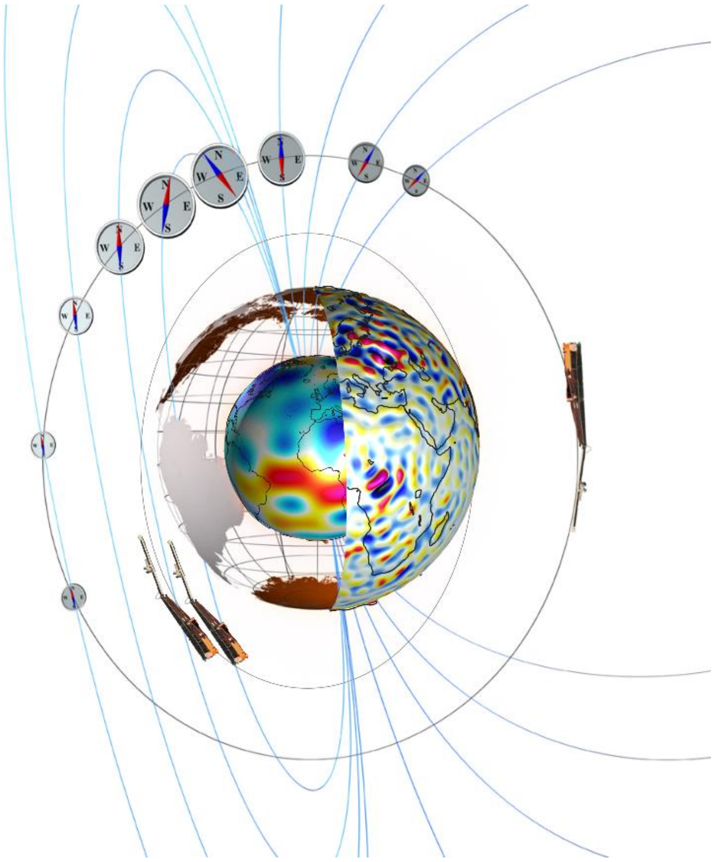
Data, Innovation, and Science Cluster

Swarm equatorial electric field (EEF) Level 2 Product



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Record of Changes

Reason	Description	Rev	Date
Cat-2 > Cat-1	*Transfer of production validation of the Swarm EEF data products and provision to DTU.* Transfer of SW-TN-IPGP-GS-0002, Rev: 2A to DISC doc template. Added section 5 for product file format.	1	2019-08-27

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1 Introduction

1.1 Scope and applicability

This document is available on the SVN at https://smart-svn.spacecenter.dk/svn/smart/SwarmESL-All/L2_Technical/Releases_and_Related_Documents/Cat-1/SW-TN-CIR-GS-001_EEF_Product_Description.pdf when approved.

2 Applicable and Reference Documentation

2.1 Applicable Documents

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

[AD-1] ESRIN Contract No. 4000109587/13/I-NB, Swarm ESL

[AD-2] SWAM-GSEG-EOPG-SW-12-0059, ESL Statement of Work (Appendix 1 of [AD-1])

Details of the algorithm for recovering the EEF from Swarm geomagnetic field measurements are provided below.

[AD-3] Alken, P., Maus, S., Vigneron, P., Sirol, O., Hulot, G., Swarm SCARF Equatorial Electric Field Inversion Chain, Earth Planets Space, 65, 1309-1317, 2013, doi:10.5047/eps.2013.09.008 http://www.terrapub.co.jp/journals/EPS/abstract/6511/65111309.html

[AD-4] Alken, P., S. Maus, A. Chulliat, P. Vigneron, O. Sirol and G. Hulot, Swarm equatorial electric field chain: first results, Geophys. Res. Lett., 42, 673680, doi: 10.1002/2014GL062658, 2015.

[AD-5] SW-DS-IPGP-GS-0001, IPGP Cat-2 Detailed Processing Models, rev. 4B, 2017-04-07

2.2 Abbreviations

A list of acronyms and abbreviations used by Swarm partners can be found here.

