigators (PIs) and their teams. It is composed by two separate datasets, corresponding to the two instruments which compose the EFI: the Langmuir Probes derived data (plasma density, electron temperature and spacecraft potential) have been prepared by the Swedish Institute for Space Science (IRF) at Uppsala; the Thermal Ion Imagers derived data (O^+ bulk velocity and temperature, ionospheric convection electric field) have been prepared by the University of Calgary (Canada).

Due to thorough calibration activities on the instruments and the processing algorithms evolutions still on-going to achieve the best possible data quality, this plasma dataset is a work in progress and can be considered as preliminary. The use of such data by the scientific community is encouraged by the EFI PIs, provided interested scientists and users carefully read the notes which follow below concerning the state of the art of plasma data quality and the information about data formats and content. In case of doubts, the PIs will be pleased to answer your questions:

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    - Johnathan Burchill, j.burchill@ucalgary.ca
- Swedish Institute for Space Physics (IRF), in Uppsala:
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2 THE LANGMUIR PROBE DATASET

This dataset contains the preliminary L1b products of the Swarm Langmuir probes, part of the Electric Field Instrument (EFI). The main products are the local electron density and the electron temperature, N_e and T_e. Also the spacecraft potential, V_s , is estimated, which is used for processing data from the EFI's thermal ion imager (TII). For convenience, also the spacecraft locations and the sun's position at such locations are provided. Please refer to the Swarm Product Data Handbook for further information (http://swarm-wiki.spacecenter.dk/mediawiki-1.21.1/index.php/Main_Page).

2.1 File format and names

The data are listed in text files, one file per day and per Swarm satellite A, B, or C. The files are zipped and compressed into a file about 6 MB in size per day and spacecraft.
The file names are SW_PREL_EFI<SC>_LP_1B_<start>_<end>_0101.txt
<SC> is either "A", "B" or "C" for satellites A, B, and C respectively. <start> corresponds to the second of the first data record of the day, <end> to the second of the last record point. Both <start> and <end> are in the format YYYYMMDDThhmmss (UTC). The last second is normally 235959 with two data points in it before the end of the day.
The compressed/archived file names end with .zip and also include a separate header file (.hdr) containing the name of the master data file at IRF and the production date from this master file. In order to create a larger data set in a single file, the data files (*.txt) can be concatenated, (the headers are in separate files to make this easily possible).

2.2 Data periods

Currently, all EFI L0 normal mode files available from December 9, 2013 have been processed, with the exclusion of the EFI TII and LP calibration modes. The processed data include (rare) periods when the spacecraft were flown with unusual attitude or other unusual configurations that a user might want to exclude in his/her analysis. Generally this LP data set has only information about the state of the LP.

2.3 Data sequence

All preliminary LP L1b data are from the instruments' normal (harmonic) mode which has 2 cycles per second. Every 128 s a so-called “sweep” is performed which is not included in this output. When a sweep occurs, the satellites resend also the most recent normal mode packet, but time-stamped like the sweep. Therefore the preliminary L1b data appear to be regular. However, every 128 s the data are in reality missing. This is flagged: a quality flag value ≥ 256 indicates that the data are duplicates with a "cheating" packet time stamp. A user may want to discard these data, or interpolate them in a better way (the packet duplication results in a sequence of values like ...ab**cdcd**ghij..., because there are 2 normal mode data points per second). For example:

```
A 2014-06-13T03:50:04.217 5277 13804217 -29.409 -111.142 476.763 6849.774 131.9   96   133286   2388
-1.455    1

A 2014-06-13T03:50:04.716 5277 13804716 -29.377 -111.142 476.750 6849.771 131.9   96   134086   2388
-1.455    1

A 2014-06-13T03:50:05.217 5277 13805217 -29.345 -111.142 476.737 6849.769 131.9   96   133286   2388
-1.455  257

A 2014-06-13T03:50:05.716 5277 13805716 -29.313 -111.142 476.724 6849.766 131.9   96   134086   2388
-1.455  257

A 2014-06-13T03:50:06.217 5277 13806217 -29.281 -111.142 476.710 6849.763 131.9   96   135357   2405
-1.463    1
```

```
A 2014-06-13T03:50:06.716 5277 13806716 -29.249 -111.142 476.697 6849.760 131.9   96   136280   2409
-1.461    1
```

