Open Call for Ideas for

New data products, tools and services for Swarm

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Product Idea

A statistical model of the occurrence rate of equatorial plasma density depletions based on in situ plasma density data from LEO satellites

Product Description

Description of proposed product

The proposed product consists of a statistical model which estimates the occurrence probability of night-time electron density depletions at low latitudes. These estimates are provided for a set of parameters (e.g., day of year, solar flux index, longitude, local time) given by the user.

Description of current state of the art and level of maturity of proposed algorithm

A statistical model of the occurrence rate of plasma irregularities based on magnetic observations (IBI-index) of the CHAMP and Swarm missions has been developed and is publicly available (called IBP-model, Stolle et al., 2024a). The model output was validated against a test data set of Swarm IBI data and ground-based GPS observations. An extended validation against fully independent plasma density data from the GRACE mission was presented by Stolle et al. (2024b). The validation against a test data set of Swarm IBI index obtained a Gini coefficient (GC) of 0.66 and against the GRACE electron density data for strong depletions obtained a GC of 0.76 (Note: GC=0/1 represents unskilled/perfect forecast capability). In this respect, the model is considered highly refined. During COSPAR 2024, the model's performance garnered interest from the International Reference Ionosphere (IRI) for the potential implementation of the IBP-model.

However, comparisons against GRACE for weak depletions have shown a low GC of 0.1. This is supported by comparisons to other published data statistics based on electron density, e.g., by COSMIC-2 (Zakharenkova et al., 2023). These have revealed that the present IBP-model cannot capture weaker bubbles, particularly those occurring after midnight (Figure 1). In addition, the detection of bubbles fails during geomagnetic active times, as recently been noticed during the May-2024 storm (Figure 2). In these cases, a detection based on electron density would promise more consistent bubble identifications.

Data input needs

The data input consists of time series of electron density sampled at a regular 2Hz, as provided by the Swarm mission. Further input data will be the F10.7 index for solar and the Hp30-Index for geomagnetic activity.

Expected output

The output is a statistical model which estimates the occurrence probability of night-time electron density depletions at low latitudes. These estimates are provided for a set of input parameters (e.g., day of year, solar flux index, longitude, local time) given by the user.

The estimates will be updated yearly with new Swarm data and can be extended by in situ electron density observations of other satellites (such as CHAMP, GRACE, GRACE-FO, ect.).
The forward model for deriving the irregularity occurrence rates will be made publicly available, similar to the existing model based on magnetic data (https://igit.iap-kborn.de/ibp/ibp-model).

Scientific/application benefits, complementarity with other relevant ESA and non-ESA activities including opportunities for new scientific activities based on implementation of the proposed product.

The proposed model well complements the IBP model. While the IBP model has proven effective in detecting irregularities that cause GNSS scintillations, the proposed model will additionally be capable of representing the occurrence of irregularities that do not necessarily trigger GNSS scintillations. Additionally, geomagnetic activity will be tested as an extra input parameter, which was not meaningful in the IBP model based on magnetic data. The model will be made freely accessible and available to a wide community. It will help in categorizing plasma structures detected by LEO satellites and will provide statistical predictions for radio link scintillations at a multitude of frequencies which are sensitive to different scale lengths of plasma structures, as the model will be based on the detection of both strong and weak plasma depletions. Potentially, the proposed model may apply a detection method similarly to Wan et al. (2018) which can also provide the strength of the depletions.
The high interest in developing models for estimating the occurrence rate of equatorial plasma irregularities is demonstrated in recent studies by Reddy et al. (2023), and Seba and Lapenta (2024). They employed Machine Learning techniques using the Swarm IBI index or the first time-derivative of electron density respectively, as indicators in their models. However, to our best knowledge these models are not openly accessible.

The proposed product could be well-suited for a DISC Idea or for a new development within the main DISC line extending the existing IBP model.

Expected user community

The user community is scientific (geomagnetism, space science, geodesy) for detecting plasma irregularities in data or, for example, for implementation as a module in the IRI model. It can also be used by the private sector, e.g., for probability estimates of radio link irregularities.