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3 Overview

Ultraviolet radiation from the Sun shines on the Earth's upper atmosphere during the day, ionizing a percentage of neutral molecules. Forces then act on this ionized plasma to drive a number of electric current systems throughout the ionosphere region. These forces include electromagnetic fields, friction due to collisions with neutral molecules, pressure gradients and gravity. The neutral-ion friction, when coupled with the electromagnetic force arising from the plasma interacting with the geomagnetic field, produces strong, large-scale currents on the day side at low latitudes, known as the Solar quiet (Sq) and equatorial electrojet (EEJ) currents. At the lower portion of the ionosphere, known as the E-region (90-120 km altitude), near the equator these currents can be enhanced even further by the horizontal geometry of the geomagnetic main field in addition to the zonal electric field component. The zonal electric field near the equator drives vertical electron drift, but due to the ionization process, non-conducting boundaries are formed at the lower and upper parts of the E-region, restricting vertical electric currents. This results in strong vertical polarization electric fields, which can significantly enhance the strength of the currents near the equator.

The zonal electric field component also drives the so-called equatorial plasma fountain, lifting plasma hundreds of kilometres to the upper regions of the ionosphere, where it then diffuses back down to settle in the ionospheric F-region, around 20 degrees north and south of the magnetic equator.

The zonal component of the global electric field near the equator has an enormous influence on the geometry and dynamics of the current systems at low-latitudes. The purpose of this Swarm Level-2 product is to produce estimates of this zonal (or eastward) equatorial electric field component, by using magnetic measurements of the equatorial electrojet (EEJ) current as the satellites fly overhead. Since the magnetic signal of the EEJ current is directly measured by the satellite, this product also provides an estimate of the EEJ current strength, which is itself of great importance and interest to low-latitude ionospheric dynamics. Because this product is based on analysing the EEJ current for each orbit, the procedure works only when an EEJ signal is present, typically between 6AM and 6PM local time. EEF and EEJ estimates are not provided during the night-time.

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4 Methodology

Since this product is based on analysing signatures of the equatorial electrojet signature in Swarm data, the first step of the process is to isolate the EEJ signal from the many other geomagnetic sources detected by Swarm. Therefore, main, crustal and magnetospheric field models are subtracted from the Swarm scalar field measurements, leaving a signal, which is primarily composed of ionospheric sources, as well as possible unmodelled sources from the planet's interior and magnetosphere. This results in a profile as shown by an example in the figure below.

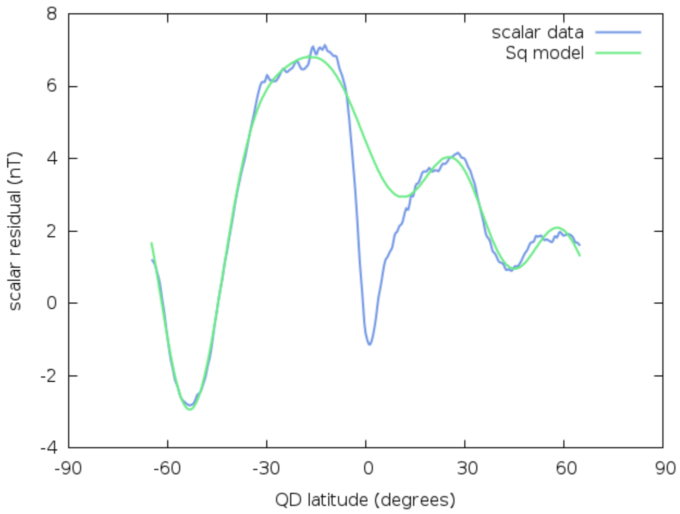

Figure 1: Ionospheric residual after removing main, crustal and magnetospheric field models (blue). A fitted Sq signal is shown in green.

This figure shows a prominent EEJ signal at the magnetic equator, as well as a larger-scale variation at higher latitudes, which we attribute to the Sq currents. In order to eliminate the Sq contribution to this track, we fit a low-degree spherical harmonic model to the higher-latitude data (outside a 10 degree window centred on the magnetic equator), extrapolating across the equatorial region (shown in green). This "Sq model" is then subtracted to yield the final EEJ signal, as shown below.