The first and second records in the list above (first blue/red sequence) correspond to good normal mode measurements (**flag = 1**); the third and fourth records (second blue/red sequence) correspond to sweep mode timestamps (**flag = 257**) and the physical parameters (density, temperature and S/C potential) are merely duplicated from the previous pair. Afterward, the normal mode sequence starts again and still good data are available (**flag = 1**).

2.4 Data fields

The data fields are listed and described in Table 1 below:

Field name	Type	Units	Description
Sat	TEXT	N/A	Spacecraft identifier: A,B, or C
Date	TEXT (23 characters)	N/A	Date in format: yyyy-mo-dyThr:mi:sc.msc
Day2000	INTEGER	MD2000	Day of observation, days since 2000-01-01, UTC
Msec	INTEGER	Ms	millseconds of day of observation, UTC
Latitude	REAL	Deg	Position in ITRF – Latitude
Longitude	REAL	Deg	Position in ITRF – Longitude
Height	REAL	Km	Height above reference ellipsoid
Radius	REAL	Km	Position in ITRF – Radius
Sza	REAL	Deg	Solar zenith angle
Azimuth	REAL	Deg	Solar azimuth
N_e	REAL	cm^{-3}	Plasma density (electrons)
T_e	REAL	K	Plasma electron temperature
V_s	REAL	V	Spacecraft potential
Flag	INTEGER	N/A	Quality flag (see sect 1.4.7 and **Table 2** for more details)

Table 1: Langmuir probe dataset fields

2.5 Data description

2.5.1 Latitude, longitude, height, radius

The spacecraft location (latitude, longitude, height, radius) is calculated from TLEs, provided by ESOC FOS, and the usual sgdp4 software. The accuracy is completely sufficient when working with LP data alone. But it is not a precise orbit determination and users shall be careful when using the LP data in conjunction with other Swarm data products, particularly with magnetic data.

2.5.2 Solar zenith and azimuth angles

The reference for calculating the solar zenith angle and azimuth (in geodetic coordinates, not relative to the satellite) is:

% SUN_ALG1 - sun position according algorithm 1, short version
% in R. Grena (2012), Five new algorithms for the computation of sun position from 2010 to 2110, Solar Energy, vol. 86(5), 1323-1337, doi:10.1016/j.solener.2012.01.024.

2.5.3 High and low gain probes

Each Swarm satellite has two Langmuir probes. Almost always one probe is set to high gain, and the other to low gain. This is necessary to cover the full range of plasma densities in the ionosphere at Swarm altitudes.
Only one set of plasma parameters, namely density, electron temperature and spacecraft potential, is derived from the raw L0 data, which have the measurements from both probes. The users of the L1b products need to worry about low or high gain only in order to understand some of the limitations of the data and the flags field, as it will be detailed in the following sections.

2.5.4 Electron density

The electron (plasma) density is derived from the high gain ion current (when the probe potential is a few Volts negative). Instrumentally this always works, flags indicating overflow or a bad 0-tracking (explanation below) should not be considered for the density.

The electron density has not been calibrated yet (an absolute validation will be possible using Incoherent Scatter radars). According to a first quick comparison with other independent measurements and models, the current values are up to a few 10% too high at low density, but a more systematic work on this is ongoing.

2.5.5 Electron temperature

The natural temperature unit for a Langmuir probe is eV. Nevertheless, in the present dataset the temperature is provided in K, which is more suitable for most scientific uses.
As for the density, T_e has not been calibrated yet; a first quick comparison with other independent measurements and models suggests that it might be up to several hundred K too high.

