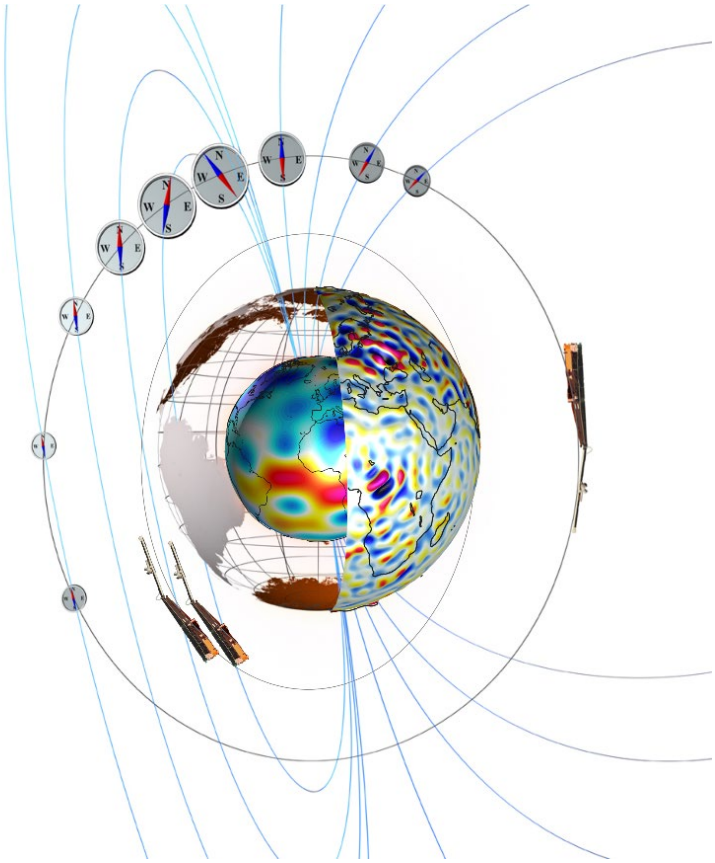
Swarm-AEBS Product Definition



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Record of Changes

Reason	Description	Rev	Date
Initial vers.	Released	1 dA	30 jan 2018
Updated in response to Swarm_AEBS Project Meeting #001	Added Section 3 with Product Summary Updated data products in Section 4	1 dB	08 mar 2018
Comments from GFZ, FMI and DTU	All products revised in Section 4	1 dC	04 june 2018
Refining by FMI and DTU	Clarifications in several places of the document	1 dD	27 june 2018
Updated in response to Swarm_AEBS MTR Meeting	All products revised in Section 4	1 dE	29 june 2018
Updated in response to Swarm AEBS progress meeting 28/02/2019	Note about version information of Input Data in the CDF global attributes added to all products in Section 4 AOB product revised in Section 4.3	1 dF	7 march 2019
Updated in response to Swarm AEBS progress meeting 27/05/2019	Latitude Profiles and Auroral Electrojet Peaks and Boundaries products revised in Sections 4.1 and 4.2. Peak ground magnetic field disturbance removed from PBL product in Section 4.2. Output time span and update rate revised for AOB product in Section 4.3 CDF_EPOCH units and descriptions revised for all products in Section 4.	1 dG	12 june 2019