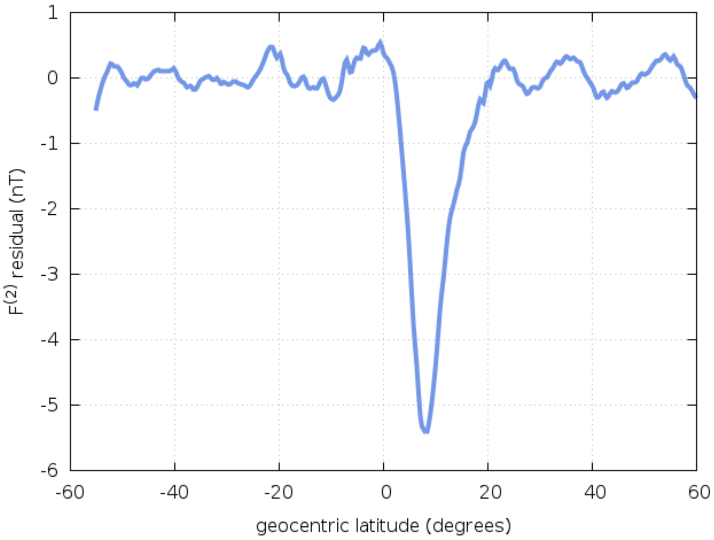

Figure 2: Ionospheric signal after removing Sq model.

This figure now shows most of the signal occuring at the magnetic equator, as expected for the EEJ current. The next step is to invert this magnetic signal for an estimate of the current density producing it. Since we know the EEJ flows primarily in the magnetic zonal direction in a narrow band of +/- 5 degrees near the magnetic equator at an altitude of about 110km, we define a set of line currents in this region, following lines of constant magnetic latitude, spaced 0.25 degrees apart. The strengths of these line currents are then estimated by inverting the magnetic data shown above. This results in a profile shown in the following figure.

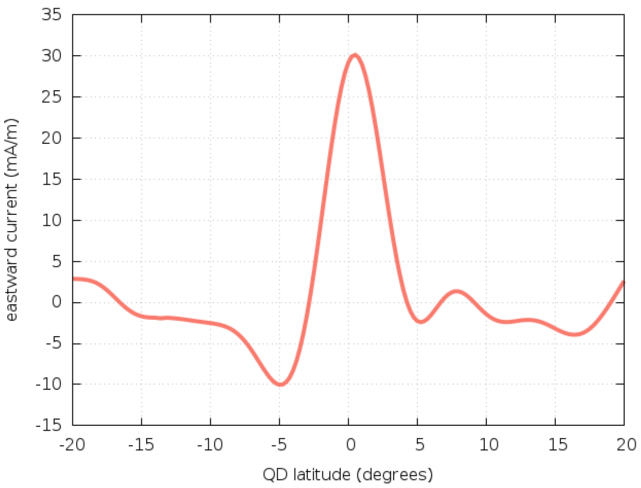

Figure 3: EEJ current density as predicted from line current model

The peak strength of this current profile (the current value at 0 degrees magnetic latitude) is taken to be the estimate of the EEJ current strength, and is a primary output of the Level-2 product, called **EEJ**. Because we map everything to a shell at 110km altitude, this current density represents the height-integrated current density throughout the E-region, and so it is in units of A/m.

The final step of the process is to determine the zonal (eastward) electric field value at the equator which is responsible for producing the current observed in the above figure. This is done by a combination of physics-based modeling and empirical inputs. We solve the governing electrostatic equations for the ionosphere, using a-priori models of the ionospheric and neutral densities and temperatures. The only free parameter in this scheme is the zonal electric field component, and so we solve for this value by minimizing the difference between the modeled EEJ signal and the satellite-derived signal shown above. The figure below shows a sample EEJ signal with its modeled behavior.

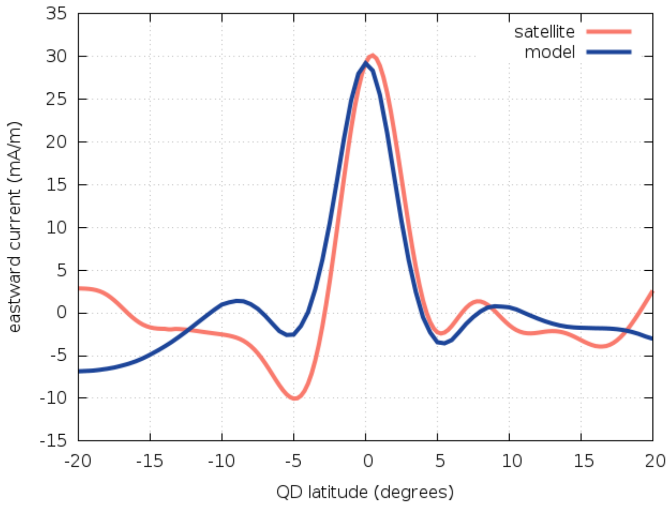

Figure 4: Satellite-derived EEJ signal (orange) with modelled EEJ signal (blue)