As described above, a sweep is performed every 128 s. The sweep measurements are not directly used for producing this data set. But the sweeps have an effect on T_e: right after each sweep the temperature is higher by up to about 100 K (0.01 eV) and decreases slowly, over several seconds, to values just before the sweep. The time series of T_e data shows upward jumps every 128 s. This effect is most pronounced at high densities, and becomes almost invisible at low density. The cause is not fully understood. Efforts to understand the

effect and possibly mitigating it are going on. Very likely it is not a true temperature variation.

We report about short duration events (few seconds) where T_e varies strongly and erratically and reaches extremely high values. An example can be seen in Figure 1. Such events occur at all latitudes, but more often at high ones. The problem is under investigation and in the next release of the preliminary data these events could be flagged relatively reliably. Until then it is recommended to use T_e only in event studies where these bursts are easily visible in plots of the data, and the user can manually mask them.

Under certain (rare) instrumental conditions the temperature estimates should not be used, but it is still provided to complete the data row with a valid density. This is described as follows: to estimate the electron temperature T_e, the current at a suitable positive bias with respect to the spacecraft potential needs to be measured. To set this bias in an optimal way, a so-called zero current tracking is performed, which occasionally fails. When this happens, then often it fails only on one probe, the high gain one, sometimes also only on the low gain probe. If 0-tracking is successful with only one probe, this probe is used for estimating T_e. Very rarely, <0.1 % of all times, 0-tracking fails on both probes, and it is recommend to discard then T_e. This is flagged in data by setting **Flag ≥ 192**.

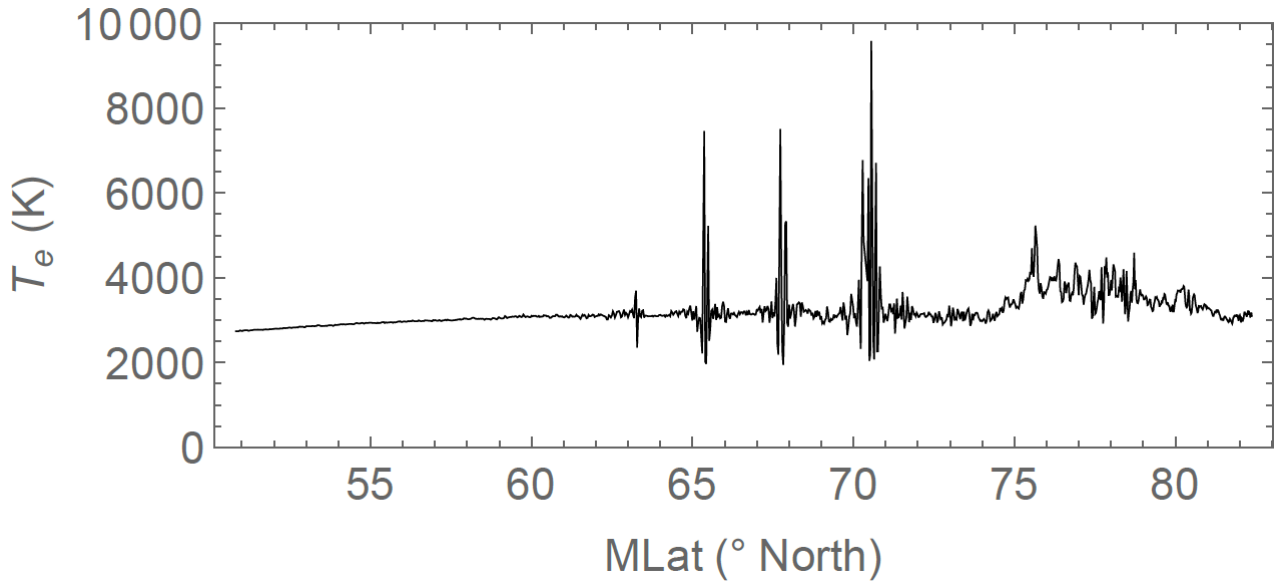

Figure 1: Example of T_e unexpected features.