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Reason	Description	Rev	Date
Updated in response to Swarm AEBS progress meeting 20/06/2019	Variable names revised for all products in Section 4 Note about start/end time based on orbit crossings added to all products in Section 4 Note on timestamps of missing peaks and boundaries added to Auroral Electrojet Peaks and Boundaries products in Section 4.2. Flags revised for Auroral Electrojet Peaks and Boundaries products in Section 4.2. Flags and Pair t_b changed to Quality and Pair_Indicator respectively for Auroral Oval Boundaries product in Section 4.3	1 dH	5 july 2019
	$Latitude_{POLEQD}$ and $Longitude_{POLEQD}$ moved from Output Data to Notes as CDF global attributes for LPS product in Section 4.1 Note about Flag values specified in binary added to Auroral Electrojet Peaks and Boundaries products in Section 4.2 as well as small refining of Flag Description text.	1 dI	7 aug 2019
Signature	Approved	1	11 Aug 2019
Signature	Authorised	1	12 Aug 2019
Updated in response to Swarm AEBS progress meeting 27/09/2019	Description of Output Data revised for Auroral Electrojet Peaks and Boundaries products in Section 4.2. Resolution, Uncertainty and Data volume information added to all products in Section 4 Pair_Indicator revised and Latency added to Auroral Oval Boundaries product in Section 4.3	2 dA	11 Okt 2019
Updated in response to Swarm AEBS progress meeting 28/10/2019 and 12/10/2019	Variable descriptions in Section 4 homogenized to become consistent with descriptions in the corresponding CDFs AOB product changed from files containing one day to files containing up to one calendar year in Section 4.3 Dimension of Quality changed from “1” to “2” in AOB product in Section 4.3	2 dB	22 Nov 2019

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Reason	Description	Rev	Date
Updated in response to Swarm AEBS progress meeting 13/01/2020 and 18/02/2020	Description of Quality indicators revised for Auroral Electrojet Peaks and Boundaries products in Section 4.2.	2 dC	18 Feb 2020
Signature	Approved	2	25 Mar 2020
Signature	Authorised	2	25 Mar 2020
Updated in response to Swarm AEBS discussions after the Final presentations	Description of the different mappings between Swarm and ionosphere used in the three methods added. Descriptions added by Kirsti Kauristie	3a	21 SEP 2020
Corrections to Sections 4.2 and 4.3 after DISC evaluation	In Section 4.2 the "Input Time Span" has been changed from 24h to one year and the altitude of footprints in PB product (110 km) has been added. In Section 4.3 for "Output Data" the type of "Quality" has been changed from CDF_UINT1 to CDF_DOUBLE. Corrections has been done by Kirsti Kauristie	3b	4 NOV 2020

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1 Introduction

1.1 Scope and applicability

This document provides a product description of all the Swarm-AEBS products in response to the requirements of [AD-1], section 3.3.

This document is available on the SVN, https://smart-svn.spacecenter.dk/svn/smart/SwarmDISC/DISC_Projects/ITT1_2_Swarm_AEBS/Deliverables/.

2 Applicable and Reference Documentation

2.1 Applicable Documents

The following documents are applicable to the definitions within this document.

[AD-1] SW-OF-FMI-GS-112_1-2_AEBS_Proposal, Proposal for Swarm DISC ITT 1.2, Swarm-AEBS – Auroral Electrojet and auroral Boundaries estimated from Swarm observations

[AD-2] SW-DS-GFZ-GS-001_AEBS_DPA, Swarm-AEBS Description of the Processing Algorithm

2.2 Reference Documents

The following documents contain supporting and background information to be taken into account during the activities specified within this document.

[RD-1] Juusola, L., Amm, O., and Viljanen, A. (2006). One-dimensional spherical elementary current systems and their use for determining ionospheric currents from satellite measurements. Earth Planet Space, 58(5), 667–678, doi:10.1186/BF03351964.

[RD-2] Xiong, C., Lühr, H., Wang, H., and Johnsen, M. G.: Determining the boundaries of the auroral oval from CHAMP field-aligned current signatures – Part 1, Ann. Geophys., 32, 609-622, https://doi.org/10.5194/angeo-32-609-2014, 2014.