While we rarely achieve a perfect match between the observed and modelled profiles, we often get a good agreement in the main EEJ peak, which is sufficient for achieving a good estimate of the EEF value. The EEF is mainly responsible for the height and shape of the main peak at the equator, while the winds are responsible for the profile's shape at higher latitudes. The wind variability is very difficult to accurately model, and so often we have worse agreement at higher latitudes. But much of the time we can recover reliable estimates of the EEF by achieving good agreement near the equator.

We have performed a validation study, by running this EEF chain on 10 years of CHAMP satellite data, as well as 2 years of Swarm data. The resulting EEF estimates are compared with independent measurements made by a ground radar station at Jicamarca, Peru. The results are shown in the following figure.

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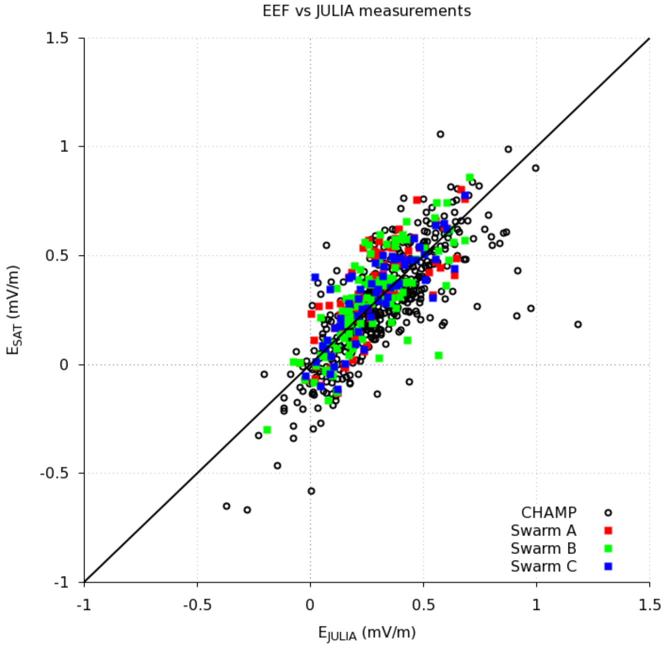

Figure 5: Validation of EEF derived from Swarm Level-2 chain against JULIA radar measurements

The validation plot shows a good correlation (0.80) between the Swarm Level-2 product and the JULIA measurements, with an rms difference less than 0.15 mV/m.

5 Product File Format

The EEFxTMS_2F data files are provided in Common Data Format (CDF) and contain the following fields:

Data	Description	Rate	Units	Comments
Timestamp	Timestamp of the EEF measurement (time of satellite crossing of magnetic equator)	1 per orbit	milliseconds elapsed since 00:00:00 January 1, 2000 UTC	CDF_EPOCH format
Longitude	Geographic longitude of the SWARM satellite crossing of the magnetic equator	1 per orbit	degrees	
Latitude	Geographic latitude of the SWARM satellite crossing of the magnetic equator	1 per orbit	degrees	
EEF	Equatorial eastward electric field estimate	1 per orbit	V/m	
EEJ	Height-integrated latitude profile of equatorial eastward current	1 per orbit	mA/m	Profile vector has length 81 (see section 5.1)
RelErr	Relative error between modelled and observed equatorial electrojet current	1 per orbit	N/A	see [AD-3]
Flags	Value describing the quality of the EEF estimate. Also contains identification information for SWARM satellite (A,B,C)	1 per orbit		See [AD-3]

5.1 EEJ vector

The output data files contain an EEJ field, which is the height-integrated current density as a function of quasi-dipole latitude, derived from Swarm scalar field magnetic measurements. Each EEJ vector has length 81, and corresponds to QD latitudes ranging from -20° to +20° in steps of 0.5°. So for example, the corresponding QD latitude vector could be constructed using the following MATLAB syntax:

```
qdvec = [-20:0.5:20];
```

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