2.5.6 Spacecraft potential

The spacecraft potential V_s is mainly needed for computing the Thermal Ion Imagers data. For this data set always the measurements from the low gain probe were used, except when the 0-tracking on this probe failed.
The spacecraft potential shows inverse tops similar to T_e right after sweeps.

2.5.7 *Quality Flags*

The quality flags are bit-coded numbers (from bit 0 to bit 8) converted in decimal values in the dataset.

The meaning of some of the flag bits have already been described above. Bit 8 indicates duplicated normal mode data at sweeps, which can optionally be discarded or replaced by interpolated data. When bit 6 and 7 are both set (<0.1 % of all data), both probes had a failed 0-tracking, and temperature and spacecraft potential, but not density, should be discarded/interpolated.
For completeness here is an explanation of the remaining flag bits in use, which, however, the user could normally ignore:

- Bits 0 and 1 indicate, whether the probes are set to high or low gain. The nominal situation is: Bit 0=1 and bit 1=0, i.e. probe 1 is the high gain one, and probe 2 the low gain one. Exceptions are certain periods in the commissioning phase (until Jan 2, 2014), and later some short periods, ~1 min, probably related to instrument switch ons.
- Bits 2-5 indicate overflows on the electron current side (positive bias). They are expected for the high gain probe when the density is sufficiently high. The data processor uses automatically only the non-overflowing probes to estimate T_e. There are a few rare special conditions when the overflow flags are relevant.

In Table 2 an overview of the Langmuir probes flags is given.

Flag value	Description
0 (bit0=0, bit1=0)	Probe 1 & Probe 2 in low gain (never happened to date)
1 (bit0=1, bit1=0)	Probe 1 = high gain, Probe 2 = low gain (nominal situation)
2 (bit0=0, bit1=1)	Probe 1 = low gain, Probe 2 = high gain (short periods during Commissioning Phase)
3 (bit0=1, bit1=1)	Probe 1 & Probe 2 in high gain (never happened to date)
4 – 7 (bit 2 activated)	overflows on the linear electron current region for Probe 1
8 – 11 (bit 3 activated)	overflows on the linear electron current region for Probe 2
12 – 15 (bits 2 – 3 activated)	overflows on the linear electron current region for both Probes 1 & 2
16 – 19 (bit 4 activated)	overflows on the retarded electron current region for Probe 1
20 – 31 (bits 2-3-4 activated)	Combinations of the above situations
32 – 35 (bit 5 activated)	overflows on the retarded electron current region for Probe 2
36 – 63 (bits 2-3-4-5 activated)	Combinations of the above situations
64 – 127 (bit 6 activated)	Zero tracking failure on Probe 1 (+ overflow combinations)
128 – 191 (bit 7 activated, bit 6 non	Zero tracking failure on Probe 2 (+ overflow

activated)	combinations)
192 -255 (bit 6-7 both activated)	**Zero tracking failure on both probes (+ overflow combinations): electron temperature and spacecraft potential not usable.**
≥ 256 (bit 8 activated)	**Timestamps corresponding to sweep mode intervals: to be discarded**

Table 2: Langmuir Probes quality flags description

3 THE THERMAL ION IMAGERS DATASET

3.1 Data Format

Data are provided in ZIP-archived files with the following naming convention:
SW_PREL_EFIX_TII1B_YYYYMMDDTHHMMSS_yyyymmddThhmss_VVVV.cdf.zip
Where:

- PREL indicates the data are preliminary;
- X is the satellite letter, one of A, B or C;
- TII1B indicates this file contain a subset of TII-related L1b plasma products;
- YYYYMMDDTHHMMSS marks the beginning of the interval;
- yyyymmddThhmmss marks the end of the interval;
- VVVV is the dataset version

Each file un-compresses to a NASA/CDF file containing the following variables (Table 3):