2.3 Abbreviations

Acronym ***or abbreviation***	***Description***
AEJ	Auroral Electrojet
ASM	Absolute Scalar Magnetometer
Aux	Auxiliary
Cat-1	Products that are processed by the L2PS Consortium
Cat-2	Products that are processed by PDGS
CDF	Common Data Format developed by NSSDC at NASA in 1985
DIP	Spherical IGF dipole frame

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Acronym *or abbreviation*	***Description***
DTU	Technical University of Denmark, DK
EEJ	Eastward ElectroJet, i.e. latitudinal zone of positive eastward ionospheric sheet currents
ESA	European Space Agency
FAC	Field-Aligned Currents
FMI	Finnish Meteorological Institute, FI
FTP	File Transfer Protocol
GFZ	Helmholtz Centre Potsdam - German Research Centre for Geoscience, DE
GEO	Spherical GEOgraphic Reference Frame
L2	Level 2 (satellite data)
L2PS	Level 2 Processing System, comprising 12 chains, located at six institutes in CH, DE, DK, FR, NL and UK.
LC	Line Current (method)
PDGS	Payload Data Ground Segment
QD	Quasi-Dipole (coordinate frame)
SECS	Spherical Elementary Current Systems (method)
SVN	SVN Repository with server located at DTU. Presently, the following URLs apply: https://smart-svn.spacecenter.dk/svn/smart/SwarmDISC/DISC_Projects/ITT1_2_Swarm_AEBS/
SW	Software
Swarm	Constellation of 3 ESA satellites, http://earth.esa.int/swarm
TBC	To Be Confirmed
TBD	To Be Defined
TDS	Test Data Set
VFM	Vector Field Magnetometer
WEJ	Westward Electrojet, i.e. latitudinal zone of negative eastward ionospheric sheet currents

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3 Product Summary

The Swarm-AEBS product series consists of a total of five products. Two products contain the Latitude Profiles of the ionospheric sheet current densities, namely **AEJxLPL_2F** determined using the Line Current (LC) method, and **AEJxLPS_2F** which uses the Spherical Elementary Current Systems (SECS) method. LC method output will be the horizontal sheet current density in the ionospheric E-layer while SECS will provide both ionospheric sheet current and radial current densities. Both AEJxLPL_2F and AEJxLPS_2F products comes as daily files. Two products contain the locations of Auroral Electrojet Peaks (minima and maxima) and Boundaries, namely **AEJxPBL_2F** based on the LC method, and **AEJxPBS_2F** which uses the SECS method. Both products comes as yearly files that are augmented on a daily basis. The last product, named **AOBxFAC_2F**, contains the Auroral Oval Boundaries derived from FAC observations. This product also comes as a yearly file that is updated on a daily basis. Detailed descriptions of the products are provided in Section 4.

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4 Specification of Products

This section contains the detailed description of the Swarm-AEBS products. The two products **AEJxLPL_2F** and **AEJxLPS_2F** that contain the Latitude Profiles of the ionospheric sheet current densities (plus radial current densities in the case of **AEJxLPS_2F**) are described in Section 4.1. The two products **AEJxPBL_2F** and **AEJxPBS_2F** that contain the locations of Auroral Electrojet Peaks and Boundaries are described in Section 4.2. The product **AOBxFAC_2F** containing the Auroral Oval Boundaries derived from FAC data is described in Section 4.3.

4.1 Latitude Profiles

Product identifier	**AEJxLPL_2F**
Definition	Latitude profiles of high-latitude ionospheric horizontal sheet current densities using the Line Current method
Input Data	MAGx_LR_1B, Latest CHAOS model[1] including, core, lithosphere, magnetosphere and secondary currents.
Input Time Span	24 h
Spatial representation	One geographic and quasi-dipole latitude/longitude pair for each output value. Longitudes and latitudes of nearest magnetic-field measurement. Given at Swarm footprints (at 110 km altitude) according to the time representation of this product. The footprints have been determined with radial mapping.
Time representation	1 deg latitude corresponding to ~ 15 s
Units	A/km
Resolution	Full resolution (Double precision)
Uncertainty	c.f. Olsen, N, Geophys. Res. Lett., 23, 3635-3638 and Aakjaer, C. D. et al., doi:10.1186/s40623-016-0509-y
Quality indicator	RMS characterizing the misfit between modelled and measured magnetic field by Swarm
Data volume	~250 kB
Data format	CDF
Output Data	