References

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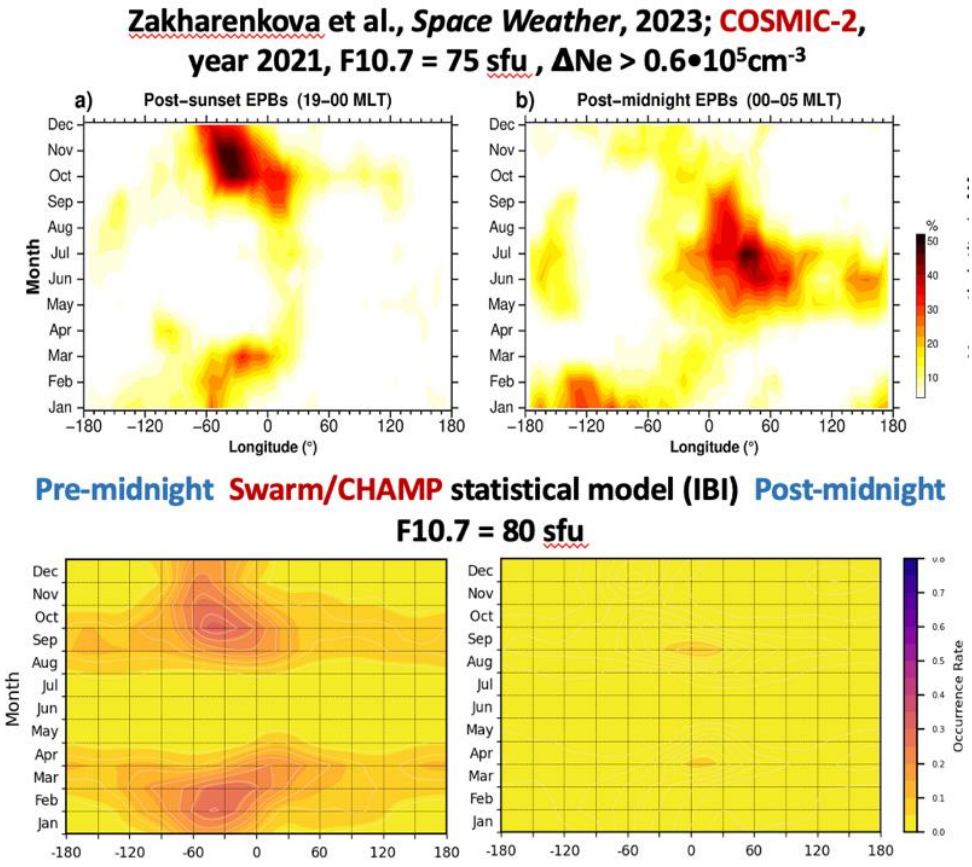


Fig. 1: Occurrence probability of plasma irregularities based on COSMIC-2 electron density data during low solar flux during pre- (upper left) and post-midnight (upper right). Predictions of the IBP model (lower left and right) for similar conditions as in the above panel. The low amplitude post-midnight depletions are rarely represented in the magnetic data.

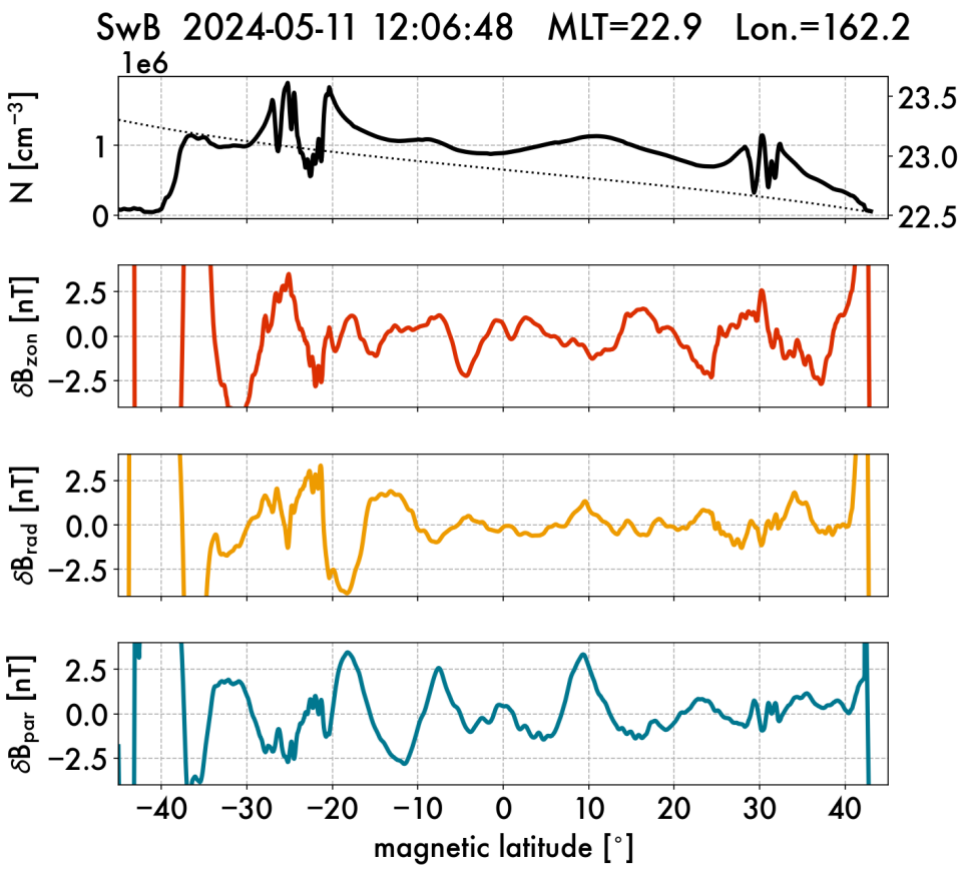


Fig. 2: Time series of Swarm B during a pre-midnight pass during the May-2024 storm. Strong plasma depletions (upper panel) are reflected in the parallel magnetic field (lower panel), but are superposed by signatures of other geomagnetic phenomena during the storm. This makes the detection of depletions challenging to impossible. However, it is unambiguously detected in the electron density.