Variable	Type	Unit	Dimension	Note
Timestamp	double	s	1	*Times are seconds from 1 Jan 2000 00:00:00 UT. To convert to modified Julian day: tMJD2000=Timestamp/86400.*
latitude	double	deg.	1	ITRF spherical latitude, derived from L1b Medium Or-bit Determination (MOD).
longitude	double	deg.	1	ITRF spherical longitude, derived from L1b MOD.
radius	double	m	1	ITRF spherical radius, derived from L1b MOD.
v_SC	double	m/s	3	Satellite velocity vector in North, East, Centre (NEC) frame.
v_ion	double	m/s	3	Ion velocity vector in NEC frame.
E	double	mV/m	3	Electric field vector in NEC frame.
T_ion	double	K	1	Ion temperature.

v_ion_H	double	m/s	2	Horizontal sensor ion velocity in TII coordinates (x and y).
v_ion_V	double	m/s	2	Vertical sensor ion velocity in TII coordinates (x and y).
rms_fit_H	double	DN	1	RMS error from TII x-profile 2-Gaussian fits, H sensor.
rms_fit_V	double	DN	1	RMS error from TII x-profile 2-Gaussian fits, V sensor.
var_x_H	double	Pixel2	1	Variance of 16 Hz X moment, H sensor.
var_y_H	double	pixel2	1	Variance of 16 Hz Y moment, H sensor.
var_x_V	double	pixel2	1	Variance of 16 Hz X moment, V sensor.
var_y_V	double	pixel2	1	Variance of 16 Hz Y moment, V sensor.
SAA	int32	N/A	1	South Atlantic Anomaly proximity indicator.
Flags_TII	int32	N/A	1	TII quality flag.
Flags_Platform	int32	N/A	1	Satellite platform flag.
Maneuver_Id	int32	N/A	1	Satellite manoeuvre identification code.

Table 3: TII CDF file content

The CDF also includes annotations for measurement units, labels, descriptions, and processor version.

3.2 Data description

The users shall be aware of the following information:

1. **For the time being only data from Swarm A and B are distributed**. The TII instrument on Swarm C is still undergoing intense calibration activities and the data distribution is therefore delayed.
2. The “Flags_TII”, “Flags_Platform”, and “Maneuver_Id” variables are described here: http://swarm-wiki.spacecenter.dk/mediawiki-1.21.1/index.php/Main_Page
3. Satellite positions are derived from the 1 Hz MOD L1b measurements, and are cubically-interpolated at the TII measurement times.
4. Spacecraft potential is provided by IRF as part of the Langmuir Probe (LP) dataset, and is based on estimates from LP Probe 2 only. Accordingly, the TII electromotive force (emf) corrections are made relative to the position of Probe 2 only.
5. Electron density, which is used in the TII quality flag calculation, is provided by IRF as well.

6. Magnetotorquer-induced velocity deflections are not calculated.
7. TII profile fits are weighted evenly.
8. Measurement errors are not calculated.
9. TII quality flag **greater than or equal to 20**, indicates that data are affected by serious quality issues and should not be used.

3.3 Known problems or limitations

All data should be treated with caution as to its interpretation. The following issues are known, but not yet always properly flagged:

1. Large offsets in ion drift, electric field, and ion temperature associated with imperfect calibrations, or with artifacts in the TII detector. Currently, variations in measurements relative to the back-ground signal are more scientifically meaningful than absolute values.

2. Noisy ion velocities, ion temperatures, and electric fields. This occurs at low plasma density due to low signal-to-noise ratio.

3. Measurement jitter occurred routinely prior to May 2014 due to sub-optimal configuration of on-board image processing algorithms in the EFI TII flight software.

4 WHERE TO FIND DATA?

The interested user shall first visit the “Swarm Data Access” web page:

https://earth.esa.int/web/guest/swarm/data-access

and follow the instructions in order to register in the “MyEarthnet” system and understand the structure of the Swarm FTP server. Then, he/she can access the ESA dissemination server and download Swarm data.
In particular, once logged into the FTP server, the preliminary plasma dataset can be found here:

/Advanced/Provisional_Plasma_dataset

Sub-folders inside are rather self-explanatory: Langmuir Probe and Thermal Ion Imagers datasets are given in separate folders and further divided by Spacecraft.