Variable Name	Type	Dim	Unit	Description
t	CDF_EPOCH	1		Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	Position in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	Position in ITRF – Geocentric longitude
$Latitude_{QD}$	CDF_DOUBLE	1	deg	Quasi-dipole latitude
$Longitude_{QD}$	CDF_DOUBLE	1	deg	Quasi-dipole longitude
MLT	CDF_DOUBLE	1	hour	Magnetic Local Time (QD)

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Product identifier	AEJxLPL_2F				
	J	CDF_DOUBLE	2	A/km	North- and East-component of horizontal sheet current density vector in geocentric frame
	J_{QD}	CDF_DOUBLE	1	A/km	East-component of horizontal sheet current density in QD frame
	t_qual	CDF_EPOCH	1		Time instants of quality information (RMS_misfit and Confidence), UTC
	RMS_misfit	CDF_DOUBLE	1	nT	Root Mean Square misfit between observations and model values for the oval crossing[3]
	Confidence	CDF_DOUBLE	1	N/A	Goodness of fit computed as 1 – (residual rms / signal rms) for the oval crossing[3]
Output time span	24 h[2]				
Update rate	Daily				
Latency	< 1 day				
Notes	[1]Version information of Input Data are available in the CDF global attributes. [2]Product always contain data from the start of the first oval crossing of the day until the end of the last oval crossing starting that day, i.e. may contain data from the next day if oval crossing occurs around midnight. [3]In Line Current method the equatorward boundary of oval crossing is always at +/- 50 QD latitude and the poleward boundary is at the most poleward point in QD latitude of the satellite trajectory.				

Product identifier	AEJxLPS_2F
Definition	Latitude profiles of high-latitude ionospheric horizontal sheet current densities and radial current densities using the Spherical Elementary Current Systems method [RD-1]
Input Data	MAGx_LR_1B, Latest CHAOS model[1] including, core, lithosphere, magnetosphere and secondary currents.
Input Time Span	24 h
Spatial representation	One geographic, quasi-dipole latitude/longitude pair for each output value, given at Swarm footprints (at 110 km altitude) according to the time representation of this product.[2] The footprints have been determined with mapping along the geomagnetic field line.
Time representation	1 Hz
Units	A/km and A/km^2
Resolution	Full resolution (Double precision)
Uncertainty	c.f. Juusola et al., doi:10.1002/2016JA022961
Quality indicator	RMS and confidence characterizing the misfit between modelled and measured magnetic field by Swarm

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Product identifier	**AEJxLPS_2F**
Data volume	~3 MB
Data format	CDF
Output Data	

Variable Name	Type	Dim	Unit	Description
t	CDF_EPOCH	1		Time of observation, UTC
Latitude	CDF_DOUBLE	1	deg	Position in ITRF – Geocentric latitude
Longitude	CDF_DOUBLE	1	deg	Position in ITRF – Geocentric longitude
Latitude_{QD}	CDF_DOUBLE	1	deg	Quasi-dipole latitude
Longitude_{QD}	CDF_DOUBLE	1	deg	Quasi-dipole longitude
MLT	CDF_DOUBLE	1	hour	Magnetic Local Time (QD)
$\mathbf{J}_{CF}$	CDF_DOUBLE	2	A/km	North- and East-component of the curl-free horizontal sheet current density vector in geocentric frame
$\mathbf{J}_{DF}$	CDF_DOUBLE	2	A/km	North- and East-component of the divergence-free sheet horizontal sheet current density vector in geocentric frame
$J_{CF,SemiQD}$	CDF_DOUBLE	1	A/km	North-component of the curl-free horizontal sheet current density in SemiQD[3] frame
$J_{DF,SemiQD}$	CDF_DOUBLE	1	A/km	East-component of the divergence-free horizontal sheet current density in SemiQD[3] frame
J_r	CDF_DOUBLE	1	A/km^2	Radial ionospheric current density at 110 km altitude in SemiQD[3] frame (positive outwards from the Earth centre)
t_qual	CDF_EPOCH	1		Time instants of quality information (RMS_misfit and Confidence), attached to the beginning time of the oval crossing[4], UTC
RMS_misfit	CDF_DOUBLE	1	nT	Root Mean Square misfit between observations and model values of each oval crossing[4]
Confidence	CDF_DOUBLE	1	N/A	Goodness of fit computed as 1 – rms(Bpar-Bparmod)/rms(Bpar), where Bpar is the measured residual field in the (r,theta) plane and Bparmod is the modelled residua

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Product identifier	AEJxLPS_2F
	field. Computed for each oval crossing[4]
Output time span	24 h[5]
Update rate	Daily
Latency	< 1 day
Notes	[1]Version information of Input Data are available in the CDF global attributes. [2]Although the Spatial Representation is given with 1 Hz (~7 km) resolution, the method can resolve current structures with ~1 deg resolution. [3]Horizontal current components will be given both in geocentric frame and in a spherical frame whose north pole is defined by the QD frame [AD-2]. The latitude and longitude of QD north pole are available in the CDF global attributes Latitude$_{POLEQD}$ and Longitude$_{POLEQD}$ respectively. These are vectors of two elements. The 1st (2nd) value is for the case when Swarm is in the northern (southern) hemisphere. [4]In SECS method the equatorward boundary of oval crossing is always +/- 50 QD latitude and the poleward boundary is at +/-85 QD latitude if the satellite trajectory covers such high latitudes. [5]Product always contain data from the start of the first oval crossing of the day until the end of the last oval crossing starting that day, i.e. may contain data from the next day if oval crossing occurs around midnight.

4.2 Auroral Electrojet Peaks and Boundaries

Product identifier	AEJxPBL_2F
Definition	High-latitude ionospheric sheet current boundary locations, the locations of minimum (WEJ) and maximum (EEJ) eastward current density in QD frame, peak current intensity (in QD).
Input Data	MAGx_LR_1B, Latest CHAOS model[1] including, core, lithosphere, magnetosphere and secondary currents.
Input Time Span	Up to one year
Spatial representation	One geographic and quasi-dipole latitude/longitude pair for each output value. Longitudes and latitudes are taken from the nearest magnetic-field measurement. The Swarm footprints at 110 km altitude have been determined with radial mapping.
Time representation	20 – 25 min (4 values per orbit)
Units	A/km (for peak sheet current density) nT (for ground B) and degree (for locations)
Resolution	Full resolution (Double precision)
Uncertainty	c.f. Olsen, N, Geophys. Res. Lett., 23, 3635-3638 and Aakjaer, C. D. et al., doi:10.1186/s40623-016-0509-y
Quality indicator	Note: Flag values are specified in binary. If two or more situations occurs simultaneously, the Flag value will be a sum of the different Flags values. For more information and examples, see [AD-2].

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Product identifier	AEJxPBL_2F

Value	Meaning
0000000000000	Both EEJ and WEJ are detected, and their current densities are zero at all boundaries.
0000000000001	No eastward currents detected.
0000000000010	No westward currents detected.
0000000000100	Equatorward EEJ boundary occurs at the edge of the analysis area[2], and the density is larger than 20% of peak value.
0000000001000	Poleward EEJ boundary occurs at the edge of the analysis area[2], and the density is larger than 20% of peak value.
0000000010000	Equatorward WEJ boundary occurs at the edge of the analysis area[2], and the density is larger than 20% of peak value.
0000000100000	Poleward WEJ boundary occurs at the edge of the analysis area[2], and the density is larger than 20% of peak value.
0000001000000	Swarm orbit does not fully cover the predefined oval latitude range[2]. Latitude gap is 2 degrees or larger.
0000010000000	Equatorward EEJ boundary occurs at the edge of the analysis area[2].
0000100000000	Poleward EEJ boundary occurs at the edge of the analysis area[2].
0001000000000	Equatorward WEJ boundary occurs at the edge of the analysis area[2].
0010000000000	Poleward WEJ boundary occurs at the edge of the analysis area[2].
0100000000000	Peak value of EEJ occurs at the edge of the analysis area[2].
1000000000000	Peak value of WEJ occurs at the edge of the analysis area[2].

Data volume	Up to 6 MB
Data format	CDF

Output Data

Variable Name	Type	Dim	Unit	Description
t_{Peak}	CDF_EPOCH	2		Time of WEJ and EEJ peaks in the order as they appear in the satellite flight direction, UTC[3]
$Latitude_{Peak}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
$Longitude_{Peak}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of WEJ and EEJ peaks in the order

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Product identifier	AEJxPBL_2F				
					as they appear in the satellite flight direction
	$Latitude_{Peak,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
	$Longi-tude_{Peak,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
	MLT_{Peak}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
	J	CDF_DOUBLE	2	A/km	Peaks (minimum (WEJ) and maximum (EEJ)) of sheet current intensity in QD frame in the order as they appear in the satellite flight direction
	t_{EB}	CDF_EPOCH	2		Time of WEJ and EEJ equatorward boundaries in the order as they appear in satellite flight direction, UTC[3]
	$Latitude_{EB}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction.
	$Longitude_{EB}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of equatorward boundaries in the order as they appear in the satellite flight direction
	$Latitude_{EB,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
	$Longitude_{EB,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
	MLT_{EB}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
	t_{PB}	CDF_EPOCH	2		Time of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction, UTC[3]

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Product identifier	AEJxPBL_2F				
	$Latitude_{PB}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	$Longitude_{PB}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	$Latitude_{PB,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	$Longitude_{PB,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	MLT_{PB}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	Flags	CDF_UINT2	1	N/A	Quality indicator
Output time span	Up to one year[4]				
Update rate	Daily				
Latency	< 1 day				
Notes	[1]Version information of Input Data are available in the CDF global attributes. [2]QD latitudes from 50 to 85 (Northern hemisphere) or -50 to -85 (Southern hemisphere). Note that Swarm orbits does not always cover this area completely. [3]If only eastward current detected timestamps for westward peak and boundaries are set to time of eastward peak and predefined oval boundaries, and vice versa. [4]Product contain data from the start of the first oval crossing of the year up until the end of the last oval crossing starting that year, i.e. may contain data from the next year if oval crossing occurs around midnight on the last day of the year.				

Product identifier	AEJxPBS_2F
Definition	High-latitude ionospheric sheet current boundary locations, the locations of minimum (WEJ) and maximum (EEJ) eastward current density in semiQD[1] frame, the locations of minimum and maximum ground northward magnetic field disturbance (in semiQD[1]).
Input Data	MAGx_LR_1B, Latest CHAOS model[2] including, core, lithosphere, magnetosphere and secondary currents.
Input Time Span	Up to one year
Spatial representation	One geographic and QD latitude/longitude pair for each output value. The Swarm footprints at 110 km altitude have been determined with mapping along the geomagnetic field line.
Time representation	One timestamp for each latitude/longitude pair

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Product identifier	AEJxPBS_2F
Units	Degrees (locations), A/km (for peak currents) and nT (for ground B)
Resolution	Full resolution (Double precision)
Uncertainty	c.f. Juusola et al., doi:10.1002/2016JA022961
Quality indicator	Note: Flag values are specified in binary. If two or more situations occurs simultaneously, the Flag value will be a sum of the different Flags values. For more information and examples, see [AD-2].
Data volume	Up to 6 MB
Data format	CDF

Value	Meaning
0000000000000	Both EEJ and WEJ are detected, and their current densities are zero at all boundaries.
0000000000001	No eastward currents detected.
0000000000010	No westward currents detected.
0000000000100	Equatorward EEJ boundary occurs at the edge of the analysis area[3], and the density is larger than 20% of peak value.
0000000001000	Poleward EEJ boundary occurs at the edge of the analysis area[3], and the density is larger than 20% of peak value.
0000000010000	Equatorward WEJ boundary occurs at the edge of the analysis area[3], and the density is larger than 20% of peak value.
0000000100000	Poleward WEJ boundary occurs at the edge of the analysis area[3], and the density is larger than 20% of peak value.
0000001000000	Swarm orbit does not fully cover the predefined oval latitude range[3]. Latitude gap is 2 degrees or larger.
0000010000000	Equatorward EEJ boundary occurs at the edge of the analysis area[3].
0000100000000	Poleward EEJ boundary occurs at the edge of the analysis area[3].
0001000000000	Equatorward WEJ boundary occurs at the edge of the analysis area[3].
0010000000000	Poleward WEJ boundary occurs at the edge of the analysis area[3].
0100000000000	Peak value of EEJ occurs at the edge of the analysis area[3].
1000000000000	Peak value of WEJ occurs at the edge of the analysis area[3].

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Product identifier	**AEJxPBS_2F**

Output Data

Variable Name	Type	Dim	Unit	Description
t_{Peak}	CDF_EPOCH	2		Time of WEJ and EEJ peaks in the order as they appear in the satellite flight direction, UTC[4]
$Latitude_{Peak}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
$Longitude_{Peak}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
$Latitude_{Peak,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
$Longi\text{-}tude_{Peak,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ peaks in the order as they appear in the satellite flight direction
MLT_{Peak}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ peaks (QD) in the order as they appear in the satellite flight direction
J_{DF}	CDF_DOUBLE	2	A/km	Peaks (minimum (WEJ) and maximum (EEJ)) of divergence-free sheet current intensity in semiQD[1] frame in the order as they appear in the satellite flight direction
t_{EB}	CDF_EPOCH	2		Time of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction, UTC[4]
$Latitude_{EB}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
$Longitude_{EB}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of WEJ and EEJ of equatorward boundaries in the order as they appear in the satellite flight direction
$Latitude_{EB,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction

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Product identifier	AEJxPBS_2F				
	$Longitude_{EB,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
	MLT_{EB}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ equatorward boundaries in the order as they appear in the satellite flight direction
	t_{PB}	CDF_EPOCH	2		Time of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction, UTC[4]
	$Latitude_{PB}$	CDF_DOUBLE	2	deg	Geocentric latitude in ITRF of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction
	$Longitude_{PB}$	CDF_DOUBLE	2	deg	Geocentric longitude in ITRF of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction
	$Latitude_{PB,QD}$	CDF_DOUBLE	2	deg	QD latitude of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction
	$Longitude_{PB,QD}$	CDF_DOUBLE	2	deg	QD longitude of WEJ and EEJ poleward boundaries in the order as they appear in the satellite flight direction
	MLT_{PB}	CDF_DOUBLE	2	hour	Magnetic Local Time (QD) of WEJ and EEJ Poleward boundaries in the order as they appear in the satellite flight direction
	$Latitude_{B}$	CDF_DOUBLE	2	deg	Geodetic latitude of peaks (minimum and maximum) in ground magnetic field disturbance in the order as they appear in the satellite flight direction
	$Longitude_{B}$	CDF_DOUBLE	2	deg	Geodetic longitude of peaks (minimum and maximum) in ground magnetic field disturbance in the order as they appear in the satellite flight direction
	B	CDF_DOUBLE	2	nT	2x2 matrix containing the maximum (1st row) and minimum (2nd row) of horizontal ground magnetic field[5]. The 1st (2nd) column gives the North (East) component of the field in geodetic frame

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Product identifier	AEJxPBS_2F				
	Flags	CDF_UINT2	1	N/A	Quality indicator
Output time span	Up to one year[6]				
Update rate	Daily				
Latency	< 1 day				
Notes	[1]Horizontal current components will be given both in geographic frame and in a spherical frame whose north pole is defined by the QD frame [AD-2]. The latitude and longitude of QD north pole are available in the CDF global attributes Latitude$_{POLEQD}$ and Longitude$_{POLEQD}$ respectively. These are vectors of two elements. The 1st (2nd) value is for the case when Swarm is in the northern (southern) hemisphere. [2]Version information of Input Data are available in the CDF global attributes. [3]QD latitudes from 50 to 85 (Northern hemisphere) or -50 to -85 (Southern hemisphere). Note that Swarm orbits does not always cover this area completely.[4]If only eastward current detected timestamps for westward peak and boundaries are set to time of eastward peak and predefined oval boundaries, and vice versa. [5]Ground magnetic field caused by the ionospheric currents is determined in the semiQD frame, where its horizontal part has only the North component. Geodetic vector components are derived from the minimum and maximum of that North component. [6]Product contain data from the start of the first oval crossing of the year up until the end of the last oval crossing starting that year, i.e. may contain data from the next year if oval crossing occurs around midnight on the last day of the year.				

4.3 Auroral Oval Boundaries

Product identifier	AOBxFAC_2F
Definition	Auroral Oval Boundaries using the FAC method
Input Data	FACxTMS_2F[1]
Input Time Span	Up to one year
Spatial representation	One geographic and quasi-dipole latitude/longitude as well as magnetic local time for each output value at the nearest magnetic-field measurement.
Time representation	One timestamp for each boundary represented by the geographic and quasi-dipole latitude/longitude as well as magnetic local time.
Units	Degrees
Resolution	Full resolution (Double precision)
Uncertainty	3 deg, c.f. Xiong, C. and Lühr, H., https://doi.org/10.5194/angeo-32-623-2014, 2014.
Quality indicator	

Value	Meaning
Pa	Slop of linear fit of *S* value. Users are suggested to use boundaries with pa larger than 0.2
Sigma	The standard deviation of the linear fit of S value. Users are suggested to use boundaries with σ less than 0.4. See [RD-2] for the S value definition

Data volume	Up to 2.5 MB

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<table>
<tr><td>Product identifier</td><td>AOBxFAC_2F</td></tr>
<tr><td>Data format</td><td>CDF</td></tr>
<tr><td>Output Data</td><td>CDF file with time series
<table>
<tr><th>Variable Name</th><th>Type</th><th>Dim</th><th>Unit</th><th>Description</th></tr>
<tr><td>t</td><td>CDF_EPOCH</td><td>1</td><td></td><td>Time of observation, UTC</td></tr>
<tr><td>Latitude</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Position in ITRF – Geocentric latitude</td></tr>
<tr><td>Longitude</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Position in ITRF – Geocentric longitude</td></tr>
<tr><td>Radius</td><td>CDF_DOUBLE</td><td>1</td><td>km</td><td>Position in ITRF – Geocentric radius (from the Earth centre)</td></tr>
<tr><td>$Latitude_{QD}$</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Quasi-dipole latitude</td></tr>
<tr><td>$Longitude_{QD}$</td><td>CDF_DOUBLE</td><td>1</td><td>deg</td><td>Quasi-dipole longitude</td></tr>
<tr><td>MLT</td><td>CDF_DOUBLE</td><td>1</td><td>hour</td><td>Magnetic Local Time (QD)</td></tr>
<tr><td>Boundary_Flag</td><td>CDF_UNIT1</td><td>1</td><td>N/A</td><td>Indicator for equatorward (=1) or poleward (=2) boundary</td></tr>
<tr><td>Quality</td><td>CDF_DOUBLE</td><td>2</td><td>N/A</td><td>Quality indicator of equatorward/poleward boundary (Pa, Sigma) (See Quality indicator)</td></tr>
<tr><td>Pair_Indicator</td><td>CDF_UINT1</td><td>1</td><td>N/A</td><td>Indicator of equatorward/poleward boundary of auroral oval. If the auroral oval boundaries are detectable as one pair, the pair indicator represents the record of previous (-1) or next (1) equatorward/poleward boundary within one pair; otherwise, the pair indicator is set to 0</td></tr>
</table></td></tr>
<tr><td>Output time span</td><td>Up to one year[2]</td></tr>
<tr><td>Update rate</td><td>Daily</td></tr>
<tr><td>Latency</td><td>< 1 day</td></tr>
<tr><td>Notes</td><td>[1]Version information of Input Data are available in the CDF global attributes.
[2]Product always contain data from the start of the first oval crossing of the year until the end of the last oval crossing starting that year, i.e. may contain data from the next year if oval crossing occurs around midnight.</td></tr>
</table>

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